Environmental ENGINEERING

WATER, WASTEWATER, Soil and Groundwater Treatment and Remediation

SIXTH EDITION

Nelson L. NEMEROW, Franklin J. AGARDY, Patrick SULLIVAN, and Joseph A. SALVATO

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Doctors Agardy and Sullivan would like to dedicate this sixth edition of *Environmental Engineering* to Nelson L. Nemerow who passed away in December of 2006. Dr. Nemerow was born on April 16, 1923 and spent most of his productive years as an educator and prolific author. He spent many years teaching at Syracuse University, the University of Miami, North Carolina State, Florida International, and Florida Atlantic University. He authored some 25 books dedicated to advancing the art of waste disposal and utilization. His passion was waste minimization and the title of one of his most recent publications, *Zero Pollution for Industry*, summed up more than fifty years of teaching and consulting. A devoted husband and father, he divided his time between residences in Florida and Southern California. Nelson served in the United States Merchant Marine during World War II. His commitment to excellence was second to none.

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PREFACE

As the global population grows and many developing countries modernize, the importance of water supply and water treatment becomes a much greater factor in the welfare of nations. In similar fashion, the need to address both domestic and industrial wastes generated by these nations moves higher on the scale of importance. Clearly, in today's world the competition for water resources coupled with the unfortunate commingling of wastewater discharges with freshwater supplies creates additional pressure on treatment systems.

This volume attempts to address issues of water supply including the demand for fresh water, the treatment technologies available to treat water, and the treatment and disposal of community-generated wastewaters. The focus is the practicality and appropriateness of treatment—in sufficient detail so that the practicing public health official, water treatment engineer and plant operator, as well as those in the domestic and industrial waste treatment professions, can address their problems in a practical manner. The emphasis is on basic principles and practicality.

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CHAPTER 1

WATER SUPPLY

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INTRODUCTION

A primary requisite for good health is an adequate supply of water that is of satisfactory sanitary quality. It is also important that the water be attractive and palatable to induce its use; otherwise, consumers may decide to use water of doubtful quality from a nearby unprotected stream, well, or spring. Where a municipal water supply passes near a property, the owner of the property should be urged to connect to it because such supplies are usually under competent supervision.

When a municipal water supply is not available, the burden of developing a safe water supply rests with the owner of the property. Frequently, private supplies are so developed and operated that full protection against dangerous or objectionable pollution is not afforded. Failure to provide satisfactory water supplies in most instances must be charged either to negligence or ignorance because it generally costs no more to provide a satisfactory installation that will meet good health department standards.

The following definitions are given in the National Drinking Water Regulations as amended through July, 2002:

Public water system means either a community or noncommunity system for the provision to the public of water for human consumption through pipes or other constructed conveyances, if such system has at least 15 service connections, or regularly serves an average of at least 25 individuals daily at least 60 days out of the year. Such a term includes (1) any collection, treatment, storage, and distribution facilities under the control of the operator of such system and used primarily in connection with such system, and

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(2) any collection or pretreatment storage facilities not under such control which are used primarily in connection with such system.

A *community water system* has at least 15 service connections used by year-round residents, or regularly serves at least 25 year-round residents. These water systems generally serve cities and towns. They may also serve special residential communities, such as mobile home parks and universities, which have their own drinking water supply.

A *noncommunity water system* is a public water system that is not a community water system, and can be either a "transient noncommunity water system" (TWS) or a "non-transient noncommunity water system" (NTNCWS). TWSs typically serve travelers and other transients at locations such as highway rest stops, restaurants, and public parks. The system serves at least 25 people a day for at least 60 days a year, but not the same 25 people. On the other hand, NTNCWSs serve the same 25 persons for at least 6 months per year, but not year round. Some common examples of NTNCWSs are schools and factories (or other workplaces) that have their own supply of drinking water and serve 25 of the same people each day.

In 2007 there were approximately 156,000 public water systems in the United States serving water to a population of nearly 286 million Americans. There were approximately 52,110 community water systems, of which 11,449 were surface water supplies and 40,661 were groundwater supplies. There were 103,559 noncommunity water systems, of which 2557 were surface water supplies and 101,002 were groundwater supplies. Of the community water systems, 43,188 are small systems that serve populations less than 3300; 4822 are medium systems and serve populations between 3300 and 10,000; and 4100 are large systems serving populations over 10,000. In terms of numbers, the small and very small community and noncommunity water systems represent the greatest challenge to regulators and consultants—both contributing to over 88 percent of the regulatory violations in 2007.[1]

In addition to public water systems, the U.S. Geological Survey estimated that 43.5 million people were served by their own individual water supply systems in 2000. These domestic systems are—for the most part—unregulated by either state or county health departments.[2]

A survey made between 1975 and 1977 showed that 13 to 18 million people in communities of 10,000 and under used individual wells with high contamination rates.[3] The effectiveness of state and local well construction standards and health department programs has a direct bearing on the extent and number of contaminated home well-water supplies in specific areas.

A safe and adequate water supply for 2.4 billion people,[4] about one-third of the world's population, is still a dream. The availability of any reasonably clean water in the less-developed areas of the world just to wash and bathe would go a long way toward the reduction of such scourges as scabies and other skin diseases, yaws and trachoma, and high infant mortality. The lack of safe water makes high incidences of shigellosis, amebiasis, schistosomiasis,* leptospirosis, infectious hepatitis, giardiasis, typhoid, and paratyphoid fever commonplace.[5] Ten million persons suffer from dracunculiasis or guinea worm disease in Africa and parts of Asia.[6] The World Health Organization (WHO) estimates that some 3.4 million people die each year from water-borne diseases caused by microbially contaminated water supplies or due to a lack of access to sanitation facilities. Tragically, over one half of these deaths are children under the age of five years old.[7] Three-fourths of all illnesses in the developing world are associated with inadequate water and sanitation.[8] It is believed that the provision of safe water supplies, accompanied by a program of proper excreta disposal and birth control, could vastly improve the living conditions of millions of people in developing countries of the world.[9] In 1982, an estimated 46 percent of the population of Latin America and the Caribbean had access to piped water supply and 22 percent had access to acceptable types of sewage disposal.[10]

The diseases associated with the consumption of contaminated water are discussed in Chapter 1 of *Environmental Engineering, Sixth Edition: Prevention and Response to Water-, Food-, Soil,- and Air-Borne Disease and Illness* and summarized in Table 1.4 of that volume.

Groundwater Pollution Hazard

Table 1.1 shows a classification of sources and causes of groundwater pollution. The 20 million residential cesspool and septic tank soil absorption systems alone discharge about 400 billion gallons of sewage per day into the ground, which in some instances may contribute to groundwater pollution. This is in addition to sewage from restaurants, hotels, motels, resorts, office buildings, factories, and other establishments not on public sewers.[11] The contribution from industrial and other sources shown in Table 1.1 is unknown. It is being inventoried by the EPA, and is estimated at 900 billion gal/year,[12] the EPA, with state participation, is also developing a groundwater protection strategy. Included in the strategy is the classification of all groundwater and protection of existing and potential drinking water sources and "ecologically vital" waters.

Groundwater pollution problems have been found in many states. Primarily, the main cause is organic chemicals, such as trichloroethylene, 1,1,1-trichloroethane, benzene, perchlorate, gasoline (and gasoline additives such as MTBE), pesticides and soil fumigants, disease-causing organisms, and nitrates. Other sources are industrial and municipal landfills; ponds, pits, and lagoons; waste oils and highway deicing compounds; leaking underground storage tanks and pipelines; accidental spills; illegal dumping; and abandoned oil and gas wells. With 146 million people in the United States dependent on groundwater

*Two hundred million cases of schistosomiasis worldwide were estimated in 2004, spread mostly through water contact (Centers for Disease Control and Prevention).

TABLE 1.1 Classification of Sources and Causes of Groundwater Pollution Used in Determining Level and Kind of Regulatory Control

Wastes		Nonwastes	
Category I[a]	Category II[b]	Category III[c]	Category IV[d]
Land application of wastewater: spray irrigation, infiltration–percolation basins, overland flow	Surface impoundments: waste-holding ponds, lagoons, and pits	Buried product storage tanks and pipelines	Saltwater intrusion: seawater encroachment, upward coning of saline groundwater
Subsurface soil absorption systems: septic systems	Landfills and other excavations: landfills for industrial wastes, sanitary landfills for municipal solid wastes, municipal landfills	Stockpiles: highway deicing stockpiles, ore stockpiles	River infiltration
Waste disposal wells and brine injection wells	Water and wastewater treatment plant sludges, other excavations (e.g., mass burial of livestock)	Application of highway deicing salts	Improperly constructed or abandoned wells
Drainage wells and sumps	—	Product storage ponds	Farming practices (e.g., dryland farming)
Recharge wells	Animal feedlots	Agricultural activities: fertilizers and pesticides, irrigation return flows	
	Leaky sanitary sewer lines Acid mine drainage Mine spoil pipes and tailings	Accidental spills	

[a] Systems, facilities, or activities designed to discharge waste or wastewaters (residuals) to the land and groundwaters.
[b] Systems, facilities, or activities that may discharge wastes or wastewaters to the land and groundwaters.
[c] Systems, facilities, or activities that may discharge or cause a discharge of contaminants that are not wastes to the land and groundwaters.
[d] Causes of groundwater pollution that are not discharges.

Source: The Report to Congress, Waste Disposal Practices and Their Effects on Ground Water, Executive Summary, U.S. Environmental Protection Agency, Washington, DC, January 1977, p. 39.

sources for drinking water,* these resources must be protected from physical, chemical, radiological, and microbiological contamination.

Whereas surface water travels at velocities of feet per second, groundwater moves at velocities that range from less than a fraction of a foot per day to several feet per day. Groundwater organic and inorganic chemical contamination may persist for decades or longer and, because of the generally slow rate of movement of groundwater, may go undetected for many years. Factors that influence the movement of groundwater include the type of geological formation and its permeability, the rainfall and the infiltration, and the hydraulic gradient. The slow uniform rate of flow, usually in an elongated plume, provides little opportunity for mixing and dilution, and the usual absence of air in groundwater to decompose or break down the contaminants add to the long-lasting problem usually created. By contrast, dilution, microbial activity, surface tension and attraction to soil particles, and soil adsorptive characteristics might exist that could modify, immobilize, or attenuate the pollutant travel. More attention *must* be given to the *prevention* of ground-water pollution and to wellhead protection.

TRAVEL OF POLLUTION THROUGH THE GROUND

Identification of the source of well pollution and tracing the migration of the incriminating contaminant are usually not simple operations. The identification of a contaminant plume and its extent can be truly complex. Comprehensive hydrogeological studies and proper placement and construction of an adequate number of monitoring wells are necessary.

Geophysical methods to identify and investigate the extent and characteristics of groundwater pollution include geomagnetics, electromagnetics, electrical resistivity, ground-probing radar, and photoionization meters.[13] *Geomagnetics* uses an instrument producing a magnetic field to identify and locate buried metals and subsurface materials that are not in their natural or undisturbed state. *Electromagnetics* equipment measures the difference in conductivity between buried materials such as the boundaries of contaminated plumes or landfills saturated with leachate and uncontaminated materials. *Electrical resistivity* measures the resistance a material offers to the passage of an electric current between electric probes, which can be interpreted to identify or determine rock, clay and other materials, porosity, and groundwater limits. *Ground-probing radar* uses radar energy to penetrate and measure reflection from the water table and subsurface materials. The reflection from the materials varies with depth and the nature of the material, such as sandy soils versus saturated clays. *Photoionization meters* are used to detect the presence of specific volatile organic compounds such as gasoline, and methane in a landfill, through the use of shallow boreholes. Other detection methods are remote imagery and aerial photography, including infrared.

*Ninety-eight percent of the rural population in the United States and 32 percent of the population served by municipal water systems use groundwater (U.S. Geological Survey, 2000).

Sampling for contaminants must be carefully designed and performed. Errors can be introduced: Sampling from an unrepresentative water level in a well, contamination of sampling equipment, and incorrect analysis procedure are some potential sources of error. The characteristics of a pollutant, the subsurface formation, the hydraulic conductivity of the aquifer affected, groundwater slope, rainfall variations, and the presence of geological fractures, faults, and channels make determination of pollution travel and its sampling difficult. Geophysical techniques can help, and great care must be used in determining the number, spacing, location, and depths of sampling wells and screen entry levels. As a rule, monitoring wells and borings will be required to confirm and sample subsurface contamination.

Since the character of soil and rock, quantity of rain, depth of groundwater, rate of groundwater flow, amount and type of pollution, absorption, adsorption, biological degradation, chemical changes, and other factors usually beyond control are variable, one cannot say with certainty through what thickness or distance sewage or other pollutants must pass to be purified. Microbiological pollution travels a short distance through sandy loam or clay, but it will travel indefinite distances through coarse sand and gravel, fissured rock, dried-out cracked clay, or solution channels in limestone. Acidic conditions and lack of organics and certain elements such as iron, manganese, aluminum, and calcium in soil increase the potential of pollution travel. Chemical pollution can travel great distances.

The Public Health Service (PHS) conducted experiments at Fort Caswell, North Carolina, in a sandy soil with groundwater moving slowly through it. The sewage organisms (coliform bacteria) traveled 232 feet, and chemical pollution as indicated by uranin dye traveled 450 feet.[14] The chemical pollution moved in the direction of the groundwater flow largely in the upper portion of the groundwater and persisted for 2-1/2 years. The pollution band did not fan out but became narrower as it moved away from the pollution source. It should be noted that in these tests there was a small draft on the experimental wells and that the soil was a sand of 0.14 mm effective size and 1.8 uniformity coefficient. It should also be noted that, whereas petroleum products tend to float on the surface, halogenated solvents gradually migrate downward.

Studies of pollution travel were made by the University of California using twenty-three 6-inch observation wells and a 12-inch gravel-packed recharge well. Diluted primary sewage was pumped through the 12-inch recharge well into a confined aquifer having an average thickness of 4.4 feet approximately 95 feet below ground surface. The aquifer was described as pea gravel and sand having a permeability of 1900 gal/ft^2/day. Its average effective size was 0.56 mm and uniformity coefficient was 6.9. The medium effective size of the aquifer material from 18 wells was 0.36 mm. The maximum distance of pollution travel was 100 feet in the direction of groundwater flow and 63 feet in other directions. It was found that the travel of pollution was affected not by the groundwater velocity but by the organic mat that built up and filtered out organisms, thereby preventing them from entering the aquifer. The extent of the pollution then regressed as the organisms died away and as pollution was filtered out.[15]

Butler, Orlob, and McGauhey[16] made a study of the literature and reported the results of field studies to obtain more information about the underground travel of harmful bacteria and toxic chemicals. The work of other investigators indicated that pollution from dry-pit privies did not extend more than 1 to 5 feet in dry or slightly moist fine soils. However, when pollution was introduced into the underground water, test organisms (*Balantidium coli*) traveled to wells up to 232 feet away.[17] Chemical pollution was observed to travel 300 to 450 feet, although chromate was reported to have traveled 1,000 feet in 3 years, and other chemical pollution 3 to 5 miles. Leachings from a garbage dump in groundwater reached wells 1,476 feet away, and a 15-year-old dump continued to pollute wells 2,000 feet away. Studies in the Dutch East Indies (Indonesia) report the survival of coliform organisms in soil 2 years after contamination and their extension to a depth of 9 to 13 feet, in decreasing numbers, but increasing again as groundwater was approached. The studies of Butler et al. tend to confirm previous reports and have led the authors to conclude "that the removal of bacteria from liquid percolating through a given depth of soil is inversely proportional to the particle size of the soil."[18]

Knowledge concerning viruses in groundwater is limited, but better methodology for the detection of viruses is improving this situation. Keswick and Gerba[19] reviewed the literature and found 9 instances in which viruses were isolated from drinking water wells and 15 instances in which viruses were isolated from beneath land treatment sites. Sand and gravel did not prevent the travel of viruses long distances in groundwater. However, fine loamy sand over coarse sand and gravel effectively removed viruses. Soil composition, including the presence of clay, is very important in virus removal, as it is in bacteria removal. The movement of viruses through soil and in groundwater requires further study. Helminth eggs and protozoa cysts do not travel great distances through most soils because of their greater size but can travel considerable distances through macropores and crevices. However, nitrate travel in groundwater may be a major inorganic chemical hazard. In addition, organic chemicals are increasingly being found in groundwater. See (1) "Removal of Gasoline, Fuel Oil, and Other Organics in an Aquifer"; (2) "Prevention and Removal of Organic Chemicals"; and (3) "Synthetic Organic Chemicals Removal" in Chapter 2.

When pumping from a deep well, the direction of groundwater flow around the well within the radius of influence, not necessarily circular, will be toward the well. Since the level of the water in the well will probably be 25 to 150 feet, more or less, below the ground surface, the drawdown cone created by pumping may exert an attractive influence on groundwater, perhaps as far as 100 to 2,000 feet or more away from the well, because of the hydraulic gradient, regardless of the elevation of the top of the well. The radius of the drawdown cone or circle of influence may be 100 to 300 feet or more for fine sand, 600 to 1,000 feet for coarse sand, and 1,000 to 2,000 feet for gravel. See Figure 1.1. In other words, distances and elevations of sewage disposal systems and other sources of pollution must be considered relative to the hydraulic gradient and elevation of the water level in the well, while it is being pumped. It must also be recognized that pollution can travel in three dimensions in all or part of the aquifer's vertical thickness, dependent on the contaminant viscosity and density, the formation transmissivity,

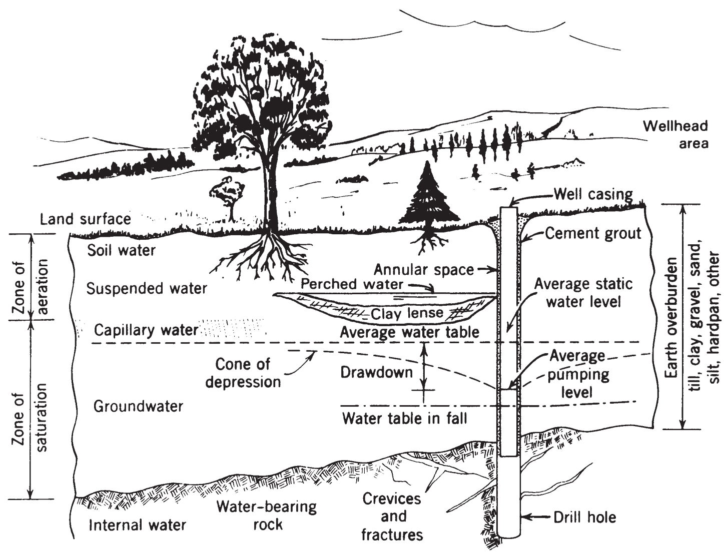


FIGURE 1.1 A geologic section showing groundwater terms. (*Source: Rural Water Supply*, New York State Department of Health, Albany, 1966.)

and the groundwater flow. Liquids lighter than water, such as gasoline, tend to collect above the groundwater table. Liquids heavier or more dense tend to pass through the groundwater and accumulate above an impermeable layer.

A World Health Organization (WHO) report reminds us that, in nature, atmospheric oxygen breaks down accessible organic matter and that topsoil (loam) contains organisms that can effectively oxidize organic matter.[20] However, these benefits are lost if wastes are discharged directly into the groundwater by way of sink holes, pits, or wells or if a subsurface absorption system is water-logged.

From the investigations made, it is apparent that the safe distance between a well and a sewage or industrial waste disposal system is dependent on many variables, including chemical, physical, and biological processes.* These four factors should be considered in arriving at a satisfactory answer:

1. The amount of sand, clay, organic (humus) matter, and loam in the soil, the soil structure and texture, the effective size and uniformity coefficient, groundwater level, and unsaturated soil depth largely determine the ability of the soil to remove microbiological pollution deposited in the soil.
2. The volume, strength, type, and dispersion of the polluting material, rainfall intensity and infiltration, and distance, elevation, and time for pollution to travel with relation to the groundwater level and flow and soil penetrated are important. Also important is the volume of water pumped and well drawdown.

*A summary of the distances of travel of underground pollution is also given in Task Group Report, "Underground Waste Disposal and Control," *J. Am. Water Works Assoc.*, **49**, (October 1957): 1334–1341.

3. The well construction, tightness of the pump line casing connection, depth of well and well casing, geological formations penetrated, and sealing of the annular space have a very major bearing on whether a well might be polluted by sewage, chemical spills or wastes, and surface water.
4. The well recharge (wellhead) area, geology, and land use possibly permit groundwater pollution. Local land-use and watershed control is essential to protect and prevent pollution of well-water supplies.

Considerable professional judgment is needed to select a proper location for a well. The limiting distances given in Table 1.2 for private dwellings should

TABLE 1.2 Minimum Separation Distances (feet) from On-Site Wastewater Sources

Sources	To Well or Suction Line[a]	To Stream, Lake, or Water Course	To Property Line or Dwelling
House sewer (water-tight joints)	25 if cast iron pipe or equal, 50 otherwise	25	—
Septic tank	50	50	10
Effluent line to distribution box	50	50	10
Distribution box	100	100	20
Absorption field	100[b]	100	20
Seepage pit or cesspool	150[b] (more in coarse gravel)	100	20
Dry well (roof and footing)	50	25	20
Fill or built-up system	100	100	20
Evapotranspiration–absorption system	100	50	20
Sanitary privy pit	100	50	20
Privy, water-tight vault	50	50	10
Septic privy or aqua privy	50	50	10

[a] Water service and sewer lines may be in the same trench if cast-iron sewer with water-tight joints is laid at all points 12 in. below water service pipe; or sewer may be on dropped shelf at one side at least 12 in. below water service pipe, provided that sewer pipe is laid below frost with tight and root-proof joints and is not subject to settling, superimposed loads, or vibration. Water service lines under pressure shall not pass closer than 10 ft of a septic tank, absorption tile field, leaching pit, privy, or any other part of a sewage disposal system.

[b] Sewage disposal systems located of necessity upgrade or in the general path of drainage to a well should be spaced 200 ft or more away and not in the direct line of drainage. Wells require a minimum 20 ft of casing extended and sealed into an impervious stratum. If subsoil is coarse sand or gravel, do not use seepage pit; use absorption field with 12 in. medium sand on bottom of trench. Also require oversize drill hole and grouted well to a safe depth. See Table 1.15.

be used as a guide. Experience has shown them to be reasonable and effective in most instances *when coupled with a sanitary survey of the drainage area and proper interpretation of available hydrologic and geologic data and good well construction, location, and protection*.[21] See Figure 1.1 for groundwater terms. Well location and construction for public and private water systems should follow regulatory standards. See "Source and Protection of Water Supply" later in this chapter.

Disease Transmission

Water, to act as a vehicle for the spread of a specific disease, must be contaminated with the associated disease organism or hazardous chemical. Disease organisms can survive for days to years, depending on their form (cyst, ova) and environment (moisture, competitors, temperature, soil, and acidity) and the treatment given the wastewater. All sewage-contaminated waters must be presumed to be potentially dangerous. Other impurities, such as inorganic and organic chemicals and heavy concentrations of decaying organic matter, may also find their way into a water supply, making the water hazardous, unattractive, or otherwise unsuitable for domestic use unless adequately treated. The inorganic and organic chemicals causing illness include mercury, lead, chromium, nitrates, asbestos, polychlorinated biphenyl (PCB), polybrominated biphenyl (PBB), mirex, Kepone vinyl chloride, trichloroethylene, benzene, and others.

Communicable and noninfectious diseases that may be spread by water are discussed in Table 1.4 in Chapter 1 of *Environmental Engineering, Sixth Edition: Prevention and Response to Water-, Food-, Soil,- and Air-Borne Disease and Illness*.

WATER QUANTITY AND QUALITY

Water Cycle and Geology

The movement of water can be best illustrated by the hydrologic, or water, cycle shown in Figure 1.2. Using the clouds and atmospheric vapors as a starting point, moisture condenses out under the proper conditions to form rain, snow, sleet, hail, frost, fog, or dew. Part of the precipitation is evaporated while falling; some of it reaches vegetation foliage, the ground, and other surfaces. Moisture intercepted by surfaces is evaporated back into the atmosphere. Part of the water reaching the ground surface runs off to streams, lakes, swamps, or oceans whence it evaporates; part infiltrates the ground and percolates down to replenish the groundwater storage, which also supplies lakes, streams, and oceans by underground flow. Groundwater in the soil helps to nourish vegetation through the root system. It travels up the plant and comes out as transpiration from the leaf structure and then evaporates into the atmosphere. In its cyclical movement, part of the water is temporarily retained by the earth, plants, and animals to sustain life. The average annual precipitation in the United States is about 30 inches, of which 72 percent evaporates from water and land surfaces and transpires from

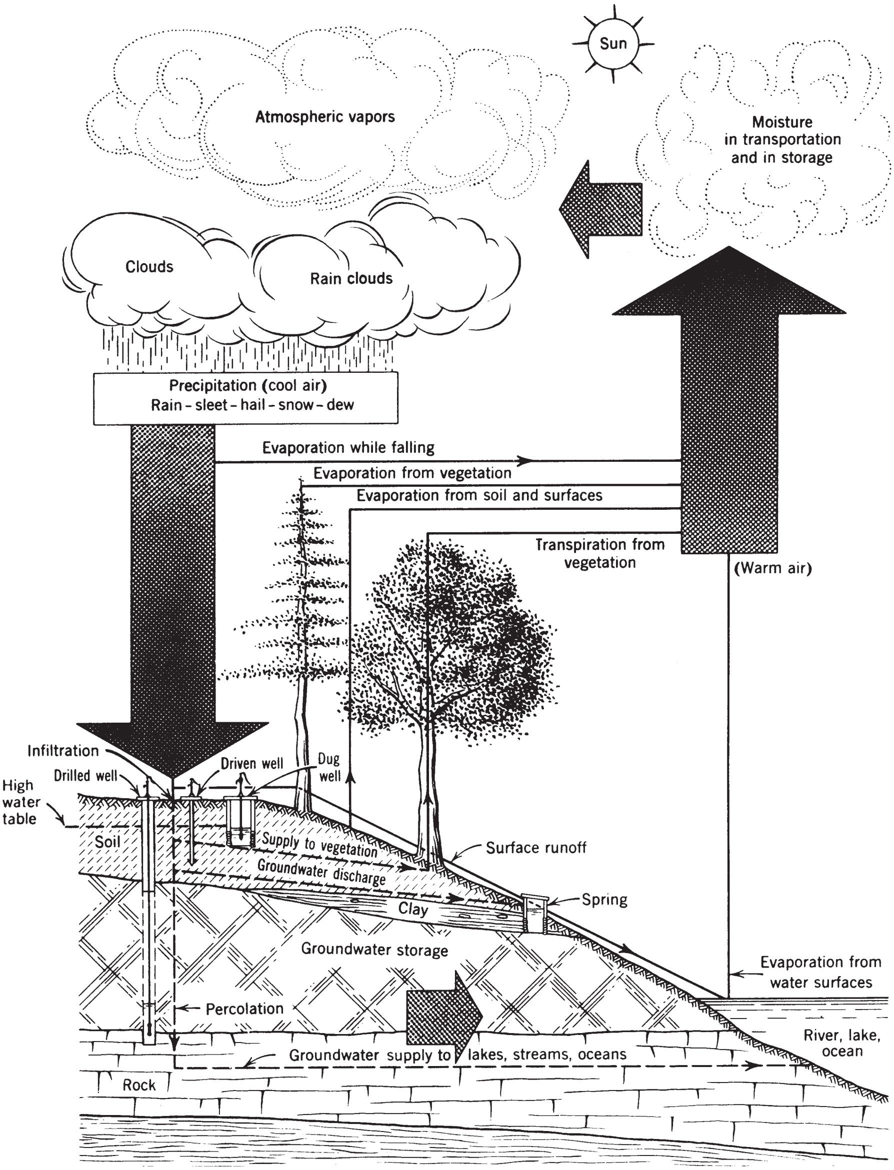


FIGURE 1.2 Figure hydrologic or (water) cycle. The oceans hold 317,000,000 mi^3 of water. Ninety-seven percent of the Earth's water is salt water; 3 percent of the Earth's fresh water is groundwater, snow and ice, fresh water on land, and atmospheric water vapor; 85 percent of the fresh water is in polar ice caps and glaciers. Total precipitation equals total evaporation plus transpiration. Precipitation on land equals 24,000 mi^3/year. Evaporation from the oceans equals 80,000 mi^3/year. Evaporation from lakes, streams, and soil and transpiration from vegetation equal 15,000 mi^3.

plants and 28 percent contributes to the groundwater recharge and stream flow.[22] See also "Septic Tank Evapotranspiration System," in Chapter 3.

The volume of fresh water in the hydrosphere has been estimated to be 8,400,000 mi^3 with 5,845,000 mi^3 in ice sheets and glaciers, 2,526,000 mi^3 in groundwater, 21,830 mi^3 in lakes and reservoirs, 3,095 mi^3 in vapors in the atmosphere, and 509 mi^3 in river water.[23]

When speaking of water, we are concerned primarily with surface water and groundwater, although rainwater and saline water are also considered. In falling through the atmosphere, rain picks up dust particles, plant seeds, bacteria, dissolved gases, ionizing radiation, and chemical substances such as sulfur, nitrogen, oxygen, carbon dioxide, and ammonia. Hence, rainwater is not pure water as one might think. It is, however, very soft. Water in streams, lakes, reservoirs, and swamps is known as *surface water*. Water reaching the ground and flowing over the surface carries anything it can move or dissolve. This may include waste matter, bacteria, silt, soil, vegetation, and microscopic plants and animals and other naturally occurring organic matter. The water accumulates in streams or lakes. Sewage, industrial wastes, and surface and groundwater will cumulate, contribute to the flow, and be acted on by natural agencies. On the one hand, water reaching lakes or reservoirs permit bacteria, suspended matter, and other impurities to settle out. On the other hand, microscopic as well as macroscopic plant and animal life grow and die, thereby removing and contributing impurities in the cycle of life.

Part of the water reaching and flowing over the ground infiltrates and percolates down to form and recharge the groundwater, also called underground water. In percolating through the ground, water will dissolve materials to an extent dependent on the type and composition of the strata through which the water has passed and the quality (acidity) and quantity of water. Groundwater will therefore usually contain more dissolved minerals than surface water. The strata penetrated may be unconsolidated, such as sand, clay, and gravel, or consolidated, such as sandstone, granite, and limestone. A brief explanation of the classification and characteristics of formations is given next.

Igneous rocks are those formed by the cooling and hardening of molten rock masses. The rocks are crystalline and contain quartz, feldspar, mica, hornblende, pyroxene, and olivene. Igneous rocks are not usually good sources of water, although basalts are exceptions. Small quantities of water are available in fractures and faults. Examples are granite, dioxite, gabbro, basalt, and syenite.

Sedimentary formations are those resulting from the deposition, accumulation, and subsequent consolidation of materials weathered and eroded from older rocks by water, ice, or wind and the remains of plants, animals, or material precipitated out of solution. Sand and gravel, clay, silt, chalk, limestone, fossils, gypsum, salt, peat, shale, conglomerates, loess, and sandstone are examples of sedimentary formations. Deposits of sand and gravel generally yield large quantities of water. Sandstones, shales, and certain limestones may yield abundant groundwater, although results may be erratic, depending on bedding planes and joints, density, porosity, and permeability of the rock.

Metamorphic rocks are produced by the alteration of igneous and sedimentary rocks, generally by means of heat and pressure. Gneisses and schists, quartzites, slates, marble, serpentines, and soapstones are metamorphic rocks. A small quantity of water is available in joints, crevices, and cleavage planes.

Karst areas are formed by the movement of underground water through carbonate rock fractures and channels, such as in limestone and gypsum, forming caves, underground channels, and sink holes. Because karst geology can be so porous, groundwater movement can be quite rapid (several feet per day). Therefore, well water from such sources is easily contaminated from nearby and distant pollution sources.

Glacial drift is unconsolidated sediment that has been moved by glacier ice and deposited on land or in the ocean.

Porosity is a measure of the amount of water that can be held by a rock or soil in its pores or voids, expressed as a percentage of the total volume. The volume of water that will *drain* freely out of a saturated rock or soil by gravity, expressed as a percentage of the total volume of the mass, is the *effective porosity* or *specific yield*. The volume of water retained is the *specific retention*. This is due to water held in the interstices or pores of the rock or soil by molecular attraction (cohesion) and by surface tension (adhesion). For example, plastic clay has a porosity of 45 to 55 percent but a specific yield of practically zero. In contrast, a uniform coarse sand and gravel mixture has a porosity of 30 to 40 percent with nearly all of the water capable of being drained out.

The *permeability* of a rock or soil, expressed as the standard coefficient of permeability or *hydraulic conductivity*, is the rate of flow of water at 60°F (16°C), in gallons per day, through a vertical cross-section of 1 ft^2, under a head of 1 foot, per foot of water travel. There is no direct relationship between permeability, porosity, and specific yield.

Transmissivity is the hydraulic conductivity times the saturated thickness of the aquifer.

Groundwater Flow

The flow through an underground formation can be approximated using Darcy's law,[24] expressed as $Q = KIA$, where

Q = quantity of flow per unit of time, gpd
K = hydraulic conductivity (water-conducting capacity) of the formation, gpd/ft^2 (see Table 1.3)
I = hydraulic gradient, ft/ft (may equal slope of groundwater surface)
A = cross-sectional area through which flow occurs, ft^2, at right angle to flow direction

For example, a sand aquifer within the floodplain of a river is about 30 feet thick and about a mile wide. The aquifer is covered by a confining unit of glacial till, the bottom of which is about 45 feet below the land surface. The difference in

TABLE 1.3 Porosity, Specific Yield, and Hydraulic Conductivity of Some Materials

Material	Porosity (vol %)	Specific Yield (%)	Hydraulic Conductivity or Permeability Coefficient,[a] K (gpd/ft^2)
Soils	55[b]	40[b]	10^{-5}–10 (glacial till)
	50–60[e]		
Clay	50[b]	2[b]	10^{-2}–10^{2} (silt, loess)
	45[d]	3[d]	10^{-6}–10^{-2} (clay)
	45–55[c]	1–10[e]	
Sand	25[b]	22[b]	1–10^{2} (silty sand)
	35[d]	25[d]	10–10^{4}
	30–40[c]	10–30[c]	
Gravel	20[b]	19[b]	10^{3}–10^{5}
	25[d]	22[d]	
	30–40[c]	15–30[c]	
Limestone	20[b]	18[b]	10^{-3}–10^{5} (fractured to cavernous, carbonate rocks)
	5[d]	2[d]	
	1–10[c]	0.5–5[e]	
Sandstone	11[b]	6[b]	10^{-4}–10 (fractured to semiconsolidated)
	15[d]	8[d]	
	10–20[c]	5–15[e]	
Shale	5[d]	2[d]	10^{-7}–10^{-3} (unfractured to fractured)
	1–10[c]	0.5–5[c]	
Granite	0.1[b]	0.09[b]	10^{-7}–10^{2} (unfractured to fractured, igneous and metamorphic)
	0.1[d]	0.5[d]	
	1[c]		
Basalt	11[b]	8[d]	10^{-7}–10^{5} (unfractured, fractured, to lava)

[a] *Protection of Public Water Supplies from Ground-Water Contamination*, Seminar Publication, EPA/625/4-85/016, Center for Environmental Research Information, Cincinnati, OH, September 1985, p. 11.
[b] R. C. Heath, *Basic Ground-Water Hydrology*, U.S. Geological Survey Paper 2220, U.S. Government Printing Office, Washington, DC, 1983.
[c] H. Ries and T. L. Watson, *Engineering Geology*, Wiley, New York, 1931.
[d] R. K. Linsley and J. B. Franzini, *Water Resources Engineering*, McGraw-Hill, New York, 1964.
[e] F. G. Driscoll, *Groundwater and Wells*, 2nd ed., Johnson Division, St. Paul, MN, 1986, p. 67.

Source: D. K. Todd, *Ground Water Hydrology*, 2nd ed., Wiley, New York, 1980.

water level between two wells a mile apart is 10 feet. The hydraulic-conductivity of the sand is 500 gpd/ft^2. Find Q:

$$\begin{aligned} Q &= KIA \\ &= 500\,\text{gpd/ft}^2 \times (10\,\text{ft}/5280\,\text{ft}) \times 5{,}280\,\text{ft} \times 30\,\text{ft} \\ &= 150{,}000\,\text{gpd} \end{aligned}$$

Also,

$$v = \frac{KI}{7.48n}$$

where

v = groundwater velocity, ft/day
n = effective porosity as a decimal

Find v:

$$\begin{aligned} v &= \frac{500\,\text{gpd} \times 10\,\text{ft}/5280\,\text{ft}}{7.48\,\text{g/ft}^3 \times 0.2} \\ &= 0.63\,\text{ft/day} \end{aligned}$$

Another example is given using Figure 1.3 and Darcy's law, expressed as

$$v = Ks$$

where

v = velocity of flow through an aquifier
K = coefficient of permeability (hydraulic conductivity)
s = hydraulic gradient

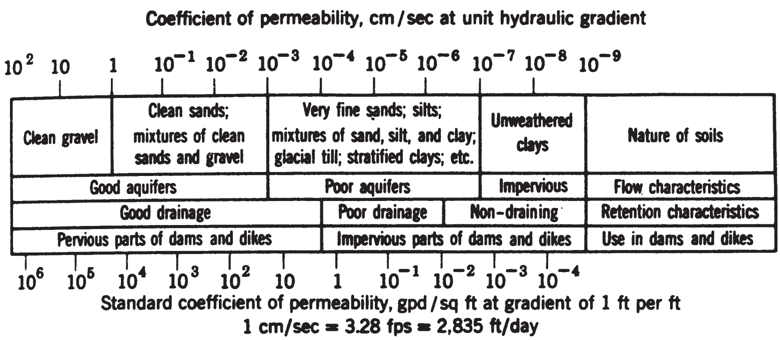


FIGURE 1.3 Magnitude of coefficient of permeability for different classes of soils. (*Source*: G. M. Fair, J. C. Geyer, and D. A. Okun, *Water and Wastewater Engineering*, Wiley, New York, 1966, pp. 9–13.)

Also,

$$Q = va$$

where

Q = discharge
a = cross-sectional area of aquifer

Example: (1) Estimate the velocity of flow (ft/day) and the discharge (gpd) through an aquifer of very coarse sand 1,000 feet wide and 50 feet thick when the slope of the groundwater table is 20 ft/m.

(2) Find the standard coefficient of permeability and the coefficient of transmissibility on the assumption that the water temperature is 60°F (16°C).

1. From Figure 1.3, choose a coefficient of permeability $K = 1.0$ cm/sec = 2835 ft/day. Because $s = 20/5280$, $v = 2835 \times 20/5280 = 11$ ft/day and $Q = 11 \times 1000 \times 50 \times 7.5 \times 10^{-6} = 4.1$ mgd.
2. The standard coefficient of permeability is $2{,}835 \times 7.5 = 2.13 \times 10^4$, and the coefficient of transmissibility becomes $2.13 \times 10^4 \times 50 = 1.06 \times 10^6$.

The characteristics of some materials are given in Table 1.3.

Groundwater Classification

The EPA has proposed the following groundwater classification system:

Class I: *Special Ground Water* are those which are highly vulnerable to contamination because of the hydrological characteristics of the areas in which they occur *and* which are also characterized by either of the following two factors:

a. Irreplaceable, in that no reasonable alternative source of drinking water is available to substantial populations; or
b. Ecologically vital, in that the aquifer provides the base flow for a particularly sensitive ecological system that, if polluted, would destroy a unique habitat.

Class II: *Current and Potential Sources of Drinking Water and Waters Having Other Beneficial Uses* are all other groundwaters which are currently used or are potentially available for drinking water or other beneficial use.

Class III: *Ground Waters Not Considered Potential Sources of Drinking Water and of Limited Beneficial Use* are ground waters which are heavily saline, with Total Dissolved Solids (TDS) levels over 10,000 mg/1, or are otherwise contaminated beyond levels that allow cleanup using methods employed in public water system treatment. These ground waters also must not migrate to Class I or Class II ground waters or have a discharge to surface water that could cause degradation.[25]

This classification system has been debated at great length. Some states have adopted stricter standards and eliminated class III, whereas others have added classifications.

Water Quality

The cleanest available sources of groundwater and surface water should be protected, used, and maintained for potable water supply purposes. Numerous parameters are used to determine the suitability of water and the health significance of contaminants that may be found in untreated and treated water. Watershed and wellhead protection regulations should be a primary consideration.

Microbiological, physical, chemical, and microscopic examinations are discussed and interpreted in this chapter under those respective headings. Water quality can be best assured by maintaining water clarity, chlorine residual in the distribution system, confirmatory absence of indicator organisms, and low bacterial population in the distributed water.[26]

Table 1.4 shows the standards for drinking water coming out of a tap served by a public water system. These are based on the National Primary Drinking Water Standards developed under the Safe Drinking Water Act of 1974 as amended in 1986 and 1996. The maximum contaminant level goals (MCLGs) in Table 1.4 are nonenforceable health goals that are to be set at levels at which no known or anticipated adverse health effects occur and that allow an adequate margin of safety. Maximum contaminant levels (MCLs) are enforceable and must be set as close to MCLGs as is feasible, based on the use of best technology, treatment techniques, analytical capabilities, costs, and other means. The EPA has based the MCLs on the potential health effects from the ingestion of a contaminant on the assumption that the effects observed (of a high dose) in animals may occur (at a low dose) in humans. This assumption has engendered considerable debate.

Secondary regulations, shown in Table 1.5, have also been adopted, but these are designed to deal with taste, odor, and appearance of drinking water and are not mandatory unless adopted by a state. Although not mandatory, these parameters have an important indirect health significance. Water that is not palatable is not likely to be used for drinking, even though reported to be safe, in both developed and underdeveloped areas of the world. A questionable or contaminated water source may then be inappropriately used. Water industry professionals in the United States should adhere to the USEPA primary and secondary standards without deviation or risk jeopardizing public health, either acutely (in the short term) or chronically (exposure over a long period.) It is also important to note that while each of the 50 states (and territories) must adopt and enforce USEPA's standards, they are free to either promulgate standards that are more stringent that USEPA or regulate contaminants that are of particular concern in their state. California, for example, regulates perchlorate even though there is no federal mandate to do so.

Tables 1.6 to 1.10 give World Health Organization (WHO) water-quality guidelines. It is not intended that the individual values in Tables 1.6 to 1.10 be

TABLE 1.4 Summary of National Primary Drinking Water Regulations, March 2008 (USEPA)

Name of Contaminant	Maximum Contaminant Level (MCL) (mg/1 unless noted)	Health Effects of Contaminant
	Inorganic Chemicals	
Antimony	0.006	Decreased longevity, blood effects
Arsenic	0.010	Cancer risk/cardiovascular and dermal effects
Asbestos (fiber length >10 μm)	7 million fibers per liter (MFL)	Lung tumors/cancer risk
Barium	2	Circulatory/gastrointestinal effects
Beryllium	0.004	Bone/lung effects/cancer risk
Cadmium	0.005	Liver/kidney/bone/circulatory effects
Chromium (total)	0.1	Liver/kidney/circulatory effects
Copper	Treatment technique (action limit 1.3)	Gastrointestinal/liver/kidney effects
Cyanide	0.2	Thyroid/neurologic effects
Fluoride	4	Skeletal effects
Lead	Treatment technique (action limit 0.015)	Cancer risk/kidney/nervous system effects Highly toxic to infants
Mercury (inorganic)	0.002	Kidney damage
Nickel	0.1	Nervous system/liver/heart effects/dermatitis
Nitrate (as N)	10	Methemoglobinemia (blue baby syndrome)/diuresis
Nitrite (as N)	1	Methemoglobinemia (blue baby syndrome)
Selenium	0.05	Nervous system/kidney/liver/circulatory effects
Thallium	0.002	Kidney/liver/brain/intestine effects
Radionuclides		
Combined radium-226 and radium-228	5 pCi/1	Cancer risk
Gross alpha (excluding radon and uranium)	15 pCi/1	Cancer risk

Beta particle and photon	4 mrem/year	Cancer risk
Radioactivity, uranium	0.030	Kidney effects/cancer risk
	Organic Chemicals	
SYNTHETIC ORGANIC COMPOUNDS		
2,3,7,8-TCDD (Dioxin)	0.00000003	Cancer risk/reproductive effects
2,4,5-TP (Silvex)	0.05	Liver/kidney effects
2,4-D	0.07	Nervous system/liver/kidney effects
Acrylamide	Treatment technique	Cancer risk/nervous system effects
Alachlor	0.002	Cancer risk/liver/kidney/spleen effects
Aldicarb[a]	0.003	Nervous system effects
Aldicarb sulfone[a]	0.003	Nervous system effects
Aldicarb sulfoxide[a]	0.004	Nervous system effects
Atrazine	0.003	Cardiologic effects/cancer risk/muscular degeneration
Carbofuran	0.04	Nervous/reproductive system effects
Chlordane	0.002	Cancer risk/liver/kidney/spleen effects
Dalapon	0.2	Kidney effects
Di(2-ethylhexyl)adipate	0.4	Liver/bone effects/cancer risk
1,2-Dibromo-3-chlorpropane (DBCP)	0.0002	Cancer risk/kidney/reproductive effects
Di(2-ethylhexyl)phthalate (DEHP)	0.006	Cancer risk/liver/reproductive effects
Dinoseb	0.007	Thyroid/reproductive organ effects
Diquat	0.02	Ocular effects
Endothall	0.1	Kidney/liver/gastrointestinal effects
Endrin	0.002	Liver effects
Epichlorohydrin	Treatment technique	Cancer risk/circulatory/stomach effects
Ethylene dibromide (EDB)	0.00005	Cancer risk/liver/heart/kidney/nervous system effects
Glyphosate	0.7	Kidney/reproductive effects

(*continues*)

TABLE 1.4 (*continued*)

Name of Contaminant	Maximum Contaminant Level (MCL) (mg/1 unless noted)	Health Effects of Contaminant
Heptachlor	0.0004	Cancer risk/liver effects
Heptachlor epoxide	0.0002	Cancer risk
Hexachlorobenzene	0.001	Cancer risk/liver/reproductive effects
Hexachlorocyclopentadiene (HEX)	0.05	Kidney/stomach effects
Lindane	0.0002	Kidney/liver/nervous/circulatory effects
Methoxychlor	0.04	Kidney/liver/nervous/developmental effects
Oxamyl (Vydate)	0.2	Nervous system effects
PAHs (benzo[*a*]pyrene)	0.0002	Cancer risk/developmental/reproductive effects
PCBs (polychlorinated biphenyls)	0.0005	Cancer risk/liver/gastrointestinal effects
Pentachlorophenol	0.001	Cancer risk/reproductive/liver/kidney effects
Picloram	0.5	Nervous system/liver effects
Simazine	0.004	Cancer risk/liver/kidney/thyroid effects
Toxaphene	0.003	Cancer risk/liver/kidney/nervous system effects
VOLATILE ORGANIC COMPOUNDS		
1,1-Dichloroethylene	0.007	Kidney/liver effects/cancer risk
1,1,1-Trichloroethane	0.2	Liver/circulatory/nervous system effects
1,1,2-Trichloroethane	0.005	Kidney/liver effects/cancer risk
1,2-Dichloroethane	0.005	Cancer risk
1,2-Dichloroprapane	0.005	Cancer risk/liver/kidney/gastrointestinal effects
1,2,4-Trichlorobenzene	0.07	Kidney/liver/adrenal gland effects
Benzene	0.005	Cancer risk/nervous system effects
Carbon tetrachloride	0.005	Cancer risk/liver effects
Chlorobenzene	0.1	Nervous system/liver effects
Cis-1,2-dichloroethylene	0.07	Liver/nervous/circulatory effects

Dichloromethane	0.005	Cancer risk/liver effects
Ethylbenzene	0.7	Kidney/liver/nervous system effects
Ortho-dichlorobenzene	0.6	Kidney/liver/blood cell/nervous system effects
Para-dichlorobenzene	0.075	Cancer risk/liver/circulatory effects
Styrene	0.1	Liver/nervous system effects/cancer risk
Tetrachloroethylene (PCE)	0.005	Cancer risk/liver/kidney/nervous system effects
Toluene	1	Kidney/liver effects
Trans-1,2-dichloroethylene	0.1	Nervous system/liver/circulatory effects
Trichloroethylene (TCE)	0.005	Cancer risk/liver effects
Vinyl chloride	0.002	Cancer risk/neurologic/liver effects
Xylenes (total)	10	kidney/liver/nervous system effects
	Microbiologic Contaminants	
TOTAL COLIFORM RULE (TCR)		
Total coliforms; fecal coliforms; *Escherichia coli*	Less than 40 samples/month; no more than one positive for total coliforms. If 40 samples or more per month, or more than 5% positive. Maximum contaminate level goal (MCLG) = 0 for total coliform, fecal coliform, and *E. coli*. Every sample containing total coliforms must be analyzed for fecal coliforms.	Presence of fecal coliform or *E. coli* may indicate potential contamination that can cause diarrhea, cramps, nausea, headaches, or other symptoms.
SURFACE WATER TREATMENT RULE		
Turbidity	Treatment technique	None; interferes with disinfection
Giardia	Treatment technique (MCLG = 0)	Giardiasis
Enteric Viruses	Treatment technique (MCLG = 0)	Gastrointestinal and other viral infections
Legionella	Treatment technique (MCLG = 0)	Legionnaire's disease
Heterotrophic plate count (HPC)	Treatment technique (MCLG = none)	Gastrointestinal infections
INTERIM ENHANCED SURFACE WATER TREATMENT RULE (IESWTR)		
Turbidity	Treatment technique	None; interferes with disinfection
Cryptosporidium	Treatment technique (MCLG = 0)	Cryptosporidiosis

(*continues*)

TABLE 1.4 (*continued*)

Name of Contaminant	Maximum Contaminant Level (MCL) (mg/1 unless noted)	Health Effects of Contaminant
FILTER BACKWASH RULE		
Cryptosporidium	Treatment technique (MCLG = 0)	Cryptosporidiosis
LONG TERM 2 ENHANCED SURFACE WATER TREATMENT RULE (LT2ESWTR)		
Cryptosporidium	Treatment technique (MCLG = 0) PWSs to monitor for cryptosporidium between 2006–2010 (staggered by system size). Additional treatment (if necessary) in place by 2012-2014.	Cryptosporidiosis
Giardia	Treatment technique (MCLG = 0)	Giardiasis
Viruses	Treatment technique (MCLG = 0)	Gastrointestinal and other viral infections
Disinfectants and Disinfection By-Products: Stage 1,2 D/DBPR		
DISINFECTANTS		
Chlorine	Maximum disinfectant residual level (MRDL)-4.0 (as Cl_2)	Eye/nose irritation, stomach discomfort
Chloramines	MRDL-4.0 (as Cl_2)	Hemolytic anemia in dialysis
Chlorine dioxide	MRDL-0.8 (as ClO_2)	Anemia; nervous system effects
DISINFECTION BY-PRODUCTS		
Total trihalomethanes (TTHMs)	0.080	Cancer risk/reproductive effects
Haloacetic acids (HAA5)	0.060	Cancer risk
Chlorite	1.0	Cancer risk
Bromate	0.010	Cancer risk/nervous system/liver effects
Total organic carbon (TOC)	Treatment technique	

[a] Aldicarb and metabolites are presently stayed, pending reproposal.

TABLE 1.5 Secondary Drinking Water Regulations, 2008 (USEPA)

Contaminant	Effect	Level
pH	Water should not be to acidic or too basic.	6.5–8.5
Aluminum	Colored water	0.05–0.2 mg/l
Chloride	Taste and corrosion of pipes	250 mg/1
Copper	Taste and staining of porcelain	1 mg/1
Foaming agents	Aesthetic	0.5 mg/1
Sulfate	Taste and laxative effects	250 mg/1
Total dissolved solids (hardness)	Taste and possible relation between low hardness and cardiovascular disease, also an indicator of corrosivity (related to lead levels in water); can damage plumbing and limit effectiveness of soaps and detergents	500 mg/1
Silver	Skin and eye discoloration	0.1 mg/l
Zinc	Taste	5 mg/1
Fluoride	Dental fluorosis (a brownish discoloration of the teeth)	2 mg/1
Color	Aesthetic	15 color units
Corrosivity	Aesthetic and health related (corrosive water can leach pipe materials, such as lead, into the drinking water)	Noncorrosive
Iron	Taste	0.3 mg/1
Manganese	Taste	0.05 mg/1
Odor	Aesthetic	3 threshold odor number

Source: U.S. Environmental Protection Agency, Fact Sheet, Office of Ground Water and Drinking Water, Washington, DC, March 2008.

used directly. Guideline values in the tables must be used and interpreted in conjunction with the information contained in the appropriate sections of Chapters 2 to 5 of *Guidelines for Drinking-Water Quality*, 2nd ed., volume 2, WHO, Geneva, 1996, 1998. Water treatment plant designers, operators and regulators worldwide should evaluate their water-quality goals and strive to produce the best water quality possible given the available technology, regardless of regulatory parameters.

TABLE 1.6 Microbiological and Biological Quality (WHO)

	Unit	Guideline Value	Remarks
		I. Microbiological Quality	
A. PIPED WATER SUPPLIES			
A.1 Treated Water Entering Distribution System			
Fecal coliforms	Number/100 ml	0	Turbidity <1 NTU; for disinfection with chlorine, pH preferably <8.0; free chlorine residual 0.2–0.5 mg/l following 30 min (minimum) contact.
Coliform organisms	Number/100 ml	0	—
A.2 Untreated Water Entering Distribution System			
Fecal coliforms	Number/100 ml	0	
Coliform organisms	Number/100 ml	0	In 98% of samples examined throughout the year, in the case of large supplies when sufficient samples are examined.
		3	In an occasional sample, but not in consecutive samples.
A.3 Water in Distribution System			
Fecal coliforms	Number/100 ml	0	—
Coliform organisms	Number/100 ml	0	In 95% of samples examined throughout year, in the case of large supplies when sufficient samples are examined.
		3	In an occasional sample, but not in consecutive samples.

B. UNPIPED WATER SUPPLIES			
Fecal coliforms	Number/100 ml	0	
Coliform organisms	Number/100 ml	10	Should not occur repeatedly; if occurrence is frequent and if sanitary protection cannot be improved, an alternative source must be found if possible.
C. BOTTLED DRINKING WATER			
Fecal coliforms	Number/100 ml	0	Source should be free from fecal contamination.
Coliform organisms	Number/100 ml	0	—
D. EMERGENCY WATER SUPPLIES			
Fecal coliforms	Number/100 ml	0	Advise public to boil water in case of failure to meet guideline values.
Coliform organisms	Number/100 ml	0	—
Enteroviruses	—	No guideline value set	—
		II. Biological Quality	
Protozoa (pathogenic)	—	No guideline value set	—
Helminths (pathogenic)	—	No guideline value set	—
Free-living organisms (algae, others)	—	No guideline value set	—

Source: Guidelines for Drinking-Water Quality, Vol. 1: *Recommendations*, World Health Organization, Geneva, 1984, Table 1. Reproduced with permission.

TABLE 1.7 Inorganic Constituents of Health Significance (WHO)

Constituent	Unit	Guideline Value
Arsenic	mg/l	0.05
Asbestos	—	No guideline value
Barium	—	No guideline value
Beryllium	—	No guideline value
Cadmium	mg/l	0.005
Chromium	mg/l	0.05
Cyanide	mg/l	0.1
Fluoride[a]	mg/l	1.5
Hardness	—	No health-related guideline value
Lead	mg/l	0.05
Mercury	mg/l	0.001
Nickel	—	No guideline value
Nitrate	mg/l (N)	10
Nitrite	—	No guideline value
Selenium	mg/l	0.01
Silver	—	No guideline value
Sodium	—	No guideline value

[a]Natural or deliberately added; local or climatic conditions may necessitate adaptation.

Source: Guidelines for Drinking-Water Quality, Vol. 1: *Recommendations*, World Health Organization, Geneva, 1984, Table 2. Reproduced with permission.

National secondary drinking water regulations shown in Table 1.5 are federally nonenforceable regulations that control contaminants in drinking water affecting the aesthetic qualities related to public acceptance of drinking water. These levels represent reasonable goals for drinking water quality. States may establish higher or lower levels, which may be appropriate, depending on local conditions such as unavailability of alternate source waters or other compelling factors, provided that public health and welfare are not adversely affected.

It is recommended that the parameters in these regulations be monitored at intervals no less frequent than the monitoring performed for inorganic chemical contaminants listed in the National Primary Drinking Water Regulations as applicable to community water systems. More frequent monitoring would be appropriate for specific parameters such as pH, color, and odor under certain circumstances as directed by the state.

Sampling and Quality of Laboratory Data

Raw and finished water should be continually monitored. Prior arrangements should also be made for the treatment plant to be immediately notified by upstream dischargers in case of wastewater treatment plant operational failures or accidental releases of toxic or other hazardous substances. A water treatment plant should have a well-equipped laboratory, certified operator, and qualified chemist. Disinfectant residual, turbidity, and pH should be monitored continuously where

TABLE 1.8 Organic Constituents of Health Significance (WHO)

	Unit	Guideline Value	Remarks
Aldrin and dieldrin	μg/l	0.03	
Benzene	μg/l	10[a]	
Benzol[*a*]pyrene	μg/l	0.01[a]	
Carbon tetrachloride	μg/l	3[a]	Tentative guideline value[b]
Chlordane	μg/l	0.3	—
Chlorobenzenes	μg/l	No health-related guideline value	Odor threshold concentration between 0.1 and 3 μg/l
Chloroform	μg/l	30[a]	Disinfection efficiency must not be compromised when controlling chloroform content
Chlorophenols	μg/l	No health-related guideline value	Odor threshold concentration 0.1 μg/l
2,4-D	μg/l	100[c]	
DDT	μg/l	1	
1,2-Dichloroethane	μg/l	10[a]	
1,1-Dichloroethene[d]	μg/l	0.3[a]	
Heptachlor and heptachlor epoxide	μg/l	0.1	
Hexachlorobenzene	μg/l	0.01[a]	
Gamma-HCH (lindane)	μg/l	3	
Methoxychlor	μg/l	30	
Pentachlorophenol	μg/l	10	
Tetrachloroethene[e]	μg/l	10[a]	Tentative guideline value[b]
Trichloroethene[f]	μg/l	30[a]	Tentative guideline value[b]
2,4,6-Trichlorophenol	μg/l	10[a, c]	Odor threshold concentration, 0.1 μg/l
Trihalomethanes		No guideline value	See chloroform

[a] These guideline values were computed from a conservative hypothetical mathematical model that cannot be experimentally verified and values should therefore be interpreted differently. Uncertainties involved may amount to two orders of magnitude (i.e., from 0.1 to 10 times the number).
[b] When the available carcinogenicity data did not support a guideline value but the compounds were judged to be of importance in drinking water and guidance was considered essential, a tentative guideline value was set on the basis of the available health-related data.
[c] May be detectable by taste and odor at lower concentrations.
[d] Previously known as 1,1-dichloroethylene.
[e] Previously known as tetrachloroethylene.
[f] Previously known as trichloroethylene.

Source: Guidelines for Drinking-Water Quality, Vol. 1: *Recommendations*, World Health Organization, Geneva, 1984, Table 3. Reproduced with permission.

TABLE 1.9 Aesthetic Quality (WHO)

Characteristic	Unit	Guideline Value	Remarks
Aluminum	mg/l	0.2	
Chloride	mg/l	250	
Chlorobenzenes and chlorophenols	—	No guideline value	These compounds may affect taste and odor.
Color	True color units (TCU)	15	
Copper	mg/l	1.0	
Detergents	—	No guideline value	There should not be any foaming or taste and odor problems.
Hardness	mg/l (as $CaCO_3$)	500	
Hydrogen sulfide	—	Not detectable by consumers	
Iron	mg/l	0.3	
Manganese	mg/l	0.1	
Oxygen, dissolved	—	No guideline value	
pH	—	6.5–8.5	
Sodium	mg/l	200	
Solids, total dissolved	mg/l	1000	
Sulfate	mg/l	400	
Taste and odor	—	Inoffensive to most consumers	
Temperature	—	No guideline value	
Turbidity	Nephelometric turbidity units (NTU)	5	Preferably <1 for disinfection efficiency.
Zinc	mg/l	5.0	

Source: Guidelines for Drinking-Water Quality, Vol. 1: *Recommendations*, World Health Organization, Geneva, 1984, Table 4. Reproduced with permission.

TABLE 1.10 Radioactive Constituents (WHO)

	Unit[a]	Guideline Value
Gross alpha activity	Bq/1	0.1
Gross beta activity	Bq/1	1

[a]*Notes:* (a) If the levels are exceeded, more detailed radionuclide analysis may be necessary, (b) Higher levels do not necessarily imply that the water is unsuitable for human consumption [a]One bequerel (Bq) = 2.7×10^{-11} curie.

Source: Guidelines for Drinking-Water Quality, Vol. 1: *Recommendations*, World Health Organization, Geneva, 1984, Table 5. Reproduced with permission.

possible. In addition to routine testing equipment, equipment at large plants usually include a zeta meter for coagulant dosing measurements, a nephelometer for turbidity readings, a flame spectrophotometer for measuring inorganic chemicals, and a gas chromatograph with spectrophotometer instrument to measure organic chemicals in low concentrations (micrograms per liter or less). The analytical methods for MCL determination approved by the EPA for volatile chemicals include gas chromatography and gas chromatography–spectrometry techniques. The MCLG for a probable human carcinogen is proposed to be "zero," the limit of detection for regulatory purposes. The MCLGs are unenforceable health goals for public water systems that cause no known or adverse health effects and incorporate an adequate margin of safety. The MCL is an enforceable standard established in the primary drinking water regulations that takes economic factors into consideration, in addition to no unreasonable risk to health. It should be understood that failure to report the presence of certain chemicals or microorganisms does not mean they are not present if the laboratory does not examine for them. All examinations should be made in accordance with the procedures given in *Standard Methods for the Examination of Water and Wastewater*, latest edition or one approved by the EPA (see the Bibliography).

Water samples may be continuous (such as for turbidity or particle counting), grab (instantaneous), composite (an accumulation of grab samples of equal volume), or flow-weighted composite (proportional to volume of flow). Most drinking water samples are grab, although this can be misleading when sampling for organic chemicals or heavy metals. Wastewater samples are composite or flow-weighted composite. When sampling, laboratory collection procedures should be followed.

Drinking water samples should be collected at times of maximum water usage from representative locations including residences. The sampling tap should be clean, not leaking (except in the case of lead and copper monitoring), and flushed for two to three minutes before sample collection. A 1-inch air space should be left on top of the bottle for a bacteriological sample. The bottle should be completely filled for a chemical sample; there must be no air bubble at the top. A laboratory-prepared bottle should be used.

Examination of a nonrepresentative sample is a waste of the sample collector's and the laboratory's time. It will give misleading information that can lead to incorrect and costly actions, discredit the agency or organization involved, and destroy a legal action or research conclusion.

There is a tendency to collect more samples and laboratory data than are needed. The tremendous resources in money, manpower, and equipment committed to the proper preparation, collection, and shipment of the samples and to the analytical procedures involved are lost sight of or misunderstood. Actually, a few carefully selected samples of good quality can usually serve the intended purpose.

The purpose or use of the laboratory data should determine the number of samples and quality of the laboratory work. Data of high quality are needed for official reporting and to support enforcement action or support a health effects study, while data of lesser quality may be acceptable for trend, screening, or monitoring purposes. High-quality legal data must follow official sample collection, identification, shipment, and analytical procedures exactly and without deviation.

The goal of a quality assurance program is to obtain scientifically valid, defensible data of known precision and accuracy to fulfill the water and/or wastewater utility's responsibility to protect and enhance the nation's environment.[27]

The laboratory is an essential ingredient of the effectiveness of the environmental program. However, the laboratory must resist the temptation to become involved in program operation and regulation activities, since its function does not involve sanitary surveys, routine inspection, performance evaluation, program enforcement, responsibility, regulation continuity, and effectiveness. In addition, its limited resources would be misdirected and diluted to the detriment of its primary function. This does not mean that the laboratory should not be involved in training, treatment plant laboratory certification, and solving difficult water plant operational problems.

Sanitary Survey and Water Sampling

A sanitary survey is necessary to determine the reliability of a water system to continuously supply safe and adequate water to the consumer.[28] It is also necessary to properly interpret the results of water analyses and evaluate the effects of actual and potential sources of pollution on water quality. The value of the survey is dependent on the training and experience of the investigator. When available, one should seek the advice of the regulatory agency sanitary engineer or sanitarian. Watershed protection includes enactment of watershed rules and regulations and regular periodic surveillance and inspections. It, in effect, becomes epidemiological surveillance and is a study of environmental factors that may affect human health. Watershed rules and regulations are legal means to control land use that might cause pollution of the water draining off and into the watershed of the water supply source.

If the source of water is a natural or manmade lake, attention would be directed to the following, for each contributes distinctive characteristics to the water: entire drainage basin and location of sewage and other solid and liquid waste disposal or treatment systems; bathing areas; stormwater drains; sewer outfalls; swamps; cultivated areas; feed lots; sources of erosion, sediment and pesticides; and wooded areas, in reference to the pump intake. When water is obtained from a stream or creek, all land and habitation above the water supply intake should be investigated. This means inspection of the entire watershed drainage area so that actual and potential sources of pollution can be determined and properly evaluated and corrective measures instituted. All surface-water supplies must be considered of doubtful sanitary quality unless given adequate treatment, depending on the type and degree of pollution received.

Sanitary surveys have usually emphasized protection of surface-water supplies and their drainage areas. Groundwater supplies such as wells, infiltration galleries, and springs have traditionally been protected by proper construction and location (at an arbitrary "safe" distance from potential sources of pollution and not directly downgrade). The rule-of-thumb distance of 75, 100, or 200 feet, coupled with well construction precautions, has usually served this purpose in most instances, such as for on-site residential wells, in the absence of hydrogeological and engineering investigation and design. However, greater attention is being given to potential distant sources of pollution, especially chemical sources.

The 1996 amendments to the Safe Drinking Water Act require a more sophisticated approach referred to as wellhead protection of groundwater sources. The wellhead is defined as "the surface and subsurface area surrounding a water well or wellfield supplying a public water system through which contaminants are reasonably likely to move toward and reach such well or wellfield."* Determination of the aquifer limits and the drainage area tributary to a well or wellfield, an infiltration gallery, or spring, and the reasonable time of potential contaminants' travel, requires knowledge of the geological formations in the area and the groundwater movement in adjacent and distant tributary areas. In confined or artesian aquifers, this is not readily apparent. The water may originate nearby or at a considerable distance, depending on the extent to which the aquifer formation is confined, channeled, or fractured and on its depth. The U.S. Geological Survey and state geological and water resources agencies may be able to provide information on the local geology and the aquifers. Protection of the tributary wellhead area would require governmental land-use controls, watershed rules and regulations, water purveyor ownership, and public cooperation. To accomplish this, it is first necessary to geographically identify the wellhead area, including groundwater flow, and all existing and potential sources of contamination in that area. This must be supplemented by the controls mentioned, including enactment of watershed (wellhead) protection rules and regulations, and their enforcement. See "Source and Protection of Water Supply," later in this chapter.

The sanitary survey would include, in addition to the source as already noted, the potential for and effects of accidental chemical spills and domestic sewage or industrial waste discharges and leachate from abandoned and existing hazardous waste and landfill sites. Included in the survey would be inspection and investigation of the reservoir, intake, pumping station, treatment plant, and adequacy of each unit process; operation records; distribution system carrying capacity, head losses, and pressures; storage facilities; emergency source of water and plans to supply water in emergency; integrity of laboratory services; connections with other water supplies; and actual or possible cross-connections with plumbing fixtures, tanks, structures, or devices that might permit backsiphonage or backflow. Certification of operators, the integrity and competence of the person in charge of the plant, and adequacy of budgetary support are important factors. Consideration should also be given to land-use plans and the purchase of hydrogeologically sensitive areas and zoning controls.

*Also defined as the area between a well and the 99 percent theoretical maximum extent of the stabilized cone of depression. CFR Title 40, Subchapter D, Part 141, U.S. Government Printing Office, July 1999.

Water samples are collected as an adjunct to the sanitary survey as an aid in measuring the quality of the raw water and effectiveness of treatment given. Microbiological examinations; chemical, radiochemical, and physical analyses; and microscopic examinations may be made, depending on the sources of water, climate, geology, hydrology, waste disposal practices on the watershed, problems likely to be encountered, and purpose to be served. In any case, all samples should be properly collected, transported, and preserved as required, and tests should be made by an approved laboratory in accordance with the procedures provided in the latest edition of *Standard Methods for the Examination of Water and Wastewater*[29] or as approved by the EPA.

A sanitary technique and a glass or plastic sterile bottle supplied and prepared by the laboratory for the purpose should be used when collecting a water sample for bacteriological examination. Hands or faucet must not touch the edge of the lip of the bottle or the plug part of the stopper. The sample should be taken from a clean faucet that does not have an aerator or screen and that is not leaking or causing condensation on the outside. Flaming of the tap is optional. The water should be allowed to run for about two to three minutes to get a representative sample. To check for metals and bacteria in household plumbing, the sample must be taken as a "standing" sample without preliminary running of water. A household water softener or other treatment unit may introduce contamination. If a sample from a lake or stream is to be collected, the bottle should be dipped below the surface with a forward sweeping motion so that water coming in contact with the hands will not enter the bottle. When collecting a sample for bacteriological examination, there should be an air space in the bottle. When collecting samples of chlorinated water, the sample bottle should contain sodium thiosulfate to dechlorinate the water. It is recommended that all samples be examined promptly after collection and within 6 to 12 hours if possible. After 24 to 48 hours, examinations may not be reliable.

The chemical and physical analyses may be for industrial or sanitary purposes, and the determinations made will be either partial or complete, depending on the information desired. Water samples for inorganic chemical analyses are usually collected in 1-liter polyethylene containers, new or acid washed if previously used. Samples for lead in drinking water at a tap or from a drinking fountain should be collected in the morning before the system has been used and flushed out and also during the day when the water is being used. Samples for organic chemical analyses are usually collected in 40-ml glass vials or 1-liter glass bottles with Teflon-lined closure.[30] Special precautions are necessary to ensure collection of representative samples free of incidental contamination and without loss of volatile fractions.[31] Containers must be completely filled. A special preservative is added for certain tests, and delivery time to the laboratory is sometimes specified. Samples are also collected for selected tests to control routine operation of a water plant and to determine the treatment required and its effectiveness.

Samples for microscopic examination should be collected in clean, wide-mouth bottles having a volume of 1 or 2 liters from depths that will yield representative organisms. Some organisms are found relatively close to the surface, whereas others are found at middepth or near the bottom, depending on the food, type of organism, and clarity and temperature of the water. Microscopic examinations can determine the changing types, concentrations, and locations of microscopic organisms, control measures or treatment indicated, and time to start treatment. A proper program can prevent tastes and odors by eliminating the responsible organisms that secrete certain oils before they can cause the problem. In addition, objectionable appearances in a reservoir or lake are prevented and sedimentation and filter runs are improved. Attention should also be given to elimination of the conditions favoring the growth of the organisms. See also "Microscopic Examination" in this chapter and "Control of Microorganisms", in Chapter 2.

Sampling Frequency

The frequency with which source and distribution system water samples are collected and used for bacteriologic, chemical, radiologic, microscopic, and physical analyses is usually determined by the regulatory agency, the water quality historical record, plant operational control requirements, and special problems. Operators of public water systems and industrial and commercial water systems will want to collect more frequent but carefully selected samples and make more analyses to detect changes in raw water quality to better control treatment, plant operation, and product quality.

The number of distribution system samples is usually determined by the population served, quality of the water source, treatment, past history, and special problems. Table 1.11 shows the minimum required sampling frequency for coliform density at community water systems in the United States. If routine sampling results in a "positive" indication of coliform bacteria, repeat sampling must be performed to verify the presence of actual bacteria. Table 1.11a presents the number of repeat samples necessary to verify whether or not the system is contaminated. At noncommunity water supplies a sample is collected in each quarter during which the system provides water to the (traveling) public. The minimum sampling frequency recommended by the WHO is shown in Table 1.12. Sampling points should reflect the quality of the water in the distribution system and be at locations of greatest use.

Fecal coliforms/E. coli; Heterotrophic Bacteria (HPC)

- If any routine or repeat sample is total coliform positive, the system must also analyze that total coliform positive culture to determine if fecal coliforms or *E. coli* are present. If fecal coliforms or *E. coli* are detected, the system must notify the state before the end of the same business day, or, if detected after the close of business for the state, by the end of the next business day.
- If any repeat sample is fecal coliform or *E. coli* positive or if a fecal coliform- or *E. coli*-positive original sample is followed by a total coliform-positive repeat sample and the original total coliform-positive sample is not invalidated, it is an acute violation of the MCL for total coliforms.

TABLE 1.11 Total Coliform Sampling Requirements According to Population Served

Population Served	Minimum Number of of Routine Samples per Month[a]	Population Served	Minimum Number of Routine Samples per Month[a]
25–1000[b]	1[c]	59,001–70,000	70
1001–2500	2	70,001–83,000	80
2501–3300	3	83,001–96,000	90
3301–4100	4	96,001–130,000	100
4101–4900	5	130,001–220,000	120
4901–5800	6	220,001–320,000	150
5801–6700	7	320,001–450,000	180
6701–7600	8	450,001–600,000	210
7601–8500	9	600,001–780,000	240
8501–12900	10	780,001–970,000	270
12,901–17,200	15	970,001–1,230,000	300
17,201–21,500	20	1,230,001–1,520,000	330
21,501–25,000	25	1,520,001–1,850,000	360
25,001–33,000	30	1,850,001–2,270,000	390
33,00–41,000	40	2,270,001–3,020,000	420
41,001–50,000	50	3,020,001–3,960,000	450
50,001–59,000	60	3,960,001 or more	480

[a]In lieu of the frequency specified, a noncommunity water system (NCWS) using groundwater and serving 1000 persons or fewer may monitor at a lesser frequency specified by the state until a sanitary survey is conducted and reviewed by the state. Thereafter, NCWS using groundwater and serving 1,000 persons or fewer must monitor in each calendar quarter during which the system provides water to the public, unless the state determines that some other frequency is more appropriate and notifies the system (in writing). Five years after promulgation, NCWSs using groundwater and serving 1,000 persons or fewer must monitor at least once a year. A NCWSs using surface water or groundwater under the direct influence of surface water, regardless of the number of persons served, must monitor at the same frequency as a like-sized community water system (CWS). A NCWS using groundwater and serving more than 1000 persons during any month must monitor at the same frequency as a like-sized CWS, except that the state may reduce the monitoring frequency for any month the system serves 1,000 persons or fewer.

[b]Include public water systems that have at least 15 service connections but serve fewer than 25 persons.

[c]For CWS serving 25–1,000 persons, the state may reduce this sampling frequency if a sanitary survey conducted in the last 5 years indicates that the water system is supplied solely by a protected groundwater source and is free of sanitary defects. However, in no case may the state reduce the frequency to less than once a quarter.

Source: Fact Sheet, Drinking Water Regulations under the Safe Drinking Water Act, Office of Drinking Water, U.S. Environmental Protection Agency, Washington, DC, May 1990, p. 22.

TABLE 1.11a Monitoring and Repeat Sample Frequency after Total Coliform-Positive Routine Sample

Samples per Month	Number of Repeat Samples[a]	Number of Routine Samples Next Month[b]
1	4	5
2	3	5
3	3	5
4	3	5
5 or greater	3	See Table 1.11

[a]Number of repeat samples in the same month for each total coliform-positive routine sample.
[b]Except where state has invalidated the original routine sample, substitutes an on-site evaluation of the problem or waives the requirement on a case-by-case basis.

Source: Fact Sheet, Drinking Water Regulations under the Safe Drinking Water Act, Office of Drinking Water, U.S. Environmental Protection Agency, Washington, DC, December 1990, pp. 23–25.

TABLE 1.12 Distribution System Sampling

Population Served	Minimum Number of Samples
<5000	1 per month
5000–100,000	1 per 5000 population per month
100,000	1 per 10,000 population per month

Source: Guidelines for Drinking-Water Quality, Vol. 1: *Recommendations*, World Health Organization, Geneva, 1984, p. 24.

- The state has the discretion to allow a water system, on a case-by-case basis, to forgo fecal coliform or *E. coli* testing on total coliform-positive samples if the system complies with all sections of the rules that apply when a sample is fecal coliform positive.
- State invalidation of the routine total coliform-positive sample invalidates subsequent fecal coliform- or *E. coli*-positive results on the same sample.
- Heterotrophic bacteria can interfere with total coliform analysis. Therefore, if the total coliform sample produces (1) a turbid culture in the absence of gas production using the multiple-tube fermentation (MTF) technique; (2) a turbid culture in the absence of an acid reaction using the presence–absence (PA) coliform test; or (3) confluent growth or a colony number that is "too numerous to count" using the membrane filter (MF) technique, the sample is invalid (unless total coliforms are detected, in which case the sample is valid). The system must collect another sample within 24 hours of being notified of the result from the same location as the original sample and have it analyzed for total coliforms.

Analytical Methodology

- Total coliform analyses are to be conducted using the 10-tube MTF technique, the MF Technique, the PA coliform test, or the minimal media ONPG-MUG test (Autoanalysis Colilert System). The system may also use the five-tube MTF technique (20-ml sample portions) or a single culture bottle containing the MTF medium as long as a 100-ml water sample is used in the analysis.
- A 100-ml standard sample volume must be used in analyzing for total coliforms, regardless of the analytical method used.

Invalidation of Total Coliform-Positive Samples

- All total coliform-positive samples count in compliance calculations, except for those samples invalidated by the state. Invalidated samples do not count toward the minimum monitoring frequency.
- A state may invalidate a sample only if (1) the analytical laboratory acknowledges that improper sample analysis caused the positive result; (2) the system determines that the contamination is a domestic or other nondistribution system plumbing problem; or (3) the state has substantial grounds to believe that a total coliform-positive result is due to some circumstance or condition not related to the quality of drinking water in the distribution system if (a) this judgment is explained in writing, (b) the document is signed by the supervisor of the state official who draws this conclusion, and (c) the documentation is made available to the EPA and the public.

Variances and Exemptions: None Allowed Sanitary Surveys

- Periodic sanitary surveys are required for all systems collecting fewer than five samples a month every 5 years at community water systems and every 10 years at noncommunity water systems using protected and disinfected groundwater.

Water Analyses

All analyses should be made in accordance with *Standard Methods*[32] in order to provide confidence in the analytical results. As indicated previously, the interpretation of water analyses is based primarily on the sanitary survey of the water system and an understanding of the criteria used in the regulatory development of the drinking water standards. A water supply that is coagulated and filtered would be expected to be practically clear, colorless, and free of iron, whereas the presence of some turbidity, color, and iron in an untreated surface water supply may be accepted as normal. A summary is given in this section of the constituents and concentrations considered significant in water examinations. Other compounds and elements not mentioned are also found in water. The effectiveness of unit treatment processes can be measured using the tests for total coliforms, fecal coliforms, fecal streptococci, and the standard plate count 6 months prior to and 12 months after the process is put into use.

A properly developed, protected, and chlorinated well-water supply showing an absence of coliform organisms can usually be assumed to be free of viruses, protozoa, and helminths if supported by a satisfactory sanitary survey. This is not necessarily so with a surface-water supply. Chemical examinations are needed to ensure the absence of toxic organic and inorganic chemicals.

A final point: The results of a microbiological or chemical examination reflect the quality of the water only at the time of sampling and must be interpreted in the light of the sanitary survey. However, inorganic chemical examination results from well-water supplies are not likely to change significantly from day to day or week to week when collected under the same conditions. Nevertheless, any change is an indication of probable contamination and reason for investigation to determine the cause. The chemical characteristics of well water are a reflection of the geological formations penetrated. Some bacterial and chemical analyses are shown in Table 1.13.

Heterotrophic Plate Count — The Standard Plate Count

The standard plate count is the total colonies of bacteria developing from measured portions (two 1 ml and two 0.1 ml) of the water being tested, which have been planted in petri dishes with a suitable culture medium (agar) and incubated for 48 hours at 95°F (35°C). Bottled water is incubated at 35°C for 72 hours.[33] Only organisms that grow on the media are measured. Drinking water will normally contain some nonpathogenic bacteria; it is almost never sterile.

The test is of significance when used for comparative purposes under known or controlled conditions to show changes from the norm and determine if follow-up investigation and action are indicated. It can monitor changes in the quality (organic nutrients) of the water in the distribution system and storage reservoirs; it can be used to detect the presence of *Pseudomonas, Flavobacterium*, and other secondary invaders that could pose a health risk in the hospital environment; it can call attention to limitations of the coliform test when the average of heterotrophic plate counts in a month exceeds 100 to 500 per ml; it can show the effectiveness of distribution system residual chlorine and possible filter breakthrough; it can show distribution system deterioration, main growth, and sediment accumulation; and it can be used to assess the quality of bottled water. Large total bacterial populations (greater than 1,000 per ml) may also support or suppress growth of coliform organisms. Taste, odor, or color complaints may also be associated with bacterial or other growths in mains or surface-water sources.[34] Bacterial counts may increase in water that has been standing if nutrients are present, such as in reservoirs after copper sulfate treatment and algae destruction or in dead-end mains. These are of no sanitary significance. Mesophilic fungi and actinomycetes, sometimes associated with tastes and odors, may be found in treated water.

TABLE 1.13 Some Bacterial and Chemical Analyses

Source of Sample	Dug Well	Lake	Reservoir	Deep Well	Deep Well
Time of year	—	April	October	—	—
Treatment	None	Chlorine	None	None	None
Bacteria per milliliters agar, 35°C, 24 hr	—	3	—	1	>5000
Coliform MPN per 100 ml	—	<2.2	—	<2.2	≥2400
Color, units	0	15	30	0	0
Turbidity, units	Trace	Trace	Trace	Trace	5.0
Odor					
Cold	2 vegetative	2 aromatic	1 vegetative	1 aromatic	3 disagreeable
Hot	2 vegetative	2 aromatic	1 vegetative	1 aromatic	3 disagreeable
Iron, mg/1	0.15	0.40	0.40	0.08	0.2
Fluorides, mg/1	<0.05	0.005	—	—	—
Nitrogen as ammonia, free, mg/1	0.002	0.006	0.002	0.022	0.042
Nitrogen as ammonia, albuminoid, mg/1	0.026	0.128	0.138	0.001	0.224
Nitrogen as nitrites, mg/1	0.001	0.001	0.001	0.012	0.030
Nitrogen as nitrates, mg/1	0.44	0.08	0.02	0.02	0.16
Oxygen consumed, mg/1	1.1	2.4	7.6	0.5	16.0
Chlorides, mg/1	17.0	5.4	2.2	9.8	6.6
Hardness (as $CaCO_3$), total, mg/1	132.0	34.0	84.0	168.0	148.0
Alkalinity (as $CaCO,_3$), mg/1	94.0	29.0	78.0	150.0	114.0
pH value	7.3	7.6	7.3	7.3	7.5

Bacterial Examinations

The bacterial examinations for drinking water quality should always include, as a minimum, tests for total organisms of the coliform group, which are *indicative* of fecal contamination or sewage pollution. They are a normal inhabitant of the intestinal tract of humans and other animals. The goal is no coliform organisms in drinking water. In the past, the coliform group was referred to as the *B. coli* group and the *coli–aerogenes* group. The count for the total coliform group of organisms may include *Escherichia coli*, which is most common in the feces of humans and other warm-blooded animals; *Klebsiella pneumoniae*,* which is

*May have been identified in the past as *Aerobacter aerogenes*.

found in feces and sputum, on fresh vegetables, and in organically rich surface water; *Enterobacter cloacae*, which is found in feces of warm-blooded animals in smaller number than *E. coli*, also in pipe joints, soil, and vegetation; *Citrobacter freundii*, which is normally found in soil and water, also in feces of humans and other warm-blooded animals; and *Enterobacter aerogenes*, which is found in human and other warm-blooded animal feces, soil, pipe joints, and vegetation.* Coliforms are also found in slimes, pump leathers, swimming pool ropes, stormwater drainage, surface waters, and elsewhere.

The tests for fecal coliforms, *E. coli*, fecal streptococci, and *Clostridium perfringens* may be helpful in interpreting the significance of surface-water tests for total coliforms and their possible hazard to the public health. Tests for *Pseudomonas* spp. may indicate the condition in water mains.

Coliform bacteria are not normally considered disease organisms. However, pathogenic (enterotoxigenic) strains of *E. coli* have caused outbreaks of "traveler's diarrhea" and gastroenteritis in institutions and in communities associated with food, raw milk, water, or fomites. The enteropathogenic strains have been associated with outbreaks in newborn nurseries. The test for *E. coli* at 95°F (35°C) is recommended as being a more specific indicator of fecal contamination in Denmark, Belgium, England, France,[35] and the United States. More extensive laboratory procedures are needed to identify *E. coli* and the enteropathogenic *E. coli. Escherichia coli* makes up about 95 percent of the fecal coliforms.

The coliform group of organisms includes all of the aerobic and facultative anaerobic, gram-negative, non-spore-forming, rod-shaped bacteria that ferment lactose with acid and gas formation within 24 to 48 hours at 95° to 90°F (35°–37°C). This is the presumptive test that can be confirmed and completed by carrying the test further, as outlined in *Standard Methods*.[36] Coliform species identification is useful in interpreting the significance of the total coliform test where the cause is unclear. Differentiation can confirm the presence of *E. coli*, and hence fecal contamination, or other types of coliforms as previously explained. Prior to December 31, 1990, the results in the MTF were reported as the most probable number (MPN) of coliform bacteria, a statistical number most likely to produce the test results observed, per 100 ml of sample.

A review of the coliform rule by the EPA, as required by the 1986 amendment to the Safe Drinking Water Act, led to the development of a new regulatory standard effective December 31, 1990. This new standard is based on the presence or absence of total coliform bacteria rather than bacterial density. The new standard sets the MCL for total coliforms as follows:

Monthly Number of Samples	**MCL**
Fewer than 40	No more than 1 positive sample
40 or more	No more than 5.0% positive

**Enterobacter* and *Klebsiella* are not considered pathogenic to humans, but may be associated with disease-causing organisms found in feces.

In addition, an acute violation necessitates immediate public notification via broadcast media if a routine sample tests positive for total coliforms and for fecal coliforms or *E. coli* and any repeat sample tests positive for total coliforms or a routine sample tests positive for total coliforms and negative for fecal coliforms or *E. coli* and any repeat sample is positive for fecal coliforms or *E. coli*.

If the MTF method is used, the sample size is 100 ml. Either five 20-ml portions or ten 10-ml portions can be used. If any tube has gas formation, the sample is total coliform positive.

If the membrane filter technique is used, the coliform bacteria trapped on the filter produce dark colonies with a metallic sheen within 24 hour (18–22 hours) on an Endo-type medium containing lactose when placed in a 35°C incubator. The dark colonies are presumed to be of the coliform group and the sample is reported as coliform positive. The test can be carried further for coliform differentiation by following the procedure in *Standard Methods*.[37] Suspended matter, algae, and bacteria in large amounts interfere with the membrane filter (0.45 μm) procedure. Bacterial overgrowth on the filter would indicate an excessive bacterial population that should be investigated as to cause and significance.

For many years, the MTF test and the membrane filtration (MF) test have been the approved methods for detecting the presence of coliform organisms. Another test, known as the Colilert test, was approved by the EPA in 1989 for the presence or absence of total coliform. A 100-ml sample and one 100-ml tube with a specially prepared media or a set of five 10-ml tubes* are used to which the test water is added and incubated at 95 to 99°F (35°–37°C). A sterile technique must of course be used. The results are available within 24 hours or may be extended to 48 hours. The presence of coliform is shown by a color change to yellow, the absence by no color change. The presence of *E. coli* is also shown by fluorescence of the tube when viewed under ultraviolet (UV) light. Heterotrophic bacteria levels of 5,000 to 700,000 per ml did not interfere with the Colilert test.

The *fecal coliform test* involves incubation at 112°F (44.5°C) for 24 hours and measures mostly *E. coli* in a freshly passed stool of humans or other warm-blooded animals. A loop of broth from each positive presumptive tube incubated at 95°F (35°C) in the total coliform test is transferred to EC (*E. coli*) broth and incubated at 112°F (44.5°C) in a waterbath; formation of gas within 24 hours indicates the presence of fecal coliform and hence also possibly dangerous contamination. Maintenance of 112°F (44.5 ± 0.2°C) is critical. Nonfecal organisms generally do not produce gas at 112°F (44.5°C). The test has greatest application in the study of stream pollution, raw water sources, sea waters, wastewaters, and the quality of bathing waters. An average individual contributes about 2 billion coliform per day through excrement.

The *fecal streptococci* test (enterococci) uses special agar media incubated at 95°F (35°C) for 48 hours. Dark red to pink colonies are counted as fecal streptococci. They are also normally found in the intestinal tract of warm-blooded

*Standard tables are used to determine the MPN when more than one tube is used.

animals, including humans. Most (about 80 percent) of the human fecal streptococci are *Streptococcus faecalis; Streptococcus bovis* is associated with cows, and *Streptococcus equinus* with horses. These organisms may be more resistant to chlorine than coliform and survive longer in some waters but usually die off quickly outside the host. If found, it would indicate recent pollution. An average individual contributes approximately 450 million *fecal streptococci* per day.

The test for *C. perfringens (Clostridium welchii*), which is found in the intestines of humans and animals, may be of value in the examination of polluted waters and waters containing certain industrial wastes. Clostridia sporulate under unfavorable conditions and can survive indefinitely in the environment; they are more resistant than escherichia and streptococci. Therefore, their presence indicates past or possibly intermittent pollution.

In domestic sewage, the fecal coliform concentration is usually at least four times that of the fecal streptococci and may constitute 30 to 40 percent of the total coliforms. In stormwater and wastes from livestock, poultry, animal pets, and rodents, the fecal coliform concentration is usually less than 0.4 of the fecal streptococci. In streams receiving sewage, fecal coliforms may average 15 to 20 percent of the total coliforms in the stream. The presence of fecal coliform generally indicates fresh and possibly dangerous pollution. The presence of intermediate *aerogenes–cloacae* (IAC) subgroups of coliform organisms suggests past pollution or, in a municipal water supply, defects in treatment or in the distribution system.[38] A ratio of fecal coliforms to *C. perfringens* greater than 100 indicates sewage discharge.

The presence of any coliform organism in drinking water is a danger sign: It must be carefully interpreted in the light of water turbidity, chlorine residual, bacterial count, and sanitary survey, and it must be promptly eliminated. There may be some justification for permitting a low coliform density in developing areas of the world where the probability of other causes of intestinal diseases greatly exceeds those caused by water, as determined by epidemiological information. The lack of any water for washing promotes disease spread.

It must be understood and emphasized that the absence of coliform organisms or other indicators of contamination does not in and of itself ensure that the water is always safe to drink unless it is supported by a satisfactory, comprehensive sanitary survey of the drainage area, treatment unit processes, storage, and distribution system (including backflow prevention). Nor does the absence of coliforms ensure the absence of viruses, protozoa, or helminths unless the water is coagulated, flocculated, settled, gravity filtered, and chlorinated to yield a free residual chlorine of at least 0.5 mg/1, preferably for 1 hour before it is available for consumption. The WHO recommends a free residual chlorine of at least 0.5 mg/1 with a contact period of at least 30 minutes at a pH below 8.0 and a nephelometric turbidity unit (NTU) of 1 or less. A free ozone of 0.2 to 0.4 mg/1 for 4 minutes has been found to be effective to inactivate viruses in clean water (ref. 39, Vol. 2, p. 28). Chlorine dioxide and chloramine treatment may also be used. See “Disinfection,” in Chapter 2.

Biological Monitoring

A seven-day biological toxicity test of raw water may be useful to measure chronic effects. Indicators may include the fathead minnow and *Ceriodaphnia*, their survival, growth rate, and reproduction. In some instances, biological monitoring will be more meaningful than environmental monitoring: It can measure the combined effect of air, water, and food pollutants on an organism or animal; this information can be more closely related to potential human health effects.

Virus Examination

The examination of water for enteroviruses has not yet been simplified to the point where the test can be made routinely for compliance monitoring, as for coliform. Viruses range in size from 0.02 to 0.1 μm. There are more than 100 different types of enteric viruses known to be infective. Fecal wastes may contain enteroviruses (echoviruses, polioviruses, and coxsackieviruses—groups A and B) as well as adenoviruses, reoviruses, rotaviruses, Norwalk viruses, and infectious hepatitis viruses (viral hepatitis A).

Enteroviruses may be more resistant to treatment and environmental factors than fecal bacteria, persist longer in the water environment, and remain viable for many months, dependent on temperature and other factors. Enteric viruses, such as protozoa (*Giardia lamblia, Entamoeba histolytica*, and *Cryptosporidium* spp.), may be present even if coliform are absent.

Normally, a large volume of water (100–500 gal) must be sampled and an effective system used to capture, concentrate, and identify viruses. Results may not be available until one or two weeks later.[39] Special analytical laboratory facilities and procedures are required. See *Standard Methods*.[40] A virus standard for drinking water has not been established. A goal of zero to not more than one plaque-forming unit (pfu) per 1,000 gal of drinking water has been suggested.

Since monitoring for enteric viruses is not feasible for routine control of water treatment plant operation, the EPA is requiring specific treatment, or the equivalent, of all surface waters and mandatory chlorination, or equivalent protection, of all groundwaters. Coagulation, flocculation, settling, and rapid sand filtration; slow sand filtration; and lime-soda softening process remove 99 percent or more of the viruses. A pH above 11 inactivates viruses.

Free chlorine is more effective than combined chlorine in inactivating viruses and is more effective at low pH. Turbidity can shield viruses and make chlorination only partially effective. Based on available information, the WHO considers treatment adequate if a turbidity of 1 NTU or less is achieved and the free residual chlorine is at least 0.5 mg/1 after a contact period of at least 30 minutes at a pH below 8.0. Prudence would dictate that water obtained from a source known to receive sewage wastes should be coagulated, flocculated, settled, filtered, and disinfected to produce at least 0.4 mg/1 free residual chlorine for 2 hours before delivery. Ozone is also an effective disinfectant for clean water if residuals of 0.2 to 0.4 mg/1 are maintained for 4 min, but the residual does not remain in the distribution system.[41] The EPA requires 99.99 percent removal and/or inactivation of enteric viruses.

Protozoa and Helminths Examination

The complex procedure to sample, collect, prepare, and positively identify the protozoan cysts of *Giardia lamblia* is impractical for the routine control of water treatment. Because of this, the EPA requires complete treatment of surface waters unless the absence of giardia cysts can be demonstrated and assured by other acceptable means. Sampling for giardia cysts usually involves the filtration of about 500 gal of the water through a 1-μm-pore-size cartridge filter at a rate of about 1 gal/min. The filter extract and sediment collected are concentrated, slides are prepared, and the giardia cyst identified microscopically. Giardia cysts cannot be cultured. Ongerth[42] developed a procedure using a 5-μm-pore-size filter and a 10-gal sample that was reported to be efficient in recovering giardia cysts. Reservoir retention of 30 to 200 days did not reduce cyst concentration. It should be noted that whereas the giardia cyst is about 10 to 15 μm in size, the cryptosporidium oocyst is about 3 to 6 μm in size. The absence of coliform organisms does not indicate the absence of protozoa. Waterborne diseases caused by protozoa include amebic dysentery (amebiasis, *E. histolytica*), giardiasis (*G. lamblia*), cryptosporidiosis (*Cryptosporidium* spp.), meningoencephalitis (*Naegleria fowleri* and *Acanthamoeba culbertsoni*), and balantidiasis (*B. coli*.) Person-to-person contact, poor personal hygiene, and food are also common means of transmission of the diseases. Meningoencephalitis, also known as primary amebic meningoencephalitis, a rare but almost always fatal disease, is associated with swimming or bathing in warm, fresh, and brackish water. Immersion of the head (nasal passages) in the contaminated water is usually involved. The organism is commonly found in soil, fresh water, and decaying vegetation.

The helminths include roundworms, tapeworms, and flukes. The most common disease, spread by *Dracunculus medinensis* in drinking water, is dracontiasis, also known as Guinea-worm infection. Other helminths, such as *Fasciola, Schistosoma, Fasciolopsis, Echinococcus*, and *Ascaris*, are more likely to be transmitted by contaminated food and hand to mouth, particularly in areas where sanitation and personal hygiene are poor. Helminths are 50 to 60 μm in size.

Because of the resistance of the protozoa and helminths to normal chlorination and the lack of routine analytical procedures for water-treatment plant operation control, complete water treatment is required for drinking water.

Specific Pathogenic Organisms

It is not practical to routinely test for and identify specific disease organisms causing typhoid, paratyphoid, infectious hepatitis A, shigellosis, cholera, and others. (See Figure 1.2 for water treatment plant operation control.) The procedures would be too complex and time consuming for routine monitoring. However, laboratory techniques, media, and equipment are available for special studies and investigations where specific organism identification is indicated.

Physical Examinations

Odor Odor should be absent or very faint for water to be acceptable, less than 3 threshold odor number (TON). Water for food processing, beverages, and pharmaceutical manufacture should be essentially free of taste and odor. The test is very subjective, being dependent on the individual senses of smell and taste. The cause may be decaying organic matter, wastewaters including industrial wastes, dissolved gases, and chlorine in combination with certain organic compounds such as phenols. Odors are sometimes confused with tastes. The sense of smell is more sensitive than taste. Activated carbon adsorption, aeration, chemical oxidation (chlorine, chlorine dioxide, ozone, potassium permanganate), and coagulation and filtration will usually remove odors and tastes. Priority should first be given to a sanitary survey of the watershed drainage area and the removal of potential sources or causes of odors and tastes.

A technique for determining the concentration of odor compounds from a water sample to anticipate consumer complaints involves the "stripping" of odor compounds from a water sample that is adsorbed onto a carbon filter. The compounds are extracted from the filter and injected into a gas chromatograph-mass spectrometer for identification and quantification.[43]

Taste The taste of water should not be objectionable; otherwise, the consumer will resort to other sources of water that might not be of satisfactory sanitary quality. Algae, decomposing organic matter, dissolved gases, high concentrations of sulfates, chlorides, and iron, or industrial wastes may cause tastes and odors. Bone and fish oil and petroleum products such as kerosene and gasoline are particularly objectionable. Phenols in concentrations of 0.2 ppb in combination with chlorine will impart a phenolic or medicinal taste to drinking water. The taste test, like the odor test, is very subjective and may be dangerous to laboratory personnel. As in odor control, emphasis should be placed on the removal of potential causes of taste problems. See discussions of causes and methods to remove or reduce tastes and odors, later in this chapter.

Turbidity Turbidity is due to suspended material such as clay, silt, or organic and inorganic materials. Enhanced surface-water regulations in the United States require that the maximum contaminant level for turbidity not exceed 0.5 NTU in 95 percent of the samples taken every month and must never exceed 1 NTU. Additionally, the utility must maintain a minimum of 0.2 mg/1 free chlorine residual at representative points within the distribution system. Turbidity measurements are made in terms of nephelometric turbidity units (NTU), Formazin turbidity units (FTU), and Jackson turbidity units (JTU). The lowest turbidity value that can be measured directly on the Jackson candle turbidimeter is 25 units. There is no direct relationship between NTU or FTU readings and JTU readings.[44] The NTU is the standard measure, requiring use of a nephelometer, which measures the amount of light scattered, usually at 90° from the light direction, by suspended particles in the water test sample. It can measure turbidities of less than 1 unit and differences of 0.02 unit. Secondary turbidity measurement standards calibrated against the Formazin standard may also be accepted by the EPA.

The public demands sparkling clear water. This implies a turbidity of less than 1 unit; a level of less than 0.1 unit, which is obtainable when water is coagulated, flocculated, settled, and filtered, is practical. Turbidity is a good measure of sedimentation, filtration, and storage efficiency, particularly if supplemented by the total microscopic and particle count. Increased chlorine residual, bacteriological sampling, and main flushing is indicated when the maximum contaminant level for turbidity is exceeded in the distribution system until the cause is determined and eliminated. Turbidity will interfere with proper disinfection of water, harbor microorganisms, and cause tastes and odors. As turbidity increases, coliform masking in the membrane filter technique is increased.

The American Water Works Association recommends an operating level of no more than 0.3 NTU in filter plant effluent and a goal of no more than 0.2 NTU.

An increase in the turbidity of well water after heavy rains may indicate the entrance of inadequately purified groundwater.

Color Color should be less than 15 true color units* (sample is first filtered), although persons accustomed to clear water may notice a color of only 5 units. The goal is less than 3 units. Water for industrial uses should generally have a color of 5 to 10 or less. Color is caused by substances in solution, known as true color, and by substances in suspension, mostly organics causing apparent or organic color. Iron, copper, manganese, and industrial wastes may also cause color.

Water that has drained through peat bogs, swamps, forests, or decomposing organic matter may contain a brownish or reddish stain due to tannates and organic acids dissolved from leaves, bark, and plants. Excessive growths of algae or microorganisms may also cause color.

Color resulting from the presence of organics in water may also cause taste, interfere with chlorination, induce bacterial growth, make water unusable by certain industries without further treatment, foul anion exchange resins, interfere with colorimetric measurements, limit aquatic productivity by absorbing photosynthetic light, render lead in pipes soluble, hold iron and manganese in solution causing color and staining of laundry and plumbing fixtures, and interfere with chemical coagulation. Chlorination of natural waters containing organic water color (and humic acid) results in the formation of trihalomethanes, including chloroform. This is discussed later.

Color can be controlled at the source by watershed management. Involved is identifying waters from sources contributing natural organic and inorganic

*Cobalt platinum units.

color and excluding them, controlling beaver populations, increasing water flow gradients, using settling basins at inlets to reservoirs, and blending water.[45] Coagulation, flocculation, settling, and rapid sand filtration should reduce color-causing substances in solution to less than 5 units, with coagulation as the major factor. Slow sand filters should remove about 40 percent of the total color. True color is costly to remove. Oxidation (chlorine, ozone) or carbon adsorption also reduces color.

Temperature The water temperature should preferably be less than 60°F (16°C). Groundwaters and surface waters from mountainous areas are generally in the temperature range of 50° to 60°F (10°–16°C). Design and construction of water systems should provide for burying or covering of transmission mains to keep drinking water cool and prevent freezing in cold climates or leaks due to vehicular traffic. High water temperatures accelerate the growth of nuisance organisms, and taste and odor problems are intensified. Low temperatures somewhat decrease the disinfection efficiency.

Microscopic Examination

Microscopic and macroscopic organisms that may be found in drinking water sources include bacteria, algae, actinomycetes, protozoa, rotifers, yeasts, molds, small crustacea, worms, and mites. Most algae contain chlorophyll and require sunlight for their growth. The small worms are usually insect larvae. Larvae, crustacea, worms, molds or fungi, large numbers of algae, or filamentous growths in the drinking water would make the water aesthetically unacceptable and affect taste and odor. Immediate investigation to eliminate the cause would be indicated.

The term *plankton* includes algae and small animals such as cyclops and daphnia. Plankton are microscopic plants and animals suspended and floating in fresh and salt water and are a major source of food for fish. Algae include diatoms, cyanophyceae or blue-green algae (bacteria), and chlorophyceae or green algae; they are also referred to as phytoplankton. Protozoan and other small animals are referred to as zooplankton. They feed on algae and bacteria. The microbial flora in bottom sediments are called the benthos.[46] Phototrophic microorganisms are plankton primarily responsible for the production of organic matter via photosynthesis.

Algal growths increase the organic load in water, excrete oils that produce tastes and odors, clog sand filters, clog intake screens, produce slimes, interfere with recreational use of water, may cause fish kills when in “bloom” and in large surface “mats” by preventing replenishment of oxygen in the water, become attached to reservoir walls, form slimes in open reservoirs and recirculating systems, and contribute to corrosion in open steel tanks[47] and disintegration of concrete. Algae increase oxygen, and heavy concentrations reduce hardness and salts. In the absence of carbon dioxide, algae break down bicarbonates to carbonates, thereby raising the water pH to 9 or higher. Algae also contribute organics, which on chlorination add to trihalomethane formation.

Microscopic examination involves collection of water samples from specified locations and depths. The sample is preserved by the addition of formaldehyde if not taken immediately to the laboratory. At the laboratory, the plankton in the sample is concentrated by means of a centrifuge or a Sedgwick–Rafter sand filter. A 1-ml sample of the concentrate is then placed in a Sedgwick-Rafter counting cell for enumeration using a compound microscope fitted with a Whipple ocular micrometer. The Lackey Drop Microtransect Counting Method is also used, particularly with samples containing dense plankton populations.[48] Enumeration methods include total cell count, clump count, and areal standard unit count.

Examinations of surface-water sources, water mains, and well-water supplies, which are sources of difficulty, should be made weekly to observe trends and determine the need for treatment or other controls and their effectiveness before the organisms reach nuisance proportions. The "areal standard unit" represents an area 20 microns (μm) square or 400 μm^2. One micrometer equals 0.001 mm. Microorganisms are reported as the number of areal standard units per milliliter. Protozoa, rotifers, and other animal life are individually counted. Material that cannot be identified is reported as areal standard units of amorphous matter (detritus). The apparatus, procedure, and calculation of results and conversion to "Cubic Standard Units" is explained in *Standard Methods*.[49]

When more than 300 areal standard units, or organisms, per milliliter is reported, treatment with $CuSO_4$ is indicated to prevent possible trouble with tastes and odors or short filter runs. When more than 500 areal standard units or cells per milliliter is reported, complaints can be expected and the need for immediate action is indicated. A thousand units or more of amorphous matter indicates probable heavy growth of organisms that have died and disintegrated or organic debris from decaying algae, leaves, and similar materials.

The presence of asterionella, tabellaria, synedra, beggiatoa, crenothrix, *Sphaerotilis natans*, mallomonas, anabaena, aphanizomenon, volvox, ceratium, dinobryon, synura, uroglenopsis, and others, some even in small concentrations, may cause tastes and odors that are aggravated where marginal chlorine treatment is used. Free residual chlorination will usually reduce the tastes and odors. More than 25 areal standard units per milliliter of synura, dinobryon, or uroglena, or 300 to 700 units of asterionella, dictyosphaerium, aphanizomenon, volvox, or ceratium in chlorinated water will usually cause taste and odor complaints. The appearance of even 1 areal standard unit of a microorganism may be an indication to start immediate copper sulfate treatment if past experience indicates that trouble can be expected.

The blue-green algae, anabaena, microcystis (polycystis), nodularia, gloeotrichia, coelosphaerium, *Nostoc rivulare*, and aphanizomenon in large concentrations have been responsible for killing fish and causing illness in horses, sheep, dogs, ducks, chickens, mice, and cattle.[50] Illness in humans from these causes has been suspected, but confirmatory evidence is limited.[51] Gorham[52] estimated that the oral minimum lethal dose of decomposing toxic microcystis bloom for a 150-lb man is 1 to 2 quarts of thick, paintlike suspension and concluded that toxic waterblooms of blue-green algae in public water supplies are not a significant health hazard. Red tides caused by the dinoflagellates *Gonyaulax monilata* and *Gymnodinium brevis* have been correlated with mass mortality of fish.[53] Coagulation, flocculation, sedimentation, and filtration do not remove algal toxins, nor does the usual activated carbon treatment.

Investigation of conditions contributing to or favoring the growth of plankton in a reservoir and their control should reduce dependence on copper sulfate treatment. See "Control of Microorganisms", in Chapter 2.

Chemical Examinations*

The significance of selected chemical elements and compounds in drinking water is discussed next. An intake of 2 liters of water per day per person is assumed in determining health effects. The MCL is the National Drinking Water Regulation maximum contaminant level. The maximum contaminant level goal (MCLG) is a desirable one and is nonmandatory unless specifically made so by a state. The WHO level represents a guideline value "of a constituent that ensures an aesthetically pleasing water and does not result in any significant risk to the health of the consumer."[54] A value in excess of the guideline value does not in itself imply that the water is unsuitable for consumption. A comprehensive discussion of health-related inorganic and organic constituents can be found in *Guidelines for Drinking-Water Quality*, Vol. 2, WHO, Geneva, 1984.[55] Gas chromatographic mass spectrometry is considered the best method for identifying and quantifying specific organic compounds in an unknown sample. The removal of organic and inorganic chemicals from drinking water is reviewed later in this chapter.

Albuminoid Ammonia Albuminoid ammonia represents "complex" organic matter and thus would be present in relatively high concentrations in water-supporting algae growth, receiving forest drainage, or containing other organic matter. Concentrations of albuminoid ammonia higher than about 0.15 mg/1, therefore, should be appraised in the light of origin of the water and the results of microscopic examination. In general, the following concentrations serve as a guide: low—less than 0.06 mg/1; moderate—0.06 to 0.15 mg/1; high—0.15 mg/1 or greater. When organic nitrogen and ammonia nitrogen forms are found together, they are measured as Kjeldahl nitrogen.

Alkalinity The alkalinity of water passing through distribution systems with iron pipe should be in the range of 30 to 100 mg/1, as $CaCO_3$, to prevent serious corrosion; up to 500 mg/1 is acceptable, although this factor must be appraised from the standpoint of pH, hardness, carbon dioxide, and dissolved-oxygen content. Corrosion of iron pipe is prevented by the maintenance of calcium carbonate stability. Undersaturation will result in corrosive action in iron water mains and

*Results are reported as milligrams per liter (mg/1), which for all practical purposes can be taken to be the same as parts per million (ppm), except when the concentrations of substances in solution approach or exceed 7000 mg/1, when a density correction should be made.

cause red water. Oversaturation will result in carbonate deposition in piping and water heaters and on utensils. See “Corrosion Cause and Control”, in Chapter 2. Potassium carbonate, potassium bicarbonate, sodium carbonate, sodium bicarbonate, phosphates, and hydroxides cause alkalinity in natural water. Calcium carbonate, calcium bicarbonate, magnesium carbonate, and magnesium bicarbonate cause hardness, as well as alkalinity. Sufficient alkalinity is needed in water to react with added alum to form a floc in water coagulation. Insufficient alkalinity will cause alum to remain in solution. Bathing or washing in water of excessive alkalinity can change the pH of the lacrimal fluid around the eye, causing eye irritation.

Aluminum The EPA-recommended goal is less than 0.05 mg/1; the WHO guideline is 0.2 mg/1.[56] Aluminum is not found naturally in the elemental form, although it is one of the most abundant metals on the earth’s surface. It is found in all soils, plants, and animal tissues. Aluminum-containing wastes concentrate in and can harm shellfish and bottom life.[57] Alum as aluminum sulfate is commonly used as a coagulant in water treatment; excessive aluminum may pass through the filter with improper pH control. Precipitation may take place in the distribution system or on standing when the water contains more than 0.5 mg/1. Its presence in filter plant effluent is used as a measure of filtration efficiency. Although ingested aluminum does not appear to be harmful, aluminum compounds have been associated with neurological disorders in persons on kidney dialysis machines. Aluminum in the presence of iron may cause water discoloration. There may be an association between aluminum and Alzheimer’s disease, but this has not been confirmed.[58]

Arsenic The MCL for arsenic in drinking water was lowered from 0.05 mg/1 to 0.01 mg/1 by the EPA in January 2001. The WHO guideline is also 0.01 mg/1. (The Occupational Safety and Health Administration (OSHA) standard is 10 μg/m^3 for occupational exposure to inorganic arsenic in air over an 8-hour day; 2 μg/m^3 for 24 hour exposure to ambient air.[59]) A probable lethal oral dose is 5 to 20 mg/kg, depending on the compound and individual sensitivity. Sources of arsenic are natural rock formations (phosphate rock), industrial wastes, arsenic pesticides, fertilizers, detergent “presoaks,” and possibly other detergents. It is also found in foods, including shellfish and tobacco, and in the air in some locations.

There is ample evidence that defines a relationship between certain cancers (e.g., skin, bladder, kidney, lung, liver) and high levels of arsenic in drinking water (i.e., above 0.2 mg/1). There is significant debate, however, if these cancers are seen at lower levels of arsenic. Arsenic occurs naturally as arsenic, +3 (arsenite) and arsenic, +5 (arsenate). Arsenites are more toxic than arsenates. Arsenic may be converted to dimethylarsine by anaerobic organisms and accumulate in fish, similar to methylmercury.[60] After many years of scientific research and debate, the USEPA concluded that a concentration of 10 μg/1 (0.01 mg/1) is protective of public health. Promulgated in 2001, the lowered MCL required over 3,000 public water systems to install removal systems (or blend or abandon the high arsenic wells) by the Rule deadline of February 2006. For treatment, see "Removal of Inorganic Chemicals", in Chapter 2.

Asbestos Most asbestos-related diseases (mesotheliomas) are associated with the breathing of air containing asbestos fibers as long as 20 years earlier. Sources of exposure include working or living in the immediate vicinity of crocidolite mines, asbestos insulation and textile factories, and shipyards. Asbestos in drinking water may come from certain naturally occurring silicate materials in contact with water or from eroded asbestos cement pipe. A study (1935–1973) on the incidence of gastrointestinal cancer and use of drinking water distributed through asbestos cement (A/C) pipe reached the preliminary conclusion that "no association was noted between these asbestos risk sources and gastrointestinal tumor incidence."[61] A subsequent study concluded, "The lack of coherent evidence for cancer risk from the use of A/C pipe is reassuring."[62] An EPA study shows no statistical association between deaths due to certain types of cancer and the use of A/C pipe. British researchers reported that the cancer risk was "sensibly zero" or exceedingly low[63]: "Available studies on humans and animals do not provide evidence to support the view that ingestion of drinking water containing asbestos causes organ-specific cancers." Nevertheless, exposure to the asbestos fibers in drinking water should be reduced. Conventional water treatment, including coagulation and filtration, will remove more than 90 percent of the asbestos fibers in the raw water.[64]

Asbestos cement pipe was found to behave much like other piping materials, except polyvinyl chloride (PVC), that are commonly used for the distribution of drinking water. It has been concluded that, where "aggressive water conditions exist, the pipe will corrode and deteriorate; if aggressive water conditions do not exist, the pipe will not corrode and deteriorate."[65] Aggressive water can leach calcium hydroxide from the cement in A/C pipe. The American Water Works Association (AWWA) Standard C400-77 establishes criteria for the type of pipe to use for nonaggressive water ($\geq$12.0), moderately aggressive water (10.9–11.9), and highly aggressive water ($\leq$10.0), based on the sum of the pH plus the log of the alkalinity times the calcium hardness, as calcium carbonate. Remedial measures, in addition to pH adjustment and control of corrosion, include chemical addition to build up a protective film, elimination of hydrogen sulfide, rehabilitation and lining of existing pipe, pipe replacement, and a flushing program. Asbestos cement pipe should not be used to carry aggressive water.

If the water is heavily contaminated, its use for humidifiers, showers, food preparation, clothes laundering, and drinking is not advised since the asbestos fibers can become airborne and be inhaled. The EPA has recommended a maximum contaminant level of 7.1×10^6 asbestos fibers longer than 10 μm/1 from all sources, including naturally occurring asbestos. On July 6, 1989, the EPA ruled to prohibit manufacture, importation, and processing of asbestos in certain products and to phase out the use of asbestos in all other products. This action was meant to reduce airborne asbestos in the workplace and ambient air and thereby the carcinogenic health risk associated with the inhalation of asbestos fibers.

Barium Barium may be found naturally in groundwater (usually in concentrations less than 0.1 mg/1) and in surface water receiving industrial wastes; it is also found in air. It is a muscle stimulant and in large quantities may be harmful to the nervous system and heart. The fatal dose is 550 to 600 mg. The MCL is 2 mg/1 in drinking water. A WHO guideline has not been established; concentrations of 10 mg/1 are not considered significant. Barium can be removed by weak-acid ion exchange.

Benzene This chemical is used as a solvent and degreaser of metals.[66] It is also a major component of gasoline. Drinking water contamination generally results from leaking underground gasoline and petroleum tanks or improper waste disposal. Benzene has been associated with significantly increased risks of leukemia among certain industrial workers exposed to relatively large amounts of this chemical during their working careers. This chemical has also been shown to cause cancer in laboratory animals when the animals are exposed to high levels over their lifetimes. Chemicals that cause increased risk of cancer among exposed industrial workers and in laboratory animals also may increase the risk of cancer in humans who are exposed at lower levels over long periods of time. The EPA has set the enforceable drinking water standard for benzene at 0.005 mg/1 to reduce the risk of cancer or other adverse health effects observed in humans and laboratory animals. The OSHA standard is 1 mg/1 with 5 mg/1 for short-term (15-minutes) exposure.[67]

Cadmium The federal drinking water MCL for cadmium is 0.005 mg/1. The WHO guideline is 0.005 mg/1.[68] Common sources of cadmium are water mains and galvanized iron pipes, tanks, metal roofs where cistern water is collected, industrial wastes (electroplating), tailings, pesticides, nickel plating, solder, incandescent light filaments, photography wastes, paints, plastics, inks, nickel–cadmium batteries, and cadmium-plated utensils. It is also found in zinc and lead ores. Cadmium vaporizes when burned; salts of cadmium readily dissolve in water and can, therefore, be found in air pollutants, wastewater, wastewater sludge, fertilizer, land runoff, some food crops, tobacco, and drinking water. Beef liver and shellfish are very high in cadmium. Large concentrations may be related to kidney damage, hypertension (high blood pressure), chronic bronchitis, and emphysema. Cadmium builds up in the human body, plants, and food animals. It has a biological half-life of about 20 years.[69] The direct relationship between cardiovascular death rates in the United States, Great Britain, Sweden, Canada, and Japan and the degree of softness or acidity of water point to cadmium as the suspect.[70] In 1972, the Joint WHO Food and Agriculture Organization Expert Committee on Food Additives established a provisional tolerable weekly cadmium intake of 400 to 500 μg. Cadmium removal from water is discussed in Chapter 2.

Carbon–Chloroform Extract (CCE) and Carbon–Alcohol Extract (CAE) (Tests No Longer Routinely Used) Carbon–chloroform extract may include chlorinated hydrocarbon pesticides, nitrates, nitrobenzenes, aromatic ethers, and many others adsorbed on an activated carbon cartridge. Water from uninhabited and nonindustrial watersheds usually show CCE concentrations of less than 0.04 mg/1. The taste and odor of drinking water can be expected to be poor when the concentration of CCE reaches 0.2 mg/1. Carbon–alcohol extract measures gross organic chemicals including synthetics. A goal of less than 0.04 mg/1 CCE and 0.10 mg/1 CAE has been proposed.

Carbon Dioxide The only limitation on carbon dioxide is that pertaining to corrosion. It should be less than 10 mg/1, but when the alkalinity is less than 100 mg/1, the CO_2 concentration should not exceed 5.0 mg/1.

Carbon Tetrachloride This chemical was once a popular household cleaning fluid.[71] It generally gets into drinking water by improper disposal. This chemical has been shown to cause cancer in laboratory animals such as rats and mice when exposed at high levels over their lifetimes. Chemicals that cause cancer in laboratory animals may also increase the risk of cancer in humans exposed at lower levels over long periods of time. The EPA has set the enforceable drinking water standard for carbon tetrachloride at 0.005 mg/1 to reduce the risk of cancer or other adverse health effects observed in laboratory animals. The WHO *tentative* guideline value is 3 μg/1.

Chlorides of Intestinal Origin Natural waters remote from the influence of ocean or salt deposits and not influenced by local sources of pollution have a low chloride content, usually less than 4.0 mg/1. Due to the extensive salt deposits in certain parts of the country, it is impractical to assign chloride concentrations that, when exceeded, indicate the presence of sewage, agricultural, or industrial pollution, unless a chloride record over an extended period of time is kept on each water supply. In view of the fact that chlorides are soluble, they will pass through pervious soil and rock for great distances without diminution in concentration, and thus the chloride content must be interpreted with considerable discretion in connection with other constituents in the water. The concentration of chlorides in urine is about 5000 mg/1, in septic tank effluent about 80 mg/1, and in sewage from a residential community 50 mg/1 depending on the water source.

Chlorides of Mineral Origin The WHO guideline for chloride ion is 250 mg/1.[72] A goal of less than 100 mg/1 is recommended. The permissible chloride content of water depends on the sensitivity of the consumer. Many people notice a brackish taste imparted by 125 mg/1 of chlorides in combination with sodium, potassium, or calcium, whereas others are satisfied with concentrations as high as 250 mg/1. Irrigation waters should contain less than 200 mg/1. When the chloride is in the form of sodium chloride, use of the water for drinking may be inadvisable for persons who are under medical care for certain forms of heart disease. The main intake of chlorides is with foods. Hard water softened by the ion exchange or lime-soda process (with Na_2CO_3) will increase sodium concentrations in the water. Salt used for highway deicing may contaminate groundwater and surface-water supplies. Its use should be curtailed and storage depots covered. Chlorides can be removed from water by distillation, reverse osmosis, or electrodialysis and minimized by proper aquifer selection and well construction. Water sources near oceans or in the vicinity of underground salt deposits may contain high salt concentrations. Well waters from sedimentary rock are likely to contain chlorides. The corrosivity of water is increased by high concentrations of chlorides, particularly if the water has a low alkalinity.

Chromium The total chromium MCL and WHO guideline[73] is 0.1 mg/1 in drinking water. Chromium is found in cigarettes, some foods, the air, and industrial plating, paint, and leather tanning wastes. Chromium deficiency is associated with atherosclerosis. Hexavalent chromium dust can cause cancer of the lungs and kidney damage.[74]

Copper The EPA action level for copper is 1.3 mg/1; the WHO guideline is 1.0 mg/1.[75] The goal is less than 0.2 mg/1. Concentrations of this magnitude are not present in natural waters but may be due to the corrosion of copper or brass piping; 0.5 to 1.0 mg/1 in soft water stains laundry and plumbing fixtures blue–green. A concentration in excess of 0.2 to 0.3 mg/1 will cause an "off" flavor in coffee and tea; 5 mg/1 or less results in a bitter metallic taste; 1 mg/1 may affect film and reacts with soap to produce a green color in water; 0.25 to 1.0 mg/1 is toxic to fish. Corrosion of galvanized iron and steel fittings is reported to be enhanced by copper in public water supplies. Copper appears to be essential for all forms of life, but excessive amounts are toxic to fish. The estimated adult daily requirement is 2.0 mg, coming mostly from food. Copper deficiency is associated with anemia. Copper salts are commonly used to control algal growths in reservoirs and slime growths in water systems. Copper can be removed by ion exchange, conventional coagulation, sedimentation, filtration, softening, or reverse osmosis; when caused by corrosion of copper pipes, it can be controlled by proper water treatment and pH control. Copper sulfate treatment of the water source for algae control may contribute copper to the finished water. Electrical grounding to copper water pipe can add to the copper dissolution.

Corrosivity Water should be noncorrosive. Corrosivity of water is related to its pH, alkalinity, hardness, temperature, dissolved oxygen, carbon dioxide, total dissolved solids, and other factors. Waters high in chlorides and low in alkalinity are particularly corrosive. Since a simple, rapid test for corrosivity is not available, test pipe sections or metal coupons (90-day test) are used, supplemented, where possible, by water analyses such as calcium carbonate saturation, alkalinity, pH, and dissolved solids and gases. Incrustation on stainless steel test pipe or metal coupon should not exceed 0.05 mg/cm^2; loss by corrosion of galvanized iron should not exceed 5.00 mg/cm^2 (AWWA). The corrosion of copper tubing increases particularly when carrying water above 140°F (60°C). Schroeder[76] reports that pewter, britannia metal, water pipes, and cisterns may contain antimony, lead, cadmium, and tin, which leach out in the presence of soft water or acidic fluids. Soft water flowing over galvanized iron roofs or through galvanized iron pipes or stored in galvanized tanks contains cadmium and zinc. Ceramic vessels contain antimony, beryllium, barium, nickel, and zirconium; pottery glazes contain lead, all of which may be leached out if improper firing and glazing are used. Corrosivity is controlled by pH, alkalinity, and calcium carbonate adjustment, including use of lime, sodium carbonate, and/or sodium hydroxide. Other means include the addition of polyphosphate, orthophosphate, and silicates and pH control. In any case, corrosion-resistant pipe should be used where possible.

Cyanide Cyanide is found naturally and in industrial wastes. Cyanide concentrations as low as 10 μg/1 have been reported to cause adverse effects in fish. Long-term consumption of up to 4.7 mg/day has shown no injurious effects (ref. 45, pp. 128–136). The cyanide concentration in drinking water should not exceed 0.2 mg/1. The probable oral lethal dose is 1.0 mg/kg. The WHO guideline is 0.1 mg/1. An MCL and MCLG of 0.2 mg/1 has been established by the EPA. Cyanates can ultimately decompose to carbon dioxide and nitrogen gas.[77] Cyanide is readily destroyed by conventional treatment processes.

1,1-Dichloroethylene This chemical is used in industry and is found in drinking water as a result of the breakdown of related solvents.[78] The solvents are used as cleaners and degreasers of metals and generally get into drinking water by improper waste disposal. This chemical has been shown to cause liver and kidney damage in laboratory animals such as rats and mice when exposed at high levels over their lifetimes. Chemicals that cause adverse effects in laboratory animals may also cause adverse health effects in humans exposed at lower levels over long periods of time. The EPA has set the enforceable drinking water standard for 1,1-dichloroethylene at 0.007 mg/1 to reduce the risk of the adverse health effects observed in laboratory animals.

1,2-Dichloroethane This chemical is used as a cleaning fluid for fats, oils, waxes, and resins.[79] It generally gets into drinking water from improper waste disposal. This chemical has been shown to cause cancer in laboratory animals such as rats and mice when exposed at high levels over their lifetimes. Chemicals that cause cancer in laboratory animals may also increase the risk of cancer in humans exposed at lower levels over long periods of time. The EPA has set the enforceable drinking water standard for 1,2-dichloroethane at 0.005 mg/1 to reduce the risk of cancer or other adverse health effects observed in laboratory animals. The WHO guideline is 10 μg/1.

Dissolved Oxygen Water devoid of dissolved oxygen frequently has a "flat" taste, although many attractive well waters are devoid of oxygen. In general, it is preferable for the dissolved-oxygen content to exceed 2.5 to 3.0 mg/1 to prevent secondary tastes and odors from developing and to support fish life. Game fish require a dissolved oxygen of at least 5.0 mg/1 to reproduce and either die off or migrate when the dissolved oxygen falls below 3.0 mg/1. The concentration of dissolved oxygen in potable water may be related to problems associated with iron, manganese, copper, and nitrogen and sulfur compounds.

Fluorides Fluorides are found in many groundwaters as a natural constituent, ranging from a trace to 5 mg/1 or more, and in some foods. Fluorides in concentrations greater than 4 mg/1 can cause the teeth of children to become mottled and discolored, depending on the concentration and amount of water consumed. Mottling of teeth has been reported very occasionally above 1.5 mg/1 according to WHO guidelines. Drinking water containing 0.7 to 1.2 mg/1 natural or added fluoride is beneficial to children during the time they are developing permanent teeth. An optimum level is 1.0 mg/1 in temperate climates. The Centers for Disease Control and Prevention (CDC) estimates that in 2006, approximately 69.2 percent of the United States' population (or 184 million people) had access to optimum levels of fluoridated water (0.7 mg/1 to 1.2 mg/l). More than 65 percent of the nation's nine-year-old children are free of tooth decay and the CDC also considers fluoridation of community water systems one of the 10 great public health achievements of the 20th century.[80]

The maximum contaminant level in drinking water has been established in the National Drinking Water Regulations at 4 mg/1. The probable oral lethal dose for sodium fluoride is 70 to 140 mg/kg. Fluoride removal methods include reverse osmosis, lime softening, ion exchange using bone char or activated alumina, and tricalcium phosphate adsorption. It is not possible to reduce the fluoride level to 1 mg/1 using only lime.[81] The WHO and CDC reports show no evidence to support any association between fluoridation of drinking water and the occurrence of cancer (1982).

Free Ammonia Free ammonia represents the first product of the decomposition of organic matter; thus, appreciable concentrations of free ammonia usually indicate "fresh pollution" of sanitary significance. The exception is when ammonium sulfate of mineral origin is involved. The following values may be of general significance in appraising free ammonia content in groundwater: low—0.015 to 0.03 mg/1; moderate—0.03 to 0.10 mg/1; high—0.10 mg/1 or greater. In treated drinking water, the goal is less than 0.1 mg/1, but less than 0.5 mg/1 is acceptable. Special care must be exercised to allow for ammonia added if the "chlorine–ammonia" treatment of water is used or if crenothrix organisms are present. If ammonia is present or added, chloramines are formed when chlorine is added to the water. Ammonia in the range of 0.2 to 2.0 mg/1 is toxic to many fish. A recommended maximum is 0.5 mg/1 to 0.2 mg/1 for rainbow trout. Chloramines are also toxic to other aquatic life. Ammonia serves as a plant nutrient, accelerating eutrophication in receiving waters. It is converted to nitrite and then to nitrate, first by *Nitrosomonas* and then by *Nitrobacter* organisms. Ammonia can be removed by breakpoint or superchlorination.

Hardness Hardness is due primarily to calcium and secondarily to magnesium carbonates and bicarbonates (carbonate or temporary hardness that can be removed by heating) and calcium sulfate, calcium chloride, magnesium sulfate, and magnesium chloride (noncarbonate or permanent hardness, which cannot be removed by heating); the sum is the total hardness expressed as calcium carbonate. In general, water softer than 50 mg/1, as $CaCO_3$ is corrosive, whereas waters harder than about 80 mg/1 lead to the use of more soap and above 200 mg/1 may cause incrustation in pipes. Lead, cadmium, zinc, and copper in solution are usually caused by pipe corrosion associated with soft water. Desirable hardness values, therefore, should be 50 to 80 mg/1, with 80 to 150 mg/1 as passable, over 150 mg/1 as undesirable, and greater than 500 as unacceptable. The U.S. Geological Survey (USGS) and WHO[82] classify hardness, in milligrams per liter as $CaCO_3$, as 0 to 60 soft, 61 to 120 moderately hard, 121 to 180 hard, and more than 180 very hard. Waters high in sulfates (above 600 to 800 mg/1 calcium sulfate, 300 mg/1 sodium sulfate, or 390 mg/1 magnesium sulfate) are laxative to those not accustomed to the water. Depending on alkalinity, pH, and other factors, hardness above 200 mg/1 may cause the buildup of scale and flow reduction in pipes. In addition to being objectionable for laundry and other washing purposes due to soap curdling, excessive hardness contributes to the deterioration of fabrics. Hard water is not suitable for the production of ice, soft drinks, felts, or textiles. Satisfactory cleansing of laundry, dishes, and utensils is made difficult or impractical. When heated, bicarbonates precipitate as carbonates and adhere to the pipe or vessel. In boiler and hot-water tanks, the scale resulting from hardness reduces the thermal efficiency and eventually causes restriction of the flow or plugging in the pipes. Calcium chloride, when heated, becomes acidic and pits boiler tubes. Hardness can be reduced by lime-soda ash chemical treatment or the ion exchange process, but the sodium concentration will be increased. See "Water Softening," in Chapter 2. Desalination will also remove water hardness.

There seem to be higher mortality rates from cardiovascular diseases in people provided with soft water than in those provided with hard water. Water softened by the ion exchange process increases the sodium content of the finished water. The high concentration of sodium and the low concentration of magnesium have been implicated, but low concentrations of chromium and high concentrations of copper have also been suggested as being responsible. High concentrations of cadmium are believed to be associated with hypertension. Cause and effect for any of these is not firm.

Hydrogen Sulfide Hydrogen sulfide is most frequently found in groundwaters as a natural constituent and is easily identified by a rotten-egg odor. It is caused by microbial action on organic matter or the reduction of sulfate ions to sulfide. A concentration of 70 mg/1 is an irritant, but 700 mg/1 is highly poisonous. In high concentration, it paralyzes the sense of smell, thereby making it more dangerous. Black stains on laundered clothes and black deposits in piping and on plumbing fixtures are caused by hydrogen sulfide in the presence of soluble iron. Hydrogen sulfide in drinking water should not be detectable by smell or exceed 0.05 mg/1. Hydrogen sulfide predominates at pH of 7.0 or less. It is removed by aeration or chemical oxidation followed by filtration.

Iron Iron is found naturally in groundwaters and in some surface waters and as the result of corrosion of iron pipe. Iron deposits and mining operations and distribution systems may be a source of iron and manganese. Water should have a soluble iron content of less than 0.1 mg/1 to prevent reddish-brown staining of laundry, fountains, and plumbing fixtures and to prevent pipe deposits. The secondary MCL and WHO guideline level is 0.3 mg/1; the goal should be less than 0.05 mg/1. Some staining of plumbing fixtures may occur at 0.05 mg/1. Precipitated ferric hydroxide may cause a slight turbidity in water that can be objectionable and cause clogging of filters and softener resin beds. In combination with manganese, concentrations in excess of 0.3 mg/1 cause complaints. Precipitated iron may cause some turbidity. Iron in excess of 1.0 mg/1 will cause an unpleasant taste. A concentration of about 1 mg/1 is noticeable in the taste of coffee or tea. Conventional water treatment or ion exchange will remove iron. Chlorine or oxygen will precipitate soluble iron. Iron is an essential element for human health. See "Iron and Manganese Occurrence and Removal," in Chapter 2.

Lead The EPA requires that when more than 10 percent of tap water samples exceed 15 μg/1, the utility must institute corrosion control treatment. Concentrations exceeding this value occur when corrosive waters of low mineral content and softened waters are piped through lead pipe and old lead house services. Zinc-galvanized iron pipe, copper pipe with lead-based solder joints, and brass pipe, faucets, and fittings may also contribute lead. The lead should not exceed 5 μg/1 in the distribution system.

Lead, as well as cadmium, zinc, and copper, is dissolved by carbonated beverages, which are highly charged with carbon dioxide. Limestone, galena, water, and food are natural sources of lead. Other sources are motor vehicle exhaust, certain industrial wastes, mines and smelters, lead paints, glazes, car battery salvage operations, soil, dust, tobacco, cosmetics, and agricultural sprays. Fallout from airborne pollutants also contributes significant concentrations of lead to water supply reservoirs and drainage basins. About one-fifth of the lead ingested in water is absorbed. The EPA estimates that in young children about 20 percent of lead exposure comes from drinking water; dust contributes at least 30 percent, air 5 to 20 percent, and food 30 to 45 percent.[83]

The Safe Drinking Water Amendments of 1986 require that any pipe, solder, or flux used in the installation or repair of any public water system or any plumbing connected to a public water system shall be lead free. Acceptable substitutes for lead solder are tin–silver, tin–antimony, and tin–copper. Solder and flux containing not more than 0.2 percent lead and pipes and pipe fittings containing not more than 8.0 percent lead are considered to be lead free. Lead-free solder may contain trace amounts of lead, tin, silver, and copper. (Leaded joints necessary for the repair of cast-iron water mains are excluded from the prohibition.) Exposure to lead in tap water is more likely in new homes, less than 5 years old, where plumbing contains lead solder or flux. A survey by the AWWA showed an average lead concentration of 193.3 μg/1 in first-draw samples from homes less than 2 years old, 45.7 μg/1 from homes 2 to 5 years old, 16 μg/1 from homes 5 to 10 years old, and 8.2 μg/1 from homes older than 10 years.[84] Hot water would normally contain higher concentrations of lead. Lead flux is reported to dissolve at about 140° to 150°F (60°–66°C). Hot-water flushing is an economical method for removing residual flux from piping in newer buildings.[85] Galvanic corrosion due to dissimilar metals—copper and lead–tin solder—will also contribute lead. Electric water cooler piping, water contact surfaces, and fittings have also been implicated as sources of lead in drinking water. Defective coolers are being replaced.

Water containing lead in excess of the standard should not be used for baby formula or for cooking or drinking. Flushing the standing water out of a faucet for about 1 minute will minimize the lead concentration, but it does not solve the problem. The Secretary of Housing and Urban Development and the Administrator of the Veterans' Administration may not ensure or guarantee a mortgage or furnish assistance with respect to newly constructed residential property, which contains a potable water system, unless such system uses only lead-free pipe, solder, and flux.

The EPA requires the following measures and standards to control lead in community and noncommunity nontransient water systems:

1. Corrosion control when tap water sample average exceeds 0.01 mg/1, when the pH level is less than 8.0 in more than 5 percent of samples, and when the copper level exceeds 1.3 mg/1 (pH not greater than 9.0, alkalinity of 25–100 mg/1 as calcium carbonate)
2. An MCL for lead of 0.005 mg/1 and a MCLG of zero leaving the treatment plant
3. An MCL and an MCLG for copper of 1.3 mg/1
4. Tap water lead "action level" of 0.015 mg/1 in not more than 10 percent of samples of tap water that has been allowed to stand at least 6 hours (usually the first draw in the morning) from dwelling units that contain copper pipes with lead solder installed after 1982

Water treatment or use of a corrosion inhibitor is advised where indicated. Conventional water treatment, including coagulation, will partially remove natural or manmade lead in raw water. Measures to prevent or minimize lead dissolution include maintenance of pH $\geq$ 8.0 and use of zinc orthophosphate or polyphosphates. Silicates may have a long-term beneficial effect. No apparent relationship was found between lead solubility and free chlorine residual, hardness, or calcium level. Electrical grounding to plumbing increased lead levels. Alkalinity level control was not of value at pH 7.0 to $<$8.0.[86] However, since only 3 to 5 percent of the free chlorine is in the active hypochlorous acid form at pH 9.0, whereas 23 to 32 percent is in the hypochlorous acid form at pH 8.0, pH level control is critical for corrosion control and the maintenance of disinfection efficiency.

Removal of lead service lines is required if treatment is not adequate to reduce lead level.

Manganese Manganese is found in gneisses, quartzites, marbles, and other metamorphic rocks and, hence, in well waters from these formations. It is also found in many soils and sediments, such as in deep lakes and reservoirs, and in surface water. Manganese concentrations (MCL) should be not greater than 0.05 mg/1, and preferably less than 0.01, to avoid the black-brown staining of plumbing fixtures and laundry when chlorine bleach is added. The WHO guideline value for manganese is 0.1 mg/1.

Concentrations greater than 0.5 to 1.0 mg/1 may give a metallic taste to water. Concentrations above 0.05 mg/1 or less can sometimes build up coatings on sand filter media, glass parts of chlorinators, and concrete structures and in piping, which may reduce pipe capacity. When manganous manganese in solution comes in contact with air or chlorine, it is converted to the insoluble manganic state, which is very difficult to remove from materials on which it precipitates. Excess polyphosphate for sequestering manganese may prevent absorption of essential trace elements from the diet[87] it is also a source of sodium. See "Iron and Manganese Occurrence and Removal," in Chapter 2.

Mercury Episodes associated with the consumption of methylmercury-contaminated fish, bread, pork, and seed have called attention to the possible contamination of drinking water. Mercury is found in nature in the elemental and organic forms. Concentrations in unpolluted waters are normally less than 1.0 μg/1. The organic methylmercury and other alkylmercury compounds are highly toxic, affecting the central nervous system and kidneys. It is taken up by the aquatic food chain. The maximum permissible contaminant level in drinking water is 0.002 mg/1 as total mercury. The WHO guideline is 0.001 mg/1.

Methylene Blue Active Substances (MBASs) The test for MBASs also shows the presence of alkyl benzene sulfonate (ABS), linear alkylate sulfonate (LAS), and related materials that react with methylene blue. It is a measure of the apparent detergent or foaming agent and hence sewage presence. The composition of detergents varies. Household washwater in which ABS is the active agent in the detergent may contain 200 to 1,000 mg/1. Alkyl benzene sulfonate has been largely replaced by LAS, which can be degraded under aerobic conditions; if not degraded, it too will foam at greater than 1 mg/1 concentration. Both ABS and LAS detergents contain phosphates that may, if allowed to enter, fertilize plant life in lakes and streams. The decay of plants will use oxygen, leaving less for fish life and wastewater oxidation. Because of these effects, detergents containing phosphates have been banned in some areas. In any case, the presence of MBAS in well-water supply is objectionable and an indication of sewage pollution, the source of which should be identified and removed, even though it has not been found to be of health significance in the concentrations found in drinking water. The level of MBAS in a surface water is also an indicator of sewage pollution. Carbon adsorption can be used to remove MBAS from drinking water. Foaming agents should be less than 0.5 mg/1; 1.0 mg/1 is detectable by taste. Anionic (nondegradable) detergents should not exceed 0.2 mg/1.

Nitrates Nitrates represent the final product of the biochemical oxidation of ammonia. Its presence is probably due to the presence of nitrogenous organic matter of animal and, to some extent, vegetable origin, for only small quantities are naturally present in water. Septic tank systems may contribute nitrates to the groundwater if free oxygen is present. Manure and fertilizer contain large concentrations of nitrates. However, careful management practices of efficient utilization of applied manure and fertilizer by crops will reduce nitrates leaching below the root zone. Shallow (18–24-in.) septic tank absorption trenches will also permit nitrate utilization by vegetation. The existence of fertilized fields, barnyards, or cattle feedlots near supply sources must be carefully considered in appraising the significance of nitrate content. Furthermore, a cesspool may be relatively close to a well and contributing pollution without a resulting high nitrate content because the anaerobic conditions in the cesspool would prevent biochemical oxidation of ammonia to nitrites and then nitrates. In fact, nitrates may be reduced to nitrites under such conditions. In general, however, nitrates disclose the evidence of "previous" pollution of water that has been modified by self-purification processes to a final mineral form. Allowing for these important controlling factors, the following ranges in concentration may be used as a guide: low, less than 0.1 mg/1; moderate, 0.1 to 1.0 mg/1; high, greater than 1.0 mg/1. Concentrations greater than 3.0 mg/1 indicate significant manmade contribution.

The presence of more than 10 mg/1 of nitrate expressed as nitrogen, the maximum contaminant level in drinking water, appears to be the cause of methemoglobinemia, or "blue babies." The standard has also been expressed as 45 mg/1 as nitrate ion (10 mg/1 as nitrogen). Methemoglobinemia is largely a disease confined to infants less than three months old but may affect children up to age six. Boiling water containing nitrates increases the concentration of nitrates in the water. The recommended maximum for livestock is 100 mg/1.

Nitrate is corrosive to tin and should be kept at less than 2 mg/1 in water used in food canning. There is a possibility that some forms of cancer might be associated with very high nitrate levels.

Nitrates may stimulate the growth of water plants, particularly algae if other nutrients such as phosphorus and carbon are present. Nitrates seem to serve no useful purpose, other than as a fertilizer. Gould points out that

> a more objective review of literature would perhaps indicate that without any sewage additions most of our waterways would contain enough nitrogen and phosphorous (due to nonpoint pollution source) to support massive algal blooms and that the removal of these particular elements would have little effect on existing conditions.[88]

The feasible methods for the removal of nitrates are anion exchange, reverse osmosis, distillation, and electrodialysis. See "Nitrate Removal" in Chapter 2.

Nitrites Nitrites represent the first product of the oxidation of free ammonia by biochemical activity. Free oxygen must be present. Unpolluted natural waters contain practically no nitrites, so concentrations exceeding the very low value of 0.001 mg/1 are of sanitary significance, indicating water subject to pollution that is in the process of change associated with natural purification. The nitrite concentration present is due to sewage and the organic matter in the soil through which the water passes. Nitrites in concentrations greater than 1 mg/1 in drinking water are hazardous to infants and should not be used for infant feeding.

Oxidation–Reduction Potential (ORP, Also Redox) Oxidation–reduction potential is the potential required to transfer electrons from the oxidant to the reductant and is used as a qualitative measure of the state of oxidation in water treatment systems.[89] An ORP meter is used to measure in millivolts the oxidation–loss of electrons or reduction–gain of electrons.

Oxygen-Consumed Value This represents organic matter that is oxidized by potassium permanganate under the test conditions. Pollution significant from a bacteriological examination standpoint is accompanied by so little organic matter as not to significantly raise the oxygen-consumed value. For example, natural waters containing swamp drainage have much higher oxygen-consumed values than water of low original organic content that are subject to bacterial pollution. This test is of limited significance.

Para-Dichlorobenzene This chemical is a component of deodorizers, mothballs, and pesticides.[90] It generally gets into drinking water by improper waste disposal. This chemical has been shown to cause liver and kidney damage in laboratory animals such as rats and mice exposed to high levels over their lifetimes. Chemicals that cause adverse effects in laboratory animals also may cause adverse health effects in humans exposed at lower levels over long periods of time. The EPA has set the enforceable drinking water standard for *para*-dichlorobenzene at 0.075 mg/1 to reduce the risk of the adverse health effects observed in laboratory animals.

Pesticides Pesticides include insecticides, herbicides, fungicides, rodenticides, regulators of plant growth, defoliants, or desiccants. Sources of pesticides in drinking water are industrial wastes, spills and dumping of pesticides, and runoff from fields, inhabited areas, farms, or orchards treated with pesticides. Surface and groundwater may be contaminated. Conventional water treatment does not adequately remove pesticides. Powdered or granular activated carbon treatment may also be necessary. Maximum permissible contaminant levels of certain pesticides in drinking water and their uses and health effects are given in Table 1.4.

pH* The pH values of natural water range from about 5.0 to 8.5 and are acceptable except when viewed from the standpoint of corrosion. A guideline value of

*pH is defined as the logarithm of the reciprocal of the hydrogen ion concentration. The concentration increases and the solution becomes more acidic as the pH value decreases below 7.0; the solution becomes more alkaline as the concentration decreases and the pH value increases above 7.0.

6.5 to 8.5 is suggested. The pH is a measure of acidity or alkalinity using a scale of 0.0 to 14.0, with 7.0 being the neutral point, a higher value being alkaline and lower value acidic. The bactericidal, virucidal, and cysticidal efficiency of chlorine as a disinfectant increases with a decrease in pH. The pH determination in water having an alkalinity of less than 20 mg/1 by using color indicators is inaccurate. The electrometric method is preferred in any case. The ranges of pH color indicator solutions, if used, are as follows: bromphenol blue, 3.0 to 4.6; bromcresol green, 4.0 to 5.6; methyl red, 4.4 to 6.0; bromcresol purple, 5.0 to 6.6; bromthymol blue, 6.0 to 7.6; phenol red, 6.8 to 8.4; cresol red, 7.2 to 8.8; thymol blue, 8.0 to 9.6; and phenol phthalein, 8.6 to 10.2. Waters containing more than 1.0 mg/1 chlorine in any form must be dechlorinated with one or two drops of 1/4 percent sodium thiosulfate before adding the pH indicator solution. This is necessary to prevent the indicator solution from being bleached or decolorized by the chlorine and giving an erroneous reading. The germicidal activity is greatly reduced at a pH level above 8.0. Corrosion is associated with pH levels below 6.5 to 7.0 and with carbon dioxide, alkalinity, hardness, and temperature.[91]

Phenols The WHO guideline for individual phenols, chlorophenols, and 2,4,6-trichlorophenol is not greater than 0.1 μg/1 (0.1 ppb), as the taste and odor can be detected at or above that level after chlorination. The odor of some chlorophenols is detected at 1 μg/1. In addition, 2,4,6-trichlorophenol, found in biocides and chlorinated water containing phenol, is considered a chemical carcinogen based on animal studies.[92] The guideline for pentachlorophenol in drinking water, a wood preservative, is 0.001 mg/1 based on its toxicity. It also causes objectionable taste and odor. If the water is not chlorinated, phenols up to 100 μg/1 are acceptable.[93] Phenols are a group of organic compounds that are byproducts of steel, coke distillation, petroleum refining, and chemical operations. They should be removed prior to discharge to drinking water sources. Phenols are also associated with the natural decay of wood products, biocides, and municipal wastewater discharges. The presence of phenols in process water can cause serious problems in the food and beverage industries and can taint fish. Chlorophenols can be removed by chlorine dioxide and ozone treatment and by activated carbon. The AWWA advises that phenol concentrations be less than 2.0 μg/l at the point of chlorination. Chlorine dioxide, ozone, or potassium permanganate pretreatment is preferred, where possible, to remove phenolic compounds.

Phosphorus High phosphorus concentrations, as phosphates, together with nitrates and organic carbon are often associated with heavy aquatic plant growth, although other substances in water also have an effect. Fertilizers and some detergents are major sources of phosphates. Uncontaminated waters contain 10 to 30 μg/l total phosphorus, although higher concentrations of phosphorus are also found in “clean” waters. Concentrations associated with nuisances in lakes would not normally cause problems in flowing streams. About 100 μg/l complex phosphate interferes with coagulation. Phosphorus from septic tank subsurface absorption system effluents is not readily transmitted through sandy soil and groundwater.[94] Most waterways naturally contain sufficient nitrogen and phosphorus to support massive algal blooms.

Polychlorinated Biphenyls (PCBs) Polychlorinated biphenyls give an indication of the presence of industrial wastes containing mixtures of chlorinated byphenyl compounds having various percentages of chlorine. Organochlorine pesticides have a similar chemical structure. The PCBs cause skin disorders in humans and cancer in rats. They are stable and fire resistant and have good electrical insulation capabilities. They have been used in transformers, capacitors, brake linings, plasticizers, pumps, hydraulic fluids, inks, heat exchange fluids, canvas waterproofing, ceiling tiles, fluorescent light ballasts, and other products. They are not soluble in water but are soluble in fat. They cumulate in bottom sediment and in fish, birds, ducks, and other animals on a steady diet of food contaminated with the chemical. Concentrations up to several hundred and several thousand milligrams per liter have been found in fish, snapping turtles, and other aquatic life. Polybrominated biphenyl, a derivative of PCB, is more toxic than PCB. Aroclor is the trade name for a PCB mixture used in a pesticide. The manufacture of PCBs was prohibited in the United States in 1979 under the Toxic Substances Control Act of 1976. The use in transformers and electromagnets was banned after October 1985 if they pose an exposure risk to food or animal feed. Continued surveillance of existing equipment and its disposal is necessary for the life of the equipment. The toxicity of PCB and its derivatives appears to be due to its contamination with dioxins. The Food and Drug Administration (FDA) action levels are 1.5 mg/l in fat of milk and dairy products; 3 mg/l in poultry and 0.3 mg/l in eggs; and 2 mg/l in fish and shellfish. The MCL for drinking water is 0.0005 mg/l with zero as the EPA MCLG. The OSHA permissible 8-hour time-weighted average (TWA) airborne exposure limit is 0.5 mg/m^3 for PCBs containing 42 percent chlorine.[95] The National Institute of Occupational Safety and Health (NIOSH) recommended that the 8-hour TWA exposure by inhalation be limited to 1.0 μg/m^3 or less.[96] A level not exceeding 0.002 μg/l is suggested to protect aquatic life.[97] The PCBs are destroyed at 2000°F (1093°C) and 3 percent excess oxygen for 2 seconds contact time. They are vaporized at 1584°F (862°C). The PCB contamination of well water has been associated with leakage from old submersible well pumps containing PCB in capacitors. These pumps were manufactured between 1960 and 1978, are oil cooled rather than water cooled, and have a two-wire lead rather than three-wire. Pumps using 220-volt service would not be involved.[98] Activated carbon adsorption and ozonation plus UV are possible water treatments to remove PCBs.

Polynuclear Aromatic Hydrocarbons Polynuclear aromatic hydrocarbons such as fluoranthene, 3,4-benzfluoranthene, 11,12-benzfluoranthene, 3,4-benzpyrene, 1,12-benzperyline, and indeno [1,2,3-*cd*] pyrene are known carcinogens and are potentially hazardous to humans. The WHO set a limit of 0.2 μg/l for the sum of these chemicals in drinking water, comparable in quality with unpolluted groundwater. Because of its carcinogenicity, a guideline value of 0.01 μg/l is proposed for benzo[*a*]pyrene in drinking water. It is also recommended that the use of cool-tar-based pipe linings be discontinued. [99]

Polysaccharides In soft drink manufacturing, polysaccharides* in surface waters may be found in the water used. In waters of low pH, the polysaccharides come out of solution to form a white precipitate. The CO_2 in carbonated water is also sufficient to cause this. Coagulation and sedimentation or reverse osmosis treatment can remove polysaccharides.

Brewing water should ideally be low in alkalinity and soft but high in sulfates.[100]

Radioactivity The maximum contaminant levels for radioactivity in drinking water are given in Table 1.4. The exposure to radioactivity from drinking water is not likely to result in a total intake greater than recommended by the Federal Radiation Council. Naturally occurring radionuclides include Th-232, U-235, and U-238 and their decay series, including radon and radium 226 and 228. They may be found in well waters, especially those near uranium deposits. (Radium is sometimes found in certain spring and well supplies.) Since these radionuclides emit alpha and beta radiation (as well as gamma), their ingestion or inhalation may introduce a serious health hazard, if found in well-water supplies.[101] Possible manmade sources of radionuclides in surface waters include fallout (in soluble form and with particulate matter) from nuclear explosions in precipitation and runoff, releases from nuclear reactors and waste facilities, and manufacturers. Radon is the major natural source of radionuclides.

Radon Radon is a natural decay product of uranium and is a byproduct of uranium used in industry and the manufacture of luminescent faces of clocks and instruments. It is also found in soil, rock, and well water and is readily released when water is agitated such as in a washing machine (clothes and dish), when water flows out of a faucet, and when water is sprayed from a shower head. Radon is particularly dangerous when released and inhaled in an enclosed space such as indoors. Radon-222 is emitted from tailings at uranium mill sites.

The EPA estimates that 10,000 pCi/l in water will result in a radon air concentration of about 1 pCi/l. The EPA has proposed a maximum contaminant level of 300 pCi/l for drinking water supplies.

Radon can be removed from water by aeration—packed tower or diffused air, filtration through granular activated carbon, ion exchange, and reverse osmosis. The concentration of radon in removal raises a disposal problem.

Selenium Selenium is associated with industrial pollution (copper smelting) and vegetation grown in soil containing selenium. It is found in meat and other foods. Selenium causes cancers and sarcomas in rats fed heavy doses. Chronic exposure to excess selenium results in gastroenteritis, dermatitis, and central

*One of a group of carbohydrates.

nervous system disturbance.[102] Selenium is considered an essential nutrient and may provide protection against certain types of cancer. Selenium in drinking water should not exceed the MCL of 0.05 mg/l. An intake of 25 or 50 μg/day is not considered harmful.

Silver The secondary MCL for silver in drinking water is 0.10 mg/l. Silver is sometimes used to disinfect small quantities of water and in home faucet purifiers. Colloidal silver may cause permanent discoloration of the skin, eyes, and mucous membranes. A continuous daily dose of 400 μg of silver may produce the discoloration (argyria). Only about 10 percent of the ingested silver is absorbed.[103]

Sodium Persons on a low-sodium diet because of heart, kidney, or circulatory (hypertension) disease or pregnancy should use distilled water if the water supply contains more than 20 mg/l of sodium and be guided by a physician's advice. The consumption of 2.0 liters of water per day is assumed. Water containing more than 200 mg/l sodium should not be used for drinking by those on a moderately restricted sodium diet. It can be tasted at this concentration when combined with other anions. Many groundwater supplies and most home-softened (using ion exchange) well waters contain too much sodium for persons on sodium-restricted diets. If the well water is low in sodium (less than 20 mg/l) but the water is softened by the ion exchange process because of excessive hardness, the cold-water system can be supplied by a line from the well that bypasses the softener and low-sodium water can be made available at cold-water taps. A home water softener adds 0.46 times the hardness removed as $CaCO_3$. Sodium can be removed by reverse osmosis, distillation, and cation exchange, but it is costly. A laboratory analysis is necessary to determine the exact amount of sodium in water. The WHO guideline for sodium in drinking water is 200 mg/l. Common sources of sodium, in addition to food, are certain well waters, ion exchange water-softening units, water treatment chemicals (sodium aluminate, lime-soda ash in softening, sodium hydroxide, sodium bisulfite, and sodium hypochlorite), road salt, and possibly industrial wastes. Sodium added in fluoridation and corrosion control is not significant.

Specific Electrical Conductance Specific electrical conductance is a measure of the ability of a water to conduct an electrical current and is expressed in micromhos per cubic centimeters of water at 77°F (25°C). Because the specific conductance is related to the number and specific chemical types of ions in solution, it can be used for approximating the dissolved-solids content in the water, particularly the mineral salts in solution if present. The higher the conductance, the more mineralized the water and its corrosivity. Different minerals in solutions give different specific conductance. Commonly, the amount of dissolved solids (in milligrams per liter) is about 65 percent of the specific conductance. This relationship is not constant from stream to stream from well to well, and it may even vary in the same source with changes in the composition of the water.

Specific conductance is used for the classification of irrigation waters. In general, waters of less than 200 μmho/cm^3 are considered acceptable, and conductance in excess of 300 μmho/cm^3 unsuitable. Good fresh waters for fish in the United States are reportedly under 1100 μmho/cm^3.[104] Wastewater with a conductivity up to 1,200 to 4,000 μmho/cm^3 may be acceptable for desert reclamation. Electrical conductivity measurements give a rapid approximation of the concentration of dissolved solids in milligrams per liter.

Sulfates The sulfate content should not exceed the secondary MCL of 250 mg/l. The WHO guideline is 400 mg/l.[105] With zeolite softening, calcium sulfate or gypsum is replaced by an equal concentration of sodium sulfate. Sodium sulfate (or Glauber salts) in excess of 200 mg/l, magnesium sulfate (or Epsom salts) in excess of 390 to 1,000 mg/l, and calcium sulfate in excess of 600 to 800 mg/l are laxative to those not accustomed to the water. Magnesium sulfate causes hardness; sodium sulfate causes foaming in steam boilers. Sulfate is increased when aluminum sulfate is used in coagulation. High sulfates also contribute to the formation of scale in boilers and heat exchangers. Concentrations of 300 to 400 mg/l cause a taste. Sulfates can be removed by ion exchange, distillation, reverse osmosis, or electrodialysis. Sulfates are found in surface waters receiving industrial wastes such as those from sulfate pulp mills, tanneries, and textile plants. Sulfates also occur in many waters as a result of leaching from gypsum-bearing rock.

Total Dissolved Solids (TDS) The total solid content should be less than 500 mg/l; however, this is based on the industrial uses of public water supplies and not on public health factors. Higher concentrations cause physiological effects and make drinking water less palatable. Dissolved solids, such as calcium, bicarbonates, magnesium, sodium, sulfates, and chlorides, cause scaling in plumbing above 200 mg/l. The TDS can be reduced by distillation, reverse osmosis, electrodialysis, evaporation, ion exchange, and, in some cases, chemical precipitation. Water with more than 1000 mg/l of dissolved solids is classified as *saline*, irrespective of the nature of the minerals present.[106] The USGS classifies water with less than 1000 mg/l as fresh, 1,000 to 3,000 as slightly saline, 3,000 to 10,000 as moderately saline, 10,000 to 35,000 as very saline, and more than 35,000 as briny.

1,1,1-Trichloroethane This chemical is used as a cleaner and degreaser of metals.[107] It generally gets into drinking water by improper waste disposal. This chemical has been shown to damage the liver, nervous system, and circulatory system of laboratory animals such as rats and mice exposed at high levels over their lifetimes. Some industrial workers who were exposed to relatively large amounts of this chemical during their working careers also suffered damage to the liver, nervous system, and circulatory system. Chemicals that cause adverse effects among exposed industrial workers and in laboratory animals may also cause adverse health effects in humans exposed at lower levels over long periods of time. The EPA has set the enforceable drinking water standard for 1,1,1-trichloroethane at 0.2 mg/l to protect against the risk of adverse health effects observed in humans and laboratory animals.

Trichloroethylene This chemical is a common metal-cleaning and dry-cleaning fluid.[108] It generally gets into drinking water by improper waste disposal. This chemical has been shown to cause cancer in laboratory animals such as rats and mice when exposed at high levels over their lifetimes. Chemicals that cause cancer in laboratory animals may also increase the risk of cancer in humans exposed at lower levels over long periods of time. The EPA has set forth the enforceable drinking water standard for trichloroethylene at 0.005 mg/l to reduce the risk of cancer or other adverse health effects observed in laboratory animals.

Trihalomethanes Trihalomethanes (THMs) and other nonvolatile, higher molecular weight compounds are formed by the interaction of free chlorine with humic and fulvic substances and other organic precursors produced either by normal organic decomposition or by metabolism of aquatic biota. The precursor level is determined through testing by prechlorination of a sample and then analyzing the sample after seven days storage under controlled temperature and pH. A rapid surrogate THM measurement can be made using UV absorbent measurement. Two gas chromatographic analytic techniques are acceptable by the EPA for THM analysis. The THMs include chloroform (trichloromethane), bromoform (tribromomethane), dibromochloromethane, bromodichloromethane, and iodoform (dichloroiodomethane). Toxicity, mutagenicity, and carcinogenicity have been suspected as being associated with the ingestion of trihalomethanes. The EPA has stated that:

> epidemiological evidence relating THM concentrations or other drinking water quality factors and cancer morbidity-mortality is not conclusive but suggestive. Positive statistical correlations have been found in several studies,* but causal relationships cannot be established on the basis of epidemiological studies. The correlation is stronger between cancer and the brominated THMs than for chloroform.[109]

Chloroform is reported to be carcinogenic to rats and mice in high doses and hence is a suspected human carcinogen. The Epidemiology Subcommittee of the National Research Council (NRC) says that cancer and THM should not be linked.[110] The Report on Drinking Water and Health, NRC Safe Drinking Water and Health, states: “A review of 12 epidemiological studies failed either to support or refute the results of positive animal bioassays suggesting that certain trihalomethanes, chloroform for example, may cause cancer in humans.”[111] However, the National Drinking Water Advisory Council, based on studies in the review and evaluation by the National Academy of Sciences, the work done by

*The reliability and accuracy of studies such as these are often subject to question.

the National Cancer Institute, and other research institutions within the EPA, has accepted the regulation of trihalomethanes on "the belief that chloroform in water does impose a health threat to the consumer."[112] The EPA has established a standard of 80 μg/l for total THMs for public water supplies. The WHO guideline for chloroform is 30 μg/l[113] and 35 μg/l for THM in Canada.

Uranyl Ion This ion may cause damage to the kidneys. Objectionable taste and color occur at about 10 mg/l. It does not occur naturally in most waters above a few micrograms per liter. The taste, color, and gross alpha MCL will restrict uranium concentrations to below toxic levels; hence, no specific limit is proposed.[114]

Vinyl Chloride This chemical is used in industry and is found in drinking water as a result of the breakdown of related solvents.[115] The solvents are used as cleaners and degreasers of metals and generally get into drinking water by improper waste disposal. This chemical has been associated with significantly increased risks of cancer among certain industrial workers who were exposed to relatively large amounts of this chemical during their working careers. This chemical has also been shown to cause cancer in laboratory animals when exposed at high levels over their lifetimes. Chemicals that cause increased risk of cancer among exposed industrial workers and in laboratory animals also may increase the risk of cancer in humans exposed at lower levels over long periods of time. The EPA has set the enforceable drinking water standard for vinyl chloride at 0.002 mg/l to reduce the risk of cancer or other adverse health effects observed in humans and laboratory animals. Packed-tower aeration removes vinyl chloride.

Zinc The concentration of zinc in drinking water (goal) should be less than 1.0 mg/l. The MCL and the WHO guideline is 5.0 mg/l.[116]Zinc is dissolved by surface water. A greasy film forms in surface water containing 5 mg/l or more zinc upon boiling. More than 5.0 mg/l causes a bitter metallic taste and 25 to 40 mg/l may cause nausea and vomiting. At high concentrations, zinc salts impart a milky appearance to water. Zinc may contribute to the corrosiveness of water. Common sources of zinc in drinking water are brass and galvanized pipe and natural waters where zinc has been mined. Zinc from zinc oxide in automobile tires is a significant pollutant in urban runoff.[117] The ratio of zinc to cadmium may also be of public health importance. Zinc deficiency is associated with dwarfism and hypogonadism.[118] Zinc is an essential nutrient. It can be reduced by ion exchange, softening, reverse osmosis, and electrodialysis.

Drinking Water Additives

Potentially hazardous chemicals or contaminants may inadvertently be added directly or indirectly to drinking water in treatment, well drilling, and distribution. Other contaminants potentially may leach from paints, coatings, pumps, storage tanks, distribution system pipe and plumbing systems, valves, pipe fittings, and other equipment and products.

Chemicals (direct additives) used in water treatment for coagulation, corrosion control, and other purposes may contain contaminants such as heavy metals or organic substances that may pose a health hazard. In addition, significant concentrations of organic and inorganic contaminants (indirect additives) may leach or be extracted from various drinking water system components.

Since its inception, the EPA has maintained an advisory list of acceptable products for drinking water contact, but this function was transferred to the private sector on April 7, 1990. In 1985, the EPA provided seed funding for a consortium to establish a program for setting standards and for the testing, evaluation, inspection, and certification to control potentially hazardous additives. The consortium included the AWWA, the American Water Works Association Research Foundation (AWWARF), the Association of State Drinking Water Administrators (ASDWA), and the National Sanitation Foundation (NSF).

In 1988, the NSF published American National Standards Institute (ANSI)/NSF Standard 60, Drinking Water Treatment Chemicals—Health Effects, and ANSI/NSF Standard 61, Drinking Water System Components—Health Effects.[119]The ANSI approved NSF Standards 60 and 61 in May of 1989.

Third-party certification organizations, like the NSF, Underwriters Laboratories (UL), and the Safe Water Additives Institute,[120]* can certify products for compliance with the ANSI/NSF standards. In addition to the NSF listing of certified products, the AWWA plans to maintain and make available a directory of all products certified as meeting the ANSI/NSF standards.

In mid-1990, the ANSI announced a program to "certify the certifiers." Because each state regulates drinking water additives products, the ANSI program is expected to provide the basis for state acceptance of independent certification organizations to test and evaluate equipment and products for compliance with the standards. The ANSI program includes minimum requirements for certification agencies that address chemical and microbiological testing, toxicology review and evaluation, factory audits, follow-up evaluations, marking, contracts and policies, and quality assurance. Many state drinking water regulations and rules require independent third-party certification of additives products.

Water Quantity

The quantity of water used for domestic purposes will generally vary directly with the availability of the water, habits of the people, cost of water, number and type of plumbing fixtures provided, water pressure, air temperature, newness of a community, type of establishment, metering, and other factors. Wherever possible, the actual water consumption under existing or similar circumstances and the number of persons served should be the basis for the design of a water and sewage system. Special adjustment must be made for unaccounted-for water

*The NSF is accredited by the ANSI, UL has applied for accrediation, and the Safe Water Additives Institute is developing a program for ANSI review (*AWWA MainStream*, May 1991).

and for public, industrial, and commercial uses. The average per-capita municipal water use has increased from 150 gpd in 1960 to 168 gpd in 1975 to 183 gpd in 1980 and remained relatively steady at 179 gpd in 1995. Approximately 70 gal is residential use, 50 gal industrial, 35 gal commercial, and 10 gal public and 14 gal is lost.[121] Included is water lost in the distribution system and water supplied for firefighting, street washing, municipal parks, and swimming pools. USGS estimated rural water use at 68 gpd in 1975 and 79 gpd in 1980.[122]

Table 1.14 gives estimates of water consumption at different types of places and in developing areas of the world. Additions should be made for car washing, lawn sprinkling, and miscellaneous uses. If provision is made for firefighting requirements, then the quantity of water provided for this purpose to meet fire underwriters' standards will be in addition to that required for normal domestic needs in small communities.

Developing Areas of the World Piped water delivery to individual homes and waterborne sewage disposal are not affordable in many developing countries. This calls for sequential or incremental improvements from centrally located hand pumps to water distribution systems. Social, cultural, and economic conditions, hygiene education, and community participation must be taken into account in project selection and design.[123] Community perception of needs, provision of local financial management, operation, and maintenance must be taken into consideration and assured before a project is started. The annual cost of water purchased from a water vendor may equal or exceed the cost of piped metered water. In addition, much time is saved where water must be hauled from a stream. Hand pumps, where used, should be reliable, made of corrosion-resistant materials, with moving parts resistant to abrasion, including sand, and readily maintained at the local level. A detailed analysis of hand pump tests and ratings has been made by Arlosoroff et al.[124] It is important to keep mechanical equipment to a minimum and to train local technicians. Preference should be given to drilled wells where possible. For surface-water supplies, slow sand filters are generally preferred over the more complex rapid sand filters.

Water Conservation

Water conservation can effect considerable saving of water with resultant reduction in water treatment and pumping costs and wastewater treatment. With water conservation, development of new sources of water and treatment facilities and their costs can be postponed or perhaps made unnecessary, and low-distribution system water pressure situations are less likely. However, the unit cost of water to the consumer may not be reduced; it may actually increase because the fixed cost will remain substantially the same. The revenue must still be adjusted to meet the cost of water production and distribution.

Water conservation can be accomplished, where needed, by a continuing program of leak detection and repair in the community distribution system and in buildings; use of low water-use valves and plumbing fixtures; water pressure and flow control in the distribution system and in building services (orifices);

TABLE 1.14 Guides for Water Use in Design

Type of Establishment	gpd[a]
Residential	
Dwellings and apartments (per bedroom)	150
Rural	60
Suburban	75
Urban	180
Temporary Quarters	
Boarding houses	65
Additional (or nonresident boarders)	10
Campsites (per site), recreation vehicle with individual connection	100
Campsites, recreational vehicle, with comfort station	40–50
Camps without toilets, baths, or showers	5
Camps with toilets, without baths or showers	25
Camps with toilets and bathhouses	35–50
Cottages, seasonal with private bath	50
Day camps	15–20
Hotels	65–75
Mobile home parks (per unit)	125–150
Motels	50–75
Public Establishments	
Restaurants (toilets and kitchens)	7–10
Without public toilet facilities	$2\frac{1}{2}$–3
With bar or cocktail lounge, additional	2
Schools, boarding	75–100
Day with cafeteria, gymnasium, and showers	25
Day with cafeteria, without gymnasium and shower	15
Hospitals (per bed)	175–400
Institutions other than hospitals (per bed)	75–125
Places of public assembly	3–10
Turnpike rest areas	5
Turnpike service areas (per 10% of cars passing)	15–20
Prisons	120
Amusement and Commercial	
Airports (per passenger), add for employees and special uses	3–5
Car wash (per vehicle)	40
Country clubs, excluding residents	25
Day workers (per shift)	15–35
Drive-in theaters (per car space)	5
Gas station (per vehicle serviced)	10
Milk plant, pasteurization (per 100 lb of milk)	11–25
Movie theaters (per seat)	3
Picnic parks with flush toilets	5–10
Picnic parks with bathhouse, showers, bathrooms	20
Self-service laundries (per machine) (or 50 gal per customer)	400–500

(*continues*)

TABLE 1.14 **(*continued*)**

Type of Establishment	gpd[a]
Shopping center (per 1,000 ft^2 floor area), add for employees, restaurants, etc.	250
Stores (per toilet room)	400
Swimming pools and beaches with bathhouses	10
Fairgrounds (based on daily attendance), also sports arenas	5
Farming (per Animal)	
Cattle or steer	12
Milking cow, including servicing	35
Goat or sheep	2
Hog	4
Horse or mule	12
Cleaning milk bulk tank, per wash	30–60
Milking parlor, per station	20–30
Liquid manure handling, cow	1–3
Poultry (per 100)	
Chickens	5–10
Turkeys	10–18
Cleaning and sanitizing equipment	4

Miscellaneous Home Water Use	Estimated (gal)
Toilet, tank, per use[b]	1.6–3.5
Toilet, flush valve 25 psi (pounds per square inch), per use[b]	1.6–3.5
Washbasin, gpm[b]	2–3
Bathtub	30/use
Shower, gpm[b]	2.5–3
Dishwashing machine, domestic, 15.5/load	9.5–
Garbage grinder, 2/day	1–
Automatic laundry machine, domestic	
34–57/load, top load	
22–33/load, front load	
Garden hose	
$\frac{5}{8}$ in., 25-ft head	200/hr
$\frac{3}{4}$ in., $\frac{1}{4}$ in. nozzle, 25-ft head	300/hr
Lawn sprinkler, 3,000-ft^2 lawn, 1 in. per week	120/hr
Air conditioner, water-cooled, 3-ton, 8 hr per day	1,850/week 2,880/day

Household Water Use	Percent	Municipal Water Use	Percent
Toilet flushing	36	Residential	38
Bathing	26	Industrial: factories	27
Drinking and cooking	5	Commercial: hospitals, restaurants	19
Dishwashing	6	Public: fires, parks	6
Clothes washing	15	Waste: leaks	10
Cleaning and miscellaneous	12		

TABLE 1.14 **(*continued*)**

Water Demand per Dwelling Unit: Surburban, Three-Bedrooms (BR)	Water Use (gpd)
Average day	300
Maximum day	600
Maximum hourly rate	1500
Maximum hourly rate with appreciable lawn watering	1800

Home Water System (Minimums)	2 BR	3 BR	4 BR	5 BR
Pump capacity, gal/hr	250	300	360	450
Pressure tank, gal minimum	42	82	82	120
Service line from pump, diameter (in.)[c]	$\frac{3}{4}$	$\frac{3}{4}$	1	$1\frac{1}{4}$

Other Water Use	Gallons
Fire hose, $1\frac{1}{2}$ in., $\frac{1}{2}$ in. nozzle, 70-ft head	2400/hr
Drinking fountain, continuous flowing	75/hr
Dishwashing machine, commercial	
Stationary rack type, 15 psi	6–9/min
Conveyor type, 15 psi	4–6/min
Fire hose, home, 10 gpm at 60 psi for 2 hr, $\frac{3}{4}$ in.	600/hr
Restaurant, average	35/seat
Restaurant, 24-hr	50/seat
Restaurant, tavern	20/seat
Gas station	500/set of pumps
Developing Areas of the World	
One well or tap/200 persons; controlled tap or hydrant:	
Fordilla or Robovalve type	
Average consumption, 5 gal/capita/day at well or tap, water carried	
Water system design, 30 gal/capita/day (10 gal/capita is common)	
(50 gal is recommended)	
Pipe size, 2 in. and preferably larger (1 and $1\frac{1}{2}$ in. common)	
Drilled well, cased, 6–8 in. diameter	
Water system pressure, 20 lb/in.^{2}	
(Keep mechanical equipment to a minimum.)	

Developing Country[d]	Liters	Gallons
China	80	21
Africa	15–35	4–9
Southeast Asia	30–70	8–19
Western Pacific	30–90	8–24
Eastern Mediterranean	40–85	11–23
Europe (Algeria, Morocco, Turkey)	20–65	5–17
Latin America and Caribbean	70–190	19–51
World average	35–90	9–24

[a] Per person unless otherwise stated.
[b] Water conservation fixtures. See text.
[c] Service lines less than 50 ft long, brass or copper. Use next larger size if iron pipe is used. Use minimum $\frac{1}{3}$-in. service with flush valves. Minimum well yield, 5 gal/min.
[d] Assumes hydrant or hand pump available within 200 m; 70 liters per capita per day (Lpcd) or more could mean house or central courtyard outlet.) Mechanical equipment kept at a minimum.

universal metering and price adjustment; conservation practices by the consumer; and a rate structure that encourages conservation.

Leak detection activities would include metering water use and water production balance studies; routine leak detection surveys of the distribution system; investigation of water ponding or seepage reports and complaints; and reporting and prompt follow-up on leaking faucets, running flushometer valves and water closet ball floats, and other valves. Universal metering will make possible water balance studies to help detect lost water and provide a basis for charging for water use. Meters must be periodically tested for accuracy and read. However, centralized remote meter reading can simplify this task. Reduction in water use, perhaps 20 percent, may be temporary in some instances; many users may not economize.

Low water-use plumbing fixtures and accessories would include the low-flush water closets; water-saving shower-head flow controls, spray taps, and faucet aerators; and water-saving clothes washers and dishwashers. In a dormitory study at a state university, the use of flow control devices (pressure level) on shower heads effected a 40 to 60 percent reduction in water use as a result of reducing the shower-head flow rates from 5.5 gpm to 2.0 to 2.5 gpm.[125] Plumbing codes should require water-saving fixtures and pressure control in new structures and rehabilitation projects. For example, only water-efficient plumbing fixtures meeting the following standards are permitted to be sold or installed in New York State*:

- Sink 3 gpm, lavatory faucet not greater than 2 gpm;
- Shower heads not greater than 3 gpm;
- Urinals and associated flush valve, if any, not greater than 1 gal of water per flush;
- Toilets and associated flush valve, if any, not greater than 1.6 gal of water per flush
- Drinking fountains, sinks, and lavatories in public restrooms with self-closing faucets[126]

Special fixtures such as safety showers and aspirator faucets are exempt, and the commissioner may permit use of fixtures not meeting standards if necessary for proper operation of the existing plumbing or sewer system.

On March 1, 1989, Massachusetts became the first state to require ultra-low-flow toilets using 1.6 gal per flush. The federal government adopted (effective January 1991) the following standards[127]:

- Toilets 1.6 gal per flush
- Urinals 1.0 gal per flush

*The Washington Suburban Sanitary District plumbing code has similar requirements. (R. S. McGarry and J. M. Brusnighan, "Increasing Water and Sewer Rate Schedules: A Tool for Conservation," *J. Am. Water Works Assoc*. (September 1979): 474–479.) The National Small Flows Clearinghouse, West Virginia University, reported in *Small Flows*, July 1991, that 12 states have adopted low-flow plumbing fixture regulations.

Showerheads 2.5 gpm

Lavatory faucets 2.0 gpm

Kitchen faucets 2.5 gpm

An ultra-low-flush toilet using 0.8 gal per flush was found to perform equal to or better than the conventional toilet.[128] One might also add to the list of water conservation possibilities, where appropriate, use of the compost toilet, recirculating toilet, chemical toilet, incinerator toilet, and various privies. Air-assisted half-gallon flush toilets are also available.[129]

Pressure-reducing valves in the distribution system (pressure zones) to maintain a water pressure of 20 to 40 psi at fixtures will also reduce water use. A water saving of 6 percent can be expected at new single-family homes where water pressure in the distribution system is reduced from 80 to 30 to 40 psi based on HUD studies.[130] The potential water saving through pressure control is apparent from the basic hydraulic formulas:

$$Q = VA \quad Q = (2gpw)^{1/2} \times AQ = (2gh)^{1/2} \times A$$

where

$$\begin{aligned} Q &= \text{cfs} \\ V &= \text{fps} \\ A &= \text{ft}^2 \\ g &= 32.2\,\text{ft/sec/sec} \\ p &= \text{lb/ft}^2 \\ w &= \text{lb/ft}^3\ (62.4) \\ h &= \text{ft of water} \end{aligned}$$

which show that the quantity of water flowing through a pipe varies with the velocity or the square root of the pressure head. For example, a pressure reduction from 80 to 40 psi will result in a flow reduction of 29 percent, but the actual water savings would probably be 6 percent, as previously noted.

The success of water-use conservation also depends largely on the extent to which consumers are motivated. They can be encouraged to repair leaking faucets and running toilets immediately; to not waste water; to understand that a leak causing a 1/8-inch-diameter stream adds up to 400 gal in 24 hours, which is about the amount of water used by a family of five or six in one day; to purchase a water-saving clothes washer and dishwasher; to add 1-liter bottles or a "dam" to the flush tank to see if the closet still flushes properly; to install water-saving shower heads and not use the tub; to install mixing faucets with single-lever control; and to install aerators on faucets. Consumer education and motivation must be a continuing activity. In some instances, reuse of shower, sink, and laundry wastewater for gardens is feasible.[131]

Water Reuse

An additional way of conserving drinking water and avoiding or minimizing large capital expenditures is to reduce or eliminate its use for nonpotable purposes by substituting treated municipal wastewater. This could increase the available supply for potable purposes at least cost and reduce the wastewater disposal problem. However, a distinctly separate nonpotable water system and monitoring protocol would be required.

Discussion of wastewater reuse should clearly distinguish between direct reuse and indirect reuse. In *direct reuse*, the additional wastewater treatment (such as storage, coagulation, flocculation, sedimentation, sand or anthracite filtration or granular activated-carbon filtration, and disinfection) is usually determined by the specific reuse. The wastewater is reclaimed for *nonpotable* purposes such as industrial process or cooling water, agricultural irrigation, groundwater recharge, desert reclamation, and fish farming; lawn, road median, tree farm, and park irrigation; landscape and golf-course watering; and toilet flushing. The treated wastewater must *not* be used for drinking, culinary, bathing, or laundry purposes. The long-term health effects of using treated wastewater for potable purposes are not fully understood at this time, and fail-safe, cost-effective treatment technology for the removal of all possible contaminants is not currently available.[132] In *indirect reuse*, wastewater receiving various degrees of treatment is discharged to a surface water or a groundwater aquifer, where it is diluted and after varying detention periods and treatment may become a source of water for potable purposes. *Recycling* is the reuse of wastewater, usually by the original user.

Direct municipal wastewater reuse, where permitted, would require a clearly marked dual water system, one carrying potable water and the other reclaimed wastewater. It has been estimated that the average person uses only about 25 to 55 gal of water per day for potable purposes.[133] The reclaimed water is usually bacteriologically safe but questionable insofar as other biological or organic and inorganic chemical content is concerned. A dye added to the reclaimed water would help avoid its inadvertent use for potable purposes. Okun emphasizes that the reclaimed or nonpotable water should.

> equal the quality of the potable systems that many communities now provide—the health hazard that results from the continuous ingestion of low levels of toxic substances over a period of years would not be present.[134]

Advanced wastewater treatment, monitoring, and surveillance cannot yet in practice guarantee removal of all harmful substances (microcontaminants) from wastewater at all times. However, numerous projects are now investigating reuse of water for potable purposes.[135]* More knowledge is needed concerning acute and long-term effects on human health of wastewater reuse.[136] In Windhoek, Namibia, Southwest Africa, reclaimed sewage, which is reported to contain no industrial wastes, blended with water from conventional sources has occasionally been used for drinking for many years without any apparent problems. The sewage is given very elaborate treatment involving some 18 unit processes.[137]

*The July 1985 issue of the *Journal of the American Water Works Association* is devoted to wastewater reuse.

Monitoring is done for *Salmonella, Shigella*, enteropathogenic *E. coli, Vibrio*, enterovirus, *Schistosoma*, viral hepatitis, meningitis, and nonbacterial gastroenteritis, in addition to turbidity and organic and inorganic chemicals. None of the pathogens was associated with the reclaimed wastewater.

More emphasis is needed on the removal of hazardous substances at the source and on adequate wastewater treatment prior to its discharge to surface and underground water supply sources. This will at least reduce the concentrations of contaminants discharged from urban and industrial areas and, it is hoped, the associated risks.

In any case, it is axiomatic that, in general, the cleanest surface and underground water source available should be used as a source of drinking water, and water conservation practiced, before a polluted raw water source is even considered, with cost being secondary.

SOURCE AND PROTECTION OF WATER SUPPLY

General

The sources of water supply are divided into two major classifications: groundwater and surface water. To these should be added rainwater and demineralized water. The groundwater supplies include dug, bored, driven and drilled wells, rock and sand or earth springs, and infiltration galleries. The surface-water supplies include lake, reservoir, stream, pond, river, and creek supplies.

The location of groundwater supplies should take into consideration the recharge tributary wellhead area,[138] the probable sources and travel of pollution through the ground, the well construction practices and standards actually followed, depth of well casing and grouting, and the type of sanitary seal provided at the point where the pump line(s) pass out of the casing.

Wellhead area has been defined under the 1986 Amendments to the Safe Drinking Water Act as "the surface and subsurface area surrounding a water well or wellfield, supplying a public water system, through which contaminants are reasonably likely to move toward and reach such water well or wellfield." The time of travel of a potential contaminant, distance, drawdown, flow boundaries, and assimilative capacity are critical factors in determining the wellhead protection area.[139] Some of the other hydrogeological considerations, in addition to well drawdown, radius of influence,* withdrawal rate, recharge area, and aquifer formation, are the hydraulic gradient, natural dilution, filtration, attenuation, and degradation of the contaminant in its movement through the zone of aeration (unsaturated zone) to the saturated zone and into the water table of the wellhead drainage area. These factors must be evaluated in the light of available topographic, geologic, and engineering information and the practicality of land-use controls, conservation easements, and dedication of land to parks to

*Circular only with flat water table, when drawdown cone of depression is 99 percent stabilized.

effectively prevent or adequately minimize the potential effects of contaminants on the recharge area. See earlier discussion under "Sanitary Survey and Water Sampling."

The chemical quality of shallow groundwater (8–20 ft) and its quantity can be expected to vary substantially throughout the year and after heavy rains, depending on the soil depth and characteristics in the unsaturated zone above the water table.

It is sometimes suggested that the top of a well casing should terminate below the ground level or in a pit. This is not considered good practice except when the pit can be drained above flood level to the surface by gravity or to a drained basement. Frost-proof sanitary seals with pump lines passing out horizontally from the well casing are generally available. Some are illustrated later in Figures 1.7 through 1.10.

In order that the basic data on a new well may be recorded, a form such as the well driller's log and report shown in Figure 1.4 should be completed by the well driller and kept on file by the owner for future reference. A well for a private home should preferably have a capacity (well yield) of at least 500 gal/hr, but 300 gal/hr is usually specified as a minimum for domestic water use in serving a three-bedroom home. The long-term yield of a well is dependent on the seasonal static water level, other withdrawals from the aquifer, the recharge area and storage in the aquifer, and the hydraulic characteristics of the aquifer. Because of this and the uncertainty of when stabilized drawdown is reached, the determined well yield should be reduced to compensate for long-term use and possible decline of aquifer yield. Pumping tests should therefore ensure that the water level in the well returns to the original static level. See Tables 1.14 and 1.15.

Surface-water supplies are all subject to continuous or intermittent pollution and must be treated to make them safe to drink. One never knows when the organisms causing typhoid fever, gastroenteritis, giardiasis, infectious hepatitis A, or dysentery, in addition to organic and inorganic pollutants, may be discharged or washed into the water source. The extent of the treatment required will depend on the results of a sanitary survey made by an experienced professional, including physical, chemical, and microbiological analyses. The minimum required treatments are coagulation, flocculation, sedimentation, filtration, and chlorination, unless a conditional waiver is obtained from the regulatory agency. If more elaborate treatment is needed, it would be best to abandon the idea of using a surface-water supply and resort to a protected groundwater supply if possible and practical. Where a surface supply must be used, a reservoir or a lake that provides at least 30 days *actual* detention, that does not receive sewage, industrial, or agricultural pollution, and that can be controlled through ownership or watershed rules and regulations would be preferred to a stream or creek, the pollution of which cannot from a practical standpoint be controlled. There are many situations where there is no practical alternative to the use of polluted streams for water supply. In such cases, carefully designed water-treatment plants providing multiple barriers must be provided.

Well at .... in .... County of ....
Name of place City, village or town

Owner .... P.O. Address ....

Depth of well .... Diameter .... Yield .... Was well disinfected? ....
ft in. gpm yes or no

Amt. of casing above ground .... Below ground .... Well seal ....
in. ft cement grout

Draw a well diagram in the space provided below and show the depth and type of casing, the well seal, kind and thickness of formations penetrated, water-bearing formations, diameter of drill holes with dotted lines, and casing(s) with solid lines.

Well Diagram			Formations Penetrated
Diameter, in.		Depth in ft	Kind, thickness, and if water bearing
		Grade	
		25	
		50	
		75	
		100	
		150	
		200	
		250	

Remarks

Type of well ....
Drilling method ....
Was well dynamited? ....

Pumping Tests

Details	#1	#2	#3
Static water level, in feet below grade			
Pumping rate in gpm			
Pumping level in feet below grade			
Duration of test, in hours			

Water at end of test:
Clear ..... Cloudy ..... Turbid .....
Recommended depth of pump in well, ft below grade ..... Capacity .... gpm

Wells in sand & gravel:
Sand Eff. size .... mm
Unif. Coef. ....
Length of screen .... ft
Diam. of screen .... in.
Type of screen ....
Screen openings .... x ....
Comments:

Show cross-section of well & formations penetrated above. Draw a sketch of the property on the back of this sheet locating the well and sewage disposal systems within 200 ft, also land uses.

Drilling started .... Completed ....

Well driller ....
Signature

FIGURE 1.4 Well driller's log and report. *Well yield* is the volume of water per unit of time, such as gallons per minute, discharged from a well either by pumping to a stabilized drawdown or by free flow. The *specific capacity* of a well is the yield at a stabilized drawdown and given pumping rate, expressed as gallons per minute per foot of drawdown. Chalked tape, electric probe, or known length of air line is used with pressure gauge. Test run is usually 4 to 8 hours for small wells; 24 to 72 hours for wells serving the public, or for 6 hours at a stabilized drawdown when pumping at 1.5 times the design pumping rate.

TABLE 1.15 Standards for Construction of Wells[a]

Water-Bearing Formation	Overburden	Oversize Drill Hole: Diameter	Oversize Drill Hole: Depth[b]	Cased Portion
1. Sand or gravel	Unconsolidated caving material; sand or sand and gravel	None required	None	2 in. minimum, 5 in. or more preferred
2. Sand or gravel	Clay, hardpan, silt, or similar material to depth of more than 20 ft	Casing size plus 4 in.	Minimum 20 ft	2 in. maximum, 5 in. or more preferred
3. Sand or gravel	Clay, hardpan, silt, or similar material containing layers of sand or gravel within 15 ft of ground surface	Casing size plus 4 in.	Minimum 20 ft	2 in. minimum, 5 in or more preferred
4. Sand or gravel	Creviced or fractured rock, such as limestone, granite, quartzite	Casing size plus 4 in.	Through rock formation	4 in. minimum
5. Creviced, shattered, or otherwise fractured limestone, granite, quartzite, or similar rock types	Unconsolidated caving material, chiefly sand or sand and gravel to a depth of 40 ft or more and extending at least 2000 ft in all directions from the well site	None required	None required	6 in. minimum

Well Diameter					
Uncased Portion	Well Screen Diameter[c]	Minimum Casing Length or Depth[b]	Liner Diameter (If Required)	Construction Conditions[b]	Miscellaneous Requirements
Does not apply	2 ft minimum	20 ft minimum; but 5 ft below pumping level[d]	2 in. minimum		
Does not apply	2 ft minimum	5 ft below pumping level[d]	2 in. minimum	Upper drill hole shall be kept at least one-third filled with clay slurry while driving permanent casing; after casing is in permanent position annular space shall be filled with clay slurry or cement grout.	An adequate well screen shall be provided where necessary to permit pumping sand-free water from the well.
Does not apply	2 ft minimum	5 ft below pumping level[d]	2 in. minimum	Annular space around casing shall be filled with cement grout.	
Does not apply	2 in. minimum	5 ft below overburden of rock	2 in. minimum	Annular space around casing shall be filled with cement grout.	
6 in. preferred	Does not apply	Through caving overburden	4 in. minimum	Casing shall be firmly seated in the rock.	

(*continues*)

TABLE 1.15 (*continued*)

Water-Bearing Formation	Overburden	Oversize Drill Hole Diameter	Oversize Drill Hole Depth[b]	Cased Portion
6. Creviced, shattered, or otherwise fractured limestone, granite, quartzite, or similar rock types	Clay, hardpan, shale, or similar material to a depth of 40 ft or more and extending at least 2000 ft in all directions from well site	Casing size plus 4 in.	Minimum 20 ft	6 in. minimum
7. Creviced, shattered, or otherwise fractured limestone, granite, quartzite, or similar rock	Unconsolidated materials to a depth of less than 40 ft and extending at least 2,000 ft in all directions	Casing size plus 4 in.	Minimum 40 ft	6 in. minimum
8. Sandstone	Any material except creviced rock to a depth of 25 ft or more	Casing size plus 4 in.	15 ft into firm sandstone or to 30 ft depth, whichever is greater	4 in. minimum
9. Sandstone	Mixed deposits mainly sand and gravel, to a depth of 25 ft or more	None required	None required	4 in. minimum

Well Diameter					
Uncased Portion	Well Screen Diameter[c]	Minimum Casing Length or Depth[b]	Liner Diameter (If Required)	Construction Conditions[b]	Miscellaneous Requirements
6 in. preferred	Does not apply	Through overburden	4 in. minimum	Annular space around casing shall be grouted. Casing shall be firmly seated in rock.	
6 in. preferred	Does not apply	40 ft minimum	4 in. minimum	Casing shall be firmly seated in rock. Annular space around casing shall be grouted.	If grout is placed through casing pipe and forced into annular space from the bottom of the casing, the oversize drill hole may be only 2 in. larger than the casing pipe.
4 in. preferred		Same as oversize drill hole or greater	2 in. minimum	Annular space around casing shall be grouted. Casing shall be firmly seated in sandstone.	Pipe 2 in. smaller than the drill hole and liner pipe 2 in. smaller than casing shall be assembled without couplings.
4 in. preferred		Through overburden into firm sandstone	2 in. minimum	Casing shall be effectively seated into firm sandstone.	

(*continues*)

TABLE 1.15 (*continued*)

Water-Bearing Formation	Overburden	Oversize Drill Hole Diameter	Oversize Drill Hole Depth[b]	Cased Portion
10. Sandstone	Clay, hardpan, or shale to a depth of 25 ft or more	Casing size plus 4 in.	Minimum 20 ft	4 in. minimum

Well Diameter					
Uncased Portion	Well Screen Diameter[c]	Minimum Casing Length or Depth[b]	Liner Diameter (If Required)	Construction Conditions[b]	Miscellaneous Requirements
4 in. preferred		Through overburden into sandstone	2 in. minimum	Casing shall be effectively seated into firm sandstone. Oversized drill hole shall be kept at least one-third filled with clay slurry while driving permanent casing; after the casing is in the permanent position, annular space shall be filled with clay slurry or cement grout.	Pipe 2 in. smaller than the oversize drill hole and liner pipe 2 in. smaller than casing shall be assembled without couplings.
	2 in. minimum, if well screen required to permit pumping sand-free water from partially cemented sandstone				

(*continues*)

TABLE 1.15 (*continued*)

Water-Bearing Formation	Overburden	Oversize Drill Hole Diameter	Oversize Drill Hole Depth[b]	Cased Portion
11. Sandstone	Creviced rock at variable depth	Casing size plus 4 in.	15 ft or more into firm sandstone	6 in. minimum

Note: For wells in creviced, shattered, or otherwise fractured limestone, granite, quartzite, or similar rock in which the overburden is less than 40 ft and extends less than 2,000 ft in all directions and no other practical acceptable water supply is available, the well construction described in line 7 of this table is applicable.

[a] Requirements for the proper construction of wells vary with the character of subsurface formations, and provisions applicable under all circumstances cannot be fixed. The construction details of this table may be adjusted, as conditions warrant, under the procedure provided by the Health Department and in the Note above.

[b] In the case of a flowing artesian well, the annular space between the soil and rock and the well casing shall be tightly sealed with cement grout from within 5 ft of the top of the aquifer to the ground surface in accordance with good construction practice.

[c] These diameters shall be applicable in circumstances where the use of perforated casing is deemed practicable. Well points commonly designated in the trade as $1\frac{1}{4}$-in. pipe shall be considered as being 2 ft nominal diameter well screens for purposes of these regulations.

[d] As used herein, the term *pumping level* shall refer to the lowest elevation of the surface of the water in a well during pumping, determined to the best knowledge of the water well contractor, taking into consideration usual seasonal fluctuations in the static water level and drawdown level.

Source: Recommended State Legislation and Regulations, Public Health Service, Department of Health, Education, and Welfare, Washington, DC, July 1965.

Well Diameter					
Uncased Portion	Well Screen Diameter[c]	Minimum Casing Length or Depth[b]	Liner Diameter (If Required)	Construction Conditions[b]	Miscellaneous Requirements
6 in. preferred		15 ft into firm sandstone	4 in. minimum	Annular space around casing shall be filled with cement grout.	If grout is placed through casing pipe and forced into annular space from the bottom of the casing, the oversize drill hole may be only 2 in. larger than the casing pipe. Pipe 2 in. smaller than the drill hole and liner pipe 2 in. smaller than casing shall be assembled without couplings.

Groundwater

About one-half of the U.S. population depends on groundwater for drinking and domestic purposes; 98 percent of the rural population is almost entirely dependent on groundwater. Some 43.5 million people are served by individual, on-site well-water systems (2000 USGS). These are not protected or regulated under the Safe Drinking Water Act. In view of this, protection of our groundwater resources must receive the highest priority. Elimination of groundwater pollution and protection of aquifers and their drainage areas by land-use and other controls require state and local regulations and enforcement.

It is estimated that there is more than 100 times more water stored underground than in all the surface streams, lakes, and rivers. Protection and development of groundwater sources can significantly help meet the increasing water needs. Exploration techniques include use of data from USGS and state agencies, previous studies, existing well logs, gains or losses in stream flow, hydrogeologic mapping using aerial photographs, surface resistivity surveys electromagnetic induction surveys or other geophysical prospecting, and exploratory test wells.

A technique for well location called *fracture-trace mapping* is reported to be a highly effective method for increasing the ratio of successful to unsuccessful well-water drilling operations and to greatly improve water yields (up to 50 times). Aerial photographs give the skilled hydrogeologist clues of the presence of a zone of fractures underneath the earth's surface. Clues are abrupt changes in the alignment of valleys, the presence of taller or more lush vegetation, the alignment of sink holes or other depressions in the surface, or the existence of shallow, longitudinal depressions in the surface overtop of the fracture zone. The soil over fracture zones is often wetter and, hence, shows up darker in recently plowed fields. The aerial photograph survey is then followed by a field investigation and actual ground location of the fractures and potential well-drilling sites.[140]

It has been suggested that all groundwater supplies be chlorinated. Exceptions may be properly located, constructed, and protected wells *not* in limestone or other channeled or fractured rock and where the highest water table level is at least 10 feet below ground level; where sources of pollution are more than 5,000 feet from the well; and where there is a satisfactory microbiological history. Other criteria include soil permeability, rate and direction of groundwater flow, and underground drainage area to the well. Chlorination should be considered a factor of safety and not reason to permit poor well construction and protection.

Dug Well

A dug well is one usually excavated by hand, although it may be dug by mechanical equipment. It may be 3 to 6 feet in diameter and 15 to 35 feet deep, depending on where the water-bearing formation or groundwater table is encountered. Wider and deeper wells are less common. Hand pumps over wells and pump lines entering wells should form watertight connections, as shown in Figure 1.5 and Figure 1.6. Since dug wells have a relatively large diameter, they have large storage capacity. The level of the water in dug wells will lower at times of

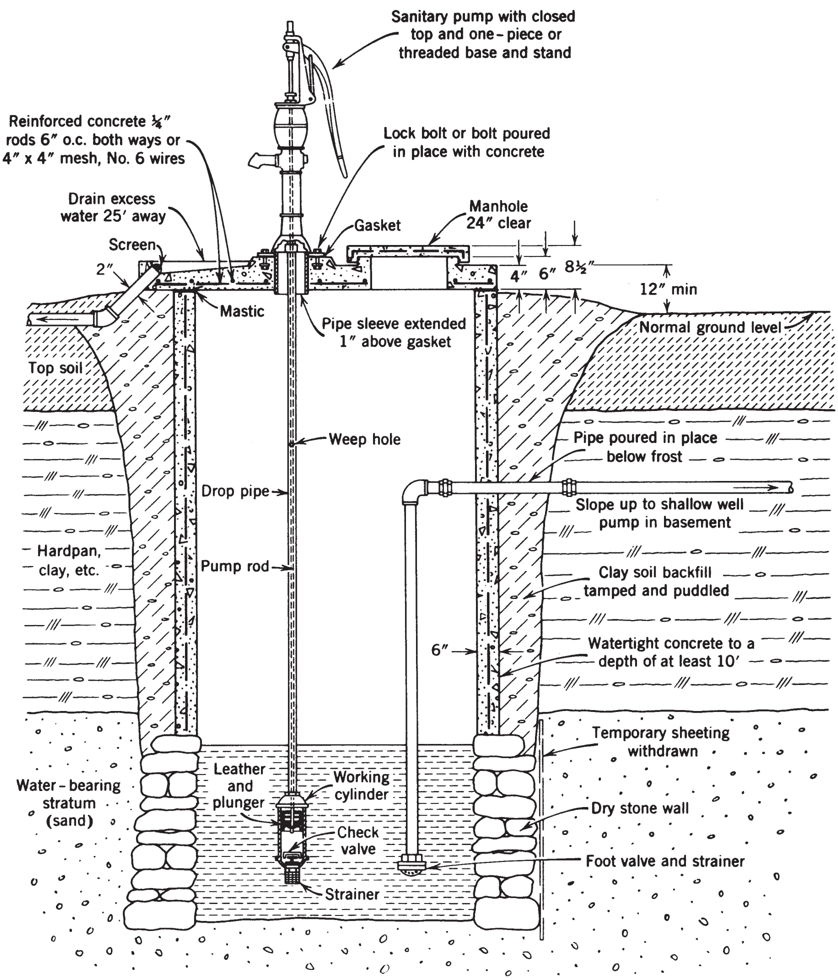


FIGURE 1.5 A properly developed dug well.

drought and the well may go dry. Dug wells are not usually dependable sources of water supply, particularly where modern plumbing is provided. In some areas, properly developed dug wells provide an adequate and satisfactory water supply. However, dug wells are susceptible to contamination deposited on or naturally present in the soil when subjected to heavy rains, particularly if improperly constructed. This potential hazard also applies to shallow bored, driven, and jetted wells. Water quality can be expected to change significantly.

Bored Well

A bored well is constructed with a hand- or machine-driven auger. Bored wells vary in diameter from 2 to 30 inches and in depth from 25 to 60 feet. A casing

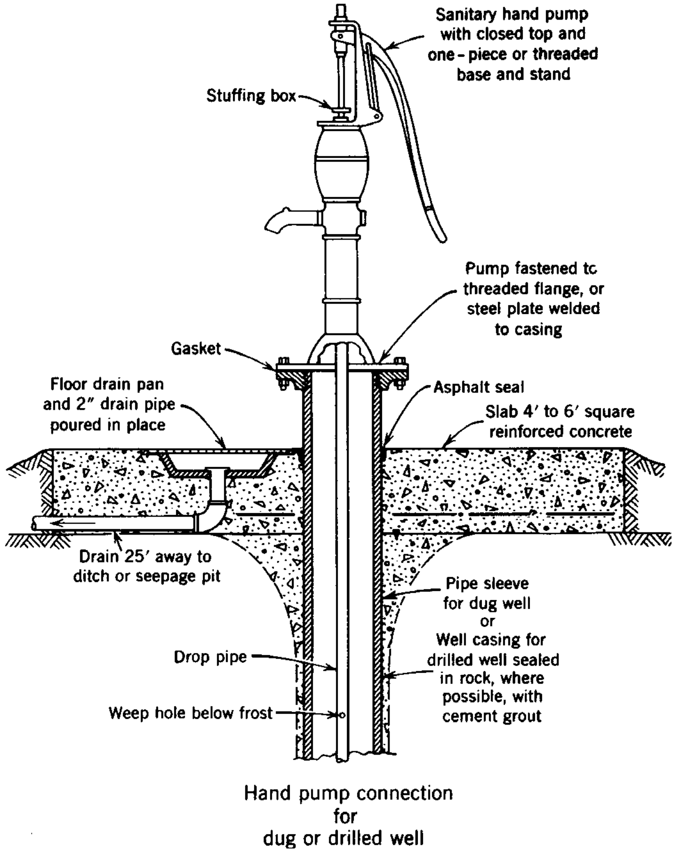


FIGURE 1.6 Sanitary hand pump and well attachment. Place 2 feet of gravel under slab where frost is expected.

of concrete pipe, vitrified clay pipe, metal pipe, or plastic pipe is necessary to prevent the relatively soft formation penetrated from caving into the well. Bored wells have characteristics similar to dug wells in that they have small yields, are easily polluted, and are affected by droughts.

Driven and Jetted Well

These types of wells consist of a well point with a screen attached, or a screen with the bottom open, which is driven or jetted into a water-bearing formation found at a comparatively shallow depth. A series of pipe lengths are attached to the point or screen as it is forced into position. The driven well is constructed by driving the well point, preferably through at least 10 to 20 feet of casing, with the aid of a maul or sledge, pneumatic tamper, sheet pile driver, drive monkey, hand-operated driver, or similar equipment. In many instances, the casing is omitted, but then less protection is afforded the driven well, which also serves as the pump suction line. The jetted well is constructed by directing a stream of water at the bottom of the open screen, thereby loosening and flushing the soil up the casing to the surface as the screen is lowered. Driven wells are commonly between 1-1/4 and 2 inches in diameter and less than 50 feet in depth; jetted wells may be 2 to 12 inches in diameter and up to 100 feet deep, although larger and deeper wells can be constructed. In the small-diameter wells, a shallow well hand or mechanical suction pump is connected directly to the well. Large-diameter driven wells facilitate installation of the pump cylinder close to or below the water surface in the well at greater depth, in which case the hand pump must be located directly over the well. In all cases, however, care must be taken to see that the top of the well is tightly capped, the concrete pump platform extends 2 or 3 feet around the well pipe or casing, and the annular space between the well casing and drop pipe(s) is tightly sealed. This is necessary to prevent the entrance of unpurified water or other pollution from close to the surface.

A radial well is a combination dug-and-driven well in which horizontally driven well collectors radiate out from a central sump or core and penetrate into a water-bearing stratum.

Drilled Well

Studies have shown that, in general, drilled wells are superior to dug, bored, or driven wells and springs. But there are some exceptions. Drilled wells are less likely to become contaminated and are usually more dependable sources of water. When a well is drilled, a hole is made in the ground, usually with a percussion (cable tool) or rotary (air or mud) drilling machine. Drilled wells are usually 4 to 12 inches in diameter or larger and may reach 750 to 1,000 feet in depth or more. Test wells are usually 2 to 5 inches in diameter with a steel casing. A steel or wrought-iron casing is lowered as the well is drilled to prevent the hole from caving in and to seal off water of doubtful quality. Special plastic pipe is also used if approved. Lengths of casing should be threaded and coupled or properly field welded. The drill hole must, of course, be larger than the casing, thereby leaving an irregular space around the outside length of the casing. Unless this space or channel is closed by cement grout or naturally by formations that conform to the casing almost as soon as it is placed, pollution from the surface or crevices close to the surface or from polluted formations penetrated will flow down the side of the casing and into the water source. Water can also move up and down this annular space in an artesian well and as the groundwater and pumping water level changes.

The required well diameter is usually determined by the size of the discharge piping, fittings, pump, and motor placed inside the well casing. In general, for well yields of less than 100 gpm, a 6-inch-inside-diameter casing should be used; for 75 to 175 gpm an 8-inch casing; for 150 to 400 gpm a 10-inch casing; for 350 to 650 gpm a 12-inch casing; for 600 to 900 gpm a 14-inch-outside-diameter casing; for 850 to 1,300 gpm a 16-inch casing; for 1,200 to 1,800 gpm a 20-inch casing; and for 1,600 to 3,000 gpm a 24-inch casing.[141] Doubling the diameter of a casing increases the yield up to only 10 to 12 percent.

When the source of water is water-bearing sand and gravel, a gravel well or gravel-packed well with screen may be constructed. Such a well will usually yield more water than the ordinary drilled well with a screen of the same diameter and with the same drawdown. A slotted or perforated casing in a water-bearing sand will yield only a fraction of the water obtainable through the use of a proper screen selected for the water-bearing material. On completion, the well should be developed and tested, as noted previously. A completed well driller's log should be provided to the owner on each well drilled. See Figure 1.4.

Only water well casing of clean steel or wrought iron should be used. Plastic pipe may be permitted. Used pipe is unsatisfactory. Standards for well casing are available from the American Society for Testing Materials, the American Iron and Steel Institute, and state health or environmental protection agencies.

Extending the casing at least 5 feet below the pumping water level in the well—or if the well is less than 30 feet deep, 10 feet below the pumping level—will afford an additional measure of protection. In this way, the water is drawn from a depth that is less likely to be contaminated. In some sand and gravel areas, extending the casing 5 to 10 feet below the pumping level may shut off the water-bearing sand or gravel. A lesser casing depth would then be indicated, but in no instance should the casing be less than 10 feet, provided sources of pollution are remote and provision is made for chlorination. The recommended depth of casing, cement grouting, and need for double-casing construction or the equivalent are given in Table 1.15.

A vent is necessary on a well because, if not vented, the fluctuation in the water level will cause a change in air pressure above and below atmospheric pressure in a well, resulting in the drawing in of contaminated water from around the pump base over the well or from around the casing if not properly sealed. Reduced pressure in the well will also increase lift or total head and reduce volume of water pumped.

It must be remembered that well construction is a very specialized field. Most well drillers are desirous of doing a proper job, for they know that a good well is their best advertisement. However, in the absence of a state or local law dealing with well construction, the enforcement of standards, and the licensing of well drillers, price alone frequently determines the type of well constructed. Individuals proposing to have wells drilled should therefore carefully analyze bids received. Such matters as water quality, well diameter, type and length of casing, minimum well yield, type of pump and sanitary seal where the pump line(s) passes through the casing, provision of a satisfactory well log, method used to seal off undesirable formations and cement grouting of the well, plans to pump the well until clear, and disinfection following construction should all be taken into consideration. See Figures 1.6 through 1.12.

Recommended water well protection and construction practices and standards are given in this text. More detailed information, including well construction and development, contracts, and specifications, is available in federal, state, and other

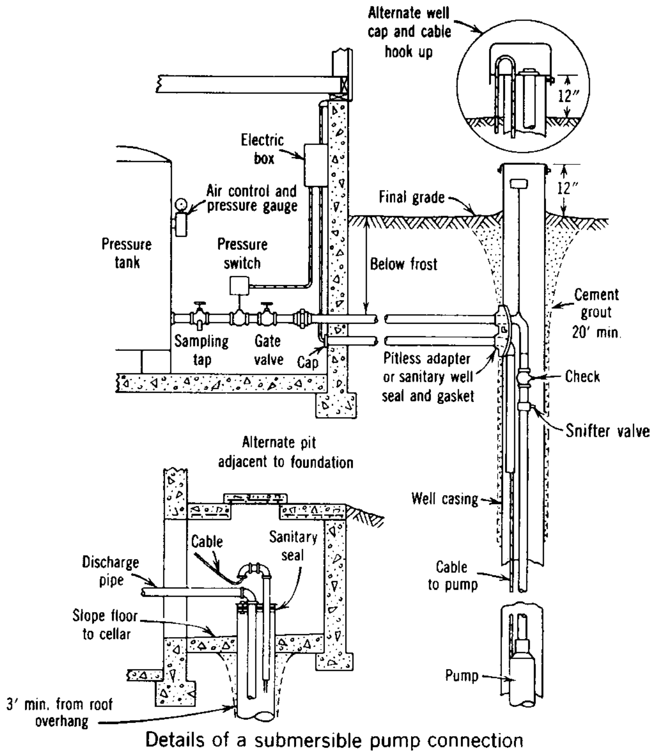
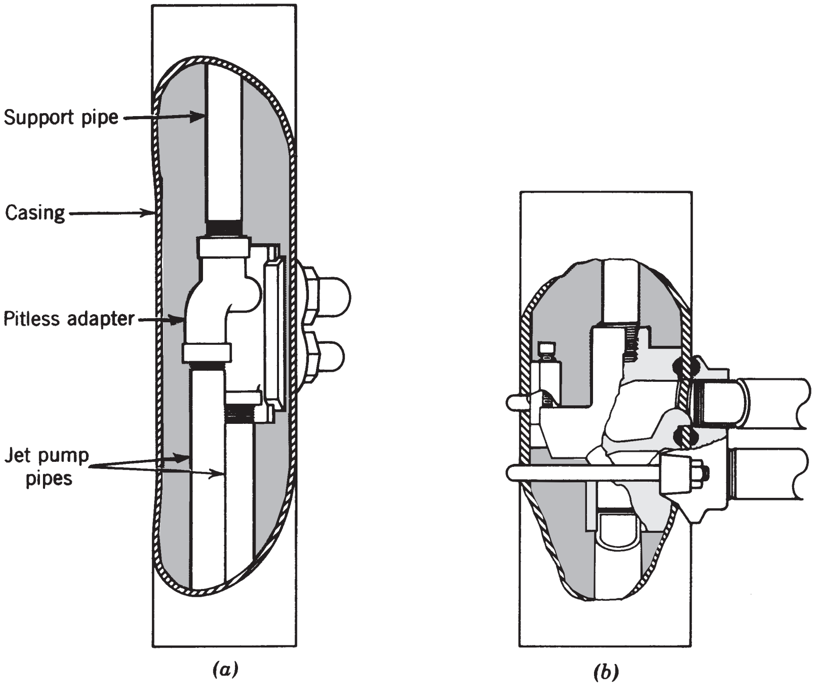


FIGURE 1.7 Sanitary well caps and seal and submersible pump connection.

publications.[142] A hydrogeologist or professional engineer can help assure proper location, construction, and development of a well, particularly for a public water supply. It has been estimated that the radius of the cone of depression of a well in fine sand is 100 to 300 feet, in coarse sand 600 to 1,000 feet, and in gravel 1,000 to 2,000 feet. In a consolidated formation, determination of the radius of the cone of depression requires a careful hydrogeological analysis. Remember, the cheapest well is not necessarily the best buy.

Well Development

Practically all well-drilling methods, and especially the rotary drill method, cause smearing and compaction or cementing of clay, mud, and fine material on the bore hole wall and in the crevices of consolidated formations penetrated. This will reduce the sidewall flow of water into the well and, hence, the well yield. Various methods are used to remove adhering mud, clay, and fines and to develop a well to its full capacity. These include pumping, surging (valved surge device, solid surge device, pumping with surge device, air surge), and fracturing (explosives, high-pressure jetting, backwashing). Adding a polyphosphate or a nonfoaming



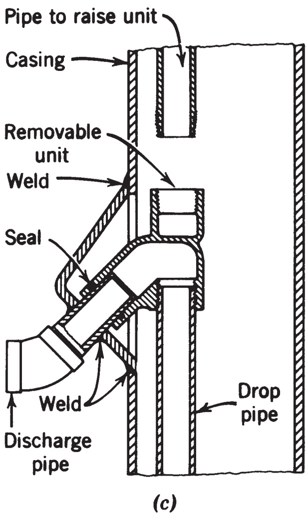


FIGURE 1.8 Pitless adapters. ((*a*) Courtesy Martin Manufacturing Co., Ramsey, NJ. (*b*) Courtesy Williams Products Co., Joliet, IL. (*c*) Courtesy Herb Maass Service, Milwaukee, WI.)

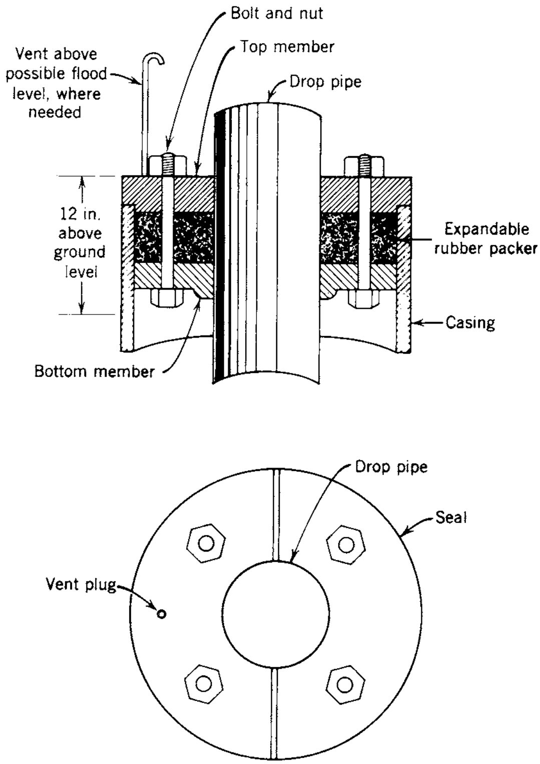


FIGURE 1.9 Sanitary expansion well cap.

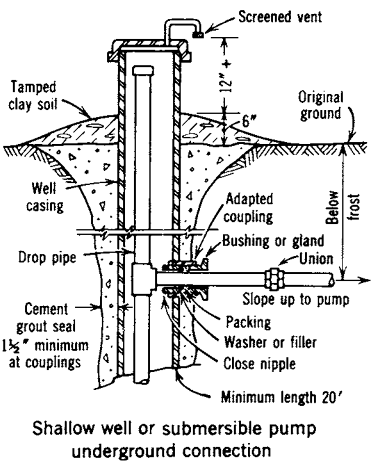


FIGURE 1.10 Improved well seal.

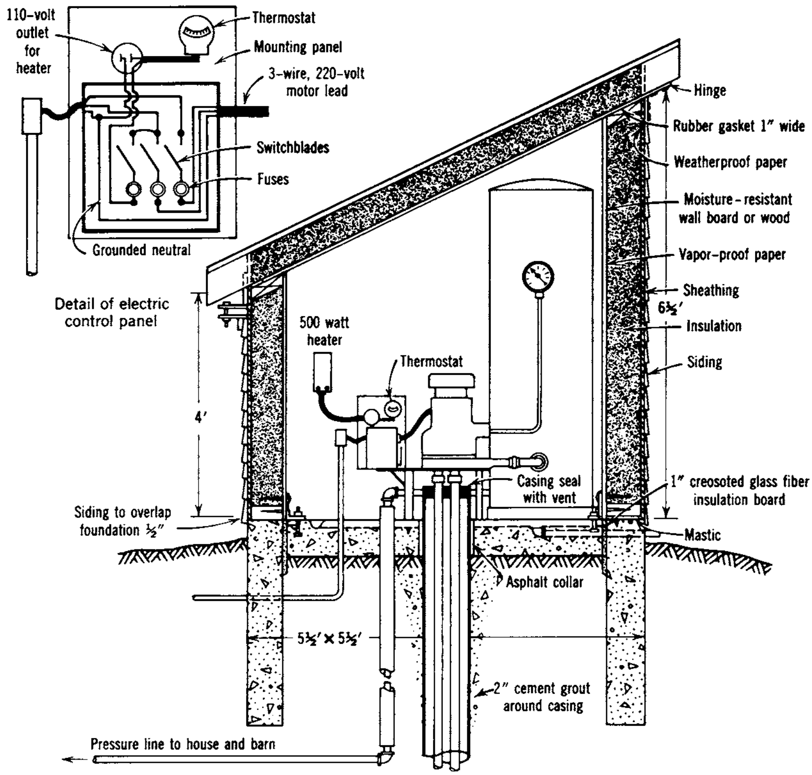


FIGURE 1.11 Insulated pumphouse. (*Source: Sewage Disposal and Water Systems on the Farm*, Extension Bulletin 247, University of Minnesota Extension Service, revised 1956. Reproduced with permission.)

detergent can also aid in removing adhering materials. The well development operation is continued until the discharge becomes practically clear of sand (5 ppm or less). Following development, the well should be tested to determine the dependable well yield. The well is then disinfected and the log completed.

Grouting

One of the most common reasons for contamination of wells drilled through rock, clay, or hardpan is failure to properly seal the annular space around the well casing. A proper seal is needed to prevent water movement between aquifers, protect the aquifers, and prevent entry of contaminated water from the surface or near the surface.

A contaminated well supply causes the homeowner or municipality considerable inconvenience and extra expense, for it is difficult to seal off contamination after the well is drilled. In some cases, the only practical answer is to build a new well.

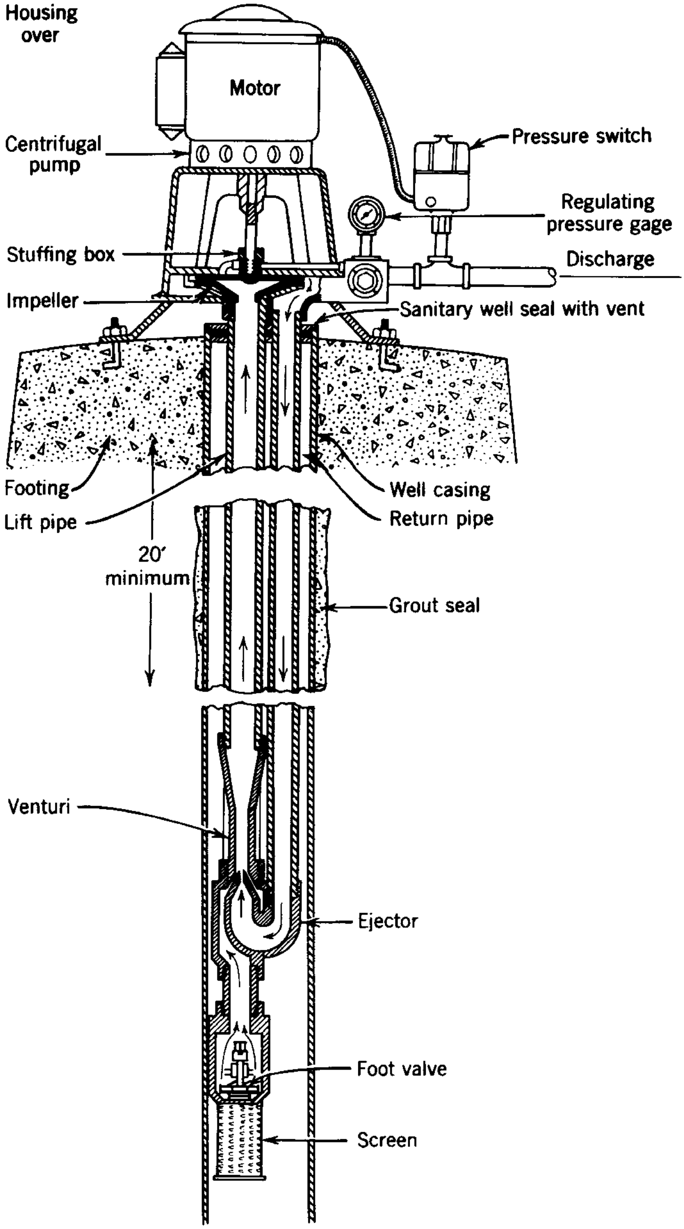


FIGURE 1.12 Sanitary well seal and jet pump.

Proper *cement grouting* of the space between the drill hole and well casing, the annulus, where the overburden over the water-bearing formation is clay, hardpan, or rock, can prevent this common cause of contamination. (See Table 1.15.)

There are many ways to seal well casings. The best material is neat cement grout.* However, to be effective, the grout must be properly prepared (a proper mixture is 5-1/2 to 6 gal of clean water to a bag of cement), pumped as one continuous mass, and placed upward from the bottom of the space to be grouted. An additive such as bentonite may be used to minimize shrinkage and increase fluidity, if approved.

The clear annular space around the outside of the casing couplings and the drill hole must be at least 1-1/2 in. on all sides to prevent bridging of the grout. Guides must be welded to the casing.

Cement grouting of a well casing along its entire length of 50 to 100 feet or more is good practice but expensive for the average farm or rural dwelling. An alternative is grouting to at least 20 feet below ground level. This provides protection for most installations, except in limestone and fractured formations. It also protects the casing from corrosion.

For a 6-inch-diameter well, a 10-inch hole is drilled, if 6-inch welded pipe is used, to at least 20 feet or to solid rock if the rock is deeper than 20 feet. If 6-inch coupled pipe is used, a 12-inch hole will be required. From this depth the 6-inch hole is drilled deeper until it reaches a satisfactory water supply. A temporary outer casing, carried down to rock, prevents cave-in until the cement grout is placed.

Upon completion of the well, the annular space between the 6-inch casing and temporary casing or drill hole is filled from the bottom up to the grade with cement grout. The temporary pipe is withdrawn as the cement grout is placed—it is not practical to pull the casing after all the grout is in position.

The extra cost of the temporary casing and larger drill hole is small compared to the protection obtained. The casing can be reused as often as needed. In view of this, well drillers who are not equipped should consider adding larger casing and equipment to their apparatus.

A temporary casing or larger drill hole and cement grouting are not required where the entire earth overburden is 40 feet or more of silt or sand and gravel, which immediately close in on the total length of casing to form a seal around the casing; however, this condition is not common.

Drilled wells serving public places are usually constructed and cement grouted as explained in Table 1.15.

In some areas, limestone and shale beneath a shallow overburden represent the only source of water. Acceptance of a well in shale or limestone might be conditioned on an extended observation period to determine the sanitary quality of the water. Continuous chlorination should be required on satisfactory supplies serving the public and should be recommended to private individuals. However,

*Sand–cement grout, two parts sand to one part Portland cement by weight, with not more than 6 gal of water per sack of cement, may also be used. The curing time for neat cement is 72 hr; for high early strength cement, at least 36 hr.

chlorination should not be relied on to make a heavily contaminated well-water supply satisfactory. Such supplies should be abandoned and filled in with concrete or puddled clay unless the source of contamination can be eliminated.

Well drillers may have other sealing methods suitable for particular local conditions, but the methods just described utilizing a neat cement or sand-cement grout will give reasonably dependable assurance that an effective seal is provided, whereas this cannot be said of some of the other methods used. Driving the casing, a lead packer, drive shoe, rubber sleeves, and similar devices do not provide reliable annular space seals for the length of the casing.

Well Contamination — Cause and Removal

Well-water supplies are all too often improperly constructed, protected, or located, with the result that microbiological examinations show the water to be contaminated. Under such conditions, all water used for drinking or culinary purposes should first be boiled or adequately treated. Boiling will not remove chemical contaminants other than volatiles; treatment may remove some. If practical, abandonment of the well and connection to a public water supply would be the best solution. A second alternative would be investigation to find and remove the cause of pollution; however, if the aquifer is badly polluted, this may take considerable time. A third choice would be a new, properly constructed and located drilled well in a clean aquifer. See "Travel of Pollution through the Ground," earlier in this chapter.

When a well shows the presence of bacterial contamination, it is usually due to one or more of four probable causes: lack of or improper disinfection of a well following repair or construction; failure to seal the annular space between the drill hole and the outside of the casing; failure to provide a tight sanitary seal at the place where the pump line(s) passes through the casing; and wastewater pollution of the well through polluted strata or a fissured or channeled formation. On some occasions, the casing is found to be only a few feet in length and completely inadequate. Chemical contamination usually means the aquifer has been polluted.

If a new well is constructed or if repairs are made to the well, pump, or piping, contamination from the work is probable. The well, pump, storage tank, and piping should be disinfected, as explained in this chapter.

If a sewage disposal system is suspected of contamination, a dye such as water-soluble sodium or potassium fluorescein or ordinary salt can be used as a tracer. A solution flushed into the disposal system or suspected source may appear in the well water within 12 to 24 hours. It can be detected by sight, taste, or analysis if a connection exists. Samples should be collected every few hours and set aside for comparison. If the connection is indirect, fluoroscopic or chemical examination for the dye or chlorides is more sensitive. One part of fluorescein in 10 to 40 million parts of water is visible to the naked eye, and in 10 billion parts if viewed in a long glass tube or if concentrated in the laboratory. The chlorides in the well before adding salt should, of course, be known. Where chloride determinations are routinely made on water samples, sewage pollution may be apparent without making the salt test. Dye is not decolorized by passage through sand, gravel, or manure; it is slightly decomposed by calcareous soils and entirely decolorized by peaty formations and free acids, except carbonic acid.[143] A copper sulfate solution (300 mg/1), nonpathogenic bacteria and spores, radionuclides, strong electrolytes, and nonfluorescent dyes have also been used. Dyes include congo red, malachite green, rhodamine, pyranine, and photine.[144]

If the cause of pollution is suspected to be an underground seal where the pump line(s) passes through the side of the casing, a dye or salt solution or even plain water can be poured around the casing. Samples of the water can be collected for visual or taste test or chemical examination. The seal might also be excavated for inspection. Where the upper part of the casing can be inspected, a mirror or strong light can be used to direct a light beam inside the casing to see if water is entering the well from close to the surface. Sometimes it is possible to hear the water dripping into the well. Inspection of the top of the well will also show if the top of the casing is provided with a sanitary seal and whether the well is subject to flooding. See Figures 1.7 to 1.12.

The path of pollution entry can also be holes in the side of the casing, channels along the length of the casing leading to the well source, crevices or channels connecting surface pollution with the water-bearing stratum, or the annular space around the casing. A solution of dye, salt, or plain water can be used to trace the pollution, as previously explained.

The steps taken to provide a satisfactory water supply would depend on the results of the investigation. If a sanitary seal is needed at the top or side of the casing where the pump lines pass through, then the solution is relatively simple. On the other hand, an unsealed annular space is more difficult to correct. A competent well driller could be engaged to investigate the possibility of grouting the annular space and installing an inner casing or a new casing carefully sealed in solid rock. If the casing is found tight, it would be assumed that pollution is finding its way into the water-bearing stratum through sewage-saturated soil or creviced or channeled rock at a greater depth. It is sometimes possible, but costly, to seal off the polluted stratum and, if necessary, drill deeper.

Once a stratum is contaminated, it is very difficult to prevent future pollution of the well unless all water from such a stratum is effectively sealed off. Moving the offending sewage disposal system to a safe distance or replacing a leaking oil or gasoline tank is possible, but evidence of the pollution may persist for some time.

If a dug well shows evidence of contamination, the well sidewalls may be found to consist of stone or brick lining, which is far from being watertight. In such cases, the upper 6 to 10 feet should be removed and replaced with a poured concrete lining and platform. As an alternative, a concrete collar 6 to 12 inches thick, 6 to 10 feet deep could be poured around the *outside* of the stone or brick lining (see Figure 1.5). Take safety precautions (see *Safety* in Index).

Chemical contamination of a well and the groundwater aquifer can result from spills, leaking gasoline and oil tanks, or improper disposal of chemical wastes such as by dumping—on the ground in landfills—lagooning, or similar methods. Gasoline and oil tanks typically have a useful life of about 20 years, depending on the type of soils and tank coatings. Since many tanks have been in the ground 20 to 30 years or longer, their integrity must be uncertain and they are probably leaking to a greater or lesser degree. New tanks are not necessarily immune from leakage. If not already being done, oil, gasoline, and other buried tanks containing hazardous chemicals should be tested periodically and, of course, at the first sign of leakage promptly replaced with approved tanks. The number of tanks, surreptitious dumpings, discharges to leaching pits, and other improper disposals make control a formidable task. This subject is discussed further in this chapter; see "Groundwater Pollution Hazard" and "Travel of Pollution through the Ground."

Unless all the sources of pollution can be found and removed, it is recommended that the well be abandoned and filled with neat cement grout, puddled clay, or concrete to prevent the pollution from traveling to other aquifers or wells. In some special cases and under controlled conditions, use of a slightly contaminated water supply may be permitted provided approved treatment facilities are installed. Such equipment is expensive and requires constant attention. If a public water supply is not available and a new well is drilled, it should be located and constructed as previously explained.

Spring

Springs are broadly classified as either rock springs or earth springs, depending on the source of water. To obtain satisfactory water, it is necessary to *find the source*, properly develop it, eliminate surface water, and prevent animals from gaining access to the spring area.

Protection and development of a source of water are shown in Figure 1.13. A combination of methods may also be possible under certain ground conditions and would yield a greater supply of water than either alone.

In all cases, the spring should be protected from surface-water pollution by constructing a deep diverting ditch or the equivalent above and around the spring. The spring and collecting basin should have a watertight top, preferably concrete, and water obtained by gravity flow or by means of a properly installed sanitary hand or mechanical pump. Access or inspection manholes, when provided, should be tightly fitted (as shown) and kept locked. Water from limestone or similar type channeled or fissured rock springs is not purified to any appreciable extent when traveling through the formation and hence may carry pollution from nearby or distant places. Under these circumstances, it is advisable to have periodic bacteriological examinations made and chlorinate the water.

Infiltration Gallery

An infiltration gallery consists of a system of porous, perforated, or open-joint pipe or other conduit draining to a receiving well. The pipe is surrounded by gravel and located in a porous formation such as sand and gravel below the water table. The collecting system should be located 20 feet or more from a lake or stream or under the bed of a stream or lake if installed under expert supervision. It

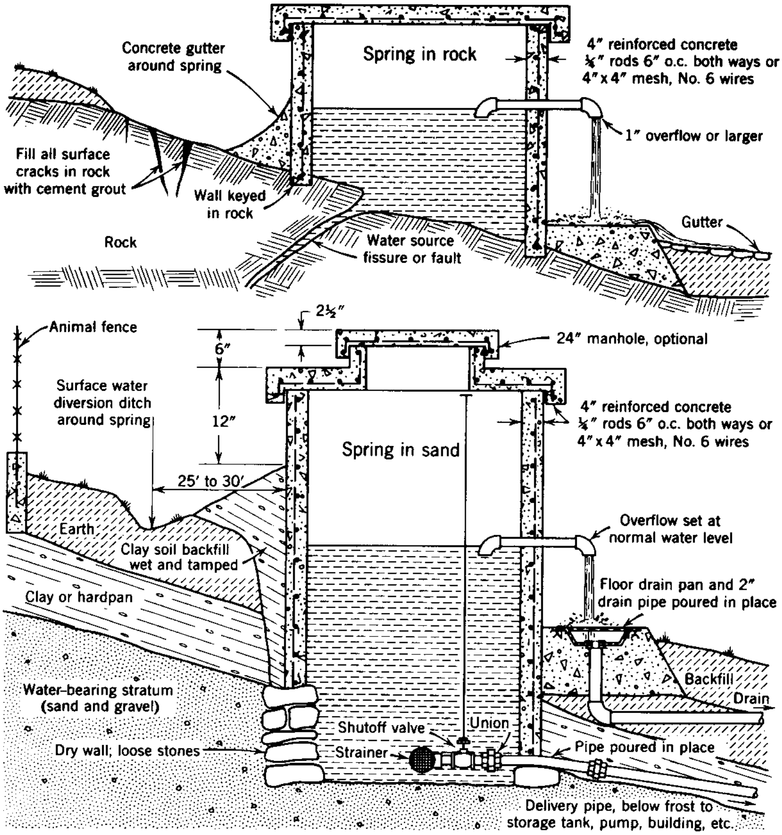


FIGURE 1.13 Properly constructed springs.

is sometimes found desirable, where possible, to intercept the flow of groundwater to the stream or lake. In such cases, a cofferdam, cutoff wall, or puddled clay dam is carefully placed between the collecting conduit and the lake or stream to form an impervious wall. It is not advisable to construct an infiltration gallery unless the water table is relatively stable and the water intercepted is free of pollution. The water-bearing strata should not contain cementing material or yield a very hard water, as it may clog the strata or cause incrustation of the pipe, thereby reducing the flow. An infiltration gallery is constructed similar to that shown in Figure 1.14. The depth of the collecting tile should be about 10 feet below the normal ground level, and below the lowest known water table, to assure a greater and more constant yield. An infiltration gallery may also be located at a shallow depth, above a highly mineralized groundwater, such as saline water, to collect the fresh or less mineralized water. An infiltration system consisting of horizontally perforated or porous radial collectors draining to a collecting well can also be designed and constructed where hydrogeological conditions are suitable, usually under a stream bed or lake, or where a thin water-bearing stratum exists. The

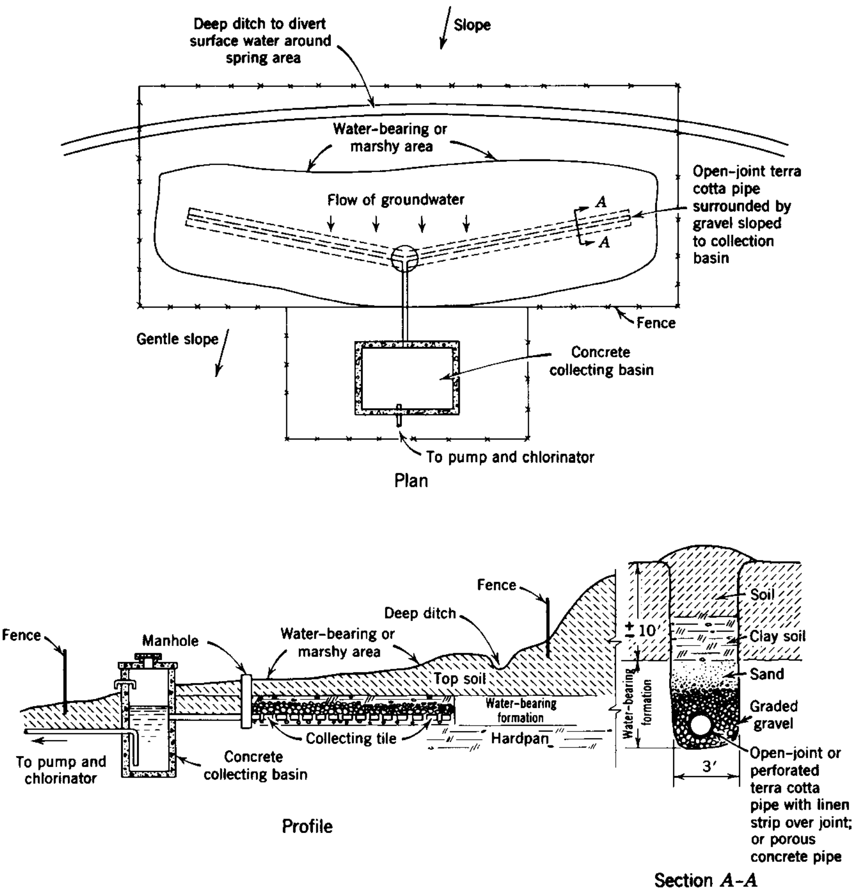


FIGURE 1.14 Development of a spring in a shallow water-bearing area.

infiltration area should be controlled and protected from pollution by sewage and other wastewater and animals. Water derived from infiltration galleries should, at the minimum, be given chlorination treatment.

Cistern

A cistern is a watertight tank in which rainwater collected from roof runoff or other catchment area is stored. When the quantity of groundwater or surface water is inadequate or the quality objectionable and where an adequate municipal water supply is not available, a cistern supply may be acceptable as a limited source of water. On the one hand, because rainwater is soft, little soap is needed when used for laundry purposes. On the other hand, rain will wash air pollutants, dust, dirt, bird and animal droppings, leaves, paint, and other material on the roof or in roofing materials or catchment area into the cistern unless special provision is made to bypass the first rainwater and filter the water. The bypass may consist of a simple manually or float-operated damper or switch placed in the leader drain. When in one position, all water will be diverted to a float control tank or to waste away from the building foundation and cistern; when in the other position, water will be run into the cistern. The filter will not remove chemical pollutants. If the water is to be used for drinking or food preparation, it should also be pointed out that because rainwater is soft and acidic, and therefore corrosive, hazardous concentrations of zinc from galvanized iron sheet roofing, gutters, and pipe and lead and copper from soldered copper pipe may also be released, in addition to cadmium.

The capacity of the cistern is determined by the size of the roof or catchment area, the probable water consumption, the maximum 24-hour rainfall, the average annual rainfall, and maximum length of dry periods. Suggested rainwater cistern sizes are shown in Figure 1.15. The cistern storage capacity given allows for a reserve supply, plus a possible heavy rainfall of 3-1/2 inches in 24 hours. The calculations assume that 25 percent of the precipitation is lost. Weather bureaus, the *World Almanac*, airports, water departments, and other agencies give rainfall figures for different parts of the country. Adjustment should therefore be made in

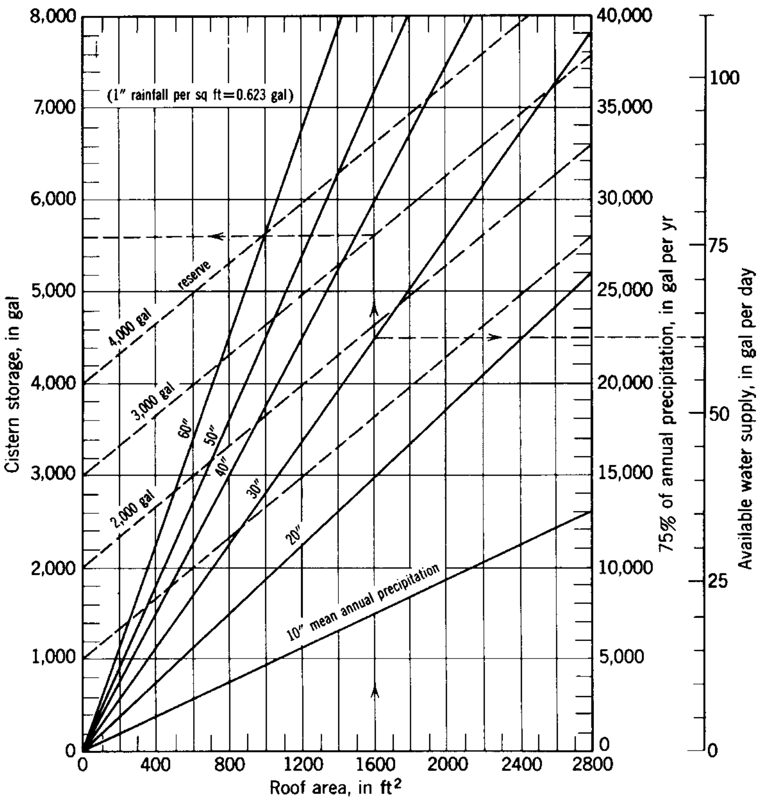


FIGURE 1.15 Suggested cistern storage capacity and available supply.

TABLE 1.16 Quantity and Type of Chlorine to Treat 1,000 gal of Clean Water at Rate of 1 mg/l

Chlorine Compound	Quantity
High test, 70% chlorine	1/5 oz or 1/4 heaping tablespoon
Chlorinated lime, 25% chlorine	1/2 oz or 1 heaping tablespoon
Sodium hypochlorite	
14% chlorine	1 oz
10% chlorine	1-1/3 oz
Bleach, 5-1/4 chlorine	2-3/5 oz

the required cistern capacity to fit local conditions. The cistern capacity will be determined largely by the volume of water one wishes to have available for some designated period of time, the total volume of which must be within the limits of the volume of water that the roof or catchment area and annual rainfall can safely yield. Monthly average rainfall data can be expected to depart from the true values by 50 percent or more on occasion. The drawing of a mass diagram is a more accurate method of estimating the storage capacity, since it is based on past actual rainfall in a given area.

It is recommended that the cistern water be treated after every rain with a chlorine compound of at least 5 mg/l chlorine. This may be accomplished by adding five times the quantities of chlorine shown in Table 1.16, mixed in 5 gallons of water to each 1,000 gallon of water in the cistern. A stack or tablet chlorinator and carbonate (limestone) contact tank on the inlet to the cistern is advised for disinfection and acidity neutralization. In areas affected by air pollution, fallout on the roof or catchment area will contribute chemical pollutants that may not be neutralized by limestone or chlorine treatment. Soft water flowing over galvanized iron roofs or through galvanized iron pipe or stored in galvanized tanks contains cadmium and zinc.[145]

Example With a roof area of 1,600 ft^2, in a location where the mean annual precipitation is 30 inches and it is desired to have a reserve supply of 3,000 gallon, the cistern storage capacity should be about 5,600 gallons. This should yield an average annual supply of about 62 gallons per day.

In some parts of the world, large natural catch basins are lined to collect rainwater. The water is settled and chlorinated before distribution. The amount of water is of course limited and may supplement groundwater, individual home cisterns, and desalinated water.

Domestic Well-Water Supplies — Special Problems*

Domestic well-water supply problems are discussed in this section.[146] The local health department and commercial water-conditioning companies may be of assistance to a homeowner.

*This section is adapted from ref.146.

Hard Water Hard water makes it difficult to produce suds or rinse laundry, dishes, or food equipment. Water hardness is caused by dissolved calcium and magnesium bicarbonates, sulfates, and chlorides in well water. Pipes clog and after a time equipment and water heaters become coated with a hard mineral deposit, sometimes referred to as lime scale. A commercial zeolite or synthetic resin water softener is used to soften water. The media must be regenerated periodically and disinfected with chlorine to remove contamination after each regeneration. Softeners do not remove contamination in the water supply. A filter should be placed ahead of a softener if the water is turbid. See also "Water Softening," in Chapter 2.

The sodium content of the water passing through a home water softener will be increased. Individuals who are on a sodium-restricted diet should advise their physician that they are using home-softened water since such water is a continual source of dietary sodium. A cold-water bypass line can be installed around the softener to supply drinking water and water for toilet flushing.

Turbidity or Muddiness This usually occurs in water from a pond, creek, or other surface source. Such water is polluted and requires coagulation, flocculation, sedimentation, filtration, and chlorination treatment. Wells sometimes become cloudy from cave-in or seepage from a clay or silt stratum but usually clear up with prolonged pumping. If the clay is in the colloidal state, coagulation, such as with aluminum sulfate (alum), is needed.

Sand filters can remove mud, dirt, leaves, foreign matter, and most bacteria, viruses, and protozoa if properly operated, but they may clog rapidly. Chlorination is also required to ensure destruction of pathogens. Charcoal, zeolite, or carbon filters are not suitable for this purpose, and, in addition, they clog. Iron and iron growths that sometimes cause turbidity in well water are discussed next. See also "Filtration", in Chapter 2.

Iron and Manganese in Well Water Iron and manganese may be found in water from deep wells and springs. In high concentrations it causes a bitter taste in tea or coffee. When exposed to the air, iron, and manganese are oxidized and settle out. Red to brown or black (manganese) stains form on plumbing fixtures, equipment, and laundry. Chlorine bleach exacerbates the staining problem. Iron and manganese in solution (colloidal) form may be found in shallow wells, springs, and surface waters. In this form, the water has a faint red or black color.

A commercial home zeolite water softener removes 1.5 to 2.0 mg/l, and an iron removal filter removes up to 10 mg/l iron from well water devoid of oxygen. The water should *not* be aerated prior to zeolite filtration, as this will cause precipitation of oxidized (ferric) iron rather than the exchange of sodium by ferrous iron, which is washed out as ferrous chloride when regenerated. An iron removal filter will also remove some hydrogen sulfide. The water softener is regenerated with salt water. The iron removal filter is backwashed to remove the precipitated iron and regenerated with potassium permanganate. Since potassium permanganate is toxic, it must all be flushed out before the treated water is used. The controlled addition of a polyphosphate can keep 1.0 to 2.0 mg/l iron in solution, but, as with the zeolite softener, sodium is also added to the water. Heating of water to 140° to 150°F (60°–66°C) nullifies the effectiveness of polyphosphate.

With higher concentrations of iron, the water is chlorinated to oxidize the iron in solution and allowed a short contact period, but the water should then be filtered to remove the iron precipitate before it enters the distribution system. The pH of the water should be raised to above 7.0 if the water is acid; soda ash, added to the chlorine solution, is usually used for this purpose. Hydrogen peroxide or potassium permanganate will also oxidize the iron.

Another approach is to discharge the water to the air chamber of a pressure tank, or to a sprinkler over a cascade above a tank, but this will require double pumping. It is necessary to flush out the iron that settles in the tank and filter out the remainder. Air control is needed in a pressure tank. Air is admitted with the well water entering and air is vented from the tank. Manganese is also removed with iron treatment.

Injecting a chlorine solution into the water at its source, where possible, controls the growth of iron bacteria, if this is a problem. See also “Iron and Manganese Occurrence and Removal” and “Iron Bacteria Control,” in Chapter 2. Before purchasing any equipment, seek expert advice and a proper demonstration should be sought.

Corrosive Water Water having a low pH or alkalinity and dissolved oxygen or carbon dioxide tends to be corrosive. Corrosive water dissolves metal, shortens the life of water tanks, discolors water, and clogs pipes. Iron corrosion causes rusty water; copper or brass pipe causes blue-green stains. Water can be made noncorrosive by passing it through a filter containing broken limestone, marble chips, or other acid neutralizers. The controlled addition of a polyphosphate, silicate, or soda ash to raise the water pH (commercial units are available) usually prevents metal from going into solution. The water remains clear and staining is prevented. However, bear in mind that a sodium polyphosphate would add sodium to the water, making it undesirable for individuals on a low-sodium diet. The use of low-lead solder (95:5 tinantimony solder), plastic pipe, maintenance of water temperature below 140°F (60°C), and a glass-lined hot water storage tank will minimize the problems associated with corrosion in home plumbing.

Taste and Odors Activated-carbon filters or cartridges are normally used to remove undesirable tastes and odors from domestic water supplies, but they do not remove microbiological contamination. Hydrogen sulfide in water causes a rotten-egg odor; corrosion of iron, steel, and copper; and black stains on laundry and crockery. It can also be eliminated by aeration and chlorination followed by filtration. An activated-carbon filter is not efficient. The activated carbon will have to be replaced when its capacity has been exhausted. Filtration alone, through a pressure filter containing a special synthetic resin, also removes up to 5 mg/l hydrogen sulfide in most cases. The water in question should be used to check the effectiveness of a process before any equipment is purchased. See also "Hydrogen Sulfide, Sources and Removal" in Chapter 2.

Detergents Detergents in water can be detected visually, by taste, or by laboratory examination. When some detergents exceed 1 mg/l, foam appears in a glass of water drawn from a faucet. Detergents themselves have not been shown to be harmful, but their presence is evidence that wastewater from one's own sewage disposal system or from a neighbor's system is entering the water supply source. In such circumstances, the sewage disposal system may be moved, a well constructed in a new area, or the well extended and sealed into a deeper water-bearing formation not subject to pollution. There is no guarantee that the new water-bearing formation will not be or become polluted later. The solution to this problem is connection to a public water supply and/or a public sewer. A granular activated-carbon (GAC) filter may be used to remove detergent, but its effectiveness and cost should first be demonstrated. See also "Methylene Blue Active Substances (MBAS)," previously in this chapter.

Salty Water In some parts of the country, salty water may be encountered. Since the salt water generally is overlain by fresh water, the lower part of the well in the salt water zone can be sealed off. But when this is done, the yield of the well is decreased.

Sometimes, waste salt water resulting from the backwashing of a home ion exchange water softener is discharged close to the well. Since salt water is not filtered out in seeping through the soil, it may find its way into the well. The best thing to do is to discharge the wastewater as far as possible and downgrade from the well or utilize a commercial water softener service. Salt water is corrosive; it will damage grass and plants and sterilize soil. Road salting or salt storage areas may also contribute to well pollution.

Special desalting units (using distillation, deionization, and reverse osmosis) are available for residential use, but they are of limited capacity and are relatively expensive, and pretreatment of the water may be needed. Complete information, including effectiveness with the water in question and annual cost, should be obtained before purchase. See "Desalination," this chapter, for additional information.

Radon in Well Water See "Radon," in this chapter.

Gasoline or Fuel Oil in Water See "Removal of Gasoline, Fuel Oil, and Other Organics in an Aquifer" and "Travel of Pollution through the Ground," in Chapter 2.

Household Treatment Units (Point-of-Use and Point-of-Entry)

Sometimes a chlorinator, faucet filter (point-of-use unit), dwelling filter (point-of-entry unit), or UV light disinfection unit is suggested to make an on-site polluted water supply safe for drinking without regard to the type, amount, or cause of pollution. This is hazardous. Instead, every effort should first be made to identify the pollutant and remove the source. This failing, every effort should be made to obtain water from a public water system. As a last resort, a household treatment unit or bottled water may have to be used. But the treatment units do not remove all microbiological, chemical, and physical pollutants. Careful selection of the proper treatment unit, which will resolve the particular pollution problem, in addition to cost, required maintenance and operation control, must be considered.

Household treatment unit processes include filtration, UV light radiation, chlorination, granular or powdered activated-carbon filtration, reverse osmosis, cartridge filters, cation exchange, anion exchange, distillation, pasteurization,[147] and activated-alumina filtration, as well as sand, porous stone, and ceramic filters. Each has limitations.

Ultraviolet light radiation and chlorination units are not considered satisfactory for the purification of surface-water supplies such as from ponds, lakes, and streams, which usually vary widely in physical, chemical, and microbiological quality, or for well or spring supplies, which may contain turbidity, color, iron, or organic matter. Pretreatment, usually including coagulation, flocculation, sedimentation, filtration, and disinfection or the equivalent, would be required to remove organic and inorganic contaminants that interfere with the effectiveness of the treatment. Chlorination and UV radiation treatment may be considered microbiologically acceptable only if the water supply is always clean, clear, and not subject to chemical or organic pollution and the units are operated as intended.* Certain controls are needed to ensure that the efficiency of the UV unit is not impaired by changes in light intensity, loss of power, rate of water flow, short circuiting, condition of the lamp, slime accumulation, turbidity, color, and temperature of the water.[148] Public Health Service 1974 standards state that acceptable UV units must have a flow rate of less than 0.2 gpm/effective inch of lamp, which must emit 2437 Å at an intensity of 4.85 UV watts/ft^2 at a distance of 2 inches, or an equivalent ratio of lamp intensity to flow, with a minimum retention time of 15 seconds at the maximum flow rate.[149] A flow control device, UV light-sensing device, alarm, and shutdown device are also needed.[150] Ultraviolet radiation units have application in the dairy, beverage, pharmaceutical, cosmetic, electronic, and food industries for the treatment of wash and cooling waters and for lowering the bacterial count in potable water used for soft drinks and bottled water. A chlorination unit requires inspection, solution replacement, and daily residual chlorine tests to ensure the unit operates as intended.

Most household filters contain activated carbon for the removal of organic substances. Taste and odor compounds are reduced, including chlorine, radon, and volatile halogenated organics such as trichloroethylene and carbon

*Normal chlorination treatment and UV radiation treatment do not inactivate the *Giardia lamblia* and *Cryptosporidium* protozoan cysts.

tetrachloride.[151] Sediment is trapped in the filter, and organic compounds, such as trihalomethanes resulting from chlorination, are removed to some extent. The activated-carbon filter cartridge needs periodic replacement, as recommended by the manufacturer. Microorganisms may grow in the filter and be released, but no harmful effects have been reported.[152] Many volatile organic compounds and radon are also removed by boiling and aeration. A cartridge filter to remove particulates should precede the carbon filter if the raw water is turbid. It should be understood that the water to be filtered must be potable. Microbiological and inorganic contaminants in solution are not removed.

A reverse-osmosis filter can reduce the concentrations of fluoride, mercury, lead, nitrates, sodium, iron, sulfate, alkalinity, total dissolved solids, and similar substances that might be present in drinking water, but not radon (GAC is effective). Sediment and many organic compounds are also removed, but prefiltration through a filter that removes particulates is indicated if sediment is present to prevent premature membrane clogging, followed by an activated-carbon filter to remove taste and odor compounds and other organics.[153] Arsenic and uranium are also removed under certain operating conditions.[154] The unit should have an automatic shut-off valve. The filter membrane requires backwashing.*

An activated-alumina unit can reduce the fluorides, arsenic, barium, and nitrates if sulfates are not too high. Uranium is also reduced.[155] The unit requires periodic regeneration. The activated-alumina lead removal cartridge is effective in removing lead.[156]

Electric distillation units that boil and condense water are also available. These units remove most microorganisms and inorganic compounds, including lead, salt, and nitrates, but not volatile organic compounds like benzene and chloroform—their capacity is limited.

Special ion exchange cartridge filters can remove inorganic contaminants from drinking water, including fluoride, uranium, and arsenic.[157] Ion exchange units can be regenerated with sodium chloride.

Porous stone "candles" and unglazed porcelain Pasteur or Berkefield filters for microbiological control are available and can be attached to a faucet spigot. They may develop hairline cracks and become unreliable for the removal of pathogenic microorganisms. They should be scrubbed, cleaned, and sterilized in boiling water once a week. Portable pressure-type ceramic microfiltration units, with single or multiple candles, having a capacity to remove 0.2-μm particles (bacteria, protozoa, helminths, and fungi), but not all viruses or chemical contaminants, are also available.[158]

Environmental Protection Agency studies of home water treatment filter devices showed THM removals of 6 to 93 percent and total organic carbon removals of 2 to 41 percent, depending on the unit. In some cases, higher bacterial counts were found in the water that had passed through the filter.[159] A subsequent study showed similar results.[160] Another study of halogenated organic

*Typically, about 75 percent of the tap water put into the reverse-osmosis system is wasted. ("FACTS for Consumers," Federal Trade Commission, Washington, DC, August 1989, p. 2.)

removal showed reductions ranging from 76 percent for a faucet-mount unit to 99 percent for several line bypass units.[161] These filter units do not remove nitrates, fluorides, or chlorides; do not soften water; remove little dissolved lead, iron, manganese, and copper; and do not remove microorganisms. They should not be used on any water supply that does not otherwise meet drinking water standards. The ability of a unit to remove the particular deleterious contaminants in the raw water should be confirmed with the manufacturer and the health department before purchase.* In general, reverse osmosis and distillation are most effective for inorganic contaminant reduction and granular activated carbon for organic contaminant removal.

Household treatment units have a limited flow capacity, which can be compensated for in part by incorporating a storage tank in the water system. Provision must be made for replacement or washing and disinfection of the filter element on a planned basis.

The satisfactory operation of a large number of household point-of-entry units in an area requires an effective management system, including monitoring, maintenance, and timely replacement of units or components and, in some instances, pre–and post–water treatment such as preclarification and postdisinfection.[162]

Desalination

Desalination or desalting is the conversion of seawater or brackish water to fresh water for potable and industrial purposes. The conversion of treated wastewater to potable water using multiple desalination processes is also being utilized in water scarce areas of the world. This conversion uses a variety of technologies to separate the dissolved solids from a source water. Desalination technology is being used to remove contaminants from surface and underground waters, including inorganics, radionuclides, emerging contaminants (such as pharmaceuticals), and THM precursors.

Many countries have used desalination technology for decades having either exhausted all of their primary sources of freshwater or to supplement and diversify their portfolio of water supplies. Considered by many as a drought-proof and inexhaustible supply of *new* water, municipal planners in the United States are also turning to desalination treatment plants as a means to ensure water supply in times of extended drought or as a back-up supply during an emergency. California for example, has 16 desalination plants with a combined capacity exceeding 400 mgd, in either planning, design, piloting, or construction as of 2008.

About seven-tenths of our globe is covered by seawater. The world's oceans have a surface area of 139,500,000 mi^2 and a volume of 317,000,000 mi^3.[163] The oceans contain about 97 percent of the world's water; brackish inland sites

*The National Sanitation Foundation, 3475 Plymouth Road, Ann Arbor, MI 48106, can provide a list of units certified for specific purposes. Also, The Water Quality Research Council, 4151 Naperville Road, Lisle, IL 60532.

and polar ice make up 2.5 percent, leaving less than 0.5 percent fresh water to be used and reused for municipal, industrial, agricultural, recreational, and energy-producing purposes.[164] In addition, more than half of the earth's surface is desert or semidesert. Under circumstances where adequate and satisfactory groundwater, surface water, or rainwater is not available and a high-quality water is required but where seawater or brackish water is available, desalination may provide an answer to the water problem. For seawater applications however, construction of intakes and the discharge of brine concentrate make siting new seawater plants a challenge. Prior to 2000, the high amounts of energy used in a desalination plant rendered plants feasible only where: 1) energy was plentiful and cheap; 2) where there were absolutely no other choices in water supply, or 3) the application was low volumes of high value product water such as for beverages, pharmaceuticals, or the electronics industry. Today however and with technology advances in both membrane materials and energy recovery, desalination costs are now affordable—even for high volumes of low-value water such as a municipal application.

Having begun in the arid Middle East 40 years ago with thermal (or distillation processes), desalting plants are now in use all over the world. Global Water Intelligence and the International Desalination Association reports 12,791 plants worldwide with capacity exceeding 11,000 mgd (over 42 million cubic meters per day) in operation as of 2006.[165]

Seawater has a total dissolved solids (TDS) concentration of about 35,000 mg/l. About 78 percent is sodium chloride, 11 percent magnesium chloride, 6 percent magnesium sulfate, 4 percent calcium sulfate, with the remainder primarily potassium sulfate, calcium carbonate, and magnesium bromide, in addition to suspended solids and microbiological organisms. The U.S. Geological Survey classifies water with less than 1,000 mg/l TDS as fresh, 1,000 to 3,000 mg/l as slightly saline, 3,000 to 10,000 mg/l as moderately saline, 10,000 to 35,000 mg/l as very saline, and more than 35,000 mg/l as brine. The U.S. Office of Technology Assessment defines potable water as generally having less than 500 ppm TDS (salt and/or dissolved solids), less brackish water as 500 to 3,000 ppm, moderately brackish water as 3,000 to 10,000 ppm, and highly brackish water as 10,000 to 35,000 ppm.[166] The source of brackish water may be groundwater or surface-water sources such as oceans, estuaries, saline rivers, and lakes. Its composition can be extremely variable, containing different concentrations of sodium, magnesium, sulfate, calcium, chloride, bicarbonate, fluoride, potassium, and nitrate. Iron, manganese, carbon dioxide, and hydrogen sulfide might also contribute to the variability of brackish water quality.

Desalting will remove dissolved salts and minerals such as chlorides, sulfates, and sodium, in addition to hardness. Nitrates, nitrites, phosphates, fluorides, ammonia, and heavy metals are also removed to some degree, depending on the process. Very hard brackish water will require prior softening to make reverse osmosis or electrodialysis very effective.[167] Desalination is not normally used to remove iron, manganese, fluorides, calcium, or magnesium.

Some known methods for desalting water are as follows[168]:

- *Membrane:* Reverse osmosis; electrodialysis and electrodialysis reversal; transport depletion; piezodialysis
- *Distillation or Thermal:* Multistage flash distillation; multieffect multistage distillation; vapor compression; vertical tube distillation; solar humidification
- *Crystallization:* Vacuum freezing–vapor compression; secondary refrigerant freezing; eutectic freezing; hydrate formation
- *Chemical:* Ion exchange

Distillation In distillation or thermal desalination, seawater is heated to the boiling point and then into steam, usually under pressure, at a starting temperature of 250°F (121°C). The steam is collected and condensed in a chamber by coming into contact with tubes (condenser–heat exchanger) containing cool seawater. The heated saline water is passed through a series of distillation chambers in which the pressure is incrementally reduced and the water boils (made to "flash"), again at reduced temperature, with the production of steam, which is collected as fresh water. The remaining, more concentrated, seawater (brine) flows to waste. In each step, the temperature of the incoming seawater is increased by the condenser–heat exchangers as it flows to the final heater. The wastewater (brine) and distilled water are also used to preheat the incoming seawater. This process is referred to as multistage flash distillation (MSF). There may be as many as 15 to 25 stages. A major problem is the formation of scale (calcium carbonate, calcium sulfate, and magnesium hydroxide) on the heat transfer surfaces of the pipe or vessel in which the seawater is permitted to boil. This occurs at a temperature of about 160°F (71°C), but scale can be greatly minimized by pretreating the seawater to remove either the calcium or the carbon dioxide. Distilled sea water normally has 5 to 50 mg/l salt. Most volatile substances are removed.

Vertical-tube distillation, multieffect multistage distillation, vapor compression distillation, and solar distillation are distillation variations. Solar humidification (distillation) depends on water evaporation at a rate determined by the temperature of the water and the prevailing humidity. The unit is covered with a peaked glass or plastic roof from which the condensate is collected. Distilled water is tasteless and low in pH if not aerated and adjusted before distribution.

Reverse Osmosis Normally, if salt water and fresh water are separated by a semipermeable membrane, the fresh water diffuses through to the salt water as if under pressure, actually osmotic pressure. The process is known as osmosis. In reverse osmosis, hydraulic pressures of 200 to 500 psi for brackish water and 800 to 1,200 psi for seawater[169] are applied to the concentrated salt water on one side of a special flat or cylindrical supported membrane, a spiral wound, or hollow-fiber unit. The life of the membrane decreases with increasing pressure. In the process, fresh water is separated out from the salt water into a porous or hollow channel from which the fresh water is collected. The concentration of

TDS in the salt water flowing through the unit must be kept below the point at which calcium sulfate precipitation takes place. Some of the dissolved solids, 5 to 10 percent, will pass through the membrane, including total hardness, sulfates, chlorides, ammonium, chemical oxygen demand (COD) materials, color, bacteria, and viruses. Chlorinated methanes and ethanes, which are common solvents, are not removed by reverse osmosis; however, air stripping is effective.[170] An increase in the TDS will result in a small increase of solids in the fresh water.

In reverse osmosis, the salt water to be treated must be relatively clear and free of excessive hardness, iron, manganese, and organic matter to prevent fouling of the system membranes. The maximum water temperature must be between 86° and 122°F (30° and 50°C), depending on membrane type.[171] Since the RO elements are designed to remove only the dissolved material in the source water, all suspended particles must be removed before entering the RO membranes, or the elements will become fouled prematurely. The pretreatment of the source water is a critical component of a well-designed plant and may consist of:

1. Softening to remove hardness;
2. Coagulation and filtration (sand, anthracite, multimedia; cartridge, or diatomaceous earth) to remove turbidity, suspended matter, iron, and manganese;
3. Low pressure micro filtration (MF) or ultra filtration (UF) membranes for turbidity and suspended particle removal; and
4. Filtration through activated-carbon columns to remove dissolved organic chemicals.

If the pretreatment design uses conventional process (coagulation/sedimentation/sand filtration), a 1 micron cartridge or bag filter is installed between the sand filter and the RO elements. This disposable filter is an insurance step to prevent an accidental loading of unwanted foulant material onto the RO elements. Acid is used if necessary to lower the pH and prevent calcium carbonate and magnesium hydroxide scale. Citric acid is used to clean membranes of inorganic and chlorine bleach for organics removal. Special cleaners may be needed to remove silicates, sulfates, hydroxides, and sulfides. Chlorine might also be used to control biological growths on the membranes,[172] but prior filtration of water through GAC is necessary to protect membranes not resistant to chlorine and prevent the formation of trihalomethanes (bromoform). Salt, dissolved solids, some microorganisms, organic and colloidal materials, and other contaminants, including radiologic, are removed. Reverse-osmosis treated water usually requires posttreatment for pH adjustment, degasification (H_2S and CO_2), corrosion adjustment, and disinfection, possibly further demineralization by ion exchange, and UV radiation disinfection for certain industrial waters. Other membrane processes include nanofiltration, ultrafiltration, and microfiltration.

Electrodialysis In electrodialysis, the dissolved solids in the brackish water (less than 10,000 mg/l TDS) are removed by passage through a cell in which a direct electric current is imposed. Dissolved solids in the water contain positively charged ions (cations) and negatively charged ion (anions). The cations migrate to and pass through a special membrane allowing passage of the positive ions. Another special membrane allows the negative ions to pass through. The concentration of dissolved solids determines the amount of current needed. The process removes salt, other inorganic materials, and certain low-molecular-weight organics.[173] Operating pressures vary from 70 to 90 psi. The partially desalted–demineralized water is collected and the wastewater is discharged to waste. Maximum water operating temperature is 113°F (45°C).[174]

The plant size is determined in part by the desired amount of salt removal. However, a change in the TDS in the brackish water will result in an equal change in the treated water.[175] As in reverse osmosis, pretreatment of the brackish water is necessary to prevent fouling of the membranes and scale formation. Scaling or fouling of membranes is reported to be prevented in most units by reversing the electric current at 15- to 30-minute intervals.[176] The cost of electricity limits the use of electrodialysis.

Transport depletion is a variation of the electrodialysis process. Piezodialysis is in the research stage; it uses a new membrane desalting process.

Ion Exchange In the deionization process, salts are removed from brackish water (2,000 to 3,000 mg/l TDS). Raw water passes through beds of special synthetic resins that have the capacity to exchange ions held in the resins with those in the raw water.

In the two-step process, at the first bed (acidic resin) sodium ions and other cations in the water are exchanged for cations (cation exchange) in the resin bed. Hydrogen ions are released and, together with the chloride ions in the raw water, pass through to the second resin bed as a weak hydrochloric acid solution. In the second resin bed, the chloride ions and other anions are taken up (anion exchange) from the water, are exchanged for hydroxide ions in the resin bed that are released, combine with the hydrogen ions to form water, and pass through with the treated water. The ion exchange beds may be in a series or in the same shell.

When the resins lose their exchange capacity and become saturated, the treatment of water is interrupted and the beds are regenerated, with acids or bases. The resins may become coated or fouled if the raw water contains excessive turbidity, microorganisms, sediment, color, or organic matter, including dissolved organics, hardness, iron, or manganese. In such cases, pretreatment to remove the offending contaminant is necessary. Chlorine in water would attack the cation resin and must also be removed prior to deionization.

Waste Disposal The design of a desalting plant must make provision for the disposal of waste sludge from pretreatment and also of the concentrated salts and minerals in a solution removed in the desalting process. The amount or volume of waste is dependent on the concentration of salts and minerals in the raw water and the amount of water desalted. The percent disposed as waste concentrate from a reverse osmosis unit treating brackish water may be 20 to 50 percent, from a seawater unit 60 to 80 percent, from an electrodialysis unit 10 to 20 percent, and from a distillation unit 5 to 75 percent.[177]

TABLE 1.17 Country Inventory of Global Desalination Treatment Plants

		Treatment Technology		User Category		Source Water		
Country	No. of Plants	Membrane	Thermal	Municipal	Industrial[a]	Seawater	Brackish	Other[b]
Algeria	147	75%	25%	68%	32%	73%	19%	8%
Australia	181	74%	26	15%	85%	18%	46%	36%
Bahrain	140	26%	74%	77%	23%	91%	9%	—
China	189	84	16	48	52	45	13	42
India	193	57	43	9	91	68	18	14
Israel	50	97	3	98	2	87	11	3
Japan	1457	95	5	19	81	17	16	67
Kuwait	84	16	84	85	15	84	2	14
Libya	295	18	82	74	26	87	13	—
Oman	133	39	61	92	8	96	3	1
Qatar	87	2	98	96	4	99	1	—
Saudi Arabia	2086	41	59	84	16	79	20	1
Spain	760	95	5	83	17	72	21	7
UAE	351	20	80	95	5	98	2	—
USA	2174	95	5	63	37	12	49	39
Total[c]	8327							

[a]Industrial includes other categories such as power, irrigation, military, tourism
[b]Other source waters include: river water, wastewater, pure water
[c]These 15 countries contain 8327 of the total number of 12,791 global plants

Source: IDA Desalination Yearbook 2007-2008, T. Pankratz and E. Yell; Media Analytics, Ltd., Oxford, UK 2008.

The waste from mildly brackish water (1000 to 3000 mg/l TDS) will contain from 5,000 to 10,000 mg/l (TDS). The waste from a seawater desalting plant can contain as much as 70,000 mg/l (TDS).[178]

The waste disposal method will usually be determined by the location of the plant and the site geography. Methods that would be considered include disposal to the ocean, inland saline lakes and rivers, existing sewer outfalls, injection wells or sink holes where suitable rock formations exist, solar evaporation ponds, lined or tight-bottom holding ponds, or artificially created lakes. In all cases, prior approval of federal (EPA) and state regulatory (water pollution and water supply) agencies having jurisdiction must be obtained. Surface and underground sources of drinking water and irrigation water must not be endangered.

Table 1.17 presents an inventory of the top 15 countries incorporating desalination technology as of 2006. In addition to the number of installed plants in each country, the table presents the technology used, the application categories, and the source of the water supply.

Costs The Office of Water Research and Technology reported that the cost of desalted water from global desal plants varies from upward from 85 cents per 1,000 gallons, except where fuel is available at very low cost.[179]. In 2007, the costs in the United States for seawater ranged from $2.00 to $6.00 per 1000 gallons depending on the size of the plant. Commissioned in late 2007 for example, the total cost of water from the Tampa Bay Water desalination plant cost approximately $3.18 per 1000 gallons. This is the largest operating plant in the United States at 28 mgd, although two 50 mgd plants are scheduled to begin construction in Carlsbad and Huntington Beach California in 2009. [180] Costs in 1985 (capital and operating costs) were estimated to be $2 to $2.50 per 1,000 gallons for brackish water, reverse osmosis, and electrodialysis treatment, with conventional treatment at approximately $0.40 to $2 per 1,000 gallon.[181]

An analysis was made by Miller[182] of 15 municipalities in the western United States demineralizing brackish water by reverse osmosis, electrodialysis, or ion exchange and combinations thereof. Flows varied from 0.13 to 7.18 mgd and TDS from 941 to 3,236 mg/l. The demineralization cost varied from $0.37 to $1.56 per 1,000 gal. Reverse osmosis was found to be the least costly process by most of the communities. Reverse osmosis plant construction and operating costs for seawater desalting were reported to be usually less than for distillation.[183] This may not be the case, however, where large volumes of seawater are to be distilled and where a convenient source of heat energy is available,[184] such as from a power plant or incinerator or where fuel costs are low. In another report, the energy break-even point of the reverse osmosis and electrodialysis treatment of brackish water and wastewater was approximately 1,200 mg/l. Electrodialysis was more energy efficient below 1,200 mg/l and reverse osmosis above that level.[185]

Construction and operating cost comparisons must be made with care. They are greatly influenced by location; material, labor, and energy costs; size; TDS concentration; and amount of pollutants such as suspended and other dissolved solids in the water to be desalted. Waste disposal and water distribution are additional factors usually considered separately.

General The use of desalted water usually implies a dual water distribution and plumbing system, one carrying the potable desalted water and the other carrying nonpotable brackish water or seawater. Obviously, special precaution must be taken to prevent interconnections between these two water systems. The brackish water or seawater may be used for firefighting, street flushing, and possibly toilet flushing.

The finished desalted water requires pH adjustment for corrosion control (lime, sodium hydroxide) and disinfection prior to distribution. It must contain not more than 500 mg/l total dissolved solids to meet drinking water standards. Up to 1,000 mg/l dissolved solids might be acceptable in certain circumstances. Other standards would apply if the desalted water is used for industrial purposes. The EPA considers a groundwater containing less than 10,000 mg/l TDS as a potential source of drinking water.[186]

Indirect benefits of desalting brackish water may include the purchase of less bottled water, use of less soap and detergents, no need for home water softeners and water-conditioning agents, and fewer plumbing and fixture repairs and replacements due to corrosion and scale buildup.[187]

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CHAPTER 2

WATER TREATMENT

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TREATMENT OF WATER — DESIGN AND OPERATION CONTROL

Introduction

Safe, abundant, and affordable; these are the primary goals of water treatment professionals across the globe. No matter how poor the original source of water supply, the finished drinking water that emerges from the consumer's tap must be a high quality free from pathogenic (or disease-causing) microorganisims. It must also not contain concentrations of either natural or manmade contaminants in concentrations that could produce adverse health impacts. The aesthetics of drinking water are important since consumers will link the appearance, taste, and odor of the water to its safety. Although the amount of tap water that is actually consumed by humans or used for cooking and food preparation is less than 5 percent that enters the home, *all* of the water treated must meet these goals for safety and aesthetics. Other nonpotable uses such as washing, flushing wastes, irrigation, and so on must also meet acceptable standards so the water treatment plant must produce a sufficient quantity of water that meets all these needs. Achieving these objectives at a reasonable and affordable cost is perhaps the greatest challenge facing the water community today.

Water treatment in the twenty-first century accomplishes these goals using a range of principals and practices, some new, some not so modern. The quest for potable water dates as far back as the earliest recorded history. Water treatment is described in Sanskrit and Greek writings 6,000 years ago:

> Impure water should be purified by being boiled over a fire, or heated in the sun or by dipping a heated iron into it and then allowed to cool, or it may be purified through sand and coarse gravel.[1]

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In 1854, Dr. John Snow's landmark epidemiological studies linked for the first time, a contaminated water well to an outbreak of cholera in London, although he didn't know exactly why. (The now infamous well located at No. 40 Broad Street, London is marked by a plaque commemorating this achievement.) This question was answered following Louis Pasteur's novel "germ theory" linking microorganisims to disease in the late 1880s. Soon thereafter, modern water treatment was born and at the turn of the last century, centralized water treatment facilities for communities became standard in the United States. By the 1920s, "state-of-the-art" water treatment consisted of sand filtration and chlorine disinfection and the threat of waterborne disease outbreaks such as typhoid and cholera were virtually eliminated.

Today, newer technologies such as low pressure polymetric membranes have improved the ability to filter impurities from raw water and will ultimately replace sand filters. Similarly, disinfection practices have improved to balance the chemical's use; a sufficient dose to destroy microorganisms but low enough not to produce harmful halenogated byproducts.

Surface Water

The quality of surface water depends on the watershed area drained, land use, location and sources of natural and manmade pollution, and natural agencies of purification, such as sedimentation, sunlight, aeration, nitrification, filtration, and dilution. Since these are variable, they cannot be depended on to continuously purify water effectively. However, large reservoirs providing extended storage permit natural purification to take place, but short-circuiting and direct contamination must be avoided. In addition, increasing urbanization, industrialization, and intensive farming have caused heavy organic and inorganic chemical discharges to streams, which are not readily removed by the usual water treatment. Treatment consisting of coagulation, flocculation, sedimentation, rapid sand filtration, and chlorination has little effect on some chemical contaminants noted. Because of these factors and to reduce risk, heavily polluted surface waters should be avoided as drinking water supplies, if possible, and upland protected water sources should be used and preserved consistent with multipurpose uses in the best public interest:

> The American Water Works Association (AWWA) is dedicated to securing drinking water from the highest quality sources available and protecting those sources to the maximum degree possible.[2]

The growing demand for use of reservoirs for recreational purposes requires that the public understand the need for strict controls to prevent waterborne diseases and watershed disturbance. Involved are added capital and maintenance and operating costs that may increase the charges for the water and use of the recreational facilities, if the multipurpose uses are permitted.

Treatment Required

The treatment required is dependent on the federal and state regulations and on the probable changing physical, chemical, and microbiological quality of the water source. This emphasizes the importance of adequate meteorological and hydrological information, the sanitary survey previously discussed, and its careful evaluation. The evaluation should take into consideration the existing land-use zoning and probable development. Water treatment plants should not have to bear the total burden and cost of elaborate treatment because of water pollution of its source water. The water purveyor should therefore take an active role in stream, lake, and land-use classifications and be aware of all existing and proposed industrial and municipal wastewater outlets and nonpoint pollution sources. The pollution from these sources should ideally be eliminated or minimized to the extent possible and adequately treated. Continual supervision and enforcement of watershed, land-use, and wellhead area protection rules and regulations must be assured.

The EPA rules, based on the 1986 Amendments to the Safe Drinking Water Act, require the following:[3]

1. Surface water complete filtration treatment if one of these two conditions applies:
   a. fecal coliforms exceed 20 per 100 ml
   b. total coliforms exceed 100 per 100 ml in more than 10 percent of the measurements for the previous 6 months, calculated each month
2. Minimum sampling frequency for fecal or total coliforms per week:
   a. 1 for systems serving fewer than 501 people
   b. 2 for systems serving 501 to 3,300
   c. 3 for systems serving 3,301 to 10,000
   d. 4 for systems serving 10,001 to 25,000
   e. 5 for systems serving 25,000 or more
3. Turbidity measurements every 4 hours; once a day for systems serving less than 501 people. Filtration treatment is required if turbidity level exceeds 5 NTU unless the state determines that the event is unusual.
4. Treatment to achieve at least 99.9 percent removal or inactivation of *Giardia lamblia* cysts (also *Cryptosporidium*) and 99.99 percent removal or inactivation of viruses, also *Legionella*.
5. Maintenance of disinfecting residuals in the distribution system—not less than 0.2 mg/l chlorine in at least 95 percent of the samples tested.
6. A watershed protection program; annual sanitary survey; absence of waterborne disease outbreaks; compliance with the total coliform and trihalomethane maximum contaminant levels (MCLs); turbidity of 0.5 NTU in 95 percent of monthly measurements; certified operators; and increased monitoring and reporting.

People expect the water to be safe to drink, attractive to the senses, soft, nonstaining, and neither scale forming nor corrosive to the water system. The various treatment processes used to accomplish these results are briefly discussed under the appropriate headings below. In all cases, the water supply must meet the federal and state drinking water standards.[4] The untrained individual should not attempt to design a water treatment plant, for public health will be jeopardized. This is a job for a competent environmental engineer. Submission and approval of plans and specifications are usually required by the regulatory agency.[5] Computerized control of water treatment and distribution is considered essential to a greater or lesser degree, dependent on the operator skills and immediate availability of manufacturer assistance.

Disinfection

The more common chemicals used for the disinfection of drinking water are chlorine (gas and hypochlorite), chlorine–ammonia, chlorine dioxide, and ozone. Chlorine is discussed next; the others are discussed in relation to the removal or reduction of objectionable tastes and odors and trihalomethanes. Ozone and chlorine dioxide are receiving greater attention as primary disinfectants and chlorine–ammonia for maintenance of a residual in the distribution system. Other disinfectants that may be used under certain circumstances include UV radiation,* bromine, iodine, silver, and chlorinated lime.

The National Research Council–National Academy of Science, in a study of disinfectants, concluded that there had not been sufficient research under actual water treatment conditions for the reactions of disinfectants and their byproducts to be adequately understood and that the chemical side effects of disinfectants "should be examined in detail."[6]† There is need to identify the byproducts associated with the use of not only chlorine but also chloramines, ozone, and chlorine dioxide and their health significance.

Chlorination is the most common method of destroying the disease-producing organisms that might normally be found in water used for drinking in the United States. The water so treated should be relatively clear and clean with a pH of 8.0 or less and an average monthly MPN of coliform bacteria of not more than 50/100 ml.‡ Clean lake and stream waters and well, spring, and infiltration gallery

*UV disinfection is being used as a primary disinfectant more in Europe (approximately 2000), with free chlorine for residual maintenance. (R. L. Wolfe, "Ultraviolet Disinfection of Potable Water," *Environ. Sci. Technol*., June 1990, pp. 768–772.)

†Greenburg points out that "the health effects of their (chlorine dioxide and ozone) reaction products, particularly the chlorite ion from chlorine dioxide and oxidized organic compounds from ozone are uncertain" and adds that "if unequivocal safety information becomes available, changes from chlorine to chlorine dioxide or ozone may be indicated but only if the manipulation of chlorination methods proves incapable of minimizing carcinogen hazard." (A. E. Greenburg, "Public Health Aspects of Alternative Water Disinfectants," *J. Am. Water Works Assoc*. (January 1981): 31–33.)

‡Suggested criteria include total coliform <100/100 ml, fecal coliform <20/100 ml, turbidity <1–5 NTU, color 15 units, chlorine demand $\ngtr$2 mg/l, plus others.

supplies not subject to significant pollution can be made of safe sanitary quality by continuous and effective chlorination, but surface sources also usually require complete filtration treatment to protect against viruses, bacteria, protozoa, and helminths. The effectiveness of chlorine is dependent on the water pH, temperature, contact time, water clarity, and absence of interfering substances.

Operation of the chlorinator should be automatic, proportional to the flow of water, and adjusted to the temperature and chlorine demand of the water. A standby source of power and a spare machine including chlorine should be on the line. A complete set of spare parts for the equipment will make possible immediate repairs. The chlorinator should provide for the positive injection of chlorine and be selected with due regard to the pumping head and maximum and minimum water flow to be treated. The point of chlorine application should be selected to provide a contact time of 2 hours for surface water receiving free residual chlorination treatment and 3 hours with combined residual chlorination. A lesser time may be accepted for groundwater.[7] The chlorinator should have a capacity to provide at least 2 mg/l free chlorine residual after 30 minutes contact at maximum flow and chlorine demand.

Hypochlorinators are generally used to feed relatively small quantities of chlorine as 1 to 5 percent sodium or calcium hypochlorite solution. Positive feed machines are fairly reliable and simple to operate. Hypochlorite is corrosive and may produce severe burns. It should be stored in its original container in a cool, well-ventilated, dry place. Gas machines usually feed larger quantities of chlorine and require certain precautions as noted next. Chlorine addition, with either a hypochlorinator or gas machine, should be proportional to the flow, direct or through corrosion-resistant piping; iron or steel piping or fittings should not be used. Note that the addition of an acid such as ferric chloride to sodium hypochlorite will release chlorine gas.

Gas Chlorinator

When a dry feed gas chlorinator or a solution feed gas chlorinator is used, the chlorinator and liquid chlorine cylinders should be located in a separate gas-tight room that is mechanically ventilated to provide one air change per minute, with outside switch and the exhaust openings at floor level opposite the air inlets at ceiling level. Exhaust ducts must be separate from any other ventilating system of ducts and extend to a height and location that will not endanger the public, personnel, or property and ensure adequate dispersion. The door to the room should have a shatter-resistant glass inspection panel at least 12-inches square, and a chlorine gas mask, or preferably self-contained breathing apparatus, approved by the NIOSH, available just outside of the chlorinator and chlorine cylinder room. Vapor from a plastic squeeze bottle containing aqua ammonia will produce a white cloud at a chlorine leak.* The chlorine canister-type of mask is only suitable for

*In an emergency, do not try to neutralize chlorine; leave this to the professionals. Call CHEMTREC at 800-424-9300 or the nearest supplier or producer. The permissible 8 hours concentration exposure is 1 ppm, 3 ppm for 15 min.

low concentrations of chlorine in air and only for a brief period. It does not supply oxygen. The self-contained breathing apparatus* with full-face piece (pressure demand) with at least 30-minute capacity meeting NIOSH standards is usually required. It can be used during repairs and for high concentrations of chlorine. A factory-built chlorinator housing, completely equipped, is available.

The temperature around the chlorine cylinders should be cooler than the temperature of the chlorinator room to prevent condensation of chlorine in the line conducting chlorine or in the chlorinator. Cylinders must be stored at a temperature below 140°F.[8†] A platform scale is needed for the weighing of chlorine cylinders in use to determine the pounds of chlorine used each day and anticipate when a new cylinder will be needed. Cylinders should be in a safety bracket or chained to prevent being tipped. They should be connected to a manifold to allow chlorine to be drawn from several cylinders at a time and to facilitate cylinder replacement without interrupting chlorination. It is advisable to not draw more than 35 to 40 pounds of chlorine per day at a continuous rate from a 100- or 150-pound cylinder to prevent clogging by chlorine ice. Liquid chlorine comes in 100- and 150-pound cylinders, in 1-ton containers, and in 16- to 90-ton rail-tank cars. Smaller cylinders, as little as 1 pound, are available. The major factors affecting withdrawal rates are ambient air temperature and size and type cylinder. The normal operating temperature is 70°F (21°C).

A relatively clear source of water of adequate volume and pressure is necessary to prevent clogging of injectors and strainers and ensure proper chlorination at all times. The water pressure to operate a gas chlorinator should be at least 15 psi and about three times the back pressure (water pressure at point of application plus friction loss in the chlorine solution hose and a difference in elevation between the point of application and the chlorinator) against which the chlorine is injected. About 40 to 50 gpd of water is needed per pound of chlorine to be added. Residual chlorine recorders and alarms and chlorine feed recorders provide additional protection and automatic residual chlorine control.

Testing for Residual Chlorine

The recommended field tests for measuring residual chlorine in water are the *N,N*-diethyl-*p*-phenylenediamine (DPD) colorimetric and the stabilized neutral orthotolidine (SNORT) methods.[9] The DPD and amperometric titration methods are approved by the EPA. In any case, all tests should be made in accordance with accepted procedures such as in *Standard Methods for the Examination of Water and Wastewater*.[10]

The DPD test procedure for residual chlorine measurement and the Free Available Chlorine Test, syringaldazine (FACTS) test procedure are reported to be

*At least two units are recommended, including worker protective clothing.

†The fusible plugs are designed to soften or melt at a temperature between 158 and 165°F (70 and 74°C). The chlorinator should have automatic shutoff if water pressure is lost or if chlorine piping leaks or breaks. See *The Chlorine Manual*, 5th ed., Chlorine Institute, Washington, DC, 1986.

equivalent. The FACTS and amperometric procedures are also equivalent.[11] A comprehensive evaluation of residual chlorine, chlorine dioxide, and ozone measurement methods is available.[12] The use of dry reagents is recommended for the DPD test as the liquid form is unstable. High concentrations of iron and manganese and dirty glassware cause interference with residual chlorine readings. The evaluation should be read immediately to also minimize interference from chloramines.

Chlorine Treatment for Operation and Microbiological Control

To ensure that only properly treated water is distributed, it is important to have a competent and trustworthy person in charge of the chlorination plant. He or she should keep daily records showing the gallons of water treated, the pounds of chlorine or quarts of chlorine solution used and its strength, the gross weight of chlorine cylinders if used, the setting of the chlorinator, the time residual chlorine tests made, the results of such tests, and any repairs or maintenance, power failures, modifications, or unusual occurrences dealing with the treatment plant or water system. Where large amounts of chlorine are needed, the use of ton containers can effect a saving in cost, as well as in labor, and possibly reduce chlorine gas leakage, although if a chlorine leak does occur, it can be of major consequence.

The required chlorine dosage should take into consideration the appearance as well as the quality of a water. Pollution of the source of water, the type of micro-organisms likely to be present, the pH of the water, contact time, interfering substances, temperature, and degree of treatment a water receives are all very important. Disinfection effectiveness is also dependent on the absence of turbidity, less than 1 NTU.

The chlorine residual that will give effective disinfection of a relatively demand-free *clear* water has been studied by Butterfield[13] and others. The germicidal efficiency of chlorine is primarily dependent on the percent-free chlorine that is in the form of hypochlorous acid (HOCl), which in turn is dependent on the pH, contact time, and temperature of the water, as can be seen in Table 2.1. Hypochlorous acid is about 80 to 150 times more effective than the hypochlorite ion, 150 times more effective than monochloramine, and 80 times more effective than dichloramine. The percentage of hypochlorous acid is the major factor determining destruction or inactivation of enteric bacteria and amebic cysts.[14] *Giardia* cysts are almost always present in raw sewage.

In a review of the literature, Greenberg and Kupka concluded that a chlorine dose of at least 20 mg/l with a contact time of 2 hours is needed to adequately disinfect a biologically treated sewage effluent containing tubercle bacilli.[15]

Laboratory studies by Kelly and Sanderson indicated that, depending on pH level and temperature, residual chlorine values of greater than 4 ppm, with 5-minutes contact, or contact periods of at least 4 hours with a residual chlorine value of 0.5 ppm, are necessary to inactivate viruses, and that the recommended standard for disinfection of sewage by chlorine (0.5 ppm residual after 15-minutes contact) does not destroy viruses.[16]

TABLE 2.1 Chlorine Residual for Effective Disinfection of Demand-Free Water (mg/l)

	Approximate Percent at 32–68°F[b]		Bactericidal Treatment[a]		Cysticidal Treatment Free Available Chlorine after 30 min		
pH	HOCl	OCl^-	Free Available Chlorine after 10 min, 32–78°F	Combined Available Chlorine after 60 min, 32–78°F	36–41°F[c]	60°F[c]	78°F[b]
5.0	—	—	—	—	—	2.3	—
6.0	98–97	2–3	0.2	1.0	7.2	—	1.9[d]
7.0	83–75	17–25	0.2	1.5	10.0	3.1	2.5[d]
7.2	74–62	26–38	—	—	—	—	2.6[d]
7.3	68–57	32–43	—	—	—	—	2.8[d]
7.4	64–52	36–48	—	—	—	—	3.0[d]
7.5	58–47	42–53	—	—	14.0[d]	4.7	3.2[d]
7.6	53–42	47–58	—	—	—	—	3.5[d]
7.7	46–37	53–64	—	—	16.0[d]	6.0	3.8[d]
7.8	40–32	60–68	—	—	—	—	4.2[d]
8.0	32–23	68–77	0.4	1.8	22.0	9.9	5.0[d]
9.0	5–3	95–97	0.8	Reduce pH of water to below 9.0	—	78.0	20.0[d]
10.0	0	100	0.8		—	761	170[d]

[a]Ethylene Glycol Intoxication Due to Contamination of Water Systems," *MMWR* (September 18, 1987): 611–614.

[b]Water Treatment Plant Design, American Water Works Association, New York, 1969, pp. 153, 165; E. W. Moore, "Fundamentals of Chlorination of Sewage and Waste," *Water Sewage Works*, 130–136 (March 1951).

[c]S. L. Chang, "Studies on *Endamoeba histolytica,*" *War Med*., 5, 46 (1944); see also W. Brewster Snow, "Recommended Chlorine Residuals for Military Water Supplies," *J. Am. Water Works Assoc*., 48, 1510 (December 1956).

[d]Approximations. All residual chlorine results reported as milligrams per liter. One milligram per liter hypochlorous acid gives 1.35 mg/l free available chlorine as HOCl and OCl^- distributed as noted above. The HOCl component is the markedly superior disinfectant, about 80–150 times more effective than the hypochlorite ion (OCl^-).

Note: Free chlorine = HOCl. Free available chlorine = HOCl + OCl^-. Combined available chlorine = chlorine bound to nitrogenous matter as chloramine. Only free available chlorine or combined available chlorine is measured by present testing methods; therefore, to determine actual free chlorine (HOCl), correct reading by percent shown above. "Chlorine residual," as the term is generally used, is the combined available chlorine and free available chlorine, or total residual chlorine. When the chlorine–ammonia ratio reaches 15:1 or 20:1 and pH < 4.4, nitrogen trichloride is formed; it is acrid and highly explosive. Ventilate.

Viricidal treatment requires a free available chlorine of 0.53 mg/l at pH 7 and 5 mg/l at pH 8.5 in 32°F demand-free water. For water at a temperature of 77–82.4°F and pH 7–9, a free available chlorine of 0.3 mg/l is adequate. (See *Manual for Evaluating Public Drinking Water Supplies*, PHS Pub. 1820, Environmental Control Administration, Cincinnati, OH, 1969.) At a pH 7 and temperature of 77°F at least 9 mg/l combined available chlorine is needed with 30 minutes contact time. Turbidity should be less than one turbidity unit. The above results are based on studies made under laboratory conditions using water free of suspended matter and chlorine demand.

Another study showed that inactivation of partially purified poliomyelitis virus in water required a free-residual chlorine after 10 minutes of 0.05 mg/l at a pH of 6.85 to 7.4. A residual chloramine value of 0.50 to 0.75 mg/l usually inactivated the virus in 2 hours.[17] Weidenkopf reported on Polio 1 inactivation by free chlorine as 0.1 mg/l at pH 6.0 and 0.53 mg/l at pH 8.5.[18] Destruction of coxsackievirus required 7 to 46 times as much free chlorine as for *E. coli*.[19] Infectious hepatitis virus was not inactivated by 1.0 mg/l total chlorine after 30 minutes or by coagulation, settling, and filtration (diatomite), but coagulation, settling, filtration, and chlorination to 1.1 mg/l total and 0.4 mg/l free chlorine was effective.[20] Bush and Isherwood suggest the following:

> The use of activated sludge with abnormally high sludge volume index followed by sand filtration may produce the kind of control necessary to stop virus. Chlorination with five tenths parts per million chlorine residual for an eight hour contact period seems adequate to inactivate Coxsackie virus.[21]

Malina[22] summarized the effectiveness of water and wastewater treatment processes on the removal of viruses. The virus concentration in untreated municipal wastewater was found to range from about 200 plaque-forming units per liter (PFU/l) in cold weather to about 7,000 in warm months in the United States, with 4,000 to 7,000 PFU/l common. In contrast, the virus concentration in South Africa was found to be greater than 100,000 PFU/l. Virus removal in wastewater is related in part to particulate removal. Possible virus removal values by various wastewater treatment systems are as follows:

Primary sedimentation	0–55%
Activated sludge	64–99%
Contact stabilization	74–95%
Trickling filters	19–94%
Stabilization ponds	92–100%
Coagulation–flocculation	86–100%
Chlorine (as final treatment)	99–100%
Iodine	100%
Ozone	100%
Anaerobic digestion	62–99%

Chemical coagulation, with adequate concentrations of aluminum sulfate or ferric chloride, of surface water used as a source of drinking water or of wastewater that has received biological treatment can remove 99 percent of the viruses. Hepatitis A virus, rotavirus, and poliovirus removal of 98.4 to 99.7 percent was also achieved in a pilot plant by softening during Ca^{2+} and Mg^{2+} hardness reduction.[23] A high pH of 10.8 to 11.5, such as softening with excess lime, can achieve better than 99 percent virus removal, but pH adjustment is then necessary.

Filtration using sand and/or anthracite following coagulation, flocculation, and settling can remove 99 percent or more of the viruses, but some viruses penetrate the media with floc breakthrough and turbidity at low alum feed.[24] Diatomaceous earth filtration can remove better than 98 percent of the viruses, particularly if the water is pretreated. Activated-carbon adsorption is not suitable for virus removal. The infectivity of hepatitis A virus is destroyed by 2.0 to 2.5 mg/l free residual chlorine. Reverse osmosis and ultra filtration, when followed by disinfection, can produce a virus-free water. However, it has been found that both enteroviruses and rotaviruses could be isolated from water that received complete treatment containing more than 0.2 mg/l free chlorine, less than one coliform bacteria per 100 ml, and turbidity of less than 1 NTU.[25] The WHO states that a contaminated source water may be considered adequately treated for viruses infectious to humans if it has a turbidity of 1 NTU or less and is disinfected to provide a free residual chlorine of at least 0.5 mg/l after a contact period of at least 30 minutes at a pH below 8.0.[26]

A conventional municipal biological wastewater treatment plant can produce an effluent with less than 10 PFU/l. When followed by conventional water treatment incorporating filtration and chlorination, a virus-free water can be obtained.[27] The product of the contact time (t) in minutes and free residual chlorine, or other approved disinfectant, in milligrams per liter (C) produces a value that is a measure of the adequacy of disinfection. The Ct value for a particular organism will vary with the water pH, temperature, degree of mixing, turbidity, and presence of interfering substances, in addition to disinfectant concentration and contact time. For example, a turbidity less than 1 to 5 NTUs and a free chlorine as HOCl (that penetrates the cell wall of microorganisms and destroys their nucleic acid) are necessary. A smaller Ct value is effective at lower pH and at higher temperature.[28] The Ct value effective to inactivate 99.9 percent of the Giardia cyst will also inactivate 99.99 percent or greater of the bacteria and viruses at a given pH and temperature.

For protozoa (*Giardia lamblia*) a Ct value of 150 to 200 at pH 8.0 or less is required with water at 50°F (10°C). Experimental results based on animal infectivity data show that a 99.99 percent cyst inactivation can be obtained at Ct values of 113 to 263, at pH 6, temperature 33°F (0.5°C), and chlorine concentration of 0.56 to 3.93 mg/l for 39 to 300 minutes. At pH 8, temperature 33°F (0.5°C), chlorine concentration of 0.49 to 3.25 mg/l, and contact time of 132 to 593 minutes, the Ct values varied from 159 to 526. If a large enough Ct value can be maintained to ensure adequate *Giardia* cyst disinfection to EPA satisfaction, then filtration may not be required.[29]

Chlorine dioxide can achieve 99.9 percent *Giardia lamblia* inactivation at Ct values of 63, in water at 34°F (1°C) or less, to 11 at 77°F (25°C) or greater. Inactivation using ozone is achieved at Ct values of 2.9, in water at 34°F (1°C) or less, to 0.48 at 77°F (25°C) or greater. These Ct values also achieve greater than 99.99 percent inactivation of enteric viruses. See state regulatory agency for required Ct values to inactivate *Giardia lamblia* and enteric viruses using chlorine, chloramine, chlorine dioxide, and ozone.

Naegleria fowleri cyst is a pathogenic flagellated protozoan. It causes primary amebic meningoencephalitis, a rare disease generally fatal to humans. The organism is free living, nonparasitic, found in soil and water. *Naegleria gruberi*, a nonpathogenic strain, was used in experimental inactivation studies. At pH 5.0 the *N. gruberi* cyst was inactivated in 15.8 to 2.78 minutes by 0.45 to 2.64 mg/l free chlorine residual at 25°C (77°F). At pH 7.0 it was inactivated in 21.5 to 2.9 minutes by 0.64 to 3.42 mg/l; and at pH 9.0 in 11.5 to 2.36 minutes by 15.4 to 87.9 mg/l residual chlorine. Also, it was reported that *Acanthamoeba* sp. 4A cysts (pathogenic) were inactivated after 24 hours by an initial chlorine dose of 8.0 mg/l but ending with a chlorine residual of 6.0 mg/l. *Naegleria fowleri* was reported to be inactivated by 4 mg/l chlorine residual in 10 minutes at a temperature of 77°F (25°C) and a pH of 7.2 to 7.3.[30] *Giardia lamblia* cysts are inactivated in 60 minutes by 2.0 mg/l free chlorine residual at pH 6.0 and 41°F (5°C); in 60 minutes by 2.5 mg/l free chlorine at pH 6.0, 7.0, and 8.0 and 60°F (15°C); in 10 minutes by 1.5 mg/l free chlorine at pH 6.0, 7.0, and 8.0 and 77°F (25°C); and in 30 minutes by 6.2 mg/l total chlorine at pH 7.9 and 37°F (3°C).[31]

Entamoeba histolytica cysts are inactivated by 2 mg/l free chlorine in 15 minutes at a temperature of 68°F (20°C) and pH 7.0,[32] by 2.5 mg/l free chlorine in 10 minutes at a temperature of 86°F (30°C) and pH 7.0, by 5.0 mg/l free chlorine in 15 minutes at a temperature of 50°F (10°C) and pH 7.0, and by 7.0 mg/l free chlorine in 10 to 15 minutes at a temperature of 86°F (30°C) and pH 9.0.[33]

The removal of nematodes requires prechlorination to produce 0.4 to 0.5 mg/l residual after a 6-hour retention period followed by settling. The pathogenic fungus *Histoplasma capsulatum* can be expected in surface-water supplies, treated water stored in open reservoirs, and improperly protected well-water supplies. Fungicidal action is obtained at a pH of 7.4 and at a water temperature of 78.8°F (26°C) with 0.35 mg/l free chlorine after 4 hour contact and with 1.8 mg/l free chlorine after 35 minutes contact. Complete rapid sand filter treatment completely removed all viable spores even before chlorination.[34]

Cysts of *E. histolytica* and *Giardia lamblia* (also worms and their eggs) are removed by conventional water treatment, including coagulation, flocculation, sedimentation, and filtration (2–6 gpm/ft^2). Direct and high-rate filtration, diatomaceous earth filtration with good precoat (1 kg/m^2), and special cartridge filters ($<7 \times 8$-μm pore size) can also be effective. The slow sand filter is also considered effective. Pressure sand filtration is not reliable. The inactivation of *Giardia lamblia* by free chlorine is similar to that for *E. histolytica*.[35]

Coliform bacteria can be continually found in a chlorinated surface-water supply (turbidity 3.8 to 84 units, iron particles, and microscopic counts up to 2,000 units) containing between 0.1 and 0.5 mg/l of free residual chlorine and between 0.7 and 1.0 mg/l total residual chlorine after more than 30 minutes contact time.[36]

It is evident from available information that the coliform index may give a false sense of security when applied to waters subject to intermittent doses of pollution. The effectiveness of proper disinfection, including inactivation of viruses, other conditions being the same, is largely dependent on the freedom from suspended material and organic matter in the water being treated. Treated water having a turbidity of less than 5 NTU (ideally less than 0.1), a pH less than 8, and an HOCl residual of 1 mg/l after 30 minutes contact provides an acceptable level of protection.[37]

Free residual chlorination is the addition of sufficient chlorine to yield a free chlorine residual in the water supply in an amount equal to more than 85 percent of the total chlorine present. When the ratio of chlorine to ammonia is 5:1 (by weight), the chlorine residual is all monochloramine; when the ratio reaches 10:1, dichloramine is also formed; when the ratio reaches 15:1 or 20:1, nitrogen trichloride is formed, reaching a maximum at pH less than 4.5 and at a higher pH in polluted waters. Nitrogen trichloride as low as 0.05 mg/l causes an offensive and acrid odor that can be removed by carbon, aeration (natural or forced draft), exposure to sunlight, or forced ventilation indoors.[38] It can titrate partly as free chlorine and is also highly explosive. The reaction of chlorine in water is shown in Figure 2.1.

The minimum free chlorine residual at distant points in the distribution system should be 0.2 to 0.5 mg/l. Combined chlorine residual, if use is approved, should be 1.0 to 2.0 mg/l at distant points in the distribution system.[39]

In the presence of ammonia, organic matter, and other chlorine-consuming materials, the required chlorine dosage to produce a free residual will be high. The water is then said to have a high chlorine demand. With free residual chlorination, water is bleached, and iron, manganese, and organic matter are oxidized by chlorine and precipitated, particularly when the water is stored in a reservoir or basin for at least 2 hours. Most taste- and odor-producing compounds are destroyed; the reduction of sulfates to taste- and odor-producing sulfides is prevented; and objectionable growths and organisms in the mains are controlled or eliminated, provided a free chlorine residual is maintained in the water. An indication of accidental pollution of water in the mains is also obtained if the free chlorine residual is lost, provided chlorination is not interrupted.

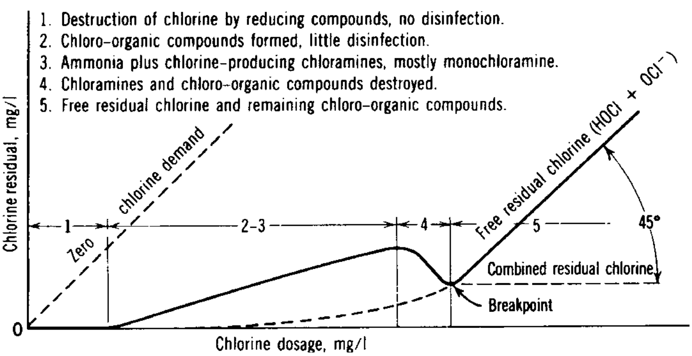


FIGURE 2.1 Reaction of chlorine in water. (Adapted from *Manual of Instruction for Water Plant Chlorinator Operators*, New York State Department of Health, Albany.)

The formation of trihalomethanes and other chloro-organics, their prevention, control, and removal, and the use of other disinfectants are discussed later in this chapter.

Distribution System Contamination

Once a water supply distribution system is contaminated with untreated water, the presence of coliform organisms may persist for an extended period of time. A surface-water supply or an inadequately filtered water supply may admit into a distribution system organic matter, minerals, and sediment, including fungi, algae, macroscopic organisms, and microscopic organisms. These flow through or settle in the mains or become attached and grow inside the mains when chlorination is marginal or inadequate to destroy them. Suspended matter and iron deposits will intermingle with and harbor the growths. Hence, the admission of contaminated water into a distribution system, even for a short time, will have the effect of inoculating the growth media existing inside the mains with coliform and other organisms. Elimination of the coliform organisms will therefore involve removal of the growth media and harborage material, which is not always readily possible, and disinfectant penetration. Bacteriological control of the water supply is lost until the biofilm and incrustation harboring coliform and other organisms are removed, unless a free chlorine residual of at least 0.2 to 0.4 mg/l is maintained in active parts of a distribution system. Even this may be inadequate if unfiltered water is admitted or if contaminants or particulates are released in the distribution system, such as after fire flows.

If a positive temporary program of continuous heavy chlorination at the rate of 5 to 10 mg/l, coupled with routine flushing of the main, is maintained, it is possible in most cases to eliminate the coliform on the inside surface of the pipes[40] and hence the effects of accidental contamination in 2 to 3 weeks or less. If a weak program of chlorination is followed, with chlorine dosage of less than 5 mg/l, the contamination may persist for an extended period of time. The rapidity with which a contaminated distribution system is cleared will depend on many factors: admission of only low-turbidity filtered water; uninterruption of chlorination even momentarily; the chlorine dosage and residual maintained in the entire distribution system; the growths in the mains and degree of pipe incrustation and their removal; conscientiousness in flushing the distribution system; the social, economic, and political deterrents; and, mostly, the competency of the responsible individual. A solution to main bacterial growths might be main cleaning and relining. The deterioration of water quality in a distribution system may be due to biological, physical, and chemical factors. The causes are usually complex and require laboratory participation and evaluation of data to identify possible causes and action measures. Species identification may be helpful in determining the significance of coliform-positive samples collected from a water system.[41] Physical analyses may include temperature, suspended and attached solids, chemical analyses including iron, dissolved oxygen, pH, alkalinity, nitrate and nitrite ions, ammonium, microbiological analyses including heterotrophic and direct microscopic counts, and residual chlorine over the long term.[42]

Plain Sedimentation

Plain sedimentation is the quiescent settling or storage of water, such as would take place in a reservoir, lake, or basin, without the aid of chemicals, preferably for a month or longer, particularly if the source water is a sewage-polluted river water. This natural treatment results in the settling out of suspended solids; reduction of hardness, ammonia, lead, cadmium, and other heavy metals; breakdown of organic chemicals and fecal coliform; removal of color (due to the action of sunlight); and die-off of pathogenic microorganisms principally because of the unfavorable temperature, lack of suitable food, and sterilizing effect of sunlight. Certain microscopic organisms, such as protozoa, consume bacteria, thereby aiding in purification of the water. Experiments conducted by Sir Alexander Houston showed that polluted water stored for periods of 5 weeks at 32°F (0°C), 4 weeks at 41°F (5°C), 3 weeks at 50°F (10°C), or 2 weeks at 64.4°F (18°C) effected the elimination of practically all bacteria.[43] A bacteria and virus removal of 80 to 90 percent can be expected after 10 to 30 days storage.[44] Plain sedimentation, however, has some disadvantages that must be taken into consideration and controlled. The growth of microscopic organisms causing unpleasant tastes and odors is encouraged, and pollution by watershed surface wash, fertilizers, pesticides, recreational uses, birds and animals, sewage, and industrial wastes may occur unless steps are taken to prevent or reduce these possibilities. Although subsidence permits bacteria, including pathogens, to die off, it also permits bacteria to accumulate and grow in reservoir bottom mud under favorable conditions. In addition, iron and manganese may go into solution, carbon dioxide may increase, and hydrogen sulfide may be produced.

Presettling basins or upflow roughing filters are sometimes used to eliminate heavy turbidity or pollution and thus better prepare the water for treatment by coagulation, flocculation, settling, and filtration. Ordinarily, at least two basins are provided to permit one to be cleaned while the other is in use. A capacity sufficient to give a retention period of at least two or three days is desirable. When heavily polluted water is to be conditioned, provision can be made for preliminary coagulation at the point of entrance of the water into the basins followed by chlorination or other disinfection at the exit. Consideration must be given to the possible formation of trihalomethanes and their prevention.

Microstraining

Microstraining is a process designed to reduce the suspended solids, insects, and nuisance organisms, including plankton, in water. The filtering surface may consist of very finely woven fabrics of stainless steel, nylon, bronze, or other resistant material on a revolving drum. Water flows into the drum, which is closed at the other end, and out through the filtering surface. Applications to water supplies are primarily the clarification of relatively clean surface waters low in true color and colloidal turbidity, in which microstraining and disinfection constitute the pretreatment, before water coagulation and clarification, ahead of slow or rapid sand filters and diatomite filters. Removal of the more common types of algae have been as high as 95 percent. Washwater consumption by the outside cleaning jets may run from 1 to 3 percent of the flow through the unit. The wastewater is collected and carried off by a trough in the upper part of the drum for proper disposal. Blinding of the fabric rarely occurs but may be due to inadequate washwater pressure or the presence of bacterial slimes. Cleansing is readily accomplished with commercial sodium hypochlorite.[45] Small head losses and low maintenance costs may make the microstrainer attractive for small installations.

Unit sizes start at about 2.5 feet in diameter by 2 feet wide. These have a capacity varying between 50,000 and 250,000 gpd, depending on the type and amount of solids in the water and the fabric used. Larger units have capacities in excess of 10 mgd.

Coagulation, Flocculation, and Settling

Adding a coagulant such as alum (aluminum sulfate) to water permits particles to come together and results in the formation of a flocculent mass, or floc, which enmeshes and agglomerates microorganisms, suspended particles, and colloidal matter, removing and attracting these materials in settling out. Removal of 90 to 99 percent of the bacteria and viruses and more than 90 percent of the protozoa and phosphate can be expected.[46] Total organic carbon and THM precursors and around 80 percent of the color and turbidity are also removed. The common coagulants used, in addition to alum, are copperas (ferrous sulfate), ferric sulfate, ferric chloride, sodium aluminate, pulverized limestone, bentonite, and clays. Sodium silicate and polyelectrolytes, including polymers, are also used at times as coagulant aids to improve coagulation and floc strength, usually resulting in less sludge and lower chemical dosages. The use of ozone as a microflocculant has also led to the need for less alum.

Proper respiratory protection should be provided for water plant operators handling water treatment plant chemicals, including chlorine and fluoride. Safety professionals, safety equipment suppliers, and chemical manufacturers can be of assistance. All chemicals must meet EPA purity standards.

To adjust the chemical reaction (alkalinity and pH) for improved coagulation, it is sometimes necessary to first add soda ash, hydrated lime, quicklime, or sulfuric acid. Color is best removed at a pH of 6.0 to 6.5. The mixing of the coagulant is usually done in two steps. The first step is rapid or flash mix and the second is slow mix, during which flocculation takes place. Rapid mix is a violent agitation for a few seconds, not more than 30 seconds, and may be accomplished by a mechanical agitator, pump impeller and pipe fittings, baffles, hydraulic jump, Parshall flume, in-line mixer, or other means. Slow mix and flocculation are accomplished by means of baffles or a mechanical paddle mixer to promote formation of a floc and provide a detention of at least 30 minutes with a flow-through velocity of 0.5 to 1.5 fpm. The flocculated water then flows to the settling basin designed to provide a retention of 4 to 6 hours, an overflow rate of about 500 gpd/ft^2 of area, or 20,000 gpd/ft of weir length. The velocity through the basin should not exceed 0.5 fpm. Cold water has a higher viscosity than warm water, hence the rate of particle or floc settling is much less in cold water; this must be taken into consideration in the design of a sedimentation basin. It is always recommended that mixing tanks and settling basins be at least two in number to permit cleaning and repairs without completely interrupting the water treatment, even though mechanical cleaning equipment is installed for sludge removal.

For the control of coagulation, jar tests are made in the laboratory to determine the approximate dosage of the chemicals (not laboratory grade) used, at the actual water temperature, that appear to produce the best results.[47] The best pH and coagulant and coagulant aid are also determined. Then, with this as a guide, the chemical dosing equipment, dry feed, or solution feed is adjusted to add the desired quantity of chemical proportional to the flow of water treated to give the best results. See Figure 2.5 later in the chapter. The dosages may be further adjusted or refined based on actual operating conditions. Aluminum breakthrough is minimized with coagulation pH control at the prevailing water temperature. It should be remembered that the algal level in a surface-water source will affect the dissolved-oxygen, carbon dioxide, and pH levels in the raw water and produce changes between night and day.

Zeta potential is also used to control coagulation. It involves determination of the speed at which particles move a given distance through an electric field caused by a direct current passing through the raw water. Best flocculation takes place when the charge approaches zero, giving best precipitation when a coagulant such as aluminum sulfate, assisted by a polyelectrolyte (polymer) if necessary, is added. Polymers may contain hazardous impurities. Quality control specifications should be met.

The addition of a polymer, silicate, and special clays may assist coagulation and clarification of certain waters as previously noted. A faster settling and more filterable floc is reported, which is less affected by temperature change or excessive flows. Less plugging of filters, longer filter runs, more consistent effluent turbidity, less backwash water, less sludge volume, and easier dewatering of sludge are claimed for polymer, clay–alum treatment.[48] High-rate filtration however may require surface wash in order to adequately clean the filter during the backwash cycle.

Another device for coagulating and settling water consists of a unit in which the water, to which a coagulant has been added, is introduced near the bottom, mixes with recirculated sludge, and flows upward through a blanket of settled floc. The clarified water flows off at the top. Sludge is drawn off at the bottom. These basins are referred to as upflow suspended-solids contact clarifiers. The detention period used in treating surface water is 4 hours, but may be as little as 1.5 to 2 hours, depending on the quality of the raw water. The normal upflow rate is 1,440 gpd/ft^2 of clarifier surface area and the overflow rate is 14,400 gpd per foot of weir length. A major advantage claimed, where applicable, is a reduction of the detention period and hence savings in space. Disadvantages include possible loss of sludge blanket with changing water temperature and variable water quality.

Tube settlers are shallow tubes, usually inclined at an angle of approximately 60 degrees from horizontal. Flow is up through the tubes that extend from about middepth to a short distance below the water surface and are inclined in the direction of water flow. Solids settle in the tube bottom, should slide down against the flow, and accumulate on the bottom of the basin. Effective operation requires laminar flow, adequate retention, nonscouring velocities, and floc particle settling with allowance for sludge accumulation and desludging at maximum flow rates.[49] Pilot plant studies are advisable prior to actual design and construction. Algal growths may clog tubes. Inclined plate settlers are similar to the tube settlers except that 45 to 60 degree inclined plates are used instead of tubes; the settled sludge slides down the smooth plates (plastic) opposite the direction of flow; the water enters through the sides and flows upward. If the depth is adequate, tube and inclined plate settlers can be used in existing settling basins to increase their capacity and improve their efficiency.

Filtration

Filters are of the slow sand, rapid sand, or other granular media (including multimedia) and pressure (or vacuum) type. Each has application under various conditions. The primary purpose of filters is to remove suspended materials, although microbiological organisms and color are also reduced. Of the filters mentioned, the slow sand filter is recommended for use at small communities, in developing areas, and in rural places, where adaptable. A rapid sand filter is not recommended because of the rather complicated control required to obtain satisfactory results unless competent supervision and operation can be ensured. This precaution also applies to package plants. The pressure filter, including the diatomaceous earth type, is commonly used for the filtration of industrial water supplies and swimming pool water; it is not generally recommended for the treatment of drinking water, except where considered suitable under the conditions of the proposed use. Variations of the conventional rapid sand filter, which may have application where raw water characteristics permit, are direct filtration, deep-bed filtration (4 to 8 feet media depth and 1.0 to 2.0 mm media size), high-rate filtration (up to 10 gpm/ft^2), declining flow rate filtration, and granular activated-carbon filters. In all cases, pilot plant studies at the site should first be conducted to demonstrate their feasibility and effectiveness.

Slow Sand Filter

A slow sand filter consists of a watertight basin, usually covered, built of concrete, and equipped with a rate controller and loss-of-head gauge. The basin holds a special sand 30 to 48 inches deep that is supported on a 12- to 18-inch layer of graded gravel placed over an underdrain system that may consist of open-joint, porous, or perforated 2- to 4-inch-diameter pipe or conduit spaced no greater than 3 feet. The velocity in the underdrain system should not exceed 0.75 fps. The sand should have an effective size of 0.25 to 0.35 mm and a uniformity coefficient not greater than 2.5. Operation of the filter is controlled so that filtration will take place at a rate of 1 to 4 million gallons per acre per day, with 2.5 million gallons as an average rate. This would correspond to a filter rate of 23 to 92 gal/ft^2 of sand area per day or an average rate of 57 gal. A rate up to 10 million gallons may be permitted by the approving authority if justified.

From a practical standpoint, the water that is to be filtered should have low color, less than 30 units, and low coliform concentration (less than 1,000 per 100 ml) and be low in suspended matter and algae, with a low turbidity not exceeding an occasional 50 units; otherwise, the filter will clog quickly. A plain sedimentation basin, roughing filter, or other pretreatment ahead of the filter can be used to reduce the suspended matter, turbidity, and coliform concentration of the water if necessary. It could also serve as a balancing tank. A loss-of-head gauge should be provided on the filter to show the resistance the sand bed offers to the flow of water through it and to show when the filter needs cleaning, usually 30 to 60 days, more or less, depending on raw water quality and filter rate. This is done by draining the water down to 6 inches below the surface of the sand bed and scraping about 1 inch of sand with adhering particles and *schmutzdecke* off the top of the bed. The sand is washed and replaced when the depth of sand is reduced to about 24 inches. A scraper or flat shovel is practical for removing the top layer of clogged sand with the aid of a motorized cart. The sand surface can also be washed in place by a special washer traveling over the sand bed. Filtered water is readmitted to a depth of several inches above the sand to prevent scour when placed in operation. Slow sand filters should be constructed in pairs as a minimum. These filters, *operated without interruption*, are easily controlled and, when followed by disinfection, produce a consistently satisfactory water. The filtration process is primarily biological rather than chemical/physical.

A well-operated plant will remove 98 to 99.5 percent of the coliform bacteria, protozoa, and viruses, as well as some organic and inorganic chemicals in the raw water (after a biological film has formed on the surface and within the sand bed). Effluent turbidity of less than 0.3 NTU and coliform of 1 per 100 ml or less can (and *must*) be regularly obtained. Chlorination of the filtered water is necessary to destroy microorganisms passing through the filter and growing or entering the storage basin and water system. This type plant will also remove about 25 to 40 percent of the color in the untreated water. Chlorination of the sand filter itself is desirable either continuously or periodically to destroy microorganisms growing within the sand bed, supporting gravel, or underdrain system. Continuous prechlorination at a rate that produces 0.3 to 0.5 mg/l in the water on top of the filter will not harm the filter film; it will increase the length of the filter run. A high chlorine residual (5 mg/l) is detrimental. Sand filters should also have the capability to discharge to the waste-stream to allow the filter to ripen. Filtration to waste may be required for 6 hours to 2 weeks after cleaning, depending on the age of the filter, particulate matter in the raw water, and filtrate quality.[50] In any case, continuous postchlorination should be provided.

A slow sand filter suitable for a small rural water supply is shown in Figure 2.2. Details relating to design are given in Table 2.2. The rate of filtration in this filter is controlled by selecting an orifice and filter area that will deliver not more than 50 gal/ft^2 of filter area per day, thus preventing excessive rates of filtration that could endanger the quality of the treated

water. Where competent and trained personnel are available, the rate of flow can be controlled by manipulating a gate or butterfly valve on the effluent line from each filter, provided a venturi, orifice, triangular weir, or other suitable meter, with indicating and preferably recording instruments, is installed on the outlet to measure the rate of flow. The valve can then be adjusted to give the desired rate of filtration until the filter needs cleaning. Another practical method of controlling the rate of filtration is by installing a float valve on the filter effluent line, as shown in Figure 2.3. The valve is actuated by the water level in a float chamber, which is constructed to maintain a reasonably constant head over an orifice in the float chamber that would yield the desired filter rate of flow. A hydraulically operated float can be connected to a control valve by tubing and located at some distance from the valve. A solenoid valve can accomplish the same type of control. A modulating float valve is more sensitive to water level control than the ordinary float valve. Riddick describes a remote float-controlled weighted butterfly valve, with spring-loaded packing glands and stainless steel shafts.[51] A special rate control valve can also be used if it is accurate within the limits of flow desired. The level of water over the orifice or filter outlet must be *above* the top of the sand to prevent the development of a negative head. If a negative head is permitted to develop, the mat on the surface of the sand may be broken and dissolved air in the water may be released in the sand bed, causing the bed to become air bound. At least 3 inches of water over the sand or a flexible influent hose will minimize any possible disturbance of the sand when water from the influent line falls into the filter. Postchlorination should be provided. A cartridge-type tablet or stack chlorinator may meet the needs in a rural situation. The filter should operate without interruption to produce uniform results, and daily operation reports should be kept.

Rapid Sand (Granular Media) Filter

$$\text{Rate of filtration} = \frac{7.48}{\text{minutes for water in filter to fall 1 ft}}$$

Fill filter with water, shut off influent, and open drain.

Backwash time = 10 to 15 minutes minimum, until water entering through is clear

Normal washwater usage = 2 to 2.5% or less of water filtered

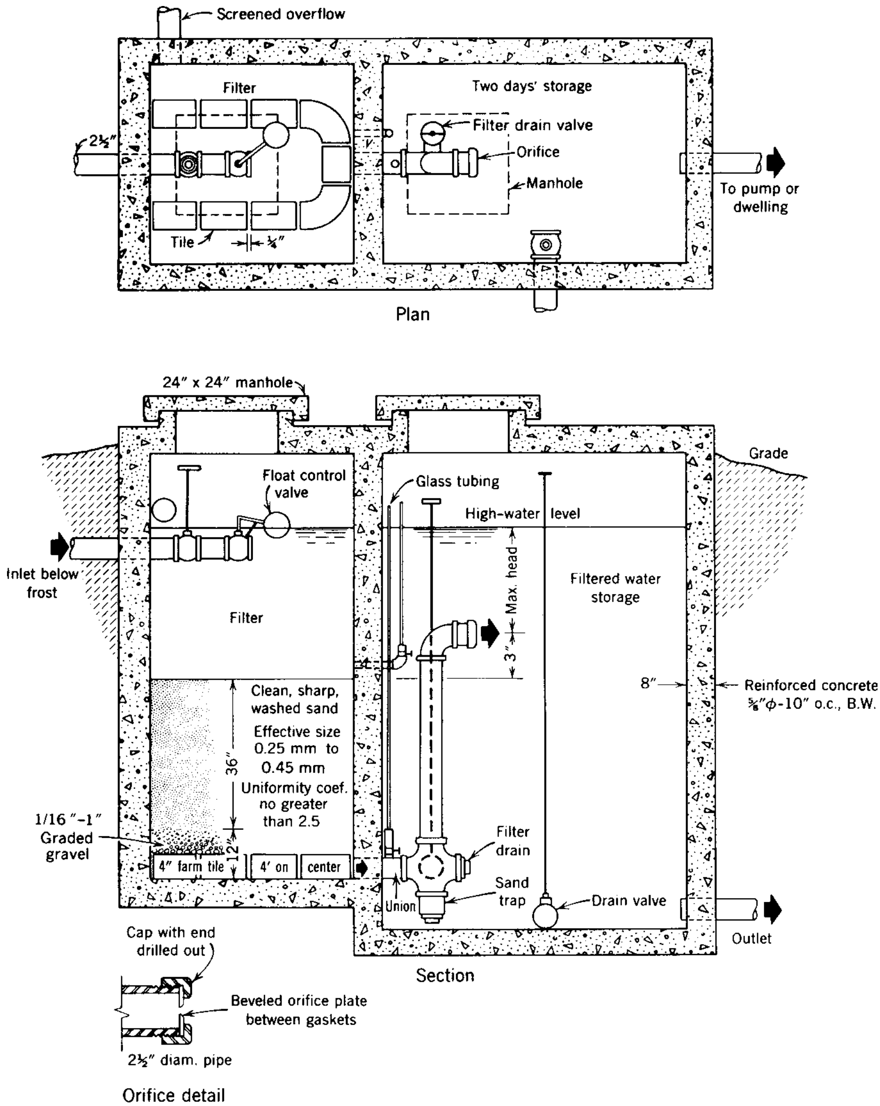


FIGURE 2.2 Slow sand filter for a small water supply. Minimum of two units. The difference in water level between the two glass tubes represents the frictional resistance to the flow of water through the filter. When this difference approaches the maximum head and the flow is inadequate, the filter needs cleaning. To clean, scrape the top 1 in. of sand bed off with a mason's trowel, wash in a pan or barrel, and replace clean sand on bed. Float control valve may be omitted where water on filter can be kept at a desirable level by gravity flow or an overflow valve. Add a meter, venturi, or other flow-measuring device on the inlet to the filter. Rate of flow can also be controlled by maintaining a constant head with a weighted float valve over an orifice or weir. See 1.18. Filtered water should be disinfected before use. Allow sufficient head room for cleaning the filter. Separation of the filter box from the filtered water storage clear well is usually required by health officials for public water supplies. Thoroughly ventilate filter box and water storage tank before entering and during occupancy.

TABLE 2.2 Orifice Flow for Selected Orifice Diameters

Maximum Head, (ft of water)	Maximum Flow by Orifice Diameter[a] (gpd)[b]														
	$\frac{1}{16}$	$\frac{3}{32}$	$\frac{1}{8}$	$\frac{5}{16}$	$\frac{1}{4}$	$\frac{5}{16}$	$\frac{3}{8}$	$\frac{7}{16}$	$\frac{1}{2}$	$\frac{9}{16}$	$\frac{5}{8}$	$\frac{11}{16}$	$\frac{3}{4}$	$\frac{7}{8}$	1
1	67	149	266	597	1,060	1,660	2,390	3,240	4,240	5,370	6,640	8,010	9,550	13,030	17,000
$1\frac{1}{2}$	82	183	326	732	1,305	2,040	2,930	3,990	5,220	6,580	8,130	9,850	11,700	15,950	20,800
2	96	213	380	852	1,520	2,370	3,410	4,650	6,060	7,680	9,480	11,480	14,300	18,600	24,200
$2\frac{1}{2}$	107	236	421	945	1,680	2,620	3,780	5,150	6,720	8,500	10,500	12,680	15,100	20,600	26,800
3	116	259	462	1,036	1,840	2,880	4,140	5,640	7,380	9,130	11,520	13,920	16,550	22,600	29,500
$3\frac{1}{2}$	126	279	498	1,120	1,990	3,100	4,470	6,060	7,950	10,050	12,420	14,900	17,900	24,300	30,700
4	135	300	534	1,200	2,125	3,330	4,790	6,530	8,520	10,800	13,300	16,100	19,150	26,100	34,000
$4\frac{1}{4}$	145	322	574	1,290	2,290	3,580	5,160	7,020	9,150	11,600	14,350	17,300	20,600	28,000	36,600
5	150	333	594	1,332	2,370	3,700	5,340	7,260	9,480	12,000	14,800	17,950	21,400	29,000	38,700
$5\frac{1}{2}$	157	350	624	1,400	2,490	3,890	5,600	7,620	9,960	12,600	15,550	18,850	22,400	30,500	39,300
6	164	366	650	1,460	2,600	4,070	5,850	7,980	10,400	13,150	16,250	19,900	23,400	31,800	41,500
$6\frac{1}{2}$	169	376	672	1,510	2,680	4,180	6,030	8,220	10,700	13,580	16,750	20,200	24,200	32,800	42,800

[a]In inches.

[b]No loss head through sand and gravel or pipe is assumed; flow is based on $Q = C_d VA$, where $V = \sqrt{2gh}$ and $C_d = 0.6$, with free discharge. (Design filter for twice the desired flow to ensure an adequate delivery of water as the frictional resistance in the filter to the flow builds up. *Use two or more units in parallel*.)

Note: The loss of head through a clean filter is about 3 in.; hence add 3 in. to the "maximum head" in the table and sketch to obtain the indicated flow in practice. A minimum 3–4 ft of water over the sand is advised. Example: To find the size of a filter that will deliver a maximum of 500 gpd: From above, a filter with a $\frac{1}{8}$-in. orifice and a head of water of 3 ft 9 in. will meet the requirements. Filtering at the rate of 50 gpd/ft^2 of filter area, the required filter area is 500 gpd/[50 gal/(ft^2)(day)] = 10 ft^2. Provide at least 2 days storage capacity.

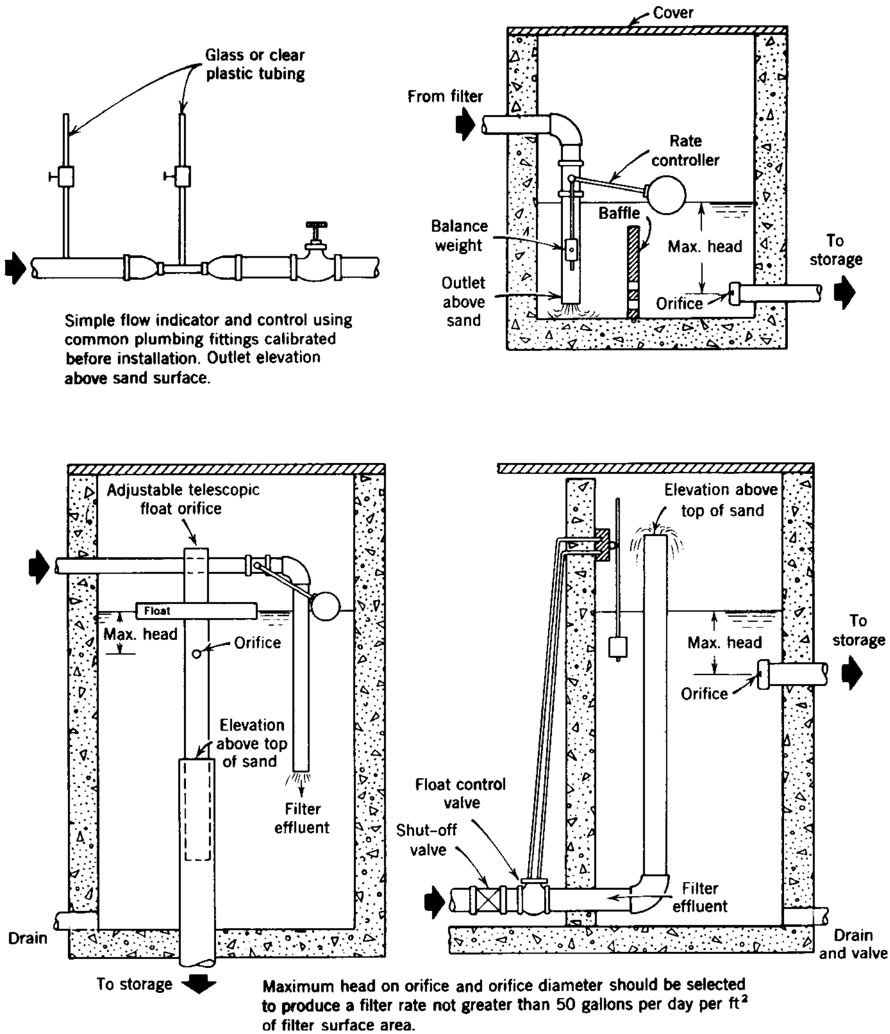


FIGURE 2.3 Typical devices for the control of the rate of flow or filtration. Plant capacity: 50 to 100 percent greater than average daily demand, with clear well.

Sand expansion = 40 to 50% = 33.6 to 36 in. for 24-in. sand bed
= 25 to 35% for dual media, anthracite, and sand

$$\text{Rate of backwash} = \frac{7.48}{\text{minutes for water in filter to rise 1 ft}}$$

Lower water level to sand, slowly open backwash valve, 20 to 25 gpm/ft^2 minimum (32 to 40 in. rise/min).

Orifice area = 0.25 to 0.30% of filter area

Lateral area = 2 × Orifice area

Manifold area = 1.5 to 2 × Total area of laterals

The rate controller is omitted in a declining-rate filter. A gate valve or orifice is used in its place. An acceptable rate of flow (filtration) is set at the start of a run but decreases as the head loss increases. The use of this concept is recommended in developing countries and other areas where skilled operators are not generally available.[52] See also "Slow Sand Filter" (filtration rate control) in this chapter and Table 2.2.

In a combination anthracite over sand bed filter (dual media), use is made of the known specific gravity of crushed anthracite of 1.35 to 1.75 and the specific gravity of sand of 2.5 to 2.65. The relative weight of sand in water is three times that of anthracite. The anthracite effective size is 0.9 to 1.1 and uniformity coefficient 1.6 to 1.8. The sand effective size is 0.45 to 0.55 and uniformity coefficient 1.5 to 1.7 (see Figure 2.4). Anthracite grains can be twice as large as sand grains; after backwashing, the sand will settle in place before the anthracite in two separate layers.[53] High-rate sand–anthracite filters require careful operating attention and usually use of a filter conditioner to prevent floc passing through while at the same time obtaining a more uniform distribution of suspended solids throughout the media depth. Longer filter runs, such as two to three times the conventional filter, at a rate of 4 to 6 gpm/ft^2 and up to 8 or 10 gpm/ft^2 and less washwater are reported. A mixed or multimedia may consist of anthracite on top, effective size 0.95 to 1.0 mm and uniformity coefficient 1.55 to 1.75; silica sand in the middle, effective size 0.45 to 0.55 and uniformity coefficient 1.5 to 1.65; and garnet sand* on the bottom, effective size 0.2 to 0.35 mm and uniformity coefficient 1.6 to 2.0. Total media depth is 24 to 48 in. Under the same conditions, filter runs will increase with dual media and increase further with mixed media over single-media sand. The turbidity of the effluent can be expected to be less than 0.5 NTU in a well-operated plant. Granular activated-carbon media (GAC) in place of sand and anthracite can function both as an adsorbent of organics and as a filter medium, but backwash rates will have to be reduced and carefully controlled. If the organics are synthetic chemicals, frequent regeneration will be required. If the organics are taste- and odor-producing compounds, activated carbon may remain effective for several years. The GAC will dechlorinate water that has been chlorinated.

Treatment of the raw water by coagulation, flocculation, and settling to remove as much as possible of the pollution is usually necessary and an important preliminary step in the rapid sand filtration of water. Without coagulation, virus removal is very low. The settled water, in passing to the filter, carries with it some flocculated suspended solids, color, and microorganisms. This material forms a mat on top of the sand that aids greatly, together with adsorption on the

*Garnet sand has a specific gravity of 4.0–4.2.

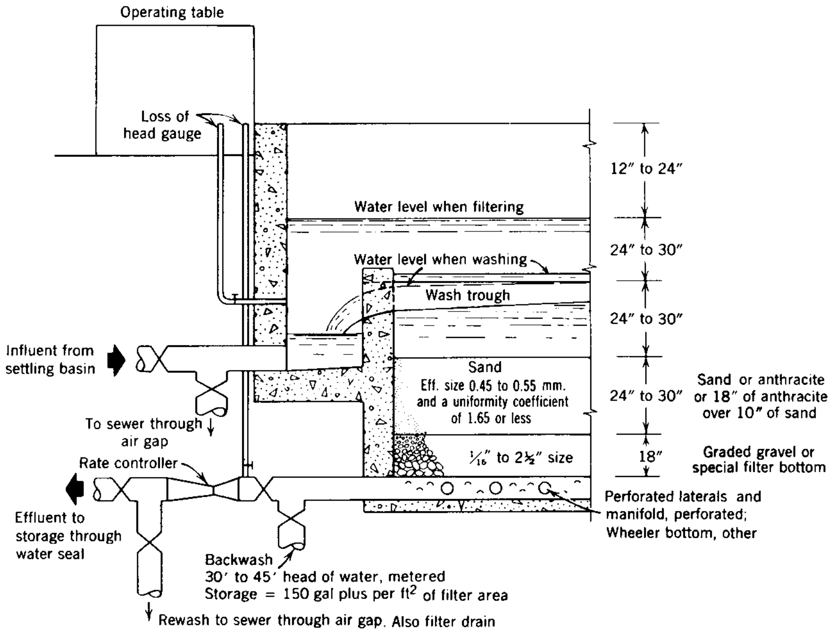


FIGURE 2.4 Essential parts of a rapid sand filter. The minimum total depth is 8.5 ft, 12 ft preferred.

bed granular material, in the straining and removal of other suspended matter, color, and microorganisms, but this also causes rapid clogging of the sand. Special arrangement is therefore made in the design for washing the filter (every 48 to 72 hours, depending on the head loss) by forcing water backward up through the filter at a rate that will provide a sand expansion of 40 to 50 percent based on the backwash rate, water temperature, and sand effective size. For example, with a 0.4-mm-effective-size sand, a 40 percent sand expansion requires a washwater rate rise of 21 in./min with 32°F (0°C) water and a rise of 32.5 inches with water at 70°F (21°C).[54] The dirty water is carried off to waste by troughs built in above the sand bed 5 to 6 feet apart. Separate air laterals in the underdrain system can increase the backwash efficiency. A system of water jets or rakes or a 1.5- to 2-in. pressure line at 45 to 75 psi with a hose connection (including vacuum breaker) should be provided to scour the surface of the sand to assist in loosening and removing the material adhering to it, in the pores of the sand on the surface, and in the filter depth. Air scour or wash is also very effective for cleaning the entire bed depth, especially in beds 4 to 6 feet deep. A backwash rate of 10 gpm/ft^2 may be acceptable with an anthracite or granular activated-carbon bed. Effective washing of the sand is essential. Backwash should start when the turbidity begins to rise above 0.1 to 0.2 NTU, not after the turbidity reaches 1.0 NTU. Before being placed back into service the filter effluent should be sent to waste for 5 to 20 minutes to reestablish filtration efficiency. Aluminum in the filtered water should be less than 0.15 mg/l. Filters that have been out of service should be backwashed before being returned to service. The filter sand should be inspected periodically. Its condition can be observed by lowering the water level below the sand and looking for mounds and craters, debris on the surface, or cracks on the surface or along the walls. Depth samples of the sand may also be taken for laboratory observation. During the washing operation the samples should be inspected for uneven turbulence and the presence of small lumps known as mud balls. Any of these conditions requires further investigation and correction. A conventional rapid sand filter plant flow diagram and unit processes are shown in Figure 2.5.

When properly operated, a filtration plant, including coagulation, flocculation, and settling, can be expected to remove 90 to 99.9 percent of the bacteria, protozoa, and viruses,[55] a great deal of the odor and color, and practically all of the suspended solids. Adequate pretreatment is essential. Nevertheless, chlorination must be used to ensure that the water leaving the plant is safe to drink. Construction of a rapid sand filter should not be attempted unless it is designed and supervised by a competent environmental engineer. Pilot plant studies, including preliminary treatment for heavily polluted water, may be required to ensure the proposed treatment will produce a water meeting drinking water standards at all times. Adequate coagulation, flocculation, and settling, in addition to granular media filtration and disinfection, are necessary to ensure the removal of bacteria, protozoa (*Giardia* and *E. histolytica* cyst), and viruses. Improper pH control can result in weak floc and passage of dissolved coagulant.

A flow diagram of a typical treatment plant is shown in Figure 2.6.

Direct Filtration

Direct filtration of waters with low suspended matter and turbidity, color, coliform organisms, and plankton, and free of paper fiber, has been attractive because of the lower cost in producing a good quality water, if substantiated by prior pilot plant studies reflecting seasonal variations in raw water quality. Direct filtration removals of bacteria, viruses, and turbidity tend to be more erratic than with conventional treatment.[56] In direct filtration, the sedimentation basin is omitted. The unit processes prior to filtration (dual or mixed media) may consist of only rapid mix, rapid mix and flocculation, or rapid mix and contact basin (1-hour detention) without sludge collector. A flocculation or contact basin is recommended for better water quality control. Rapid sand filtration with coagulation and flocculation is reported to remove 90 to 99 percent of the viruses, bacteria, and protozoa.[57] A polymer is normally used in addition to a coagulant. Direct filtration is a good possibility[58] if either of three conditions holds:

1. The raw water turbidity and color are each less than 25 units.
2. The color is low and the maximum turbidity does not exceed 200 NTU.
3. The turbidity is low and the maximum color does not exceed 100 units.

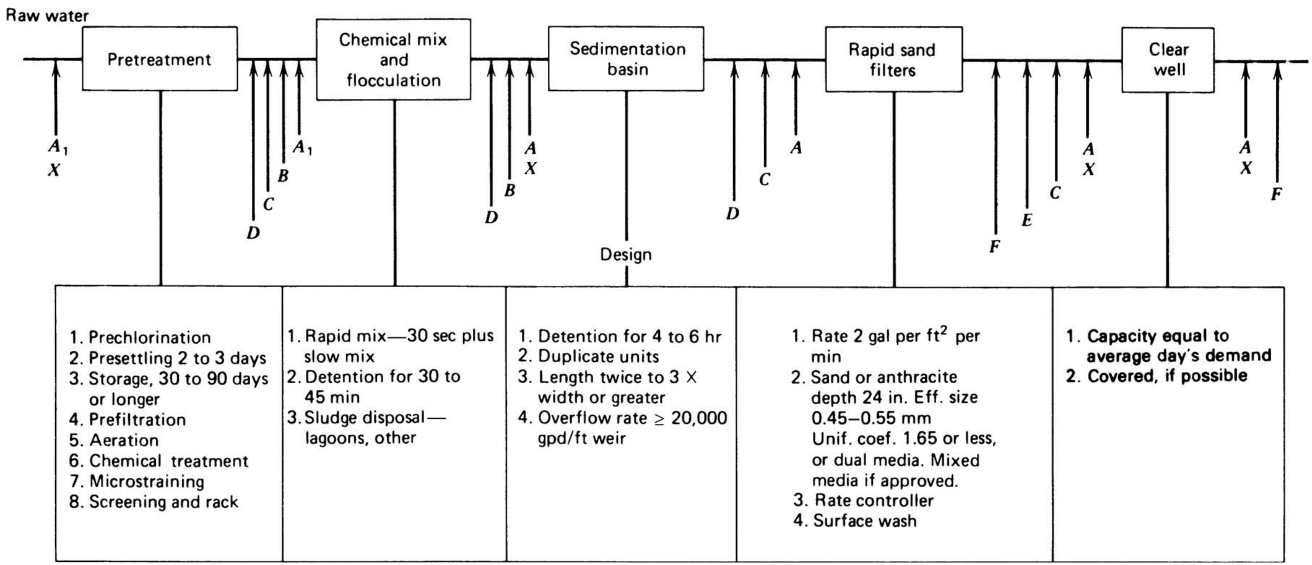


FIGURE 2.5 Conventional rapid sand filter plant flow diagram. Possible chemical combinations: *A*: Chlorine. A_1 Eliminate if THMs formed. *B*: Coagulant; aluminum sulfate (pH 5.5–8.0), 10 to 50 mg/l; ferric sulfate (pH 5.0–11.0), 10 to 50 mg/l; ferrous sulfate (pH 8.5–11.0), 5 to 25 mg/l; ferric chloride (pH 5.0–11.0); sodium aluminate, 5 to 20 mg/l; activated silica, organic chemicals (polyelectrolytes). *C*: Alkalinity adjustment; lime, soda ash, or polyphosphate. *D*: Activated carbon, potassium permanganate. *E*: Dechlorination; sulfur dioxide, sodium sulfite, sodium bisulfite, activated carbon. *F*: Fluoridation treatment. *X*: Chlorine dioxide, ozone, chlorine-ammonia. Note that the chlorinator should be selected to postchlorinate at 3 mg/l. Provide for a dose of 3 mg/l plus chlorine demand for groundwater. Additional treatment processes may include softening (ion exchange, lime-soda, excess lime and recarbonation), iron and manganese removal (ion exchange, chemical oxidation and filtration, ozone oxidation, sequestering), organics removal (activated carbon, superchlorination, ozone oxidation), and demineralization (distillation, electrodialysis, reverse osmosis, chemical oxidation and filtration, freezing).

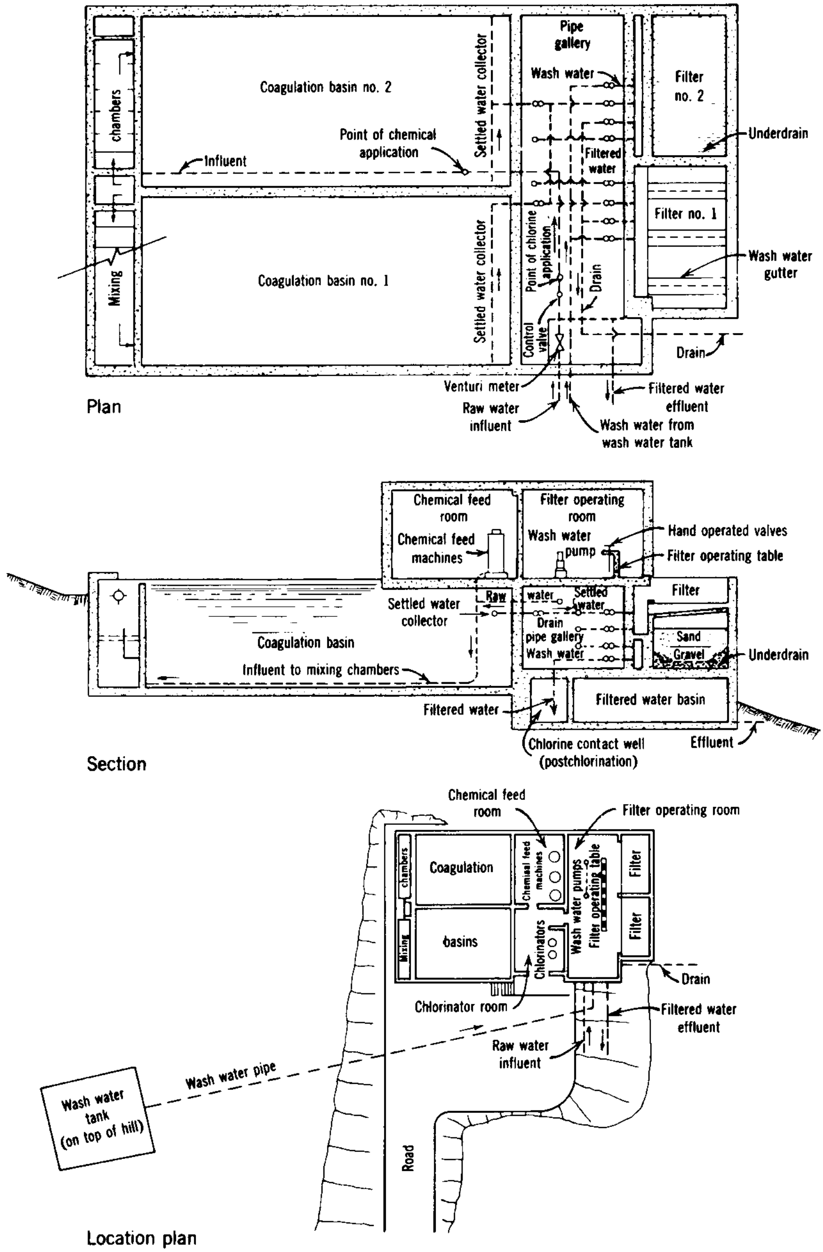


FIGURE 2.6 Flow diagram of typical treatment plant. This plant is compactly arranged and adaptable within a capacity range of 0.25 to 1.0 mgd. Operation is simple as the emphasis is on manual operation with only the essentials in mechanical equipment provided. Design data are described in the text. (*Source: Water Treatment Plant Design*, American Water Works Association, New York, 1969. Copyright 1969 by the American Water Works Association. Reprinted with permission.)

The presence of paper fiber or of diatoms in excess of 1,000 areal standard units per milliliter (asu/ml) requires that settling (or microscreening) be included in the treatment process chain. Diatom levels in excess of 200 asu/ml may require the use of special coarse coal on top of the bed in order to extend filter runs. Coliform MPNs should be low. Filter rates of 4 to 5 gpm/ft^2 and as high as 15 gpm/ft^2 may produce satisfactory results with some waters, but caution is advised. Decreased chemical dosage, and hence sludge production but increased filter washwater, will usually result in reduced net cost as compared to conventional treatment.[59] Surface wash, subsurface wash, or air scour is required. Good pretreatment and operation control are essential.

Pressure Sand Filter

A pressure filter is similar in principle to the rapid sand gravity filter except that it is completely enclosed in a vertical or horizontal cylindrical steel tank through which water under pressure is filtered. The normal filtration rate is 2 gpm/ft^2 of sand. Higher rates are used. Pressure filters are most frequently used in swimming pool and industrial plant installations and for precipitated iron and manganese removal. It is possible to use only one pump to take water from the source or out of the pool (and force it through the filter and directly into the plant water system or back into the pool), which is the main advantage of a pressure filter. This is offset by difficulty in introducing chemicals under pressure, inadequate coagulation facilities, and lack of adequate settling. The appearance of the water being filtered and the condition of the sand cannot be seen; the effectiveness of backwashing cannot be observed; the safe rate of filtration may be exceeded; and it is difficult to look inside the filter for the purpose of determining loss of sand or anthracite, need for cleaning, replacing of the filter media, and inspection of the washwater pipes, influent, and effluent arrangements. Because of these disadvantages and weaknesses, a pressure filter is not considered dependable for the treatment of contaminated water to be used for drinking purposes. It may, however, have limited application for small, slightly contaminated water supplies and for turbidity removal if approved. In such cases, the water should be coagulated and flocculated in an open basin before being pumped through a pressure filter. This will require double pumping. Pressure filters are not used to filter surface water or other polluted water or following lime-soda softening.

Diatomaceous Earth Filter

The pressure-filter type consists of a closed steel cylinder, inside of which are suspended septa, the filter elements. In the vacuum type, the septa are in an open tank under water that is recirculated with a vacuum inside the septa. Normal rates of filtration are 1 to 1.5 gpm/ft^2 of element surface. To prepare the filter for use, a slurry or filter aid (precoat) of diatomaceous earth is introduced with the water to be treated at a rate of about 1.5 oz/ft^2 of filter septum area, which results in about 1/16 inch depth of media being placed evenly on the septa, and the water is recirculated for at least 3 minutes before discharge. Then more filter aid (body feed) is continuously added with the water to maintain the permeability of the filter media. Use of a cationic polymer enhances the removal of bacteria and viruses. The rate of feed is roughly 2 to 3 mg/l per unit of turbidity in the water. Filter aid comes in different particle sizes. It forms a coating or mat around the outside of each filter element. Because of smaller media pore size, it is more efficient than sand in removing from the water suspended matter and organisms such as protozoal cysts (which cause amebiasis and giardiasis), cercariae (which cause schistosomiasis), flukes (which cause paragonimiasis and clonorchiasis), and worms (which cause dracunculiasis, ascariasis, and trichuriasis). Expected bacteria removal is 90 to 99 percent, viral 95 percent, and protozoan 99 percent. These organisms, except for *Giardta* cysts, are not common in the United States. Effluent turbidity of 0.10 NTU or less is normal with proper operation.

The diatomite filter has found its greatest practical application in swimming pools, iron removal for groundwaters, and industrial and military installations. It has a special advantage in the removal of oil from condensate water, since the diatomaceous earth is wasted. It should not be used to treat a public water supply unless pilot plant study results on the water to be treated meet the regulatory agency requirements. The filter should not be used to treat raw water with greater than 2400 MPN per 100 ml, 30 turbidity units, or 3,000 areal standard microscopic units per 100 ml. It does not remove color or taste- and odor-producing substances. In any case, disinfection is considered a necessary adjunct to filtration.

A major weakness in the diatomite filter is that failure to add diatomaceous earth to build up the filtering mat, either through ignorance or negligence, will render the filter entirely ineffective and give a false sense of security. In addition, the septa will become clogged and require replacement or removal and chemical cleaning. During filtration, the head loss through the filter should not exceed 30 lb/in.^{2}, thereby requiring a pump and motor with a wide range in the head characteristics.[60] The cost of pumping water against this higher head is therefore increased. Diatomite filters cannot be used where pump operation is intermittent, as with a pressure tank installation, for the filter cake will slough off when the pump stops, unless sufficient continuous recirculation of 0.1 gpm/ft^2 of filter area is provided by a separate pump. A reciprocating pump should not be used. Head loss should not exceed a vacuum of 15 in. of mercury in a vacuum system.[61]

The filter is backwashed by reversing the flow of the filtered water back through the septa, thereby forcing all the diatomite to fall to the bottom of the filter shell, where it is flushed to waste. Only about 0.5 percent of the water filtered is used for backwash when the filter run length equals the theoretical or design length. As with other filters, the diatomite filter must be carefully operated by trained personnel in order to obtain dependable results, where its use is approved.

Package Water Treatment Plant

These plants are usually predesigned gravity rapid sand filter plants. They are compact and include chemical feeders, coagulation, flocculation, and/or settling, filtration, and water conditioning if needed. Filter design rates are usually 3 to 5 gal/ft^2. Provision must be made for adequate sludge storage and removal and for chlorine contact time. Because of variable raw water quality, it is necessary to first demonstrate that a water of satisfactory sanitary quality can be produced under all conditions. Since these plants include automated equipment, it is essential that a qualified operator be available to make treatment adjustments as needed. Approval of the regulatory agency is usually required.

Water Treatment Plant Wastewater and Sludge

Water treatment plant sludge from plain sedimentation and coagulation–flocculation settling basins and backwash wastewater from filters are required by the Clean Water Act (PL 72–500) to be adequately treated prior to discharge to a surface-water course. Included are softening treatment sludge, brines, iron and manganese sludge, and diatomaceous earth filter wastes. The wastes are characteristic of substances in the raw water and chemicals added in water treatment; they contain suspended and settleable solids, including organic and inorganic chemicals as well as trace metals, coagulants (usually aluminum hydroxide), polymers, clay, lime, powdered activated carbon, and other materials. The aluminum could interfere with fish survival and growth.

The common waste treatment and disposal processes include sand sludge drying beds where suitable, lagooning where land is available, natural or artificial freezing and thawing, chemical conditioning of sludge using inorganic chemicals and polymers to facilitate dewatering, and mechanical dewatering by centrifugation, vacuum filtration, and pressure filtration.[62]

Sludge dewatering increases sludge solids to about 15 to 20 percent. The use of a filter press involves a sludge thickener, polymer, sludge decant, lime, retention basin, addition of a precoat, and mechanical dewatering by pressure filtration. The filter cake solids concentration is increased to 40 percent. The use of a polymer with alum for coagulation could reduce the amount of alum used to less than one-fifth, the cost of coagulant chemicals by one-third, and the sludge produced by over 50 percent. Lime softening results in large amounts of sludge, increasing with water hardness. Recovery and recycling of lime may be economical at large plants. Sludge may be disposed of by lagooning, discharge to a wastewater treatment plant, or mechanical dewatering and landfilling, depending on feasibility and regulations.[63] Brine wastes may be discharged at a controlled rate to a stream if adequate dilution is available or to a sanitary sewer if permitted.

The ultimate disposal of sludge can be a problem in urban areas and land disposal where the runoff or leachate might be hazardous to surface or underground waters. Sludge analyses may be required for sludge disposal approval.

Causes of Tastes and Odors

Tastes and odors in water supplies are caused by oils, minerals, gases, organic matter, and other compounds and elements in the water. Some of the common causes are oils and products of decomposition exuded by algae and some other microorganisms; wastes from gas plants, coke ovens, paper mills, chemical plants, canneries, tanneries, oil refineries, and dairies; high concentrations of iron, manganese, sulfates, and hydrogen sulfide in the water; decaying vegetation such as leaves, algae, weeds, grasses, brush, and moss in the water; and chlorine compounds and high concentrations of chlorine. The control of taste and odor-producing substances is best accomplished by eliminating or controlling the source when possible. When this is not possible or practical, study of the origin and type of the tastes and odors should form the basis for the necessary treatment.

Control of Microorganisms

For the most part, microorganisms that cause tastes and odors are harmless. They are visible under a microscope and include plankton, fungi, bacteria, viruses, and others. Plankton are aquatic organisms; they include algae, protozoa, rotifers, copepods, and certain larvae. Phytoplankton are plant plankton. Zooplankton are animal plankton that feed on bacteria and small algae. Crenothrix, gallionella, and leptothrix, also known as iron bacteria, can also be included. *Thiobacillus thiooxidans* and sulfur bacteria have been implicated in the corrosion of iron. Phytoplankton, including algae, contain chlorophyll; utilize carbon, nitrogen, phosphorus, and carbon dioxide in water; produce oxygen; are eaten by zooplankton; and serve as a basic food for fish. All water is potentially a culture medium for one or more kinds of algae. Bacteria and algae are dormant in water below a temperature of about 48°F (10°C). Heavy algal growths cause a rise in pH and a decrease in water hardness during the day and the opposite at night.

Crenothrix and leptothrix are reddish-brown, gelatinous, stringy masses that grow in the dark inside distribution systems or wells carrying water devoid of oxygen but containing iron in solution. Control, therefore, may be effected by the removal of iron from the water before it enters the distribution system, maintenance of pH at 8.0 to 8.5, increase in the concentration of dissolved oxygen in the water above about 2 mg/l, or continuous addition of chlorine to provide a free residual chlorine concentration of about 0.3 mg/l, or 0.5 to 1.0 mg/l total chlorine. Chemical treatment of the water will destroy and dislodge growths in the mains, with resulting temporary intensification of objectionable tastes and odors, until all the organisms are flushed out of the water mains. A consumer information program should precede the treatment. Iron bacteria may grow in ditches draining to reservoirs. Copper sulfate dosage of 3 mg/l provides effective control.[64] The slime bacteria known as actinomycetes are also controlled by this treatment.

High water temperatures, optimum pH values and alkalinities, adequate food such as mineral matter (particularly nitrates, phosphorus, potassium, and carbon dioxide), low turbidities, large surface area, shallow depths, and sunlight favor the growth of plankton. Exceptions are diatoms, such as asterionella, which grow also in cold water at considerable depth without the aid of light. Fungi can also grow in the absence of sunlight. Extensive growths of anabaena, oscillaria, and microcystis resembling pea green soup are encouraged by calcium and nitrogen. Protozoa such as synura are similar to algae, but they do not need carbon dioxide; they grow in the dark and in cold water. The blue-green algae do not require direct light for their growth, but green algae do. They are found in higher concentrations within about 5 feet of the water surface.

Sawyer[65] has indicated that any lake having, at the time of the spring overturn, inorganic phosphorus greater than 0.01 mg/l and inorganic nitrogen greater than 0.3 mg/l can be expected to have major algal blooms. Reduction of nutrients therefore should be a major objective, where possible. In a reservoir, this can be accomplished by minimizing the entrance of nutrients such as farm and forest drainage, by watershed control, by removal of aquatic weeds before the fall die-off, and by draining the hypolimnion (the zone of stagnation) during periods of stratification since this water stratum has the highest concentration of dissolved minerals and nutrients. See also “Aquatic Weed Control” and “Reservoir Management, Intake Control, and Stratification,” this chapter.

Inasmuch as the products of decomposition and the oils given off by algae cause disagreeable tastes and odors, preventing their growth will remove the cause of difficulty. Where it is practical to cover storage reservoirs to exclude light, this is the easiest way to prevent the growth of those organisms that require light and cause difficulty. Where this is not possible, copper sulfate, potassium permanganate, or chlorine can be applied to prevent the growth of the organisms. A combination of chlorine, ammonia, and copper sulfate has also been used with good results. However, in order that the proper chemical dosage required may be determined, it is advisable to make microscopic examinations of samples collected at various depths and locations to determine the type, number, and distribution of organisms and the chemical crystal size for maximum contact. This may be supplemented by laboratory tests using the water to be treated and the proposed chemical dose before actual treatment. In New England, diatoms usually appear in the spring; blue-green algae appear between the diatoms and green algae. Shallow areas usually have higher concentrations of algae.

In general, the application of about 2.5 pounds of copper sulfate per million gallons of water treated at intervals of two to four weeks between April and October in the temperate zone will prevent difficulties from most microorganisms. A chelating agent such as citric acid improves the performance of the copper sulfate in a high-alkalinity water. Follow-up treatment with potassium permanganate will also kill and oxidize the algae. More exact dosages for specific microorganisms are given in Table 2.3. The required copper sulfate dose can be based on the volume of water in the upper 10 feet of a lake or reservoir, as most plankton are found within this depth. Bartsch[66] suggests an arbitrary dosage related to the alkalinity of the water being treated. A copper sulfate dosage of 2.75 pounds per million gallons of water in the reservoir is recommended when the methyl orange alkalinity is less than 50 mg/l. When the alkalinity is greater than 40 mg/l, a dosage of 5.4 lb/acre of reservoir surface area is recommended.[67] Higher doses are required for the more resistant organisms. The dose needed should be based on the type of algae making their appearance in the affected areas, as determined

TABLE 2.3 Dosage of Copper Sulfate to Destroy Microorganisms

Organism	Taste, Odor, Other	Dosage (lb/10^6 gal)
Diatomaceae (Algae)	(Usually brown)	
Asterionella	Aromatic, geranium, fishy	1.0–1.7
Cyclotella	Faintly aromatic	Use chlorine
Diatoma	Faintly aromatic	—
Fragilaria	Geranium, musty	2.1
Meridon	Aromatic	—
Melosira	Geranium, musty	1.7–2.8
Navicula	—	0.6
Nitzchia	—	4.2
Stephanodiscus	Geranium, fishy	2.8
Synedra	Earthy, vegetable	3.0–4.2
Tabellaria	Aromatic, geranium, fishy	1.0–4.2
Chlorophyceae (Algae)	(Green algae)	
Cladophora	Septic	4.2
Closterium	Grassy	1.4
Coelastrum	—	0.4–2.8
Conferva	—	2.1
Desmidium	—	16.6
Dictyosphaerium	Grassy, nasturtium, fishy	Use chlorine
Draparnaldia	—	2.8
Entomophora	—	4.2
Eudorina	Faintly fishy	16.6–83.0
Gloeocystis	Offensive	—
Hydrodictyon	Very offensive	0.8
Miscrospora	—	3.3
Palmella	—	16.6
Pandorina	Faintly fishy	16.6–83.0
Protococcus	—	Use chlorine
Raphidium	—	8.3
Scenedesmus	Vegetable, aromatic	8.3
Spirogyra	Grassy	1.0
Staurastrum	Grassy	12.5
Tetrastrum	—	Use chlorine
Ulothrix	Grassy	1.7
Volvox	Fishy	2.1
Zygnema		4.2
Cyanophyceae (Algae)	(Blue-green algae)	
Anabaene	Moldy, grassy, vile	1.0
Aphanizomenon	Moldy, grassy, vile	1.0–4.2
Clathrocystis	Sweet, grassy, vile	1.0–2.1
Coelosphaerium	Sweet, grassy	1.7–2.8
Cylindrospermum	Grassy	1.0
Gloeocopsa	(Red)	2.0
Microcystis	Grassy, septic	1.7
Oscillaria	Grassy, musty	1.7–4.2
Rivularia	Moldy, grassy	—

(*continues*)

TABLE 2.3 (*continued*)

Organism	Taste, Odor, Other	Dosage (lb/10^6 gal)
Protozoa		
Bursaria	Irish moss, salt marsh, fishy	—
Ceratium	Fishy, vile (red-brown)	2.8
Chlamydomonas	—	4.2–8.3
Cryptomonas	Candied violets	4.2
Dinobryon	Aromatic, violets, fishy	1.5
Entamoeba histolytica		Use chlorine
(cyst)	—	5–25 mg/l
Euglena	—	4.2
Glenodinium	Fishy	4.2
Mallomonas	Aromatic, violets, fishy	4.2
Peridinium	Fishy, like clam shells, bitter taste	4.2–16.6
Synura	Cucumber, musk melon, fishy	0.25
Uroglena	Fishy, oily, cod liver oil	0.4–1.6
Crustacea		
Cyclops	—	16.6
Daphnia	—	16.6
Schizomycetes		
Beggiatoa	Very offensive, decayed	41.5
Cladothrix	—	1.7
Crenothrix	Very offensive, decayed	2.8–4.2
Leptothrix	Medicinal with chlorine	—
Sphaerotilis natans	Very offensive, decayed	3.3
Thiothrix (sulfur bacteria)		Use chlorine
Fungi		
Achlya	—	—
Leptomitus	—	3.3
Saprolegnia	—	1.5
Miscellaneous		
Blood worm	—	Use chlorine
Chara	—	0.8–4.2
Nitella flexilis	Objectionable	0.8–1.5
Phaetophyceae	(Brown algae)	—
Potamogeton	—	2.5–6.7
Rhodophyceae	(Red algae)	—
Xantophyceae	(Green algae)	—

Note: Chlorine residual 0.5 to 1.0 mg/l will also control most growths, except melosira, cysts of *Entamoeba histolytica*, Crustacea, and Synura (2.9 mg/l free).

by periodic microscopic examinations. An inadequate dosage is of very little value and is wasteful. Higher dosages than necessary have caused wholesale fish destruction. For greater accuracy, the copper sulfate dose should be increased by 2.5 percent for each degree of temperature above 59°F (15°C) and 2 percent for each 10 mg/l organic matter. Consideration must also be given to the dosage

TABLE 2.4 Dosage of Copper Sulfate and Residual Chlorine That If Exceeded May Cause Fish Kill

	Copper Sulfate		Free Chlorine	Chloramine
Fish	lb/10^6 gal	mg/l	(mg/l)	(mg/l)
Trout	1.2	0.14	0.10 to 0.15	0.4
Carp	2.8	0.33	0.15 to 0.2	0.76 to 1.2
Suckers	2.8	0.33		
Catfish	3.5	0.40		
Pickerel	3.5	0.40		
Goldfish	4.2	0.50	—	0.25
Perch	5.5	0.67		
Sunfish	11.1	1.36	—	0.4
Black bass	16.6	2.0		
Minnows	—	—	0.4	0.76–1.2
Bullheads	—	—	—	0.4
Trout fry	—	—	—	0.05–0.06
Gambusia	—	—	—	0.5–1.0

applied to prevent the killing of fish. If copper sulfate is evenly distributed, in the proper concentration, and in accordance with Table 2.4, there should be very little destruction of fish. Fish can withstand higher concentrations of copper sulfate in hard water. If a heavy algal crop has formed and then copper sulfate applied, the decay of algae killed may clog the gills of fish and reduce the supply of oxygen to the point that fish will die of asphyxiation, especially at times of high water temperatures. Tastes and odors are of course also intensified. Certain blue-green algae* may produce a toxin that is lethal to fish and animals. Other conditions may also be responsible for the destruction of fish. For example, a lower dissolved oxygen, a pH value below 4 to 5 or above 9 to 10, a free ammonia or equivalent of 1.2 to 3 mg/l, an unfavorable water temperature, a carbon dioxide concentration of 100 to 200 mg/l or even less, free chlorine of 0.15 to 0.3 mg/l, chloramine of 0.4 to 0.76 mg/l, 0.5 to 1.0 mg/l hydrogen sulfide and other sulfides, cyanogen, phosphine, sulfur dioxide, and other waste products are all toxic to fish.[68†] Even a chlorine residual of greater than 0.1 mg/l may be excessive.[69] Lack of food, overproduction, and species survival also result in mass "fish kills." The total chlorine residual to protect fish in the "full-channel mixing zone" should not exceed 0.005 mg/l.

Copper sulfate may be applied in several ways. The method used usually depends on such things as the size of the reservoir, equipment available, proximity of the microorganisms to the surface, reservoir inlet and outlet arrangement, and

*Some belonging to the genera *Microcystis* and *Anabaena. Prymnesium parvum* is incriminated in fish mortality in brackish water. Marine dinoflagellates *Gymnodinium* and *Gonyaulax* toxins cause death of fish and other aquatic life.

†Trout are usually more sensitive.

time of year. One of the simplest methods of applying copper sulfate is the burlap-bag method. A weighed quantity of crystals (blue-stone) is placed in a bag and towed at the desired depth behind a rowboat or, preferably, motor-driven boat. The copper sulfate is then drawn through the water in accordance with a planned pattern, first in one direction in parallel lanes about 25 feet apart and then at right angles to it so as to thoroughly treat the entire body of water, including shallow areas. The rapidity with which the chemical goes into solution may be controlled by regulating the fabric of the bag used, varying the velocity of the boat, using crystals of large or small size, or combinations of these variables. In another method, a long wedge-shaped box (12×6 in.) is attached vertically to a boat. Two bottom sides have double 24-mesh copper screen openings 1 foot high; one has a sliding cover. Copper sulfate is added to a hopper at the top. The rate of solution of copper sulfate is controlled by raising or lowering the sliding cover over the screen, by the boat speed, and by the size of copper sulfate crystals used. Where spraying equipment is available, copper sulfate may be dissolved in a barrel or tank carried in the boat and sprayed on the surface of the water as a 0.5 or 1 percent solution. Pulverized copper sulfate may be distributed over large reservoirs or lakes by means of a mechanical blower carried on a motor-driven boat. Larger crystals are more effective against algae at lower depths. Where water flows into a reservoir, it is possible to add copper sulfate continuously and proportional to the flow, provided fish life is not important. This may be accomplished by means of a commercial chemical feeder, an improvised solution drip feeder, or a perforated box feeder wherein lumps of copper sulfate are placed in the box and the depth of submergence in the water is controlled to give the desired rate of solution. In the winter months, when reservoirs are frozen over, copper sulfate may be applied if needed by cutting holes in the ice 20 to 50 feet apart and lowering and raising a bag of copper sulfate through the water several times. If an outboard motor is lowered and rotated for mixing, holes may be 1,000 feet apart. Scattering crystals on the ice is also effective in providing a spring dosage when this is practical. Dosage should limit copper to less than 1 mg/l in the water treatment plant effluent. Potassium permanganage crystals may be used where copper sulfate is ineffective.

It is possible to control microorganisms in a small reservoir, where chlorine is used for disinfection and water is pumped to a reservoir, by maintaining a free residual chlorine concentration of about 0.3 mg/l in the water. However, chlorine will combine with organic matter and be used up or dissipated by the action of sunlight unless the reservoir is covered and there is a sufficiently rapid turnover of the reservoir water. Where a contact time of 2 hours or more can be provided between the water and disinfectant, the chlorine–ammonia process may be used to advantage. Chlorine may also be added as chloride of lime or in liquid form by methods similar to those used for the application of copper sulfate.

Mackenthum[70] cautions that the control of one nuisance may well stimulate the occurrence of another under suitable conditions and necessitate additional control actions. For example, the control of algae may lead to the growth of weeds. Removal of aquatic weeds may promote the growth of phytoplankton or bottom algae such as chara. The penetration of sunlight is thereby facilitated, but nutrients are released by growth and then decay of chara. The primary emphasis should be elimination of nutrients.

Gnat flies sometimes lay their eggs in reservoirs. The eggs develop into larvae, causing consumer complaints of worms in the water. The best control measure is covering the reservoir or using fine screening to prevent the entrance of gnats.

Zebra Mussel and Its Control

The zebra mussel is 1 to 2 in. (2.5–5 cm) long. An adult female can release 30,000 to 40,000 eggs per year. The eggs hatch into larvae (veligers) in several days, drift with the currents, hatch within 3 weeks, and attach themselves to any hard surface such as water intakes, boat and ship hulls, rock reefs, and canals, where they grow. Waters having less than 15 mg/l calcium, pH less than 6.5, temperatures below 45°F (7°C) or above 90°F (32°C), and salinity greater than 600 mg/l chloride ion limit growth. The mussels mature in about two years and have a life span of three to five years, depending on the environment. A major concern is the accumulation of the zebra mussels inside industrial plant, power plant, and drinking water intakes, causing restriction in flows and eventual clogging. Flows of 3.3 to 5.0 ft/sec (1.0–1.5 m/s) prevent attachment of the mussel, but infestation has extended to intake screens, raw water wells, settling tanks, condensers, and cooling towers. The mussel imparts a very disagreeable taste to drinking water when it dies.

The zebra mussel is believed to have been introduced into the United States via the St. Lawrence River and the Great Lakes through international ship freshwater ballast discharges. This practice is prohibited but is not entirely effective. The mussels are spreading to inland waters by attachment to recreation boats and by waterfowl carrying the veligers.

Suggested control measures include location of water intakes under sand, cleanable screens, mechanical scraping or pigging of intake pipes, electrical currents, certain sound frequencies, flushing intakes with hot water [113–131°F (45–55°C)] for not less than 10 min, oxygen deprivation, chlorine if trihalomethane production is not a problem, and ozone injection. Dual cleanable intake lines may be needed.

Although the zebra mussel improves water clarity (it filters about 1 liter of water per day and consumes phytoplankton and organic material), it deprives fish of algae and other food. The problems created, prevention or treatment, and costs involved remain to be fully resolved.[71]

Aquatic Weed Control

The growth of aquatic plants (and animals) is accelerated in clear water by nutrients in the water and bottom sediment and when the temperature of the surface water is about 59°F (15°C). Vegetation that grows and remains below the water surface does not generally cause difficulty. Decaying submergent, emergent, and floating aquatic vegetation as well as decaying leaves, brush, weeds, grasses, and debris in the water can cause tastes and odors in water supplies. The discharge of organic wastes from wastewater treatment plants, overflowing septic tank systems, storm sewers, and drainage from lawns, pastures, and fertilized fields contains nitrogen and phosphorus, which promote algal and weed growth. The contribution of phosphorus from sewage treatment plants and septic tank systems can be relatively small compared to that from surface runoff. Unfortunately, little can be done to permanently prevent the entrance of all wastes and drainage or destroy growths of rooted plants, but certain chemical, mechanical, and biological methods can provide temporary control.

Reasonably good temporary control of rooted aquatic plants may be obtained by physically removing growths by dredging; wire or chain drags, rakes, and hand pulling; and mechanical cutting. Winter drawdown and deepening of reservoirs, lakes, and ponds edges to a depth of 2 feet or more will prevent or reduce plant growths. Weeds that float to the surface should be removed before they decay. Sandy, gravelly, rocky, or clayey bottoms inhibit plant growths.

Where it is possible, the water level should be drained or lowered 3 to 6 feet to expose the affected areas of the reservoir for about 1 month during the freezing winter months, followed by drying the weeds and roots and clearing and removal. Drying out the roots and burning and removing the ash are effective for a number of years. Flooding 3 feet or more above normal is also effective where possible.

Biological control with plant-eating fish, such as white amur or grass carp, is illegal in many states. They eat aquatic insects and other invertebrates and are detrimental to other fish and water quality.

As a last resort, aquatic weeds may be controlled by chemical means. Tastes and odors may result if the water is used for drinking purposes; the chemical may kill fish and persist in the bottom mud, and it may be hazardous to the applicator. The treatment must be repeated annually or more often, and heavy algal blooms may be stimulated, particularly if the plant destroyed is allowed to remain in the water and return its nutrients to the water. Chemical use should be restricted and permitted only after careful review of the toxicity to humans and fish, the hazards involved, and the purpose to be served. Copper sulfate should not be used for the control of aquatic weeds, except for algae, since the concentration required to destroy the vegetation will assuredly kill any fish present in the water and probably exceed permissible levels in drinking water. Diquat and endothal have been approved by the EPA, if applied according to directions. Diquat use requires a 10-day waiting period. Endothal use requires a waiting period of 14 days with the amine salt formulation and 7 days with the potassium or sodium salts formulation.[72] The health and conservation departments should be consulted prior to any work. A permit is usually required.

Other Causes of Tastes and Odors

In new reservoirs, clearance and drainage reduce algal blooms by removing organic material beneficial to their growth. Organic material, which can cause anaerobic decomposition, odors, tastes, color, and acid conditions in the water, is also removed. If topsoil is valuable, its removal may be worthwhile.

Some materials in water cause unpleasant tastes and odors when present in excessive concentrations, although this is not a common source of difficulty. Iron and manganese, for example, may give water a bitter, astringent taste. In some cases, sufficient natural salt is present, or salt water enters to cause a brackish taste in well water. It is not possible to remove the salt in the well water without going to great expense. Elimination of the cause by sealing off the source of the salt water, groundwater recharge with fresh water, or controlling pump drawdown is sometimes possible.

Other causes of tastes and odors are sewage and industrial or trade wastes and spills. Sewage would have to be present in very large concentrations to be noticeable in a water supply. If this were the case, the dissolved oxygen in the water receiving the sewage would most probably be used up, with resultant nuisance conditions. On the other hand, the billions of microorganisms introduced, many of which would cause illness or death if not removed or destroyed before consumption, are the greatest danger in sewage pollution. Trade or industrial wastes introduce in water suspended or colloidal matter, dissolved minerals and organic chemicals, vegetable and animal organic matters, harmful bacteria, and other materials that are toxic and produce tastes and odors. Of these, the wastes from steel mills, paper plants, and coal distillation (coke) plants have proved to be the most troublesome in drinking water, particularly in combination with chlorine. Tastes produced have been described as “medicinal,” “phenolic,” “iodine,” “carbolic acid,” and “creosote.” Concentrations of 1 part phenol to 500 million parts of water will cause very disagreeable tastes even after the water has traveled 70 miles.[73] The control of these tastes and odors lies in the prevention and reduction of stream pollution through improved plant operation and waste treatment. Chlorine dioxide has been found effective in treating a water supply not too heavily polluted with phenols. The control of stream pollution is a function and responsibility of federal and state agencies, municipalities, and industry. Treatment of water supplies to eliminate or reduce objectionable tastes and odors is discussed separately.

Sometimes high uncontrolled doses of chlorine produce chlorinous tastes and chlorine odors in water. This may be due to the use of constant feed equipment rather than a chlorinator, which will vary the chlorine dosage proportional to the quantity of water to be treated. In some installations, chlorine is added at a point that is too close to the consumers, and in others, the dosage of chlorine is marginal or too high or chlorination treatment is used where coagulation, filtration, and chlorination should be used instead. Where superchlorination is used and high concentrations of chlorine remain in the water, dechlorination with sodium sulfite, sodium bisulfite, sodium thiosulfate, sulfur dioxide, or activated carbon is indicated. Sulfur dioxide is most commonly used in manner similar to that used for liquid chlorine and with the same precautions; dosage must be carefully controlled to avoid lowering the pH and dissolved oxygen, as reaeration may then be necessary.

Methods to Remove or Reduce Objectionable Tastes and Odors

Some of the common methods used to remove or reduce objectionable tastes and odors in drinking water supplies, not in order of their effectiveness, are as follows:

- Free residual chlorination or superchlorination
- Chlorine–ammonia treatment
- Aeration or forced-draft degasifier
- Application of activated carbon
- Filtration through granular activated-carbon or charcoal filters
- Coagulation and filtration of water (also using an excess of coagulant)
- Control of reservoir intake level
- Elimination or control of source of trouble
- Chlorine dioxide treatment
- Ozone treatment
- Potassium permanganate treatment
- Hydrogen sulfide removal
- Removal of gasoline, fuel oil, and other organics

Bench and pilot studies over a representative period of time are advised, including laboratory studies, possible treatment or combinations of treatment, and source control.

Free Residual Chlorination Free residual chlorination will destroy, by oxidation, many taste- and odor-producing substances and inhibit growths inside water mains. Biochemical corrosion is also prevented in the interior of water mains by destroying the organisms associated with the production of organic acids. The reduction of sulfates to objectionable sulfides is also prevented. However, chloro-organics (THMs), which are suspected of being carcinogenic, may be formed, depending on the precursors in the water treated, pH, temperature, contact time, and point of chlorination.

Nitrogen trichloride is formed in water high in organic nitrogen when a very high free chlorine residual is maintained. It is an explosive, volatile, oily liquid that is removed by aeration or carbon. Nitrogen trichloramine exists below pH 4.5 and at higher pH in polluted waters. See “Chlorine Treatment for Operation and Microbiological Control,” this chapter.

Chlorine–Ammonia Treatment In practice, chlorine–ammonia treatment is the addition of about three or four parts chlorine to one part ammonia. Ammonia is available as a liquid and as a gas in 50-, 100-, and 150-pound cylinders. The ammonia is added a few feet ahead of the chlorine. Nitrogenous organic compounds reduce the effectiveness of inorganic chloramines and give misleading residual readings. Chloramines are weak disinfectants. Chloramine (monochloramine) concentration should be increased by 25 and contact time 100 times to obtain the same effectiveness as free chlorine disinfection. Because of this, chlorine–ammonia treatment is not recommended as the primary disinfectant. The disinfection efficiency of chloramines decreases with increases in pH. Chloramines prevent chlorinous tastes due to the reaction of chlorine with taste-producing substances in water. However, other taste and odor compounds may develop. An excess of ammonia can cause bacterial growth in the extremities of distribution systems. Chloramines may stimulate the growth of algae and bacteria in open reservoirs and will interfere with the maintenance of a free chlorine residual if insufficient chlorine is used. Chloramines are toxic to fish, including tropical fish, if not removed prior to use. Hospitals should also be informed that chloramines may adversely affect dialysis patients. Soft-drink manufacture may also be affected.

Chloroform is not formed as in free residual chlorination; but other chloro-organic compounds that may cause adverse health effects are formed.[74] Free residual chlorination followed by dechlorination and then chlorination of the water distributed is sometimes practiced with good bacteriological control.[75] Chlorine–ammonia treatment of the filtered water to maintain a chloramine residual in the distribution system, instead of a free residual, is sometimes used to minimize trihalomethane formation, but microbiological quality must not be compromised.

Aeration Aeration is a natural or mechanical process of increasing the contact between water and air for the purpose of releasing entrained gases, adding oxygen, and improving the chemical and physical characteristics of water. Some waters, such as water from deep lakes and reservoirs in the late summer and winter seasons, cistern water, water from deep wells, and distilled water, may have an unpleasant or flat taste due to a deficient dissolved-oxygen content. Aeration will add oxygen to such waters and improve their taste. In some instances, the additional oxygen is enough to make the water corrosive. Adjustment may be needed. Free carbon dioxide and hydrogen sulfide will be removed or reduced, but tastes and odors due to volatile oils exuded by algae are not effectively removed.[76] Aeration is advantageous in the treatment of water containing dissolved iron and manganese in that oxygen will change or oxidize the dissolved iron and manganese to insoluble ferric and manganic forms that can be removed by settling, contact, and filtration. It is also useful to remove carbon dioxide before lime–soda ash softening.

Aeration is accomplished by allowing the water to flow in thin sheets over a series of steps, weirs, splash plates, riffles, or waterfalls; by water sprays in fine droplets; by allowing water to drip out of trays, pipes, or pans that have been slotted or perforated with 3/16- to 1/2-inch holes spaced 1 to 3 inches on centers to maintain a 6-inch head; by causing the water to drop through a series of trays containing 6 to 9 inch of coke or broken stones; by means of spray nozzles; by using air-lift pumps; by introducing finely divided air in the water; by permitting water to trickle over 1 $\times$ 3-inch cypress wood slats with 1/2- to

3/4-inch separations in a tank through which air is blown up from the bottom; by forced or induced draft aeration; and by similar means. Water is applied at the rate of 1 to 5 gpm/ft^2 of total tray area.[77] Coke will become coated, and hence useless if the water is not clear, if the coke is not replaced. Slat trays are usually 12 inches apart.

Louvered enclosures are necessary for protection from wind and freezing. Many of these methods are adaptable to small rural water supplies, but care should be taken to protect the water from insects and accidental or willful contamination. Screening of the aerator is necessary to prevent the development of worms. Aerated water must be chlorinated before distribution for potable purposes. Corrosion control may also be necessary.

Activated Carbon—Powdered and Granular The sources of raw material for activated carbon include bituminous coal, lignite, peat, wood, bone, petroleum-based residues, and nutshells. The carbon is activated in an atmosphere of oxidizing gases such as CO_2, CO, O_2, steam, and air at a temperature of between 572° and 1,832°F (300°–1,000°C), usually followed by sudden cooling in air or water. The micropores formed in the carbonized particles contribute greatly to the adsorption capacity of the activated carbon. Granular carbon can be reactivated by heat treatment as, for example, in a multihearth furnace at a temperature of 1508° to 1,706°F (820°–930°C) in a controlled low-oxygen steam atmosphere, where dissolved organics in the carbon pores are volatilized and released in gaseous form. The regenerated carbon is cooled by water quenching.[78] In any case, the spent carbon, whether disposed of in a landfill or incinerator or regenerated, must be handled so as not to pollute the environment.

Granular activated-carbon (GAC) filters (pressure type) are used for treating water for soft drinks and bottled drinking water. The GAC filter beds are used at water treatment plants to remove taste- and odor-producing compounds, as well as color and synthetic organic chemicals suspected of being carcinogenic. Colloids interfere with adsorption if not removed prior to filtration. The GAC filters or columns normally follow conventional rapid sand filters but can be used alone if a clear, clean water is being treated.

Granular activated carbon is of limited effectiveness in the removal of trihalomethane precursor compounds. It is effective for only a few weeks. In contrast, GAC beds for taste and odor control need regeneration every three to six years.[79] When the GAC bed becomes saturated with the contaminant being removed, the contaminant appears in the effluent (an event known as breakthrough) if the GAC is not replaced or regenerated.

Activated carbon in the powdered form is used quite generally and removes by adsorption, if a sufficient amount is used, practically all tastes and odors found in water. The powdered carbon may be applied directly to a reservoir as a suspension with the aid of a barrel and boat (as described for copper sulfate) or released slowly from the bag in water near the propeller, but the reservoir should be taken out of service for one to two days, unless the area around the intake can be isolated. The application of copper sulfate within this time will improve the settling of the carbon.

Doses vary from 1 to 60 pounds or more of carbon to 1 million gallons of water, with 25 pounds as an average. In unusual circumstances, as much as 1,000 pounds of carbon per million gallons of water treated may be needed, but cost may make this impractical. Where a filtration plant is provided, carbon is fed by means of a standard chemical dry-feed machine or as a suspension to the raw water, coagulation basin, or filters. However, carbon can also be manually applied directly to each filter bed after each wash operation. Ten to 15 minutes contact time between the carbon and water being treated and good mixing will permit efficient adsorption of the taste and color compounds. Activated carbon is also used in reservoirs and settling basins to exclude sunlight causing the growth of algae. This is referred to as "blackout" treatment. The dosage of carbon required can be determined by trial and error and tasting the water, or by a special test known as the "threshold odor test," which is explained in *Standard Methods*.[80] If the water is pretreated with chlorine, after 15 to 20 minutes, the activated carbon will remove up to about 10 percent of its own weight of chlorine; hence, they should *not* be applied together. Careful operation control can make possible prompt detection of taste- and odor-producing compounds reaching the plant and the immediate application of corrective measures.

The GAC filters are usually 2.5 to 3 feet deep and operate at rates of 2 to 5 gpm/ft^2. They are supported on a few inches of sand. Pressure filters containing sand and activated carbon are used on small water supplies. The GAC columns are up to 10 feet deep. The water, if not clear, must be pretreated by conventional filtration, including coagulation and clarification.

Charcoal Filters Charcoal filters, either of the open-gravity or closed-pressure type, are also used to remove substances causing tastes and odors in water. The water so treated must be clear, and the filters must be cleaned, reactivated, or replaced when they are no longer effective in removing tastes and odors. Rates of filtration vary from 2 to 4 gpm/ft^2 of filter area, although rates as high as 10 gpm/ft^2 are sometimes used. Trays about 4 ft^2 containing 12 inch of coke are also used. The trays are stacked about 8 inches apart, and the quantity is determined by the results desired.

Coagulation Coagulation of turbidity, color, bacteria, organic matter, and other material in water followed by flocculation, settling, and then filtration will also result in the removal of taste- and odor-producing compounds, particularly when activated carbon is included. The use of an excess of coagulants will sometimes result in the production of a better tasting water. In any case, a surface-water supply should be treated to produce a very clear water so as to remove the colloids, which together with volatile odors account for the taste and odors of most finished waters.[81]

Reservoir Management, Intake Control, and Stratification The quality of reservoir and lake water varies with the depth, season of the year or temperature, wave action, organisms and food present, condition of the bottom, clarity of the water, and other factors. Stratification is more likely to be pronounced in deep-water bodies. Lakes are classified as eutrophic (productive) or oligotrophic (unproductive).

Temperature is important in temperate zones. At a temperature of 39.2°F (4°C), water is heaviest, with a specific gravity of 1.0. Therefore, in the fall of the year, the cool air will cause the surface temperature of the water to drop, and when it reaches 39.2°F, this water, with the aid of wind action, will move to the bottom and set up convection currents, thereby forcing the bottom water up. Then in the winter the water may freeze, and conditions will remain static until the spring, when the ice melts and the water surface is warmed. A condition is reached when the entire body of water is at a temperature of about 39.2°F, but a slight variation from this temperature, aided by wind action, causes an imbalance, with the bottom colored, turbid water deficient in oxygen (usually also acidic and high in iron, manganese, and nutrient matter) rising and mixing with the upper water. The warm air will cause the temperature of the surface water to rise, and a temporary equilibrium is established, which is upset again with the coming of cold weather. This phenomenon is known as reservoir turnover. In a shallow reservoir or lake, less than about 25 feet deep, wind action rather than water density induces water mixing.

In areas where the temperature does not fall below 39.2°F and during warm months of the year, the water in a deep reservoir or lake will be stratified in three layers: the top mixed zone (epilimnion), which does not have a permanent temperature stratification and which is high in oxygen and algae; the middle transition zone (metalimnion or thermocline), in which the drop in temperature equals or exceeds 1.8°F (1°C) per meter and oxygen decreases; and the bottom zone of stagnation (hypolimnion), about one-half or more of the depth, which is generally removed from surface influence. The hypolimnion is cold, below 54°F (12°C), and often deficient in oxygen. The metalimnion is usually the source of the best quality water. The euphotic zone, in the epilimnion, extends to the depth at which photosynthesis fails to occur because of inadequate light penetration. The reservoir or upper lake layer or region, in which organic production from mineral substances takes place because of light penetration, is called the trophogenic region. The layer in the hypolimnion in which the light is deficient and in which nutrients are released by dissimilation (the opposite of assimilation) is called the tropholytic region. Hydrogen sulfide, manganese, iron, and ammonia may occur at the bottom, making for poor-quality, raw water.

A better quality water can usually be obtained by drawing from different depth levels, except during reservoir turnover. To take advantage of this, provision should be made in deep reservoirs for an intake tower with inlets at different elevations so that the water can be drawn from the most desirable level. Where an artificial reservoir is created by the construction of a dam, it is usually better to waste surplus water through a bottom blowoff rather than over a spillway. Then stagnant hypolimnion bottom water, usually the colder water except in the winter, containing decaying organic matter (hydrogen sulfide), phosphorus, color, manganese, iron, and silt, can be flushed out.

Chlorine Dioxide Treatment Chlorine dioxide treatment was originally developed to destroy tastes produced by phenols. However, it is also a strong disinfectant over a broad pH range and effective against other taste-producing compounds such as from algae, decaying vegetation, and industrial wastes. It also oxidizes iron and manganese and aids in their removal.

Chlorine dioxide is manufactured at the water plant where it is to be used. Sodium chlorite solution and chlorine water are usually pumped into a glass cylinder where chlorine dioxide is formed and from which it is added to the water being treated, together with the chlorine water previously acidified with hydrochloric acid. A gas chlorinator is needed to form chlorine water, and for a complete reaction with full production of chlorine dioxide, the pH of the solution in the glass reaction cylinder must be less than 4.0—usually 2.0 to 3.0. Where hypochlorinators are used, the chlorine dioxide can be manufactured by adding hypochlorite solution, a dilute solution of hydrochloric acid, and a solution of sodium chlorite in the glass reaction cylinder so as to maintain a pH of less than 4.0. Three solution feeders are then needed. Cox gives the theoretical ratio of chlorine to sodium chlorite as 1.0 to 2.57 with chlorine water or hypochlorite solution and sodium chlorite to chlorine dioxide produced as 1.0 to 0.74.[82] A chlorine dioxide dosage of 0.2 to 0.3 mg/l will destroy most phenolic taste-producing compounds. Chlorine dioxide does not react with nitrogenous compounds or other organic materials in solution having a chlorine demand. Chloramine and trihalomethane formation is prevented or reduced, provided free chlorine is not present. It is an effective disinfectant, about equivalent to hypochlorous acid. In contrast to free chlorine, chlorine dioxide efficiency increases as the pH increases: Chlorine dioxide is a more efficient bactericide and virucide at pH 8.5 to 9.0 than at pH 7.0.[83] Chlorine dioxide may have to be supplemented by chlorine to maintain an effective residual in the distribution system. The EPA requires that chlorine dioxide residual oxidants be controlled so that the sum of chlorine dioxide, chlorite ion, and chlorate ion does not exceed 0.5 to 1.0 mg/l. The chlorite ion is said to be very toxic. Because of this and other uncertainties, caution is urged. Chlorine dioxide is a very irritating gas and is more toxic than chlorine. It explodes on heating. The permissible 8-hour exposure concentration is 0.1 ppm and 0.3 ppm for 15 minutes.[84]

Ozone Treatment Ozone in concentrations of 1.0 to 1.5 mg/l has been used for many years as a disinfectant and as an agent to remove color, taste, and odors from drinking water.[85] It effectively eliminates or controls color, taste, and odor problems not amenable to other treatment methods; controls disinfection byproducts formation; and improves flocculation of surface waters in low concentrations. Doses of 5 mg/l are reported to interfere with flocculation and support bacterial growths. Ozone also oxidizes and permits iron and manganese removal by settling and filtration and aids in turbidity removal. About 2 mg/l or less is required.[86] Like chlorine, ozone is a toxic gas. Source water quality affects ozonation effectiveness. Pilot plant studies are indicated.

In contrast to chlorine, ozone is a powerful oxidizing agent over a wide pH and temperature range. It is an excellent virucide, is effective against amoebic and *Giardia* cysts, and destroys bacteria, humic acid, and phenols. The potential for the formation of chlorinated organics such as THMs is greatly reduced with preozonation; the removal of soluble organics in coagulation is also reported to be improved.[87] Ozone is reported to be 3,100 times faster and more effective than chlorine in disinfection.[88] Ozone attacks the protein covering protecting a microorganism; it inactivates the nucleic acid, which leads to its destruction. Ozonation provides no lasting residual in treated water but increases the dissolved oxygen; it has a half-life of about 20 minutes in 70°F (21°C) distilled water. Ozone is more expensive as a disinfectant than either chlorine or chlorine dioxide. The disadvantage of no lasting residual can be offset by adding chlorine or chlorine–ammonia to maintain a chlorine residual in the distribution system.

New products can also be formed during the ozonation of wastewaters; not all low-molecular-weight organic compounds are oxidized completely to CO_2 and H_2O. Careful consideration must be given to the possibility of the formation of compounds with mammalian toxicity during ozonation of drinking water.[89]

However, at least one study concludes that the probability of potentially toxic substances being formed is small.[90] Ozone disinfection before chloramination yielded less than 1 μg/1 total trihalomethane.[91]

Ozone must be generated at the point of use; it cannot be stored as a compressed gas. Although ozone can be produced by electrolysis of perchloric acid and by UV lamps, the practical method for water treatment is by passage of dry, clean air between two high-voltage electrodes. Pure oxygen can be added in a positive-pressure injection system. High-purity oxygen will produce about twice the amount of ozone from the same ozonator at the same electrical input.[92] The ozonized air is injected in a special mixing and contact chamber (30 min) with the water to be treated. The space above the chamber must be carefully vented, after its concentration is reduced, using an ozone-destruct device to avoid human exposure, as ozone is very corrosive and toxic.

The vented ozone may contribute to air pollution. It should not exceed 0.12 ppm in the ambient air. As with chlorine, special precautions must be taken in the storage, handling, piping, respiratory protection, and housing of ozone. Exhaust air and plant air must be continuously monitored. The permissible 8-hours exposures are 0.1 and 0.3 ppm for 15 minutes.[93] Exposure to 0.05 ppm 24 hr/day, 7 days/week, is reported to be detrimental. Greater than 0.1 ppm calls for investigation. A concentration of 10,000 ppm is lethal in 1 minute; 500 ppm is lethal after 16 hours.

The generation of ozone results in the production of heat, which may be utilized for heating.

Hydrogen Sulfide, Sources and Removal Hydrogen sulfide is undesirable in drinking water for aesthetic and economic reasons. Its characteristic "rotten-egg" odor is well known, but the fact that it tends to make water corrosive to iron, steel, stainless steel, copper, and brass is often overlooked. The permissible 8-hours occupational exposure to hydrogen sulfide is 20 ppm, but only 10 minutes for 50 ppm exposure.[94] Death is said to result at 300 ppm. As little as 0.2 mg/l in water causes bad taste and odor and staining of photographic film.

The sources of hydrogen sulfide are both chemical and biological. Water derived from wells near oil fields or from wells that penetrate shale or sandstone frequently contain hydrogen sulfide. Calcium sulfate, sulfites, and sulfur in water containing little or no oxygen will be reduced to sulfides by anaerobic sulfur bacteria or biochemical action, resulting in liberation of hydrogen sulfide. This is more likely to occur in water at a pH of 5.5 to 8.5, particularly in water permitted to stand in mains or in water obtained from close to the bottom of deep reservoirs. Organic matter often contains sulfur that, when attacked by sulfur bacteria in the absence of oxygen, will release hydrogen sulfide. Another source of hydrogen sulfide is the decomposition of iron pyrites or iron sulfide.

The addition of 2.0 to 4 mg/l copper sulfate or the maintenance of at least 0.3 mg/l free residual chlorine in water containing sulfate will inhibit biochemical activity and also prevent the formation of sulfides. The removal of H_2S already formed is more difficult, for most complete removal is obtained at a pH of around 4.5. Aeration removes hydrogen sulfide, but this method is not entirely effective; carbon dioxide is also removed, thereby causing an increase in the pH of the water, which reduces the efficiency of removal. Therefore, aeration must be supplemented. Aeration followed by settling and filtration is an effective combination. Chlorination alone can be used without precipitation of sulfur, but large amounts, theoretically 8.4 mg/l chlorine to each milligram per liter of hydrogen sulfide, would be needed. The alkalinity (as $CaCO_3$) of the water is lowered by 1.22 parts for each part of chlorine added. Chlorine in limited amounts, theoretically 2.1 mg/l chlorine for each milligram per liter of hydrogen sulfide, will result in formation of flowers of sulfur, which is a fine colloidal precipitate requiring coagulation and filtration for removal. If the pH of the water is reduced to 6.5 or less by adding an acid to the water or a sufficient amount of carbon dioxide as flue gas, for example, good hydrogen sulfide removal should be obtained. But pH adjustment to reduce the aggressiveness of the water would be necessary. Another removal combination is aeration, chlorination, and filtration through an activated-carbon pressure filter. Pilot plant studies are indicated.

Pressure tank aerators, that is, the addition of compressed air to hydropneumatic tanks, can reduce the entrained hydrogen sulfide in well water from 35 to 85 percent, depending on such factors as the operating pressures and dissolved oxygen in the hydropneumatic tank effluent.[95] The solubility of air in water increases in direct proportion to the absolute pressure. Carbon dioxide is not removed by this treatment. Air in the amount of 0.005 to 0.16 ft^3/gal water and about 15 minutes detention is recommended, with the higher amount preferred. The air may be introduced through perforated pipe or porous media in the tank bottom or with the influent water. Unoxidized hydrogen sulfide and excess air in the tank must be bled off. Air-relief valves or continuous air bleeders can be used for this purpose. It is believed that oxidation of the hydrogen sulfide through the sulfur stage to alkaline sulfates takes place, since observations show no precipitated sulfur in the tank. Objections to pressure tank aerators are milky water caused by dissolved air and corrosion. The milky water would cause air binding or upset beds in filters if not removed.

A synthetic resin has been developed that has the property of removing hydrogen sulfide with pH control. It can be combined with a resin to remove hardness so that a low-hardness water can be softened and deodorized. The resin is manufactured by Rohm and Haas Company (Philadelphia).

Removal of Gasoline, Fuel Oil, and Other Organics in an Aquifer Leaking storage tanks and piping (50 percent of old tanks leak after 20 years), overflow from air vent or in filling, or accidental spillage near a well may cause gasoline or fuel oil to seep into an aquifer. Correction requires on-site studies and identification, location, and elimination of the cause. Removal of the source is a first and immediate step, followed possibly by pumping out and recovery of the contaminant, bioremediation, or other measures, based on the site geology, soils, and plume.

Sometimes lowering the pump or drop pipe intake in a well may help, if this is possible. However, the contaminant is likely to coat or fill soil pore spaces and persist in the contaminated zone a long time. Gasoline and oil tend to adhere to soil particles by surface tension and attraction, particularly in the unsaturated soil zone until dissipated through adsorption, dispersion, diffusion, and ion exchange[96] or flushed out or broken down by soil microorganisms. The gasoline, benzene, or fuel oil will gradually collect on the groundwater surface and in the well and can be skimmed off over a period of time. Denser liquids, such as chlorinated solvents, tend to move down through the groundwater.

A well that is contaminated by gasoline or fuel oil might be rehabilitated by extended pumping after removal of the source. The objective would be to create a cone of depression so that the zone of influence due to pumping encompasses the underground contaminated area or plume. This is not very effective if a large area is involved. Many withdrawal wells would be needed. One pump would lower the water table around the well to create a cone of depression; another with the intake close to the water surface in the well serves as an oil or gasoline skimmer. Of course, the contaminated water pumped must be treated before disposal. Continual leaching of gasoline and oil or other contaminant in pore spaces, on soil particles in both the saturated and unsaturated zones, and in rock fractures and faults can be expected for some time. The process may be expedited, under professional direction, by purging and the use of nontoxic, biodegradable detergents; however, it may not be completely effective in restoring the aquifer.

An aquifer was cleaned by treatment of the water from extraction wells using a combination of high-temperature air stripping, biological treatment, and granular activated-carbon filtration. Volatile organics, nonvolatile organics, and trace metals were removed. Soluble organics and some nonvolatile organics were destroyed.[97] Different options should be compared.

Soils contaminated with gasoline from underground storage tanks have been successfully treated by excavating and stockpiling when mixed with bacteria specifically cultivated for petroleum decomposition. Nutrients were applied to enhance growth and soil piles turned intermittently to ensure adequate concentrations of oxygen and soil/bacteria mixing. Spraying of a ditch contaminated by diesel oil with a solution of bacteria and nutrients was also successful.[98]

An activated-carbon filter will remove small amounts of oil or gasoline from a contaminated water supply. It may become expensive if large quantities must be removed and the activated carbon must be replaced frequently. Air stripping is effective for the removal of petroleum products but is more suitable for large water systems. Air stripping may also be used to decontaminate an unsaturated sandy soil. Preheated air is injected through injection wells and released through venting wells. Vacuum wells may also be used to extract volatile contaminants in unsaturated loose soil.

Ozone has also been found effective in removing volatile organic chemicals from drinking water, including 1,1-dichloroethene, 1,1,2-tetrachloroethene, trichloroethene, vinyl chloride, chlordane, polychlorinated biphenyls, and toxaphene. The treatment may include UV–ozone, UV–hydrogen peroxide, and ozone–hydrogen peroxide.[99]

Treatment methods for the removal of synthetic organic chemicals are also discussed later in this chapter.

Containment of a chemical contaminant in the aquifer may also be possible. This may be accomplished by the use of barriers such as a bentonite slurry trench, grout curtain, sheet piling, or freshwater barrier and by the provision of an impermeable cap over the offending source if it cannot be removed. The method used would depend on the problem and the hydrogeological conditions. However, there are many uncertainties in any method used, and no barrier can be expected to be perfect or maintain its integrity forever.

Bioremediation and Aquifer Restoration In situ aerobic microbial degradation, also referred to as bioremediation, biorestoration, or bioreclamation, has also been used to treat soil contaminated with biodegradable, nonhalogenated organics. The process is complex in view of the many variables and unknowns. In general, as much as possible of the contaminated water and surface soil is removed; oxygen, nutrients such as nitrogen and phosphorus, enzymes, and/or bacteria are added, then reinjected through injection wells and recirculated. Favorable soil conditions include neutral pH, high soil permeability, and 50 to 75 percent moisture content.[100]

Progress is also being made in the use of genetically engineered microorganisms to break down (metabolize) pentachlorophenol (PCP) compounds into water carbon dioxide and cell protoplasm. Microorganisms are also being engineered to break down other toxic chemicals.[101] Naturally occurring soil bacteria that use hydrocarbons for food may be present at shallow depths and possibly in soil at greater depths.[102]

The decontamination procedure should be tailored to the soils and pollutants present and their characteristics. Competent prior background information—including interviews; hydrogeological, land-use, and soil investigations; microbiological and chemical analyses; laboratory bench-scale studies; and well monitoring—are usually necessary to characterize the problem, determine the best remediation treatment, and evaluate effectiveness. Aerial photographs, topographic maps, and nearby well logs are valuable aids. It is also important to know the hydraulic conductivity of the affected formation(s), depth to groundwater, direction of groundwater flow, and types and extent of contamination. Adequate hydraulic conductivities are required to obtain in situ bioreclamation. The feasibility of biodegradation is determined in the laboratory using soil samples from several locations on the site.[103]

Iron and Manganese Occurrence and Removal

Iron in excess of 0.3 to 0.5 mg/l will stain laundry and plumbing fixtures and cause water to appear rusty. When manganese is predominant, the stains will be brown or black. Neither iron nor manganese is harmful in the concentrations found in water. Iron may be present as soluble ferrous bicarbonate in alkaline well or spring waters; as soluble ferrous sulfate in acid drainage waters or waters containing sulfur; as soluble organic iron in colored swamp waters; as suspended insoluble ferric hydroxide formed from iron-bearing well waters, which are subsequently exposed to air; and as a product of pipe corrosion producing red water.

Most soils, including gravel, shale, and sandstone rock, and most vegetation contain iron and manganese in addition to other minerals. Decomposing organic matter in water, such as in the lower levels of reservoirs, removes the dissolved oxygen usually present in water. This anaerobic activity and acidic condition dissolves mineral oxides, changing them to soluble compounds. Water containing carbon dioxide or carbonic acid, chlorine, or other oxidizing agent will have the same effect. In the presence of air or dissolved oxygen in water, soluble ferrous bicarbonate and manganous bicarbonate will change to insoluble ferric iron and manganic manganese, which will settle out in the absence of interfering substances. Ferrous iron and manganous manganese may be found in the lower levels of deep reservoirs, flooding soils, or rock containing iron and manganese or their compounds; hence, it is best to draw water from a higher reservoir level but below the upper portion, which supports microscopic growths like algae. This requires the construction and use of multiple-gate intakes, as previously mentioned. Consideration must be given to vertical circulation, such as in the spring and fall when the ferrous iron and manganous manganese are brought into contact with dissolved oxygen and air and convert to the insoluble state and settle out, if not drawn out in the intake.

The presence of as little as 0.1 mg/l iron in a water will encourage the growth of such bacteria as leptothrix and crenothrix. Carbon dioxide also favors their growth. These organisms grow in distribution systems and cause taste, odor, and color complaints. Mains, service lines, meters, and pumps may become plugged by the crenothrix growths. Gallionella bacteria can grow in wells and reduce capacity. Complaints reporting small gray or brownish flakes or masses of stringy or fluffy growths in water would indicate the presence of iron bacteria. The control of iron bacteria in well water is also discussed under "Control of Microorganisms," and "Corrosion Cause and Control," this chapter.

Corrosive waters that are relatively free of iron and manganese may attack iron pipe and house plumbing, particularly hot-water systems, causing discoloration and other difficulties. Such corrosion will cause red water, the control of which is discussed separately.

Iron and manganese can be removed by aeration or oxidation with chlorine, chlorine dioxide, ozone, potassium permanganate, or lime and lime–soda softening followed by filtration. A detention of at least 20 minutes may be required following aeration if the raw water is high in manganese or iron. Manganese can also be removed by filtration through manganese green sand capped with at least 6 inches of anthracite, but potassium permanganate is added ahead of the filter. Iron and manganese can be kept in solution (sequestered) if present in combination or individually at a concentration of 1 mg/l or less. Sodium silicates may be used to sequester up to 2 mg/l iron and/or manganese in well water prior to air contact.[104] Each method has limitations and requirements that should be determined by on-site pilot plant studies. A summary of processes used to remove iron and manganese is given in Table 2.5.

Most of the carbon dioxide in water is removed by aeration; then the iron is oxidized and the insoluble iron is removed by settling or filtration. If organic matter and manganese are also present, the addition of lime or chlorine will assist in changing the iron to an insoluble form and hence simplify its removal.

The open coke-tray aerator is a common method to oxidize and remove iron and manganese. Two or more perforated wooden trays containing about 9 inches of coke are placed in tiers. A 20- to 40-minute detention basin is provided beneath the stack of trays; there the heavy precipitate settles out. The lighter precipitate is pumped out with the water to a pressure filter, where it is removed. Carbon dioxide and hydrogen sulfide are liberated in the coke-tray aerator, and when high concentrations of carbon dioxide are present, it may be necessary to supplement the treatment by the addition of soda ash, caustic soda, or lime to neutralize the excess carbon dioxide to prevent corrosion of pipelines.

Open slat-tray aerators operate similarly to the coke-tray type but are not as efficient; however, they are easier to clean than the coke tray, and there is no coke to replace. When the trays are enclosed and air under pressure is blown up through the downward falling spray, a compact unit is developed in which the amount of air can be proportioned to the amount of iron to be removed. Theoretically, 0.14 mg/l oxygen is required to precipitate 1 mg/l iron. The unit may be placed indoors or outdoors.

Another method for iron removal utilizes a pressure tank with a perforated air distributor near the bottom. Raw water admitted at the bottom of the pressure tank mixes with the compressed air from the distributor and oxidizes the iron present. The water passes to the top of a pressure tank, at which point air is released and automatically bled off. The amount of air injected is proportioned to the iron content by a manually adjusted needle valve ahead of a solenoid valve on the air line.[105]

At a pH of 7.0, 0.6 parts of chlorine removes 1 part iron and 0.9 parts alkalinity. At a pH of 10.0, 1.3 parts of chlorine removes 1 part of manganese and 3.4 parts alkalinity.[106]

TABLE 2.5 Processes of Iron and Manganese Removal

Treatment Process	Oxidation Required	Character of Water	Equipment Required	pH Range Required	Chemicals Required	Remarks
1. Aeration, sedimentation, filtration	Yes	Iron alone in absence of appreciable concentrations of organic matter	Aeration, settling basin, sand filter	>7	None	Easily operated, no chemical control required
2. Aeration, contact oxidation, sedimentation, sand filtration	Yes	Iron and manganese loosely bound to organic matter but no excessive carbon dioxide or organic acid content	Contact aerator of coke, gravel, or crushed pyrolusite; settling basin; sand filter	>7 for iron removal, 7.5–10 for manganese	None	Double pumping required; easily controlled
3. Aeration, contact filtration	Yes	Iron and manganese bound to organic matter but no excessive organic acid content	Aerator and filter bed of manganese-coated sand, Birm, crushed pyrolusite ore, or manganese zeolite	>7 for iron removal, 7.5–10 for manganese	Lime for manganese removal	Double pumping required unless air compressor or "sniffler" valve used to force air into water; limited air supply adequate; easily controlled

4. Contact filtration	Yes, but not by aeration	Iron and manganese bound to organic matter but no excessive carbon dioxide or organic acid content	Filter bed of manganese-coated sand, Birm, crushed pyrolusite ore, or manganese zeolite	>7 for iron removal, >8.5 for manganese	Filter bed reactivated or oxidized with chlorine at intervals or with potassium permanganate applied continuously	Single pumping; aeration not required
5. Catalytic action, aeration, sedimentation, filtration	Yes	Manganese in combination with organic matter	Closed pyrolusite bed, aerator, second open-contact bed, sand filter	>7	None	Manganese changed to manganous hydroxide by catalytic action in absence of air, then oxidized
6. Aeration, chlorination, sedimentation, sand filtration	Yes	Iron and manganese loosely bound to organic matter	Aerator and chlorinator or chlorinator alone, settling basin, sand filter	7–8	Chlorine or potassium permanganate	Required chlorine dose reduced by previous aeration, but chlorination alone permits single pumping pH control required
7. Aeration, lime treatment, sedimentation, sand filtration	Yes	Iron and manganese in combination with organic matter; organic acids	Effective aerator, lime feeder mixing basin, settling basin, sand filter	8.5–10	Lime	pH control required

(*continues*)

TABLE 2.5 (*continued*)

Treatment Process	Oxidation Required	Character of Water	Equipment Required	pH Range Required	Chemicals Required	Remarks
8. Aeration, coagulation and lime treatment, sedimentation, sand filtration	Yes	Colored turbid surface water containing iron and manganese combined with organic matter	Conventional rapid sand filtration plant	8.5–9.6	Lime and ferric chloride or ferric sulfate, or chlorinated copperas, or lime and copperas	Complete laboratory control required
9. Zeolite softening	No	Well water devoid of oxygen, containing < 0.5 ppm iron and manganese for each 17.0 ppm hardness removed	Conventional sodium zeolite unit, with manganese zeolite unit (or equivalent) for treatment of bypassed water	> 6.5	None added continuously but bed is regenerated at intervals with salt solution	Only soluble ferrous and manganese bicarbonate can be removed by base exchange, so aeration or double pumping not required
10. Lime treatment, sedimentation, sand filtration	No	Soft well water devoid of oxygen, containing iron as ferrous bicarbonate	Lime feeder, enclosed mixing and settling tanks, pressure filter	8.1–8.5	Lime	Iron precipitated as ferrous carbonate in absence of oxygen; minimizes or prevents corrosion; double pumping not required

Source: C. R. Cox, *Operation and Control of Water Treatment Processes*, WHO Monograph Series, No. 49, World Health Organization, Geneva, 1964, pp. 212–213. Reproduced with permission.

Corrosion Cause and Control

Internal Pipe Corrosion Internal pipe corrosion usually occurs in unlined metal distribution system piping and building plumbing in contact with soft water of low hardness, pH, and alkalinity containing carbon dioxide and oxygen. In serious cases, water heaters are damaged, the flow of water is reduced, the water is red or rusty where unprotected iron pipe is used, and the inside surface of pipe and fittings is dissolved, with consequent release of trace amounts of possibly harmful chemicals and weakening or pitting of pipe. Dissolved iron may be redeposited as tubercules with a reduction of pipe diameter and water flow. Biochemical changes take place in pipe where iron bacteria such as crenothrix and leptothrix use iron in their growth. High water velocities, carbon dioxide, dissolved solids, and high water temperatures [(140°–150°F) (60°–66°C)] all accelerate corrosion. Free chlorine residual less than 2 mg/l in water at pH 7 to 8 results in minimal corrosion. However, significant metal leaching (copper, cadmium, zinc, and lead) can occur in home water systems served with private wells when the water has high pH and hardness.[107]

Although much remains to be learned concerning the mechanism of corrosion, a simple explanation as related to iron may aid in its understanding. Water in contact with iron permits the formation of soluble ferrous oxide and hydrogen gas. Gaseous hydrogen is attracted to the pipe and forms a protective film if allowed to remain. But gaseous hydrogen combines with oxygen usually present in "aggressive" water, thereby removing the protective hydrogen film and exposing the metal to corrosion. High water velocities also remove the hydrogen film. In addition, ferrous oxide combines with the water and part of the oxygen usually present to form ferric hydroxide when the carbonate concentration is low, which redeposits in other sections of pipe or is carried through with the water. When the carbonate concentration is high, ferrous carbonate is formed. Another role is played by carbon dioxide. It has the effect of lowering the pH of the water since more hydrogen ions are formed, which is favorable to corrosion.

Pipe Materials and Corrosion Lined steel and ductile iron pipe, asbestos-cement, wood-stave, plastic, vitrified clay, and concrete pressure pipe are corrosion resistant.* Plastic pipe may be polybutylene (PB), polyethylene (PE), or polyvinyl chloride (PVC). The PVC pipe comes in diameters of 0.5 to 30 inches, 10 to 20 foot lengths, and 100 to 235 psi working pressures. It is very resistant to corrosion. Fiberglass-reinforced plastic pipe is available in diameters up to 144 inches and lengths up to 60 feet. Polyethylene pipe comes in 18 to 120 inches in diameter and 20 foot lengths. Fiber–epoxy pipe comes in 20-foot lengths and 2 to 12 inches in diameter and is easily installed. It combines light weight with high tensile and compressive strength. The pipe withstands pressures of 300 psi, electrolytic attack, as well as embrittlement associated with

*See the AWWA/ANSI C104/A 21.4–85 Standard for Cement-Mortar Lining for Ductile-Iron Pipe and Fittings for water. Thermoplastic pipe should have the National Sanitation Foundation seal of approval. The AWWA standards C900-89 and C905 apply to 4- to 12-in. PVC pipe.

cold temperatures and aging. Ductile iron pipe comes in diameters of 4 to 54 inches and for pressures of 250 to 350 psi. Concrete pressure pipe withstands pressures of 400 psi and is available in diameters from 16 to 60 inches. With soft waters, calcium carbonate tends to be removed from new concrete, cement-lined, and asbestos-cement pipe for the first few years. Salt used in deicing can seep through the ground and greatly weaken reinforced concrete pipe and corrode the steel. Wood-stave, vitrified clay, and concrete pipes have limited applications. Iron and steel pipes are usually lined or coated with cement, tar, paint, epoxy, or enamel, which resist corrosion provided the coating is unbroken. Occasionally, coatings spall off or are imperfect, and isolated corrosion takes place. It should be remembered that even though the distribution system is corrosion resistant, corrosive water should be treated to protect household plumbing systems.

Polycyclic aromatic carbons, some of which are known to be carcinogenic, are picked up from bituminous lining of the water distribution system, not from oil-derived tarry linings. On general principles, bituminous linings are being discontinued in England by the Department of the Environment.[108] The WHO recommends that polynuclear aromatic hydrocarbon (PAH) levels in drinking water not exceed 10 to 50 μg/1, the levels found in unpolluted groundwater. Since some PAHs are carcinogenic in laboratory animals and may be carcinogenic in humans, the WHO also recommends that the use of coal-tar based and similar materials for pipe linings and coatings on water storage tanks *should be discontinued*. This recommendation was made with the knowledge that food contributes almost 99 percent of the total exposure to PAHs and that drinking water contributes probably less than 1 percent. Tetrachloroethylene can leach from vinyl-toluene-lined asbestos–cement pipe at dead-end or low-flow sections. The health risk is considered negligible.[109] Petroleum distillates, such as gasoline, can pass through PB and PE pipe and impart taste and odor to drinking water, but PVC pipe is penetrated to a lesser extent by gasoline. The PE, PB, PVC, asbestos–cement, and plastic joining materials may permit permeation by lower molecular weight organic solvents or petroleum products. The manufacturer should be consulted as to whether pipe may pass through contaminated soil.[110] See also "Drinking Water Additives," in Chapter 1.

Corrosion Control The control of corrosion involves the removal of dissolved gases, treatment of the water to make it noncorrosive, building up of a protective coating inside pipe, use of resistant pipe materials or coating, cathodic protection, the insulation of dissimilar metals, prevention of electric grounding on water pipe, and control of growths in the mains. Therefore, if the conditions that are responsible for corrosion are recognized and eliminated or controlled, the severity of the problem will be greatly minimized. The particular cause(s) of corrosion should be determined by proper chemical analyses of the water as well as field inspections and physical tests. The applicable control measures should then be employed.

The gases frequently found in water and that encourage corrosion are oxygen and carbon dioxide. Where practical, as in the treatment of boiler water or hot water for a building, the oxygen and carbon dioxide can be removed by heating or by subjecting the water, in droplets, to a partial vacuum. Some of the oxygen is restored if the water is stored in an open reservoir or storage tank.

Dissolved oxygen can also be removed by passing the water through a tank containing iron chips or filings. Iron is dissolved under such conditions, but it can be removed by filtration. The small amount of oxygen remaining can be treated and removed with sodium sulfite. Ferrous sulfate is also used to remove dissolved oxygen.

All carbon dioxide except 3 to 5 mg/l can be removed by aeration, but aeration also increases the dissolved-oxygen concentration, which in itself is detrimental. Sprays, cascades, coke trays, diffused air, and zeolite are used to remove most of the carbon dioxide. A filter rate of 25 gpm/ft^2 in coke trays 6 inches thick may reduce the carbon dioxide concentration from 100 to 10 mg/l and increase pH from about 6.0 to 7.0.[111] The carbon dioxide remaining, however, is sufficient to cause serious corrosion in water having an alkalinity caused by calcium carbonate of less than about 100 mg/l. It can be removed where necessary by adding sodium carbonate (soda ash), lime, or sodium hydroxide (caustic soda). With soft waters having an alkalinity greater than 30 mg/l, it is easier to add soda ash or caustic soda in a small water system to eliminate the carbon dioxide and increase the pH and alkalinity of the water. The same effect can be accomplished by filtering the water through broken limestone or marble chips. Well water that has a high concentration of carbon dioxide but no dissolved oxygen can be made noncorrosive by adding an alkali such as sodium carbonate, with pH adjusted to 8.1 to 8.4. Soft waters that also have a low carbon dioxide content (3 to 5 mg/l) and alkalinity (20 mg/l) may need a mixture of lime and soda ash to provide both calcium and carbonate for the deposition of a calcium carbonate film.*

Sodium and calcium hexametaphosphate, tetrasodium pyrophosphate, zinc phosphates, sodium silicate (water glass), lime, caustic soda, and soda ash are used to build up an artificial coating inside of pipe. Health department approval of chemical use and pilot plant studies are usually required. The sodium concentration in drinking water is increased when sodium salts are added.

Sodium hexametaphosphate dissolves readily and can be added alone or in conjunction with sodium hypochlorite by means of a solution feeder. Concentrated solutions of metaphosphate are corrosive. A dosage of 5 to 10 mg/l is normally used for 4 to 8 weeks until the entire distribution system is coated, after which the dosage is maintained at 1 to 2 mg/l with pH maintained at 7.2 to 7.4. The initial dosage may cause precipitated iron to go into solution with resultant temporary complaints, but flushing of the distribution system will minimize this problem. Calcium metaphosphate is a similar material, except that it dissolves slowly and can be used to advantage where this property is desirable.

*One grain per gallon (17.1 mg/l) of lime, caustic soda, and soda ash remove, respectively, 9.65, 9.55, and 7.20 mg/l free CO^2; the alkalinity of the treated water is increased by 23.1, 21.4, and 16.0 mg/l, respectively. One milligram per liter of chlorine decreases alkalinity (as $CaCO^3$) 0.7 to 1.4 mg/l and 1 mg/l alum decreases natural alkalinity 0.5 mg/l.

Inexpensive and simple pot-type feeders that are particularly suitable for small water supplies are available. Sodium pyrophosphate is similar to sodium hexametaphosphate. All these compounds are reported to coat the interior of the pipe with a film that protects the metal, prevents lime scale and red water trouble, and resists the corrosive action of water. However, heating of water above 140° to 150°F (60°–66°C) will nullify any beneficial effect. The phosphate in these compounds may stimulate biological growths in mains. In any case, the corrosion control method used should be monitored to determine its effectiveness.

Sodium silicate in solution is not corrosive to metals and can easily be added to a water supply with any type of chemical feeder to form calcium silicate, provided the water contains calcium. Doses vary between 25 and 240 lb/million gal, 70 lb/million gal being about average. The recommendations of the manufacturer should be followed in determining the treatment to be used for a particular water.

Adjustment of the pH and alkalinity of a water so that a thin coating is maintained on the inside of piping will prevent its corrosion. Any carbon dioxide in the water must be removed before this can be done, as previously explained. Lime* is added to water to increase the alkalinity and pH so as to come within the limits shown in Figure 2.7. The approximate dosage may be determined by the marble test, but the Langelier saturation index, Ryznar index, and Enslow stability indicator are more accurate methods. Under these conditions, calcium carbonate is precipitated from the water and deposited on the pipe to form a protective coating, provided a velocity of 1.5 to 3.0 fps is maintained to prevent heavy precipitation near the point of treatment and none at the ends of the distribution

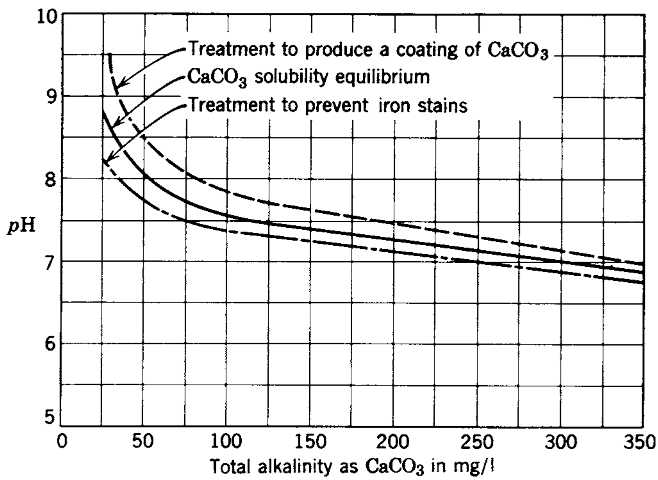


FIGURE 2.7 Solubility of $CaCO_3$ at 71°F (Baylis curve). (*Source*: C. R. Cox, *Water Supply Control*, Bulletin No. 22, New York State Department of Health, Albany, 1952, p. 185.)

*At a pH above 8.3, calcium carbonate is soluble to 13–15 mg/l.

system. The addition of 0.5 to 1.5 mg/l metaphosphate will help obtain a more uniform calcite coating throughout the distribution system. The addition of lime must be carefully controlled so as not to exceed a pH of 8.0 to 8.5 to maintain chlorination disinfection effectiveness. Calcium carbonate is less soluble in hot water than in cold water. It should be remembered that the disinfecting capacity of chlorine (HOCl) decreases as the pH increases; hence, the free available chlorine concentration maintained in the water should be increased with the higher pH. See Table 2.1. Also note that soft corrosive water with a high pH will increase corrosion of copper and zinc; old, yellow brass plumbing can be dezincified and galvanizing can be removed from iron pipe.[112]

The Langelier saturation index (the difference between the measured pH and the calculated pH) can be used to determine the point of calcium carbonate stability for corrosion control with waters having an alkalinity greater than 35 to 50 mg/l. A positive Langelier index is indicative primarily of calcium carbonate (scale) deposition; a negative index number is indicative of increasing water corrosivity with −2.0 considered high. Slightly positive is the goal. The point of calcium carbonate stability is also indicated by the Ryznar index. A Ryznar index number of less than about 6.0 is indicative primarily of the start of calcium carbonate (scale) deposition; an index number greater than 6.0 to 7.0 is indicative of increasing water corrosivity. Other measures are the Enslow stability indicator and the aggressiveness index. The Caldwell–Lawrence diagram[113] is useful for solving water-conditioning problems, but raw water concentration of calcium, magnesium, total alkalinity, pH, and TDS values must be known. See *Standard Methods*[114] for procedures. Do not rely on only one method.

The AWWA recognizes the coupon test to measure the effects of physical factors and substances in water on small sections of stainless steel and galvanized iron inserted in a water line for 90 days. Measurement of the weight loss due to corrosion or weight gained due to scale formation can thus be determined under the actual use conditions. The gain on stainless steel should not exceed 0.05 mg/cm^2; the loss from the galvanized iron should not exceed 5.0 mg/cm^2. Temperature, pH, velocity, dissolved oxygen, and water quality affect corrosion rates. Coupons should preferably remain in the pipe for 1 year or longer. The test does not show the inside condition of the pipe.[115]

The danger of lead or zinc poisoning and off-flavors due to copper plumbing can be greatly reduced when corrosive water is conducted through these pipes by simply running the water to waste in the morning. This will flush out most of the metal that has had an opportunity to go into solution while standing during the night. Maintenance of a proper balance between pH, calcium carbonate level, and alkalinity as calcium carbonate is necessary to reduce and control lead corrosion by soft aggressive water. Formation and then *maintenance* of a carbonate film are necessary. See Figure 2.7. In a soft, corrosive water, sodium hydroxide can be used for pH adjustment and sodium bicarbonate for carbonate addition. Lead pipe should not be used to conduct drinking water. Low lead solders and use of plastic pipe and glass-lined water heaters will minimize the problems associated with corrosion in the home. See "Lead Removal," this chapter.

Biochemical actions such as the decomposition of organic matter in the absence of oxygen in the dead end of mains, the reduction of sulfates, the biochemical action within tubercles, and the growth of crenothrix and leptothrix, all of which encourage corrosion in mains, can be controlled by the maintenance of at least 0.3 mg/l free residual chlorine in the distribution system.

External Pipe Corrosion External corrosion of underground pipe may be caused by stray direct electric currents; buried defective electric, telephone, and TV cables and grounding connections to water mains; grounding of household systems, appliances, and equipment; direct current welding equipment; acidic soils; abrasions and breaks in external coating; anaerobic bacteria; and dissimilar metals in contact. Stray currents from electric trolleys and subways also contribute to the problem. Soil around pipe serves as the electrolyte and the pipe serves as the conductor.

Corrosion caused by electrolysis or stray direct electric currents can be prevented by making a survey of the piping and removing grounded electrical connections and defective electric cables. Moist soils will permit electric currents to travel long distances. A section of nonconducting pipe in dry soil may confine the current. In the vicinity of power plants, this problem is very serious and requires the assistance of the power company involved.

Where dissimilar metals are to be joined, a plastic, hard rubber, or porcelain fitting can be used to separate them. It must be long enough to prevent the electric charge from jumping the gap. A polyethylene tube or encasement around cast-iron and ductile iron pipe and mastic, coal-tar enamel, epoxy, or similar coating protected with a wrapping will protect pipe from corrosive soil.

Corrosion of water storage tanks and metal pipelines can be controlled by providing "cathodic protection," in which a direct current is imposed to make the metal (cathode) more electronegative than an installed anode. But it is necessary to repaint the metal above the water line in a water storage tank with an approved coating. Consult with the provider of cathodic protection equipment. A number of galvanic anodes, which are higher in the galvanic electromotive series,* such as magnesium or zinc, may be used adjacent to pipelines. The higher metal in the electromotive series will be the anode and will corrode; the lower metal (the pipe) is the cathode. The current flows from the anode to the cathode. The moist soil serves as the electrolyte. Eventually, the anode will have to be replaced.

Well Clogging and Cleaning A common problem with wells in anaerobic zones is the reduction in production capacity, usually due to clogging of the formation or incrustation of the well screen openings. This may be due to mineral scale precipitation formed around the screen and on the screen; to bacteria that oxidize iron such as crenothrix, leptothrix, and gallionella; and plugging when silt, fine sand, and clay build-up in the formation or gravel pack around the well

*Galvanic series from most active to least active: sodium, magnesium, zinc, aluminum, steel, iron, lead, tin, brass, copper, nickel, silver, gold, platinum.

screen. Anaerobic waters may contain sulfides or iron and possibly manganese. If sulfates predominate, the water will contain sulfides. Iron bacteria are found where dissolved oxygen and dissolved iron are present. The source may also be surface water contamination.

As much information as possible should be obtained concerning the well-water characteristics to suggest a possible cause of reduced well capacity before any unclogging work is done. Chemical analysis of a representative water sample and a marble test or calculation of the Langelier saturation index or Ryznar index can show if calcium carbonate could precipitate out on the well screen or if iron or manganese and incrustations are present. Comparison with analyses made when the well was new may provide useful information. High bacterial plate counts may indicate organic growths in or on the well screen. Microscopic examination can show if iron bacteria or other objectionable growths are present.[116]

Treatment methods include the use of acids to dissolve mineral scale and bacterial iron precipitate, but care is necessary to minimize corrosion of the well, screen, and pump. Chlorination (sodium hypochlorite) to disinfect a well will also remove and retard growth of the iron bacteria. A 1-mg/1 copper sulfate solution or a quaternary ammonium compound might also be effective. Sodium polyphosphates have been found effective in unplugging wells caused by clay and silt particles.[117] Repeat treatment is usually needed, including well surging to purge the well screen and adjacent aquifer.

Water Softening Water softening is the removal of minerals causing hardness from water. For comparative purposes, one grain per gallon of hardness is equal to 17.1 mg/l. Water hardness is caused primarily by the presence of calcium bicarbonate, magnesium bicarbonate (carbonate hardness), calcium sulfate (gypsum), magnesium sulfate (epsom salts), calcium chloride, and magnesium chloride (noncarbonate hardness) in solution. In the concentrations usually present these constituents are not harmful in drinking water. The presence of hardness is demonstrated by the use of large quantities of soap in order to make a lather*; the presence of a gritty or hard curd in laundry or in a basin; the formation of hard chalk deposits on the bottom of pots and inside of piping causing a reduced water flow; and the lowered efficiency of heat transfer in boilers caused by the formation of an insulating scale. Hard water is not suitable for use in boilers, laundries, textile plants, and certain other industrial operations where a zero hardness of water is needed.

In softening water the lime or lime–soda ash process, zeolite process, and organic resin process are normally used. In the lime–soda ash method, the soluble bicarbonates and sulfates are removed by conversion to relatively insoluble forms. In the zeolite process, the calcium and magnesium are replaced with sodium,

*With a water hardness of 45 mg/l the annual per-capita soap consumption was estimated at 29.23 lb; with 70 mg/l hardness, soap consumption was 32.13 lb; with 298 mg/l hardness, soap consumption was 39.89 lb; and with 555 mg/l, soap consumption was 45.78 lb. (M. L. Riehl, *Hoover's Water Supply and Treatment*, National Lime Association, Washington, DC, April 1957.)

forming sodium compounds in the water that do not cause hardness but add to the sodium content. With synthetic organic resins, dissolved salts can be almost completely removed. Table 2.6 gives ion exchange values. Caustic soda can also remove both carbonate and noncarbonate hardness, but it is more costly.

Lime–soda ash softening requires the use of lime to convert the soluble bicarbonates of calcium and magnesium (carbonate hardness) to insoluble calcium carbonate and magnesium hydroxide, which are precipitated. Prior aeration of excess lime is needed to remove carbon dioxide if it is present in the raw water. The soluble calcium and magnesium sulfate and chlorides (noncarbonate hardness) are converted to insoluble calcium carbonate and magnesium carbonate by the addition of soda ash and lime and precipitated. Lime softening will also remove 90 to 99 percent of the bacteria and viruses but does not remove the need for disinfection. The sodium chloride and sodium sulfate formed remain in the water. Excess lime is needed to achieve a pH of about 9.5 to precipitate calcium carbonate, and a pH of about 11 is needed to precipitate magnesium hydroxide when it is greater than about 40 mg/l. Then pH adjustment is needed to control calcium carbonate precipitation on filters and in the distribution system. Carbon dioxide gas is usually added (recarbonation) to change the calcium hydroxide to calcium carbonate to improve precipitation and to adjust the pH to 8.6 or less in the finished water. Carbon dioxide is usually produced by the burning of gas, oil, coke, or coal. A coagulant such as aluminum sulfate (filter alum), ferrous sulfate (copperas), ferric sulfate, or sodium aluminate is usually used to coagulate and settle the compounds formed, followed by filtration to remove turbidity and color. Large volumes of sludge with high water content are produced. Disposal may present a problem. Options include reclamation and land disposal. The lime–soda ash method is not suitable for softening small quantities of water because special equipment and technical control are necessary. The process is more economical for softening moderately hard water. As water hardness increases, the lime requirement increases, which makes the zeolite process more attractive. The lime–soda ash process is usually controlled to reduce hardness to about 50 to 80 mg/l.

The zeolite and synthetic resin softening methods are relatively simple ion exchange processes that require little control. Only a portion of the hard water need be passed through a zeolite softener since a water of zero hardness is produced by the zeolite filter. The softener effluent can be mixed with part of the untreated water to produce a water of about 50 to 80 mg/l hardness. The calcium and magnesium in water to be treated replace the sodium in the zeolite filter media, and the sodium passes through with the treated water. This continues until the sodium is used up, after which the zeolite is regenerated by bringing a 5 to 10 percent solution of common salt in contact with the filter media. Units are available to treat the water supply of a private home or a community. Water having a turbidity of more than 5 units will coat the zeolite grains and reduce the efficiency of a zeolite softener. Iron in the ferric form and organic substances are also detrimental. Iron or manganese or iron plus manganese should not exceed 0.3 mg/l. Pretreatment to remove turbidity, organic matter, and iron would be

TABLE 2.6 Ion Exchange Materials and Their Characteristics

Exchange Material	Exchange Capacity (grains/ft^3)	Effluent Content	Regeneration Material	Remarks
Natural zeolites	3,000–5,000	Sodium bicarbonate, chloride, sulfate	0.37–0.45 lb salt per 1,000 grains hardness removed	Ferrous bicarbonate and manganous bicarbonate also removed from well water devoid of oxygen, pH of water must be 6.0–8.5, moderate turbidity acceptable. Use 5–10% brine solution. Saturated brine is about 25%.
Artificial zeolites	9,000–12,000	Sodium bicarbonate, chloride,	0.37–0.45 lb salt per 1,000 grains hardness removed	
Carbonaceous zeolites	9,000–12,000	Carbon dioxide and acids, sodium chloride and sulfate	0.37–0.45 lb salt per 1,000 grains hardness removed	Acid waters may be filtered. CO_2 in effluent removed by aeration, acid by neutralization with bypassed hard water or addition of caustic soda.
Synthetic organic resins	10,000–30,000	Carbon dioxide and acids	0.2–0.3 lb salt per 1,000 grains hardness removed	Dissolved salts are removed by resins. To remove CO_2 and acids, add soda ash or caustic soda, or CO_2 by aeration, and acids by synthetic resin filtration.

Note: One gallon of saturated brine weighs 10 lb and contains 2.5 lb of salt. Hardness is caused by calcium bicarbonate, magnesium bicarbonate, calcium sulfate, magnesium sulfate, and calcium chloride. Natural zeolite is more resistant to waters of low pH than artificial zeolite. Natural zeolite is also known as greensand.

indicated. The filters are not less than 3 feet deep. Downward-flow filters generally operate at rates between 3 and 5 gpm/ft^2; upward-flow filters operate at 4 to 6 gpm/ft^2. The maximum rate should not exceed 7 gpm/ft^2.

Synthetic resins for the removal of salts by ion exchange are discussed under "Desalination" in Chapter 1. Consideration must be given to the disposal of the brine waste from the ion exchange process.

Small quantities of water can be softened in batches for laundry purposes by the addition of borax, washing soda, ammonia, or trisodium phosphate. Frequently, insufficient contact time is allowed for the chemical reaction to be completed, with resultant unsatisfactory softening.

Lime softening removes arsenic, barium, cadmium, chromium, fluoride, lead, mercury, selenium, radioactive contaminants, copper, iron, manganese, and zinc.

The extent to which drinking water is softened should be evaluated in the light of the relationship of soft water to cardiovascular diseases. In view of the accumulating evidence, the wisdom of constructing municipal softening plants is being questioned. There is evidence associating the ingestion of sodium with cardiovascular diseases, kidney disease, and cirrhosis of the liver. See "Hardness and Sodium," in Chapter 1.

Fluoridation Since about 1943 fluorides have been added to public water supplies in controlled amounts to aid in the reduction of tooth decay. The compounds commonly used are sodium fluoride (NaF), sodium silicofluoride (Na_2SiF_6), and hydrofluosilicic acid (H_2SiF_6), also called fluosilicic acid. They are preferred because of cost, safety, and ease of handling. Ammonium silicofluoride may be used in conjunction with chlorine where it is desired to maintain a chloramine residual in the distribution system, if permitted by the regulatory agency. Calcium fluoride (fluospar) does not dissolve readily. Hydrofluoric acid is hazardous; unsealed storage containers should be vented to the atmosphere. Backflow devices are required on all fluoride and water feed lines.

Solution and gravimetric or volumetric dry feeders are used to add the fluoride, usually after filtration treatment and before entry into the distribution system. Fluoride solutions for small water systems are usually added by means of a small positive-feed displacement pump. Corrosion-resistant piping must be used. Calcium hypochlorite and fluoride should not be added together, as a calcium fluoride precipitate would be formed. Fluoride compounds should not be added before lime–soda ash or ion exchange softening. Personnel handling fluorides are required to wear protective clothing. Proper dust control measures, including exhaust fans, must be included in the design where dry feeders are used. Dosage must be carefully controlled.

The average annual per-capita cost of fluoridation of a public water supply is small. Softened water should be used to prepare a sodium fluoride solution whenever the hardness, as calcium carbonate, of the water used to prepare the solution is greater than 75 mg/l, or even less. This is necessary to prevent calcium and magnesium precipitation, which clogs the feeder. Small quantities of water can be softened by ion exchange, or polyphosphates may be used.[118] See "Fluorides" in Chapter 1.

Removal of Inorganic Chemicals

The sources, health effects, permissible concentrations, and control measures related to certain inorganic chemicals are also discussed under the appropriate headings earlier in Chapter 1 under “Chemical Examinations”. Fundamental to the control of toxic inorganic chemicals in drinking water is a sanitary survey and identification of the sources, types, and amounts of pollutants followed by their phased elimination as indicated, *starting at the source*. Watershed and land-use controls are usually the best preventive measures in both the short term and long term, coupled with point and nonpoint source control.

Table 2.7 summarizes treatment methods for the removal of inorganic chemicals from drinking water. Several are discussed in some detail as follows.

Arsenic Removal Inorganic arsenic in water occurs naturally in two oxidation states, arsenite [As(III)] and arsenate [As(V)]. Arsenate is a negatively charged molecule and is relatively easy to remove since it strongly adsorbs onto the surface of metal hydroxide particles. Arsenite, however, is more difficult to remove due to its neutral charge. If the water being treated contains only arsenite (or enough that achieving the MCL is questionable) the treatment should begin with an oxidation step to convert all inorganic arsenic to arsenate. Oxidation is effectively achieved using simple chlorination, ozonation, or use of potassium permanganate.

For surface water systems with a conventional process using either ferric or alum coagulation, arsenic is easily removed during the coagulation–semination process. Groundwater systems (with or without disinfection) will likely choose one of the following treatment processes, which will all achieve greater than 95 percent removal:

- Sorption process (ion exchange or adsorption onto an iron, aluminum, or copper media)
- Precipitation process (coagulation followed by filtration)
- Membrane process (nanofiltration or reverse osmosis)

The final choice of treatment technology will depend on several factors, including the availability of sewers to handle waste brine; the presence of competing ions such as nitrate and sulfate; the number of bed-volumes of an adsorbent media (i.e., useful life); and the presence of other constituents such as hardness or TDS. Following an assessment of the most appropriate technology, pilot studies should be conducted to confirm the treatment efficacy prior to full-scale implementation.[119]

Cadmium Removal Cadmium removal of greater than 90 percent can be achieved by iron coagulation at about pH 8 and above. Greater percentage removal is obtained in higher turbidity water. Lime and excess lime softening remove nearly 100 percent cadmium at pH 8.7 to 11.3. Ion exchange treatment

TABLE 2.7 Most Effective Treatment Methods for Inorganic Contaminant Removal

Contaminant	Most Effective Methods
Arsenic As^{3+}	Ferric sulfate coagulation, pH 6–8
	Alum coagulation, pH 6–7
	Excess lime softening
	Oxidation before treatment required
As^{5+}	Ferric sulfate coagulation, pH 6–8
	Alum coagulation, pH 6–7
	Excess lime softening
Barium	Lime softening, pH 10–11
	Ion exchange
Cd^{3+}	Ferric sulfate coagulation, above pH 8
	Lime softening
	Excess lime softening
Chromium	Ferric sulfate coagulation, pH 6–9
Cr^{3+}	
	Alum coagulation, pH 7–9
	Excess lime softening
	Ferrous sulfate coagulation, pH 7–9.5
Cr^{6+}	
Fluoride	Ion exchange with activated alumina or bone char media
Lead	Ferric sulfate coagulation, pH 6–9
	Alum coagulation, pH 6–9
	Lime softening
	Excess lime softening
Mercury	
Inorganic	Ferric sulfate coagulation, pH 7–8
Organic	Granular activated carbon
Nitrate	Ion exchange
Selenium	Ferric sulfate coagulation, pH 6–7
Se^{4+}	Ion exchange
	Reverse osmosis
Se^{6+}	Ion exchange
	Reverse osmosis
Silver	Ferric sulfate coagulation, pH 7–9
	Alum coagulation, pH 6–8
	Lime softening
	Excess lime softening

Source: T. J. Sorg, "Treatment Techniques for the Removal of Inorganic Contaminants from Drinking Water," *Manual of Treatment Techniques for Meeting the Interim Primary Drinking Water Regulations*, U.S. Environmental Protection Agency, Cincinnati, OH, May 1977, p. 3.

with cation exchange resin should remove cadmium from drinking water. Powdered activated carbon is not efficient and granular activated carbon will remove 30 to 50 percent. Reverse osmosis may not be practical for cadmium removal.[120]

Lead Removal Normal water coagulation and lime softening remove lead—99 percent for coagulation at pH 6.5 to 8.5 and for lime softening at pH 9.5 to 11.3. Turbidity in surface water makes particulate lead removal easier by coagulation, flocculation, settling, and filtration. Powdered activated carbon removes some lead; GAC effectiveness is unknown; and reverse osmosis, electrodialysis, and ion exchange should be effective.[121] Lead in the soluble form may be removed by reverse osmosis or distillation.

Nitrate Removal Treatment methods for the removal of nitrates from drinking water include chemical reduction, biological denitrification, anion exchange, reverse osmosis, distillation, and electrodialysis. Ion exchange is the most practical method. At one community water system,* the water has approximately 200 mg/l total dissolved solids; the nitrate–nitrogen levels are reduced from 20 to 30 mg/l to less than 2 mg/l.[122] Little plant-scale data are otherwise available. Reverse osmosis and electrodialysis are effective (40 to 95 percent), but these methods are more costly than ion exchange.

Fluoride Removal Treatment methods for the removal of fluorides from drinking water have been summarized by Sorg.[123] They include high (250–300 mg/l) alum doses, activated carbon at pH 3.0 or less; lime softening if sufficient amounts of magnesium (79 mg/l to reduce fluoride from 4 to 1.5 mg/l) are present or added for coprecipitation with magnesium hydroxide; ion exchange using activated alumina, bone char, or granular tricalcium phosphate; and reverse osmosis. Of these methods, alum coagulation and lime softening are not considered practical. Reverse osmosis has not been demonstrated on a full-scale basis for this purpose, but ion exchange has. Activated alumina and bone char have been successfully used, but the former is the method of choice for the removal of fluoride from drinking water.[124]

Selenium Removal Selenium is predominantly found in water as selenite and selenate. Selenite can be removed (40–80 percent) by coagulation with ferric sulfate, depending on the pH, coagulant dosage, and selenium concentration. Alum coagulation and lime softening are only partially effective, 15 to 20 percent and 35 to 45 percent, respectively. Selenite and selenate are best removed by ion exchange, reverse osmosis, and electrodialysis, but the effectiveness of these methods in removing selenium has not been demonstrated in practice.[125]

*Garden City Park Water District, Garden City, NY. Nitrates have also been reduced in Bridge-water, MA, since 1979 and in McFarland, CA, since 1983. ("Letters," *AWWA MainStream*, January 1986, p. 2.)

Radionuclide Removal Coagulation and sedimentation are very effective in removing radioactivity associated with turbidity and are fairly effective in removing dissolved radioactive materials—with certain exceptions. The type of radioactivity, the pH of the treatment process, and the age of the fission products in the water being treated must be considered. For these reasons, jar-test studies are advised before plant-scale operation is initiated. A comprehensive summary of the effectiveness of different chemical treatment methods with various radionuclides is given by Straub.[126] The effectiveness of rapid and slow sand filtration, lime–soda ash softening, ion exchange, and other treatment processes is also discussed.

Studies for military purposes show that radioactive materials present in water as undissolved turbidity can be removed by coagulation, hypochlorination, and diatomite filtration. Soluble radioisotopes are then removed by ion exchange using a cation exchange column followed by an anion exchange column operated in series. Hydrochloric acid is used for regenerating the cation resin and sodium carbonate the anion resin. The standard Army vapor compression distillation unit is also effective in removing radioactive material from water. Groundwater sources of water can generally be assumed to be free of fallout radioactive substances and should, if possible, be used in preference to a surface-water source[127] in emergency situations. However, radionuclides can travel great distances in groundwater.

Kosarek[128] reviewed the water treatment processes used to reduce dissolved radium contamination to an acceptable level (5 pCi/l or less) in water for industrial and municipal purposes. Processes for industrial water uses are selective membrane mineral extraction, reverse osmosis, barium sulfate co-precipitation, ion exchange, activated alumina, lime–soda ash softening, and sand filtration. Processes for municipal water uses are reverse osmosis, ion exchange, lime–soda ash softening, aeration, greensand filtration, and sand filtration. Aeration, greensand filtration, and sand filtration have low radium removal efficiency. Lime–soda ash has a 50 to 85 percent efficiency; the other remaining processes have an efficiency of 90 to 95 percent or better. A manganese dioxide–coated fiber filter can effectively remove radium from drinking water by adsorption.[129]

Packed tower aerators can remove more than 95 percent of the radon and conventional cascading tray aerators better than 75 percent.[130] Radon is effectively removed from well water by GAC adsorption. However, as in other processes, the spent carbon and other solid and liquid wastes collected present a disposal problem because of the radioactive materials retained in the waste. Possible waste disposal options for treatment plant solid and liquid wastes containing radium, if approved by the regulatory authority, include sanitary sewers, storm sewers, landfills, and land spreading. Conditions for disposal must be carefully controlled.[131]

Uranium can be removed from well water to a level as low as 1 μg/l using conventional anion exchange resins in the chloride form. Gamma radiation build-up in the system does not appear to be significant.[132] Treatment methods to remove uranium from surface waters and groundwaters include iron coagulation (80–85 percent), alum coagulation (90–95 percent), lime softening (99 percent), cation exchange (70–95 percent), anion exchange (99 percent), activated alumina (99 percent), granular activated carbon (90+ percent), and reverse osmosis (99 percent).[133]

The EPA is considering the setting of MCLs for certain radionuclides in water and a proposal of best available treatment (BAT) technologies to achieve the MCLs and MCLGs. Radon MCLs may fall between 300 and 4,000 pCi/l in water, equivalent to about 0.03 to 0.4 pCi/l in air. The BATs given are aeration and GAC. Radium-226 and Ra-228 MCLs may fall between 2 and 20 pCi/l each. The BATs given are cation exchange, lime softening, and reverse osmosis. Uranium MCLs may fall between 5 and 40 pCi/l. The BATs given are coagulation/filtration, reverse osmosis, anion exchange, and lime softening. Beta particle and photon emitter MCL concentrations may be equal to the risk posed by a 4-mrem effective dose equivalent. The BATs given for betas are reverse osmosis and ion exchange (mixed bed).[134]

Prevention and Removal of Organic Chemicals

As noted for inorganic chemicals, the control of organic chemicals in drinking water should start with a sanitary survey to identify the sources, types, and amounts of pollutants, followed by their phased elimination as indicated by the associated hazard. Included would be watershed use regulation and protection, watershed management to minimize turbidity and organic and inorganic runoff, vigorous compliance with the national and state water and air pollution elimination objectives, enforcement of established water and air classification standards, and complete effective drinking water treatment under competent supervision. It is obvious that selection of the cleanest available protected source of water supply, for the present and the future, would greatly minimize the problems associated not only with organic chemicals but also with inorganic, physical, and microbiological pollution. In any case, water treatment plants must be upgraded where needed to consistently produce a water meeting the national drinking water standards.

Trihalomethanes, Removal and Control The halogenated, chloro-organic compounds* include the trihalomethanes: trichloromethane (chloroform), bromodichloromethane, dibromochloromethane, and tribromomethane (bromoform). These chlorination byproducts are formed by the reaction of *free* chlorine with certain organic compounds in water. The major cause of trihalomethane (THM) formation in chlorinated drinking water is believed to be humic and fulvic substances (natural organic matter in soil, peat, other decay products of plants and animals, and runoff) and simple low-molecular-weight compounds not removed by conventional filtration treatment—all referred to as precursors. Treatment to remove turbidity should remove high-molecular-weight

*Halogenated organics are organic compounds that contain one or more halogens—fluorine, chlorine, bromide, iodine, and astatine.

compounds. Low-molecular-weight compounds are best reduced by GAC treatment. Chlorination of municipal wastewater also results in the formation of halo-organics, but their concentration is very low when combined chlorine is formed,[135] which is usually the case. However, chloramination produces other yet undefined chloro-organic compounds. The reaction is dependent on chlorine dose, pH, temperature, and contact time. The point of chlorination, to avoid precursors, is critical in drinking water treatment to minimize or prevent the formation of THMs. Total trihalomethane concentration in treated water has been found to be higher in the summer, after reservoir turnover, and lowest in the winter. It is also related to the presence of phytoplankton and correlates well with chlorine demand of untreated water, but not with organic carbon and chloroform extract.[136] The potential for THM formation in groundwater was found to be strongly correlated with total organic carbon (TOC) concentration, ammonia, iron, and manganese, but very few sources were found to exceed 100 μg/l.[137]

Prechlorination with long contact periods and sunlight increases the formation of THMs, as does increased chlorine dosage and the addition of chlorine prior to coagulation and settling. Preozonation is effective in oxidizing in part naturally present organic compounds, thereby reducing the potential for THM production after subsequent postchlorination. Alternative disinfectants are chloramines and chlorine dioxide as well as potassium permanganate and ultraviolet radiation if approved. Ozone and chloramine treatment is reported to produce only about 2 percent of the THMs produced by free chlorine.

Granular activated carbon has been found to be of limited effectiveness in removing precursor materials; GAC is effective for only a few weeks.[138] In contrast, GAC for taste and odor control needs regeneration every three to six years.[139] It is not efficient for the removal of THMs once formed. Treatment to remove suspended, colloidal, and dissolved materials by coagulation, flocculation, settling, and filtration should precede GAC treatment if used for taste and odor control. The same holds true for the removal of synthetic organic chemicals so as not to coat and reduce the adsorptive capacity of the carbon. Such treatment will also remove most THM precursors, as previously noted.

Recommended Standards for Water Works summarizes recommended practice in the "Policy Statement on Trihalomethane Removal and Control for Public Water Supplies."[140]

Trihalomethanes (THMs) are formed when free chlorine reacts with organic substances, most of which occur naturally. These organic substances (called *precursors*), are a complex and variable mixture of compounds. Formation of THMs is dependent on such factors as amount and type of chlorine used, temperature, concentration of precursors, pH, and contact time. Approaches for controlling THMs include:

1. Control of precursors at the source.
   a. Selective withdrawal from reservoirs—varying depths may contain lower concentrations of precursors at different times of the year.

   b. Plankton control—Algae and their oils, humic acid, and decay products have been shown to act as THM precursors.
   c. Alternative sources of water may be considered, where available.
2. Removal of THM precursors and control of THM formation.
   a. Moving the point of chlorination to minimize THM formation.
   b. Removal of precursors prior to chlorination by optimizing:
      (1) Coagulation/flocculation including sedimentation and filtration
      (2) Precipitative softening/filtration
      (3) Direct filtration
   c. Adding oxidizing agents such as potassium permanganate, ozone or chlorine dioxide to reduce or control THM formation potential.
   d. Adsorption by powdered activated carbon (PAC).
   e. Lowering the pH to inhibit the reaction rate of chlorine with precursor materials. Corrosion control may be necessary.
3. Removal of THM.
   a. Aeration—by air stripping towers.
   b. Adsorption by:
      (1) Granular Activated Carbon (GAC)
      (2) Synthetic Resins
4. Use of Alternative Disinfectants—Disinfectants that react less with THM precursors may be used as bacteriological quality of the finished water is maintained. Alternative disinfectants may be less effective than free chlorine, particularly with viruses and parasites. Alternative disinfectants, when used, must be capable of providing an adequate distribution system residual. Use of alternative disinfectants may also produce possible health effects and must be taken into consideration. The following alternative disinfectants may be used:
   a. Chlorine dioxide
   b. Chloramines
   c. Ozone

Using various combinations of THM controls and removal techniques may be more effective than a single control or a treatment method.

Any modifications to existing treatment process must be approved by the reviewing authority. Pilot plant studies are desirable.

The maximum contaminant level for total THMs in drinking water in the United States is 100 μg/l. The goal is 10 to 25 μg/l. The Canadian maximum acceptable level is 350 μg/l.[141] The WHO has set a guideline for chloroform only at 30 μg/l; several countries have set limits of 25 to 250 μg/l for the sum of four specific THMs.[142]

Synthetic Organic Chemicals and Their Removal The major sources of synthetic organic chemical pollution (also inorganic pollution in many places) are industrial wastewater discharges; air pollutants; municipal wastewater discharges; runoff from cultivated fields, spills, and waste storage sites; and leachate from sanitary landfills, industrial and commercial dump sites, ponds, pits, and lagoons. Illegal dumping and coal-tar-based pipe coating and linings may also contribute organics. Both surface waters and groundwaters may be affected. It cannot be emphasized enough that *control of all pollutants must start at the source*, including raw-material selection, chemical formulation, and manufacturing process control. Separation of floating oils and collection of low-solubility, high-density compounds in traps on building drains and improved plant housekeeping could reduce pollutant discharges and recover valuable products. Such actions would reduce the extent of needed plant upgrading, sophisticated wastewater treatment and control, burden on downstream aquatic life and water treatment plants, and hence risks to the consumer associated with the ingestion of often unknown hazardous or toxic chemicals.

Waters containing a mixture of organic chemicals and soluble metals are difficult to treat and require special study.

The more common water treatment methods considered to reduce the concentration of volatile organic chemicals (VOCs) and other synthetic organic chemicals (SOCs) in drinking water sources are aeration and adsorption through GAC. Other possible methods include ozonation, oxidation, osmosis, ion exchange, and ultrafiltration.[143] However, before a treatment method is selected and because of the many variables involved, characterization of the organic contaminants involved and bench-scale and pilot plant studies of aeration and GAC are generally required to be carried out with the actual water to be treated to determine the effectiveness of a process and the basis for design. This is also necessary to determine the GAC adsorption capacity before exhaustion and its reactivation cost. Organics have different adsorptive characteristics on GAC. It should also be noted that bench-scale tests using strongly basic anion exchange resins showed that most organics present in surface water can be removed.[144] Conventional coagulation, flocculation, sedimentation, and sand filtration treatment does not remove VOCs to any significant extent.

Aeration (air stripping) will remove many VOCs. Methods include diffused air in which air is forced up through the falling water spray, packed tower with forced or induced draft, waterfall, mechanical surface aerators, cascade aeration, tray aeration, and air-lift pump. The extent to which aeration is successful will depend on the concentration, temperature, solubility, and volatility of the compounds in the water. The rate of removal depends on the amount of air used, contact time, and temperature of the air and water. Removals of 95 to 99 percent have been reported. Very low efficiencies are obtained at freezing temperatures. Aeration is usually more effective for removing the lighter, more volatile SOCs such as found in groundwater. The GAC is more effective for removal of heavier SOCs found in surface water. Compounds reported to be removed by aeration include trichloroethylene, carbon tetrachloride, tetrachloroethylene, benzene, toluene, napthalene, biphenyl methyl bromide, bromoform, chloroform, dibromochloromethane, bromodichloromethane, methylene chloride, vinyl chloride, sodium fluoroacetate, dichloroethylene, dichloroethane, perchloroethylene, and others. The potential for air pollution and its control must be considered. Synthetic organic chemicals, referred to as refractory compounds, resist decomposition and removal. Corrosion control is usually required after aeration. Airborne contamination, including worm growth in the aerator, must be guarded against.

Granular activated carbon is considered the best available broad-spectrum adsorber of SOCs and appears to be indicated where nonvolatile organics are present. The carbon is similar in size to filter sand. Adsorption is a complex process. It is influenced by the surface area of the carbon grains, the material being adsorbed or concentrated (adsorbate), the pH and temperature of the water being treated, the mixture of compounds present, and the nature of the adsorbent—that is, the carbon grain structure, surface area, and pores. The smaller the grain size within the range of operational efficiency, the greater the rate of adsorption obtained.[145] Disposal of spent carbon may be a problem.

The EPA has designated packed-tower aeration and GAC filtration as the BAT for the removal of regulated VOCs. The exception is vinyl chloride, for which packed-tower aeration is the preferred technology. The GAC treatment is considered more costly than air stripping.[146]

Treatment consisting of coagulation, filtration, and powdered activated carbon is reported[147] to remove 85 to 98 percent endrin, 90 to 98 percent 2,4-D, and 30 to 99 percent lindane at dosages of 5 to 79 mg/l. Reverse osmosis is also effective in removing organics, including pesticides, with proper design and membrane selection. Highly colored waters and iron can coat GAC and interfere with its adsorption of VOCs.

WATER SYSTEM DESIGN PRINCIPLES*

Water Quantity

The quantity of water upon which to base the design of a water system should be determined in the preliminary planning stages. Future water demand is based on social, economic, and land-use factors, all of which can be expected to change with time. Population projections are a basic consideration. They are made using arithmetic, geometric, and demographic methods and with graphical comparisons with the growth of other comparable cities or towns of greater population.[148] Adjustments should be made for hospital and other institution populations, industries, fire protection, military reservations, transients, and tourists, as well as for leakage and unaccounted-for water, which may amount to 10 to 15 percent or more. Universal metering is necessary for an accounting.

*Refer to *Recommended Standards for Water Works*, Great Lakes–Upper Mississippi River Board of State Public Health and Environmental Managers, Health Research Inc., Health Education Services Division, Albany, NY, 1987. See also state and design publications.

Numerous studies have been made to determine the average per-capita water use for water system design. Health departments and other agencies have design guides, and standard texts give additional information. In any case, the characteristics of the community must be carefully studied and appropriate provisions made. See “Water Quantity and Quality” in Chapter 1, for average water uses.

Design Period

The design period (the period of use for which a structure is designed) is usually determined by the future difficulties to acquire land or replace a structure or pipeline, the cost of money, and the rate of growth of the community or facility served. In general, large dams and transmission mains are designed to function for 50 or more years; wells, filter plants, pumping stations, and distribution systems for 25 years; and water lines less than 12 inches in diameter for the full future life. When interest rates are high or temporary or short-term use is anticipated, a lesser design period would be in order. Fair et al.[149] suggest that the dividing line is in the vicinity of 3 percent per annum. Treatment of water, design, and operation control has been discussed earlier.[150]

Watershed Runoff and Reservoir Design

Certain basic information, in addition to future water demand, is needed upon which to base the design of water works structures. Long-term precipitation, stream flow data, and groundwater information are available from the U.S. Geological Survey and state sources, but these seldom apply to small watersheds. Precipitation data for specific areas are also available from the National Oceanic and Atmospheric Administration, local weather stations, airports, and water works. Unit hydrographs, maximum flows, minimum flows, mass diagrams,* characteristics of the watershed, precipitation, evaporation losses, percolation, and transpiration losses should be considered for design purposes and storage determinations when these are applicable.

Watershed runoff can be estimated in different ways. The rational method for determining the maximum rate of runoff is given by this formula:

$$Q = AIR$$

where

Q = runoff, ft^3/sec
A = area of the watershed, acres
I = imperviousness ratio, that is, the ratio of water that runs off the watershed to the amount precipitated on it
R = rate of rainfall on the watershed, in./hr

*A plot of the summation of accumulated stream inflow in million gallons vs. the summation of the mean daily demand in years (25 or more if stream flow data are available) to determine the required (available) storage to meet the daily demand.

The ratio I will vary from 0.01 to 0.20 for wooded areas; from 0.05 to 0.25 for farms, parks, lawns, and meadows depending on the surface slope and character of the subsoil; from 0.25 to 0.50 for residential semirural areas; from 0.05 to 0.70 for suburban areas; and from 0.70 to 0.95 for urban areas having paved streets, drives, and walks.[151] For maximum storms, use these equations:

$$R = 360/t + 30$$

for ordinary storms in eastern United States

$$R = 105/t + 15$$

for San Francisco

$$R = 7/\sqrt{t}$$

for New Orleans

$$R = 56/(t + 5)^{0.85}$$

and for St. Louis

$$R = 19/\sqrt{t}$$

where t is time (duration) of rainfall in minutes.[152]

Another formula for estimating the average annual runoff by Vermuelé may be written as

$$F = R - (11 + 0.29R)(0.035)T - 0.65)$$

where

F = annual runoff, in.
R = annual rainfall, in.
T = mean annual temperature, °F

This formula is reported to be particularly applicable to streams in northern New England and in rough mountainous districts along the Atlantic Coast.[153] For small water systems, the design should be based on the year of minimum rainfall or on about 60 percent of the average.

In any reservoir storage study, it is important to take into consideration the probable losses due to seepage, outflows, evaporation from water surfaces during the year, and loss in storage capacity due to sediment accumulation if the sediment cannot be released during high inflow. This becomes very significant in small systems when the water surfaces exceed 6 to 10 percent of the drainage area.[154] In the North Atlantic states, the annual evaporation from land surfaces averages about 40 percent, while that from water surfaces is about 60 percent of the annual rainfall.[155] The watershed water loss due to land evaporation and transpiration is significant and hence must be taken into consideration when determining precipitation minus losses.

The minimum stream flow in New England has been estimated to yield 0.2 to 0.4 cfs/mi^2 of tributary drainage and an annual yield of 750,000 gpd/mi^2 with storage of 200 to 250 × 10^6 gal/mi^2. New York City reservoirs located in upstate

New York have a dependable yield of about 1 mgd/mi^2 of drainage area. For design purposes, long-term rainfall and stream flows should be used and a mass diagram constructed. See Figure 2.9 later.

Groundwater runoff at the 70 percent point (where flow is equaled or exceeded 70 percent of the time) for the United States land area averaged a yield of 0.23 mgd/mi^2. In the Great Lakes Basin, 25 to 75 percent of the annual flow of streams is derived from groundwater seepage.[156]

The feasibility of implementing watershed rules and regulations should have a high priority in the selection of a water supply source. The management of land use and the control of wastewater discharges, including stormwater drainage on a watershed from urban, suburban, and rural areas, are necessary. Erosion and the input of sediment and organic and inorganic materials such as oils, pesticides, heavy metals, road salt, and other synthetic chemicals must be adequately minimized. Of course, these factors will affect the water quality and reservoir eutrophication, treatment required, and overall quality of the water source. Development of a reservoir should, if possible, include removal of rich organic topsoil from the site to conserve the resource and delay the development of anaerobic conditions.

Intakes and Screens

Conditions to be taken into consideration in design of intakes include high- and low-water stages; navigation or allied hazards; floods and storms; floating ice and debris; water velocities, surface and subsurface currents, channel flows, and stratification; location of sanitary, industrial, and storm sewer outlets; and prevailing wind direction.

Small communities cannot afford elaborate intake structures. A submerged intake crib, or one with several branches and upright tee fittings anchored in rock cribs 4 to 10 feet above the bottom, is relatively inexpensive. The inlet fittings should have a coarse strainer or screen with about 1-inch mesh. The total area of the inlets should be at least twice the area of the intake pipe and provide an inlet velocity less than 0.5 fps. Low-entrance velocities reduce ice troubles and are less likely to draw in fish or debris. Sheet ice over the intake structure also helps avoid anchor ice or frazil ice. If ice clogging of intakes is anticipated, provision should be made for an emergency intake or injecting steam, hot water, or compressed air at the intake. Backflushing is another alternative that may be incorporated in the design. Fine screens at intakes will become clogged; hence, they should not be used unless installed at accessible locations that will make regular cleaning simple. Duplicate stationary screens in the flow channel with 1/8- to 3/8-inch corrosion-resistant mesh can be purchased.

Some engineers have used slotted well screens in place of a submerged crib intake for small supplies. The screen is attached to the end of the intake conduit and mounted on a foundation to keep it off the bottom, and, if desired, crushed rock or gravel can be dumped over the screen. For example, a 10-foot section of a 24-inch-diameter screen with 0.25-inch openings is said to be able to handle

12 mgd at an influent velocity of less than 0.5 fps. Attachment to the foundation should be made in such a way that removal for inspection is possible.

In large installations, intakes with multiple-level inlet ports are provided in deep reservoirs, lakes, or streams to make possible depth selection of the best water when the water quality varies with the season of the year and weather conditions. Special bottom outlets should be provided in reservoirs to make possible the flushing out of sediment and accumulated organic matter during periods of high inflow.

For a river intake, the inlet is perpendicular to the flow. The intake structure is constructed with vertical slotted channels before and after the bar racks and traveling screens for the placement of stop planks if the structure needs to be dewatered. Bar racks, 1 × 6 inch vertical steel, spaced 2 to 6 inches apart, provided with a rake operated manually or mechanically, keep brush and large debris from entering. This may be followed by a continuous slow-moving screen traveling around two drums, one on the bottom of the intake and the other above the operating floor level. The screen is usually a heavy wire mesh with square openings 3/8 to 1 inches; it is cleaned by means of water jets inside that spray water through the screen, washing off debris into a wastewater trough. In cold-weather areas, heating devices such as steam jets are needed to prevent icing and clogging of the racks and screens. Intake velocities should be maintained at less than 5 fps.

Pumping

When water must be pumped from the source or for transmission, electrically operated pumps (at least two) should have gasoline or diesel standby units having at least 50 percent of the required capacity. If standby units provide power for pumps supplying chlorinators and similar units, the full 100 percent capacity must be provided where gravity flow of water will continue during the power failure.

The distribution of water usually involves the construction of a pumping station, unless one is fortunate enough to have a satisfactory source of water at an elevation to provide a sufficient flow and water pressure at the point of use by gravity. The size pump selected is based on whether hydropneumatic storage (steel pressure tank for a small system), ground level, or elevated storage is to be used; the available storage provided; the yield of the water source; the water usage; and the demand. Actual meter readings should be used, if available, with consideration being given to future plans, periods of low or no usage, and maximum and peak water demands. Metering can reduce water use by 25 percent or more. Average water consumption figures must be carefully interpreted and considered with required fire flows. If the water system is to also provide fire protection, then elevated storage is practically essential, unless ground-level storage with adequate pumps is available.

The capacity of the pump required for a domestic water system with elevated storage is determined by the daily water consumption and volume of the storage tank. Of course, where the topography is suitable, the storage tank can be located on high ground, although the hydraulic gradient necessary to meet the highest water demand may actually govern. The pump should be of such capacity as to deliver the average daily water demand to the storage tank in 6 to 12 hours. In very small installations, the pump chosen may have a capacity to pump in 2 hours all the water used in one day. This may be desirable when the size of the centrifugal pump is increased to 60 gpm or more and the size of the electric motor to 5 to 10 hp or more, since the efficiencies of these units then approach a maximum. On the other hand, larger transmission lines, if not provided, would be required in most cases to accommodate the larger flow, which would involve increased cost. Due consideration must also be given to the increased electrical demand and the effects this has. A careful engineering analysis should be made.

Pumping stations should be at least 3 feet above the 100-year flood level or the highest known level, whichever is higher. They should be secured and weather protected.

Distribution Storage Requirements

Water storage requirements should take into consideration the peak daily water use, the maximum-day demand plus the required fire flow, the capacity of the normal and standby pumping equipment, the availability and capacity of auxiliary power, the probable duration of power failure, and the promptness with which repairs can be made. Additional considerations include land use, topography, pressure needs, distribution system capacity, special demands, and the increased cost of electric power and pumps to meet peak demands.

Water storage is necessary to help meet peak demands, fire requirements, and industrial needs; to maintain relatively uniform water pressures; to eliminate the necessity for continuous pumping; to make pumping possible when the electric rate is low; and to use the most economical pipe sizes. Surges in water pressure due to water hammer are also dissipated. Other things being equal, a large-diameter shallow tank is preferable to a deep tank of the same capacity. It is less expensive to construct, and water pressure fluctuations on the distribution system are less. The cost of storage compared to the decreased cost of pumping, the increased fire protection and possibly lowered fire insurance rate, the greater reliability of water supply, and the decreased probability of negative pressures in the distribution system will be additional factors in making a decision.

In general, it is recommended that water storage equal not less than one-half the total daily consumption, with at least one-half the storage in elevated tanks. A preferred minimum storage capacity would be a two-day average use plus fire flow, or the maximum-day usage plus fire requirements less the daily capacity of the water plant and system for the fire-flow period.

Hudson[157] suggests the provision of two tank outlets, one to withdraw the top third of tank water for general purposes and a second outlet at the bottom of the tank to withdraw the remaining two-thirds of tank water if needed to supply building sprinkling systems in developed areas with high-rise apartments, industries, shopping centers, office complexes, and the like. In small communities, real estate subdivisions, institutions, camps, and resorts, elevated storage should be equal to at least a full day's requirements during hot and dry months when lawn sprinkling is heavy. Two or three days storage is preferred. The amount of water required during peak hours of the day may equal 15 to 25 percent of the total maximum daily consumption. This amount in elevated storage will meet peak demands, but not fire requirements. Some engineers provide storage equal to 20 to 40 gal/capita, or 25 to 50 percent of the total average daily water consumption. A more precise method for computing requirements for elevated storage is to construct a mass diagram. Two examples are shown in Figures 2.8 and 2.9. Fire requirements should be taken into consideration.[158]

It is good practice to locate elevated tanks near the area of greatest demand for water and on the side of town opposite from where the main enters. Thus, peak demands are satisfied with the least pressure loss and smallest main sizes. All distribution reservoirs should be covered; provided with an overflow that will not undermine the footing, foundation, or adjacent structures; and provided with a drain, water-level gauge, access manhole with overlapping cover, ladder, and screened air vent.

Water storage tanks are constructed of concrete, steel, or wood. Tanks may be constructed above or partly below ground, except that under all circumstances the manhole covers, vents, and overflows must be well above the normal ground level and the bottom of the tank must be above groundwater or floodwater. Good drainage should be provided around the tank. Tanks located partly below ground must be at a higher level than any sewers or sewage disposal systems and not closer than 50 feet. Vents and overflows should be screened and the tanks covered to keep out dust, rain, insects, small animals, and birds. A cover will also prevent the entrance of sunlight, which tends to warm the water and encourage the growth of algae. Manhole covers should be locked and overlap at least 2 inch over a 2- to 6-inch lip around the manhole. Partly below-ground storage is usually less costly and aesthetically more acceptable than elevated storage.*

Properly constructed reinforced concrete tanks ordinarily do not require waterproofing. If tanks are built of brick or stone masonry, they should be carefully constructed by experienced craftsmen and only hard, dense material laid with full Portland cement mortar joints should be used. Two 0.5-inch coats of 1:3 Portland cement mortar on the inside, with the second coat carefully troweled, should make such tanks watertight. A newly constructed concrete or masonry tank should be allowed to cure for about one month, during which time it should be wetted down frequently. The free lime in the cement can be neutralized by washing the interior with a weak acid, such as a 10 percent muriatic acid solution, or with a solution made up of 4 pounds of zinc sulfate per gallon of water and then flushed clean.

Wooden elevated storage tanks are constructed of cypress, fir, long-leaf yellow pine, or redwood. They are relatively inexpensive and easily assembled, and need

*For small concrete reservoir construction details, see *Manual of Individual Water Supply Systems*, U.S. EPA, Washington, DC, 1973, pp. 127–128.

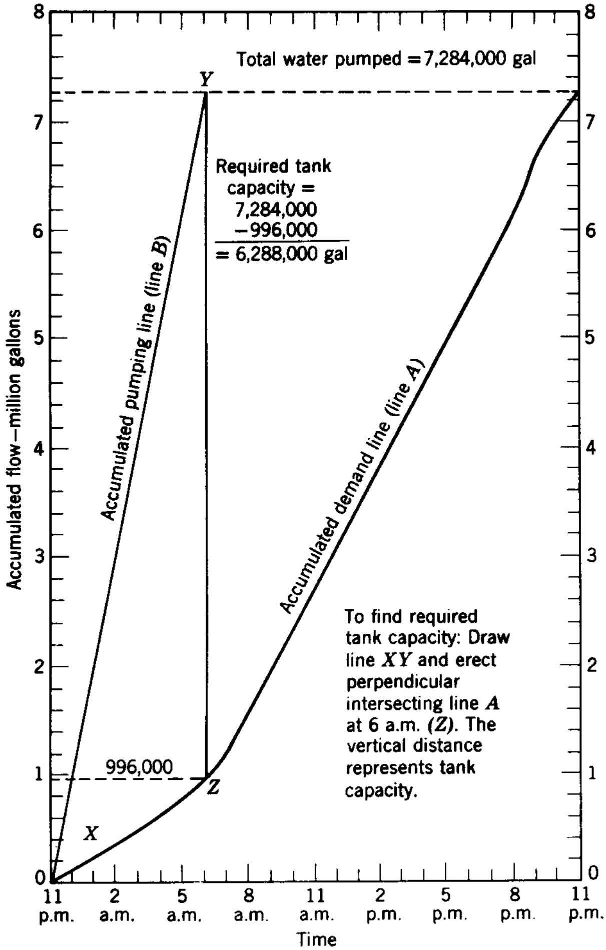


FIGURE 2.8 Mass diagram for determining capacity of tank when pumping 7 hours, from 11 p.m. to 6 a.m. (*Source*: J. E. Kiker, Jr., "Design Criteria for Water Distribution Storage," *Public Works* (March 1964): 102–104. This illustration originally appeared in the March 1964 issue of *Public Works*®, published by Public Works Journal Corporation, 200 South Broad Street, Ridgewood, NJ 07450. © 2002 Public Works Journal Corporation. All rights reserved.)

not be painted or given special treatment; their normal life is 15 to 20 years. Wooden tanks are available with capacities up to 500,000 gallons. The larger steel tanks start at 5,000 to 25,000 gallons; they require maintenance in order to prolong their life. Reinforced prestressed concrete tanks are also constructed. Underground fiberglass reinforced plastic tanks are also available up to a capacity of 25,000 to 50,000 gallons. Tanks having exterior lead-based paint needing repair present special problems regarding removal and prevention of air pollution.

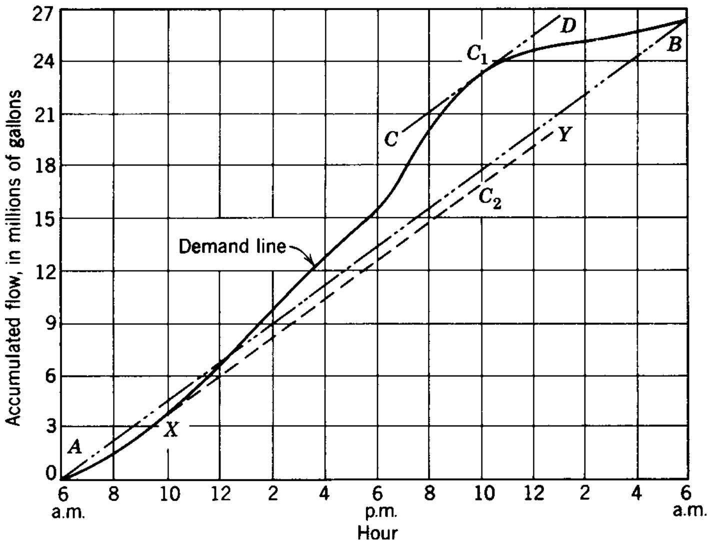


FIGURE 2.9 Mass diagram of storage requirements. The cumulative demand curve is plotted from records or estimates and the average demand line, ***AB***, drawn between its extremities. Lines ***CD*** and ***XY*** are drawn parallel to line ***AB*** and tangent to the curve at points of greatest divergence from the average. At C_1 (the point of maximum divergence), a line is extended down the coordinate to line ***XY***. This line, C_1C_2, represents the required peak-hour storage: in this case, it scales to 6.44×10^6 gal. (*Source*: G. G. Schmid, "Peak Demand Storage," *J. Am. Water Works Assoc*. (April 1956). Copyright 1956 by the American Water Works Association. Reprinted with permission.)

Steel standpipes, reservoirs, and elevated tanks are made in a variety of sizes and shapes. As normally used, a standpipe is located at some high point to make available most of its contents by gravity flow and at adequate pressure; a reservoir provides mainly storage. A standpipe has a height greater than its diameter; a reservoir has a diameter greater than its height. Both are covered, except when a reservoir is a natural body of water. The altitude of elevated tanks, standpipes, and reservoirs is usually determined, dependent on topography, to meet special needs and requirements. Elevated tanks rising more than 150 feet above the ground or located within 15,000 feet of a landing area and in a 50-mile-wide path of civil airways, must meet the requirements of the Civil Aeronautics Administration.

Peak Demand Estimates

The maximum hourly or peak-demand flow upon which to base the design of a water distribution system should be determined for each situation. A small residential community, for example, would have characteristics different from a new realty subdivision, central school, or children's camp. Therefore, the design flow to determine distribution system capacity should reflect the pattern of living or operation, probable water usage, and demand of that particular type of establishment or community. At the same time, consideration should be given to the location of existing and future institutions, industrial areas, suburban or fringe areas, highways, shopping centers, schools, subdivisions, and direction of growth. In this connection, reference to the city, town, or regional comprehensive or master plan, where available, can be very helpful. Larger cities generally have a higher per-capita water consumption than smaller cities, but smaller communities have higher percentage peak-demand flow than larger communities.

The maximum hourly domestic water consumption for cities with a population above 50,000 will vary from about 200 to 700 percent of the average-day annual hourly water consumption; the maximum hourly water demand in smaller cities will probably vary from 300 to 1,000 percent of the average-day annual hourly water consumption. The daily variation is reported to be 150 to 250 percent, and the monthly variation 120 to 150 percent of the average annual daily demand in small cities.[159] A survey of 647 utilities serving populations of 10,000 or more in 1970 found the mean maximum daily demand to be 1.78 times the average day, with a range of 1.00 to 5.22. Studies in England showed that the peak flow is about 10 times the average flow in cities with a population of 5,000.[160] It can be said that the smaller and newer the community, the greater the probable variation in water consumption from the average will be.

Various bases have been used to estimate the probable peak demand at real estate subdivisions, camps, apartment buildings, and other places. One assumption for small water plants serving residential communities is to say that, for all practical purposes, almost all water for domestic purposes is used in 12 hours.[161] The maximum hourly rate is taken as twice the maximum daily hourly rate, and the maximum daily hourly rate is 1.5 times the average maximum hourly rate. If the average maximum monthly flow is 1.5 times the average monthly annual flow, then the maximum hour's consumption rate is 9 times the average daily hourly flow rate.

Another basis used on Long Island is maximum daily flow rate = 4 times average daily flow rate; maximum 6-hour rate = 8 times average daily flow rate; and maximum 1-hour rate = 9.5 times average daily flow rate.[162]

A study of small water supply systems in Illinois seems to indicate that the maximum hourly demand rate is 6 times the average daily hourly consumption.[163]

An analysis by Wolff and Loos[164] showed that peak water demands varied from 500 to 600 percent over the average day for older suburban neighborhoods with small lots; to 900 percent for neighborhoods with 0.25- to 0.5-acre lots; and to 1,500 percent for new and old neighborhoods with 0.33- to 3-acre lots. Kuranz, Taylor, and many others have also studied the variations in residential water use.[165]

The results of a composite study of the probable maximum momentary demand are shown in Figure 2.10. It is cautioned, however, that for other than average conditions, the required supply should be supplemented as might be appropriate for fire flows, industries, and other special demands.

Peak flows have also been studied at camps, schools, apartment buildings, highway rest areas, and other places.

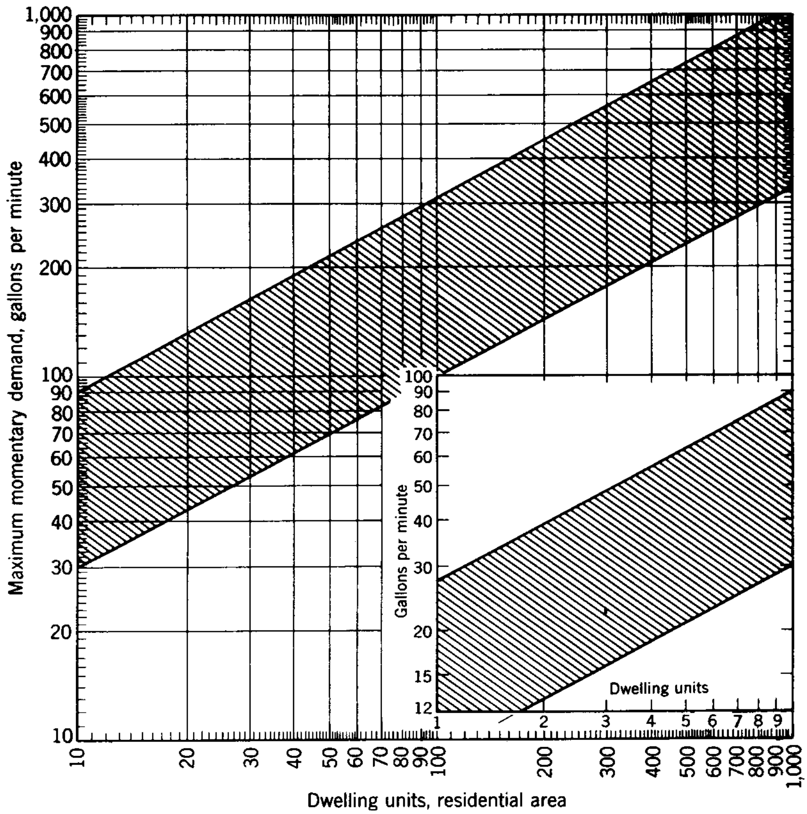


FIGURE 2.10 Probable maximum momentary water demand.

The design of water requirements at toll road and superhighway service areas introduces special considerations that are typical for the installation. It is generally assumed that the sewage flow equals the water flow. In one study of national turnpike and highway restaurant experience, the extreme peak flow was estimated at 1,890 gpd per counter seat and 810 gpd per table seat; the peak day was taken as 630 gpd per counter seat and 270 gpd per table seat.[166] In another study of the same problem, the flow was estimated at 350 gpd per counter seat plus 150 gpd per table seat.[167] The flow was 200 percent of the daily average at noon and 160 percent of the daily average at 6 p.m. It was concluded that 10 percent of the cars passing a service area will enter and will require 15 to 20 gallons per person. A performance study after 1 year of operation of the Kansas Turnpike service areas showed that 20 percent of cars passing service areas will enter; there will be 1.5 restaurant customers per car; average water usage will be 10 gallons per restaurant customer, of which 10 percent is in connection with gasoline service; and plant flows may increase four to five times in a matter of seconds.[168]

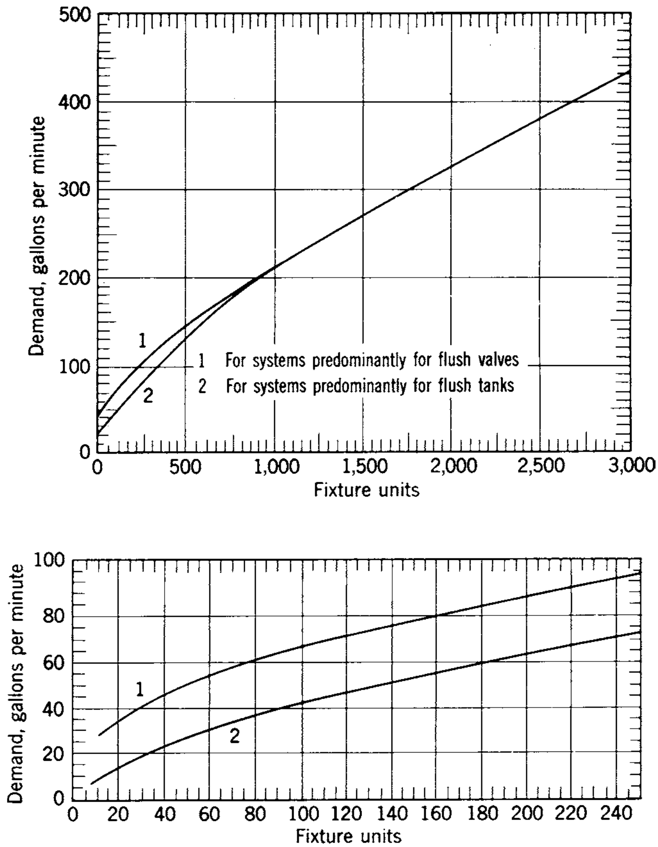


FIGURE 2.11 Estimate curves for demand load. (Source: R. B. Hunter, "Water-Distributing Systems for Buildings," Report BMS 79, National Bureau of Standards for Building Materials and Structures, November 1941.)

Peak flows for apartment-type buildings can be estimated using the curves developed by Hunter.[169] Figure 2.11 and Tables 2.8 and 2.9 can be used in applying this method. Additions should be made for continuous flows. This method may be used for the design of small water systems, but the peak flows determined will be somewhat high.

At schools, peak flows would occur at recess and lunch periods and after gym classes. At motels, peak flows would occur between 7 and 9 a.m. and between 5 and 7 p.m.

It must be emphasized that actual meter readings from a similar type establishment or community should be used whenever possible in preference to an estimate. Time spent to obtain this information is a good investment, as each installation has different characteristics. Hence, the estimates and procedures mentioned here should be used as a guide to supplement specific studies and aid in the application of informed engineering judgment. Peak demands and

TABLE 2.8 Demand Weight of Fixtures in Fixture Units[a]

Fixture or Group[b]	Occupancy	Type of Supply Control	Weight in Fixture Units[c]
Water closet	Public	Flush valve	10
		Flush tank	5
Pedestal urinal	Public	Flush valve	10
Stall or wall urinal	Public	Flush valve	5
		Flush tank	3
Lavatory	Public	Faucet	2
Bathtub	Public	Faucet	4
Shower head	Public	Mixing valve	4
Service sink	Office, etc.	Faucet	3
Kitchen sink	Hotel or restaurant	Faucet	4
Water closet	Private	Flush valve	6
		Flush tank	3
Lavatory	Private	Faucet	1
Bathtub	Private	Faucet	2
Shower head	Private	Mixing valve	2
Bathroom group	Private	Flush valve for closet	8
		Flush tank for closet	6
Separate shower	Private	Mixing valve	2
Kitchen sink	Private	Faucet	2
Laundry trays (1–3)	Private	Faucet	3
Combination fixture	Private	Faucet	3

[a]For supply outlets likely to impose continuous demands, estimate continuous supply separately and add to total for fixtures.
[b]For fixtures not listed, weights may be assumed by comparing the fixture to a listed one using water in similar quantities and at similar rates.
[c]The given weights are for total demand. For fixtures with both hot and cold water supplies, the weights for maximum separate demands may be taken as three-fourths the listed demand for supply.
Source: R. B. Hunter, *Water-Distributing System for Buildings*, Report No. BMS 79, National Bureau of Standards Building Materials and Structures, November 1941.

per-capita daily water use can be expected to decline as water-saving plumbing fixtures and devices come into general use.

Distribution System Design Standards

As far as possible, distribution system design should follow usual good waterworks practice and provide for fire protection.[170] Mains should be designed on the basis of velocities of 4 to 6 fps with maximums of 10 to 20 fps, the rates of water consumption (maximum daily demand), and fire demand, plus a residual pressure of not less than 35 psi or more than 100 psi using the Hazen and Williams coefficient $C = 100$, with a normal working pressure of about 60 psi.

Air release valves or hydrants are provided as necessary, where air can accumulate in the transmission lines, and blowoffs are provided at low drain points.

TABLE 2.9 Flow Rate and Required Pressure

Fixture	Flow Pressure[a] (psi)	Flow Rate (gpm)
Ordinary basin faucet	8	3.0
Self-closing basin faucet	12	2.5
Sink faucet		
3/8 in.	10	4.5
1/2 in.	5	4.5
Bathtub faucet	5	6.0
Laundry-tub cock, 1/2 in.	5	5.0
Shower	12	5.0
Ball cock for closet	15	3.0
Flush valve for closet	10–20	15–40[b]
Flush valve for urinal	15	15.0
Garden hose, 50 ft and sill cock	30	5.0
Dishwashing machine, commercial	15–30	6–9

[a]Flow pressure is the pressure in the pipe at the entrance to the particular fixture considered. Some codes permit 8 psi for faucet fixtures and lesser flow rates.
[b]Wide range due to variation in design and type of flush-valve closets.

Source: Report of the Coordinating Committee for a National Plumbing Code, U.S. Department of Commerce, Washington, DC, 1951.

These valves must not discharge to below-ground pits unless provided with a gravity drain to the surface above flood level. As far as possible, dead ends should be eliminated or a blowoff provided, and mains should be tied together at least every 600 feet. Lines less than 6 inches in diameter should generally not be considered, except for the smallest system, unless they parallel secondary mains on other streets. In new construction, 8-inch pipe should be used. In urban areas 12-inch or larger mains should be used on principal streets and for all long lines that are not connected to other mains at intervals close enough for proper mutual support. Although the design should aim to provide a pressure of not less than 35 psi in the distribution system during peak-flow periods, 20 psi minimum may be acceptable. A minimum pressure of 60 to 80 psi is desired in business districts, although 50 psi may be adequate in small villages with one- and two-story buildings. Thrust blocks and joint restraints must be provided on mains where indicated, such as at tees, bends, plugs, and hydrants.

Valves are spaced not more than 500 feet apart in commercial districts and 800 feet apart in other districts and at street intersections. A valve book, at least in triplicate, should show permanent ties for all valves, number of turns to open completely, left- or right-hand turn to open, manufacturer, and dates valves operated. A valve should be provided between each hydrant and street main.

Hydrants should be provided at each street intersection and spacing may range generally from 350 to 600 feet, depending on the area served for fire protection and as recommended by the state Insurance Services Office. The connection to the street main should be not less than 6 inches in diameter. Operating nuts and direction of operation should be standard on all hydrants and should conform with AWWA standards. Hydrants should be set so that they are easily accessible to fire department pumpers; they should not be set in depressions, in cutouts, or on embankments high above the street. Pumper outlets should face directly toward the street. With respect to nearby trees, poles, and fences, there should be adequate clearance for connection of hose lines. Hydrants should be painted a distinguishing color so that they can be quickly spotted at night. Hydrant drains shall not be connected to or located within 10 feet of sanitary sewers or storm drains.

Main breaks occur longitudinally and transversely. Age is not a factor. Breaks are associated with sewer and other construction, usually starting with a leaking joint. The leak undermines the pipe, making a pipe break likely due to beam action. Sometimes poor quality control in pipe manufacture contributes to the problem. Good pipe installation practice, including bedding and joint testing, followed by periodic leak surveys, will minimize main leaks and breaks. Unavoidable leakage should not exceed 70 gallons per 24 hours per mile of pipe per inch of pipe diameter. A loss of 1,000 to 3,000 gallons per mile of main is considered reasonable.

Water lines are laid below frost, separated from sewers a minimum horizontal distance of 10 feet and a vertical distance of 18 inches. Water lines may be laid closer horizontally in a separate trench or on an undisturbed shelf with the bottom at least 18 inches above the top of the sewer line under conditions acceptable to the regulatory agency. It must be recognized that this type of construction is more expensive and requires careful supervision during construction. Mains buried 5 feet are normally protected against freezing and external loads.

The selection of pipe sizes is determined by the required flow of water that will not produce excessive friction loss. Transmission mains for small water systems more than 3 to 4 miles long should not be less than 10 to 12 inches in diameter. Design velocity is kept under 5 fps and head loss under 3 ft/1,000 ft. On the one hand, if the water system for a small community is designed for fire flows, the required flow for domestic use will not cause significant head loss. On the other hand, where a water system is designed for domestic supply only, the distribution system pipe sizes selected should not cause excessive loss of head. Velocities may be 1.5 to 5.5 fps. In any case, a special allowance is usually necessary to meet water demands for fire, industrial, and other special purposes.

Design velocities as high as 10 to 15 fps are not unusual, particularly in short runs of pipe. The design of water distribution systems can become very involved and is best handled by a competent sanitary engineer. When a water system is carefully laid out, without dead ends, so as to divide the flow through several pipes, the head loss is greatly reduced. The friction loss in a pipe connected at both ends is about one-quarter the friction loss in the same pipe with a dead end. The friction loss in a pipe from which water is being drawn off uniformly along its length is about one-third the total head loss. Also, for example, an 8-inch line will carry 2.1 times as much water as a 6-inch line for the same loss of head.*

Where possible, a water system that provides adequate fire protection is highly recommended. This is discussed further below. The advantages of fire protection should at the very least be compared with the additional cost of increased pipe size and plant capacity, water storage, and the possible reduced fire insurance rate. If, for example, the cost of 8-inch pipe is only 20 percent more per foot than 6-inch pipe, the argument for the larger diameter pipe, where needed, is very persuasive, since the cost of the trench would be the same. In any case, only pipes and fittings that have a permanent-type lining or inner protective surface should be used.

Small Distribution Systems

In some communities where no fire protection is provided, small-diameter pipe may be used. In such cases, a 2-inch line should be no more than 300 feet long, a 3-inch line no more than 600 feet, a 4-inch line no more than 1,200 feet, and a 6-inch line no more than 2,400 feet. If lines are connected at both ends, 2- or 3-inch lines should be no longer than 600 feet; 4-inch lines are not more than 2,000 feet.

Transmission lines for rural areas have been designed for peak momentary demands of 2 to 3 gpm per dwelling unit and for as low as 0.5 gpm per dwelling unit with storage provided on the distribution system to meet peak demands. Adjustments are needed for constant or special demands and for population size. For example, Figure 2.10 shows a probable maximum demand of 3 to 9 gpm per dwelling unit for 10 dwelling units, 1 to 3.2 gpm per dwelling unit for 100 dwelling units, and 0.33 to 1.1 gpm per dwelling unit for 1,000 dwelling units.

A general rule of thumb is that a 6-inch main can be extended only 500 feet if the average amount of water of 1000 gpm is to be supplied for fire protection, or about 2,000 feet if the minimum amount of 500 gpm is to be supplied.

The minimum pipe sizes and rule-of-thumb guides are not meant to substitute for distribution system hydraulic analysis but are intended for checking or rough approximation. Use of the equivalent pipe method, the Hardy Cross method, or one of its modifications should be adequate for the small distribution system. Computer analysis methods are used for large-distribution-system analysis.[171]

Fire Protection

Many factors enter into the classification of municipalities (cities, towns, villages, and other municipal entities) for fire insurance rate-setting purposes.

*A 6-in. line carries 2.9 times as much as a 4-in. line; an 8-in. line carries 6.2 times as much as a 4-in. line; a 12-in. line carries 18 times as much as a 4-in. line, 6.2 times as much as a 6-in. line, and 2.9 times as much as an 8-in. line. The discharges vary as the 2.63 power of the pipe diameters being compared, based on the Hazen-Williams formula. See flow charts, nomograms, or Table 2.14.

The Insurance Services Office, their state representatives, and other authorized offices use the *Fire Suppression Rating Schedule*[172] to classify municipalities with reference to their fire defenses. This is one of several elements in the development of property fire insurance rates.

The municipal survey and grading work formerly performed by the National Board of Fire Underwriters, then by the American Insurance Association, as well as that formerly performed by authorized insurance-rating organizations are continued under the Insurance Services Office. Credit is given for the facilities provided to satisfy the needed fire flows of the buildings in the municipality.[173] (Since this discussion is intended only for familiarization purposes, the reader interested in the details of the grading system is referred to the references cited in this section for further information.)

An adequate water system provides sufficient water to meet peak demands for domestic, commercial, and industrial purposes as well as for firefighting. For fire suppression rating, the water supply has a weight of 40 percent; the fire department, 50 percent; and receiving and handling fire alarms, 10 percent. The water system rating considers the adequacy of the supply works, mains and hydrant spacing, size and type of hydrants, and inspection and condition of hydrants.

To be recognized for fire protection, a water system must be capable of delivering at least 250 gpm at 20 psi at a fire location for at least 2 hours with consumption at the maximum daily rate. The method of determining the needed fire flow for a building is given in the *Fire Suppression Rating Schedule*.[174] The needed fire flow will vary with the class of construction, its combustibility class, openings and distance between buildings, and other factors. Table 2.10 shows the needed duration for fire flow. The needed fire flow for a community of one- and two-family dwellings varies from 500 gpm for buildings over 100 feet apart, to 1,500 gpm where buildings are less than 11 feet apart.[175] There should be sufficient hydrants within 1,000 feet of a building to supply its needed fire flow. Each hydrant with a pumper outlet and within 300 feet of a building is credited at 1,000 gpm; 301 to 600 feet, 670 gpm; and 601 to 1,000 feet, 250 gpm.

Where possible, water systems should be designed to also provide adequate fire protection, and old systems should be upgraded to meet the requirements. This will also help ensure the most favorable grading, classification, and fire insurance rates. Improvements in a water system resulting in a better fire protection grade and classification would generally be reflected in a reduced fire

TABLE 2.10 Needed Duration for Fire Flow

Needed Fire Flow (gpm)	Needed Duration (hr)
≤2,500	2
3,000	3
3,500	3
≥4,000	4

Source: Fire Suppression Rating Schedule, Insurance Services Office, New York, 1980.

insurance rate on specifically rated commercial properties, although other factors based on individual site evaluation may govern. However, this is not always the case in "class-rated properties" such as dwellings, apartment houses, and motels. It generally is not possible to justify the cost to improve the fire protection class *solely* by the resulting savings in insurance premiums.[176] Nevertheless, the greater safety to life and property makes the value of improved fire protection more persuasive.

It is prudent for the design engineer to follow the state Insurance Services Office requirements.[177]

One must be alert to ensure that fire protection programs do not include pumping from polluted or unapproved sources into a public or private water system main through hydrants or blowoff valves. Nor should bypasses be constructed around filter plants or provision made for "emergency" raw-water connections to supply water in case of fire. In *extreme emergencies*, the health department might permit a temporary connection under certain conditions, but in any case, the water purveyor must immediately notify every consumer not to drink the water or use it in food or drink preparation unless first boiled or disinfected as noted at the end of this chapter.

Cross-Connection Control

There have been numerous instances of illness caused by cross-connections.[178] A discussion of water system design would not be complete without reference to cross-connection control and backflow prevention. The goal is to have no connection between a water of drinking water quality (potable) and an unsafe or questionable (nonpotable) water system or between a potable system and any plumbing, fixture, or device whereby nonpotable water might flow into the potable water system.

A *cross-connection* is any physical connection between a potable water system and a nonpotable water supply; any waste pipe, soil pipe, sewer, drain; or any direct or indirect connection between a plumbing fixture or device whereby polluted water or contaminated fluids including gases or substances might enter and flow back into the potable water system. Backflow of nonpotable water and other fluids into the potable water system may occur by backpressure or backsiphonage. In *backpressure* situations, the pressure in the nonpotable water system exceeds that in the potable water system. In *backsiphonage*, the pressure in the potable water system becomes less than that in the nonpotable water system due to a vacuum or reduced pressure developing in the potable water system.

Negative or reduced pressure in a water distribution or plumbing system may occur when a system is shut off or drained for repairs, when heavy demands are made on certain portions of the system causing water to be drawn from the higher parts of the system, or when the pumping rate of pumps installed on the system (or of fire pumps or fire pumpers at hydrants) exceeds the capacity of the supply line to the pump. Backpressure may occur when the pressure in a nonpotable water system exceeds that in the potable water system, such as when

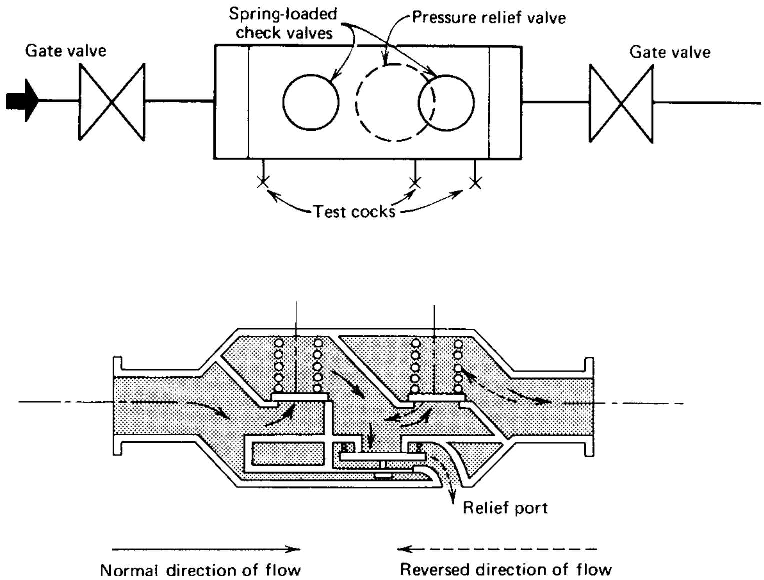


FIGURE 2.12 Reduced pressure zone backflow preventer—principle of operation. Malfunctioning of check or pressure-relief valve is indicated by discharge of water from relief port. Preferred for hazardous facility containment. (*Source: Cross-Connection Control*, EPA-430/9-73-002, U.S. EPA, Water Supply Division (WSD), Washington, DC, 1976, p. 25.)

a fire pumper at a dock or marina pumps nonpotable water into a hydrant or when a boiler chemical feed pump is directly connected to the potable water system.

The more common acceptable methods or devices to prevent backflow are air gap separation, backpressure units as shown in Figures 2.12 and 2.13, and vacuum breakers.[179] The non-pressure-type vacuum breaker is always installed on the atmospheric side of a valve and is only intermittently under pressure, such as when a flushometer valve is activated. The pressure-type vacuum breaker is installed on a pressurized system and will function only when a vacuum occurs. It is spring loaded to overcome sticking and is used only where authorized. The vacuum breaker is not designed to provide protection against backflow resulting from backpressure and should not be installed where backpressure may occur.

The barometric or atmospheric loop that extends 34 to 35 feet above the highest outlet is not acceptable as a backflow preventer because backpressure due to water, air, steam, hot water, or other fluid can negate its purpose. The swing joint, four-way plug valve, three-way two-port valve, removable pipe section, and similar devices are not reliable because nonpotable water can enter the potable water system at the time they are in use.[180]

An elevated or ground-level tank providing an air gap, the reduced pressure zone backflow preventer, and the double-check-valve assembly are generally used on public water system service connections to prevent backflow into the

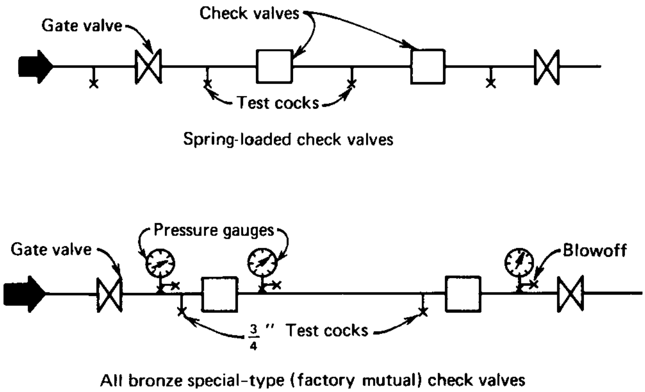


FIGURE 2.13 Double check valve–double gate valve assembly. For aesthetically objectionable facility containment.

distribution system. The vacuum breaker is usually used on plumbing fixtures and equipment.

An approved backflow preventer or air break should be required on the water service line to every building or structure using or handling any hazardous substance that might conceivably enter the potable water system. In addition, building and plumbing codes should prohibit cross-connections within buildings and premises and require approved-type backflow preventers on all plumbing, fixtures, and devices that might cause or permit backflow. It is the responsibility of the designing engineer and architect, the building and plumbing inspector, the waterworks official, and the health department to prevent and prohibit possibilities of pollution of public and private water systems.

There are two major aspects to a cross-connection control program. One is protection of the water distribution system to prevent its pollution. The other is protection of the internal plumbing system used for drinking and culinary purposes to prevent its pollution.

The water purveyor has the responsibility to provide its customers with water meeting drinking water standards. This requires control over unauthorized use of hydrants, blowoffs, and main connections or extensions. It also means requirement of a backflow prevention device at the service connection (containment) of all premises where the operations or functions on the premises involve toxic or objectionable chemical or biological liquid substances or use of a nonpotable water supply, which may endanger the safety of the distribution system water supply through backflow. However, although these precautions may protect the water system, it is also necessary to protect the consumers on the premises using the water for drinking and culinary purposes. This responsibility is usually shared by the water purveyor, the building and plumbing department, the health department, and the owner of the structure, depending on state laws and local ordinances. The AWWA Policy Statement on Cross-Connection states, in part, that the "water purveyor must take reasonable precaution to protect the community distribution system from the hazards originating on the premises of its customers that may degrade the water in the community distribution system."[181] The water purveyor has been held legally responsible for the delivery of safe water to the consumer and the Safe Drinking Water Act bases compliance with federal standards on the quality of water coming out of the consumer's tap. Under these circumstances, a cross-connection control program is needed in every community having a public water system to define and establish responsibility and ensure proper installation and adequate inspection, maintenance, testing, and enforcement.

A comprehensive cross-connection control program should include the following six components:[182]

1. An implementation ordinance that provides the legal basis for the development and complete operation of the program
2. The adoption of a list of devices acceptable for specific types of cross-connection control
3. The training and certification of qualified personnel to test and ensure devices are maintained
4. The establishment of a suitable set of records covering all devices
5. Public education seminars wherein supervisory, administrative, political, and operating personnel, as well as architects, consulting engineers, and building officials, are briefed and brought up-to-date on the reason for the program as well as on new equipment in the field
6. An inspection program with priority given to potentially hazardous connections

In some states, the legal basis for the adoption of a local cross-connection ordinance is a state law or sanitary code; hence, consultation with the state health department or other agency having jurisdiction is advised in the development of a local ordinance and program. Model ordinances and instruction manuals are available.[183]* Enforcement is best accomplished at the local level.[184]

Implementation of a control program requires, in addition to the above, that a priority system be established. Grouping structures and facilities served as "Hazardous," "Aesthetically Objectionable," and "Nonhazardous" can make inspection manageable and permit concentration of effort on the more serious conditions. Estimating the cost of installing backflow prevention devices is helpful in understanding what is involved and obtaining corrections. Some devices are quite costly. An inspection program, with first priority to hazardous situations, is followed by review of findings with the local health department public health engineer or sanitarian, official notification of the customer, request for submission and approval of plans, establishment of a correction timetable, inspection and testing of the backflow device when installed, enforcement action if indicated, follow-up inspections, and testing of installed devices. The program progress should be reviewed and adjusted as needed every six months.[185]

*See also local building and plumbing codes.

Hydropneumatic Systems

Hydropneumatic or pressure-tank water systems are suitable for small communities, housing developments, private homes and estates, camps, restaurants, hotels, resorts, country clubs, factories, and institutions and as booster installations. In general, only about 10 to 20 percent of the total volume of a pressure tank is actually available. Hydropneumatic tanks are usually made of 3/16-inch or thicker steel and are available in capacities up to 10,000 or 20,000 gal. Tanks should meet American Society of Mechanical Engineers (ASME) code requirements. Small commercial-size tanks are 42, 82, 120, 144, 180, 220, 315, 525, and 1,000 gallons. Smaller tanks are available precharged with air.

The required size of a pressure tank is determined by peak demand, the capacity of the pump and source, the operating pressure range, and air volume control (available water). The capacity of well and pump should be at least 10 times the average daily water consumption rate, and the gross tank volume in gallons should be at least 10 times the capacity of the pump in gallons per minute.[186] The EPA suggests that the pump capacity for private dwellings be based on the number of fixtures in a dwelling, as shown in Table 2.11. The Water System Council recommends a 7-minute peak-demand usage for one- to four-bedroom homes and suggests a storage of 15 gpd per dwelling unit.[187]

A simple and direct method for determining the recommended volume of the pressure storage tank and size pump to provide is given by Figure 2.14. This figure is derived from Boyle's law and is based on the following formula:

$$Q = \frac{Q_m}{1 + P_1/P_2}$$

where

Q = pressure-tank volume, gal

Q_m = 15-minutes storage at the maximum hourly demand rate

P_1 = minimum absolute operating pressure (gauge pressure plus 14.7 lb/in.^{2})

P_2 = maximum absolute pressure[188]

TABLE 2.11 Recommended Pump Capacity for Private Dwellings

Number of Fixtures	Recommended Pump Capacity (gpm)
2–7	7–8
8	8–9
10	9–11
12	10–12
14–16	11–13
18–20	12–14

Source: Manual of Individual Water Systems, EPA-570/9-82-004, U.S. Environmental Protection Agency, Office of Drinking Water, Washington, DC, October 1982, p. 99.

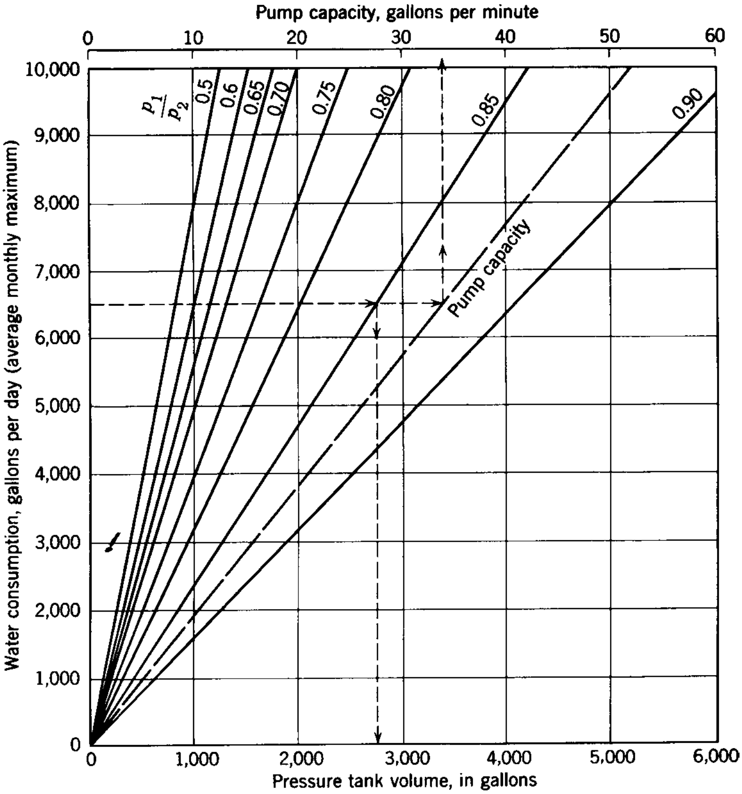


FIGURE 2.14 Chart for determining pressure storage tank volume and pump size. Pressure tank volume provides 15-minutes of storage. (*Source*: J. A. Salvato Jr., "The Design of Pressure Tanks for Small Water Systems," *J. Am. Water Works Assoc.*, June 1949, pp. 532–536. Reprinted by permission. Copyright © 1949 by the American Water Works Association.)

The pump capacity given on the curve is equal to 125 percent of the maximum hourly demand rate. The maximum hourly demand is based on the following but should be determined for each situation:

$$\text{Average daily rate} = \frac{\text{Average water use per day}}{\text{1440 min/day in gpm}} \text{based on annual water use}$$

$$\text{Average maximum monthly rate} = 1.5 \times \text{average daily rate}$$

$$\text{Maximum hourly demand rate} = 6 \times \text{average maximum monthly rate}$$

or

$$9 \times \text{average daily rate}$$

$$\text{Instantaneous rate (pump capacity)} = 1.25 \times \text{maximum hourly demand rate}$$

or

$$11.25 \times \text{average daily rate}$$

The pressure tank is assumed to be just empty when the pressure gauge reads zero. Figure 2.14 can also be used for larger or smaller flows by dividing or multiplying the vertical and horizontal axes by a convenient factor. The required pressure tank volume can be reduced proportionately if less than 15-minutes of storage is acceptable. For example, it can be reduced to one-third if 5-minutes storage is adequate, or to 1/15 if 1-minutes storage is adequate. Also, if the water consumption in Figure 2.14 is 1/10 of 6,500 gpd, that is 650 gpd, the corresponding pressure tank volume would be 1/10 of 2,800 gallons, or 280 gallons. The pump capacity would be 1/10 of 34 gpm, or 3.4 gpm. But if all water is used in 12 hours, as in a typical residential dwelling, double the required pump capacity, which in this case would be 6.8 gpm. The larger pump is usually provided in small installations for faster pressure tank recovery and to meet momentary demands that are more likely to vary widely than in large installations. See previous text and Table 2.11. Also see Figures 2.10 and 2.11. An example for a larger system is given under "Design of Small Water Systems," this chapter.

The water available for distribution is equal to the difference between the dynamic head (friction plus static head) and the tank pressure. Because of the relatively small quantity of water actually available between the usual operating pressures, a higher initial (when the tank is empty) air pressure and range are sometimes maintained in a pressure tank to increase the water available under pressure. When this is done, the escape of air into the distribution system is more likely. Most home pressure tanks come equipped with a pressure switch and an automatic air volume control (Figure 2.15), which is set to maintain a definite air-water volume in the pressure tank at previously established water pressures, usually 20 to 40 psi. Air usually needs to be added to replace that absorbed by the water to prevent the tank from becoming waterlogged. Small pressure tanks are available with a diaphragm inside that separates air from the water, thereby minimizing this problem. Some manufacturers, or their representatives, increase the pressure tank storage slightly by precharging the tank with air. With deep-well displacement and submersible pumps, an excess of air is usually pumped with the water, causing the pressure tank to become airbound unless an air-release or needle valve is installed to permit excess air to escape.

In large installations an air compressor is needed, and an air-relief valve is installed at the top of the tank. A pressure-relief valve should also be included on the tank. See Figure 2.16.

Where a well yield (source) is inadequate to meet water demand with a pressure tank, then gravity or in-well storage, an additional source of water, or double pumping with intermediate storage, may be considered. Intermediate ground-level storage can be provided between the well pump and the pressure-tank pump. The well pump will require a low-water cutoff, and *its capacity must be related to the dependable well yield*. The intermediate storage tank (tightly covered) should have a pump stop-and-start device to control the well pump and a low-water sensor to signal depletion of water in the intermediate storage tank. A centrifugal

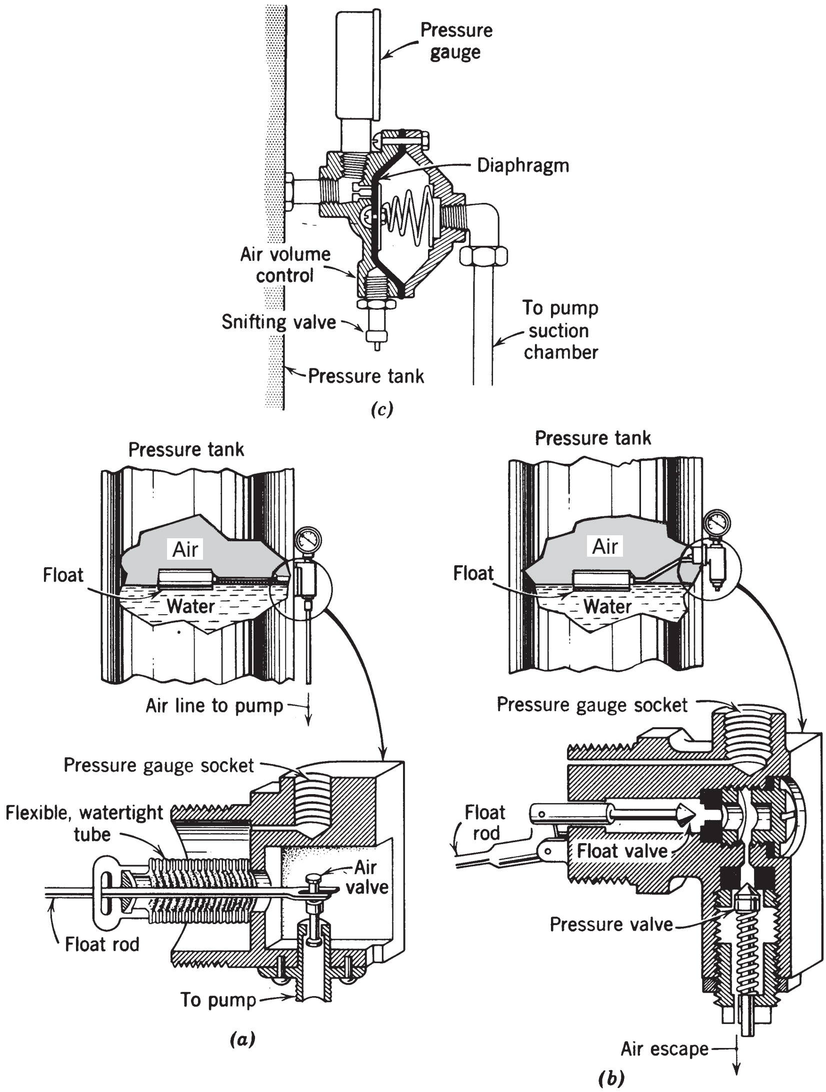


FIGURE 2.15 Pressure-tank air volume controls: (*a*) shallow-well type for adding air; (*b*) deep-well type for air release—used with submersible and piston pumps; (*c*) diaphragm-type in position when pump is not operating (used mostly with centrifugal pump). Small air precharged pressure tanks with a diaphragm to separate air and water are replacing air-volume controls. (*Source: Pumps and Plumbing for the Farmstead*, Tennessee Valley Authority, Agriculture and Engineering Development Division, November 1940.)

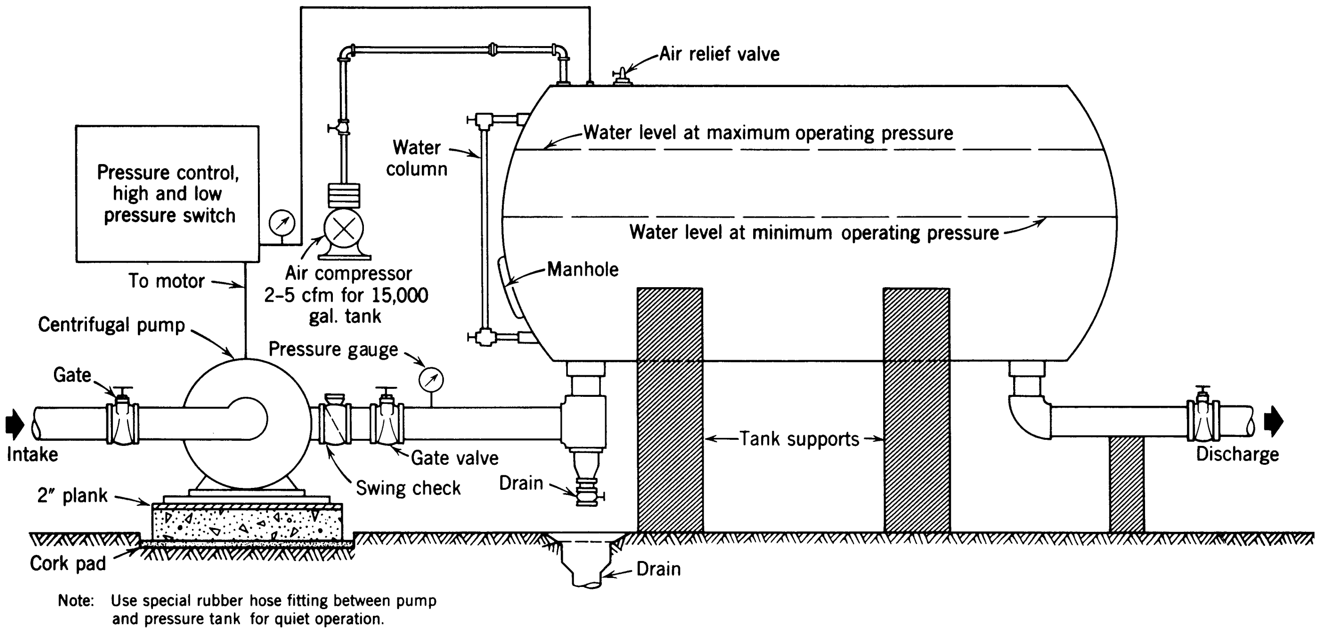


FIGURE 2.16 Typical large pressure tank installation.

pump would pump water from the intermediate tank to a pressure tank, with a pressure switch control, and thence to the distribution system.

Low-rate pumping to elevated storage, a deeper well to provide internal storage, or an oversize pressure tank may be possible alternatives to intermediate ground-level storage, depending on the extent of the problem and relative cost.

Pumps

The pump types commonly used to raise and distribute water are referred to as positive displacement, including reciprocating, diaphragm, and rotary; centrifugal, including turbine, submersible, and ejector jet; air lift; and hydraulic ram. Pumps are classified as low lift, high lift, deep well, booster, and standby. Other types for rural and developing areas include the chain and bucket pump and hand pump.

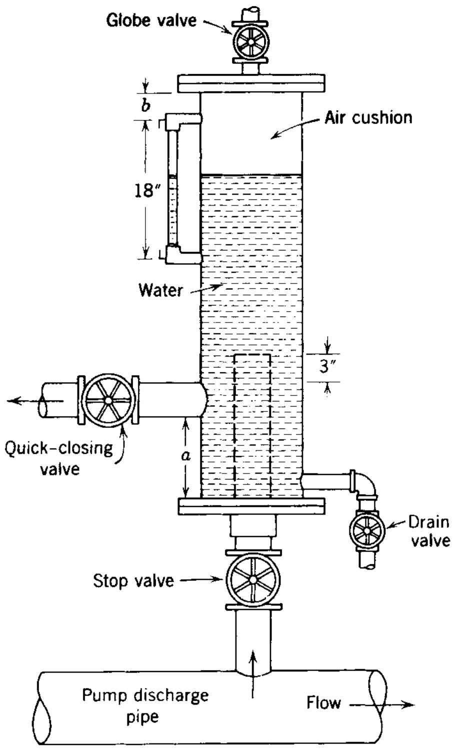
Displacement Pump

In reciprocating displacement pumps, water is drawn into the pump chamber or cylinder on the suction stroke of the piston or plunger inside the pump chamber and then the water is pushed out on the discharge stroke. This is a simplex or single-acting reciprocating pump. An air chamber (Figure 2.17) should be provided on the discharge side of the pump to prevent excessive water hammer caused by the quick-closing flap or ball valve; by the quick closing or opening of a gate valve, float valve, or pressure-reducing valve; and the sudden shutdown of a pump. The air chamber or other surge suppressor will protect piping and equipment on the line and will tend to even out the intermittent flow of water. See “Water Hammer,” this chapter. Reciprocating pumps are also of the duplex type wherein water is pumped on both the forward and backward stroke, and of the triplex type, in which three pistons pump water. The motive power may be manual; a steam, gas, gasoline, or oil engine; an electric motor; or a windmill. The typical hand pump and deep-well plunger or piston pumps over wells are displacement pumps.

A rotary pump is also a displacement pump, since the water is drawn in and forced out by the revolution of a cam, screw, gear, or vane. It is not used to any great extent to pump water.

Displacement pumps have certain advantages over centrifugal pumps. The quantity of water delivered does not vary with the head against which the pump is operating but depends on the power of the driving engine or motor. A pressure-relief valve is necessary on the discharge side of the pump to prevent excessive pressure in the line and possible bursting of a pressure tank or water line. They are easily primed and operate smoothly under suction lifts as high as 22 feet. Practical suction lifts at different elevations are given in Table 2.12.

Displacement pumps are flexible and economical. The quantity of water pumped can be increased by increasing the speed of the pump, and the head can vary within wide limits without decreasing the efficiency of the pump. A displacement pump can deliver relatively small quantities of water as high as



Air Chamber Dimensions				
Discharge Pipe	Inside Diameter of Air Chamber	Total Height	a	b
2″	8″	3′0″	4″	9″
2½″	8″	3′6″	4″	12″
3″	10″	4′0″	5″	15″
4″	10″	5′0″	6″	21″
5″	12″	6′0″	6″	27″
6″	16″	7′0″	6″	33″

FIGURE 2.17 Air chamber dimensions for reciprocating pumps. (*Source: Water Supply and Water Purification*, T.M. 5-295, War Department, Washington, DC, 1942.)

800 to 1,000 feet. Its maximum capacity is 300 gpm, although horizontal piston pumps are available in sizes of 500 to 3,000 gpm. The overall efficiency of a plunger pump varies from 30 percent for the smaller sizes to 60 to 90 percent for the larger sizes with electric motor drive. It is particularly suited to pumping small quantities of water against high heads and can, if necessary, pump air with water. This type of pump is no longer widely used.

TABLE 2.12 Atmospheric Pressure and Practical Suction Lift

Elevation Above Sea level		Atmospheric Pressure		Design Suction Life (ft)		
ft	miles	lb/in.^{2}	ft of water	Displacement Pump	Centrifugal Pump	Turbine Pump
0	—	14.70	33.95	22	15	28
1,320	$\frac{1}{4}$	14.02	32.39	21	14	26
2,640	$\frac{1}{2}$	13.33	30.79	20	13	25
3,960	$\frac{3}{4}$	12.66	29.24	18	11	24
5,280	1	12.02	27.76	17	10	22
6,600	$1\frac{1}{4}$	11.42	26.38	16	9	20
7,920	$1\frac{1}{2}$	10.88	25.13	15	8	19
10,560	2	9.88	22.82	14	7	18

Note: The possible suction lift will decrease about 2 ft for every 10°F increase in water temperature above 60°F; 1 lb/in.^{2} = 2.31 ft head of water.

Centrifugal Pump, Also Submersible and Turbine

There are several types of centrifugal pumps; the distinction lies in the design of the impeller. They include radial, mixed, and axial flow, turbine, close-coupled, submersible, and adjustable blade impeller pumps. Water is admitted into the suction pipe or pump casing and is rotated in the pump by an impeller inside the pump casing. The energy is converted from velocity head primarily into pressure head. In the submerged multistage, turbine-type pump used to pump water out of a well, the centrifugal pump is in the well casing below the drawdown water level in the well; the motor is above ground. In the submersible pump, the pump and electric motor are suspended in the well attached to the discharge pipe, requiring a minimum 3-inch- (preferably 4-inch-) diameter casing. It is a multistage, centrifugal pump unit.

If the head against which a centrifugal pump operates is increased beyond that for which it is designed and the speed remains the same, then the quantity of water delivered will decrease. By contrast, if the head against which a centrifugal pump operates is less than that for which it is designed, then the quantity of water delivered will be increased. This may cause the load on the motor to be increased, and hence overloading of the electric or other motor, unless the motor selected is large enough to compensate for this contingency.

Sometimes two centrifugal pumps are connected in series so that the discharge of the first pump is the suction for the second. Under such an arrangement, the capacity of the two pumps together is only equal to the capacity of the first pump, but the head will be the sum of the discharge heads of both pumps. At other times, two pumps may be arranged in parallel so that the suction of each is connected to the same pipe and the discharge of each pump is connected to the same discharge line. In this case, the static head will be the same as that of the individual pumps, but the dynamic head, when the two pumps are in operation, will increase because of the greater friction and may exceed the head for which the pumps are designed. It may be possible to force only slightly more water through the same line when using two pumps as when using one pump, depending on the pipe size. Doubling the speed of a centrifugal pump impeller doubles the quantity of water pumped, produces a head four times as great, and requires eight times as much power to drive the pump. In other words, the quantity of water pumped varies directly with the speed, the head varies as the square of the speed, and the horsepower varies as the cube of the speed. It is usual practice to plot the pump curves for the conditions studied on a graph to anticipate operating results.

The centrifugal pump has no valves or pistons; there is no internal lubrication; and it takes up less room and is relatively quiet. A single-stage centrifugal pump is generally used where the suction lift is less than 15 feet and the total head not over 125 to 200 feet. A single-stage centrifugal pump may be used for higher heads, but where this occurs, a pump having two or more stages, that is, two or more impellers or pumps in series, should be used. The efficiency of centrifugal pumps varies from about 20 to 85 percent; the higher efficiency can be realized in the pumps with a capacity of 500 gpm or more. The peculiarities of the water system and effect they might produce on pumping cost should be studied from the pump curve characteristics. A typical curve is shown in Figure 2.18. All head and friction losses must be accurately determined in arriving at the total pumping head.

Centrifugal pumps that are above the pumping water level should have a foot valve on the pump suction line to retain the pump prime. However, foot valves sometimes leak, thereby requiring a water connection or other priming

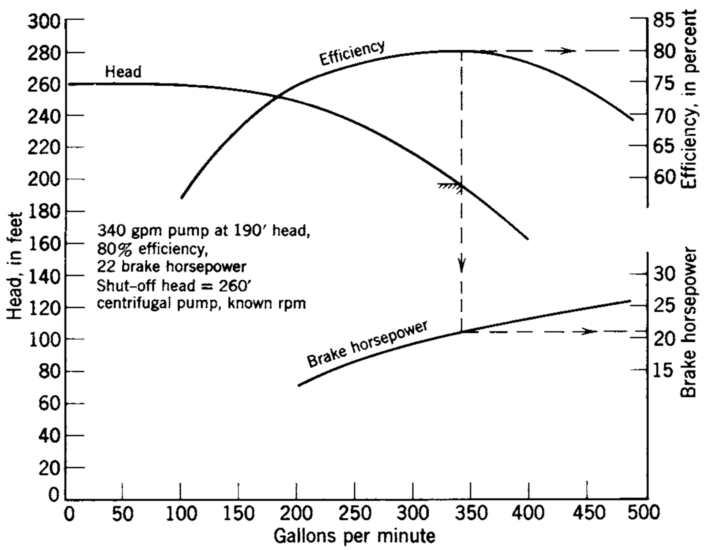


FIGURE 2.18 Typical centrifugal pump characteristic curves.

device or a new check valve on the suction side of the pump. The foot valve should have an area equal to at least twice the suction pipe. It may be omitted where an automatic priming device is provided. In the installation of a centrifugal pump, it is customary to install a gate valve on the suction line to the pump and a check valve followed by a gate valve on the pump discharge line near the pump. An air chamber, surge tank, or similar water-hammer suppression device should be installed just beyond the check valve, particularly on long pipelines or when pumping against a high head. Arrangements should be made for priming a centrifugal pump, unless the suction and pump are under a head of water, and the suction line should be kept as short as possible. The suction line should be sloped up toward the pump to prevent air pockets.

Pump maintenance items to check include cavitation, bearings, coupling alignments, packings, and mechanical seals. Pump manufacturers' catalog efficiencies do not include lift, friction losses in suction and discharge lines, elbow and increaser, or coupling, bearing frame, packing, or mechanical seal losses. Catalog efficiencies should be confirmed. Pump efficiency and capacity will vary with time—wear of bearings, disks or rings, stuffing box, impeller, and casing—as well as with pump and driver misalignment, change in pump speed, and increased pipe friction.

Jet Pump

The jet pump is actually a combination of a centrifugal pump and a water ejector down in a well below or near the water level. The pump and motor can be located some distance away from the well, but the pipelines should slope up to the pump about 1.5 inches in 20 feet. In this type of pump, part of the water raised is diverted back down into the well through a separate pipe. This pipe has attached to it at the bottom an upturned ejector connected to a discharge riser pipe that is open at the bottom. The water forced down the well passes up through the ejector at high velocity, causing a pressure reduction in the venturi throat, and with it draws up water from the well through the riser or return pipe. A jet pump may be used to raise small quantities of water 90 to 120 feet, but its efficiency is lowered when the lift exceeds 50 feet. Efficiency ranges from 20 to 25 percent. The maximum capacity is 50 gpm. There are no moving parts in the well. Jet pumps are shallow-well single-pipe-type (ejector at pump) and deep-well single- and multistage types (ejector in well). Multistage pumps may have impellers horizontal or vertical.

The air ejector pump is similar in operation to a water ejector pump except that air is used instead of water to create a reduced pressure in the venturi throat to raise the water.

Air-Lift Pump

In an air-lift pump, compressed air is forced through a small air pipe extending below the pumping water level in a well and discharged in a finely diffused state in a larger (education) pipe. The air–water mixture in the eduction pipe, being lighter than an equal volume of water, rises. The rise (weight of column of water) must at least equal the distance (weight of column of the same cross-sectional area) between the bottom of the eduction pipe and the water level in the well. A 60 percent submergence is best. For maximum efficiency, the distance from the bottom of the eduction pipe to the water level in the well should equal about twice the distance from the water surface to the point of discharge. The depth of submergence of the eduction pipe is therefore critical, as are the relative sizes of the air and eductor pipes. The area (in square inches) of the eduction pipe is

$$A = Q/20$$

where Q is the volume of water discharged (in gallons per minute) and depends on V, the rate at which air is supplied (in cubic feet per minute):

$$V = Qh/125$$

where h is the distance between the water surface and the point of discharge (in feet).

Efficiencies vary from about 20 to 45 percent. The eduction pipe is about 1 inch smaller in diameter than the casing.[189] The well casing itself can be used as the eductor pipe, provided it is not too much larger than the air pipe.

Hydraulic Ram

A hydraulic ram is a type of pump where the energy of water flowing in a pipe is used to elevate a smaller quantity of water to a higher elevation. An air chamber and weighted check valve are integral parts of a ram. Hydraulic rams are suitable where there is no electricity and the available water supply is adequate to furnish the energy necessary to raise the required quantity of water to the desired level. A battery of rams may be used to deliver larger quantities of water provided the supply of water is ample. Double-acting rams can make use of a nonpotable water to pump a potable water. The minimum flow of water required is 2 to 3 gpm with a fall of 3 feet or more. A ratio of lift to fall of 4 to 1 can give an efficiency of 72 percent, a ratio of 8 to 1 an efficiency of 52 percent, a ratio of 12 to 1 an efficiency of 37 percent, and a ratio of 24 to 1 an efficiency of 4 percent.[190] Rams are known to operate under supply heads up to 100 feet and a lift, or deliver heads, of 5 to 500 feet. In general, a ram will discharge from to of the water delivered to it. From a practical standpoint, it is found that the pipe conducting water from the source to the ram (known as the drive pipe) should be at least 30 to 40 feet long for the water in the pipe to have adequate momentum or energy to drive the ram. It should not, however, be on a slope greater than about 12 degrees with the horizontal. If these conditions cannot be met naturally, it may be possible to do so by providing an open stand pipe on the drive pipeline, so that the pipe beyond it meets the conditions given. The diameter of the delivery pipe is usually about one-half the drive pipe diameter. The following formula may be used to determine the capacity of a ram:

$$Q = \frac{\text{supply to ram} \times \text{power head} \times 960}{\text{pumping head}}$$

where

$$\begin{aligned} Q &= \text{Gallons delivered per day} \\ \text{Supply to ram} &= \text{Water delivered to and used by the ram, gpm} \\ \text{Power head} &= \text{Available supply head of water, ft or fall} \\ \text{Pumping head} &= \text{Head pumping against, ft, or delivery head} \end{aligned}$$

Note: This information plus the length of the delivery pipe and the horizontal distance in which the fall occurs are needed by manufacturers to meet specific requirements.

Pump and Well Protection

A power pump located directly over a deep well should have a watertight well seal at the casing as illustrated in Chapter 1, Figures 1.11 and 1.12. An air vent is used on a well that has an appreciable drawdown to compensate for the reduction in air pressure inside the casing, which is caused by a lowering of the water level when the well is pumped. The vent should be carried 18 inches above the floor and flood level and the end should be looped downward and protected with screening. A downward-opening sampling tap located at least 12 inches above the floor should be provided on the discharge side of the pump. In all instances, the top of the casing, vent, and motor are located above possible flood level.

The top of the well casing or pump should not be in a pit that cannot be drained to the ground surface by gravity. In most parts of the country, it is best to locate pumps in some type of housing above ground level and above any high water. Protection from freezing can be provided by installing a thermostatically controlled electric heater in the pump house. Small, well-constructed, and insulated pump housings are sometimes not heated but depend on heat from the electric motor and a light bulb to maintain a proper temperature. Some type of ventilation should be provided, however, to prevent the condensation of moisture and the destruction of the electric motor and switches. See Figure 1.11.

Use of a submersible pump in a well would eliminate the need for a pump-house but would still require that the discharge line be installed below frost. See Figure 1.7.

Pump Power and Drive

The power available will usually determine the type of motor or engine used. Electric power, in general, receives first preference, with other sources used for standby or emergency equipment.

Steam power should be considered if pumps are located near existing boilers. The direct-acting steam pump and single, duplex, or triplex displacement pump can be used to advantage under such circumstances. When exhaust steam is available, a steam turbine to drive a centrifugal pump can also be used.

Diesel-oil engines are good, economical pump-driving units when electricity is not dependable or available. They are high in first cost. Diesel engines are constant low-speed units.

Gasoline engines are satisfactory portable or standby pump power units. The first cost is low, but the operating cost is high. Variable-speed control and direct connection to a centrifugal pump are common practice. Natural gas, methane, and butane can also be used where these fuels are available.

When possible, use of electric motor pump drive is the usual practice. Residences having low lighting loads are supplied with single-phase current, although this is becoming less common. When the power load may be 3 hp or more, three-phase current is needed. Alternating-current (AC) two- and three-phase motors are of three types: the squirrel-cage induction motor, the wound-rotor or slip-ring induction motor, and the synchronous motor. Single-phase motors are the repulsion–induction type having a commutator and brushes; the capacitator or condenser type, which does not have brushes and commutator; and the split-phase type. The repulsion–induction motor is, in general, best for centrifugal pumps requiring 0.75 hp or larger. It has good starting torque. The all-purpose capacitor motor is suggested for sizes below 0.75 hp. It is necessary to ensure the electric motor is grounded to the pump and to check the electrical code.

The *squirrel-cage motor* is a constant-speed motor with low starting torque but heavy current demand, low power factor, and high efficiency. Therefore, this type of motor is particularly suited where the starting load is large. Larger power lines and transformers are needed, however, with resultant greater power use and operating cost.

The *wound-rotor motor* is similar to the squirrel-cage motor. The starting torque can be varied from about one-third to three times that of normal, and the speed can be controlled. The cost of a wound-rotor motor is greater than a squirrel-cage motor, but where the pumping head varies, power saving over a long-range period will probably compensate for the greater first cost. Larger transformers and power lines are needed.

The *synchronous motor* runs at the same frequency as the generator furnishing the power. A synchronous motor is a constant-speed motor even under varying loads, but it needs an exciting generator to start the electric motor. Synchronous motors usually are greater in size than 75 to 100 hp.

An electric motor starting switch is either manually or magnetically operated. Manually operated starters for small motors (less than 1 hp) throw in the full voltage at one time. Overload protection is provided, but undervoltage protection is not. Full-voltage magnetic starters are used on most jobs. Overload and undervoltage control to stop the motor is generally included. Clean starter controls and proper switch heater strips are necessary. Sometimes a reduced voltage starter must be used when the power company cannot permit a full voltage starter or when the power line is too long. A voltage increase or decrease of more than 10 percent may cause heating of the equipment and winding and fire.

Lightning protection should be provided for all motors. Electric motors can be expected to have efficiencies of about 84 percent for motors under 7.5 hp to about 92 percent for motors of 60 hp or larger. Overall pump and motor efficiency of 65 percent can be achieved.[191] It is important to check with manufacturer and the National Electrical Manufacturers Association (NEMA).

Automatic Pump Control

One of the most common automatic methods of starting and stopping the operation of a pump on a hydropneumatic system is the use of a pressure switch. This switch is particularly adaptable for pumps driven by electric motors, although it can also be used to break the ignition circuit on a gasoline-engine-driven pump. The switch consists of a diaphragm connected on one side with the pump discharge line and on the other side with a spring-loaded switch. This spring switch makes and breaks the electric contact, thereby operating the motor when the water pressure varies between previously established limits.

Water-level control in a storage tank can be accomplished by means of a simple float switch. Other devices are the float with adjustable contacts and the electronic or resistance probes control and altitude valve. Each has advantages for specific installations.[192]

When the amount of water to be pumped is constant, a time cycle control can be used. The pumping is controlled by a time setting.

In some installations, the pumps are located at some distance from the treatment plant or central control building. Remote supervision can be obtained through controls to start or stop a pump and report pressure and flow data and faulty operation.

Another type of automatic pump switch is the pressure flow control. This equipment can be used on ground-level or elevated water storage tanks.

When pumps are located at a considerable distance from a storage tank and pressure controls are used to operate the pumps, heavy drawoffs may cause large fluctuations in pressure along the line. This will cause sporadic pump starting and stopping. In such cases and when there are two or more elevated tanks on a water system, altitude valves should be used at the storage tanks. An altitude valve on the supply line to an elevated tank or standpipe is set to close when the tank is full; it is set to open when the pressure on the entrance side is less than the pressure on the tank side of the valve. In this way, overflowing of the water tank is prevented, even if the float or pressure switch fails to function properly.

Water Hammer

Water hammer is the change in water pressure in a closed conduit (pipe) flowing full due to a very rapid acceleration or cessation of flow, resulting in very large momentary positive and negative pressure changes (surges) from normal.

Causes are pump startup, pump power failure, valve operation, and failure of the surge protection device. Control devices used include vacuum breaker–air relief valves, controlled shutoff valves, flywheel on a pump motor, a surge tank, and a reservoir or standpipe floating on the distribution system. See Figure 2.17. Vacuum breaker–air relief valves are usually located at high points of distribution system pipelines. Pressure-relief valves are usually found in pump stations to control pressure surges and protect the pump station. Air chambers may have a diaphragm to separate the air–water interface to prevent absorption and loss of air in the chamber or an inert gas in place of air. They are used on short pipelines. Each pipeline system should be studied for possible water hammer problems and protected as indicated. Selection of the proper devices requires careful analysis and proper sizing.[193]

Rural Water Conditions in the United States

A national assessment of rural water conditions made between May 1978 and January 1979 of a 2,654 sample of 21,974,000 rural households (places with a population of less than 2,500 and in open country) in the United States is shown in Table 2.13.[194]

Ninety percent of the individual systems were well-water supplies, mostly drilled wells. The remainder relied on driven, bored, jetted, or dug wells as well as springs (275,000), cisterns (133,000), surface water (93,000), or hauled water (269,000). The median rural household system consisted of a 6-gpm pump and a 30-gallon pressure tank with an effective volume of 0.3 gallons. Systems in the west had a larger capacity. Ninety-one percent had piped water and an electric pump. Of the intermediate systems, 90 percent had two or three connections; 88 percent were drilled well supplies. Eighty-eight percent of the community systems had a median of 59 connections and 1.5 miles of distribution system. Ninety percent had groundwater sources and used an average of 36,000 gpd.

TABLE 2.13 Rural Water Service and Water Quality

Water Service	Number of Systems	Water Number of Households[a]	Quality E. coli[b]	% Fecal E. coli
Individual systems	8,765,000	8,765,000	42.1	12.2
Intermediate systems[c]	845,000	2,228,000	43.3	12.2
Community systems[d]	34,000	10,981,000	15.5	4.5

[a] Median of 2.65 persons per household.
[b] More than one per 100 ml.
[c] 2 to 14 connections.
[d] 15 or more connections.

Source: J. D. Francis et al., *National Assessment of Rural Water Conditions*, EPA 570/9-84-004, U.S. Environmental Protection Agency, Office of Drinking Water, Washington, DC, June 1984.

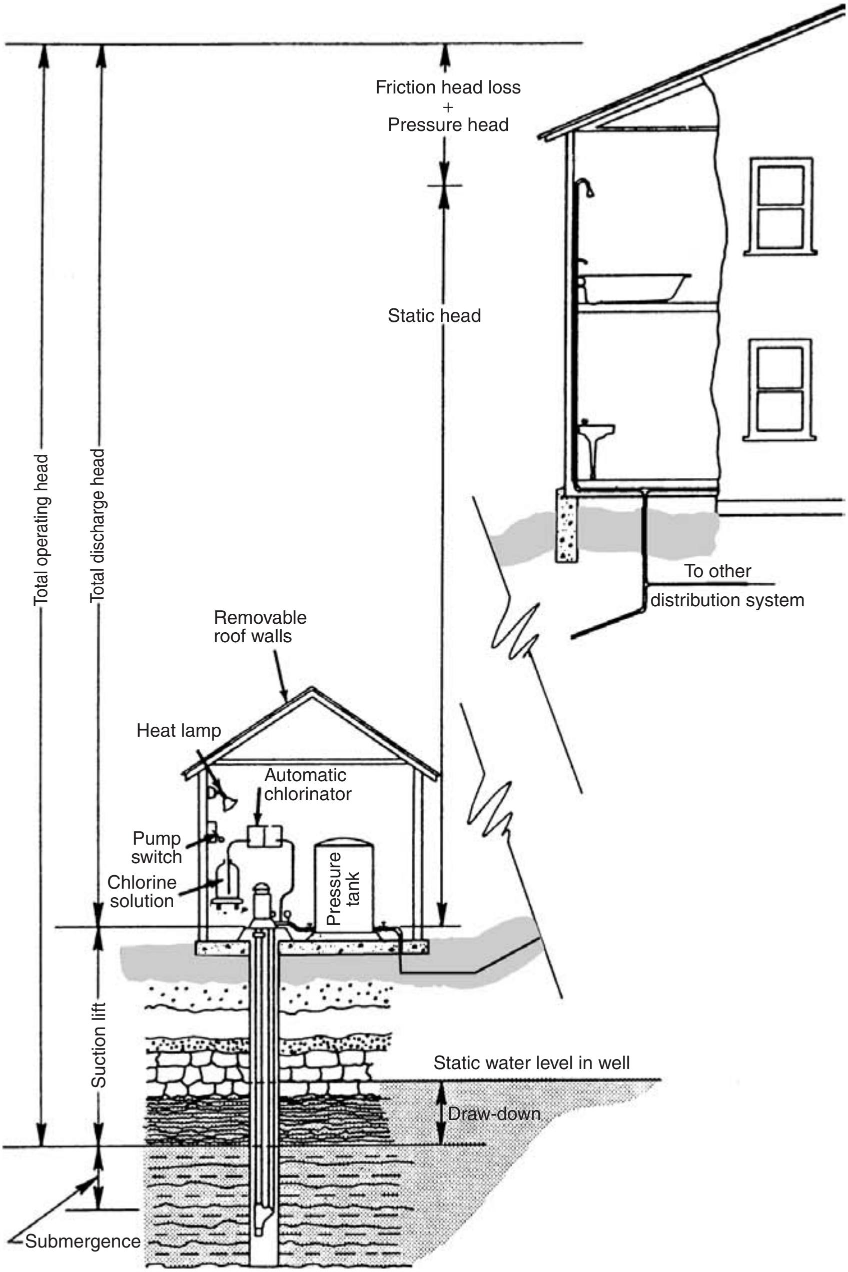


FIGURE 2.19 Components of total operating head in well pump installations. (*Source: Manual of Individual Water Systems*, EPA-570/9-82-004, U.S. EPA, Office of Drinking Water, Washington, DC, October 1982, p. 102.)

Consolidated systems had a median of 153 connections. The median for average daily use was 43,000 gpd.

Nationally, 28.9 percent of all rural household water supplies had coliform concentrations exceeding the standard of 1/100 ml. Individual and intermediate systems were more often contaminated than community systems. Dug, driven, and jetted wells and springs were more likely to be contaminated. However, even the rural community systems showed significantly higher levels of coliform contamination than the larger public water systems. This points out sharply an unresolved problem and the need for greater attention to rural water supplies, including the 34,000 rural community systems. The need for improved well and spring location, construction, and protection and competent intermediate and community system operation is apparent.

Design of a Household Water System

Major considerations in the design of a well-water system for a private dwelling are a dependable well yield and a well pump of adequate capacity and operating head. Chapter 1, Figure 1.4 shows a well log and well yield testing. Figure 2.10 shows the probable range of the maximum momentary water demand for one or more dwelling units. See also Figure 2.11 for fixture unit basis for demand load in gallons per minute and Figure 2.14 for pressure tank and pump size. Figure 2.19 shows the components that make up the total well pump operating head. Table 2.11 gives recommended pump capacities and supplements text suggestions.

EXAMPLES

Design of Small Water Systems

Small water systems, serving less than 10,000 households, supplied about 42 million people in the United States (1980 statistics). Many of these systems are marginally designed and poorly operated and maintained due to insufficient budgets, very low water rates, poorly paid and trained operators, and uninformed management. Such systems are frequently inadequately monitored and fail to meet drinking water standards. Some are too small to provide sufficient revenue to support proper operation, maintenance, and management. Very often, small water systems are the only alternative for small isolated communities and developments. A partial answer, where feasible, is the consolidation of small water systems or connection to a large municipal system. Other alternatives include regional management of several small systems, including professional supervision, administration, and technical and financial assistance. Rural water associations, local water works associations, and regulatory agencies can, and in many areas do, provide training programs, seminars, and speakers to meet some of the needs. Compliance with drinking water standards, operational problems, and maintenance can be discussed. The opportunity to share experiences is provided and made accessible to the small water system operator.

Experiences in new subdivisions show that peak water demands of 6 to 10 times the average daily consumption rate are not unusual. Lawn-sprinkling demand has made necessary sprinkling controls, metering, or the installation of larger distribution and storage facilities and, in some instances, ground storage and booster stations. As previously stated, every effort should be made to serve a subdivision from an existing public water supply. Such supplies can afford to employ competent personnel and are in the business of supplying water, whereas a subdivider is basically in the business of developing land and does not wish to become involved in operating a public utility.

In general, when it is necessary to develop a central water system to serve the average subdivision, consideration should first be given to a drilled well-water supply. Infiltration galleries or special shallow wells may also be practical sources of water if their supply is adequate and protected. Such water systems usually require a minimum of supervision and can be developed to produce a known quantity of water of a satisfactory sanitary quality. Simple chlorination treatment will normally provide the desired factor of safety. Test wells and sampling will indicate the most probable dependable yield and the chemical and bacterial quality of the water. Well logs should be kept in duplicate.

Where a clean, clear lake supply or stream is available, chlorination and slow sand filtration can provide reliable treatment with daily supervision for the small development. The turbidity of the water to be treated should not exceed 30 NTU. Preliminary settling may be indicated in some cases.

Other more elaborate types of treatment plants, such as rapid sand filters, are not recommended for small water systems unless specially trained operating personnel can be assured. Pressure filters have limitations, as explained earlier in this chapter.

The design of small slow sand filter and well-water systems is explained and illustrated earlier in Figures 2.2 and 2.3 and shown in Figure 2.22.

An example (Figure 2.20) will serve to illustrate the design bases previously discussed. The design population at a development consisting of 100 two-bedroom dwellings, at two persons per bedroom, is 400. The average water use at 75 gallons per person or 150 gallons per bedroom is 30,000 gpd for the development. From Figure 2.10, the peak demand can vary from 100 to 320 gpm. An average conservative maximum or peak demand would be 210 gpm. Adjustment should be made for local conditions. This design provides no fire protection.

Examples showing calculations to determine pipe diameters, pumping head, pump capacity, and motor size follow.

In one instance, assume that water is pumped from a lake at an elevation of 658 feet to a slow sand filter and reservoir at an elevation of 922 ft. See Figure 2.20. The pump house is at an elevation of 665 feet and the intake is 125 feet long. The reservoir is 2,000 feet from the pump. All water is automatically

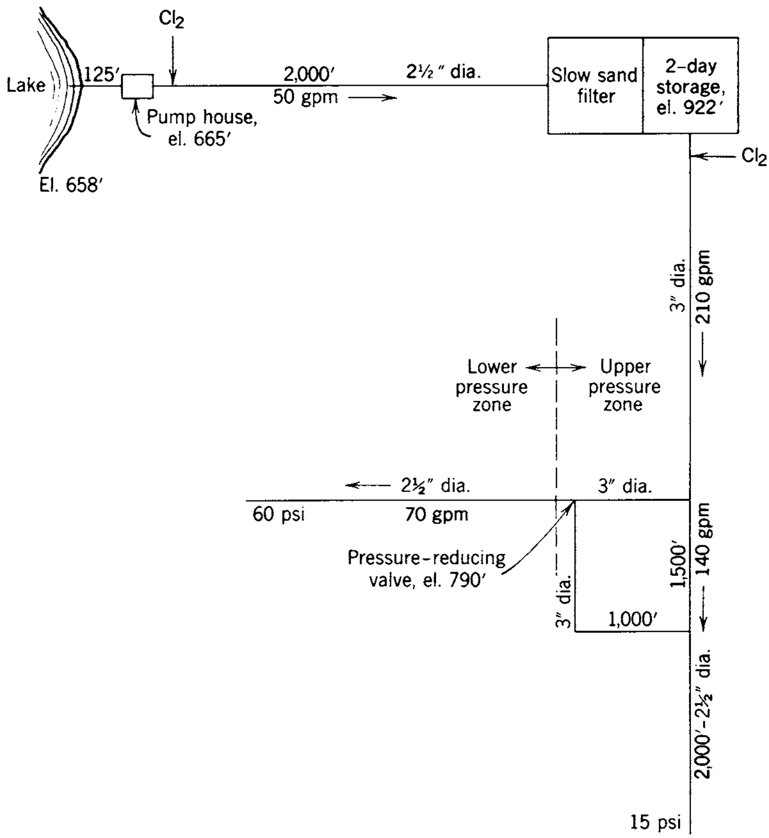


FIGURE 2.20 Water system flow diagram.

chlorinated as it is pumped. The average water consumption is 30,000 gpd. With the reservoir at an elevation of 922 feet, a pressure of at least 15 lb/in.^{2} is to be provided at the highest fixture. Find the size of the intake and discharge pipes, the total pumping head, the size pump, and motor. The longest known power failure is 14 hours and repairs can be made locally. Assume that the pump capacity is sufficient to pump 30,000 gallons in 10 hours, or 50 gpm. Provide one 50-gpm pump and one 30-gpm standby, both multistage centrifugal pumps, one to operate at any one time and one generator.

From the above, with a flow of 50 gpm, a 2-inch pipeline to the storage tank is indicated.

The head losses, using Tables 2.14 and Table 2.15, are as follows:

$$\text{Intake, 125 ft of 2-in. pipe}(3.3 \times 1.25) = 4.1\text{ ft}$$

TABLE 2.14 Friction Due to Water Flowing in Pipe

	Friction Head Loss by Pipe Diameter[a]														
Capacity (gpm)	1	3/4	1	1-1/4	1-1/2	2	2-1/2	3	4	5	6	8	10	12	14
1	2.1														
2	7.4	1.9													
3	15.8	4.1	1.3												
4	27.0	7.0	2.1	0.57											
5	41.0	10.5	3.2	0.84	0.40										
8	98.0	25.0	7.8	2.0	0.95										
10		38.0	11.7	3.0	1.4	0.50									
15		80.0	25.0	6.5	3.1	1.1									
20		136.0	42.0	11.1	5.2	1.8	0.61								
25			64.0	16.6	7.8	2.7	0.95	0.40							
30			89.0	23.5	11.0	3.8	1.3	0.54							
35			119.0	31.2	14.7	5.1	1.7	0.75							
40			152.0	40.0	18.8	6.6	2.2	0.91							
50				60.0	28.4	9.9	3.3	1.4							
60				85.0	39.6	13.9	4.6	1.9	0.47						
70				113.0	53.0	18.4	6.2	2.6	0.63						
80					68.0	23.7	7.9	3.3	0.81						
90					84.0	29.4	9.8	4.1	1.0						
100					102.0	35.8	12.0	5.0	1.2	0.41					
125						54.0	18.2	7.6	1.9	0.64					
150						76.0	26.0	10.5	2.6	0.87					
175						102.0	33.8	14.0	3.4	1.2					
200						129.0	43.1	17.8	4.4	1.5	0.62				
225							54.0	22.0	5.3	1.8	0.72				

(*continues*)

TABLE 2.14 (*continued*)

	Friction Head Loss by Pipe Diameter[a]														
Capacity (gpm)	1	3/4	1	1-1/4	1-1/2	2	2-1/2	3	4	5	6	8	10	12	14
250							65.0	27.1	6.7	2.2	0.92				
300							92.0	38.0	9.3	3.1	1.3				
400								65.0	16.0	5.4	2.2				
500								98.0	24.0	8.1	3.3	0.83			
600									33.8	11.7	4.7	1.2			
700									45.0	15.2	6.2	1.5	0.52		
800									57.6	19.4	8.0	2.0	0.67		
900									71.6	24.2	10.0	2.5	0.83		
1000									87.0	29.4	12.1	3.0	1.0	0.42	
1500										62.2	25.6	6.3	2.1	0.88	0.42
2000											43.6	10.8	3.6	1.5	0.71
3000												22.8	7.7	3.2	1.5
4000													13.1	5.4	2.6
5000													19.8	8.2	3.8

[a] In inches.

TABLE 2.15 Friction of Water in Fittings

	Friction Head Loss as Equivalent Number of Feet of Straight Pipe by Pipe Size (in.) (nominal diameter)											
Pipe Fitting	1/2	3/4	1	1-1/4	1-1/2	2	2-1/2	3	3-1/2	4	5	6
Open gate valve	0.4	0.5	0.6	0.8	0.9	1.2	1.4	1.7	2.0	2.3	2.8	3.5
Three-quarters closed gate valve	40.0	60.0	70.0	100.0	120.0	150.0	170.0	210.0	250.0	280.0	350.0	420.0
Open globe valve	19.0	23.0	29.0	38.0	45.0	58.0	70.0	85.0	112.0	120.0	140.0	170.0
Open angle valve	8.4	12.0	14.0	18.0	22.0	28.0	35.0	42.0	50.0	58.0	70.0	85.0
Standard elbow or through reducing tee	1.7	2.2	2.7	3.5	4.3	5.3	6.3	8.0	9.3	11.0	13.0	16.0
Standard tee	3.4	4.5	5.8	7.8	9.2	12.0	14.0	17.0	19.0	22.0	27.0	33.0
Open swing check	4.3	5.3	6.8	8.9	10.4	13.4	15.9	19.8	24.0	26.0	33.0	39.0
Long elbow or through tee	1.1	1.4	1.7	2.3	2.7	3.5	4.2	5.1	6.0	7.0	8.5	11.0
Elbow 45°	0.75	1.0	1.3	1.6	2.0	2.5	3.0	3.8	4.4	5.0	6.1	7.5
Ordinary entrance	0.9	1.2	1.5	2.0	2.4	3.0	3.7	4.5	5.3	6.0	7.5	9.0

Note: The frictional resistance to flow offered by a meter will vary between that offered by an open angle valve and globe valve of the same size. See manufacturers for meter and check valve friction losses; also Table 3-32. See manufacturer for head loss in butterfly, rotary, and special valves.

For this calculation, assume the entrance loss and loss through pump are negligible. Say that you have the following:

Four long elbows = 16.8 ft
Two globe valves = 140 ft
One check valve = 16 ft
Three standard elbows = 18.9 ft
Two 45° elbows = 6 ft
Total equivalent pipe = 198 ft of 2-1/2-in. pipe; head loss = 3.3 × 1.98:

Discharge pipe, 2,000 ft of 2-1/2-in. = 3.3 × 20 = 66.0 ft
Total friction head loss = 76.6 ft
Suction lift = 7 ft to center of pump = 7.0 ft
Static head, difference in elevation = 922−655 = 257.0 ft
No pressure at point of discharge; and total head = 340.6 ft

Add for head loss through meters if used (Table 2.16).

If a 3-inch intake and discharge line is used instead of a 2-1/2-inch intake, the total head can be reduced to about 300 ft. The saving thus effected in power consumption would have to be compared with the increased cost of 3-in. pipe over 2-1/2-in. pipe. The additional cost of power would be approximately $76.65

TABLE 2.16 Head Loss Through Meters

	Head Loss through Meter by Meter Size[a] (psi)								
Flow (gpm)	5/8	3/4	1	1-1/4	1-1/2	2	3	4	6
4	1								
6	2								
8	4	1							
10	6	2	1						
15	14	5	2	2					
20	25	9	4	3	1				
30		20	8	7	2	1			
40			15	12	4	2			
50			23	18	6	3			
75					14	5	1		
100					25	10	3	1	
200							10	4	1
300							24	9	2
400								16	4
500								25	6

[a]In inches.

Note: Flows of less than 1/4 gpm are not usually registered by domestic meters.

Source: Adapted from G. Roden, "Sizing and Installation of Service Pipes," *J. Am. Water Works Assoc*. **38**, 5 (May 1946). Copyright 1946 by the American Water Works Association. Reprinted with permission.

per year, with the unit cost of power at \$0.02/kW-hr. This calculation is shown below using approximate efficiencies.*

For a 340-foot head,

$$\text{Horsepower to motor} = \frac{\text{gpm X total head in ft}}{3960 \times \text{pump efficiency} \times \text{motor efficiency}}$$
$$= \frac{50 \times 340}{3960 \times 0.45 \times 0.83} = 11.5$$
$$11.5\,\text{hp} = 11.5 \times 0.746\,\text{kW} = 8.6\,\text{kW}^{\dagger}$$

In 1 hr, at 50 gpm, 50 × 60, or 3,000 gallons, will be pumped and the power used will be 8.6 kW-hr. To pump 30,000 gallons of water will require 8.6 × (30,000/3,000) = 86 kW-hr.

If the cost of power is \$0.02/kW-hr, the cost of pumping 30,000 gallons of water per day will be 86 × 0.02 = 1.72, or \$1.72.

For a 300-ft head,

$$\text{Horsepower} = \frac{50 \times 300}{3960 \times 0.45 \times 0.83} = 110.1\,\text{hp}$$
$$= 10.1 \times 0.746\,\text{kW} = 7.55\,\text{kW}$$

In 1 hour, 3,000 gallons will be pumped as before, but the power used will be 7.55 kW-hr. To pump 30,000 gallons will require 7.55 × 10 = 75.5 kW-hr.

If the cost of power is \$0.02 per kW-hr, the cost of pumping 30,000 gal will be 75.5 × 0.02 = 1.51, or \$1.51.

The additional power cost due to using 2-inch pipe is 1.72 −1.51 = \$0.21 per day, or \$76.65 per year.

At 4 percent interest (i), compounded annually for 25 years (n), \$76.65 (D) set aside each year would equal about \$3,200 (S):

$$D = \frac{i}{(1+i)^n - 1} \times S \quad 76.65 = \frac{0.04}{(1+0.04)^{25} - 1}$$
$$S = \frac{76.65}{0.024} = \$3194,\ \text{say } \$3200$$

This assumes that the life of the pipe used is 25 years and the value of money 4 percent. If the extra cost of 3-inch pipe over 2-1/2-in. pipe plus interest on the difference minus the saving due to purchasing a smaller motor and lower head pump is less than \$1,200 (present worth of \$3,200), then 3-inch pipe should be used.

*Adjust costs and interest rates to current conditions.
†Check pump and motor efficiencies with manufacturers.

The size of electric motor to provide for the 50-gpm pump against a total head of 340 feet was shown to be 11.5 hp. Since this is a nonstandard size, the next larger size, a 15-hp motor, will be provided. If a smaller motor is used, it might be overloaded when pumping head is decreased.

The size of electric motor to provide for the 30-gpm pump is

$$\text{Horsepower to motor drive} = \frac{\text{gpm} \times \text{total head in fit}}{3960 \times \text{pump efficiency} \times \text{motor efficiency}}$$

But the total head loss through 2-inch pipe when pumping 30 gpm would be as follows:

Intake, 125 ft of 2-1/2-in. pipe 125
Fittings, total equivalent pipe 198
Discharge pipe, 2,000 ft of 2-1/2-in. $\underline{2000}$
Total friction head loss $2323 \times \frac{1.3}{100} = 32\text{ ft}$
Suction lift = 9
Static head = 255
Total head = $\underline{\underline{\text{-296}}}$ ft
Horsepower to motor drive

$$\frac{30 \times 296}{3960 \times 0.35 \times 0.85} = 7.55(\text{use } 7\tfrac{1}{2}\text{-hp electric motor})$$

Because of the great difference in elevation (658 to 922 feet), it is necessary to divide the distribution system into two zones so that the maximum pressure in pipes and at fixtures will not be excessive. In this problem, all water is supplied the distribution system at elevation 922 feet. A suitable dividing point would be at elevation 790 feet. All dwellings above this point would have water pressure directly from the reservoir, and all below would be served through a pressure-reducing valve to provide not less than 15 lb/in.^{2} at the highest fixture or more than 60 lb/in.^{2} at the lowest fixture. If two-thirds of the dwellings are in the upper zone and one-third is in the lower zone, it can be assumed that the peak or maximum hourly demand rate of flow will be similarly divided (Figure 2.20).

Assume the total maximum hourly or peak demand rate of flow for an average daily water consumption of 30,000 gpd to be 210 gpm. Therefore, 70 + 140 gpm can be taken to flow to the upper zone and 70 gpm to the lower zone. If a 3-inch pipe is used for the upper zone and water is uniformly drawn off, the head loss at a flow of 210 gpm would be about 0.33 × 20 feet per 100 feet of pipe. And if 2-1/2-inch pipe is used for the lower zone and water is uniformly drawn off in its length, the head loss at a flow of 70 gpm would be about 0.33 × 6.2 feet per 100 feet of pipe. If the pipe in either zone is connected to form a loop, thereby eliminating dead ends, the frictional head loss would be further reduced to one-fourth of that with a dead end for the portion forming a loop. Check all head losses.

In all of these considerations, actual pump and motor efficiencies obtained from and guaranteed by the manufacturer should be used whenever possible. Their recommendations and installation detail drawings to meet definite requirements should be requested and followed if it is desired to fix performance responsibility.

In another instance, assume that all water is pumped from a deep well through a pressure tank to a distribution system. See Figure 2.21. The lowest pumping water level in the well is at elevation 160, the pump and tank are at elevation 200, and the highest dwelling is at elevation 350. Find the size pump, motor and pressure storage tank, operating pressures, required well yield, and size mains to supply a development consisting of 100 two-bedroom dwellings using an average of 30,000 gpd.

Use a deep-well turbine pump. The total pumping head will consist of the sum of the total lift plus the friction loss in the well drop pipe and connection to the pressure tank plus the friction loss through the pump and pipe fittings plus the maximum pressure maintained in the pressure tank. The maximum pressure in the tank is equal to the friction loss in the distribution system plus the static head caused by the difference in elevation between the pump and the highest plumbing fixture plus the friction loss in the house water system, including meter if provided, plus the residual head required at the highest fixture.

With the average water consumption at 30,000 gpd, the maximum hourly or peak demand was found to be 210 gpm. The recommended pump capacity is taken as 125 percent of the maximum hourly rate, which would be 262 gpm. This assumes that the well can yield 262 gpm, which frequently is not the case. Under such circumstances, the volume of the storage tank can be increased two or three times, and the size of the pump correspondingly decreased to one-half or one-third the original size to come within the well yield. Another alternative would be to pump water out of the well, at a rate equal to the safe average yield of the well, into a large ground-level storage tank from which water can be pumped through a pressure tank at a higher rate to meet maximum water demands. This would involve double pumping and, hence, increased cost. Another arrangement, where possible, would be to pump out of the well directly into the distribution system, which is connected to an elevated storage tank. Although it may not be

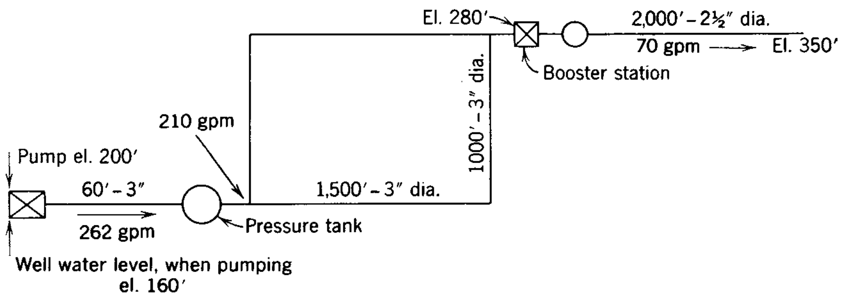


FIGURE 2.21 A water system flow diagram with booster station.

economical to use a pressure-tank water system, it would be of interest to see just what this would mean.

The total pumping head would be

$$\text{Lift from elevation } 160 - 200\,\text{ft} = 40\,\text{ft} \quad 40\,\text{ft}$$

Figure 2.21 shows a distribution system that forms a rectangle 1,000 × 1,500 feet with a 2,000-foot dead-end line serving one-third of the dwellings taking off at a point diagonally opposite the feed main. The head loss in a line connected at both ends is approximately one-fourth that in a dead-end line. The head loss in one-half the rectangular loop, from which water is uniformly drawn off, is one-third the loss in a line without drawoffs. Therefore, the total head loss in a 3-inch pipeline with a flow of about 210 gpm is equal to

$$\frac{1}{4} \times \frac{1}{3} \times \frac{20}{100} \times 2500 = 42\,\text{ft}$$

and the head loss through a 2,000-foot dead-end line, with water being uniformly drawn off, assuming a flow of 70 gpm through 2-1/2-inch pipe is equal to

$$\frac{1}{3} \times \frac{6.2}{100} \times 2000 = 41\,\text{ft}$$

This would make a total of 42 + 41, or 83, ft. = 83 ft

(For a more accurate computation of the head loss in a water distribution grid system by the equivalent pipe, Hardy Cross, or similar method, the reader is referred to standard hydraulic texts. However, the assumptions made here are believed sufficiently accurate for our purpose.)

The static head between pump and the curb of the highest dwelling plus the highest fixture is (350 −200) + 12 = 162 ft.	162 ft
The friction head loss in the house plumbing system (without a meter) is equal to approximately 20 ft.	20ft
The residual head at highest fixture is approximately 20 ft.	20 ft
The friction loss in the well drop pipe and connections to the pressure tank and distribution system with a flow of 262 gpm in a total equivalent length of 100 ft of 3-in. pipe is 30 ft.	30 ft
The head loss through the pump and fittings is assumed negligible. Total pumping head	355 = 147 psi

Because of the high pumping head and so as not to have excessive pressures in dwellings at low elevations, it will be necessary to divide the distribution system into two parts, with a booster pump and pressure storage tank serving the upper half.

If the booster pump and storage tank are placed at the beginning of the 2,000 feet of 2-1/2-inch line, at elevation 280 feet, only one-third of the dwellings need be served from this point. The total pumping head here would be as follows.

Friction loss in 2,000 feet of 2-1/2-inch pipe with water withdrawn uniformly 41 feet along its length and a flow of 70 gpm is

$$\frac{1}{3} = 210 \times \frac{6.2}{100} = 41\,\text{ft}$$

The static head between the booster pump and the curb of the highest dwelling plus the highest fixture is

$(350 - 280) + 12 = 82\,\text{ft}$	82 ft
The head loss in the house plumbing is 20 ft	20 ft
The residual pressure at highest fixture is 20 ft	20 ft
Booster pumping station total head	163 ft = 71 psi

The total pumping head at the main pumping station at the well would be as follows:

Lift in well is 40 ft	40 ft
Friction loss in distribution system forming loop* is 42 ft	42 ft
The static head between the pump and the booster station, which is also adequate to maintain a 20-ft head at the highest fixture, is $280 - 200 = 80\,\text{ft}$	80 ft
Friction loss in well-drop pipe and connections to the distribution system is 30 ft	30ft
Main pumping station, total head	192 ft = 84 psi

With an average daily water consumption of 30,000 gallons, the average daily maximum demand, on a monthly basis, would be $30{,}000 \times 1.5 = 45{,}000$ gallons. The ratio of the absolute maximum and minimum operating pressures at the main pumping station, using a 10-pound differential, would be

$$\frac{84 + 14.7}{94 + 14.7} = \frac{98.7}{108.7} = 0.908,\ \text{say } 0.90$$

From Figure 2.14 the pressure tank volume should be (28,500 gal) about 30,000 gallons if 15 minutes of storage is to be provided at the maximum demand rate, 10,000 gallons if 5 minutes storage is acceptable, or 2,000 gallons if 1 minutes storage is acceptable, with a standby pump and well of adequate

*At 210 gpm, peak flow $(\frac{1}{4} \times \frac{1}{3} \times \frac{20}{100} \times 2500) = 42\,\text{ft}$.

capacity. When the average monthly maximum water consumption exceeds that in Figure 2.14, multiply the vertical *and* horizontal axis by 5 or 10 (or other suitable factor) to bring the reading within the desired range. The pump capacity, as previously determined, should be 262 gpm. Use a 260-gpm pump. If a 20-lb pressure differential is used, $P_1/P_2 = 0.83$, and Figure 2.14 indicates an 18,000-gal pressure tank could be used to provide 15 minutes storage at the probable maximum hourly demand rate of flow, or 6,000 gallons for 5 minutes storage.

The booster pumping station serve one-third of the population; hence, the average daily maximum demand on a monthly basis would be 1/3 (45,000), or 15,000 gallons. The ratio of the absolute maximum and minimum operating pressures at the booster pumping station using a 10-lb differential would be

$$\frac{71 + 14.7}{81 + 14.7} = \frac{85.7}{95.7} = 0.90$$

From Figure 2.14, the pressure tank should have a volume of about 10,000 gallons to provide 15 minutes storage at times of peak demand. The pump capacity should be 78 gpm. Use a 75-gpm pump. By contrast, if the operating pressure differential is 20 pounds and only 5 minutes storage at peak demand is desired, the required pressure tank volume would be 1,600 gallons.

To determine the required size of motor for the main pumping station and booster pumping stations, use the average of the maximum and minimum operating gauge pressures as the pumping head. The size motor for the main pumping station using manufacturer's pump and motor efficiencies is:

$$\frac{262\,\text{gpm} \times (192 + 11\tfrac{1}{2})\,\text{ft avg. had}}{3960 \times 0.57 \times 0.85} = 27.8$$

Use a 30-hp motor. The size motor for the booster station is

$$\frac{70\,\text{gpm} \times (163 + 11\tfrac{1}{2})\,\text{ft avg. head}}{3960 \times 0.50 \times 0.80} = 7.7$$

Use a 7-1/2- or 10-hp motor.

In the construction of a pumping hydropneumatic station, provision should be made for standby pump and motive power equipment.

The calculations are based on the use of a multistage centrifugal-type pump. Before a final decision is made, the comparison should include the relative merits and cost using a displacement-type pump. Remember that price and efficiency, although important when selecting a pump, are not the only factors to consider. The requirements of the water system and peculiarities should be anticipated and a pump with the desirable characteristics selected.

Design of a Camp Water System

A typical hydraulic analysis and design of a camp water system is shown in Figure 2.22.

Water System Cost Estimates

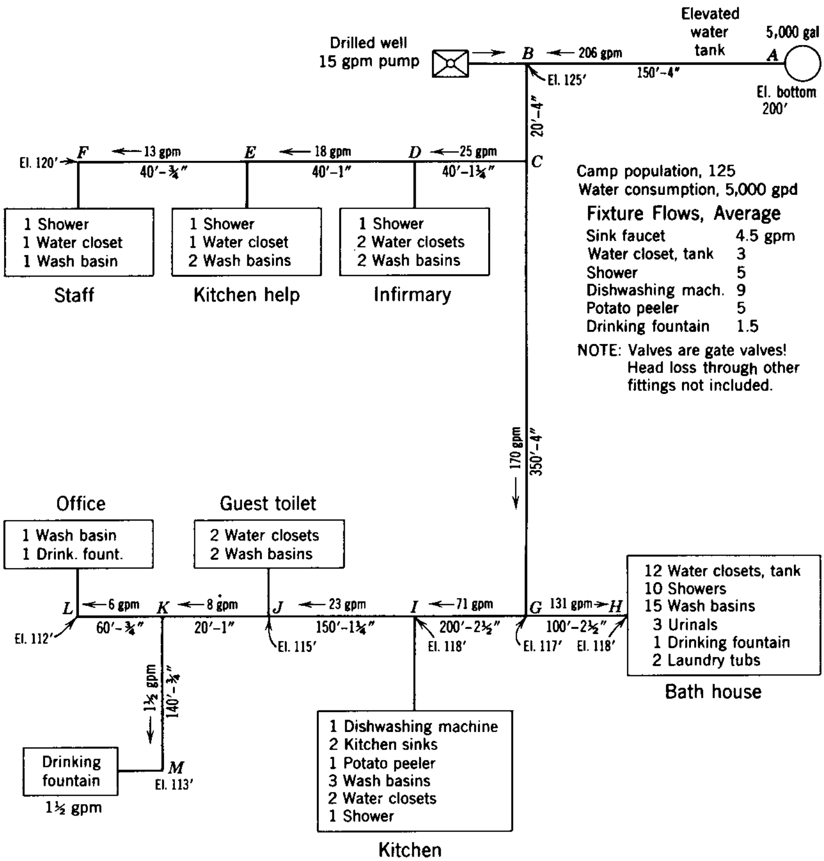
Because of the wide variations in types of water systems and conditions under which they are constructed, it is impractical to give reliable cost estimates. Some approximations are listed to provide insight into the costs involved. Adjust costs use Engineering News Record (ENR) or other appropriate construction cost index:

1. The approximate costs (1990) of water pipes, valves, and hydrants, including labor and material but not including engineering, legal, land, and administrative costs are as follows*:

3/4-in. copper pipe, per ft	$ 10
1-in. copper pipe, per ft	12
1-1/4-in. copper pipe, per ft	15
1-1/2-in. copper pipe, per ft	19
3/4-in. service taps and curb boxes	150
6-in. ductile iron pipe, per ft	$15–20
8-in. ductile iron pipe, per ft	18–23
12-in. ductile iron pipe, per ft	25–30
16-in. ductile iron pipe, per ft	32–35
6-in. ABS or PVC pipe, per ft	$15–17
8-in. ABS or PVC pipe, per ft	18–20
10-in. ABS or PVC pipe, per ft	24–28
12-in. ABS or PVC pipe, per ft	32–40
6-in. double-gate valve and box	$300–400
8-in. double-gate valve and box	500–600
12-in. butterfly valve and box	600–800
6-in. hydrant assembly including valve, and tee on main	2,300

2. Elevated storage, small capacity—20,000-gal capacity, $50,000 to $56,000; 50,000 gal, $75,000 to $134,000; 100,000 gal, $124,000 to $200,000. Ground-level storage—41,000 gal, $45,000; 50,000 gal, $54,000; 72,000 gal, $57,000; 92,000 gal, $63,000 (1990 cost).[195] For larger installations, standpipe costs may run $90,000 for capacity of 0.15×10^6 gal; $210,000 for 0.5×10^6 gal; $350,000 for 1.0×10^6 gal; and $750,000 for 3.0×10^6 gal. For elevated tanks, cost may run

*The assistance of Kestner Engineers, P. C., Troy, NY, is gratefully acknowledged in arriving at the cost estimates.



Distance			Gpm Flow			Head Available (Ft)				Pipe Size (in.)	Head Loss		Head (Ft Remaining)	
From	To	Ft	Max.	%	Probable	Initial	+ Fall	− Rise	Total		Ft per 100 ft	Total		Facility Served
A	*C*	170	295	70	206	0	75	0	75	4	4.5	7.6	67.4	
C	*D*	40	50	50	25	67.4	1.6	0	69	1¼	16.6	6.6	62.4	Inf., kitch., staff
D	*E*	40	30	60	18	62.4	1.0	0	63.4	1	36	14.4	49.0	Kitch., staff
E	*F*	40	13	90	12	49.0	1.6	0	50.6	¾	52	21	29.6	Staff cabin
C	*G*	350	245	70	170	67.4	8.0	0	75.4	4	3.4	11.9	63.5	
G	*H*	100	174	75	131	63.5	0	1	62.5	2½	20	20	42.5	Bath house
G	*I*	200	71	100	71	63.5	0	1	62.5	2½	6	12	50.5	Kitch. guest, off.
I	*J*	150	23	100	23	50.5	3.0	0	53.5	1¼	15	22	31.5	
J	*K*	20	8	100	8	31.5	0	0	31.5	1	7.8	1.6	29.9	
K	*L*	60	6	100	6	29.9	3.0	0	32.9	¾	12	7.2	25.7	Office
K	*M*	140	1½	100	1½	25.7	2.0	0	27.7	¾	1.0	1.4	26.3	Drink. fount.

FIGURE 2.22 Typical hydraulic analysis of camp water system.

$180,000 for 0.15 $\times$ 10^6 gal; $460,000 for 0.5 $\times$ 10^6 gal; $815,000 for 1.00 $\times$ 10^6 gal; and $1,900,000 for 3.0 $\times$ 10^6 gal (1990 adjusted cost).

3. A complete conventional rapid sand filter plant including roads, landscaping, lagoons, laboratory, and low-lift pumps may cost $450,000 for a 0.3-mgd plant; $660,000 for a 0.5-mgd plant; $1,120,000 for a 1.0-mgd plant; $2,500,000 for a 3.0-mgd plant; $3,700,000 for a 5.0-mgd plant; $6,000,000 for a 10.0-mgd plant; and $10,300,000 for a 20.0-mgd plant (1990 adjusted cost).
4. The annual cost of water treatment plants (at 7 percent, 20 years) has been estimated at $63,000, $126,000, and $188,000 for 70-, 350-, and 700-gpm complete treatment package plants; $600,000 for 5-mgd plant; $240,000 and $728,000 for 1- and 10-mgd direct filtration plants; and $376,000 and $1,600,000 for a 2- and 20-mgd GAC plants (1990 cost).[196]
5. Iron and manganese removal plant, well supply, 3 mgd $1,700,000, including new well pumps and disinfection equipment, site work and treatment building (1990 adjusted cost).
6. Well construction costs including engineering, legal, and site development have been estimated[197] as follows:

Cost—Adjusted to 1990 ENR Construction Cost Index

Yield, gpm	70	350	500	600	700
Type	Drilled	Gravel Pack	Gravel Pack	Drilled	Gravel Pack
Diameter, in.	10	16–12	18–12	16	16–12
Depth, ft	40	50	80	68	50
Pump	Submersible	Turbine	Turbine	Turbine	Turbine 2 wells
Average Cost	$186,000	$285,600	$276,000	$300,000	$560,000

7. The National Water Well Association reported it costs $3,000 to drill a private domestic well, $12,000 to drill an irrigation well, and $45,000 to drill a municipal or industrial well.[198] The average cost of a 6-inch drilled well is estimated at $7 to $15 per foot plus $7 to $10 per foot for steel casing. A shallow well pump may cost $270 to $450 and a deep well pump $530 to $1,900, plus installation (1990 adjusted cost).

CLEANING AND DISINFECTION

Special precautions must be taken before entering an open or covered well, spring basin, reservoir, storage tank, manhole, pump pit, or excavation to avoid accidents due to lack of oxygen (and excess carbon dioxide) or exposure to hazardous gases such as hydrogen sulfide or methane, which are found in groundwater and underground formations. Hydrogen sulfide, for example, is explosive and very toxic. Methane is flammable and in a confined space displaces oxygen. Open flames and sparks from equipment or electrical connections can cause explosion and hence must be prevented. Wells, tanks, and other confined spaces should be well ventilated before entering. Mechanical ventilation should be on and the atmosphere tested for oxygen and toxic gases *before* entering. In any case, the person entering should use a safety rope and full-body harness, and two strong persons above the ground or the tank should be ready to pull the worker out should dizziness or other weakness be experienced. Self-contained positive-pressure breathing apparatus should be available and used. It is essential to comply with state and federal occupational safety and health requirements. These include, in addition to confined space entry, such matters as hazardous operations and chemical handling, respiratory protection, electrical safety, excavations, and construction safety.

Wells and Springs

Wells or springs that have been altered, repaired, newly constructed, flooded, or accidentally polluted should be thoroughly cleaned and disinfected after all the work is completed. The sidewalls of the pipe or basin, the interior and exterior surfaces of the new or replaced pump cylinder and drop pipe, and the walls and roof above the water line, where a basin is provided, should be scrubbed clean with a stiff-bristled broom or brush and detergent, insofar as possible, and then washed down or thoroughly sprayed with water followed by washing or thorough spraying with a strong chlorine solution. A satisfactory solution for this purpose may be prepared by dissolving 1 ounce of 70 percent high-test calcium hypochlorite made into a paste, 3 ounce of 25 percent chlorinated lime made into a paste, or 1 pint of 5-1/4 percent sodium hypochlorite in 25 gallon of water. The well or spring should be pumped until clear and then be disinfected.

To disinfect the average well or spring basin, mix 2 quarts of 5-1/4 percent “bleach” in 10 gallons of water. Pour the solution into the well; start the pump and open all faucets. When the chlorine odor is noticeable at the faucets, close each faucet and stop the pump. It will be necessary to open the valve or plug in the top of the pressure tank, where provided, just before pumping is stopped in order to permit the strong chlorine solution to come into contact with the entire inside of the tank. Air must be readmitted and the tank opening closed when pumping is again started. Mix one more quart of bleach in 10 gallons of water and pour this chlorine solution into the well or spring. Allow the well to stand idle at least 12 to 24 hours; then pump it out to waste, away from grass and shrubbery, through the storage tank and distribution system, if possible, until the odor of chlorine disappears. Bypass or disconnect the carbon filter if it is part of the system; do not drain into the septic tank. *It is advisable to return the heavily chlorinated water back into the well, between the casing and drop pipe where applicable, during the first 30 minutes of pumping to wash down and disinfect the inside of the casing and the borehole, insofar as possible*. A day or two after the disinfection, *after the well has been pumped out and all the chlorine has dissipated*, a water sample may be collected for bacterial examination to determine whether all contamination has been removed. If the well is not pumped out, chlorine may persist for a week or longer and give a very misleading bacteriological result if a sample is collected and examined. It is not unusual to repeat well disinfection several times, particularly where contaminated water has been used during drilling and where the well has not been adequately surged, cleaned, and pumped out.

A more precise procedure for the disinfection of a well or spring basin is to base the quantity of disinfectant needed on the volume of water in the well or spring. This computation is simplified by making reference to Table 2.17.

Although a flowing well or spring tends to cleanse itself after a period of time, it is advisable nevertheless to clean and disinfect all wells and springs that have had any work done on them before they are used.

Scrub and wash down the spring basin and equipment. Place twice the amount of calcium hypochlorite, swimming pool chlorine erosion tablets, or granular chlorine indicated in Table 2.17 in a weighted plastic container fitted with a cover. Punch holes in the container and fasten a strong line to the container and secure the cover. Suspend the can near the bottom of the well or spring, moving it up and down or around in order to distribute the strong chlorine solution formed throughout the water entering and rising up through the well or spring.

It should be remembered that disinfection is no assurance that the water entering a well or spring will be pollution free. The cause for the pollution, if present, should be ascertained and removed. Until this is done, all water used for drinking and culinary purposes should first be boiled.

TABLE 2.17 Quantity of Disinfectant Required to Give a Dose of 50 mg/l Chlorine

Diameter of Well, Spring, or Pipe (in.)	Gallons of Water per feet of Water Depth	Ounces of Disinfectant/10-ft Depth of Water		
		70% Calcium Hypochlorite[a]	25% Calcium Hypochlorite[b]	5-1/4% Sodium Hypochlorite[c]
2	0.163	0.02	0.04	0.20
4	0.65	0.06	0.17	0.80
6	1.47	0.14	0.39	1.87
8	2.61	0.25	0.70	3.33
10	4.08	0.39	1.09	5.20
12	5.88	0.56	1.57	7.46
24	23.50	2.24	6.27	30.00
36	52.88	5.02	14.10	66.80
48	94.00	9.00	25.20	120.00
60	149.00	14.00	39.20	187.00
72	211.00	20.20	56.50	269.00
96	376.00	35.70	100.00	476.00

[a] $Ca(OCl)_2$, also known as high-test calcium hypochlorite. A heaping teaspoonful of calcium hypochlorite holds approximately 1/2 oz. One liquid ounce = 615 drops = 30 ml.

[b] $CaCl(OCl)$.

[c] $Na(OCl)$, also known as bleach, Clorox, Dazzle, Purex, Javel Water, and Regina, can be purchased at most supermarkets and drugstores.

Pipelines

The disinfection of new or repaired pipelines can be expedited and greatly simplified if special care is exercised in the handling and laying of the pipe during installation. Trenches should be kept dry and a tight-fitting plug provided at the end of the line to keep out foreign matter. Lengths of pipe that have soiled interiors should be cleansed and disinfected before being connected. Each continuous length of main should be separately disinfected with a heavy chlorine dose or other effective disinfecting agent. This can be done by using a portable hypochlorinator, a hand-operated pump, or an inexpensive mechanical electric or gasoline-driven pump throttled down to inject the chlorine solution at the beginning of the section to be disinfected through a hydrant, corporation cock, or other temporary valved connection. Hypochlorite tablets can also be used to disinfect small systems, but water must be introduced very slowly to prevent the tablets being carried to the end of the line.

The first step in disinfecting a main is to shut off all service connections, then flush out the line thoroughly by opening a hydrant or drain valve below the section to be treated until the water runs clear. A velocity of at least 3 fps should be obtained. (Use a hydrant flow gauge.) After the flushing is completed, the valve is partly closed so as to waste water at some known rate. The rate of flow can be estimated with a flow gauge (the formula is in Appendix I) or by running the water into a can, barrel, or other container of known capacity and measuring the time to fill it. With the rate of flow known, determine from Table 2.18 the strength of chlorine solution to be injected into the main at the established rate of 1 pint in 3 minutes to give a dose of 50 mg/l. The rate of water flow can be adjusted and should be kept low for small-diameter pipe. It is a simple matter to approximate the time, in minutes, it would take for the chlorine to reach the open

TABLE 2.18 Hypochlorite Solution to Give a Dose of 50 mg/l Chlorine for Main Sterilization

Rate of Water Flow in Pipeline (gpm)	Quarts of 5-1/4% Sodium Hypochlorite Made Up to 10 gal with Water	Quarts of 14% Sodium Hypochlorite Made Up to 10 gal with Water	Pounds of 25% Chlorinated Lime to 10 gal Water	Pounds of 70% Calcium Hypochlorite to 10 gal Water
5	4.6	1.7	2.0	0.7
10	9.1	3.4	4.0	1.4
15	13.7	5.1	6.0	2.1
20	18.3	6.8	8.0	2.9
25	22.8	8.5	10.0	3.5
40	36.6	13.7	16.0	5.7

[a] *Notes*: Add hypochlorite solution at rate of 1 pt in 3 min. The 10-gal solution will last 4 hr if fed at rate of 1 pt in 3 min. Mix about 50% more solution than is theoretically indicated to allow for waste. A 100-mg/1 available chlorine solution is recommended by some agencies.

hydrant or valve at the end of the line being treated by dividing the capacity of the main in gallons by the rate of flow in gallons per minute. In any case, injection of the strong chlorine solution should be continued at the rate indicated until samples of the water at the end of the main show at least 50 mg/l residual chlorine. The hydrant should then be closed, chlorination treatment stopped, and the water system let stand at least 24 hours. At the end of this time the treated water should show the presence of 25 mg/l residual chlorine. If no residual chlorine is found, the operation should be repeated. Following disinfection, the water main should be thoroughly flushed out, to where it will do no harm, with the water to be used and samples collected for bacterial examination for a period of several days. If the laboratory reports the presence of coliform bacteria, the disinfection should be repeated until two consecutive satisfactory results are received. Where poor installation practices have been followed, it may be necessary to repeat the main flushing and disinfection several times. The water should not be used until all evidence of contamination has been removed as demonstrated by the test for coliform bacteria.

If the pipeline being disinfected is known to have been used to carry polluted water, flush the line thoroughly and double the strength of the chlorine solution injected into the mains. Let the heavily chlorinated water stand in the mains at least 48 hours before flushing it out to waste and proceed as explained in the preceding paragraph. Cleansing of heavily contaminated pipe by the use of a nontoxic, biodegradable, nonfoaming detergent and a "pig," followed by flushing and then disinfection, may prove to be the quickest method. Tubercles found in cast-iron pipe in water distribution systems protect microorganisms against the action of residual chlorine.

Where pipe breaks are repaired, flush out the isolated section of pipe thoroughly and dose the section with 200 mg/l chlorine solution and try to keep the line out of service at least 2 to 4 hours before flushing out the section and returning it to service.

Potassium permanganate can also be used as a main disinfectant. The presence and then the absence of the purple color can determine when the disinfectant is applied and then when it has been flushed out.[199] See also AWWA Standard for Disinfecting Water Mains, C651-86.

Storage Reservoirs and Tanks

Make sure the tank is adequately and continuously ventilated before entering. Check with an oxygen deficiency meter. Wear protective clothing during the work, including self-contained breathing apparatus with full-face piece. *Insist on all safety precautions*.

Before disinfecting a reservoir or storage tank, it is essential to first remove from the walls (also bottom and top) all dirt, scale, and other loose material. The interior should then be flushed out (a fire hose is useful) and disinfected by one of the methods explained below.

If it is possible to enter the reservoir or tank, prepare a disinfecting solution by dissolving 1 ounce of 70 percent calcium hypochlorite (e.g., HTH, Perchloron, Pitt-Chlor) made into a paste, 3 ounces of 25 percent calcium hypochlorite (chlorinated lime) made into a paste, or 1 pint of 5-1/4 percent sodium hypochlorite (e.g., bleach, Clorox, Dazzle,) in 25 gallons of water. Apply this strong 250-mg/1 chlorine solution to the bottom, walls, and top of the storage reservoir or tank using pressure-spray equipment. Let stand for at least 2 hours. *Follow safety precautions given in this chapter*. See also AWWA Standard C652.

Another method is to compute the tank capacity. Add to the empty tank 1.25 pounds of 70 percent calcium hypochlorite, 4 pounds of 25 percent chlorinated lime completely dissolved, or 1 gallon of 5-1/4 percent sodium hypochlorite for each 1000-gallon capacity. Fill the tank with water and let it stand for 12 to 24 hours. This will give a 100+-mg/1 solution. Then drain the water to waste, where it will do no harm. Dechlorinate if necessary.

A third method involves the use of a chlorinator or hand-operated force pump. Admit water to the storage tank at some known rate and add at the same time twice the chlorine solution indicated in Table 2.18 at a rate of 1 pint in 3 minutes. Let the tank stand full for 24 hours and then drain the chlorinated water to waste. Rinse the force pump immediately after use.

It should be remembered, when disinfecting pressure tanks, that it is necessary to open the air-relief or other valve at the highest point so that the air can be released and the tank completely filled with the heavily chlorinated water. Air should be readmitted before pumping is commenced. In all cases, a residual chlorine test should show a distinct residual in the water drained out of the tanks. If no residual can be demonstrated, the disinfection should be repeated.

Coliform bacteria, klebsiella, and enterobacter have been a problem in redwood water tanks. Klebsiella have been isolated from water samples extracted from redwood, which are apparently leached from the wood (especially new tanks) when the tank is filled with water. Tanks are treated with soda ash to leach out wood tannins (7 days duration) and disinfected with 200 mg/l chlorine water prior to use. A free chlorine residual of 0.2 to 0.4 mg/l in the tank water when in use will keep bacterial counts under control.[200]

EMERGENCY WATER SUPPLY AND TREATMENT

Local or state health departments should be consulted when a water emergency arises. Their sanitary engineers and sanitarians are in a position to render valuable, expert advice based on their experience and specialized training.

The treatment to be given a water used for drinking purposes depends primarily on the extent to which the water is polluted and the type of pollution present. This can be determined by making a sanitary survey of the water source to evaluate the significance of the pollution that is finding its way into the water supply. Bear in mind that all surface waters, such as from ponds, lakes, streams, and brooks, are almost invariably contaminated and hence must be treated. The degree of treatment required is based on the pollution present. However, under emergency conditions it is not practical to wait for the results of microbiological analyses. Be guided by the results of sanitary surveys, diseases endemic and epidemic in the watershed area, and such reliable local data as may be available. Using the best information on hand, select the cleanest and most attractive water available and give it the treatment necessary to render it safe. Prior approval of the regulatory agency is usually required. Water passing through inhabited areas is presumed to be polluted with sewage and industrial wastes. It must be boiled or given complete treatment, including filtration and disinfection, to be considered safe to drink. However, all chemical wastes may not be removed by conventional treatment.

Backpacker-type water filters with hand pump, manufactured by Katadyn[201] and First Need,[202] were found to be 100 percent effective in removing *Giardia* cysts when operated and maintained in accordance with the manufacturer's directions.[203] The Katadyn filter is also reported to remove bacteria and helminths from small quantities of water.

Boiling

In general, boiling clear water vigorously for 1 to 2 minutes will kill most disease-causing bacteria and viruses, including *E. histolytica* and *Giardia* cysts. Heating water to 158°F (70°C) will completely inactivate the *Giardia* cyst.[204] If sterile water is needed, water should be placed in a pressure cooker at 250°F (121°C) for 15 minutes.[205] A pinch of salt or aerating the water from one container to another will improve the taste of the water, but be careful not to recontaminate the water in the process.

Chlorination

Chlorination treatment is a satisfactory method for disinfecting water that is not grossly polluted. It is particularly suitable for the treatment of a relatively clean lake, creek, or well water that is of unknown or questionable quality. Chlorine for use in hand chlorination is available in supermarkets, drugstores, grocery stores, and swimming pool supply stores and can be purchased as a powder, liquid, or tablet. Store solutions in the dark. Chlorine is more effective in water at 68°F (20°C) than at 36°F (2°C) as well as at low pH and turbidity.

The powder is a calcium hypochlorite and the liquid a sodium hypochlorite. Both these materials deteriorate with age. The strength of the chlorine powder or liquid is on the container label and is given as a certain percent available chlorine. The quantity of each compound to prepare a stock solution, or the quantity of stock solution to disinfect 1 gallon or 1,000 gallons of water, is given in Table 2.19. When using the powder, make a paste with a little water, then dissolve the paste in a quart of water. Allow the solution to settle and then use the clear liquid, without shaking. The stock solution loses strength and hence should be made up fresh weekly. It is important to allow the treated water to stand for 30 minutes after the chlorine is added before it is used. Double the chlorine dosage if the water is turbid or colored.

TABLE 2.19 Emergency Disinfection of Small Volumes of Water

Product	Available Chlorine (%)	Stock Solution[a]	Quantity of Stock Solution to Treat 1 gal of Water[b]	Quantity of Stock Solution to Treat 1000 gal of Water[b]
Zonite	1	Use full strength	30 drops	2 qt
S.K., 101 solution	2-1/2	Use full strength	12 drops	1 qt
Clorox, White Sail,	5-1/4	Use full strength	6 drops	1 pt
Dazzle, Rainbow, Rose-X, bleach sodium	10	Use full strength	3 drops	1/2 pt
Hypochlorite sodium	15	Use full strength	2 drops	1/4 pt
Hypochlorite calcium hypochlorite, "bleaching powder," or chlorinated lime	25	6 heaping tablespoonfuls (3 oz) to 1 qt of water	1 teaspoonful or 75 drops	1 qt
Calcium hypochlorite	33	4 heaping tablespoonfuls to 1 qt of water	1 teaspoonful	1 qt
HTH, Perchloron, Pittchlor, calcium	70	2 heaping tablespoonfuls (1 oz)	1 teaspoonful	1 qt

[a] One quart contains 135 ordinary teaspoonfuls of water.
[b] Let stand 30 min before using. To dechlorinate, use sodium thiosulfate in same proportion as chlorine. One jigger = 1-1/2 liquid oz. Chlorine dosage is approximately 5–6 mg/l. (1 liquid oz = 615 drops.) Make sure chlorine solution or powder is fresh; check by making residual chlorine test. Double amount for turbid or colored water.

Chlorine-containing tablets suitable for use on camping, hunting, hiking, and fishing trips are available at most drugstores. The tablets contain 4.6 grains of chlorine; they deteriorate with age. Since chloramines are slow-acting disinfectants, the treated water should be allowed to stand at least 60 minutes before being used. Iodine tablets (Globaline) and halazone tablets are also available at most sporting goods stores and drugstores. Check the expiration date.

Homemade chlorinators may be constructed for continuous emergency treatment of a water supply where a relatively large volume of water is needed. Such units require constant observation and supervision as they are not dependable. Figures 2.23 and 2.24 show several arrangements for adding hypochlorite solution. In some parts of the country, it may be possible to have a commercial hypochlorinator delivered and installed within a very short time. Some health departments have a hypochlorinator available for emergency use. Communicate with the local or state health department for assistance and advice relative to the manufacturers of approved hypochlorinators. Simple erosion-type chlorinators can also be purchased or improvised for very small places. A daily report should

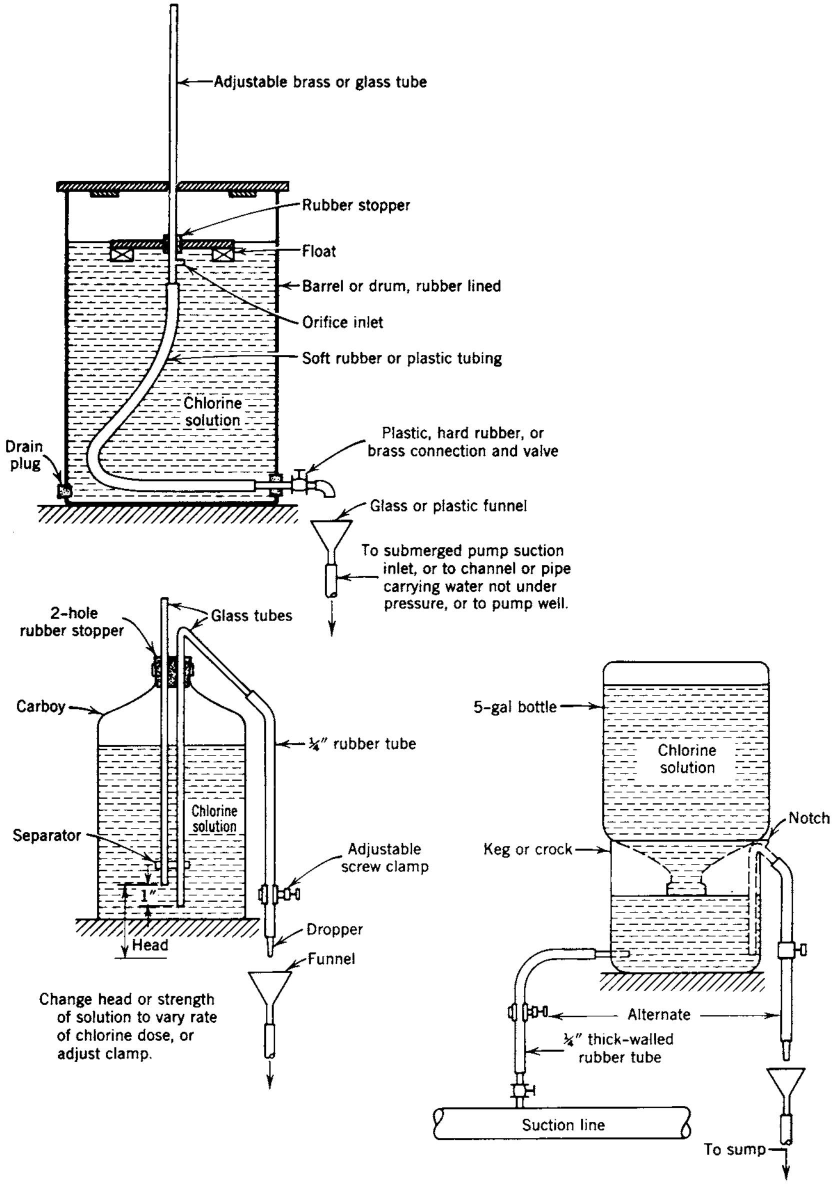
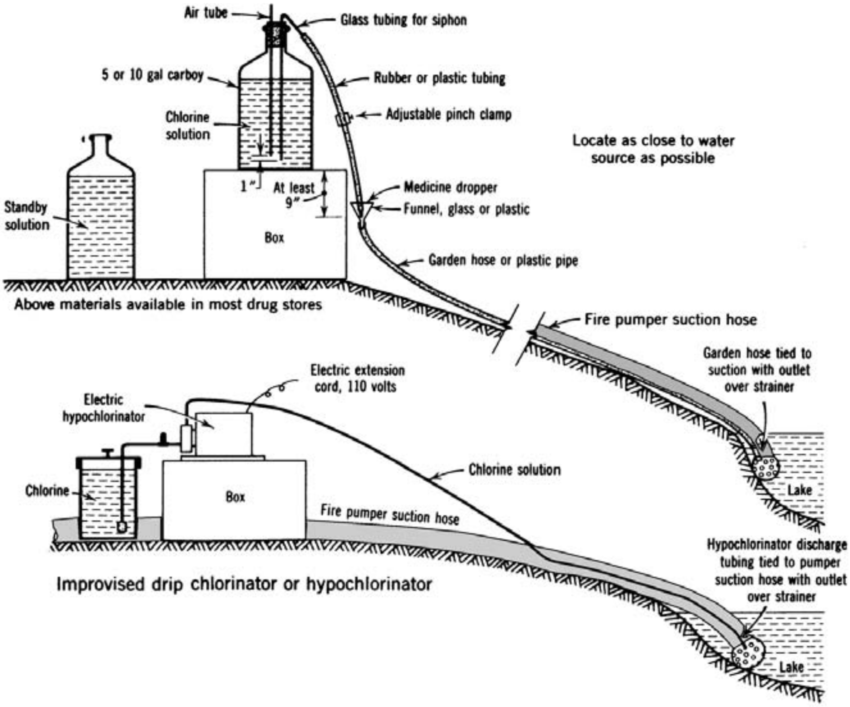


FIGURE 2.23 Homemade emergency hypochlorinators. To make chlorine solution, mix 4 pt of 5 percent hypochlorite to 5 gal of water.



Chlorine	Quantity to 5 gal Water	Rate of Feed 500 gpm Pumper
Perchloron or HTH, 70% available chlorine	4 lb*	4 oz or $\frac{1}{4}$ pt per min
Chlorinated lime, 24% available chlorine	12 lb*	4 oz or $\frac{1}{4}$ pt per min
Sodium hypochlorite, 14% available chlorine	20 pt	4 oz or $\frac{1}{4}$ pt per min

FIGURE 2.24 Emergency chlorination for fire supply, under health department supervision, for pumping into a hydrant on the distribution system, if necessary. Data for preparation and feed of chlorine solution: The asterisk denotes that the paste should be made in a jar. Add water and mix; let settle for a few minutes; then pour into carboy or other container and make up to 5 gal. Discard white deposit; it has no value. Dosage is 5 mg/l chlorine. Double solution strength if necessary to provide residual of 4 to 5 mg/l.

be kept showing the gallons of water treated, the amount of chlorine solution used, and the results of hourly residual chlorine tests.

Iodine

Eight drops of 2 percent tincture of iodine may be used to disinfect 1 quart of clear water (8 mg/l dose). Allow the water to stand at least 30 minutes before it is used. (Bromine can also be used to disinfect water, although its use has been restricted to the disinfection of swimming pool water.) Studies of the usefulness of elemental iodine show it to be a good disinfectant over a pH range of 3 to 8, even in the presence of contamination.[206] Combined amines are not formed to use up the iodine. A dosage of 5 to 10 mg/l, with an average of 8 mg/l for most waters, is effective against enteric bacteria, *Giardia* and amoebic cysts, cercariae, leptospira, and viruses within 30 minutes. Tablets that can treat about 1 quart of water may be obtained from the National Supply Service, Boy Scouts of America, large camping supply centers, drugstores, and the Army, in emergency. These tablets dissolve in less than 1 minute and are stable for extended periods of time. They are known as iodine water purification tablets, of which Globaline, or tetraglycine hydroperiodide, is preferred. They contain 8.0 mg of active iodine per tablet. The treated water is acceptable. Iodine is toxic. It should be reserved for emergency use only.[207]

Filtration in an Emergency

Portable pressure filters are available for the treatment of polluted water. These units can produce acceptable water, provided they are carefully operated by trained personnel. Preparation of the untreated water by settling, prechlorination, coagulation, and sedimentation may be necessary, depending on the type and degree of pollution in the raw water. Pressure filters contain special sand, crushed anthracite coal, or diatomaceous earth. Diatomite filtration, or slow sand filtration, should be used where diseases such as amebic dysentery, giardiasis, ascariasis, schistosomiasis, or paragonimiasis are prevalent, in addition, of course, to chlorination.

Slow sand filters (consisting of barrels or drums) may be improvised in an emergency. Their principles are given in Figure 2.2 and Table 2.2. It is most important to control the rate of filtration so as not to exceed 50 gpd/ft^2 of filter area and to chlorinate each batch of water filtered, as shown in Table 2.19, in order to obtain reliable results.

Bottled, Packaged, and Bulk Water

The bottled water industry has shown a large growth in many parts of the world because of public demand for a more palatable and "pure" water. It is not uncommon to find a wide selection of waters from various sources in the United States and Europe and in supermarkets and small grocery stores in almost all parts of the world. A major bottler in France was reported to have a capacity of 800 million bottles per year. The 1989 production in the United States was estimated at 1,384.4 million gallons per year.[208] There were an estimated 700 water-bottling plants in the United States in 1972.[209] In addition, self-service water vending machines that dispense water into an individual's container are available.* Per-capita consumption increased from 5.2 gallons in 1985 to 6.2 gallons in 1989, with a 1989 sales value of $2.375 billion, compared to $1.5

*Water vending maching sanitary design details are given in ref. 211.

billion in 1985 and $275 million in 1975.[210] The demand for bottled water is of course minimized where a safe, attractive, and palatable public water supply is provided.

In an emergency, it is sometimes possible to obtain bottled, packaged, or tank-truck water from an approved source that is properly handled and distributed. Such water should meet the federal and state drinking water standards as to source, protection, and microbiological, chemical, radiological, and physical quality. Water that is transported in tank trucks from an approved source should be batch chlorinated at the filling point as an added precaution. The tank truck, hoses, fittings, and connections should, of course, be thoroughly cleaned and disinfected (not less than 100 mg/l chlorine solution) before being placed in service. Detergents and steam are sometimes needed, particularly to remove gross pollution, followed by thorough rinsing with potable water and disinfection. Only tank trucks with a dedicated use for hauling potable water should be used. Each tank of water should be dosed with chlorine at the rate of 1 to 2 mg/l and so as to yield a free chlorine residual of not less than 0.5 mg/l. See Table 2.19.

Milk pasteurization plants and beverage bottling plants have much of the basic equipment needed to package water in paper, plastic, or glass containers. Contamination that can be introduced in processing (filtration through sand and carbon filters) and in packaging (pipelines, storage tanks, fillers) should be counteracted by germicidal treatment of the water just prior to bottling. In any case, the source of water, equipment used, and operational practices must meet recognized standards.

Bottled water should meet EPA and state water quality standards for drinking water and comply with FDA regulations and industry standards for the processing and bottling of drinking water.[212] Many states also have detailed regulations or codes including water quality standards. The National Sanitation Foundation also has guidelines and makes plant inspections. The FDA microbiological quality standards are 9 of 10 samples less than 2.2 coliforms per 100 ml, with no sample showing 9.2 or more by the multiple-tube fermentation method, and the arithmetic mean of all samples should be not greater than 1 per 100 ml with not more than one having 4.0 or more coliform organisms by the membrane filter method.[212] The standard plate count of the bottled water at the retail outlet should be less than 500 per 100 per milliliter. The FDA considers bottled water a "food" and regulates its purity.* Mineral water is exempt; its definition is vague. Mineral water has been defined as bottled water containing at least 500 ppm dissolved solids and originating entirely underground. Nevertheless, mineral waters should meet the physical, microbiological, and radiological standards for drinking water. Bottled water should also be free of *Pseudomonas aeruginosa*.

Bottled water may be labeled natural water (no change), natural sparkling water (carbon dioxide added), spring water (groundwater), purified water (demineralized), mineral water (assumed 500 ppm or greater total dissolved solids), seltzer water (carbonated tap water), and club soda (carbonated with salt

*Other standards refer to turbidity, color, odor, chemical quality, fluoride, and radiological quality.

and minerals added). Up to 0.02 percent caffeine and 0.5 percent alcohol by weight may be added to natural sparkling water, club soda, seltzer, and soda water, according to the FDA.[214]

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CHAPTER 3

WASTEWATER TREATMENT AND DISPOSAL

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DISEASE HAZARD

Improper disposal of human excreta and sewage is one of the major causes of disease in areas where satisfactory sewage treatment is not available. Because many pathogenic microorganisms are found in sewage, all sewage should be considered contaminated. The work of investigators who have studied the survival of enteric pathogens in soil, water, and wastewater has been summarized in a number of publications.[1] As an example, it is known that some pathogens can survive from less than a day in peat to more than 2 years in freezing moist soil.

The waterborne microbiological agents of greatest concern are pathogenic bacteria, viruses, helminths, protozoa, and spirochetes. Infectious bacterial agents are associated with shigellosis and salmonella infections, while viral agents are associated with infectious hepatitis A, viral gastroenteritis, and other enteric viral diseases. Helminths are associated with ascariasis, taeniasis, dracunculiasis, trichuriasis, toxocariasis, enterobiasis, and other illnesses. Protozoa are associated with amebiasis and giardiasis, while spirochetes are associated with leptospirosis.

The ability of treatment systems to remove these pathogens varies, depending on the system and the pathogen in question. For example, primary sedimentation can remove zero to 30 percent of all viruses; 50 to 90 percent of the bacteria, taenia ova and cholera vibrio; zero percent of the leptospires; 10 to 50 percent of the *Entamoeba histolytica*; 30 to 50 percent of the ascaris; and 80 percent of the schistosomes. By contrast, trickling filters can remove 90 to 95 percent of the viruses, bacteria, and cholera vibrio; zero percent of the leptospires; 50 percent of the *Entamoeba histolytica*; 70 to 100 percent of the ascaris; 50 to 99 percent

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of the schistosome ova; and 50 to 95 percent of the taenia ova. Activated sludge treatment can remove 90 to 99 percent of the viruses, bacteria, and cholera vibrio; zero percent of the leptospires; 50 percent of *Entamoeba histolytica*; 70 to 100 percent of the ascaris; and 50 to 99 percent of taenia ova. Stabilization ponds (not less than 25-day retention) can be expected to remove all viruses, bacteria, vibrio, leptospires, *Entamoeba histolytica*, ascaris, schistosome ova, and taenia ova. Septic tanks can be expected to remove 50 to 90 percent of the cholera vibrio, ascaris, schistosoma, and taenia present; 100 percent of the leptospires; and zero percent of the *Entamoeba histolytica*.[2] Waste stabilization ponds in series (three with 25-day retention) remove practically all enteric viruses, bacteria, protozoan cysts, and helminth eggs.[3] Chemical coagulation, flocculation, sedimentation, and filtration will remove nearly all viruses, bacteria, protozoa, and helminths, particularly if supplemented by chlorination or other effective disinfection treatment. Although sewage treatment does not in itself prevent the waterborne diseases caused by these pathogens (i.e., treatment of drinking water does that), proper sewage treatment is needed to minimize the pollution load on water treatment plants.

The improper treatment or disposal of untreated excreta, sewage, or other wastewater (including gray water) dramatically increases the possibility of disease transmission via direct contact with any of the following:

- Houseflies or other insects that land on excreta and then land on and/or bite people
- Inanimate objects such as children's toys that contact excreta and are subsequently handled by people
- Direct ingestion of contaminated water or food

Such occurrences are especially true in developing countries where enteric diseases are prevalent and clean water, sanitation, and personal hygiene are wanting. Studies have indicated that diarrheal illnesses, especially in young children, could be reduced 16 percent where water quality was improved, 25 percent where water, not necessarily potable, was made available, 37 percent where both water availability and quality were improved, and 22 percent where excreta disposal facilities were improved.[4]

In addition, sewage sludge accumulates heavy metals from wastewater. Because many of these metals are very toxic, the use of sewage sludge as a soil builder may result in higher levels of toxic metals in treated vegetation and animals that eat that vegetation. For that reason, sewage sludge should not be used as a soil builder or fertilizer supplement for forage crops unless it is known to be free of significant amounts of toxic metals or other pathogens. See "Biosolids Treatment and Disposal," this chapter.

Awareness of these dangers, coupled with adequate treatment of sewage, provision of potable water and sanitation, have been shown to be the primary reason why intestinal and waterborne diseases are at their present low level in many parts of the world.

Criteria for Proper Wastewater Disposal

Proper disposal of wastewater is necessary not only to protect the public's health and prevent contamination of groundwater and surface water resources, but also to preserve fish and wildlife populations and other beneficial uses (e.g., water-based recreation). To that end, the following six criteria should be used in designing and operating any wastewater disposal system:[5]

1. Prevention of microbiological, chemical, and physical pollution of water supplies and contamination of fish and shellfish intended for human consumption
2. Prevention of pollution of bathing and recreational areas
3. Prevention of nuisance, unsightliness, and unpleasant odors
4. Prevention of human wastes and toxic chemicals from coming into contact with man, grazing animals, wildlife, and food chain crops, or being exposed on the ground surface accessible to children and pets
5. Prevention of fly and mosquito breeding, and exclusion of rodents and other animals
6. Adherence to surface and groundwater protection standards as well as compliance with federal, state, and local regulations governing wastewater disposal and water pollution control

Failure to observe these criteria can result in the development of health hazards and the degradation of living conditions, recreational areas, and natural resources that are essential to the well being of the general public.

Definitions

Commonly used terms in wastewater treatment and disposal include the following:

Aerobic bacteria Bacteria that require free dissolved oxygen for their growth. Carbon, nitrogen, and phosphorus are required nutrients for growth.

Anaerobic bacteria Bacteria that grow only in the absence of free dissolved oxygen and obtain oxygen from breaking down complex organic substances.

Biochemical oxygen demand (BOD) The difference between the initial dissolved oxygen in a sample and the dissolved oxygen after a stated period of time, which is the amount of dissolved oxygen in milligrams per liter (mg/l) required during stabilization of the decomposable organic matter by aerobic bacterial action. Although incubation can be for either 5 days (carbonaceous demand satisfied) or 20 days (total carbonaceous plus nitrification demand satisfied), use of this term in this chapter refers to the 5-day demand test otherwise specified. The 20-day demand is used to measure the oxygen needed to oxidize inorganic materials such as sulfides and ferrous iron, as well as the oxygen needed to oxidize reduced nitrogen forms if the nitrifying organisms are present.

Biosolids The solid, semisolid, or liquid residue that is generated during the treatment of domestic waste. Examples of biosolids include sewage sludge and septage. Sewage sludge is the material that settles out of wastewater during its treatment in a treatment plant. Septage is the material that is pumped out of septic tanks.

Chemical oxygen demand (COD) A measure of the amount of oxygen, in mg/l, that is chemically—rather than biologically—consumed in the oxidation of organic and oxidizable inorganic materials in water. COD is usually higher than the BOD of the water. The test is relatively rapid and, while it does not oxidize some organic pollutants (pyridine, benzene, toluene), it does oxidize inorganic compounds that are not measured in the BOD analysis.

Coliform organisms Microorganisms found in the intestinal tract of humans and animals whose presence in water indicates fecal pollution and potentially adverse contamination by pathogens.

Dissolved oxygen (DO) The oxygen in water that is available to support aquatic life and that is used by wastewater discharged to a water body. Cold water holds more oxygen in solution than warm water. Game fish typically require at least 4 to 5 mg/l of DO. Absence of DO results in anaerobic conditions and foul odors.

Domestic sewage Wastewater from a home, which includes toilet, bath, laundry, lavatory, and kitchen-sink wastes. See Table 3.1. The strength of sewage is commonly expressed in terms of BOD, COD, and suspended solids. Normal domestic sewage will average less than 0.1 percent total solids in soft water regions.

Excreta The waste matter eliminated from the human body; about 27 grams per capita per day dry basis (100 to 200 grams wet). Mara[6] reports that human feces have an average weight per capita per day of 150 grams wet basis and contain 2,000 million fecal coliform, and 450 million fecal streptococci.

Facultative bacteria Bacteria that have the ability to live under both aerobic and anaerobic conditions.

Industrial waste Any liquid, gaseous, solid, or waste substance arising from industrial, manufacturing, trade, or business processes, which cause or might reasonably be expected to cause pollution of water.

National pollutant discharge elimination system (NPDES) The national system for the issuance of permits for the discharge of treated sanitary, industrial, and commercial wastes under the 1972 Federal Water Pollution Control Act. The NPDES permit specifies the treatment to be used by the discharger to protect water quality.

Nonpoint pollution Any source other than a point source that impacts the chemical, physical, biological, or radiological integrity of water.

TABLE 3.1 Characteristics of Wastewater[a]

Constituents	Domestic Wastewater (Community)[b]	Household Wastewater[c]	Septic Tank Household Effluent[d]	Gray Water[e,f]	Black Water[e,f]
Color					
nonseptic	Gray				
septic	Blackish		3.5		
Odor					
nonseptic	Musty				
septic	H_2S		4.5		
Temperature (°F)	55° to 90°[g]		63		
Total solids	800	968	820	528	621
Total volatile solids	425	514			
Suspended solids	200	376	101	162	77
Total nitrogen	40	84	36	11.3	153
Organic nitrogen	25				
Ammonia nitrogen	0.5	64	12	1.7	138
Nitrate nitrogen	0.5		0.12	0.12	0.22
Total phosphate	15	61	15	1.4	18.6
Total bacteria, per 100 ml	30×10^8		76×10^6		
Total coliform, MPN per 100 ml	30×10^6		110×10^6	24×10^6[g]	0.25×10^6
Fecal coliform, per 100 ml				1.4×10^6	0.04×10^6
BOD, 5-day	200	435	140	149	90
COD		709	675	366	258
Total organic carbon				125	97
Grease		65			
pH	7.5	8.1	7.4	6.8	7.8

[a] Average, in mg/l unless otherwise noted.
[b] Peter F. Atkins, "Water Pollution By Domestic Wastes," *Selection and Operation of Small Wastewater Treatment Facilities—Training Manual*. Charles E. Sponagle, U.S. EPA, Cincinnati, OH, April 1973, p. 3–3.
[c] K. S. Watson, R. P. Farrell, and J. S. Anderson, "The Contribution from the Individual Home to the Sewer System," *J. Water Pollution Control Fed*., December 1967, pp. 2039–2054.
[d] J. A. Salvato, Jr., "Experience with Subsurface Sand Filters," *Sewage Ind. Wastes*, **27**, 8, 909–916 (August 1955).
[e] Septic tank effluent. The higher concentration of coliform bacteria in the gray water effluent are attributed to the large amounts of undigested organic matter in kitchen wastewater.
[f] M. Brandes, Characteristics of Effluents from Separate Septic Tanks Treating Grey Water and Black Water from the Same House, Ministry of the Environment, Toronto, Canada, October 1977, pp. 9 and 27.
[g] For the Central States zone in United States.

Pollution Water pollution is the addition of agricultural, domestic, industrial, and commercial wastes in concentrations or quantities that result in the measurable degradation of water quality. A *point source* of pollution is "any discernible, confined, or discrete conveyance from which pollutants are or may be discharged,"[7] such as a pipe, ditch, well, vessel, vehicle, and feedlot.

Refractory organics Manmade organic compounds, such as chlordane, endrin, DDT, and lindane, that degrade very slowly. Also, a material having the ability to retain its physical shape and chemical identity when subjected to high temperatures.[8]

Sewer, sewerage, sewage, or wastewater treatment plant, or sewage works When stormwater and domestic sewage enter a sewer, it is called a *combined sewer*. If domestic sewage and stormwater are collected separately (i.e., in a *sanitary sewer* and a *storm sewer*), it is called a *separate sewer system*. A *sewer system* is a combination of sewer pipes and appurtenances for the collection, pumping, and transportation of sewage, or *sewerage*. When facilities for treatment and disposal of sewage are included, it is called either a *sewage* or *wastewater treatment plant* or *sewage works*.

Suspended solids Solids that are visible and in suspension in water.

Total organic carbon (TOC) A measure of the carbon as carbon dioxide. Because inorganic carbon compounds present can interfere with the test, they must be removed before the analysis is made, or a correction is applied.

Wastewater Sewage from domestic, agricultural, commercial and/or industrial establishments, which can also include surface and groundwater infiltration.

SMALL WASTEWATER DISPOSAL SYSTEMS

The number of households in the United States served by public sewers, septic tank or cesspool systems, or other means is shown in Table 3.2. With an estimated average occupancy of 3.0 persons per household in 1970, 2.7 in 1980, and 2.4 in 1990, a total of 58.5 million people were dependent on individual on-site facilities in 1970, 59.9 million in 1980, and 62.7 million in 1990. This represents 28.8 percent of the population in 1970, 26.4 percent in 1980, and 25.2 percent in 1990. Although data from the U.S. Census Bureau are not available for 2000, it is likely that the observed trends (i.e., an increase in the number of people using on-site facilities and a decrease in the percent of the total population using such facilities) continue today. At an estimated water usage of 50 gallons per capita per day, more than 3 billion gallons of sewage is discharged each day to on-site sewage disposal systems and ultimately to the groundwater that underlies these systems. For that reason alone, it is obvious that there is a need for continued support and research into ways to improve on-site sewage treatment and disposal facilities.

The most common system for wastewater treatment and disposal at homes in rural areas is by using a septic tank for the settling and treatment of the

TABLE 3.2 Housing Units Served by Public Sewers and Individual Facilities

Sewage Disposal Facility	Number of Housing Units Served[a]		
	1970	1980	1990
Public sewer	48,187,675	64,569,886	76,455,211
Septic tank or cesspool	16,601,792	20,597,165	24,670,877
Other means	2,904,375	1,602,338	1,137,590
Total housing units	67,693,842	86,769,389	102,263,678
Total population	203,302,031	226,542,203	248,709,873

[a] All units were not occupied.

Source: U.S. Census of Housing and Census Bureau.

wastewater and a subsurface absorption field for the disposal of the septic tank overflow. A soil percolation test is commonly used to determine the capacity of a soil to absorb septic tank overflow. Where soils are unsuitable, sand filters, elevated systems in suitable fill, evapotranspiration-absorption systems, evapotranspiration beds, aeration systems, stabilization ponds or lagoons, recirculating toilets, and various types of toilets and privies can be used. These systems are discussed later in this chapter.

Wastewater Characteristics

As noted in Table 3.1, wastewater from residential communities is fairly uniform. Wastewater from toilets is referred to as *black water*, while all other domestic wastewater is referred to as *gray water*. From a public health standpoint, gray water should be considered sewage and treated as such because it can also be expected to contain pathogens from shower and washbasin use, as well as the washing of baby diapers and soiled clothing.

Soil Characteristics

Soils may be divided, for classification purposes, into gravel, sand, silt, and clay. As noted in Table 3.3, the particle size of soil components decreases as classification moves from gravel to clay.

Clay and clay loam do not drain well and are usually considered unsuitable for the disposal of sewage and other wastewater by subsurface means. The permeability of a soil (i.e., its ability to absorb and allow water to pass through) is related to the chemical composition and physical structure of the soil. Soil with good structure will break apart, with little pressure, along definite cleavage planes. Prismatic and columnar structure enhances vertical percolation, and blocky and granular structure enhances both horizontal and vertical water flow.[9] If the color of the soil is yellow, brown, or red, it would indicate that air and water pass through. However, if it is blue or grayish, the soil is likely to have been saturated for extended periods and is probably unsuitable for subsurface absorption of wastewater. Magnesium and calcium tend to

TABLE 3.3 U.S. Department of Agriculture Size Limits for Soil Separates

Soil Separate	Size Range (mm)	Tyler Standard Sieve No.
Sand	2–0.05	10–270 mesh
Very coarse sand	2–1	10–16
Coarse sand	1–0.5	16–35
Medium sand	0.5–0.25	35–60
Fine sand	0.25–0.1	60–140
Very fine sand	0.1–0.05	140–270
Silt	0.25–0.002	—
Clay	<0.002	—

Source: *Design Manual, Onsite Wastewater and Disposal System*, U.S. EPA, Office of Water Program Operations, Washington, D.C., October 1980, pp. 367–374.

keep the soil loose, whereas sodium and potassium have the opposite effect. Sodium hydroxide, a common constituent of septic tank cleaners, would cause a breakdown of soil structure with resultant smaller pore space and reduced soil permeability.

Soil adsorptive capacity is an important consideration in the design of a septic tank system. Soils in which subsurface absorption fields are to be laid should have a low permeability (i.e., effective size 0.1 to 0.3 millimeter) and some adsorptive capacity to allow organic material to be retained. A minimum soil organic content of 0.5 to 1 percent is suggested and can be found in practically all agricultural soils, together with some clay and silt, which add to the adsorptive capacity. By contrast, a soil with low adsorption (e.g., coarse gravel) or a formation with solution channels, fractures, or fissures will permit pollution to travel long distances without purification.

Soil Suitability

It is necessary to have at least 2 feet of suitable soil between the bottom of absorption trenches and leaching pits and the highest groundwater level, clay, rock, or other relatively impermeable layer. This helps ensure removal of most of the pathogenic viruses, bacteria, protozoa, and helminths in septic tank effluent before they reach the groundwater. Some regulatory agencies require a minimum of 3 or 4 feet. Where the soil is relatively nonpermeable at shallow depths, an alternate treatment and disposal system is needed in place of a conventional leaching system. Preferably, construction should be postponed in such situations until sewers are available.

Pollutant Travel from Septic Systems

Groundwater contamination potential from a septic tank system is determined by the physical, chemical, and microbiological characteristics of the soil; the unsaturated soil depth to groundwater; the volume and strength of the septic tank effluent; and the biological slime or mat on the trench gravel, bottom, and sidewalls.

The percentage of clay and silt in a soil appears to be a major factor in bacteria retention and in bacteria die-off. For example, studies have shown that 4 feet of unsaturated coarse-grained sandy soil is not adequate to prevent bacteria from reaching saturated soils beneath septic tank absorption trenches. However, in loamy sandy soil, no bacteria traveled beyond 3.6 feet.[10] Soils containing loam (clay, silt, and sand) will remove most of the phosphorus, soluble orthophosphates, and microorganisms in sewage effluent. If the absorption trenches are kept shallow (top of gravel about 8 to 12 inches from the ground surface) as recommended, the vegetative cover root system over the absorption field penetrates and takes up much of the nitrogen during the growing season.

Laboratory studies have found that 40 to 50 cm of agricultural-type soil is very effective in removing viruses from water and that soil with reasonable amounts of silt and clay can remove viruses within the first 2 feet.[11] However, virus travel in sandy soil was reported at distances of 5 feet and was found in 6 and 20 foot-deep wells.[12] Also, Sorber et al. reported finding enteric viruses in soils at considerable distances from their point of application.[13]

Soil Percolation Test

The suitability of soil for the subsurface disposal of sewage can be determined by a study of soil characteristics and the soil percolation test. The test is a measure of the relatively constant rate at which clear water maintained at a depth of 6 inches will seep out of a standard size test hole that has been previously saturated and is at the same depth as the proposed absorption system. Henry Ryon first introduced this test in 1924,[14] and based on results for a wide range of soils developed "safe gallons per square foot per day subsurface irrigation rates." The work done by Ryon was confirmed by the U.S. Public Health Service (USPHS) in independent field tests and, despite of its limitations, serves as the basis for present-day design of septic systems.

Investigators have, however, differed regarding the interpolation of test results to determine the allowable rate of septic-settled sewage application per square foot of leaching area. This rate is a percentage of the actual amount volume of water a test hole accepts in 24 hours with rates ranging from 0.4 to 7.0 percent. Percolation test results are typically reported in terms of the minutes it takes for the water level in the test hole to drop 1 inch. Depending on percentage rate used, an allowable rate of settled sewage application in gallons per day per square foot (gpd/ft^2) of absorption trench bottom can be obtained from Table 3.4.

TABLE 3.4 Interpretation of Soil Percolation Test

Time for Water to Fall 1 in. (min)	Allowable Rate of Settled Sewage Application (gpd/ft^2)			
	U.S. PHS[a]	U.S. EPA[b]	GLUMR[c]	Ryon[g]
<1	5.0[d]	[b]	1.2	4.0 to 3.4
1	5.0[d]	1.2	1.2	3.3
2	3.5[d]	1.2	1.2	2.9
3	2.9[d]	1.2	1.2	2.7
4	2.5[d]	1.2	1.2	2.4
5	2.2[d]	1.2	1.2	2.2
6	2.0	0.8	0.9	
7	1.9	0.8	0.9	2.0
8	1.8	0.8	0.9	
9	1.7	0.8	0.9	
10	1.6	0.8	0.9	1.7
11	1.5	0.8	0.6	
12	1.4	0.8	0.6	
15	1.3	0.8	0.6	1.4
16	1.2	0.6	0.6	
20	1.1	0.6	0.6	1.1
25	1.0	0.6	0.6	
30	0.9	0.6	0.6	0.9
31	0.8	0.45	0.5	
35	0.8	0.45	0.5	
40	0.8	0.45	0.5	
45	0.7	0.45	0.5	0.7
46	0.7	0.45	0.45	
50	0.7	0.45	0.45	
60	0.6	0.45	0.45	0.4
61–120	[e]	0.2	[e]	0.2
>120	[f]	[e]	[e]	[f]

[a] USPHS, *Manual of Septic-Tank Practice*, USPHS Pub. 526, HEW, Washington, DC, 1967. Increase leaching area by 20 percent where a garbage grinder is installed and by additional 40 percent where a home laundry machine is installed. The required length of the absorption field may be reduced by 20 percent if 12 in. of gravel is placed under the distribution lateral, or by 40 percent if 24 in. of gravel is used, provided the bottom of the trench is at least 24 in. above the highest groundwater level.

[b] *Design Manual, Onsite Wastewater Treatment and Disposal Systems*, U.S. EPA, Cincinnati, OH, October 1980. Soils with percolation rates < 1 min/in. can be used if the soil is replaced with a suitably thick (>2 ft) layer of loamy sand or sand. Use 6 to 15 min/in. percolation rate. Reduce application rate where applied BOD and TSS is higher than domestic sewage. Additional area credit may be given for sidewall trench area if more than 6 in. of gravel is placed below the distributor. The EPA and GLUMR application rates are lower than the U.S. PHS rates. The former recognize the importance of settled sewage retention in the unsaturated zone to obtain maximum purification before it reaches the groundwater and results in a larger disposal system.

[c] GLUMR, *Recommended Standards for Individual Sewage Disposal Systems*, Great Lakes-Upper Mississippi River Board of State Sanitary Engineers, 1980 Edition. Absorption trench or bed shall not be constructed in soils having a percolation rate slower than 60 min/in., or where rapid percolation may result in contamination of water-bearing formation or surface water. The percolation rate is for *trench* bottom area. For absorption *bed*, use application rate of 0.6 gpd/ft^2 for percolation rate up to 6 min/in., then use 0.45 gpd/ft^2. Trench or bed bottom, or seepage pit bottom, should not be less than 3 ft above highest groundwater level. Maximum trench width credit shall be 24 in. for design purposes, even if trench is wider.

[d] Henry Ryon, *Notes on Sanitary Engineering*, New York State, Albany, 1924, p. 33. These and the U.S. PHS rates are given for historical perspective.

[e] Reduce rate to 2.0 gpd/ft^2 where a well or spring water supply is downgrade; increase protective distance, and place 6 to 8 in. sandy soil on trench bottom below gravel and between gravel and sidewalls.

[f] Soil not suitable.

[g] See Small Wastewater Disposal Systems for Unsuitable Soils or Sites, this chapter.

Many variations and refinements of the soil percolation test, including the use of a float gauge, inverted carboy as in a water cooler, and permeability test, have been proposed.[15] Whatever the case, enough tests should be conducted to give information representative of the soil, as indicated by a relatively constant rate of water drop in the test hole. This data should make it possible to determine an average percolation rate that can be used in design the septic tank system. A typical layout for such a system is shown in Figures 3.1 and 3.2.

Where a small subdivision is under consideration, at least three holes per acre should be tested. More holes should be tested if the percolation results vary widely, say by more than 20 percent. If rock, clay, hardpan, or groundwater is encountered within 4 feet of the ground surface, the property should be considered unsuitable for the disposal of sewage by means of conventional subsurface absorption fields.

Septic systems should not be constructed on filled-in ground until it has been thoroughly settled or otherwise stabilized. Percolation tests should be made in fill after at least a six-month settling period. Soil tests in fill often are not reliable as the soil structure, texture, moisture, and density will be quite variable and other disposal systems (see "Small Wastewater Disposal Systems for Unsuitable Soils or Sites" later in this chapter) should be considered.

When septic tank systems do fail, the cause is usually either improperly performed and interpreted soil percolation tests, high groundwater, poor construction, lack of maintenance, abuse of the system, or use of septic tanks where they were never intended. Inadequate design, lack of inspection by regulatory agencies, and failure to consider soil color, texture, and structure may also contribute to the problem.

Sewage Flow Estimates

The sewage flow to be expected from various establishments can vary, depending on the day of the week, season of the year, habits of the people, water pressure, type and number of plumbing fixtures, and type of place or business. For that reason, septic system design should be based on the average maximum flow rate to ensure adequate capacity. In the absence of actual figures, the per capita or unit estimated water flow given in Chapter 1 may be used as a guide. Alternatively, a fixture basis (see Table 3.5) can be used for estimating sewage flow rates. This approach assumes that all water used finds its way to the sewage disposal or treatment system. After adjusting for lawn watering and car washing, the total number of fixtures is multiplied by the flow from each fixture to obtain a rough estimate of the probable flow in gallons per day.

The design flow and sewage application rate for subsurface absorption systems also should take into consideration the strength of the septic tank effluent (BOD and TSS) in addition to the hydraulic loading rates already presented.

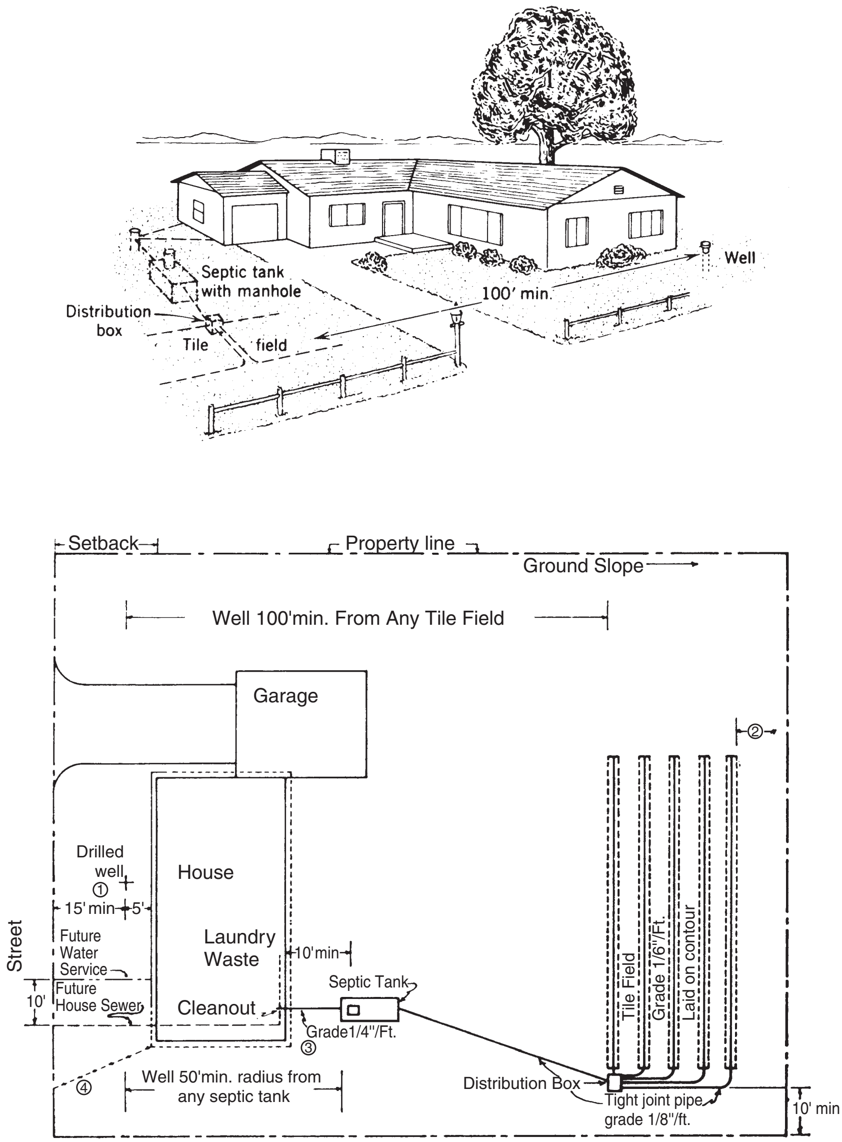


FIGURE 3.1 Typical private water supply and septic tank disposal systems. (Notes: (1) Watertight footing drain within 25 ft of well. (2) Tile field to be 50 ft or more from any lake, swamp, ditch, or watercourse and 10 ft or more from any waterline under pressure. (3) Cast-iron pipe, lead caulked joints within 50 ft of any well. (4) Discharge footing, roof, and cellar drainage away from sewerage system and well. (5) Grade lot to drain surface runoff away from the subsurface absorption system.)

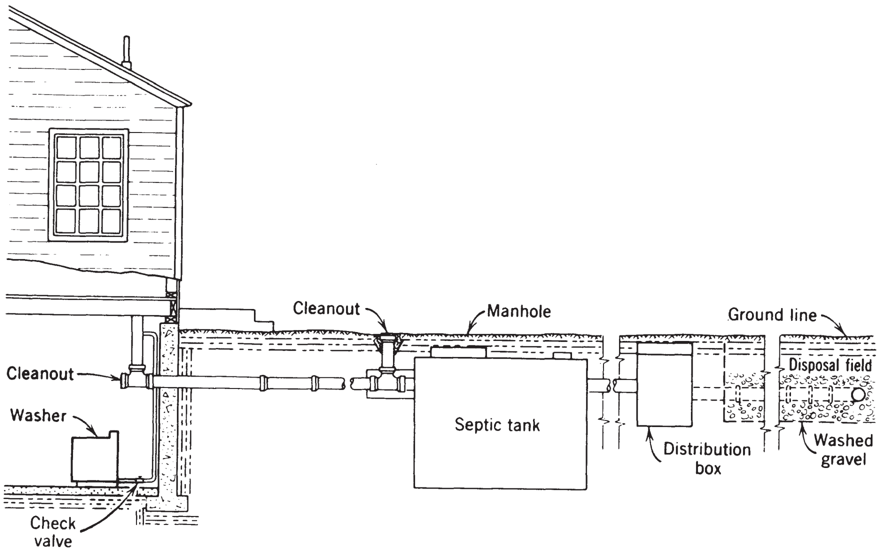


FIGURE 3.2 Cross-section of septic tank disposal system.

Septic Tank

A septic tank is a watertight tank designed to slow down the movement of raw sewage passing through it so that solids can settle out and be broken down by liquefaction and anaerobic bacterial action. Septic tanks do not purify the sewage, eliminate odors, or destroy all solid matter, but rather, simply condition sewage so that it can be disposed of using a subsurface absorption system. Suspended

TABLE 3.5 A Fixture Basis of Estimating Sewage Flow

Type of Fixture	Gallons per Day per Fixture, Country Clubs[a]	Gallons per Hour per Fixture, Public Parks[b]	Gallons per Hour per Fixture (Average), Restaurants[c]
Shower	500	150	17
Bathtub	300	—	17
Washbasin	100	—	8.5
Water closet	150	36	42 (flush valve) 21 (flush tank)
Urinal	100	10	21
Faucet	—	15	8.5, 21 (hose bib)
Sink	50	—	17 (kitchen)

[a] John E. Kiker, Jr., "Subsurface Sewage Disposal," *Fla. Eng. Exp. Sta*., Bull. No. 23 (December 1948).
[b] National Park Service.
[c] After M. C. Nottingham Companies, CA.

solids removal in such tanks is 50 to 70 percent; 5-day BOD removal is about 60 percent.

Recommended septic tank sizes based on estimated daily flows are given in Table 3.6. The septic tank should have a liquid volume of not less than 750 gallons. When a tank is constructed on the job, its liquid volume can be increased at a nominal extra cost, thereby providing capacity for possible future additional flow, garbage grinder, and sludge storage. A plastic sludge and gas deflector on the outlet as shown in Figure 3.3 is highly recommended.* The detention time for large septic tanks (see Table 3.6) should not be less than 24 to 72 hours. Schools, camps, theaters, factories, and fairgrounds are examples of places where the total or a very large proportion of the daily flow takes place within a few hours. For example, if the total daily flow takes place over a period of 6 hours, the septic tank should have a liquid volume equal to four times the 6-hour flow to provide a detention equivalent to 24 hours over the period of actual use. Septic tanks should be constructed of good-quality reinforced concrete, as shown in Figures 3.3 and 3.4. Precast-reinforced concrete and commercial tanks of metal, fiberglass, polyethylene, and other composition materials are also available. Because some metal tanks have a limited life, it is advisable that their purchase be predicated on their meeting certain minimum specifications (e.g., guaranteed 20-year minimum life expectancy, 12- or 14-gauge metal thickness, and acid-resistant coating).

If the septic tank is to receive ground garbage, its capacity should be increased by at least 50 percent. Some authorities recommend a 30 percent increase. Others recommend against garbage disposal to a septic tank.

Open-tee inlets and outlets as shown in Figure 3.3 are generally used in small tanks, and high quality reinforced concrete baffled inlets and outlets as shown in Figure 3.4 are recommended for the larger tanks.[16] Precast open concrete tees or baffles have, in some instances, disintegrated or fallen off; vitrified clay, cast-iron, PVC, ABS, or PE tees should be used. Cement mortar joints are unsatisfactory. Compartmented tanks are somewhat more efficient. The first compartment should have 60 to 75 percent of the total volume. A better distribution of flow and detention is obtained in the larger tank with a baffle arrangement of preferably rigid acid-resistant plastic. A minimum 16-inch manhole over the inlet of a small tank, and a 20- to 24-inch manhole over both the inlet and outlet of a larger tank are preferred.

An efficient septic tank design should provide for a detention period longer than 24 hours; an outlet configuration with a gas baffle to minimize suspended solids carryover (see Figure 3.3); maximized surface area to depth ratio for all chambers (ratio more than 2); and a multichamber tank with interconnections similar to the outlet design (open-tee inlet and outlet).[17]

*First suggested by Salvato in *Environmental Sanitation*, John Wiley & Sons, Inc., New York, 1958, p. 208.

TABLE 3.6 Suggested Septic Tank Dimensions

Population			Septic Tank[b,c]				Tile Field Laterals[c,d]	
Bedrooms	Persons	Sewage Flow (gpd)[a]	Length (ft)	Width (ft)	Depth (ft)	Volume (gal)	No. Length (ft)	Trench Width (in.)
2 or less	4	300	7.5	3.5	4	750		
3	6	450	9	4	4	1,000		
4	8	600	11	4	4	1,250		
5	10	750	10.5	5	4	1,500		
			12	5	4	1,750		
	(Tanks for		14	5	4	2,000		
	multiple		13	6	4	2,250		
	residences,		14.5	6	4	2,500		
	schools,		16	6	4	2,750		
	camps,		17	6	4	3,000	(DETERMINED BY SITE AND	
	fairgrounds,		16	6	5	3,500	SOIL PERCOLATION TEST)	
	factories)		16	7	5	4,000		
			19.5	7	5	5,000		
			20.5	8	5	6,000		
			24	8	5	7,000		
			23	8	6	8,000		
			28	8	6	10,000		

[a] The design basis is 75 gal per person and 150 gal per bedroom.
[b] Includes provision for home garbage grinder and laundry machine. Larger than minimum size septic tank is strongly recommended.
[c] See detail drawings for construction specifications.
[d] Based on the results of soil percolation tests. Discharge all kitchen, bath, and laundry wastes through the septic tank, but *exclude* roof and footing drainage, surface and groundwater, and softener wastes.

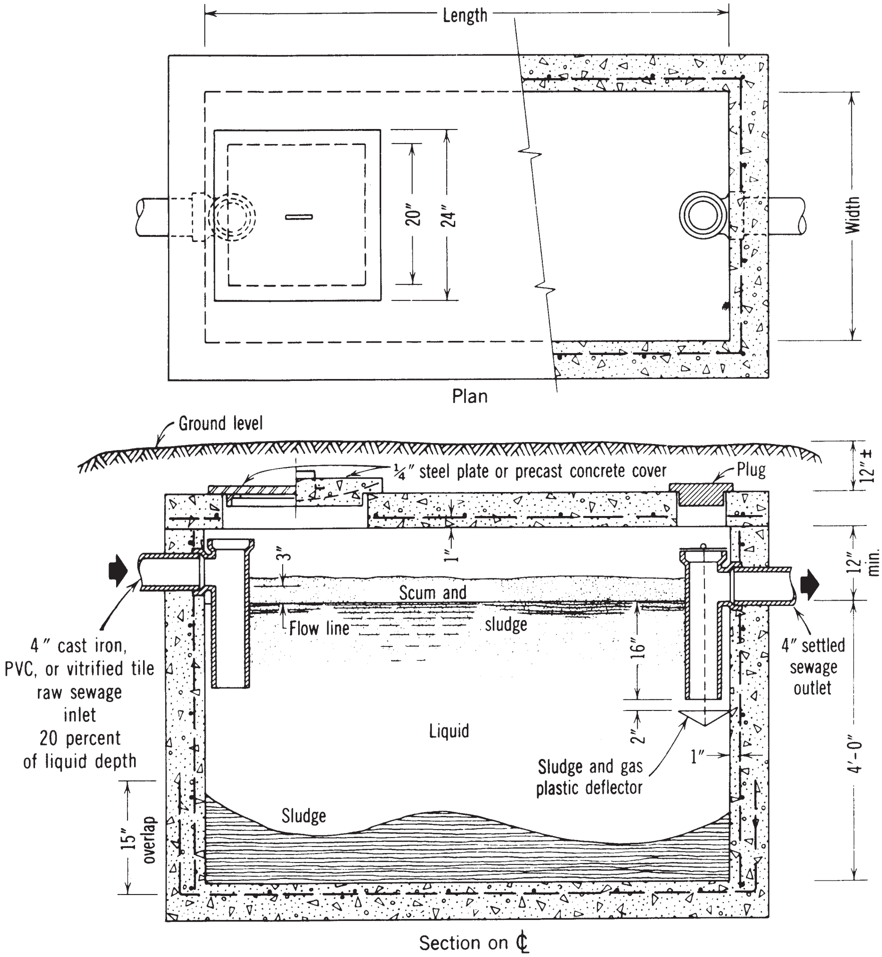


FIGURE 3.3 Details for small septic tanks. Recommended construction for small septic tanks: Top—Reinforced concrete poured 3- to 4-in. thick with two 3/8-in. steel rods per ft, or equivalent, and a 20- × 20-in. manhole over inlet, or precast reinforced concrete 1-ft slabs with sealed joints. Bottom—Reinforced concrete 4in. thick with reinforcing as in "top" or plain poured concrete 6in. thick. Walls—Reinforced concrete poured 4in. thick with 3/8-in. steel rods on 6-in. centers both ways, or equivalent; plain poured concrete 6in. thick; 8-in. brick masonry with 1-in. cement plaster inside finish and block cells filled with mortar. Concrete mix—One bag of cement to 2.25 in. of sand to 3 ft^3 of gravel with 5 gal of water for moist sand. Use 1:3 cement mortar for masonry and 1:2 mortar for plaster finish. Gravel or crushed stone and sand shall be clean, hard material. Gravel shall be 0.25 to 0.5 in. in size; sand from fine to 0.25 in. Bedding—At least 3 in of sand or pea gravel, leveled.

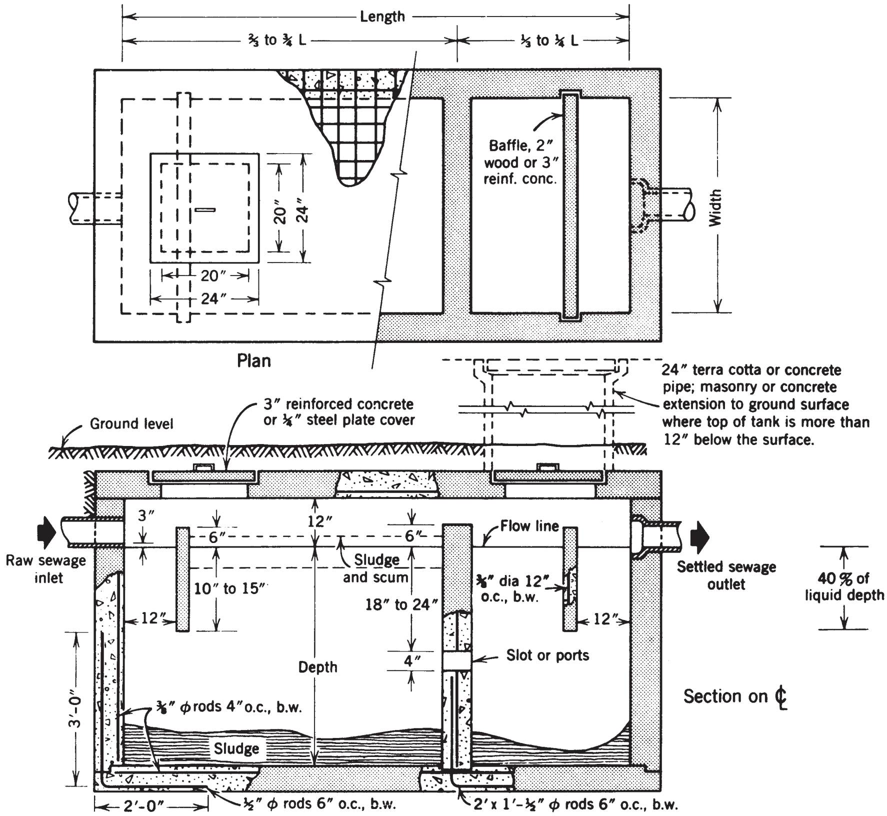


FIGURE 3.4 Details for large septic tanks. (See Table 3.6.)

Care of Septic Tank and Subsurface Absorption Systems

A septic tank for a private home will generally require cleaning every 3 to 5 years, depending on occupancy, but in any case, it should be inspected once a year. If a garbage disposal unit is used, more frequent cleaning is needed. Septic tanks serving commercial operations should be inspected at least every 6 months. When the depth of settled sludge or floating scum approaches the depth given in Table 3.7, the tank needs cleaning.[18] Sludge accumulation in a normal home septic tank has been estimated at 69 to 80 liters (18 to 21 gallons) per person per year.[19] The appearance of particles or scum in the effluent from a septic tank going through a distribution box is also an indication of the need for cleaning. Routine inspection and cleaning will prevent solids from being carried over and clogging leaching systems.

Septic tanks are generally cleaned by septic tank–cleaning firms. Sludge sticking to the inside of a tank that has just been cleaned would have a seeding effect and assist in renewing the bacterial activity in the septic tank. The septic tank

TABLE 3.7 Allowable Sludge Accumulation (in.)

Tank Capacity (gal)	Sludge Depth (in.) Tank Liquid Depth (in.)			
	30	36	48	60
250	4			
300	5	6		
400	7	9	10	
500	8	11	13	15
600	10	14	16	18
750	13	16	19	23
900	14	18	22	26
1,000	14	18	23	28
1,250		18	24	30

Source: Adapted from *Manual of Septic-Tank Practice*, U.S. PHS Pub. 526, DHEW, Cincinnati, OH, 1967.

should not be scrubbed clean. The use of septic tank cleaning solvents or additives containing halogenated hydrocarbon, aromatic hydrocarbon, or hazardous chemicals can cause carryover of solids, and clogging of absorption field as well as contamination of groundwater and should not be permitted.

An individual should never enter a septic tank that has been emptied, regardless of whether it is open or covered. Cases of asphyxiation and death have been reported due to the lack of adequate oxygen or presence of toxic gases in the emptied tank. If it should become necessary to inspect or make repairs, the tank should first be checked with a gas detector[20] for oxygen and toxic gases and thoroughly ventilated using a blower, which is kept operating.

Although soap, drain solvents, disinfectants, and similar materials used individually for household purposes are not harmful to septic tank operation unless used in large quantities, organic solvents and cleaners, pesticides, and compounds containing heavy metals could contaminate the groundwater and well-water supplies and should not be disposed of in a septic tank system. Also, sanitary napkins, absorbent pads, and tampons should not be disposed of in septic systems.

High weeds, brush, shrubbery, and trees should not be permitted to grow over an absorption system or sand filter system. It is better to crown the bed and seed the area with grass. If trees are near the sewage disposal system, difficulty with roots entering poorly joined sewer lines can be anticipated. About 2 to 3 pounds of copper sulfate crystals flushed down the toilet bowl once a year will destroy roots that the solution comes into contact with, but will not prevent new roots from entering. The application of the chemical should be done at a time, such as late in the evening, when the maximum contact time can be obtained before dilution. Copper sulfate will corrode chrome, iron, and brass, hence it should not be allowed to come into contact with these metals. Copper sulfate in the recommended dosage will not interfere with operation of the septic tank. A U.S. EPA registered herbicide, or a chemical foam, is also reported to be effective.[21]

Common causes of septic tank system failures are seasonal high groundwater; carryover of solids into the absorption field due to use of septic tank cleaning compounds, lack of routine cleaning of the septic tank, or outlet baffle disintegration or loss; excessive water use or hydraulic overloading; settlement of the septic tank, connecting pipe, or distribution box; and improper design and construction of the absorption system, including compaction and smearing of absorption trench bottom and sidewalls.

Corrective measures, once the cause is identified, include water conservation measures such as reduced water usage, low-flow toilets and showerheads, and reduced water pressure. Other measures to consider are cleaning of septic tank and flushing out distribution lines, and installation of additional leaching lines; installation of a separate absorption system and division box or gate for alternate use with the annual resting of existing system; lowering the water table with curtain drains; discontinuation of use of septic tank cleaning compounds; replacement of corroded or disintegrated baffles; replacement or releveling of distribution box; cleaning of septic tank at least every 3 years; and disconnection of roof, footing, and area drains.

Subsurface Soil Absorption Systems

The conventional system used for treating septic tank effluent is an absorption field or leaching pit. Where the soil is not suitable for subsurface disposal, a sand filter, evapotranspiration system, modified tile field system, aeration system, system in fill, mound system, stabilization pond, or some combination may be used (these systems are discussed in later sections). In all cases, it is important to avoid compaction of trench bottoms and soil of the absorption system or construction during wet weather.

Absorption Field System

Design standards and details for absorption fields are shown in Figures 2.1, 2.2, and 2.5 and in Table 3.8. Absorption field laterals should be laid in narrow trenches (18 to 24 inches), parallel to the contour and perpendicular to the groundwater flow, preferably not more than 24 inches below the ground surface, and spaced as shown in the Figure 3.5, to provide dispersion of the septic tank effluent over a larger area and promote aerobic conditions in the trenches. The highest seasonal groundwater level should be at least 2 feet, and preferably 4 feet, below the bottom of trenches. Where laterals must be laid at a greater depth, gravel fill around the laterals should extend at least to the topsoil (see Figure 3.5). After settlement and grading, the absorption field area should be seeded to grass.

When the total length of the laterals is between 500 and 1,000 linear feet, a siphon or pump should be installed between the septic tank and absorption system to distribute the sewage to all the laterals. If the lateral length is 1,000 to 3,000 linear feet, the system should be divided into two or four sections with alternating

TABLE 3.8 Suggested Minimum Standards—Subsurface Absorption Fields

Item	Material	Size	Grade	Minimum Governing Distances: To Building or Property Line	To Well or Suction Line	To Water Service Line
Sewer to septic tank	Cast iron for 10 ft from bldg. recommended.	4 in. min. diameter recommended	0.25 in. per ft max., 0.125 in. per ft min.	5 ft or more recommended	2ft if cast-iron pipe, otherwise 50 ft	10 ft hor.[a]
Septic tank	Concrete or other app'd matl. Use a 1:2, 0.25:3 mix.	Min. 750 gal 4 ft liquid depth, with min. 16 in. M.H. over inlet.	Outlet 2 in. below inlet.	10 ft	50 ft	10 ft
Lines to distribution box and disposal system	Cast iron, vit. clay, concrete, or composition pipe.	Usually 4 in. diameter on small jobs.	$\frac{1}{8}$ in. per ft; but $\frac{1}{16}$ in. per ft with pump or siphon.	10 ft	50 ft	10 ft
Distribution box	Concrete, clay tile, masonry, coated metal, etc.	Min. 12 × 12 in. inside carried to the surface. Baffled.	Outlets at same level.	10 ft	100 ft	10 ft
Absorption field[b]	Clay tile, vit. tile, concrete, composition pipe, laid in washed gravel or crushed stone, 0.75 in. to 2.5 in. size, min. 12 in. deep.	4 in. dia., laid with open joint or perforated pipe. Depth of trench 24 ft to 30 in.	$\frac{1}{16}$ in. per ft, but $\frac{1}{32}$ in. per ft with pump or siphon.	10 ft except when fill used, in which case 20 ft required	100 ft	10 ft (25 ft from any stream; 50 ft recommended)

Sand filter[b]	Clean sand, all passing 0.25 in. sieve with effective size of 0.30 to 0.60 mm and uniformity coefficient less than 3.5. Flood bed to settle sand.	Send 2-1b sample to health dept. for analysis 15 days before construction.	Laterals laid on slope $\frac{1}{16}$ in. per ft; but $\frac{1}{32}$ in. per ft with pump or siphon.	10 ft	50 ft	10 ft (25 ft from any stream; 50 ft recommended)
Leaching or seepage pit[b]	Concrete block, clay tile, brick, fieldstone, precast.	Round, square, or rectangle	Line to pit 0.125 in. per ft.	20 ft	150 ft plus in coarse gravel	20 ft (50 ft from any stream)
Chlorine contact-inspection tank	Concrete, concrete block, brick, precast.	2×4 in. and 2 in. liquid depth recommended	Outlet 2 in. below inlet.	10 ft	50 ft	10 ft

[a]Water service and sewer lines may be in same trench, if cast-iron sewer with lead-caulked joints is laid at all points 12 in. below water service pipe; or sewer may be on dropped shelf at one side at least 12 in. below water service pipe, provided sound sewer pipe is laid below frost with tight and root-proof joints, which is not subject to settlement, superimposed loads, or vibration. Separate trenches are strongly recommended.

[b]*Manual of Septic-Tank Practice*, U.S. PHS Pub. 526 (1967), states that the leaching area should be increased by 20 percent where a garbage grinder is installed, and by 40 percent where a home laundry machine is also installed. It recommends that the gravel in the tile field extend at least 2 in. above pipe and 6 in. below the bottom of the pipe.

Note: A slope of $\frac{1}{16}$" per ft = 6.25' per 100' = 0.0052 ft per ft = 0.52 percent.

Note: All parts of disposal and treatment system shall be located above groundwater and *downgrade* from sources of water supply. The architect, builder, contractor, and subcontractor shall establish and verify all grades and check construction. Laundry and kitchen wastes shall discharge to the septic tank with other sewage. Increase the volume of the septic tank by 50 percent if it is proposed to also install a garbage grinder. No softening unit wastes, roof or footing drainage, surface water or groundwater shall enter the sewerage system. Where local regulations are more restrictive, they govern, if consistent with county and state regulations.

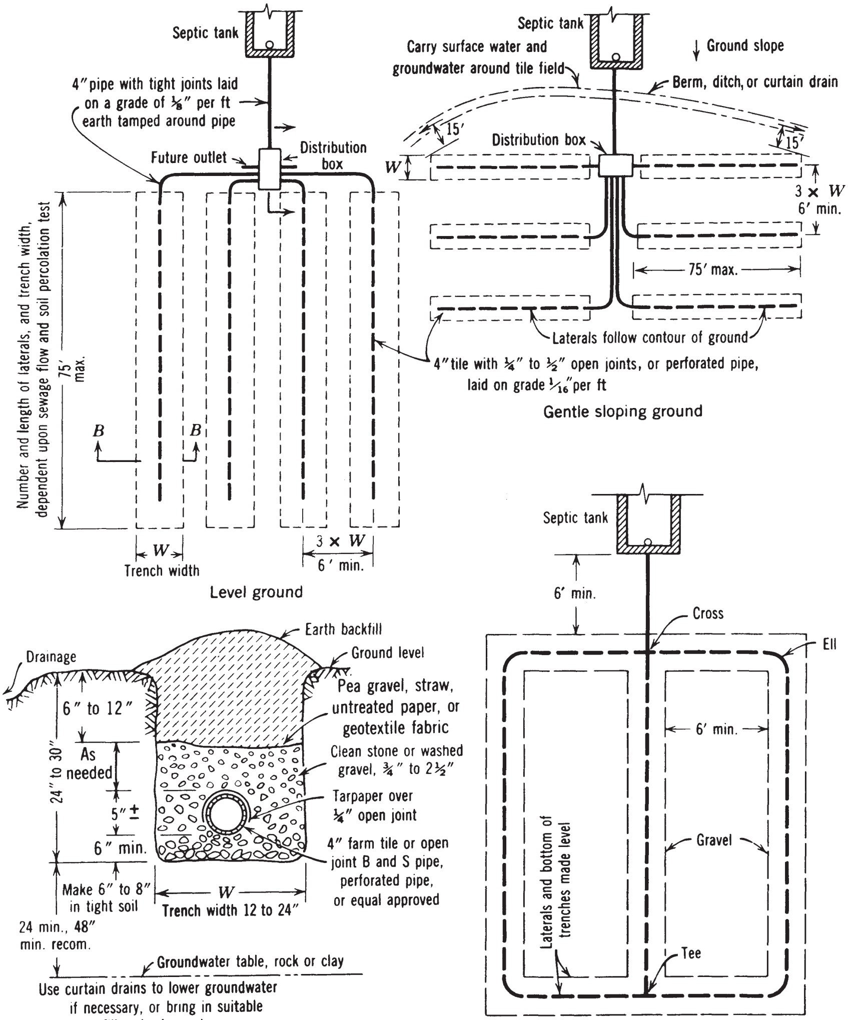


FIGURE 3.5 Typical arrangement and details for absorption field disposal system.

feed to each section. When lateral length exceeds 3,000 linear feet, it is advisable to investigate a secondary treatment process, although larger absorption systems can operate satisfactorily if the site and soil permeability are suitable to disperse effluent and prevent groundwater mounding.

The bottom of the absorption lateral trenches should be practically level to prevent sewage from running out the end of a trench or onto the ground surface. Laterals for absorption fields of less than 500 feet in total length, without siphon or pump, should be laid on a slope of $\frac{1}{16}$ inch/feet or 3 inches/50 feet. When siphons or pumps are used, the laterals should be laid on a slope of 3 inches/100 feet. Hydraulic loading rates should be kept between 0.25 and 0.5 gpd/ft^2.

Leaching Pit

Leaching pits, also referred to as seepage pits, are used for the disposal of settled sewage from septic tanks where the soil is suitable and a public water supply is used or where private well-water supplies are at least 150 to 200 feet away and at a higher elevation. Leaching pits work like a vertical absorption field, although they lack the areal extent of such fields. Pits are usually 10 to 20 feet deep and 6 to 12 feet in diameter. The bottom of the pit should be at least 2 feet, and preferably 4 feet, above the highest groundwater level. If this cannot be ensured, lateral absorption fields should be used. In special instances, where public water supply is available, suitable soil is found at greater depths, and groundwater can be protected, pits can be dug 20 to 25 feet deep or more, using precast perforated wall sections.

As part of the pit design, soil percolation tests should be conducted at mid-depth, at changes in the soil profile, and at the bottom of the proposed leaching pit. According to the 1980 *EPA Design Manual*, the weighted average of these tests should be used to obtain a design figure. Soil strata whose test results exceed 30 minutes per inch should not, however, be used in calculating the effective absorption area. Hydraulic loading rates for leaching pits should generally be kept between 0.4 and 0.8 gpd/ft^2, although the *EPA Manual* allows for up to 1.2 gpd/ ft^2 depending on the results of the percolation tests and the soil type present. The effective leaching area provided by a pit is equal to the vertical wall area of the pit below the inlet. Credit is not usually given for the pit bottom. A leaching pit is usually round to prevent cave-in. If precast perforated units are not used, the wall below the inlet is drywall construction—that is, laid with open joints, without mortar. Fieldstones, cinder or stone concrete blocks, precast perforated wall sections, or special cesspool blocks are used for the wall construction. Concrete blocks are usually placed with the cell holes horizontal. Crushed stone or coarse gravel should be filled in between the outside of the leaching pit wall and the earth hole. Table 3.9 gives the appropriate sizes for circular leaching pits and Figure 3.6 provides design details.

Since leaching pits concentrate pollution in a small area, their use should generally be avoided where the groundwater is a drinking water source. For this reason, use of such pits is frequently discouraged by regulatory agencies in favor of more diffuse systems, such as absorption fields.

Cesspool

Before septic tanks were widely used, sewage from individual dwellings was frequently discharged to cesspools. Cesspools are covered, open-joint or perforated walled pits that receive raw sewage. Their use is not recommended where the groundwater serves as a source of water supply. Many health departments

TABLE 3.9 Sidewall Areas of Circular Seepage Pits (ft^2)[a]

Seepage[b] Pit Diameter (ft)	Thickness of Effective Layers Below Inlet (ft) 1	2	3	4	5	6	7	8	9	10
1	3.1	6	9	13	16	19	22	25	28	31
2	6.3	13	19	25	31	38	44	50	57	63
3	9.4	19	28	38	47	57	66	75	85	94
4	12.6	25	38	50	63	75	88	101	113	126
5	15.7	31	47	63	79	94	110	126	141	157
6	18.8	38	57	75	94	113	132	151	170	188
7	22.0	44	66	88	110	132	154	176	198	220
8	25.1	50	75	101	126	151	176	201	226	251
9	28.3	57	85	113	141	170	198	226	254	283
10	31.4	63	94	126	157	188	220	251	283	314
11	34.6	69	104	138	173	207	242	276	311	346
12	37.7	75	113	151	188	226	264	302	339	377

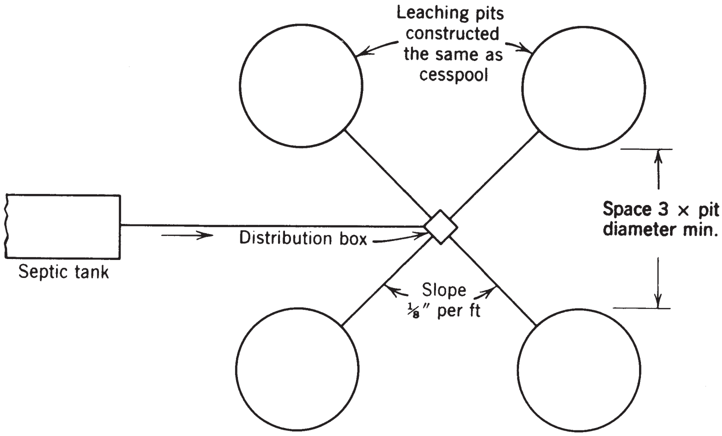
[a] Areas for greater depths can be found by adding columns. For example, the area of a 5-ft diameter pit, 15 ft deep is equal to 157 + 79, or 236 ft.
[b] Diameter of excavation.

Source: Design Manual, Onsite Wastewater Treatment and Disposal Systems, U.S. EPA, October 1980, p. 237.

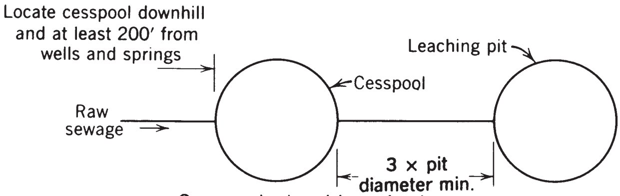
prohibit the installation of cesspools because pollution could easily travel from cesspools to wells used for water supply. Where cesspools are allowed, they should be located downgradient and 200 to 500 feet away from sources of water. The bottom of the cesspool should be at least 4 feet above the highest groundwater level. Cesspool construction is the same as a leaching pit. The cesspool system can be made more efficient under such circumstances by providing a tee outlet, as shown in Figure 3.6, with the overflow discharging to an absorption field or leaching pit. A preferable alternative would be to replace the cesspool with a septic tank and absorption field.

Dry Well

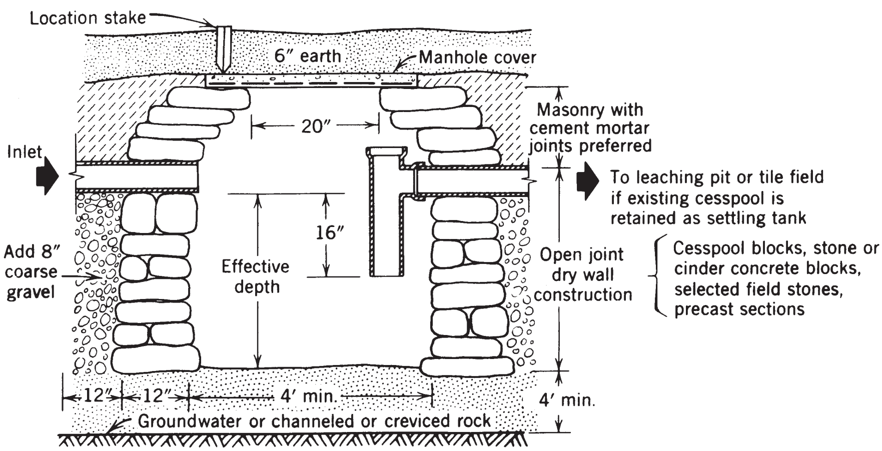
A dry well, which is constructed in the same way as a leaching pit, is used where the subsoil is relatively porous for the underground disposal of clear rainwater, surface water, or groundwater from roofs and/or basement floor drains. Roof or basement drainage should never be discharged to a septic tank because its volume will seriously overload such systems. Dry wells should not be used for the disposal of toilet, bath, laundry, or kitchen wastes. These wastes should be discharged to a septic tank. In some cases, roof drainage may be discharged to a nearby watercourse if permitted by local regulations. Dry wells should be located at least 50 feet from any water well, 20 feet from any leaching portion of a sewage disposal system, and 10 feet or more from building foundations or footings.



Septic tank – distribution box – leaching (seepage) pit plan



Cesspool – leaching pit plan



Cesspool section

FIGURE 3.6 Leaching pit details.

SMALL WASTEWATER DISPOSAL SYSTEMS FOR UNSUITABLE SOILS OR SITES

General

Wastewater treatment systems in this category are usually more complex in design and more costly than the conventional septic tank systems previously described. These systems include the modified absorption system, the capillary seepage trench, the absorption-evapotranspiration system, the sand filter system, the aerobic treatment unit, the septic tank mound system, the raised bed system, the underdrained absorption system, and the evapotranspiration system. Effluent from the sand filter system requires must be disposed of to a subsurface or land disposal system, if discharge to surface waters is not permitted. Low-pressure, vacuum, and cluster systems may also be appropriate in certain situations. Alternative systems are considered when a conventional system cannot be expected to function satisfactorily because of high groundwater, a relatively impervious formation is close to the surface, space is limited, or where a highly porous formation exists and protection of nearby well-water or surface water supplies is a major concern. Alternative systems are usually quite expensive and plans and an engineer's report are normally required for review and approval *prior to construction*.

Modified Septic Tank Soil Absorption System

A conventional subsurface soil absorption system is usually designed on the basis of soil percolation rates not exceeding 1 inch in 60 minutes. However, less permeable soils can still be used as long as application rates are reduced. Ryon in his original notes recommended the following application rates for 60-minutes or poorer soils.[22]

Time to fall 1 in. (hours)	Safe application rate (gpd/ft^2)
1	0.4
1	0.3
2.5	0.2
3	0.14
5	0.07
10	0.03

Construction of the modified system is similar to a conventional system. Intermittent or alternating dosing (siphon, pump, tipping bucket) is usually required, particularly if the total length of distributors exceeds 500 feet. Design for a relatively tight soil still uses the conventional soil percolation test but carries it beyond the 1 inch/60 minute test to a point of constant rate. Moisture loss due to evaporation and transpiration is not credited but taken as a bonus.

The following example gives the modified system design for a "tight" soil site of fairly uniform composition.

Example

Design a subsurface leaching system for a daily flow of 300 gal. The soil test shows 0.25 in./hr and a permissible settled sewage application of 0.10 gpd/ft^2.

$$\text{Required leaching area} = \frac{300}{0.10} = 300\,\text{ft}^2$$

If trenches 3 feet wide with 18-inches of gravel underneath lateral distributors are provided, each linear foot of trench can be expected to provide 5 ft^2 of leaching area. The required trench = 3,000/5 = 600 linear feet, or 8 laterals, each 75-feet long, spaced 9 feet on center. Two gravel beds, 50 by 60 feet, can also provide the leaching area needed to compensate for the loss of the sidewall trench infiltration and dispersion area (see Figure 3.7). Use an alternating dosing device. This occupies the same land area as the absorption field. Evapotranspiration can be enhanced by incorporating sand trenches or funnels in the gravel between the distributors.

Capillary Seepage Trench

Another alternative to traditional absorption field design is the use of a capillary seepage trench. The capillary seepage trench is similar to a conventional seepage trench except that it has an impermeable liner at the bottom of the trench, which extends part way up the trench's sidewalls. As a result, sewage effluent collects

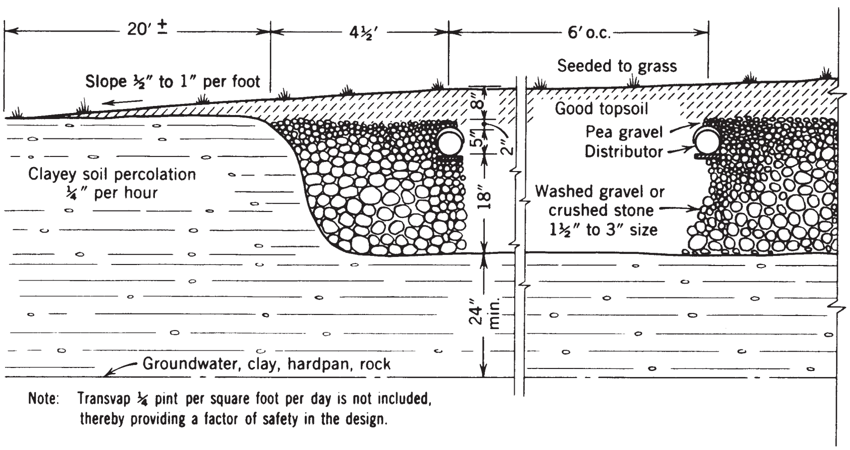


FIGURE 3.7 Absorption bed for a tight soil. Curtain drains may be needed to lower groundwater level and beds may need to be crowned to shed rainwater.

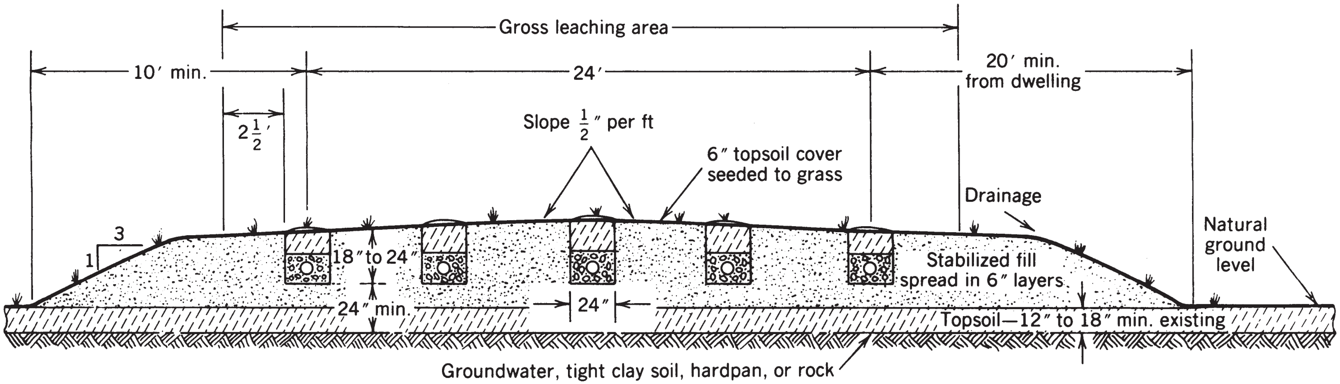
along the entire length of the trench and moves both upward and horizontally by capillary action before percolating downward. This modification in trench design results in a more even distribution and a longer time of contact. Fly ash is often used as trench fill material because it allows for more rapid capillary movement of the effluent and provides an increased surface area for microbial growth. Because a capillary seepage trench does not use the bottom of the trench as an absorption area, the trenches need to be longer than a conventional absorption trench.

Raised Bed Absorption-Evapotranspiration System

If clay, hardpan, groundwater, or rock is found within 4 feet of the ground surface, sewage disposal by a conventional absorption field is not recommended. Instead, a raised or build up area can be constructed using 12 to 18 inches of porous earth having a percolation rate of at least 1 inch in 120 minutes. A sandy, loamy, gravely soil is preferred and should be approximately 70 to 80 percent (by weight) medium to coarse sand (0.25 to 2.0 mm E.S.); 10 to 20 percent silt, fine sand and clay (0.25 or less mm E.S.); and not more than 10 percent gravel (2.0 mm to 7.5 cm E.S.). Preliminary percolation tests of the undisturbed soil can give an indication of its suitability. A long, narrow absorption field with fewer and longer laterals (75 to 100 feet), perpendicular to the groundwater flow, will provide greater area for underground wastewater dispersion, minimize possible groundwater mounding, and make seepage out of the toe of the feathered fill less likely.

The fill should be spread in 6-inch layers using a lightweight crawler tractor to achieve a uniform soil density without channels or holes. The fill soil should not be spread when it is wet or compacted. Also, sufficient fill should be provided so that the bottom of the absorption trenches are at least 2 feet above the highest ground water level, rock, clay, or hardpan. After soil stabilization (at least 6 months minimum), percolation tests should be run at four to six locations. The resultant percolation rates should be between 1 inch in 8 minutes and 1 inch in 31 minutes to prevent premature clogging, ensure effluent retention in the fill, and obtain maximum purification of sewage effluent before it reaches groundwater or ground surface.

An example of a raised bed system that uses both absorption and evapotranspiration is presented in Figure 3.8. In light of the uncertainties associated with these systems (e.g., uneven soil settlement and unreliability of percolation tests in fill), a conservative design is considered prudent. A fill percolation rate of 1 inch in 31 minutes, or 0.45 gpd/ft^2 (EPA, Table 3.4), which would correspond with a basal area application rate of 0.14 gpd/ft^2, is recommended. The basal area is the absorption field area extending 2.5 feet beyond the outer edges and ends of the distribution trenches. The absorption system should be dosed two to three times per day using a pump or siphon. The dose should be about 60 percent of the volume of the distribution lines. Intermittent operation will permit full dosage of the distribution laterals and enhance dispersion of the wastewater over the entire absorption field.



Section A–A

FIGURE 3.8 Raised bed sewage disposal system. Design basis: 300 gpd and a transvap-percolation rate of 0.45 gpd/ft^2 or trench bottom (total of 335 feet, 2 feet wide) or 0.14 gpd/ft^2 of system gross leaching area (72 × 31 feet). Pump or siphon distribution is usually required with dosing two or three times per day.

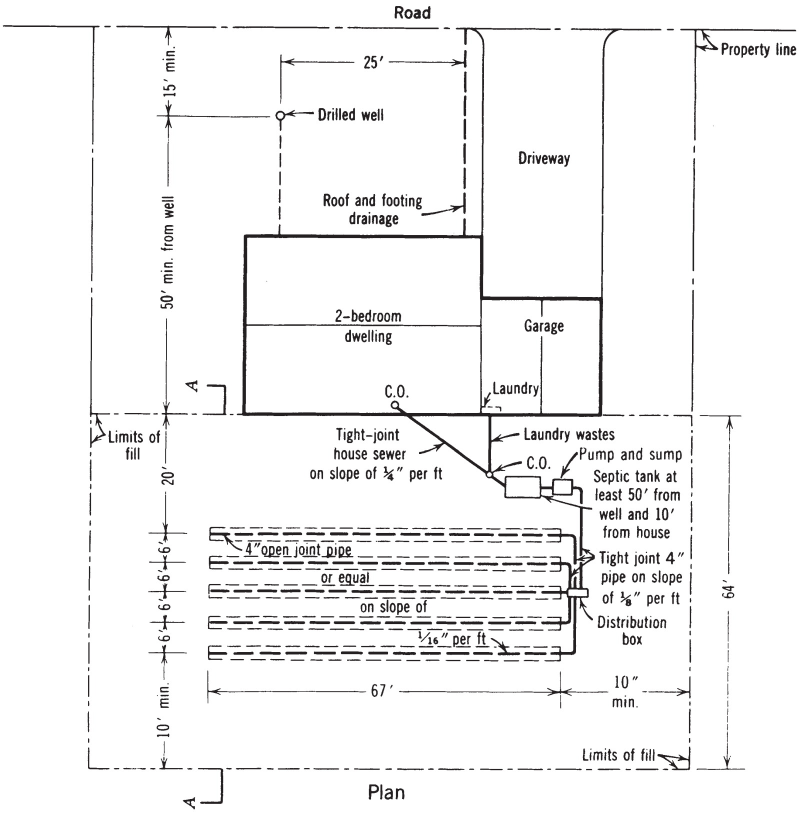
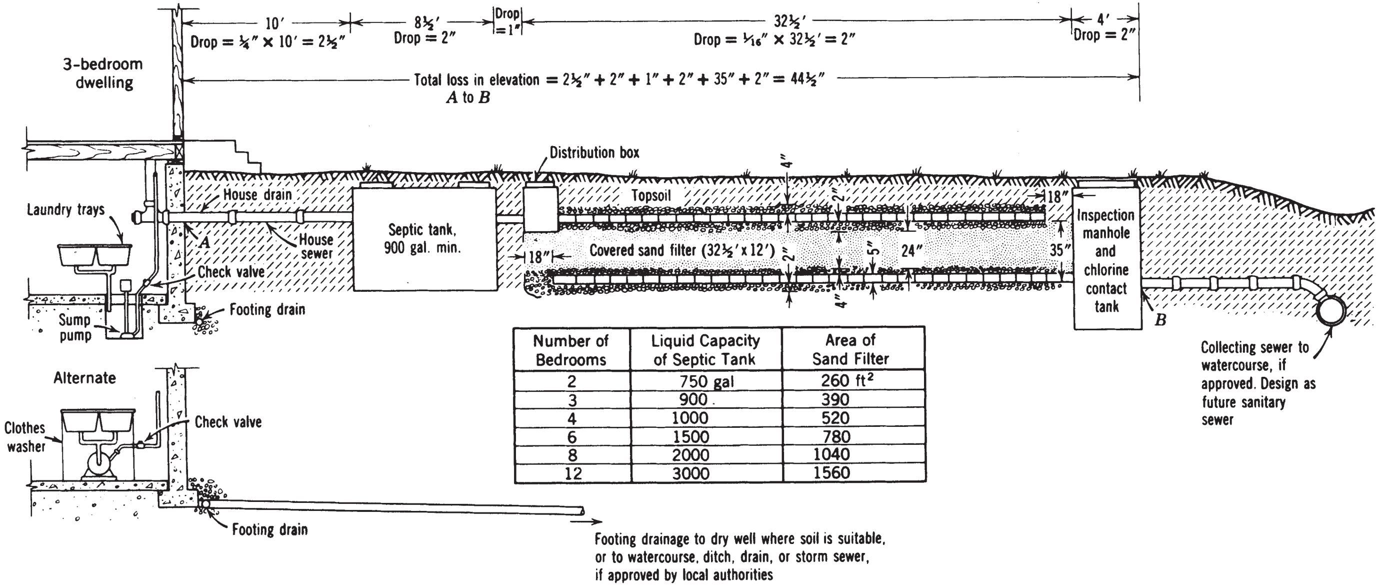


FIGURE 3.8 (*continued*)

The entire surface of the raised bed should be covered with at least 6 inches of topsoil, graded to enhance rainfall runoff, and seeded to grass. A diversion ditch or berm should be installed upgrade to divert surface runoff around the system. Also, a curtain drain may be needed in areas of high groundwater if the bottom of the trenches cannot be kept at least 2 feet above groundwater. If clay or hardpan is intercepted, the curtain drain trench and collection pipe should extend at least 6 inches into the impervious formation.

Septic Tank Sand Filter System

Sand filters can be used when conventional subsurface absorption systems are unlikely to function satisfactorily because of soil conditions or rock, or where space is very limited and discharge to a surface water or ditch is permissible. Settled sewage is typically distributed over the top of a sand filter bed by means of perforated, open-joint pipe as shown in Figure 3.9. The sewage is then filtered and oxidized through 24 to 30 inches of sand, on which a film of aerobic and nitrifying



Number of Bedrooms	Liquid Capacity of Septic Tank	Area of Sand Filter
2	750 gal	260 ft²
3	900	390
4	1000	520
6	1500	780
8	2000	1040
12	3000	1560

FIGURE 3.9 Section through covered sand filter system. Design basis is 150 gal per bedroom and filter rate 1.15 gpd/ft^2. Larger capacity septic tank (50 to 100 percent larger than minimum) is strongly recommended.

organisms form. Sand filters can provide relatively high removal efficiencies for most constituents (see Table 3.10). Such effluents should not cause a nuisance in undeveloped areas, but should be chlorinated if discharged in locations accessible to children or pets because microorganisms associated with disease transmission, although greatly reduced, are still present. Because operation of a sand filter is dependent on the rate and strength of sewage application, it is essential that suspended solids carryover from the septic tank be kept at a minimum.

The recommended sizes of covered sand filters for private homes are shown in Figure 3.9 and are based on a flow of 150 gpd per bedroom and a settled sewage application rate of 1.15 gal/ft^2 of sand filter area per day. It is extremely important to *use a proper sand* (i.e., coarse sand passing 0.25 inch mesh screen with effective size of 0.3 to 0.6 mm and a uniformity coefficient not greater than 3.5). Distributor and collector lines for the filter should laid at exact grade and a topsoil cover, preferably not exceeding 8 to 12 inches, should be placed over the gravel-covered distributor lines. Geotextile fabric should be installed between the topsoil and gravel. Filter rates for covered sand filters should not exceed 50,000 gpd/acre for settled domestic sewage and 100,000 gpd/acre for temporary summer. Rates for open filters can range from 75,000 to 100,000 gpd/acre for settled sewage and 200,000 to 400,000 gpd/acre for secondary treated sewage. Loading should normally not exceed 2.5 lb. of either 5-day BOD or suspended solids per 1,000 ft^2/day. Recommended filter rates related to climate and sand size are also given in the *Manual of Septic-Tank Practice*.[23]

In freezing weather open filters will require greater operational control and maintenance. Scraping the sand before freezing weather into furrows about 8 inches deep with ridges 24 to 48 inches apart will help maintain continuous operation, as ice sheets will form between ridges and help insulate the relatively warm sewage in the furrows. Greenhouse covers are very desirable and help ensure continuous operation of the filters; however, such covers are expensive.

TABLE 3.10 Typical Efficiencies of Subsurface Sand Filters[a]

Determination	Percent Reduction
Bacterial per ml, Agar, 36°C, 24 hr	99.5
Coliform group, MPN per 100 ml	99.6
BOD, 5-day (mg/l)	97
Suspended solids (mg/l)	88
Oxygen consumed (mg/l)	75
Total nitrogen (mg/l)	42
Free ammonia	94
Organic	72

[a]Effluent will contain 5.2 mg/l dissolved oxygen and 17 mg/l nitrates.

Source: J. A. Salvato, Jr., "Experience with Subsurface Sand Filters," *Sewage Ind. Wastes*, 27, *8*, 909–916 (August 1955).

Wood-frame covers may also be used. Regular maintenance is essential, including raking and weeding.

Aerobic Sewage Treatment Unit

Another type of treatment unit that can be used when subsurface absorption systems are not practical is the self-contained, prefabricated aeration unit. Although effluent from such units is low in suspended solids and BOD, it will still need further treatment for other constituents, such as nitrate. Such treatment can include sand filtration and/or chlorination prior to discharge to a stream, if permit, or discharge to an oxidation pond or irrigation system. Routine maintenance and operation of the unit must be ensured by a maintenance contract or other means. Design details for extended aeration and activated sludge treatment plants are given later. Small rotating biological contractors with 2- to 4-foot diameter discs and for flows of 350 to 1,500 gpd or more are also available. Their application and limitations are similar to the above aeration units. In some locations, where tight soil exists and ample property is owned, the waste stabilization pond, irrigation, oxidation ditch, or overland flow system design principles may be adapted to small installations. Design information is given under "Sewage Works Design—Small Treatment Plants."

Septic Tank Mound System

The septic tank mound system was originally developed in North Dakota in late 1947. Numerous refinements to this system have been made over the years, including those noted by Salvato,[24] Bouma, et al.,[25] and Converse, et al.[26] In the mound system, the absorption area is raised above the natural soil to keep the bottom of the trenches at least 2 feet above groundwater, bedrock, or relatively impermeable soil. In this respect, the system serves the same purpose as the built-up soil absorption system previously described. Where it differs is in the type and size of fill material and method used to apply septic tank effluent to the mound system (see Figure 3.10).

The texture and structure of the fill soil used (see Table 3.3) will affect its tendency to clog and its purification capacity; appropriate settled sewage application rates for the range of soil types used in mounds are listed in Table 3.11. In the mound system developed by Converse et al., a 2-foot bed of clean coarse sand was used (i.e., 0.5 to 1.0 mm effective size with less than 5 to 6 percent silt and clay and less than 15 to 16 percent fine and very fine sand).[27] To provide sufficient vertical and lateral spreading of the percolating wastewater, 2 feet of sand and 1 foot of natural topsoil is typically used.[28] However, experience indicates that mound systems can also be constructed (1) wholly in the natural soil, (2) partly in the natural soil, or (3) completely above the natural ground surface. Because design of a mound system is complex (i.e., involving hydraulic conductivity determinations, hydraulic analyses, pump/siphon selection and sand analyses), it should only be done by a qualified professional, preferably one with experience with mounds.

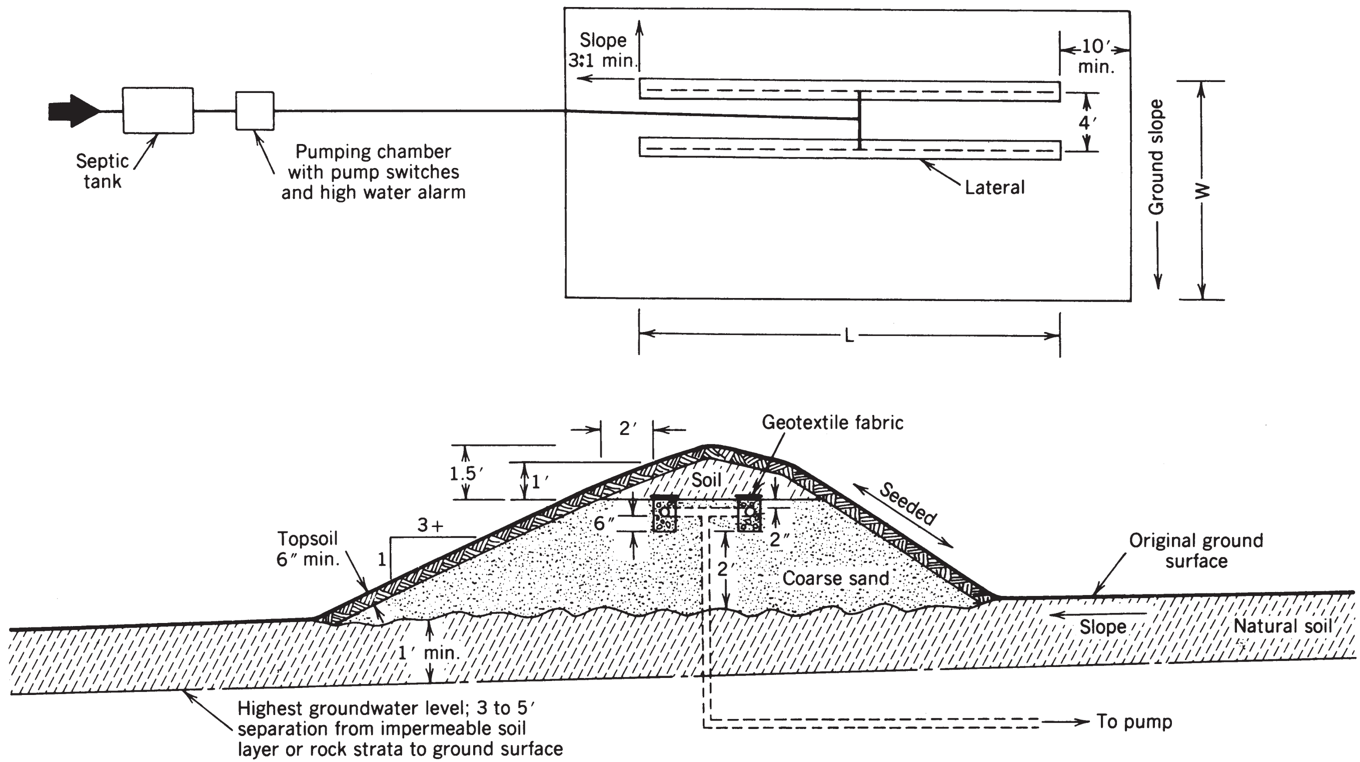


FIGURE 3.10 Details of a mound system using trenches. Basal area is L × W. Sloping ground. Laterals may be placed in a gravel bed.

TABLE 3.11 Suggested Settled Sewage Application Rates

Percolation Rate (min/inch)	Soil Type	Application Rate[a] (gpd/ft^2)	Hydraulic Conductivity[b] (gpd/ft^2)
Less than 1	Gravel, coarse sand	Unsatisfactory	—
1–5	Coarse[d] to medium sand	1.2[c]	9,600[d]–1,200
6–15	Fine sand,[d] loamy sand	0.8	540[d]–100
16–30	Sandy loam, loam	0.6	100–20
31–60	Loam, porous silt loam	0.45	20–5
61–120	Silty clay loam, clay loam	0.2	1–0.1
121 and greater	Clay loam, clay	See Ref. 14.	—

[a] Approximate vertical hydraulic conductivity.
[b] Very approximate horizontal hydraulic conductivity. Make field or laboratory determination.
[c] Reduce to 0.8 gpd/ft^2 if groundwater supplies may be affected.
[d] Fletcher G. Driscoll, *Groundwater and Wells*, Johnson Division, St. Paul, MN, 1986, p. 78. Coarse sand 0.84 to 1.17 mm size; fine sand 0.2 to 0.3 mm size.

Example 1

Design of a residential mound system on level ground for a flow of 300 gpd. Natural soil has a percolation of 1 inch in 120 minutes, or 0.2 gpd/ft^2.

1. Absorption area $= \dfrac{\text{Daily flow}}{\text{Sand infiltration rate}} = \dfrac{300}{1.2} = 250\,\text{ft}^2$
   This area can be provided by two 2-foot wide trenches 62.5 feet long.
2. Trench and lateral spacing = space laterals 4 feet on center.* Gravel trenches may be combined into one gravel bed (4 + 1 + 1) = 6 feet wide.
3. Mound height (at center) = Sand depth + Gravel depth + Soil cap and topsoil (See Figure 3.10.) = 2 + 0.75 + 1.5 = 4.25 feet
4. Mound length = Lateral length + End barriers (mound height × 3 on 1 slope × 2 = 62.5 + (4.25 × 3) × 2 = 88 feet
5. Mound width (including topsoil) = 0.5 × Trench width × 2 + Trench spacing on center + (Mound height at edge of trench + 3 on 1 slope) × 2 = (0.5 × 2 × 2) + 4 + (3.75 × 3) × 2 = 2 + 4 + 22.5 = 28.5 feet
6. Basal area: Required 300/0.2 = 1,500 ft^2.
   Provided 62.5 × 28.5 = 1,781 ft^2, excluding end areas
7. Distribution system: See Table 3.11 for lateral length and diameter and corresponding hole diameter and spacing. Make manifold 2 inches in diameter for pumping.

*A 1-in. diameter pipe holds .041 gal; a 1.25-in. pipe .064 gal; a 1.5-in. pipe .092 gal; and a 2-in. pipe .164 gal

8. Pressure distribution: For pumping chamber volume, pump size, and dosing volume, see Converse[29], and for siphon discharge. Include valve on pump discharge line for fine adjustment of pump head and discharge.
9. Pumping chamber = 500 gal capacity for 1-, 2-, 3-, or 4-bedroom dwelling is recommended.
10. Dose volume = 0.25 daily flow and at least 10 times lateral volume when pump is used.
11. Pump size: The pumping head is the difference in elevation between pump and lateral invert, plus friction loss in the pump discharge line, manifold, fittings, valve, laterals, orifices, plus head at end of lateral (2 feet). Pump capacity is 20 gpm for 1-bedroom dwelling (150 gpd) and 0.25-inch diameter orifice spaced 30 inches on center; 36 gpm for 2-bedroom, 54 gpm for 3-bedroom, and 70 gpm for 4-bedroom. For 7/32-inch diameter orifice, use a 15-gpm pump for 1-bedroom dwelling, 28-gpm for 2-bedroom, 41-gpm for 3-bedroom, and 54-gpm for 4-bedroom.

Based on historic experiences with sand filters, sands with effective size less than 0.2 to 0.35 mm can be expected to clog with a dosage of 1 to 1.5 gpd/ft^2. Also, during construction, compaction of the sand fill and the natural soil under and around the dispersal area should be kept to a minimum.

Electric Osmosis System

In this process, septic tank effluent discharged to a conventional subsurface absorption system in a soil having a percolation slower than 1 inch in 60 minutes is disposed of by evapotranspiration. Mineral rock-filled anodes adjacent to the trench and coke-filled cathodes with graphite cores a short distance away generate a 0.7 to 1.3 V potential, causing soil water, claimed to be removed by evapotranspiration, to move to the cathodes. These systems have been used successfully in several states.

Septic Tank Evapotranspiration System

An evapotranspiration system can be used, when the available soil has no absorptive capacity or where little or no topsoil exists over clay, hardpan, or bedrock, provided that a water balance study shows the evapotranspiration plus runoff exceed precipitation infiltration plus inflow. It can also be used when the groundwater level is high, provided the system is provided with a watertight liner on the bottom and sides to exclude the groundwater from the transvap bed. If an impermeable liner is not provided, elevation of the bed or curtain drains may be necessary if seasonal high water is a problem. The design of a transvap system is based on maintenance of a favorable input-output water balance.

Evaporation from water surfaces varies from about 20 inches per year in the northeastern United States to 100 to 120 inches in some southwestern areas, and that evaporation from land areas will be approximately one-third to one-half these values. Brandes found that over a 15-month period, 58 percent of the total precipitation on a sand filter in Ontario, Canada, left the filter through evapotranspiration.[30] This value is significantly higher than the average values for hydrologic water recycling given historically by McGauhey:[31]

Evaporation	30 percent
Evapotranspiration	40 percent (from soil mantle)
Surface runoff	20 percent
Groundwater storage	10 percent

Successful operation of a transvap system is largely dependent on runoff, surface vegetation, soil cover, capillarity, and evapotranspiration, in addition to controlled wastewater flow *to maintain a favorable water balance*. Plant roots can reach a depth of about 24 inches in well-developed absorption beds and take up wastewater. Maintenance of a permeable soil structure and microbial and macroscopic organisms is essential to minimize system clogging and failure, as previously explained.

Figure 3.11 provides design and construction details of a transvap disposal system, which uses sand and gravel beds to provide storage during the periods when transpiration and evaporation is low or zero. The sand ridges and sand bed are essential to provide capillarity. Soil evaporation can average one-third to one-half of lake evaporation for 6 months of a year in which average lake

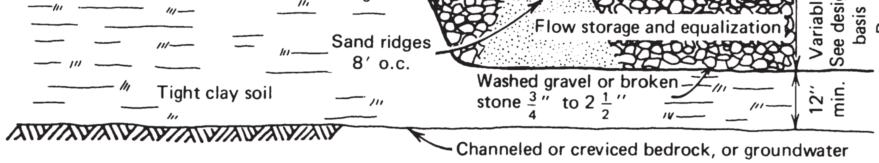


FIGURE 3.11 Transvap sewage disposal system in tight soil. (Raise bed as necessary if groundwater or bedrock is a problem.) Clean washed sand, 0.1 mm effective size for up to 12 to 16 in. gravel and sand depth, and 0.05 mm sand for up to 24 in. gravel and sand depth. Sand ridges are necessary to obtain capillarity and promote evapotranspiration. Permeable geotextile fabric is recommended over the sand ridges and in place of the 6 in. of sand over the gravel. Add 6- or 8-in.diameter perforated risers in and to bottom of gravel bed for inspection and emergency pump-out. Pressure distribution is usually required. Silt in sand will increase capillary rise.

evaporation is 30 inches/year. Sublimation during the snow-covered nongrowing season, although small, can contribute to moisture removal from the system.

Example 2

Rational design of a transvap sewage disposal system for year-round occupancy.[32]

Design basis

1. Sewage flow: 200 gpd = 6,083 gal/month = 73,000 gal/year
2. Bed surface cover: sandy, silty, clayey loam topsoil, and lawn grass, crowned 1 in./ft.
3. Use gravel bed (40 percent void space) with sand ridges, or with gravel ridges. See Figure 3.11.

Required area of evapotranspiration bed

$$\text{Outflow} = \text{Inflow}$$

$$(ET \times A) + (E \times A) = Q + (I \times A),$$

where

ET = evaporation from bed during the growing season, gal/ft^2 (as noted above)

A = area of bed, ft^2

E = land evaporation from bed during the nongrowing period, except when the bed is frozen or snow covered, gal/ft^2 (as noted above)

Q = septic tank inflow, gal/year

I = infiltration, precipitation inflow, gal/ft^2 (as noted above)

The above equation may be rewritten:

$$A = \frac{Q}{ET + E - 1};$$

Using the design basis and the parameters listed in Table 3.12:

$$A = \frac{200 \times 365}{3.12 \times 5 + .934 \times 4 - 12.076} = \frac{73{,}000}{7.26} = 10{,}055\,\text{ft}^2$$

Storage (Y) required during 7-month nongrowing period (J,F,M,S,O,N,D) (Or make monthly water balance study):

$$Y = Q_1 + I_1 E_1 = \text{sewage flow} + \text{infiltration} - \text{soil evaporation}$$

$$= 6083 \times 7 + (.206 + .196 + .810 + .966 + .810 + .872 + .271) \times 10{,}055\ (.934 \times 4) \times 10{,}055$$

$$= 42{,}583 + 41{,}537 - 37{,}565$$

$$= 46{,}555\,\text{gal}$$

TABLE 3.12 Precipitation, Infiltration, and Evaporation Rates

	Jan	Feb	Mar	Apr	May	Jun
Precipitation (ppt.), in.	2.2	2.1	2.6	2.7	3.3	3.0
Percent ppt. infilt. in bed	15	15	50	85	85	85
Infiltration ppt., gal/ft^{2a}	0.206	0.196	0.810	1.430	1.748	1.589
Land evaporation, gal/ft^{2b}	0	0	0.934	in ET	in ET	in ET
Evapotranspiration, gal/ft^{2c}	0	0	0	3.12	3.12	3.12
	Jul.	Aug	Sep	Oct.	Nov	Dec.
Precipitation (ppt.), in.	3.1	2.9	3.1	2.6	2.8	2.9
Percent ppt. infilt. in bed	85	85	50	50	50	15
Infiltration ppt., gal/ft^{2a}	1.642	1.536	0.966	0.810	0.872	0.271
Land evaporation, gal/ft^{2b}	in ET	in ET	0.934	0.934	0.934	0
Evapotranspiration, gal/ft^{2c}	3.12	3.12	0	0	0	0

[a] Infiltration = percent infiltration × precipitation/month × 0.623, in gal/ft^2/month.
[b] Land evaporation = 0.6 lake evaporation of 30 in./year = 0.6 × 30 ÷ 12 × 0.623 = 0.934 gal/ft^2/month.
[c] Evapotranspiration = 25 in. in growing season × 0.623 ÷ 5 = 3.12 gal/ft^2/month.
Note: 0.623 = gal/ft^2 per in. precipitation.

Bed depth (D) to provide required storage

$$D = \frac{Y}{A \times 7.5\,\text{gal/ft}^2 \times \text{ void surface}} = \frac{46{,}555}{10{,}055 \times 7.5 \times .4}$$
$$= 1.54\,\text{ft (This is within the fine sand capillarity range.)}$$

The storage required can be determined by means of a water balance study and by the graphical mass diagram or Rippl method. The weekly or monthly inflow (consisting of the precipitation minus runoff, or infiltration, plus wastewater input flow) and the outflow (evaporation and transpiration) is tabulated or plotted against time in weeks or months. The difference between cumulative inflow and cumulative outflow is the storage required at any point in time. Beck[33] recommended an evapotranspiration rate of 0.482 gpd/ft^2 for raised sand beds, while Lomax found that evapotranspiration systems composed of 1.65 feet depth of sand could dispose of 0.08 gpd/ft^2 satisfactorily in area, which had an annual precipitation of 55 inches.[34]

Water Conservation

Although not technically a disposal system, water conservation can provide a simple and economic way of reducing hydraulic loads on an existing septic system. Water conservation measures include the installation of low-flow fixtures, such as toilets and faucet aerators, which in and of themselves can reduce wastewater flows by up to 50 percent, maintenance of proper water pressures, elimination of leaks and drips, and discontinuation of the use of garbage disposals.

SEWAGE WORKS DESIGN — SMALL TREATMENT PLANTS

Small treatment plants typically discharge treated effluents to a surface water body as contrasted to septic systems, which discharge to groundwater systems. Surface discharges require a permit from a regulatory agency and allowable effluents are based on the minimum average 7-day flow expected to recur once in 10 years (MA7CD10), upstream and downstream discharges, and downstream uses. Some of the more common flow diagrams for small sewage treatment plants are illustrated in Figure 3.12 and predesigned and prefabricated units are available.

As noted in Figure 3.12, bar screens or comminutors and grit chambers are provided ahead of pumping equipment and settling tanks to remove larger solids. If secondary treatment is needed, primary treatment units should be designed to have water level of sufficient height to permit gravity flow to the both the secondary units and to the receiving stream without additional pumping.

Location of small treatment plants should take into consideration the type of plant desired, the availability of supervision, the location of the nearest residence, the receiving watercourse, the likelihood of flooding, prevailing winds and natural barriers, and the cost of land. A distance of 400 feet from the nearest residence is frequently recommended, although distances of 250 to 300 feet should prove adequate with good plant supervision. Oxidation ponds and lagoons should be located at least 0.25 to 0.5 mile from the nearest human habitation.

Disinfection

The need for disinfection of sewage effluent depends on the probability of disease transmission by the ingestion of contaminated water or food including shellfish, by contact, and by aerosols.

This probability should be balanced against the effects that chlorination can have on aquatic life.[35] Normal chlorination does not destroy all pathogenic viruses, fungi, bacteria, protozoa, and helminths. Although chlorine as a disinfectant is discussed here, it does not preclude dechlorination or the use of other disinfectants. Also, wastewater must be adequately treated in the first place for the disinfectant (usually chlorine) to be effective.

Chlorination treatment of raw sewage is not reliable for the destruction of pathogenic organisms since solid penetration is limited. The dosage of chlorine required to produce a 0.5 mg/l residual after 15-minute contact has been estimated for different kinds of sewage (see Table 3.13). An early study found that less than 250 coliform organisms per 100 ml remained in treated sewage if a chlorine residual of 2.0 to 4 mg/l is maintained in the effluent after 10-minute contact.[36] Other tests found that with no mixing, at least twice the chlorine residual had to be maintained in the treated sewage for 10 minutes to get results approximately equal to those obtained with mixing.

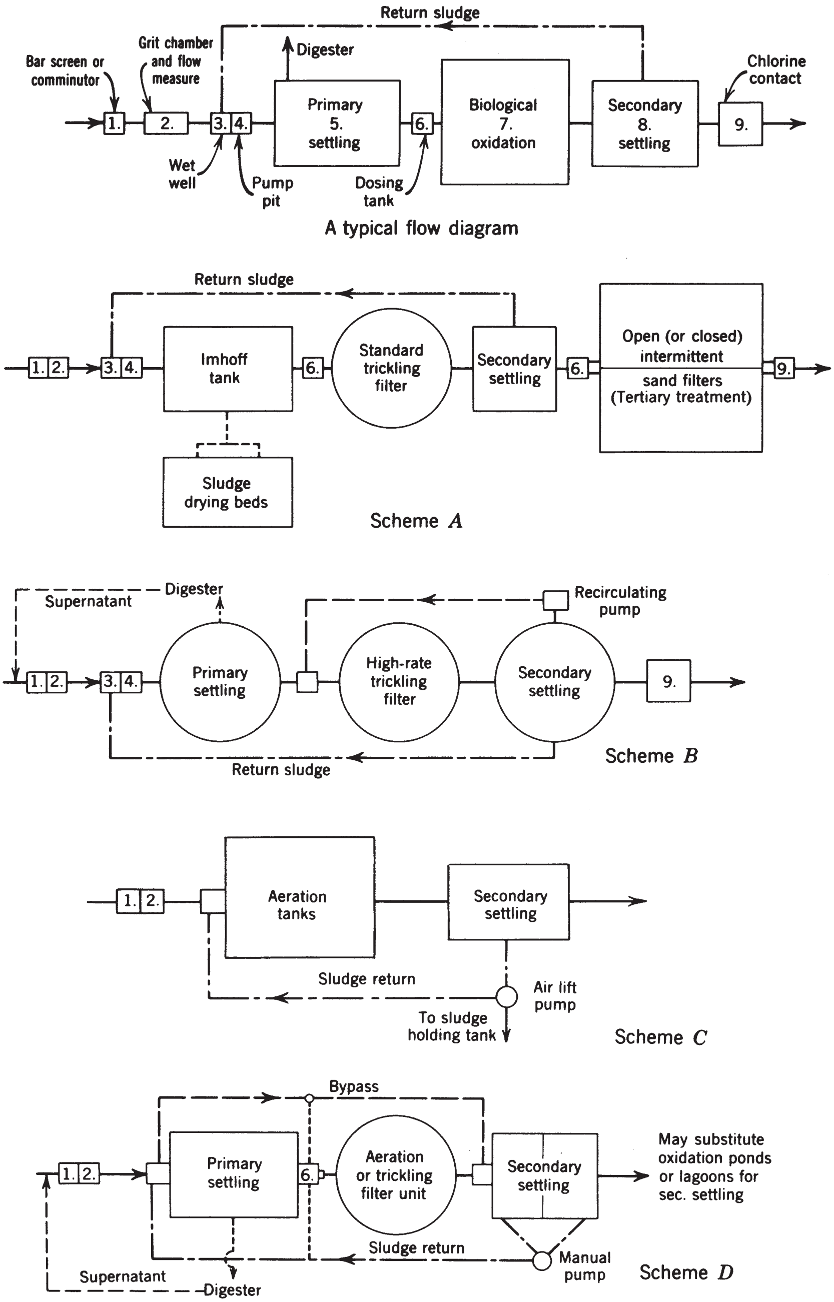


FIGURE 3.12 Typical flow diagrams.

TABLE 3.13 Probable Chlorine Dosages to Give a Residual of at Least 0.5 mg/l after 15-Min Retention in Average Sanitary Sewage or Sewage Effluent[a]

Type of Sewage Effluent	N.Y. State[d]	Dunham[e]	White[f]	Suggested Chlorine Dosages, (mg/l)[b] Griffin[g,h]	Imhoff and Fair[i]	Metcalf & Eddy[l]	GLUMRB[j]	EPA[k]
Raw sewage			8-15 15-30	6–12 fresh to stale 12–25 septic	6–25 fresh to stale	6–25		8–15 fresh
Imhoff tank or settled sewage	20–25	5–20	8–15	5–10 fresh to stale 12–40 septic	5–20	5–20	20	
Imhoff tank or settled sewage	20–25	5–20	8–15	5–10 fresh to stale 12–40 septic	5–20	5–20	20	
Trickling filter	15	3–15	3–10	3–5 normal 5–10 poor	3–20	3–15	15	
Activated sludge	8		2–8	2–4 normal 5–8 poor	2–20	2–8	8	10–15 pack plant
Intermittent sand	6	2	1-5	1–3 normal 3–5 poor	1–10		6[c]	1–5
Chemical precipitation				3–6	3–20	2–6		

[a] WHO suggests 0.5 mg/l free residual chlorine after 1 hour to inactivate viruses (after secondary treatment) with turbidity < 1.0 JTU. Combined chlorine, mostly monochloramine, is normally produced which is a slow-acting disinfectant. Eight to 10 mg/l of chlorine is needed to neutralize each mg/l of ammonia before free chlorine is produced. Most secondary effluents contain more than 1.0 mg/l ammonia.

[b] 12 mg/l = 1 lb per 10,000 gal. Each mg/l chlorine in sewage effluent reduces the BOD about 2 mg/l. No appreciable industrial wastes.

[c] Tertiary filtration effluent and for nitrified effluent.

[d] *Manual of Instruction for Wastewater Treatment Operators*, Vol. 1, New York State Dept. of Environmental Conservation, Albany, May 1979, pp. 6–9.

[e] *Military Preventive Medicine*, Military Publishing Co., Harrisburg, Pa., 1940.

[f] *Handbook of Chlorination and Alternative Disinfectants*, Van Nostrand Reinhold, New York, 1992.

[g] *Public Works Magazine*, Ridgewood, N.J. (October 1949), p. 35.

[h] *Operation of Wastewater Treatment Plants*, Water Pollution. Control Fed., Washington, DC, 1970, p. 144.

[i] *Sewage Treatment*, John Wiley & Sons, Inc., New York, 1956.

[j] *Recommended Standards for Sewage Works*, 1997 ed., Great Lakes-Upper Mississippi River Board of State and Provincial Public Health and Environmental Managers.

[k] Design Manual, Onsite Wastewater Treatment and Disposal Systems, U.S. EPA, October 1980, p. 165.

[l] *Wastewater Engineering Treatment Disposal Reuse*, revised by George Tchobanoglous, McGraw-Hill, New York, 1979, p. 376.

Although chlorine is available as a pressurized liquid, liquid chlorine is not ordinarily required or economical to use at small sewage treatment plants. Instead, either calcium hypochlorite, which is a powder containing 70 percent or less available chlorine, or sodium hypochlorite, which is a solution containing 15 percent or less available chlorine, is generally used. Both the powder and solution are mixed and diluted with water to make a 0.5 to 5.0 percent solution, which is then added to the sewage by means of a feeder known as a hypochlorinator. Positive-feed hypochlorinators are generally preferred because of their greater dependability, but gravity flow stack or tablet erosion-type chlorinators are also available.

Combined chlorine, mostly monochloramine, is produced in the conventional chlorination of sewage effluent. This result is to be expected, since most secondary effluents contain substantially more than 1 mg/l of ammonia, which alone requires 8 to 10 mg/l of chlorine for neutralization, before any free residual chlorine is produced. Although slow-acting, combined chlorine is effective in reducing fecal coliforms to 200 mg/l or less, with sufficient contact time. Conventional chlorination of municipal wastewater to the combined chlorine residual level also yields relatively small amounts of chlorinated organic compounds, which are suspected of being carcinogenic. This outcome is in contrast to the chlorination of surface drinking water supplies to the free chlorine residual level in which the formation of relatively high concentrations of chlorinated organic compounds (200 to 500 ppb) such as trihalomethanes occur. Thus, controlled chlorination of sewage to below the free residual chlorine level would seem to have public health and economic merit, although free chlorine is recognized as the more rapid, effective disinfectant.

Chlorine, chloramines, and other chlorine products formed during chlorination are toxic to aquatic organisms at very small concentrations. For that reason, U.S. EPA has recommended a maximum total residual chlorine limit of 0.002 mg/l in salmonoid fish areas and 0.01 mg/l for marine and other freshwater organisms. Dechlorination with sulfur dioxide, sodium thiosulfate, and sodium biosulfite, can remove all residual toxicity to aquatic life from chlorination. Although dechlorination is believed to be beneficial, the toxicity of compounds formed by chlorination, of dechlorinating agents, and of compounds formed by dechlorination, has been a source of concern. Because of this, pilot plant studies and the possible use of alternative disinfectants are advised.[37]

Alternative disinfectants include ultraviolet (UV) radiation, ozone, ozone plus UV, and chlorine dioxide. Some viruses, bacterial spores, and protozoan cysts survive normal UV doses. Because the UV rays must penetrate the microorganism to damage or kill it, microorganisms may be protected within particulates, making prior filtration of effluent necessary. Studies have shown that municipal wastewater that has received tertiary treatment can be disinfected using UV in a cost-effective manner.[38] Ozone is a good virucide and nontoxic to aquatic organisms, and adds dissolved oxygen to treated effluents. Because it has been found to be both reliable and effective, ozone has been received greater attention in recent years as a wastewater disinfectant, even though its cost is still higher than chlorine disinfection.[39] For example, an ozone dosage of 1.5 mg/l can meet fecal coliform permit requirements at an activated sludge plant including nitrification. Although chlorine dioxide does not result in the formation of appreciable concentrations of trihalomethanes, it can cause a drop in pH and dissolved oxygen, requiring treatment adjustment.

Physical-Chemical Treatment

Physical-chemical treatment includes a range of treatment processes, including chemical coagulation, flocculation, sedimentation, and filtration. All of these unit processes remove suspended matter. One of the better texts on the application of physical-chemical methods to wastewater treatment was written by Weber and is still extensively used.[40] Another useful text was published by Sincero in 2003.[41]

Sedimentation

Sedimentation, which is one of the most widely used processes in wastewater treatment, involves the gravitational settling of suspended particles. Sedimentation typically takes place in a settling tank, or clarifier. The three main clarifier types are horizontal flow, solids contact, and inclined surface. Horizontal flow clarifiers can be rectangular, square or circular in shape. In rectangular basins, flow is parallel to the long axis of the basin. In circular basins, it is from the center outwards. In either case, the basins must be designed to keep the influent velocity as uniform as possible to prevent currents, which would prevent settling, from forming. Flow velocities within the clarifier must be reduced to 1 to 2 feet/minute to promote settling. Also, clarifier bottoms are sloped to facilitate collection and removal of the sludge that settles out. Solids contact clarifiers make use of a suspended layer of sludge to enmesh and capture incoming solids. Inclined surface clarifiers, which are also known as high-rate settling basins, use inclined trays to divide the basin into shallower sections. These trays give the basins a larger surface area and reduce particle-settling times.

Settling basins are used in a variety of sewage treatment processes, including primary settling (particulate removal), activated sludge settling (biological floc removal), and chemical coagulation (chemical floc removal). Also, septic tanks (see Figures 3.4 and 3.5) rely primarily on sedimentation to treat sewage wastes. To be effective, settling basins must be designed to produce both a clarified effluent and a concentrated sludge. Mechanical scrappers along the bottoms of these basins are used to push the settled sludge into a hopper, where it can be pumped to a sludge-processing unit. Any floating materials (e.g., oil or scum) are skimmed from the surface, and the clarified effluent is discharged over weirs to a collection trough.

Coagulation/Flocculation

Chemical coagulation of sewage prior to sedimentation promotes the flocculation (i.e., aggregation) of finely divided solids into more easily settable flocs, which,

TABLE 3.14 Removal Efficiency of Sedimentation Compared to Coagulation plus Sedimentation

Constituent	Sedimentation Only	Coagulation followed by Sedimentation
Total suspended solids	40%–90%	60%–90%
Five-day BOD	25%–40%	40%–70%
COD		30%–60%
Phosphorus	5%–10%	70%–90%
Bacteria levels	50%–60%	80%–90%

Source: *Design of Municipal Wastewater Treatment Plants*, MOP 8, Water Environment Federation and American Society of Civil Engineers, 1998.

in turn, enhances the efficiency of sedimentation processes as noted in Table 3.14. Other advantages of coagulation include the ability to use higher flow rates and achieve more consistent performance. However, on the negative side, coagulation produces larger quantities of sludge, which must be thickened and dewatered and has higher operational costs and more attention on the part of plant operators.

Chemicals used in coagulation to remove suspended matter include polyelectrolytes, ferric chloride or ferric sulfate, aluminum sulfate (alum) and sodium aluminate, and lime. Amounts required range from 45 to 90 mg/l ferric chloride for 85 to 90 percent phosphorus reduction to 75 to 250 mg/l alum for 55 to 90 percent phosphorus reduction. Because orthophosphate is converted to an insoluble form at a pH of 9.5, lime in doses ranging from 200 to 400 mg/l can raise pH above 9.5 and precipitate out phosphorus. Polymers are costly when used alone, but are attractive as settling and filtration aids when used in conjunction with the above coagulants. At average flows, rapid mix should be achieved in 2 minutes, flocculation in 15 minutes, and sedimentation achieved as long as application rates average 900 gpd/ft^2 (1,400 gpd/ft^2 at peak hourly flow). When alum or lime is used, pH control is also necessary before filtration.

As regulations regarding the formation of disinfection byproducts have become more stringent, considerable research has been conducted into to ways that coagulation and flocculation can be used to reduce byproduct concentrations. For example, one study found that removal efficiencies for organic matter, including disinfection byproducts such as trihalomethane, could be improved if polyaluminum chloride was used in conjunction with alum and ferric chloride.[42] Another found that use of double-step coagulation (i.e., addition of coagulants in a two-step sequence) reduced the need for high coagulant doses to remove organic matter and turbidity.[43]

Filtration

Although filtration of wastewater treatment effluents is a relatively new practice, it has gained widespread acceptance as a method for removing suspended solids from chemical and biological treatment effluents. Application rates of 5 gpm/ft^2 are recommended for mixed media filtration units, but rates of up to 10 gpm/ft^2 can be used. A flow-equalization tank is often installed ahead of the filter to ensure filtration at a relatively constant rate. Typical physical-chemical treatment for the removal of heavy metals includes flash mix using calcium hydroxide or sodium hydroxide, flocculation, clarification, and sand filtration. Lime coagulation, mixed media filtration, and use of activated carbon filtration can greatly reduce U.S. EPA priority pollutants.

The removal efficiencies of various filter media have also received attention in recent years. In one study, metal removal rates for conventional and sorptive filter media, including plain sand, granular activated carbon, cementitious media, and oxide coated/admixture media, were analyzed. Of the four media, the oxide coated/admixture media provided the highest removal efficiency for lead, copper and zinc.[44]

Activated Carbon Adsorption

Carbon adsorption can be used to remove soluble organics that remain after wastewater treatment by other processes. The two most common types of activated carbon adsorption are granular activated carbon, which has a diameter of greater than 0.1 millimeter, and powdered activated carbon, whose diameter is less than 200 mesh. Granular carbon is commonly used in separate carbon adsorption units, while powdered carbon is added directly to the biological or chemical treatment unit, where it is allowed to settle out and is then removed.

Carbon adsorption units come in several types, including fixed-bed, expanded-bed and moving-bed contactors. In fixed-bed units, the wastewater is applied to the top of a column of activated carbon and withdrawn at the bottom. In expanded-bed units, the wastewater is introduced at the bottom of the column and allowed to expand. In moving-bed units, spent carbon is continuously replaced with fresh carbon. Granular activated carbon units are generally designed to provide about 30-minutes wastewater contact time. Use of countercurrent flow patterns is believed to provide more efficient utilization of the carbon, which will need to be regularly backwashed and regenerated when its adsorption capacity is exhausted. Nitrogen can be removed by adding ammonia stripping, ion exchange, and breakpoint chlorination to the treatment process.

Biological Treatment

Trickling Filters Trickling filters are the most commonly used biological treatment process for removal of organic matter from wastewater. These filters are composed of a bed of highly permeable media, such as rock or plastic packing material, to which biologic organisms are attached, forming a biological slime layer, and through which the sewage is percolated. Typically, trickling filters are used following a primary settling tank to provide secondary treatment of the sewage. Seeding of the filter stone and development of a gelatinous film of aerobic microorganisms is necessary before good results (i.e., adsorption of organic matter by the slime layer) can be produced.

While noticeable BOD reduction can be obtained within 7 days of start-up, as long as 3 months may be required to obtain equilibrium, including high nitrification. Nitrification is the aerobic process in which the ammonia from sewage is acted upon by the oxygen in the air to form nitrate and carbon dioxide. Continuous operation, particularly during cold months of the year, is necessary to maintain nitrification efficiency. High nitrification is important in reducing the nitrogenous oxygen demand on the receiving water body to which the treated sewage effluent is discharged. Analysis of historical data from trickling filter systems has found that the degree of nitrogen removal and biological denitrification is strongly influenced by the BOD load, hydraulic loading and the media size.[45] Better nitrification can be obtained if the organic loading rate is sufficiently low enough so that all of the biodegradable organic matter is removed and filter space is available for the growth of nitrifying bacteria. Organic loading rates for trickling filters and other packed bed reactors that are supportive of combined organic oxidation and nitrification are provided in Table 3.15.

Small standard-rate trickling filters are usually 6 feet deep and designed to handle application rates of 200,000 to 300,000 gpd/acre-foot. Filter loading is also expressed in terms of 5-day BOD in the sewage being applied to the filter. Typically, 35 percent of the BOD in a raw sewage is removed by the primary settling unit. Application rates for standard-rate trickling filters range from 200 to 600 pounds of BOD/acre-ft/day with an average loading are 400 pounds in northern states and 600 pounds in southern states. Since dosage must be controlled, dosing siphons may be used for very small filters and dosing tanks with siphons or pumps containing revolving distributors or stationary spray nozzles on standard filters. Also, periodic dosing with interim resting usually produces a better effluent than continuous dosing.

A trickling filter should be followed by a secondary settling tank to remove the biological growths sloughed off the filter stone, from which sludge should be removed at least twice a day. The resultant sludge is removed by pumping or by gravity flow if possible to the sludge digester or Imhoff tank.

Because odors and filter flies can be expected with a standard rate filter, filters should be at least 400 feet from any private residence. Filter flies can be

TABLE 3.15 Organic Loading Rates for Combined Carbon Oxidation and Nitrification

Reactor Type	Lb BOD_5/1,000 ft^3-day	Kg BOD_5/m^3-day
Rock media trickling filter	5–10	0.1–0.2
High rate media trickling filter	10–25	0.2–0.4
Submerged packed bed reactor	120–160	2–3

Source: Glen Diagger, "Nutrient Removal in Fixed-Film Processes: Current Design Practices," *Advances in Water and Wastewater Treatment*, American Society of Civil Engineers, 2004.

controlled by weekly chlorination (1 mg/l in effluent for 4 to 8 hours), flooding (24 hours), increased hydraulic loading, and insecticide treatment. For odor control or disinfection of the sewage effluent for bacterial reduction, chlorination of the final effluent is often required. Trickling-filter treatment can be supplemented by sand filtration, oxidation pond, solids contact basin, flocculator-clarifiers, or chemical coagulation and settling, where a higher-quality effluent is required. Variations of the standard-rate trickling filter, include high-rate filters with recirculation; biological towers (20 to 30 feet), which use a plastic media; biological aerated filters, which use a submerged media and forced air; and rotating biological contractors. Flow diagrams, which include trickling filters, are shown in Figure 3.12.

Rotating Biological Contactors A rotating biological contactor is another type of attached-growth biological process in which large closely spaced circular disks, which are mounted on horizontal shafts, rotate slowly through wastewater. The plastic disks, which are typically on 25-foot-long horizontal shafts, rotate at two to five revolutions/minute, while partially submerged (40 percent) in wastewater that has already received primary treatment. At least four sets of contactors are typically needed to achieve secondary treatment standards and, in most instances, prior trash and grit removal is considered necessary in addition to primary settling tanks.[46] The biological growth (biomass) that forms on the wetted area of the disks through contact with organic material in the wastewater is maintained by contact with air during the rotation, which makes oxygen transfer to the wastewater possible as it trickles down the disks. Some of the growth is stripped or sloughed off from the disk as it passes through the moving wastewater and is removed in the secondary settling tank.

Rotating biological contactor design is based on hydraulic and organic loading data from pilot plant and full-scale studies. These studies have shown that hydraulic loading rates need to generally range from 2 to 4 gpd/ft^2 of contactor surface, while organic loading per stage should range from 1 to 4 lb BOD/day/1,000 ft^2. A loading range of 2.5 to 3.0 lb soluble BOD is also recommended. Lower BOD loading rates (1 gpd/ft^2) are needed to produce a high-quality (10 mg/l BOD and suspended solids) effluent. Better effluent BOD quality and nitrification are also possible by controlling pH (8.4), dissolved oxygen, and raw wastewater alkalinity levels.[47]

Removal efficiencies of 85 percent BOD removal or higher can be expected if the contactors are not overloaded, but efficiencies are reduced below 55°F (13°C). Removal efficiencies can also be improved by operating the rotating biological contactors in a step-feed mode as compared to single-feed mode and by recirculating system effluent to the inlet stage.[48] Contactors should be covered to protect them from low temperatures, as well as from rainfall and heavy winds, which flush off growths, and sunlight, which embrittle the plastic disks. However, complete enclosure is not desirable because it promotes accumulation of hydrogen sulfide and high humidities, which can corrode metal parts. Although contactors are reliable and can withstand shock loading, when peak flow exceeds 2.5 times the average daily flow, or when a large organic loading occurs, appropriate flow equalization or more disks may be added.

Rotating biological contactors can also be used for carbonaceous removal (i.e., BOD, COD, and TOC reductions) as well for as nitrification, and for sulfide and methane removal. Smaller-diameter disks, 2 to 4 feet, can achieve greater BOD removals than larger diameter disks. Operation and maintenance costs typically average less than activated sludge are higher than trickling filters.[49] Contactors are usually followed by final settling tanks, which should provide at least 1.5 hours detention, a maximum surface settling rate of 600 gpd/ft^2, and an overflow rate not greater than 5,000 gpd/linear ft.[50]

Aerobic Digestion Aerobic digestion systems are frequently used in small treatment plants with activated sludge units being one of most commonly used. Activated sludge involves the use of a mass of activated microorganisms in an aeration basin, which aerobically degrade organic matter from wastewater. An aerobic environment is maintained by means of diffused or mechanical aeration, which also serves to keep the contents of the basin completely mixed. After a specified retention time, the content of the basin (the mixed liquor) is passed into a secondary clarifier where the sludge is allowed to settle. A portion of the settled sludge is then recycled back to the aeration basin to maintain the required activated sludge level. Design data for activated sludge units and other aerobic digestion processes are presented in Table 3.16.

Contact stabilization is a modification of the conventional activated sludge process in which two aeration tanks are used. In the first tank, the return sludge is re-aerated for at least 4 hours before it is permitted to flow into the second tank to be mixed with the wastewater is to be treated. An oxidation ditch is a ditch in which a revolving drumlike aerator supplies air to the circulating wastewater and by doing so reduces the organic matter in the wastewater by aerobic action. Design requirements for extended aeration units typically include the following parameters:

Average sewage flow. 400 gal/dwelling or 100 gpd/capita.

Aeration tanks. At least two tanks to treat flows greater than 40,000 gpd with 24- to 36-hour detention period for average daily flow, not including recirculation, and 1000 feet^3 per 7.5 to 15 lb of BOD, whichever is greater. If raw sewage goes directly to aeration tank, primary tank is omitted.

Air requirements. 3 cfm/foot of aeration tank length, or 2,000 to 4,000 ft^3/lb of BOD entering the tank daily, whichever is larger. Additional air required if air is needed for airlift pumping of return sludge from settling tank.

Settling tanks. At least two tanks to treat flows greater than 40,000 gpd with a 4-hour detention period based on average daily sewage flow, not including recirculation. For tanks with hopper bottoms, upper third of depth of hopper may be considered as effective settling capacity.

Rate of recirculation. At least 1:1 return activated sludge based on average daily flow.

TABLE 3.16 Aeration Digestion Tank Loading Rates and Removal Efficiencies

Process	Organic Organic Loading (lb BOD_5/day per 1000 ft^3)	F/M[a] Ratio (lb BOD_5/day per lb MLVSS[b])	MLVSS[c] (mg/l)	Detention Time (hr)	Overall BOD Removal Efficiency
Activated sludge					
Plug flow	20–40	0.2–0.5	1,000–3,000	4–8	85–95%
Completely mixed	50–120	0.2–0.5	3,000–6,000	3–6	85–95%
Step aeration				3–6	85–95%
Contact stabilization	60–75[d]	0.2–0.6	1,000–3,000	0.2–1.5	80–90%
Extended aeration	10–25	0.05–0.2	3,000–6,000	18–36	75–90%

[a]Food to microorganism ratio (F/M)
[b]Mixed liquor volatile suspended solids (MLVSS)
[c]MLVSS values are dependent upon the surface area provided for sedimentation and the rate of sludge return as well as the aeration process.
[d]Total aeration capacity, includes both contact and reaeration capacities. Normally the contact zone equals 30 to 35 percent of the total aeration capacity.

Source: *Technical Criteria Guide for Water Pollution Prevention, Control and Abatement Programs*, U.S. Department of Army, Washington, DC. April 1987, p. 6-2.

Sludge holding tanks. Provide 8 feet^3/capita. A minimum of 1,000 gallons capacity per 15,000 gallons design flow and 20- to 40-day retention. Tanks should be aerated.

Extended aeration systems require daily operational control because air blowers must be operated continuously and sludge must be returned. Aeration tubes or orifices require periodic cleaning; and dissolved oxygen and mixed liquor suspended solids concentration must be watched. Clogging of the airlift for return sludge is also a common cause of difficulty. However, with proper controls, a 90 to 97 percent BOD and suspended solids removal, as well as good nitrification of ammonia nitrogen, can be expected. Typically, a 3-month adjustment period is needed to produce an acceptable effluent, which is why these systems are not recommended for seasonal operations, such as camps and schools.

Stabilization Ponds In areas where ample space is available, stabilization ponds can be a relatively inexpensive way to treat sewage. Small stabilization ponds have even been used at resorts or motels with a septic tank ahead of the pond and not produced any odor problems.[51] Stabilization ponds, also known as oxidation ponds, are operated as high-rate aerobic ponds, aerobic-anaerobic (facultative) ponds (the most common), aerated ponds or anaerobic ponds. Table 3.17

TABLE 3.17 Types of Lagoons

Type	Detention[d] (days)	Depth (ft)	Loading, (lb/5-day/ BOD/acre/day)	BOD Removal or Conversion (percent)
High-rate aerobic pond	2–6	1–1.5	60–200	80–95
Facultative pond	7–50	3–8 (2–5)[c]	15–80	70–95
Anaerobic pond	5–50	Variable[a]	200–1000	50–80
Maturation pond[b]		3–8	<15	Variable
Aerated lagoon	2–10	Variable[a]	Up-400	70–95

[a]Usually 10- to 15-ft deep

[b]Generally used for polishing effluents from conventional secondary treatment plants.

[c]These depths are more common.

[d]W. Wesley Eckenfelder, Jr., *Water Quality Engineering for Practicing Engineers*, New York, 1970, p. 210.

Source: *Upgrading Lagoons*, U.S. EPA, EPA-625/4-73-00 lb (August 1973): 1.

summarizes the detention times, depths, loading rates, and efficiencies for each type of pond.

Facultative ponds with a minimum of three cells in series and a 20-day actual detention time, and aerated ponds with a separate settling pond prior to discharge, provide more than adequate helminth (ascaris, trichuris, hookworm, tapeworm) and protozoa (giardia, amoeba) removal. The physical, chemical, and biological activities in the ponds, as well as competing organisms, all serve to reduce the numbers of surviving enteric bacteria and viruses.[52] Using a water balance analysis, ponds can be designed for zero discharge (i.e., pond surface area is sufficient to provide an annual net evaporation after precipitation that is greater than the wastewater inflow).

BOD removal of 85 to 90 percent is not unusual for stabilization ponds, and removal of viruses, bacteria, protozoa, and helminths is also reported to be very high. Ponds in open areas and in series (a minimum of three) give best results due to their additional detention time. Pond performance is affected by temperature, solar radiation, wind speed, loading, actual detention time, and other factors.[53] Primary treatment of sewage with grit chamber, comminutor and rack prior to discharge to ponds is also recommended. Design criteria for facultative-type stabilization ponds include:

Detention time. 90 to 180 days, depending on climatic conditions; 180 days for controlled discharge pond; 45 days minimum for small systems.

Liquid depth. 5 feet plus 2 feet freeboard, with minimum liquid depth of 2 feet.

Embankment. Top width of 6 to 8 feet; inside and outside slope 3 horizontal to 1 vertical. Use dense impervious material; liner of clay soil, asphaltic coating, bentonite, plastic or rubber membrane, or other material required, if seepage expected.

Pond bottom. Level, impervious, no vegetation. Soil percolation should be less than 0.25 in./hr after saturation.

Inlet. 4-inch diameter minimum at center of square or circular pond; at one-third point if rectangular with length not more than twice width. Submerged inlet 1 foot off bottom on a concrete pad or at least 1.5 feet above highest water level.

Outlet. 4-inch minimum diameter; controlled liquid depth discharge using baffles, elbow, or tee fittings; drawoff 6 to 12 inches below water surface to control, avoid short-circuiting and minimize algae removal; discharge to concrete or paved gutter.

Normally, stabilization ponds are aerobic to some depth, depending on surface aeration, microbial activity, wastewater clarity, sunlight penetration, and mixing. In deeper ponds, wastewater at lower layers becomes facultative and then anaerobic. Anaerobic and aerated ponds are usually followed by aerobic ponds to reduce suspended solids and BOD to acceptable levels for discharge. In general, increased detention time will increase BOD removal, and decreased BOD areal loading will increase BOD removal. Thus, required BOD and suspended solids removal and effluent quality will determine the detention time and areal loading. Pond efficiency can be improved by recirculation, inlet and outlet arrangements, supplemental aeration and mixing, and algae removal by coagulation-clarification, filtration, and land treatment of the effluent.[54]

Algae formed in ponds, particularly from seasonal blooms, are the main cause of solids carryover and increased oxygen demand in receiving streams from pond discharges. Thus, further treatment of pond effluent using coagulation, settling, filtration, centrifugation or microstraining may be required to remove the algae before discharge. It is also possible to prevent algal growths by copper sulfate treatment in the final cell, effluent withdrawal from below the surface, or effluent disposal to a wetland or a wastewater reuse facility.

The practicability of using waste stabilization ponds, lagoons, or land treatment will depend on local conditions. For example, the risk of odor, nuisance, or health hazards should be evaluated before a selection is made. However, these ponds should not be dismissed too quickly either, as they can provide an acceptable answer when no other treatment is practical at a reasonable cost. Control of aquatic vegetation, embankment weeds, and floating mats is often necessary to minimize mosquito and other insect breeding.

Wastewater Reuse

Treated wastewater can be reused as long as it does pose a health hazard due to six factors:

1. Possible inhalation of aerosols containing pathogenic microorganisms
2. Consumption of raw or inadequately cooked vegetables from crops irrigated with wastewater or possible ingestion of heavy metals or other toxic materials taken up by crops during growth

3. Contamination of groundwater through infiltration of wastewater chemicals into a groundwater aquifer serving as a source of drinking water
4. Runoff, from land areas receiving wastewater effluent, to surface waters used as sources of drinking water, shellfish, bathing water, or other recreational purposes
5. Possible cross-connection between potable and nonpotable water systems
6. Buildup of detrimental chemicals in the soil

Although most pathogenic microorganisms can be removed from wastewater as it infiltrates through an adequate distance of unsaturated fine sand, loamy, or sandy soil, these microorganisms have been observed to travel several hundred feet in saturated soil and up to 2,000 feet in coarse gravel and creviced rock.

In addition, wastewater can contain a variety of chemicals such as heavy metals (cadmium, copper, nitrates, lead, mercury, zinc, nickel, and chromium), pesticides (insecticides, fungicides, and herbicides), and commercial and industrial wastes, such as trichloroethylene and polychlorinated biphenyls. Nitrification of organic material in sewage can add nitrate-nitrogen to the groundwater if not immediately used by plants and endanger sources of drinking water used by infants (methemoglobinemia).

In light of the many pathogens normally found in wastewater, irrigation, and spraying of crops with wastewater should be restricted to those foods that are not eaten raw. Many of the metals normally found in wastewater do not appear to be a problem when applied to crops because they are not significantly absorbed by plant roots.[55] However, some heavy metals (cadmium, copper, molybdenum, nickel, and zinc) can accumulate in soil and become toxic unless good management practices are followed. For that reason, crop tissue and grain analyses may be necessary to monitor crop uptake. In a study of the effects of 20 years of irrigation with secondary *domestic sewage* effluent, which contained no major industrial wastes, soil and crop (alfalfa) analyses found no accumulation of lead, copper, zinc, nickel, chromium, or cadmium.[56] However, late-crop irrigation with wastewater high in nitrate can lead to high-nitrate concentrations in both soils and crops. Excessive nitrate levels are known to be injurious when fed to animals, resulting in cyanosis. Also, boron, a constituent not normally removed by conventional treatment, is toxic to citrus crops.[57]

Wastewater Aerosol Hazard

The potential hazard from aerosols is related primarily to wastewater treatment by the activated sludge, trickling-filter, and spray irrigation processes. The presence of microbiological pathogens in sewage aeration products downwind has been well documented (particularly for *E. coli*). Although pathogens can be recovered from such aerosols, the risk human disease from the aerosols has not been clearly demonstrated in the United States.[58] Such risk has been demonstrated, however, among workers exposed to nondisinfected spray irrigation in India.[59] Also, a study of medical records at a kibbutzim showed apparent seasonal increase in enteric disease in the 0- to 4-year-olds who lived within 1,000 meters of fields sprinkler-irrigated with stabilization pond effluent.[60] In view of the potential risk, it is advisable to chlorinate wastewater and provide adequate buffer zones (1,000 feet or more) as a precautionary measure.

Regulation Standards for controlling the reuse of wastewater have been recommended by a number of agencies, including the World Health Organization; their standards for wastewater use in agriculture are presented in Table 3.18. However, the standards established by the California Department of Public Health, are among the most explicit[61] and cover "wastewater constituents, which will assure that the practice of directly using reclaimed wastewater* for the specified purposes does not impose undue risks to public health." The California fecal coliform standards for reclaimed water are complete wastewater treatment for direct discharge, including disinfection and tertiary treatment to less than 2.2 MPN per 100 ml when public access is possible; less than 23 MPN per 100 ml for secondary effluent used for golf courses, cemeteries, landscaping; and less than 2.2 per 100 ml when water is used at parks, schoolyards, playgrounds, or near residential areas for irrigation.

Wastewater Disposal by Land Treatment

Land treatment and disposal of wastewater on natural biological, physical, and chemical processes in the soil to treat wastewater. Methods used include spray or sprinkler irrigation; ridge-and-furrow and border strip irrigation; overland flow; subsurface disposal in a soil absorption system; and wetland treatment. Table 3.19 compares the design features for land treatment processes and Table 3.20 shows expected quality of wastewater treated by processes.

Irrigation Spray irrigation is the most common method of applying wastewater to land. Wastewater application is generally limited to 8 hours, followed by a 40-hour rest period to permit drainage of the soil, reaeration, plant nutrient uptake, and microbial readjustment. Physical, biological, and chemical treatment takes place during percolation, particularly in the upper soil, including BOD and COD removal. Dissolved solids and chlorides may cause a soil problem where the wastewater is high in these constituents. Phosphorus and cadmium are accumulated by plants.

Because cadmium may be hazardous in edible crops, its level should be kept below 2.5 mg/kg in the soil.

Slow-rate spray irrigation rates are generally between 0.5 to 4 inches per week, depending on soil permeability, climate, and wastewater strength. Ground slope

*"Reclaimed wastewaters" are waters, originating from sewage or other waste, which have been treated or otherwise purified so as to enable direct beneficial reuse or to allow reuse that would not otherwise occur. "Disinfected wastewater" means wastewater in which the pathogenic organisms have been destroyed by chemical, physical, or biological methods.

TABLE 3.18 Recommended Microbiological Quality Guidelines for Wastewater Use in Agriculture[a]

Category	Reuse Conditions	Exposed Group	Intestinal Nematodes[b] (arithmetic mean no. of eggs per litre[c])	Fecal Coliforms (geometric mean no. per 100 ml[c])	Wastewater Treatment Expected to Achieve the Required Microbiological Quality
A	Irrigation of crops likely to be eaten uncooked, sports fields, public parks[d]	Workers, consumers, public	≤ 1	$\leq 1,000$[d]	A series of stabilization ponds designed to achieve the microbiological quality indicated, or equivalent treatment
B	Irrigation of cereal crops, industrial crops, fodder crops, pasture and trees[e]	Workers	≤ 1	No standard recommended	Retention in stabilization ponds for 8–10 days or equivalent helminth and fecal coliform removal
C	Localized irrigation of crops in category B if exposure of workers and the public does not occur	None	Not applicable	Not applicable	Pretreatment as required by the irrigation technology, but not less than primary sedimentation

[a]In specific cases, local epidemiological, sociocultural, and environmental factors should be taken into account, and the guidelines modified accordingly.
[b]*Ascaris* and *Trichuris* species and hookworms.
[c]During the irrigation period.
[d]A more stringent guideline ($\leq$200 fecal coliforms per 100 ml) is appropriate for public lawns, such as hotel lawns, with which the public may come into direct contact.
[e]In the case of fruit trees, irrigation should cease 2 weeks before fruit is picked, and no fruit should be picked off the ground. Sprinkler irrigation should not be used.

Reproduced, with permission, from *Health Guidelines for the Use of Wastewater in Agriculture and Aquaculture*, World Health Organization, 1989 (WHO Technical Report Series No. 778).

TABLE 3.19 Comparison of Design Features and Site Characteristics for Land Treatment Processes

Feature	Principal Processes			Other processes	
	Slow rate	Rapid infiltration	Overland flow	Wetlands	Subsurface
Application techniques	Sprinkler or surface[a]	Usually surface	Sprinkler or surface	Sprinkler or surface	Subsurface piping
Annual application rate (ft)	0.5 to 6	6 to 125	3 to 20	1.2 to 30	2.4 to 27
Field area required (acres)[b]	23 to 280	3 to 23	6.5 to 44	4.5 to 113	5.3 to 57
Typical weekly application rate (in.)	1.3 to 10	10 to 240	6 to 15[c]	2.5 to 64	5.1 to 51
			15 to 40[d]		
Land slope	0 to 20% Cultivated 35% Uncultivated	Not critical	2 to 8% for final slopes		
Soil permeability	Moderate to slow	Rapid	Slow to none		
Groundwater depth (ft)	2 to 10	3 during application 5 to 10 during drying	Not critical		
Minimum pretreatment required	Primary sedimentation[e]	Primary sedimentation	Grit removal and screening	Primary sedimentation	Primary sedimentation

Disposition of applied wastewater	Evapotranspiration and percolation	Mainly percolation	Surface runoff and evapotranspiration with some percolation	Evapotranspiration, percolation, and runoff	Percolation with some evapotranspiration
Need for vegetation	Required	Optional	Required	Required	Optional

[a]Includes ridge-and-furrow and border strip.
[b]Field area in acres not including buffer areas, roads, or ditches for 1 million gpd (43.8 litre/s) flow.
[c]Range for application of screened wastewater.
[d]Range for application of lagoon and secondary effluent.
[e]Depends on the use of the effluent and the type of crop.
1 cm = 0.394 in
1 m = 3.28 ft
1 hectare = 2.47 acre

Source: *Process Design Manual for Land Treatment of Municipal Wastewater*, U.S. EPA, Washington, D.C., EPA/625/R-06/016, September 2006, p. 1-1 and *Process Design Manual for Land Treatment of Municipal Wastes*, U.S. EPA, Cincinnati, OH, October 1981, p. 1-3.

TABLE 3.20 Expected Effluent Water Quality for Land Treatment Processes (mg/l unless otherwise noted)

Constituent	Slow Rate[a]	Rapid Infiltration[b]	Overland Flow[c]
BOD	<2	5	10
Suspended solids	<1	2	10
Ammonia nitrogen as N	<0.5	0.5	<4
Total nitrogen as N	3	10	5
Total phosphorus as P	<0.1	1	4
Fecal coliform (#/100 ml)	<1	10	200+

[a]Percolation of primary or secondary effluent through 5 ft (1.5 m) of soil.
[b]Percolation of primary or secondary effluent through 15 ft (4.5 m) of soil.
[c]Runoff of comminuted municipal wastewater over about 150 ft (45 m) of slope.

Source: Process Design Manual for Land Treatment of Municipal Wastewater, U.S. EPA, EPA/625/R-06/016, September 2006, p. 1-2.

should be less than 20 percent on cultivated land and 40 percent on noncultivated land. Soil permeability should be moderately slow to moderately rapid* and the depth to groundwater a minimum of 2 to 3 feet, although 5 feet is preferred. High-rate spray irrigation rates are 4 to 40 and up to 120 inches per week. Soil permeability for high-rate systems should be rapid with a permeable soil depth of 15 feet or more. Nitrogen and phosphorus removal is usually not complete in high-rates systems.

Ridge-and-furrow ditch systems are typically 100 to 1,500 feet in length, with depth and spacing varying depending on the type of crop and the soil's ability to transmit water laterally. Border strips are 30 to 60 feet long.[62] Application rates for ridge-and-furrow (gpm/100 ft) and border strip irrigation are similar to those for spray irrigation and will vary with soil permeability, spacing, and slope of the furrow.

Overland Flow Overland flow is a treatment process in which wastewater is treated as it flows down a series of vegetated terraces. Application to the top of a grassed, slightly permeable slope (2 to 8 percent) as sheet flow allows for both physical (grass filtration and sedimentation) and chemical-biological (oxidation) treatment. Treated runoff is collected in ditches and discharged to a watercourse. Surface runoff may be 50 percent or more. Grasses, which have high nitrogen uptake capacity,† are usually chosen for cover vegetation. Viruses and bacteria are not removed. Overland flow treatment is more effective during warm weather.

*0.2 to 6.0 or more inches per hour permeability corresponding roughly to a soil percolation rate of 1 inch in 45 minutes to less than 10 minutes.

†Bent grass, Bermuda grass, Reed Canary grass, Sorghum-Sudan, Vetch; also Alfalfa, Clover, Orchard grass, Broome grass, and Timothy.

Natural or Constructed Wetlands Secondary wastewater effluent can be applied to either existing or artificial wetlands. Wetlands include inundated areas having water depths of less that 2 feet, which support emergent plants such as bulrush, reeds, hyacinths, or sedges. These plants provide surfaces to which bacterial films can attach, aid in the filtration and adsorption of wastewater constituents, and add oxygen to the water column. Natural wetlands include marshes, bogs, peat lands, and swamps. Constructed wetlands include both free water surface systems and subsurface flow systems.

Free water surface systems are generally composed of a series of parallel shallow basins from 0.3 to 2 feet in depth, which have relatively impermeable bottom soil and emergent vegetation. Wastewater is treated in these systems as it flows through the stems and roots of the emergent vegetation. Subsurface flow systems are composed of beds or channels filled with gravel, sand, or similar permeable material in which emergent plants have been planted. Wastewater is treated in these systems as it flows horizontally through the media-plant filter.

Advanced Wastewater Treatment

Advanced (tertiary) wastewater treatment may be needed in some instances to protect the water quality of the receiving surface and groundwaters from undesirable nutrients, toxic chemicals, or pathogenic organisms, which are not removed by conventional secondary treatment. For example, nitrogen and phosphorus in plant effluent may promote the growth of plankton; toxic organic and inorganic chemicals may endanger fish and other aquatic life and endanger sources of water supply, recreation, and shellfish growing; and pathogens, such as the infectious hepatitis virus and giardia, that are not removed by conventional sewage treatment increase the probability of waterborne disease outbreaks. Figure 3.13 shows wastewater treatment unit process including advanced or tertiary treatment.

Advanced wastewater treatment may include combinations of the following unit processes depending on the water quality objectives to be met. This list is meant to be illustrative and should not be considered all-inclusive.

For Nitrogen Removal

Breakpoint chlorination—to reduce ammonia nitrogen levels (nitrate and organic are not affected).

Ion exchange, after filtration pretreatment—to reduce nitrate nitrogen and ammonium levels using selective resin for each; phosphate also reduced.

Nitrification followed by dentrification, ammonia (if present) removed or converted to nitrate and then to nitrogen gas—ammonia stripping* (degasifying) to remove ammonia nitrogen, or biological oxidation of ammonia

*Wastewater pH is raised to 10.0 to 10.5 or above, usually by the addition of lime or sodium hydroxide, at which pH the nitrogen is mostly in the form of ammonia, which can be readily removed by adequate aeration, but pH adjustment of the effluent will be needed to meet stream standards. Organic or nitrate nitrogen are not removed. Ammonia stripping equipment includes tray towers, cascade aerators, step aerators, and packed columns.

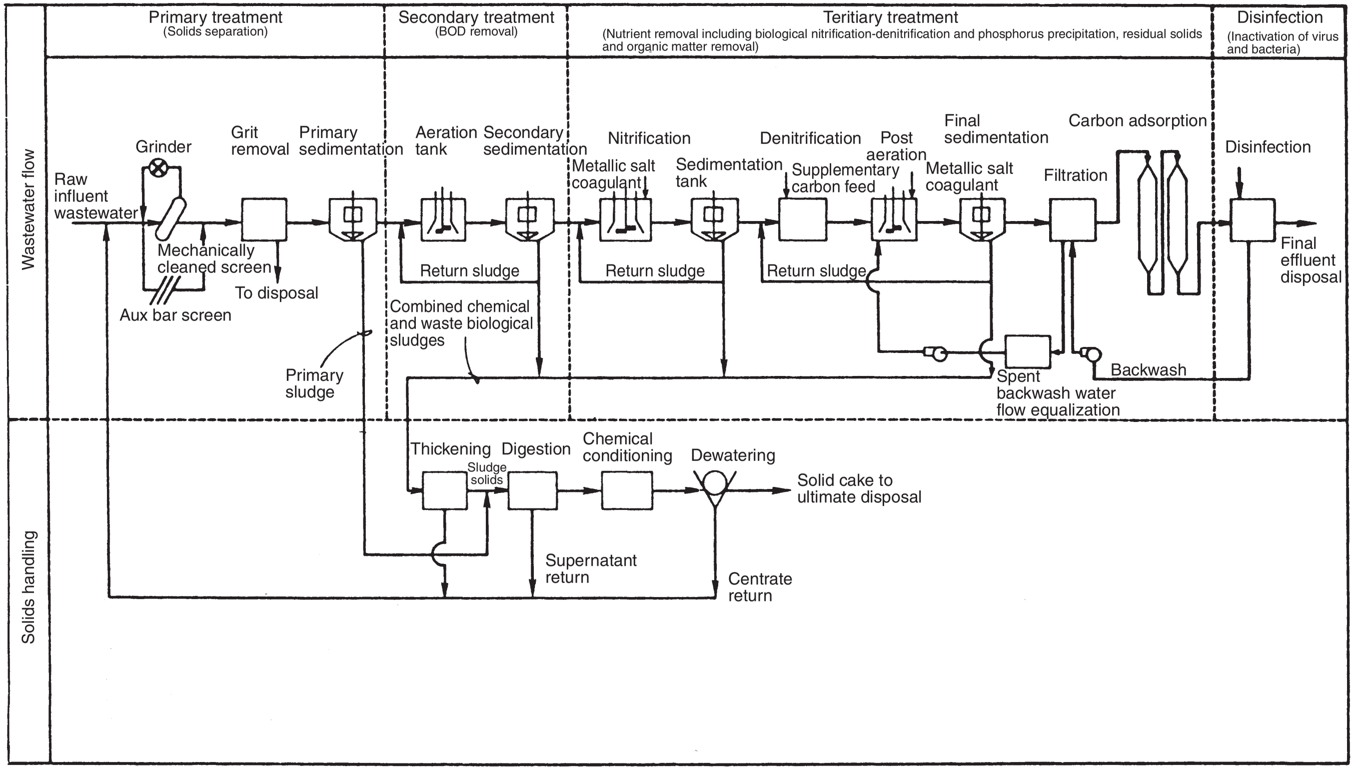


FIGURE 3.13 Typical schematic flow and process diagram. (*Source*: *Operation of Wastewater Treatment Plants*, MOP 11, Water Pollution Control Fed., Washington, DC, 1996.® 1996 WPCF, used with permission.)

in the activated sludge process to nitrate; denitrification (organic nitrogen) achieved by filtration through sand or GAC, or by biological denitrification, usually under anaerobic conditions, following activated sludge treatment (nitrification and denitrification).

Methanol—to reduce nitrate levels.

Reverse osmosis, following treatment to prevent fouling of membranes—to reduce total nitrogen levels; also dissolved solids.

Electrodialysis, following pretreatment—to reduce ammonia, organic, and nitrate nitrogen levels; also dissolved solids.

Oxidation pond—to reduce total nitrogen levels.

Land treatment, low-rate irrigation to overland flow—to reduce total nitrogen and phosphorous levels. Rapid infiltration is also effective.

For Phosphorus Removal

Coagulation (lime, alum, or ferric chloride, and polyelectrolyte) and sedimentation—to reduce phosphate levels, TDS increased, additional nitrogen removal, also some heavy metals.

Coagulation, sedimentation, and filtration (mixed media)—to further reduce phosphate levels; also suspended solids, TDS increased, additional nitrogen also removed.

Lime treatment, after biological treatment, followed by filtration—to reduce phosphorus (pH above 11) also suspended solids.

Ion exchange, with selected specific resins—to reduce phosphate, dissolved solids, and nitrogen.

For Dissolved Organic Removal

Activated carbon (granular or powdered) absorption, following filtration—to reduce COD including dissolved organics; also chlorine.

Reverse osmosis, following pretreatment—to reduce dissolved solids.

Electrodialysis following pretreatment—to reduce dissolved solids.

Distillation, following pretreatment—to reduce dissolved solids.

Biological wastewater treatment—to reduce dissolved organics.

Aeration—to remove volatile organics.

For Heavy Metals Removal

Lime treatment—to reduce heavy metals levels.

Coagulation and sedimentation—to reduce heavy metals levels.

For Dissolved Inorganic Solids Removal (Demineralization)

Ion exchange, using anionic and cationic resins, following pretreatment—to reduce total dissolved solids.

Coagulation and sedimentation—to reduce heavy metals.

Reverse osmosis—to reduce total dissolved solids.

Electrodialysis—to reduce total dissolved solids.

For Suspended Solids Removal

Filtration (sand, lime, or ferric chloride and possible polyelectrolytes), sedimentation, filtration—to reduce suspended solids, also ammonia nitrogen, and phosphate if high alum or lime dosage used; adding ammonia stripping will reduce total nitrogen further; adsorption using activated carbon will reduce dissolved organics and total nitrogen.

For Recarbonation

Carbon dioxide addition—to reduce pH where wastewater pH has been raised to 10 to 11; this is necessary to reduce deposition of calcium carbonate in pipelines, equipment, or the receiving watercourses.

TYPICAL DESIGNS FOR SMALL TREATMENT PLANTS

The following design analyses are for a treatment plant, which is meant to serve 150 persons at 100 gal per capita per day (gpcd) = 15,000 gpd.

Standard-Rate Trickling Filter Plant with Imhoff Tank

See Figure 3.14 for design details for an Imhoff tank.

1. Flowing through channel provides 2.5-hr detention.

$$\frac{15{,}000}{24} \times 2 = 1250 \text{ gal} = 167 \text{ ft}^3$$

2. Sludge storage at 5 ft^3 per capita = 5 × 150 = 750 ft^3.
3. Sludge drying beds at 1.25 ft^2 per capita = 150 × 1.25 = 188 ft^2.
4. Trickling filter loading at 4000 lb of BOD/acre-ft = 0.25 lb/yd^3. Loading based on 0.17 lb of BOD/capita with 35 percent removal in primary settling = 150 × 0.17 × 0.65 = 16.6 lb/day.

$$\text{Filter volume required} = \frac{400}{43{,}560} = \frac{16.6}{x}; \ \ x = 1800 \text{ ft}^3$$

Hence, the required filter diameter,

$$\text{assuming a 6-ft depth} = D = \sqrt{\frac{1800 \times 4}{\pi \times 6}} = 19.5 \text{ ft}$$

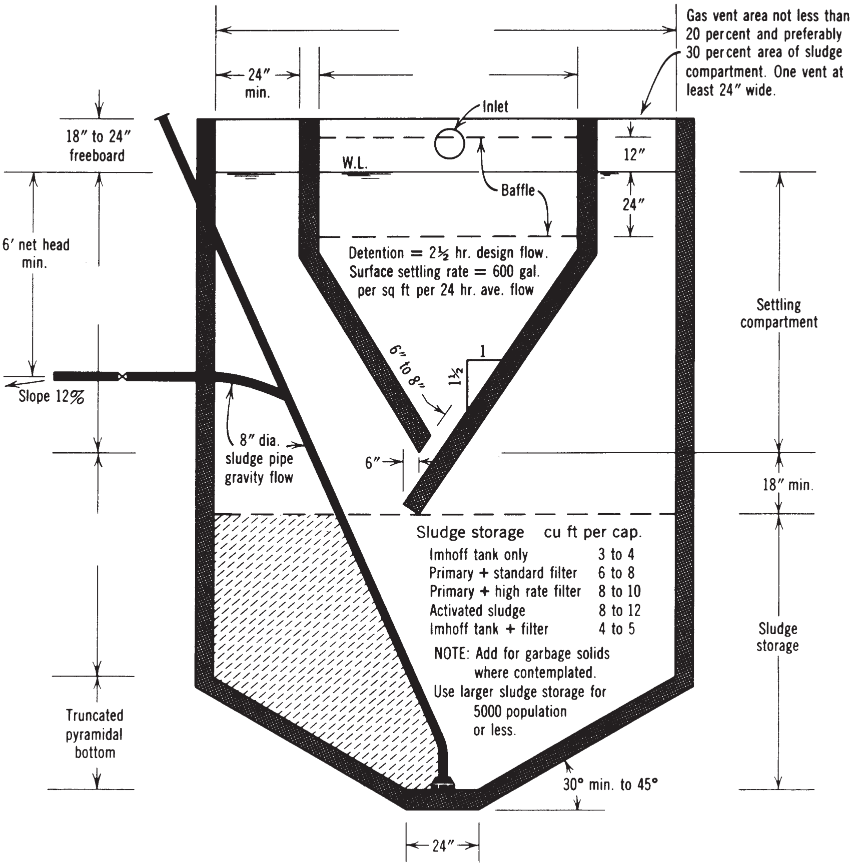


FIGURE 3.14 Section through Imhoff tank, with design details.

The volumetric loading

$$\frac{\dfrac{15{,}000}{\dfrac{\pi \times 20 \times 20}{4}}}{} = \frac{x}{43{,}500};\ x = 2{,}080{,}000 \text{ gpd / acre on a}$$

6-ft deep filter.

5. Final settling provides 2-hour detention. $\dfrac{15{,}000}{24} \times 2 = 1250 \text{ gal} = 167 \text{ ft}^3$ With a surface

$$\text{settling rate} = 500 \text{ gpd / ft}^2 = \frac{180 \times \text{tank depth}}{\text{2-hour detention}};\ \text{tank depth} = 5.6 \text{ ft.}$$

6. If the BOD in the raw sewage is 200 mg/l, and the Imhoff tank removes 35 percent, the applied BOD $= 0.65 \times 200 = 130$ mg/l. According to the National Research Council Sanitary Engineering Committee formulas,* a filter loaded at 400 lb of BOD per acre-ft will produce an average settled effluent containing 14 percent of that applied, or $0.14 \times 130 = 18$ mg/l.

High-Rate Trickling Filter Plant with Imhoff Tank

1. Flowing through channel same as with standard rate filter $= 209\ \text{ft}^3$.
2. Sludge storage at $8\ \text{ft}^3$/capita $= 8 \times 150 = 1{,}200\ \text{ft}^3$.
3. Sludge drying beds at $1.50\ \text{ft}^2$/capita $= 150 \times 1.50 = 225\ \text{ft}^2$.
4. Trickling filter loading at 3000 lb of BOD/acre ft $= 1.86\ \text{lb/yd}^3$. Loading based on 0.17 lb of BOD per capita with 35 percent removal in primary settling $= 150 \times 0.17 \times 0.65 = 16.6$ lb/day. The BOD in the raw sewage is $150 \times 0.17 = 25.5$ lb. Filter volume required $= \dfrac{3000}{43{,}560} = \dfrac{25.5}{x}\ x = 370\ \text{ft}^3$. Hence, the required filter diameter, assuming 3.25 ft depth $\times\ D = \sqrt{\dfrac{370 \times 4}{\pi \times 3.25}} = 12.0$ ft.The volumetric surface loading on a 12-ft diameter filter with influent + recirculation $[(I + R = 1 + 1 = 2)$ or $2(15{,}000)] = 30{,}000$ gal/day is $x = 11{,}500{,}000$ gpd/acre on a 3.25/ft deep filter.
5. Final settling provides 2-hour detention at flow $I + R$.

$$\frac{30{,}000}{24} \times 2 = 2500\ \text{gal} = 334\ \text{ft}^3$$

6. Without recirculation, an applied BOD of 130 mg/1 (0.65×200), at a rate of 3000 lb/acre-ft will be reduced to $0.32 \times 130 = 42$ mg/l in the settled effluent. With recirculation of $R/I = 1$, the efficiency of the high-rate filter and clarifier can be determined from the following formulas:[63]

$$F = \frac{1 + \dfrac{R}{I}}{\left(1 + 0.1\dfrac{R}{I}\right)^2}$$

where

F = recirculation factor
R = volume of sewage recirculated = 1
I = volume of raw sewage = 1
$F = (1 + 1)/(1 + 0.1^2) = 1.65$

*$E = \dfrac{100}{1 + 0.0085\sqrt{u}}$; E = percent BOD removed, standard filter and final clarifier. u = filter loading, lb of BOD per acre-ft.

and from

$$u = \frac{w}{VF}$$

where

u = unit loading on high-rate filter, lb of BOD/acre ft
w = total BOD to filter, lb/day = 16.6
V = filter volume, acre-ft based on raw sewage strength = 0.0084
F = recirculation factor = 1.65

$$u = \frac{16.6}{0.0084 \times 1.65} = 1.98\text{lb /acre-ft}$$

and from

$$E = \frac{100}{1 + 0.0085\sqrt{u}}$$

where

E = percent BOD removed by a high-rate filter and clarifier

$$E = \frac{100}{1 + 0.0085\sqrt{1198}} = 77 \text{ percent}$$

Hence, the BOD will be reduced to (1–0.77)130 = 30 mg/l.

Intermittent Sand Filter Plant with Imhoff Tank or Septic Tank

1. Flowing through channel of Imhoff tank provides 2.5-hour detention = 209 ft^3.
2. Sludge storage at 4 ft^3/capita = 4 × 150 = 600 ft^3.
3. Sludge drying bed provides 188 ft^2. OR: Septic tank provides 24-hour detention = 15,000 gal = 2,000 ft^3.
4. Sand filter, covered, designed for loading of 50,000 gpd/acre. Filter area is

$$\frac{50{,}000}{43{,}560} = \frac{15{,}000}{x}; = x = 13{,}000 \text{ ft}^2$$

If filter is open, the required area = 6,550 ft^2. Make filters in two sections. Provide dosing tank to dose each covered filter section at volume equal to 75 percent of the capacity of the distributor laterals or to dose each open filter section to depth of 2 to 4 in.

If the efficiency of BOD removal of a sand filter is 90 percent, the BOD of the effluent would be 130 × 0.10 = 13 mg/l.

DESIGN OF LARGE TREATMENT PLANTS

Although the design details for large sewage treatment plants are beyond the scope of this text, some of the major design elements are presented in the following sections for general information. Also, state and federal regulatory agencies have recommended standards and guidelines and should be consulted.[64] Treatment processes and bases of design are summarized in Figure 3.15 and Table 3.21, while process efficiencies are given in Table 3.22. Typical flow diagrams are shown in Figures 3.12 and 3.13.

Larger sewage treatment plants should be designed for a population at least 10 years in the future, although 15 to 25 years is preferred, and a per capita flow of not less than 100 gpd. Where available, actual flow studies, population trends, zoning, and growth potential should be used. Plants should be accessible from highways but as far as practical from habitation and sources of water supply, and protected from a 100-year flood. The required degree of treatment should be based on the water quality standards and objectives established for the receiving waters and other factors, as noted previously.

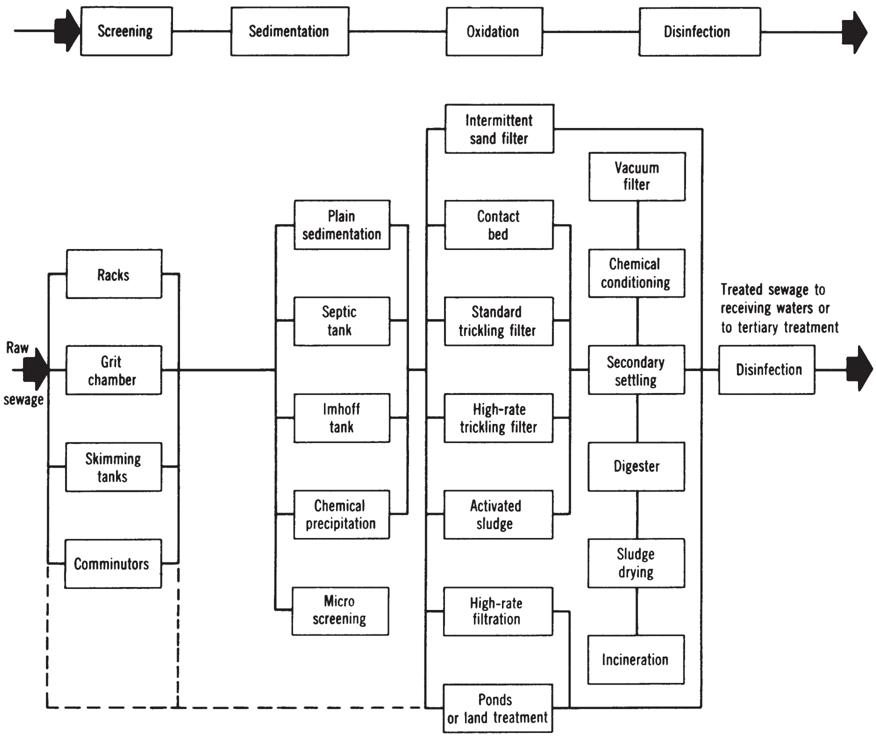


FIGURE 3.15 Conventional sewage treatment unit processes. Tertiary treatment may include denitrification, phosphorus removal; coagulation, sedimentation, and/or filtration; adsorption, ion exchange, electrodialysis, reverse osmosis, or any combination of processes depending on the end use of the renovated wastewater.

TABLE 3.21 Conventional Sewage Treatment Plant Design Factors

Preliminary Treatment	Coagulation and Sedimentation Treatment
Racks Area: 200% plus sanitary sewer; 300% plus combined sewer. Bar space: 1–1.75 in., dual channels. *Screens* Net submerged area: 2 ft^2/mgd for sanitary sewer; 3 ft^2/mgd for combined sewer. Slot opening 0.125 in. min. Dual units, preceded by racks.	*Sedimentation* Surface settling rates at peak flows: primary and intermediate set—tanks 1,500 gpd/ft^2; final set—tanks 1,200 gpd/ft^2 after trickling filters or rotating biological contactors and for activated sludge for conventional, step aeration, contact stabilization, and carbonaceous staged of separate-stage nitrification; following extended aeration 1,000 gpd/ft^2; for physicochemical treatment using lime: 1,400 gpd/ft^2. Weir rates: 10,000 gpd per linear foot for average flows to 1.0 mgd and up to 15,000 for larger flows Sludge hopper: 1 horizontal to 1.7 vertical. Sludge pipe: 6 in./min.
Grit Chamber Sewage velocity: 1 fps mean, 0.5 fps, minimum. Detention: 45–60 sec, floor 1 ft below outlet. Minimum of 2 channels.	
Skimming Tank Air or mechanical agitation with or without chemicals. Detention: 20 min for grease removal, 5–15 min for aeration, 30 min for flocculation.	*Chemical Precipitation* Rapid mix, coagulation, sedimentation. Ferric chloride, ferrous sulfate, ferric sulfate, alum, lime, or a polymer.
Comminutors Duplicate or bypass, downstream from grit chamber.	*Imhoff Tank* Detention period: 2–2.5 hours. Gas vent: 20% total area of tank minimum. Bottom slope: 1.5 vertical to 1 horizontal. Sludge compartment: 3–4 ft^3 per capita 18 in. below slot; 6–10 ft^3 per capita secondary treatment. Bottom slope: 1 to 1 or 2. Slot and overlap: 8 in. Sludge pipe: 8 in. minimum under 6 ft head. Velocity: 1 fpm. Surface settling rate: 600 gpd/ft^2

(*continues*)

TABLE 3.21 (*continued*)

Preliminary Treatment	Coagulation and Sedimentation Treatment
Flow Basis 100 gal per capita plus industrial wastes. Usual to assume total flow reaches small plants in 16 hr.	
Flow Equalization Based on 24-hr plot to smooth out hydraulic and organic loading.	
Chemical Treatment For odor control, oxidation, corrosion control, neutralization.	*Tube and Inclined Plate Settlers* PVC or metal tubes, at 45° 60°. from horizontal, 2 in. × two 6-in., 4 ft long. May be installed in existing basin.
Biological Treatment	**Sludge Treatment**
Intermittent Sand Filter rate: 50,000–100,000 (gpad)[b] with plain settling and 400,000 gpad with trickling filter or activated sludge. Sand: 24 in. all passing 0.25-in. sieve, Effective size 0.35–0.6 mm. Uniform coefficient <3.5.	*Digester*[a] Capacity: with plain sedimentation 2–3 ft^3 per capita heated or 4–6 ft^3 unheated. With standard trickling filter 3–4 ft^3 heated and 6–8 ft^3 unheated; 4–5 ft^3 heated and 8–10 ft^3 unheated with a high-rate filter. With activated sludge 4–6 ft^3 per capita heated and 8–12 ft^3 unheated. Bottom slope: 1 on 4, gravity.
Contact Bed Filter rate: 75,000–100,000 gpad/ft.	*Sludge Drying Bed* Open: 1 ft^2 per capita with plain sedimentation, 1.5 ft^2 with trickling filter.
Trickling Filter Standard rate: 400–600 lb BOD/acre-ft/day; or 2–4 mgad[c], 6 ft deep. High rate: 3000+ lb BOD/acre-ft/day, or 30 mgad for 6 ft deep. Minimum filter depth 5 ft, maximum 10 ft. 1-1/34 ft^2 with activated sludge and 2 ft^2 with chemical coagulation. Glass covered: reduce area by 25%.	*Vacuum Filtration* Pounds per square foot per hour dry solids. Primary 6 to 10, trickling filter 1.5–2.0, activated sludge 1–2.

Activated Sludge Normally 2 hr retention in primary and final sedimentation and 6–8 hr aeration.	*Centrifuging* Flow rate based on gallons per minute per horsepower.
Rapid Filtration—Tertiary Treatment 2–5 gpm/ft^2, 1–4 mm sand, 48 in., backwash 15–25 gpm/ft^2.[d]	*Wet Combustion* Sludge thickener: loading of 10 lb/day/ft^2.
Land Treatment See text.	*Land Disposal* Stabilized sludge only. See text.
Stabilization Pond—Facultative 15–35 lb BOD/acre-ft/day, 3–5 ft liquid depth, center inlet; variable withdrawal depth, 3-ft freeboard, detention 90–180 days; multiple units; winter flow retention. Use up to 50 lb BOD loading in mild climate and 15–20 lb in cold areas.	*Incineration* Tons per hr depending on moisture and solids content. Temperature 1,250–1,400°F. Pyrolysis temperature higher.
Rotating Biological Contactors See text.	*Gas Production* A properly operated heated digester should produce about 1 ft^3 of gas per capita per day from a secondary treatment plant and about 0.8 ft^3 from a primary plant. The fuel value of the gas (methane) is about 640 Btu/ft^3.
Disinfection Chlorine, ozone: see text.	

[a] Anaerobic sludge digestion will require approximately 65 days at 55°F, 56 days at 60°F, 42 days at 71°F, 27 days at 86°F, 24 days at 95°F, 20 days at 113°. The optimum temperature is 86°–95°F. Mixing of sludge can reduce digestion time up to 50%. In large plants, sludge is usually digested in two stages. Temperature of 140°F causes caking on pipes.

[b] Gallons per acre per day = gpad.

[c] Million gallons per acre per day = mgad.

[d] For multimedia, see state standards.

Note: Surface setting rate = gpd/ft^2 = $\frac{180 \times \text{tank depth in ft}}{\text{detention, hr}}$.

TABLE 3.22 Sewage Treatment Plant Unit Combinations and Efficiencies: Approximate Total Percent Reduction

Treatment Plant	Suspended Solids	Biochemical Oxygen Demand
Sedimentation plus sand filter	90–98	85–95
Sedimentation plus standard trickling filter, 600 lb BOD/acre-ft maximum loading	75–90	80–95
Sedimentation plus single-stage high-rate trickling filter	50–80	35–65[a]
Sedimentation plus two-stage high-rate trickling filter	70–90	80–95[a]
Activated sludge	85–95	85–95
Chemical treatment	65–90	45–80
Preaeration (1 hr) plus sedimentation	60–80	40–60
Plain sedimentation	40–70	25–40
Fine screening	2–20	5–10
Stabilization (aerobic) pond	—	70–90
Anaerobic lagoon	70	40–70

[a]No recirculation. Efficiencies can be increased within limits by controlling organic loading, efficiencies of settling tanks, volume of recirculation, and number of stages; however, effluent will be less nitrified than from standard rate filter but will usually contain dissolved oxygen. Filter flies and odors are reduced. Study first cost plus operation and maintenance.

Biosolids Treatment and Disposal

The U.S. EPA established standards for the use and disposal of biosolids (i.e., sewage sludge and septage) in 1993.[65] These standards, which are referred to as the Part 503 Rule, set pollutant limits and management practices for biosolids that are applied to land, placed in a surface disposal site, or fired in an incinerator.

Pollutant limits for pathogens and metals are specifically mandated under the Part 503 Rule. For biosolids applied to the land, limits on pathogen and metal levels must be met with the requirements for pathogens vary depending on the type of land application. Class A pathogen requirements must be met when biosolids are applied to lawns or home gardens. For such use, pathogens such as *Salmonella* sp. bacteria, enteric viruses, and viable helminth ova must be below detectable levels. Class B pathogen requirements, which require that pathogens be reduced to levels that are not likely to pose a threat to public health or the environment, include various site restrictions. For example, lands receiving Class B biosolids must prohibit human access to or animal grazing of the site for a specified period of time. Similarly, crops from farmlands receiving Class B biosolids must not be harvested until a set time has elapsed after sludge application has stopped. The Class B requirements and site restrictions have to be met when biosolids are applied to farmlands, forests, public contact sites (i.e., parks or sports fields), or reclamation sites. U.S. EPA pathogen standards for Class A and B sludges are presented in Table 3.23, while numerical limits for heavy metals in biosolids are listed in Table 3.24.

TABLE 3.23 Microbiological Standards for Class A and B Biosolids

Standard	Class A	Class B
Fecal coliforms per grams dry solids	<1,000	<2,000,000[a]
Salmonellae per 4 grams dry solids	<3	
Enteroviruses pfu per 4 grams dry solids	<1[b]	
Parasite ova per 4 grams dry solids	<1[b]	

[a]Geometric mean of seven samples.
[b]For processes unable to satisfy specific operational requirements.

The Part 503 Rule also stipulates that various management practices must be met when biosolids are applied to the land. For bagged biosolids, certain labeling requirements must be met. For bulk biosolids, prohibitions against its application on frozen or flooded ground or within 10 meters of surface waters are required.

U.S. EPA requirements for biosolids placed in a surface disposal site vary depending upon whether the biosolids are placed in a landfill that only accepts biosolids (i.e., a monofill) or are codisposed with municipal solid waste and on whether the site is lined and has a leachate collection system. In most instances, liners and leachate collection systems are only used in association with codisposal sites. For sites not having liners and leachate collection systems, biosolids must meet specified limits for arsenic, chromium, and nickel. These limits vary, depending on the distance between the boundary of the active biosolids disposal area and the actual property line of the disposal site. For example, the limits for arsenic range from 30 mg/kg at distances less than 25 meters up to 73 mg/kg for

TABLE 3.24 Metal Concentration Limits for Biosolids Applied to Land

Parameter	Ceiling Concentration (mg/kg)	Monthly Average Concentration (mg/kg)	Annual Loading Rate (kg/ha-yr)	Cumulative Loading Rate (kg/ha)
Arsenic	75	41	2.0	41
Cadmium	85	39	1.9	39
Chromium	N/A	N/A	N/A	N/A
Copper	4,300	1,500	75	1,500
Lead	840	300	15	300
Mercury	57	17	0.85	17
Molybdenum	75	N/A	N/A	N/A
Nickel	420	420	21	420
Selenium	100	100	5.0	100
Zinc	7,500	2,800	140	2,800

Note: Concentrations and loading rates are on dry-weight basis. A February 25, 1984, *Federal Register* notice deleted chromium, deleted the molybdenum values for all but the ceiling concentration, and increased the selenium limit for monthly average concentration from 36 to 100.

distances greater than 150 meters. The limits for chromium and nickel also vary in a similar fashion (i.e., 200 to 600 mg/kg for chromium and 210 to 420 mg/kg for nickel). However, for sites with relatively impermeable liners (i.e., hydraulic conductivity values of 10^{-7} cm/sec or less) and leachate collection systems, the above limits do not apply.

Biosolid disposal sites must also comply with certain siting criteria and management practices. For example, biosolid landfills cannot impede the flow of a 100-year flood, be located in geologically unstable areas, or in a wetland unless a special permit is obtained. The landfills used for biosolid disposal must also be able to divert runoff from a 25-year, 24-hour storm event.

U.S. EPA requirements for biosolids that are incinerated include limits on metal concentrations and total hydrocarbons. Levels of beryllium and mercury emitted from biosolid incinerators must meet the National Emission Standards for Hazardous Air Pollutants. Arsenic, cadmium, chromium, and nickel must meet risk-specific concentrations, which range from 0.023 to 2.0 ug/m^3 and are based on a combination of biosolid feed rates, dispersion factors, and incinerator control efficiencies.

Biosolid treatment and disposal can be time-consuming and costly. Biosolid handling prior to final disposal may involve collection, thickening, stabilization, conditioning, dewatering, heat drying, air-drying, lagooning, composting, and final disposal of the sludge.[66] Figure 3.13 shows some sludge treatment processes and Table 3.20 gives some treatment design parameters. Sludges, including septic tank sludge, can be expected to contain numerous organic and inorganic chemicals and pathogens that can pose a hazard to agricultural produce, grazing animals, surface water, groundwater, and human health if not properly handled. Anaerobically digested sludge has been found to contain ascaris, toxocara, and trichuris ova, which remained viable in storage lagoons for up to 5 years.[67]

Biosolid thickening processes include gravity settling, flotation and centrifugation. Biosolid stabilization is usually achieved by aerobic or anaerobic digestion, lime treatment, or composting. Digestion reduces the organic solids and pathogens in sludge. Anaerobic two-phase (first digester acid, second digester methane producer) digestion of municipal sludge at 127.4°F (53°C) for 10 days "reduces to essentially undetectable levels indicator bacteria (fecal coliforms, *Escherichia coli*, fecal streptococci), enterovisuses, and viable *Ascaris* eggs."[68] Lime treatment and composting can also reduce pathogen levels. Also, sludge can be heated and mixed to accelerate the rate of digestion with sludge usually added at a rate of about 200 lb volatile solids per 1,000 ft^3 per day.

Biosolids can also be conditioned, prior to thickening or dewatering, by the addition of chemicals. Heat treatment by means of a furnace or dryer reduces sludge moisture content. Dewatering is accomplished by means of drying beds, centrifuges, vacuum filters, continuous belt presses, plate and frame presses, or evaporation lagoons.

Final disposal of biosolids can be by composting, incineration in multiple-hearth or fluidized bed (Figures 3.16 and 3.17), pyrolysis, sanitary

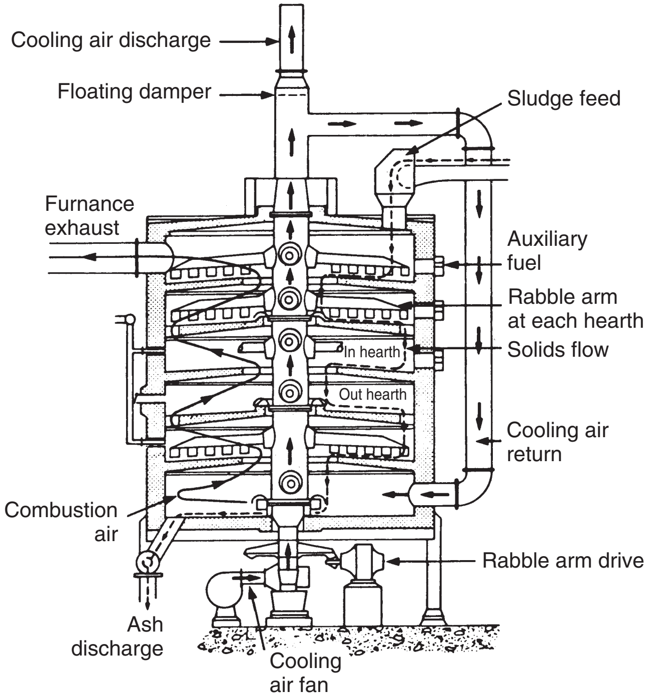


FIGURE 3.16 Cross-section of a multiple-hearth sludge incineration furnace. Temperature 1,400 to 1,500°F (769° to 816°C) in middle hearths. (*Source*: Environmental Regulations and Technology, Use and Disposal of Municipal Wastewater Sludge, U.S. EPA, Washington, DC, September 1984, p. 49.)

landfill,* land application or reclamation, or sod growing. Composting may be by the (1) window method including 5 turnings over 15 days and mixture temperatures of not less than 131°F (55°C) 6 to 8 inches below the surface, (2) static pile method in which the pile is kept at a temperature of not less than 130°F (55°C) for at least three consecutive days, or 3) enclosed vessel method in which the mixture is maintained at a temperature not less than 130°F (55°C) for at least three consecutive days.[69] Sawdust is often mixed with the finished compost.

Incineration can be combined with other industrial processes, such as cement manufacturing, to reduce the cost of disposal. This approach was used by the Los Angeles County Sanitation district to dispose of a portion of the 1,250 tons of biosolids they produce each day. Since 1996, the county has agreed to provide a local cement manufacturer with between 240 and 480 tons of biosolids per day. The biosolids are injected into the cement plant's hot exhaust gases where ammonia in the biosolids reduces plant nitrogen oxide emissions by up to 45 percent.

*Sludge dewatered to at least 20 percent solids.

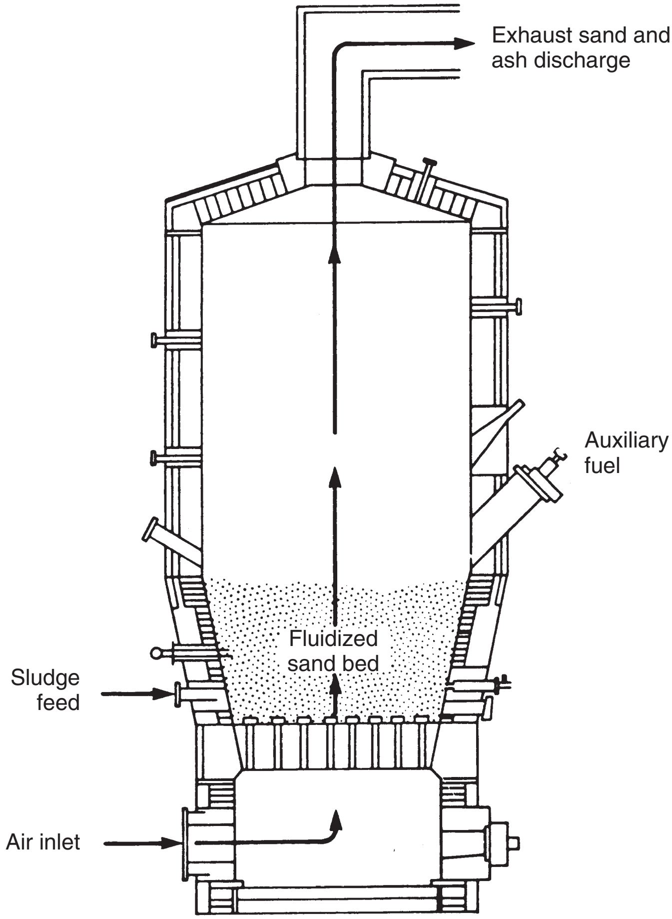


FIGURE 3.17 Cross-section of a fluidized-bed sludge incineration furnace. Temperature of bed 1,400 to 1,500°F (769° to 816°C). (*Source*: Environmental Regulations and Technology, Use and Disposal of Municipal Wastewater Sludge, U.S. EPA, Washington, D. C., September 1984, p. 49.)

While land disposal of stabilized sludge can promote the growth of vegetation and control erosion, certain precautions must be taken to ensure that sludge contaminants do not endanger the public health. For example, cadmium and zinc are known to accumulate in food crops grown on sludge disposal sites. For that reason, U.S. EPA has set limits under the Part 503 Rule for both maximum and average monthly metal levels that are not to be exceeded (see Table 3.21) for biosolids that are applied to the land.

Authority for implementation of the Part 503 Rule biosolid disposal requirements has been delegated to the states. As a result, a number of states had imposed more restrictive limits for the specified pollutants (13 states) and required testing for additional pollutants (22 states).[70] In some cases, communities (e.g., Kern County in California) have responded imposition of additional restrictions that have essentially prohibited the application of Class B biosolids to land. In response, many municipalities have converted to Class A treatment of biosolids. The treatment options usually selected for upgrading to Class A standards have been heat drying, composting, lime pasteurization, the N-Viro process (an alternative type of lime pasteurization), and thermophilic aerobic digestion.[71]

Cost of Sewage Treatment

The cost of sewage treatment systems can vary widely based on location, system size, and degree of treatment required. In general, costs can be divided into two categories: capital, and operation and maintenance. Cost estimates can be adjusted to present-day costs using the *Engineering News-Record* or other appropriate construction cost index (see Table 3.23).

The cost of individual septic tank systems will vary based on dwelling size, site conditions, and type of system. Typical costs (2006) for various on-site sewage treatment systems are given in Table 3.24.

For sewage treatment plants, typical costs can be estimated by adding 10 to 15 percent to the construction cost for contingencies. To these costs an additional 15 to 20 percent for engineering and 2 to 3 percent for legal/administrative costs needs to be added. The resulting total would be considered the total project construction cost. To this total cost an additional 3 to 6 percent needs to be added for financing costs. Taken together, these additions increase the total project cost by between 36 to 48 percent from the construction cost.

Cost comparisons should also consider the total annual costs—that is, the initial cost of construction and the annual cost of operation and maintenance (*O&M*). Typical average capital, O&M, and unit costs for selected sewage treatment processes are presented in Table 3.25.

Sometimes advanced wastewater treatment (Figure 3.13) is desired without fully realizing the large additional cost to obtain a small incremental increase in plant efficiency. Advanced wastewater treatment to remove an additional 3.8 to 10 percent BOD, 5.2 to 13 percent suspended solids, and approximately 61 to 68 percent phosphorus and ammonia-nitrogen has been found to increase capital costs by 42 to 99 percent and O&M costs by 37 to 55 percent.[72] This finding suggests that the other more cost-effective alternatives should be explored before making a decision to add advanced wastewater treatment.

Because the cost of advanced treatment can be high, some operators have opted to use natural or constructed wetlands for effluent polishing. The cost of constructing and, in particular, operating such systems can be significantly lower than those for advanced treatment processes. Typical construction and O&M costs for the natural treatment systems are given in Table 3.26 (See also Tables 3.27 and 3.28).

Many treatment plant operators have installed computer-based monitoring and control systems in an effort to reduce their operational costs. Also, the Internet revolution has offered the means for not only accessing real-time operational data,

TABLE 3.25 Cost Indices (Average per Year)

Year	Marshall & Stevens Installed Equipment Indices: 1926, 100 (All Industry)	*Engineering News-Record* Construction Index: 1913, 100 (Annual Average)	Handy-Whitman Index for Water Treatment Plants[a]: 1936, 100		*Engineering News-Record* Building Cost Index: 1913, 100 (Annual Average)	Chemical Engineering Plant Construction Index: 1957–1959, 100	U.S. EPA Sewage Treatment Plant Construction Index: 1957-1959, 100
			(Large Plant)	(Small Plant)			
1956	209	692	275	276	491	94	
1957	225	724	288	289	509	99	
1958	229	759	296	296	525	100	102
1959	235	797	311	309	548	102	104
1960	238	824	317	317	559	102	105
1961	237	847	315	315	568	101	106
1962	239	872	324	322	580	102	107
1963	239	901	330	327	594	102	109
1964	242	936	340	336	612	103	110
1965	245	971	350	346	627	104	112
1966	252	1,019	368	362	650	107	116
1967	263	1,074	380[b]	374[b]	676	110	119
1968	273	1,155	398	389	721	114	123
1969	285	1,269	441	424	790	119	132
1970	303	1,381	480	462	836	126	143
1971	321	1,581			948	132	160
1972	332	1,753			1,048	137	172
1973	344	1,895			1,138	144	182
1974	398	2,020			1,205	165	217
1975	444	2,212			1,306	182	250
1976	472	2,401			1,425	192	262
1977	491[c]	2,576			1,545	199[d]	271[d]
1978		2,776			1,654		
1979		3,003			1,919		
1980		3,237			1,941		
1981		3,535			2,097		
1982		3,825			2,234		
1983		4,066			2,384		
1984		4,146			2,417		
1985		,195			2,428		
1986		4,295			2,483		
1987		4,406			2,541		
1988		4,519			2,598		
1989		4,615			2,634		

TABLE 3.25 (*continued*)

Year	Marshall & Stevens Installed Equipment Indices: 1926, 100 (All Industry)	*Engineering News-Record* Construction Index: 1913, 100 (Annual Average)	Handy-Whitman Index for Water Treatment Plants[a]: 1936, 100		*Engineering News-Record* Building Cost Index: 1913, 100 (Annual Average)	Chemical Engineering Plant Construction Index: 1957–1959, 100	U.S. EPA Sewage Treatment Plant Construction Index: 1957-1959, 100
			(Large Plant)	(Small Plant)			
1990		4,732			2,702		
1991		4,835			2,751		
1992		4,985			2,834		
1993		5,210			2,996		
1994		5,408			3,111		
1995		5,471			3,112		
1996		5,620			3,203		
1997		5,826			3,364		
1998		5,920			3,391		
1999		6,059			3,456		
2000		6,221			3,539		
2001		6,334			3,574		
2002		6,538			3,623		
2003		6,695			3,693		
2004		7,115			3,984		
2005		7,446			4,205		
2006		7,888			4,441		

[a]Based on July of year.
[b]Based on January of year.
[c]Based on first quarter of year.
[d]Based on March of year. Example: 2006 index ÷ 1995 index = multiplier to obtain 2006 cost for a 1995 project cost.

Source: *Engineering News-Record* and *Process Design, Wastewater Treatment Facilities for Sewered Small Communities*, U.S. EPA, Environmental Research Information Center Technology Transaction, EPA-625/1-77-009, Cincinnati, OH, October 1977.

but also managing customer relations and billings more efficiently. Because of the risk-adverse nature of treatment plant operators—and regulators, implementation of such management innovations has been slow. As noted in a 1998 Environmental Law Institute report, treatment plant operators are generally slow to install innovative technologies whether they be tools like the Internet or technological innovations, such as ozonation, UV disinfection, enzyme treatment, or biological nutrient removal.

TABLE 3.26 Estimated O&M and Capital Costs for Individual Septic Systems

Type of system	Annual O&M cost	Initial Capital cost (2006)
Septic tank—absorption system	$55/year	$3,700–4,300[a]
Septic tank—built-up absorption system (excluding pumping station)	55/year	19,000–29,000[b]
Septic tank—subsurface sand filter, including chlorine and contact tank	75/year	13,000–18,000[c]
Aerobic system—excluding absorption field: including service contact[d]	850/year	10,000–24,000
Chemical recirculation toilet[e]	—	8,000–12,000

[a] 3-bedroom home for which septic tanks are pumped out every 3 years.
[b] 9,000 to 10,000 ft^2
[c] 390 to 520 ft^2
[d] *Cleaning Up the Water, Private Sewage Disposal in Maine*, Maine Dept. of Environmental Conservation, Augusta, Me., July 1974, pp. 16–17. Estimated updated costs.
[e] Peter T. Silbermann, "Alternatives to Sewers," *Wastewater Treatment Systems for Private Homes and Small Communities*, Paul S. Babar, Robert D. Hennigan, and Kevin J. Pilon, eds., Central New York Regional Planning and Development Board, Syracuse, 1978, pp. 127–188. Updated cost.

INDUSTRIAL WASTES

Hazardous and Toxic Liquid Wastes

Hazardous wastes are usually byproducts of the chemical industry, which, if not recovered, require proper treatment and disposal. Toxic wastes are chemical substances that present an unreasonable risk of injury to public health or the environment. A toxic substance is one that kills or injures an organism through chemical, physical, or biological action, having an adverse physiological effect on humans. Examples include cyanides, pesticides and heavy metals. The terms toxic and hazardous are sometimes used interchangeably.

Treatment requirements for industrial wastes are typically based on effluent standards, receiving water quality standards or, if discharged to a municipal system, the pretreatment requirements of the publicly owned wastewater treatment plant. The U.S. EPA has published national recommended water quality criteria for 157 toxic pollutants pursuant to Section 304a of the Clean Water Act. These criteria are used in a number of state and federal environmental programs, such as the National Pollutant Discharge Elimination System (NPDES) permits, for setting discharge limits.

The Clean Water Act also requires designated states and authorities operating pretreatment programs to notify industrial/commercial users of hazardous wastes of their responsibilities under Resource Conservation and Recovery Act (RCRA) and Comprehensive Environmental Response, Compensation and Liability Act

TABLE 3.27 Estimated Total Annual and Unit Costs for Selected Sewage Treatment Processes (Design Flow: 1.0 MGD)

Process	Initial Capital Cost (2006 Dollars)[a,b]	Annual Cost [b] (2006 Dollars)			Unit Cost (Dollars per 1,000 gal)[b]
		Captial[c]	O&M[d]	Total	
Imhoff tank	1,300,000	143,000	53,000	196,000	0.54
Rotating biological disks	2,700,000	297,000	196,000	493,000	1.35
Trickling-filter processes	3,100,000	341,000	199,000	540,000	1.48
Activated sludge processes					
With external digestion	3,400,000	374,000	253,000	627,000	1.72
With internal digestion[e]	1,700,000	187,000	166,000	353,000	0.97
Stabilization pond processes[f]	850,000	93,500	81,000	174,500	0.48
Land disposal processes[g]					
Basic system	1,200,000	132,000	141,000	273,000	0.75
With primary treatment	3,200,000	279,965	221,330	501,295	1.72
With secondary treatment	3,370,000	352,000	277,000	629,000	2.35

[a] Estimated average cost.
[b] Original 1975 costs adjusted to expected 2006 costs using *Engineering News-Record* Building Cost Index.
[c] Capital recovery factor = 0.11 (15 years at 7 percent).
[d] Original 1975 process O&M costs adjusted to expected 2006 O&M costs using ENR index.
[e] Extended aeration, aerated lagoon, oxidation ditches.
[f] High-rate aerobic, facultative, and anaerobic.
[g] Irrigation and overland flow.

Source: George Tchobanoglous, "Wastewater Treatment for Small Communities," *Water Pollution Control in Low Density Areas*, University Press of New England, Hanover, N.H., 1975, p. 424.

(CERCLA). However, hazardous wastes when mixed with sewage are excluded from RCRA requirements and instead regulated under Clean Water Act pretreatment programs. Since the federal and state requirements are quite complex, affected persons should consult the numerous regulations that U.S. EPA has published regarding industrial waste pretreatment. As a general rule, waste disposal should not transfer a hazardous waste from one environmental medium (i.e., land, air, water) to another.

TABLE 3.28 Typical Capital and O&M Costs for Constructed Wetlands

Type of Constructed Wetland	Average Capital Cost (2006)[a]	Yearly O&MCost[a]
Free Water Surface Wetland		
<1 MGD	\$62,320acre	\$1760–\$5900/acre
>1 MGD	\$23,310/acre	\$1070–\$2330/acre
Subsurface Flow Wetland (<1 MGD)	\$318,910/acre	Minimal

[a]Original 1998 costs adjusted to expected 2006 costs using *Engineering News-Record* Building Cost Index.

Source: Ronald Crites et al, *Natural Wastewater Treatment Systems*, CRC/Taylor & Francis, Boca Raton, FL, 2006, pp. 325-327 and 373.

Pretreatment

Industrial/commercial wastes that are hazardous or that cannot be treated by the municipal treatment plant must be excluded unless given adequate pretreatment. Examples include synthetic organic wastes and inorganic wastes that interfere with plant operation or treatment; are toxic; ignitable; emit hazardous fumes; damage wastewater treatment plant, pumping stations, or sewer system; endanger personnel; are explosive; will pass through the treatment process; or contaminate sewage sludge. Toxics of concern include mercury, cadmium, lead, chromium, copper, zinc, nickel, cyanide, phenol, and PCBs.[73] In addition, other metals and numerous organics may be prohibited or regulated. In some instances, the joint treatment of industrial wastes and municipal wastewater may be mutually advantageous and should be considered on an individual basis.[74]

One method of simplifying a waste problem is simply to spread its treatment and disposal over 24 hours rather than over a 4- or 6-hour period by means of a holding tank to equalize flows and strength of waste, accompanied by a constant discharge over 24 hours. Other approaches for dealing with liquid industrial wastes include raw material and process changes, waste volume and toxicity reduction, waste recovery and reuse.

Possible treatment of these wastes may vary from recovery, solids removal and disposal, to involved physical, chemical, and biological processes. Possibilities for recovery of waste oils include separators, air flotation, and ultrafiltration. Methods for the recovery of metals include evaporation, reverse osmosis, ultrafiltration, and ion exchange. Treatment of organic waste might consist of biological or chemical processes, activated carbon filtration, or air stripping. Possible solids removal processes include sedimentation, chemical treatment, and filtration. The sludge collection will require special handling, possibly further treatment such as dewatering, disposal to an approved facility, or incineration. More detailed information concerning the treatment of specific wastes can be obtained from standard texts, periodicals, and other publications devoted to this subject.[75]

The actual volume of a liquid waste to be discharged should be determined because many municipalities levy a charge for the treatment of industrial wastes to help pay the cost of operating their treatment works. The cost levied typically is based on the volume and strength of the waste based on COD, BOD, chlorine demand, certain organic and inorganic compounds, and/or other parameters. Pretreatment is often required if waste characteristics exceed certain predetermined values; if the waste as released may damage the facility, upset the treatment process, or is not amenable to treatment in a municipal treatment plant; or if the waste would cause a hazardous condition in the sewers or create a water quality problem in the receiving water.

Manuals prepared by the Water Environment Federation are an excellent source of information on standards and recommendations for treatment of industrial wastes and plant operation.[76] These manuals also provide regulations to exclude unacceptable or hazardous materials, protect sewers, and control the discharge of wastes that may upset municipal treatment plant operation. Unacceptable wastes include large volumes of uncontaminated wastes that may cause hydraulic overloading, storm waters, acid and alkaline wastewaters, explosive and flammable substances, toxic substances, large volumes of organic wastes unless adequately pretreated, and oil and grease.

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Prevention and Response to Water-, Food-, Soil-, And Air-Borne Disease and Illness

EDITED BY NELSON L. NEMEROW, FRANKLIN J. AGARDY, PATRICK SULLIVAN, AND JOSEPH A. SALVATO

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Doctors Agardy and Sullivan would like to dedicate this sixth edition of *Environmental Engineering* to Nelson L. Nemerow who passed away in December of 2006. Dr. Nemerow was born on April 16, 1923 and spent most of his productive years as a educator and prolific author. He spent many years teaching at Syracuse University, the University of Miami, North Carolina State, Florida International and Florida Atlantic University. He authored some 25 books dedicated to advancing the art of waste disposal and utilization. His passion was waste minimization and the title of one of his most recent publications, *Zero Pollution for Industry* summed up over fifty years of teaching and consulting. A devoted husband and father, he divided his time between residences in Florida and Southern California. Nelson served in the United States Merchant Marine during World War Two. His committment to excellence was second to none.

CONTENTS

PREFACE

The pressure placed on the environment as the global population approaches seven billion people has brought about the proliferation and spread of diseases associated with air, water and food. The pressure of population, especially in urban areas, has placed a great burden on public health agencies in attempting to deal with these problems. Many diseases which were thought to have been eliminated by prior public health efforts have not only rebounded but are often difficult if not impossible to treat.

Recognition must also be given to the fact that developing countries, by definition, do not have the resources to address water treatment and pollution problems to the same degree that more advanced nations, with much larger budgets and technical skills, have accomplished. Where economic and technical constraints limit treatment options, taking care of basic needs and minimum levels of sanitation become the driving force underlying technological implementation.

Increasingly, the world is faced with a new set of challenges to the environment, namely the need to develop plans to address emergencies—in real time. Issues such as hazard analysis, security assessment, emergency training, response logistics and standby medical equipment have taken on new meaning. Increased population densities in urban areas and along coastlines puts many more lives at risk from environmental emergencies and requires increased levels of detail and response, not seen in the past.

These problems can and are being addressed and dealt with and it is hoped that this text will aid in putting the problems into the proper prospective and bring forward solutions which can be implemented.

Franklin J. Agardy
Patrick Sullivan
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CHAPTER 1

DISEASE TRANSMISSION BY CONTAMINATED WATER

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INTRODUCTION

Water is traditionally viewed as the "universal solvent" which accounts for its vital support of all living things. The property of solvency is also responsible, in the main, for the chemical quality of natural water as pertains to the dissolution of naturally occurring minerals, atmospheric gases, and organic molecules present in plant and animal residues. Natural waters are also a vehicle for suspended matter, including microbial cells.

Fresh surface waters are collectively represented by streams, rivers, lakes, ponds, and reservoirs and constitute a major source of drinking water. Unless protected, they are prone to receiving anthropogenic discharges of domestic, industrial, and agricultural wastewaters. Such adulterations alter the natural water quality, and the severity of change is dependent on the rate, extent, and composition of the waste discharges. Groundwater (subsurface water) is the most plentiful form of available freshwater. However, owing to greater inaccessibility and higher cost, groundwaters are less utilized as a water supply than surface waters.

The consequences for utilizing polluted waters as a drinking water supply are well documented historically and will be dealt with in the section "Historical waterborne disease background." Natural water should be valued both as a commodity and a habitat for aquatic life. The former consideration pertains to public health issues and the latter deals with the ecological value of natural waters.

Surface waters can be rated according to best usage with respect to drinking, bathing, shellfish rearing, fishing, and navigation purposes. A set of minimum water-quality standards defines the best usage of a water body. Waters suitable for drinking-water supplies, recreational bathing, and shellfish rearing are monitored regularly for microbiological quality. The best usage of a water body such

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as a river may change along its course. Designation of a water according to best usage as a source of drinking water may imply high raw water quality but does not preclude the need for proper treatment of the water before release to consumers. Even then, faults in the water distribution system can permit access of disease-producing microbes to an otherwise-adequately treated water. Furthermore, drinking water sources and subsequent purification steps vary widely in quality among world nations. It cannot be assumed that water drawn from a faucet is totally safe to consume, especially, in lesser-developed countries and rural areas. During a visit to Canada in 1989, then-Czechoslovakian president Vaclav Havel remarked, “I was surprised to learn that I was drinking tap water. No one in Czechoslovakia would do that.”[1]

Only about 2.6 percent of the global content of water constitutes fresh water (atmospheric, and both surface and subsurface water bodies). Distribution of fresh-water supplies among countries of the world is uneven and without regard to population demands. Although water is a renewable resource, loss of usable drinking-water supplies through unfavorable natural and manmade environmental changes intensifies the challenge of providing adequate and safe drinking water worldwide in the coming years. There is the anticipation of major alterations in rainfall patterns and increased frequency of catastrophic floods owing to climate change, meteoric expansion of human populations, and the likelihood of increasingly unfavorable air, soil, and water quality in populous nations such as China and India, where the focus is on competitive economic development. Compromising environmental standards, especially with respect to drinking-water quality, heightens the potential for transmission of disease-producing agents within the population. Poor sanitation is unequivocally linked to the occurrence of high rates of communicable and noncommunicable diseases worldwide.

The title of this chapter is “Disease Transmission by Contaminated Water.” The classical concept of disease transmission by contaminated water is by the oral route. Other avenues of infection are possible, however. Gleeson and Gray[2] have denoted four categories of infectious behavior in humans through contact with contaminated water or lack of water:

1. *Waterborne disease*. Sickness or ailment results from ingestion of water that is harboring a pathogen.
2. *Water-washed disease*. Sickness or ailment is spread by the fecal-oral route or person-to person contact and facilitated by the lack of adequate water for personal hygiene,
3. *Water-based infection*. Sickness or ailment is caused by infection arising through ingestion of a pathogenic agent (e.g., guinea worm larvae) or invasion of the body through water contact (e.g., schistosome and other trematode larvae able to penetrate the skin of individuals in contact with water).
4. *Water-related diseases*. Sickness or ailment is facilitated by insect vectors that breed in waters (e.g., malaria mosquitoes and filariasis arthropods that carry viruses responsible for dengue ad yellow fever).

To these may be added three more:

5. *Inhalation of water aerosols contaminated by a pathogenic agent*. This could include *Legionella pneumophila*, the etiologic agent of legionellosis and Pontiac fever.
6. *Consumption of water-based foods derived from contaminated water*. Sickness might be related, for example, to ingestion of raw shellfish containing *Vibrio vulnificus* or *V. parahemolyticus*, both causative agents of diarrheal diseases.
7. *Consumption of foods that have had contact with contaminated water at some stage of production*. Sickness results from microbial contamination during production/preparation (e.g., irrigation, washing, and preservation) of food such as leafy vegetables.

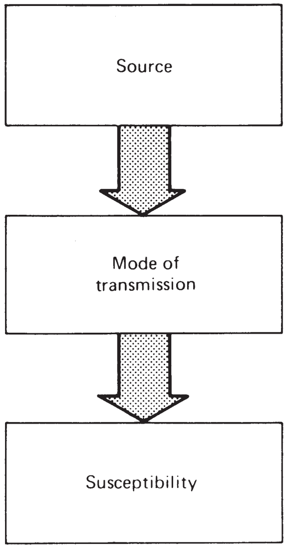
Many disease-producing viruses and bacteria have been identified in this connection, and the protozoan, *Cyclospora cayetanensis*, etiologic agent of a diarrheal disease, cyclosporiasis, with pathology resembling that of cryptosporidiosis, has been identified in imported raspberries and lettuce from South American countries.[3]

At this juncture, it is recommended that the reader consult the definition of terms in Chapter 2 in order to appreciate textural issues. Most definitions of the phrase "communicable disease" emphasize the involvement of an identifiable pathogenic agent. With any communicable disease, there is the need to transmit or communicate an infectious agent to a host by means of a vector or vehicle or person-to-person contact. Continuous propagation of the communicable disease within members of a population requires that the infectious agent be able to exit the diseased individual and find access to a healthy person. One definition of communicable disease appears in the list of definitions given in Chapter 3 and includes "toxic products" of infectious agents as an instrument of communicable diseases. Biological-based toxins alone have rarely been found to be the cause of a water-transmitted disease. However, such toxins are a potential weapon for terrorists and, notwithstanding the minimal chance of success, are an anticipated threat to water supplies.

Ingestion of chemical contaminants in water may cause acute and chronic forms of toxicity leading to the development of noncommunicable diseases in individuals. Biological agents are the cause of infectious (communicable) diseases that may or may not be contagious.

Control of Source (Agent Factors)

Certain sources of disease agents are noted in Figure 1.1. Gerstman[4] defines an agent as a biological, chemical, or physical factor whose presence or absence in varying amounts is required for the occurrence of a disease; a form of necessary factor. Gerstman identified several types of factors of varying essentiality in the propagation of a communicable disease. The agent is a necessary factor, that is, its presence in the host is required to produce a disease although its presence



Source (agent factors-physical, chemical biologic): food and infected or infested animals; poisonous plants and animals; parasites; toxic solid, liquid, and gaseous substances and natural deposits; genetic and inherited materials; ionizing and nonionizing radiations; noise.

Mode of transmission or contributing factors (environmental factors): environmental pollutants; contact; animals; personal behavior; level of hygiene, sanitation, standard of living; work, recreation, travel,home, climate.

Susceptibility (host factors): all animals or susceptibles, resulting in acute, chronic, or delayed effects, depending on portal of entry, dose, and virulence or toxicity of the agent; natural and acquired resistance of the host, and lifestyle.

Animals include humans and arthropods. *Arthropods* include insects, arachnids, crustaceans, and myriapods. *Environmental pollutants* may be transmitted by air, water, food, or contact. *Personal behavior* may involve cigarette smoking, drug use, poor nutrition, stress, lack of exercise, cultural habits, and obesity. *Physical agents* may be heat, cold, precipitation, and causes of accidents. *Biologic agents* include arthropods, helminthes, protozoa, fungi, bacteria, rickettsiae, and viruses. Chemical agents include inorganic and organic chemicals.

FIGURE 1.1 Spread of communicable and noninfectious diseases.

does not guarantee that the disease may be expressed. There is ample evidence that individuals may be carriers of a pathogenic agent (necessary factor) but not become clinically ill. The kinds of factors proposed by Gerstman are addressed elsewhere in the chapter. Elimination or control of the source and environmental exposure to disease agents or vectors is a primary step to be carried out to the extent feasible. Individuals frequently are not aware that they are being exposed to a potential source of disease, particularly when it is a minute, insidious, and cumulative substance, such as certain chemicals in the air, water, and food. An additional complication arises on the biological front when the disease agent is transmissible by more than one route. For example, many of the viral and bacterial agents of disease can be transmitted through both contaminated food and water.

In many instances, control at the source is not only possible but also practical. Measures that might be taken to reduce or eliminate the appearance of toxic substances in waters are:

1. Change the raw material or industrial process to eliminate or adequately minimize the offending substance. For example, terminate the production

of a chemical such as polychlorinated byphenyl (PCB). The U.S. Environmental Protection Agency (EPA) "zero-discharge" *goal* is a step in this direction.

2. Select the cleanest available source of drinking water, as free as possible from microbiological and toxic organic and inorganic chemicals.
3. Make available water with optimum mineral content, such as through fluoridation and water hardness control.
4. Prohibit taking of fish and shellfish from contaminated (e.g., pathogen, methylmercury, PCB) waters.
5. Regulate food production, processing, and service to ensure freedom from toxic substances and pathogens and to assure food of good nutritional content.
6. Provide decent housing in a suitable living environment.
7. Provide a safe and healthful work and recreational environment.
8. Promote recycling, reuse, and zero discharge of hazardous wastes.
9. Eliminate disease vectors (arthropods and other animals, including rodents) at the source. Practice integrated pest management.
10. Isolate infected persons and animals from others during their period of communicability and provide medical treatment to eliminate disease reservoir.
11. Educate polluters, legislators, and the public to the need for regulation and funding where indicated.
12. Adopt and enforce sound standards.
13. Support comprehensive environmental health, engineering, and sanitation planning, surveillance, and regulation programs at the state and local levels.

See also "Control of Susceptibles (Host Factors)" in this chapter.

Control of Mode of Transmission

Several types of factors may be brought into any discussion of disease expression and transmission. An environmental factor, in the context of disease transmission, would be any external physical, biological, or chemical condition, other than the agent, that contributes to the disease process.[4] As an example, several environmental factors, including high humidity, high temperature, neutral to slightly alkaline soils, presence of organic matter, variety of animal reservoirs, and infected cattle herds, appear to contribute to the high endemic rate of leptospirosis in certain tropical countries.[5] Several species of *Leptospira* are pathogenic. The causative agent of Weil's disease is the pathogenic spirochete, *Leptospira interrogans* serovar Icterohemmoragiae. The disease is one of the leading zoonoses worldwide and, while the incidence is infrequently encountered in the temperate climates (0.1 to 1 case per 100,000 individuals per year), it is more prevalent in tropical areas of high rainfall (10 to 100 cases per 100,000 individuals per year).[6] Although this chapter has the focus of water involvement within the scope of illness transmission in the environment, it is well to adopt an interconnective attitude toward the control of environmental disease transmission in general. It is necessary to continually ask the question, "Can a known pathogen or toxic substance be exposed to a susceptible population by more than one route?" Again, leptospirosis may be used to address the question. Leptospires may be found in the urine of those suffering from leptospirosis. Vehicles of transmission for this disease are urine-contaminated water, food, and direct bodily contact with contaminated materials, such as through cuts and abrasions of the skin and mucous membranes. In addition, many animals, especially rodents, are reservoirs of the leptospires. It can be appreciated, therefore, that spread of the pathogens is open to many routes of transmission.

Prevention of disease requires the continual application of control procedures such as the following 10 measures and elimination of the human element to the extent feasible:

1. Prevent the travel of disease vectors and control disease carriers.
2. Assure that all drinking water is at all times safe to drink and adequate for drinking, culinary, laundry, and bathing purposes.
3. Provide adequate spatial separation between sources of disease (and pollution) and receptors.
4. Assure that food processing, distribution, preparation, and service do not cause disease.
5. Control air, land, and water pollution, hazardous wastes, accidents, carcinogens, and toxics.
6. Prevent access to disease sources—polluted bathing waters and disease vector–infested areas.
7. Adopt and enforce environmental standards—air, water, land, noise, land use, housing.
8. Educate polluters, legislators, media, and the public to the need for regulation and funding where indicated.
9. Support comprehensive environmental health, engineering, and sanitation planning, protection, surveillance, and regulation programs at the state and local levels.
10. Adjust personal behavior to counteract cigarette smoking, poor nutrition, stress, overeating, and lack of exercise. Promote personal hygiene and handwashing to prevent person-to-person transmission of pathogenic or toxic agents.

Control of Susceptibles (Host Factors)

Host factors are personal characteristics and behaviors, genetic predispositions, and immunologic and other susceptibility-related factors that increase or decrease the likelihood of disease and may be as sufficient factors.[4] A sufficient factor is a causal factor that, in concert with a necessary factor, is "sufficient" to ensure that a disease will develop.[4] A necessary factor is a type of causal factor that is essential to, but not solely sufficient to, ensure the expression of a disease.[4] To facilitate the understanding of these factors collectively, consider the fate of an immunocompromised person who drank contaminated tap water containing the oocysts of *Cryptosporidium hominis*, an etiologic agent of the disease, cryptosporidiosis. After about 10 days, the individual begins to express symptoms of the disease. The afflicted person would be referred to as a case. A host factor and, in this instance also a sufficient factor, is the immunocompromised state of the individual. The necessary factor was the presence of the infectious material (oocysts) in the drinking water.

Individuals most susceptible to infectious diseases, especially the illnesses responsible to opportunistic pathogens, are the very young, the elderly, those with cardiovascular and respiratory disease, the immunocompromised, those occupationally exposed to airborne and other pollutants, those who smoke heavily, the obese, and those who underexercise. There are many diseases to which all persons are considered to be generally susceptible. Among these are measles, streptococcal diseases caused by group A streptococci, the common cold, ascariasis, chickenpox, amebic dysentery, bacillary dysentery, cholera, malaria, trichinosis, and typhoid fever. There are other diseases, such as influenza, meningococcus meningitis, pneumonia, human brucellosis (undulant fever), and certain water- and foodborne illnesses, to which some people apparently have an immunity or resistance. To these should be added the noninfectious diseases such as diseases of the heart, malignant neoplasms, and cerebrovascular diseases.

In order to reduce the number of persons who may be susceptible to a disease at any one time, certain fundamental disease-prevention principles should be followed to improve the general health of the public. This may be accomplished through educational programs on personal hygiene and immunization; avoidance of smoking; maintenance of proper weight; minimal liquor consumption; and conserving or improving the general resistance of individuals to disease by a balanced diet and nutritious food, fresh air, moderate exercise, sufficient sleep, rest periods, and the avoidance of stress, fatigue, and exposure. In addition, all individuals should be educated and motivated to protect themselves to the extent feasible from biological, physical, chemical, and radiation hazards and environmental pollutants.

Immunization can be carried out by the injection of vaccines, toxoids, or other immunizing substances to prevent or lessen the severity of specific diseases. Typhoid and paratyphoid fevers, poliomyelitis, and tetanus are some of the diseases against which the armed forces are routinely immunized. Children are generally immunized against diphtheria, tetanus, pertussis (whooping cough), poliomyelitis, rubeola (measles), mumps, and rubella (German measles). Revaccination of students and others born after January 1, 1957, against measles is recommended and may be required prior to school admission. It is now possible to discontinue smallpox vaccination as a routine measure in view of the global eradication of smallpox.[7]

Typhoid bacilli may be found in the feces and urine of cases and carriers. Typhoid immunization is reported to be about 70 to 90 percent effective, depending on degree of exposure,[8,9] and then only against small infectious doses. Routine typhoid vaccination is indicated only when a person is in intimate contact with a known carrier or travels in areas where there is a recognized risk of exposure, but precautions should still be taken with water and food. Routine vaccination of sewage sanitation workers is warranted only in areas with endemic typhoid fever. There is no reason to use typhoid vaccine for persons in areas of natural disaster such as floods or for persons attending rural summer camps.[8,9] There are currently two typhoid vaccines available in the United States, an oral live-attenuated vaccine (Vivotif Berna) and an injected capsular polysaccharide vaccine (Typhim Vi). Both vaccines have been shown to protect 50 to 80 percent of recipients. Boosters are required, every five years for the oral vaccine and every two years for the injected form.[10] Before choosing to forgo typhoid vaccination, travelers should be advised that a marked increase in antibiotic resistance by *S. typhi* has been documented in recent years and that the geographic location of the more resistant strains may be related to the frequency of antibiotic use.[11]

Cholera vaccine is not available in the United States. It has not been recommended for travelers because of the brief and incomplete immunity it offers. Currently, this issue is somewhat controversial; however, it is generally agreed that effective deployment of vaccines for cholera should take place in areas or countries of high endemic level of cholera, and 50 to 70 percent of the susceptible population must be immunized. Antibiotic resistance to tetracycline has been found in some *V. cholerae* isolates. However, widespread acquisition of antibiotic resistance has not been reported as in the case of *S. typhi*. No cholera vaccination requirements exist for entry or exit of any country. Yellow fever vaccine offers protection for at least 10 years and possibly up to 35 years. A certificate of vaccination is required for entry into some countries.[10] The WHO is recommending the use of five antihelminthic agents—albendazole, mebendazole, diethylcarbamazine, ivermectin, and praziquantel—to control parasitic worm infections that affect over 25 percent of the world's population.[12]

Good housing, sanitation (water, sewerage, solid wastes, and vermin control), and personal hygiene provide long-term protection against many diseases whereas an immunization protects only against a specific disease and must be repeated to remain effective. Individual and community performance, environmental hygiene, and economic levels are also improved,[13] in addition to the quality of life. This is not to minimize the importance of immunization against the childhood diseases and epidemic control where indicated.

Typical Epidemic Control

Outbreaks of illnesses such as influenza, measles, dysentery, poliomyelitis, and other diseases can still occur. At such times, the people become apprehensive and look to the health department for guidance, assurance, and information to calm their fears.

An example of the form health department assistance can take is illustrated in the precautions released June 1, 1951, in the *Illinois Health Messenger* for the control of poliomyelitis. These recommendations predate the 1955 availability of the Salk vaccine; hence, they portray a sense of urgency. For this reason, they are instructive and are generally applicable to outbreaks of other diseases. Even though poliomyelitis is under control in the United States, experience dictates that if the vaccination program is allowed to lapse, a resurgence of the disease is apt to follow.[14]

General Precautions during Outbreaks

1. The Illinois Department of Public Health will inform physicians and the general public as to the prevalence or increase in the incidence of the disease. *Note:* Incidence and prevalence are not synonyms. Incidence refers to the number of new cases occurring in a certain population *during* a defined time period. Prevalence is the number of cases of a disease *in* a defined population at a particular point in time. The terms are illustrated later in this chapter in the section "Epidemiology and Risk."
2. *Early diagnosis* is extremely important. Common early signs of polio are headache, nausea, vomiting, muscle soreness or stiffness, stiff neck, fever, nasal voice, and difficulty in swallowing, with regurgitation of liquids through the nose. Some of these symptoms may be present in several other diseases, but in the polio season they must be regarded with suspicion.
3. All children with any of these symptoms should be isolated in bed, pending diagnosis. Early medical care is extremely important.
4. Avoid undue fatigue and exertion during the polio season.
5. Avoid unnecessary travel and visiting in areas where polio is known to be prevalent.
6. Pay special attention to the practices of good personal hygiene and sanitation:
   a. Wash hands before eating.
   b. Keep flies and other insects from food.
   c. Cover mouth and nose when sneezing or coughing.

Surgical Procedures

Nose, throat, or dental operations, unless required as an emergency, should not be done in the presence of an increased incidence of poliomyelitis in the community.

General Sanitation (Including Fly Control)

1. Although there has been no positive evidence presented for the spread of poliomyelitis by water, sewage, food, or insects, certain facts derived from research indicate that they might be involved in the spread:

a. *Water*. Drinking water supplies can become contaminated by sewage containing poliomyelitis virus. Although no outbreaks have been conclusively traced to drinking water supplies, only water from an assuredly safe source should be used to prevent any possible hazards that might exist.

b. *Sewage*. Poliomyelitis virus can be found for considerable periods of time in bowel discharges of infected persons and carriers and in sewage containing such bowel discharges. Proper collection and disposal facilities for human wastes are essential to eliminate the potential hazard of transmission through this means.

c. *Food*. The infection of experimental animals by their eating of foods deliberately contaminated with poliomyelitis virus has been demonstrated in the laboratory, but no satisfactory evidence has ever been presented to incriminate food or milk in human outbreaks. Proper handling and preparation of food and pasteurization of milk supplies should reduce the potential hazard from this source.

d. *Insects*. Of all the insects studied, only blowflies and houseflies have shown the presence of the poliomyelitis virus. This indicates that these flies might transmit poliomyelitis. It does not show how frequently this might happen; it does not exclude other means of transmission; nor does it indicate how important fly transmission might be in comparison with other means of transmission.

2. Fly eradication is an extremely important activity in maintaining proper sanitation in every community.
3. Attempts to eradicate flies by spraying effective insecticides have not shown any special effect on the incidence of polio in areas where it has been tried. Airplane spraying is not considered a practical and effective means in reducing the number of flies in a city. The best way to control flies and prevent them from spreading any disease is to eliminate fly-breeding places. Eradicate flies by:

   a. Proper spreading or spraying of manure to destroy fly-breeding places.

   b. Proper storage, collection, and disposal of garbage and other organic waste.

   c. Construction of all privies with fly- and rodent-proof pits.

   Proper sanitation should be supplemented by use of effective insecticide around garbage cans, manure piles, privies, and so on. Use effective insecticide spray around houses or porches or paint on screen to kill adult flies.

Swimming Pools

1. Unsatisfactorily constructed or operated swimming pools should be closed, whether or not there is poliomyelitis in the community.
2. On the basis of available scientific information, the State Department of Public Health has no reason to expect that closure of properly equipped

and operated swimming pools will have any effect on the occurrence of occasional cases of poliomyelitis in communities.

3. In communities where a case of poliomyelitis has been associated with the use of a swimming pool, that pool and its recirculation equipment should be drained and thoroughly cleaned. (The State Department of Public Health should be consulted about specific cleansing procedures.) After the cleaning job is accomplished, the pool is ready for reopening.
4. Excessive exertion and fatigue should be avoided in the use of the pool.
5. Swimming in creeks, ponds, and other natural waters should be prohibited if there is any possibility of contamination by sewage or too many bathers.

Summer Camps

Summer camps present a special problem. The continued operation of such camps is contingent on adequate sanitation, the extent of crowding in quarters, the prevalence of the disease in the community, and the availability of medical supervision. Full information is available from the Illinois Department of Public Health to camp operators and should be requested by the latter:

1. Children should not be admitted from areas where outbreaks of the disease are occurring.
2. Children who are direct contacts to cases of polio should not be admitted.
3. The retention of children in camps where poliomyelitis exists has not been shown to increase the risk of illness with polio. Furthermore, return of infected children to their homes may introduce the infection to that community if it is not already infected. Similarly, there will be no introduction of new contacts to the camp and supervised curtailment of activity will be carried out, a situation unduplicated in the home. This retention is predicated upon adequate medical supervision.
4. If poliomyelitis occurs in a camp, it is advisable that children and staff remain there (with the exception of the patient, who may be removed with consent of the proper health authorities). If they do remain:
   a. Provide daily medical inspection for all children for two weeks from occurrence of last case.
   b. Curtail activity on a supervised basis to prevent overexertion.
   c. Isolate all children with fever or any suspicious signs or symptoms.
   d. Do not admit new children.

Schools

1. Public and private schools should not be closed during an outbreak of poliomyelitis, nor their opening delayed except under extenuating circumstances, and then only upon recommendation of the Illinois Department of Health.

2. Children in school are restricted in activity and subject to scrutiny for any signs of illness. Such children would immediately be excluded, and parents would be urged to seek medical attention.
3. Closing of schools leads to unorganized, unrestricted, and excessive neighborhood play. Symptoms of illness under such circumstances frequently remain unobserved until greater spread of the infection has occurred.
4. If poliomyelitis occurs or is suspected in a school:
   a. Any child affected should immediately be sent home, with advice to the parents to seek medical aid, and the health authority notified.
   b. Classroom contacts should be inspected daily for any signs or symptoms of illness and excluded if these are found.

Hospitals

1. There is no reason for exclusion of poliomyelitis cases from general hospitals if isolation is exercised; rather, such admissions are necessary because of the need for adequate medical care of the patient.
2. Patients should be isolated individually or with other cases of poliomyelitis in wards.
3. Suspect cases should be segregated from known cases until diagnosis is established.
4. The importance of cases to hospitals in a community where poliomyelitis is not prevalent has not been demonstrated to affect the incidence of the disease in the hospital community.

Recreational Facilities

1. Properly operated facilities for recreation should not be closed during outbreaks of poliomyelitis.
2. Supervised play is usually more conducive to restriction of physical activities in the face of an outbreak.
3. Playground supervisors should regulate activities so that overexertion and fatigue are avoided.

WATERBORNE DISEASES

General

Disease agents spread by water and food have in common the capability to incapacitate large groups of people and sometimes result in serious disability and death. The World Health Organization estimates that 80 percent of all diseases are attributable to inadequate water or sanitation and that 50 percent of hospital beds worldwide were occupied by people afflicted with water-related diseases.[15] During the period 1920 to 2000, there were 1,836 waterborne outbreaks representing 882,592 cases of illness in the United States.[16] The number of deaths recorded for the period was well under 1 percent, however. Most waterborne disease fatalities occurred before 1940 and were attributable to typhoid fever.[17] The finding probably reflects the unavailability of antibiotics during the early time frame. Diseases of a waterborne nature appear when disregard of known fundamental sanitary principles occurs, hence, in most cases are preventable. As often occurs, very young, elderly, immunocompromised, and critically ill persons with some other illness succumb with the added strain of a water- or foodborne illness. These groups of disease-sensitive people are thought to make up 20 to 25 percent of the population of the United States.[18]

Water- and foodborne diseases are sometimes referred to as the intestinal or filth diseases because they are frequently transmitted by food or water contaminated with excreta. Raw drinking water and improperly protected and treated surface and groundwater supplies may be polluted by excreta or sewage, which is almost certain to contain pathogenic microorganisms with potential to cause illness in consumers. In the United States, community waterborne outbreaks during the period 1981 to 1990 predominantly associated with inadequately treated surface water and deficiencies in the distribution system whereas untreated groundwaters were the major source of waterborne diseases for persons utilizing private water sources.[19]

Survival of Pathogens

Survival periods for selected pathogens in surface and groundwater are given in Table 1.1. The survival of pathogens is quite variable and affected by the type of organism, the presence of other antagonistic organisms, the soil characteristics, temperature, moisture, nutrients, pH, and sunlight. Table 1.1 is intended only as a comparative measure of survivability among pathogens. The amount of clay and organic matter in the soil affect the movement of pathogens, but porous soils, cracks, fissures, and channels in rocks permit pollution to travel long distances.

Some organisms are more resistant than others. Soil moisture of about 10 to 20 percent of saturation appears to be best for survival of pathogens; drier conditions increase die-off.

Nutrients may increase survival of some organisms, although elevated metabolism in vegetative cells and the germination of spores may produce the opposite effect. Typically, pH is not a major factor. As would be expected, survival of some pathogenic bacteria at very low pH (e.g., pH 2.5–3) is poor in certain media.[20,21] When pH values are below the isoelectric point of both bacteria and viruses, surface charge will be positive and, although controversial, may promote aggregation and adsorption of cells to predominantly negatively charged particulate matter and produce a protective effect against the potentially harmful effects of high hydrogen ion. In addition, hydrogen ion may effect the solubilization of nutrients. Viruses appear stable over the pH range of 3 to 9. Exposure to sunlight increases the death rate. Low temperatures favor survival.[22,23] The survival of pathogens in soil, on foods, and following various wastewater unit treatment processes, as reported by various investigators, is summarized by Bryan[24] and others.[25] Most

TABLE 1.1 Survival of Certain Pathogens in Water

	Survival Time[a]	
	In Surface water	In Groundwater
Coliform bacteria	—	7–8 days[b]
Cryptosporidium spp. oocyst	18+ months at 4°C	2–6 months, moist[c]
Excherichia coli	—	10–45 days[b]
Entamoeba histolytica	1 month[d]	
Enteroviruses	63–91+ days[e]	
Giardia lamblia cyst	1–2 months, up to 4[f]	
Leptospira interrogans serovar Ichterohemorrhagiae	3–9 days[g]	
Franciscella tularensis	1–6 months[g]	
Rotaviruses and reoviruses	30 days–1+ years[e]	
Salmonella faecalis	—	15–50 days[b]
Salmonella paratyphi	—	60–70 days[b]
Salmonella typhi	1 day–2 months[g]	8–23 days[b]
Salmonella typhimuriun	—	140–275 days[b]
Shigella	1–24 months[g]	10–35 days[b]
Vibrio cholerae	5–16 days[g] 34 days at 4°C[g] 21+ days frozen[g] 21 days in seawater[d]	
Viruses (polio, hepatitis, other enteroviruses)	—	16–140 days[b]
Enteroviuses[h]	38 days in extended aeration sludges at 5°C, pH 6–8; 17 days in oxidation ditch sludges at 5°C, pH 6–8	
Hepatitis A[i]	1+ years at 4°C in mineral water, 300+ days at room temperature	
Poliovirus[i]	1+ years at 4°C in mineral water, not detected at room temperature	

[a]Approximate.

[b]Guidelines for Delineation of Wellhead Protection Areas, Office of Ground-Water Protection, U.S. Environmental Protection Agency, Washington, DC, June 22, 1987, pp. 2–18. *Source:* Matthess et al., 1985. G. Matthess, S.S.D. Foster and A.Ch. Skinner, Theoretical background, hydrogeology and practice of groundwater protection zones, IAH International Contributions to Hydrogeology 6 (1985).

[c]A. S. Benenson (Ed.), *Control of Communicable Diseases in Man*, 15th ed., American Public Health Association, Washington, DC, 1990, p. 113.

[d]B. K. Boutin, J. G. Bradshaw, and W. H. Stroup, "Heat Processing of Oysters Naturally Contaminated with *Vibrio cholerae*, Serotype 01," *J. Food Protection*, **45**, 2 (February 1982): 169–171.

[e]G. Joyce and H. H. Weiser, *J. Am. Water Works Assoc.* (April 1967): 491–501 (at 26°C and 8° C).

[f]S. D. Lin, "*Giardia lambia* and Water Supply," *J. Am Water Works Assoc.* (February 1985): 40–47.

[g]A. P. Miller, *Water and Man's Health*, U. S. Administration for International Development, Washington, DC, 1961, reprinted 1967.

[h]G. Berg et al., "Low-Temperature Stability of Viruses in Sludges," *Appl. Environ. Microbiol.*, **54**, 839 (1988); *J. Water Pollut. Control Fed.* (June 1989): 1104.

[i]E. Biziagos et al., "Long-Term Survival of Hepatitis A Virus and Poliovirus Type 1 in Mineral Water," *Appl. Environ. Microbiol.*, **54**, 2705 (1988); *J. Water Pollut. Control Fed.* (June 1989): 1104.

enteroviruses pass through sewage treatment plants, survive in surface waters, and may pass through water treatment plants providing conventional treatment. According to WHO, water treatment plants maintaining a free residual chlorine in the distribution system of at least 0.5 mg/l for at least 30 minutes and low turbidity [less than 1 nephelometric turbidity unit (NTU)] in the finished water can achieve satisfactory virus inactivation. Other approved disinfection treatment (e.g., ozonation) can accomplish satisfactory virus destruction.

Substance Dose to Cause Illness

The development of illness is dependent on the toxicity or virulence of a substance or pathogen, the amount of the substance or pathogen ingested (at one time or intermittently), and the resistance or susceptibility of the individual. The result may be an acute or long-term illness. Sometimes two or more substances may be involved to produce a synergistic, additive, or antagonistic effect. The microbial modes of disease transmission include ingestion of a pathogen or toxin in contaminated water or food, contact with an infected person or animal, or exposure to an aerosol containing the viable pathogen.

If the dose of a chemical substance administered to a series of animals is plotted against the effect produced, such as illness, and increased doses produce no increases in illnesses, the substance is said to cause "no effect." If increased doses cause increasing illnesses, the substance has "no threshold." If increased doses cause no apparent increases in illnesses at first but then continuing increased doses show increasing illnesses, the dose at which illnesses begin to increase is referred to as the substance "threshold." Below that dose is the "no-observed-effect" range. Variations between and within animal species must be considered.

Table 1.2 contains a list various microorganisms and the approximate infectious dose required to cause disease. Bryan[24] has summarized the work of numerous investigators giving the clinical response of adult humans to varying challenge doses of enteric pathogens. For example, a dose of 10^9 *Streptococcus faecalis* was required to cause illness in 1 to 25 percent of the volunteers, 10^8 *Clostridium perfringens* type A (heat resistant) to cause illness in 26 to 50 percent of the volunteers, and 10^9 *C. perfringens* type A (heat sensitive) to cause illness in 76 to 100 percent of the volunteers.

If one were to consume 16 ounces of water containing a pathogen having a high infectious dose value (pathogen A) and the same amount of water containing a pathogen of low infectious dose value, it might be concluded that illness would be less likely through infection with pathogen A than pathogen B. Such thinking contains several fallacies, however. Pathogen infectious dose data should be used only as a guide and must be tempered in the knowledge that many variables influence the host-parasite relationship.[26] In any specific situation, virulence of the pathogen, physiological state of the pathogen, distribution of the infective units (pathogen) in a unit volume (in this case water), susceptibility of the host (infant, young, old, healthy, sick, immunocompromised), and route of infective

TABLE 1.2 Substance Dose to Cause Illness

Microorganism	Approximate Number of Organisms (Dose) Required to Cause Disease
Campylobacter jejuni[a]	10^2 or less
Coxiella burneti[b]	10^7
Cryptosporidium[c]	10^1–10^2 oocysts
Dracunculus, Ascaris, Schistosoma	1 cyst, egg, or larva
Entamoeba histolytica[d]	10–20 cysts, one in a susceptible host
Escherichia coli[b]	10^8
Giardia lamblia[c–f]	5–10^2 cysts
Salmonella typhi[b,g]	10^5–10^6
Salmonella typhimurium[g]	10^3–10^4
Shigella[b,g]	10^1–10^2
Staphylococcus aureus[b]	10^6–10^7 viable enterotoxin-producing cells per gram of food or milliliter of milk
Vibrio cholerae[b,g]	10^6–10^9
Virus, pathogenic	1 plaque-forming unit (PFU) or more

[a]Robert V. Tauxe et al., "*Campylobacter* Isolates in the United States, 1982–1986," *MMWR CDC Surveillance Summaries* (June 1988): 9.
[b]H. L. Dupont and R. B. Hornick, "Infectious Disease from Food," in *Environmental Problems in Medicine*, W. C. McKee (Ed.), Charles C. Thomas, Springfield, IL, 1974.
[c]R. M. Clark et al., "Analysis of Inactivation of *Giardia lamblia* by Chlorine," *J. Environ. Eng*. (February 1989): 80–90.
[d]*Guidelines for Drinking Water Quality*, Vol. 2, World Health Organization, Geneva, 1984, p. 44.
[e]Up to 10 cysts from beaver to human and 1 to 10 cysts to cause human to human infection.
[f]R. C. Rendtorff, "Experimental Transmission of *Giardia lamblia," Am. J. Hyg*., **59**, 209 (1954).
[g]Eugene J. Gangarosa, "The Epidemiologic Basis of Cholera Control," *Bull. Pan Am. Health Org*., **8**, 3 (1974).

contact (ingestion, inhalation, cutaneous) influence the inception of disease. The experimental conditions pertinent to the determination of infectious dose levels is important. The nature of the host subjects (human volunteers, monkeys, mice, or other), health status of the host subjects, protocol for introducing the pathogen dose to the subjects (oral, injection, aerosolization), and frequency of exposure of the host subjects to the pathogen challenge are all important to the interpretation of infectious dose values.

The low infectious dose for pathogenic viruses and protozoa would appear to suggest that viral infections ought be readily spread through drinking water, food, shellfish, and water-contact recreational activities. Fortunately, the tremendous dilution that wastewater containing viruses usually receive on discharge to a watercourse and the treatment given drinking water greatly reduce the probability of an individual receiving an infectious dose. However, some viruses do survive and present a hazard to the exposed population. Not all viruses are pathogenic in the sense that their obligate destruction of host cells to sustain replication and release of new virus particles may not trigger clinical symptoms of disesase in the host. Nonetheless, heretofore unknown insidious relationships between viruses and their effects on hosts are becoming better understood, resulting in recognition of the pathogenicity of viruses thought to be innocuous.

Data on infectious doses for many important environmentally transmitted diseases are lacking. Obtaining estimates of infectious doses is time consuming, animal or human subject intensive, and costly. An indication of the difficulty involved may be imagined in economics of testing for the effect of chemicals as given by Kennedy:[27] "A typical chronic toxicology test on compound X, done to meet a regulatory requirement with an adequate number of animals and an appropriate test protocol, costs $250,000 to 300,000" and requires 2 to 3 or more years to complete.

Information concerning the *acute* effect of ingestion of toxic substances is available in toxicology texts.[28]

Summary of Characteristics and Control of Water- and Foodborne Diseases

In view of the fact that water- and foodborne diseases result in discomfort, disability, or even death, a better understanding of their source, method of transmission, control, and prevention is desirable. Although not mutually inclusive throughout, several of the infections transmitted by contaminated food and water are caused by the same pathogenic agents. The primary focus of attack is the gastrointestinal tract.

Special attention should be paid the subject of gastroenteritis. It is a vaguely understood disease with a complex epidemiology, often without a known causal pathogen or chemical instigator. Three types of gastroenteritis may be distinguished by the pathological response to the presence of an infectious agent: (1) noninflammatory, (2) inflammatory, and (3) invasive (Table 1.3).[29] Yet, different forms of gastroenteritis typically display common symptoms such as watery diarrhea, vomiting, intestinal and stomach cramps, and muscular aches, all of which create a nausea in the victim. The purging of the gastrointestinal tract that takes place removes or inactivates the normal barriers to infection and changes the unshielded epithelium that alters the host defenses, causing malabsorption and nutrient loss. The severity of the symptoms somewhat characterizes the nature of its etiology as do the complications that accompany protracted illnesses.

There are acute and chronic forms of gastrointestinal diseases. The number of cases worldwide of gastrointestinal illnesses are estimated to be from 6 billion to 60 billion of which over 2 million directly result in death.[30] Acute forms of gastroenteritis outbreaks in countries of the world have a storied history, some of which are noted elsewhere in this chapter. The symptoms of gastroenteritis appear frequently among diseases associated with different source pathogens. This is borne out in Table 1.4, which contains a comprehensive grouping and summary of the characteristics and control of a number of these diseases for easy reference.

Although comprehensive, the body of information should not be considered exhaustive or terminally complete, rather the table should serve as an orientation

TABLE 1.3 Forms of Gastroenteritis, Symptoms, and Causative Agents

Gastroenteritis	Symptoms	Responsible Organisms
Noninflammatory gastroenteritis	Diarrhea and/or vomiting, no fecal leukocytes, no blood in stool, usually no fever.	Bacteria: *Staphylococcus aureus*,[a] *Bacillus cereus*,[a] *Clostridium perfringens*,[a] *Clostridium botulinum*[a] Viruses: noroviruses Protozoa: *Giardia lamblia (intestinalis), Cryptosporidium parvum* Algae: *Pfiesteria* spp[a].
Inflammatory gastroenteritis	Diarrhea and/or vomiting, fecal leukocytes present, usually severe fever, no blood in stool.	Bacteria: *Vibrio cholerae*,[b] enteropathogenic *Escherichia coli* (EPEC), enteroaggregative *E. coli* (EAggEC), *Clostridium difficile, Shigella* spp, enterotoxigenic *E. coli* (ETEC) Viruses: rotavirus, Caliciviruses[b] Protozoa: *Entamoeba dispar*
Invasive gastroenteritis	Invasion past epithelial layer of Gl tract, may not have any diarrhea or vomiting, dysentery may be present (mucus containing bloody feces), fecal leukocytes present, fever: may not have any Gl tract problems but instead severe systemic problems.	Bacteria. *Salmonella* spp., *Campylobacter jejuni*, enteroinvasive *E. coli* (EIEC), enterohemorrhagic *E. coli* (EHEC), *Vibrio vulnificus, Yersinia* spp., *Franciscella tularensis, Bacillus anthracis, Helicobacter pylori* Viruses: unknown Protozoa: *Entamoeba histolytica*

Source: MWH, *Water Treatment: Principles and Design*, 2nd ed., John Wiley & Sons, Hoboken, NJ, 2005.

[a]These microorganisms grow on food or in the environment and produce toxins that, when ingested, cause gastroenteritis a few hours later (only *Pfiesteria* spp. is of concern to drinking water).

[b]Often cited as not causing a fever.

to a complex field requiring much further study. There are likely many bacterial toxins, bacteria, viruses, protozoa, helminths, chemicals, and other agents that are not suspected or that are not examined for or discovered by available laboratory methods. Emerging infectious diseases worldwide are becoming recognized, particularly among the viruses, and will undoubtedly expand the list.

The primary bacterial pathogens, which have been historically linked to waterborne disease, are well known. However, a less-recognized occurrence in the

TABLE 1.4 Characteristics and Control of Water- and Foodborne Diseases

	Disease	Specific Agent	Reservoir	Common Vehicle	Symptoms in Brief	Incubation Period	Prevention and Control
Bacterial Toxins	Botulism food poisoning	*Clostridium botulinum* and *C. parabotulinum* that produce toxin	Soil, dust, fruits, vegetables, foods, mud, fish, animal and human feces	Improperly processed canned and bottled foods containing the toxin, also other foods	Gastrointestinal pain, diarrhea or constipation, prostration, difficulty in swallowing, double vision, difficulty in respiration	2 hr–8 days, usually 12–36 hr	Boil home canned nonacid food 5 min; thoroughly cook meats, fish, foods held over. Do not taste suspected food. Store fish at ≤38°F.
	Staphylococcus food poisoning	Staphylococci that produce entero-toxin, *Staphylococcus aureus*. (Toxin is stable at boiling temperature.)	Skin, mucous membranes, pus, dust, air, sputum, and throat	Contaminated custard pastries, cooked or processed meats, poultry, dairy products, hollandaise sauce, salads, milk	Acute nausea, vomiting, and prostration; diarrhea, abdominal cramps. Usually explosive in nature, followed by rapid recovery of those afflicted.	1–6 hr or longer, average 2–4 hr	Refrigerate promptly prepared food in shallow containers at a temperature below 45°F. Discard leftover food. Avoid handling food. Educate foodhandlers in personal hygiene and sanitation.
	Clostridium perfringens food poisoning	*Clostridium perfringens* (*C. welchi*), a sporeformer. (Certain spores are heat resistant.)	Soil, gastrointestinal tract of man and animals, cattle, poultry, pigs, vermin, and wastes	Contaminated food, inadequately heated meats, including roasts, stews, beef, poultry, gravies, improperly held or cooled food	Sudden abdominal pain, then diarrhea and nausea Ingestion of large numbers of vegetative cells that grow in intestine and form spores. Cast off cell releases toxin causing symptoms.	8–22 hr, usually 10–12 hr	Cook foods thoroughly, cool rapidly, and refrigerate promptly foods not consumed. Cool foods in shallow containers, cut up large pieces. Reheat thoroughly to 165°F before reserving. Educate cooks.

TABLE 1.4 ***(continued)***

	Disease	Specific Agent	Reservoir	Common Vehicle	Symptoms in Brief	Incubation Period	Prevention and Control
	Bacillus cereus food poisoning—diarrheal type	*Bacillus cereus*, toxin heat labile	Spores found in wide variety of cereals, spices, vegetables, and milk	Inadequately refrigerated cooked foods and subsequently inadequately reheated	Diarrhea, cramps; vomiting sometimes	6–16 hr	Prevent food contamination. Cool food rapidly in shallow containers, reheat rapidly.
	Bacillus cereus food poisoning—vomiting type	*Bacillus cereus*, toxin heat stable	Same as diarrheal	Boiled and fried rice	Vomiting, diarrhea, nausea, sometimes	1–6 hr	Same as diarrhea. Some spores, if present in large numbers may survive Ultra high temperture (UHT) and High temperature-short time (HTST) pasteurization.
	Gastroenteritis, dermatitis, central nervous system disorders	Cyano-bacteria	Nutrient-rich surface waters, aquatic sediments, soils	Ingestion and body contact involving waters containing dense cyanobacterial cell mass	Tremors, hypersalivation, ataxia, diarrhea (ingestion); rash, eye irritation, asthma (skin contact)	7–14 days	Water treatment may involve microscreening, coagulation, filtration; distribution system should be monitored for accumulation of cell residues and flushed
Bacteria	Salmonellosis (*Salmonella* infection)	*Salmonella typhimurium, S. newport, S. enteritidis, S. montevideo*, others	Hogs, cattle, and other livestock, poultry, pets, eggs, carriers, powdered eggs, turtles, animal feed, and rodents	Contaminated sliced cooked meat, salads, uncooked meats, equipment, warmed-over foods, milk and milk products, water, eggs	Abdominal pain, diarrhea (persists several days), chills, fever, vomiting, and nausea	6–48 hr, usually 12–24 hr	Protect storage of food. Thoroughly cook food. Eliminate rodents, pets, and carriers. Similar measures as in *Straphylococcus*, Poultry, water, and meat sanitation. Do not eat raw eggs or ground beef, Refrigerate foods.

Bacteria	Typhoid fever	Typhoid bacillus, *Salmonella typhi*	Feces and urine of typhoid carrier or patient	Contaminated water, milk and milk products, shellfish, and foods; flies	General infection characterized by continued fever, usually rose spots on the trunk, diarrheal disturbances	Average 14 days, usually 7–21 days	Protect and purify water supply. Pasteurize milk and milk products. Sanitary sewage disposal. Educate food-handlers. Food, fly, shellfish control. Supervise carriers. Personal hygiene. Isolate patients.
	Paratyphoid fever	*Salmonella paratyphi* A, *S. schott mulleri* B. *S. hirschfeldii* C	Feces and urine of carrier or patient	Contaminated water, milk and milk products, shellfish, and foods; flies	General infection characterized by continued fever, diarrheal disturbances, sometimes rose spots on trunk, other symptoms	1–10 days for gastroenteritis; 1–3 weeks for enteric fever	Similar preventive and control measures as in typhoid fever and salmonellosis
	Shigellosis (Bacillary dystentery)	Genus, *Shigella*, i.e., *flexneri*, *sonnei*, *boydii*, *dysenteriae*	Feces of carriers and infected persons	Contaminated water or foods, milk and milk products, flies, person-to-person	Acute onset with diarrhea, fever, tenesmus, frequent stools containing blood and mucus	1–7 days, usually less than 4 days	Food, water, sewage sanitation as in typhoid. Pasteurize milk (boil for infants). Control flies; supervise carriers. Personal hygiene.
	Cholera	*Vibrio comma*	Feces, vomitus; carriers	Contaminated water, raw foods, flies, shellfish	Diarrhea, rice-water stools, vomiting, thirst, pain, coma	A few hours-5 days, usually 3 days	Similar to typhoid. Quarantine. Isolate patients. Vaccine of limited value.

(*continues*)

TABLE 1.4 ***(continued)***

	Disease	Specific Agent	Reservoir	Common Vehicle	Symptoms in Brief	Incubation Period	Prevention and Control
Bacteria	Melioidosis	*Pseudomonas pseudomallei*	Rats, guinea pigs, cats, rabbits, dogs, horses	Contact with or ingestion of contaminated excreta, soil, or water	Acute diarrhea, vomiting, high fever, delirium, mania	Less than 2 days or longer	Destroy rats. Protect food. Thoroughly cook food. Control biting insects. Personal hygiene.
	Brucellosis (Undulant fever)	*Brucella melitensis*-goat, *B. abortus*-cow, *Br. suis*-pig	Tissues, blood, milk, urine, infected animals	Raw milk from infected cows or goats; also contact with infected animals	Insidious onset, irregular fever, sweating, chills, pains in joints and muscles	5–21 days or longer	Pasteurize all milk. Eliminate infected animals. Handle infected carcasses with care.
	Streptococcal infections	*Streptococcus pyogenes*	Nose, throat, mouth secretions	Contaminated salads or milk products	Sore throat and fever, sudden in onset, vomiting	1–3 days	Pasteurize all milk. Inspect contacts. Same as staphylococcus
	Diphtheria	*Coryne-bacterium diphtheriae*	Respiratory tract, patient, carrier	Contact and milk or milk products	Acute febrile infection of tonsils, throat, and nose	2–5 days or longer	Pasteurize all milk. Disinfect utensils. Inspect contacts. Immunize.
	Tuberculosis	*Mycobacterium tuberculosis (M. tuberculosis and M. bovis)*	Respiratory tract of man, rarely cattle	Contact, also eating and drinking utensils, food, and milk	Cough, fever, fatigue, pleurisy	4–6 weeks	Pasteurize all milk, eradicate TB from cattle. Skin test. Control contacts and infected persons. Selective use of BCG.

Bacteria	Tularemia	Francisella	Rodents, rabbits, horseflies, wood ticks, dogs, foxes, hogs	Meat of infected rabbit, contaminated water, handling wild animals	Sudden onset, with pains and fever, prostration	1–10 days, average of 3	Thoroughly cook meat of wild rabbits. Purify drinking water. Use rubber gloves (care in dressing wild animals).
	Campylobacter enteritis	*Campylobacter jejuni*	Chickens, swine, dogs, cats, man, raw milk, contaminated water	Undercooked beef, chicken, also pork Raw milk, contaminated water	Watery diarrhea, abdominal pain, fever, chills, nausea, vomiting, blood in stool	1–10 days 2–5 days average	Thoroughly cook chicken and pork and properly refrigerate. Treat water. Prevent cross-contamination.
	Vibrio para-haemolyticus gastroenteritis	*Vibrio para-haemolyticus*	Marine fish, shell-fish, mud, sediment, salt water, brackish and fresh water	Raw seafoods or seafood products; inadequately cooked seafoods, and cross-contamination between raw and cooked products and sea water	Nausea, headache, chills, fever, vomiting, severe abdominal cramps, watery diarrhea, sometimes with blood	2–48 hr, usually 12–24 hr	Properly cook all seafood (shrimp 7 to 10 min). Avoid cross-contamination or contact with sea water or preparation surfaces used for uncooked foods. Refrigerate prepared seafoods promptly if not immediately served.
	Diarrhea enteropath-ogenic (Traveler's diarrhea)	Enteropath-ogenic *Escherichia coli* invasive and entero-toxigenic strains	Infected persons	Food, water, and fomites contaminated with feces, raw or under-cooked meat	Fever, mucoid, occasionally bloody diarrhea; or watery diarrhea, cramps, acidosis, dehydration	12–72 hr	See Typhoid. Scrupulous hygiene and formula sanitation in hospital nursery. Food sanitation, thorough cooking.

(*continues*)

TABLE 1.4 ***(continued)***

	Disease	Specific Agent	Reservoir	Common Vehicle	Symptoms in Brief	Incubation Period	Prevention and Control
Bacteria	Yersiniosis	*Yersinia entercolitica, Yersinia pseudotuberculosis*	Wild and domestic animals, birds, man, surface water	Raw milk and milk products, seafoods, raw and rare meats, infected food-handlers, contaminated water	Diarrhea, cramps, fever, headache, vomiting, skin rash, pseudo-appendicitis	3–7 days, usually 2–3 days	Sanitary disposal of human, dog, and cat feces. Safe water. Pasteurize milk. Food sanitation. Wash hands. Organism grows at 40°F. Thoroughly cook food.
	Listeriosis	*Listeria monocytogenes*	Goats, cattle, man, fowl, soil, water, sewage	Raw milk, contaminated pasteurized milk and milk products, contaminated vegetables	Fever, headache, nausea, vomiting, meningeal symptoms	Probably a few days-3 weeks	Avoid contact with infected persons and aborted animal fetuses, raw milk and meats. Listeria grows at 37° to 113°F.
	Vibrio vulnificus gastroenteritis	*Vibrio vulnificus*	Oysters, sea water, sediment, plankton	Raw or lightly cooked seafood, i.e., oysters	Fever, chills, vomiting, nausea, diarrhea	16 hr	Same as *Vibrio parahaemolyticus* gastroenterits.
Rickettsias	Q Fever	*Coxiella burneti*	Dairy cattle, sheep, goats, ticks	Slaughterhouse, dairy employees, handling infected cattle: raw cow and goat milk, dust and aerosols from urine and feces	Heavy perspiration and chills, headache, malaise	2–3 weeks, average 20 days	Pasteurize milk and dairy products. Eliminate infected animal reservoir. Clean slaughterhouse and dairies. Keep down dust from dried wastes.

Viruses	Chorio-meningitis, lymphocytic	*choriomeningitis* virus (LCMV)	House mice urine, feces, secretions	Contaminated food	Fever, grippe, severe headache, stiff neck, vomiting, somnolence	8–13 days	Eliminate or reduce mice. General cleanliness. Sanitation.
	Infectious hepatitis	Hepatitis A virus	Feces from infected persons	Water, food, milk, oyster, clams, contacts, person-to-person, fecal-oral	Fever, nausea, loss of appetite; possibly vomiting, fatigue, headache, jaundice	10–50 days, average 30–35 days	Sanitary sewage disposal, food sanitation, personal hygiene. Coagulate and filter water supply, and plus 0.6 mg/l free Cl_2. Obtain shellfish from certified dealers. Steam clams 4 to 6 min. Exclude ill workers.
	Gastroenteritis, viral	Rotaviruses, Nor-virus agent, echo- and coxsackie-viruses, and others	Man, feces from infected foodhandler or sewage	Water, food including milk, possibly fecal-oral or fecal-respiratory route, ice, clams	Nausea, vomiting, diarrhea, abdominal pain, low fever	24–72 hr, 24–48 hr, 3–15 days	Same as hepatitis A.
	Amebiasis (Amebic dysentery)	*Entamoeba histolytica*	Bowel discharges of carrier, and infected person; possibly also rats	Cysts, contaminated water, foods, raw vegetables and fruits, flies, cockroaches	Insidious and undetermined onset, diarrhea or constipation, or neither; loss of appetite, abdominal discomfort; blood, mucus in stool	5 days or longer, average 2–4 weeks	Same as Shigellosis. Boil water or coagulate, set, filter through diatomite 5 gpm/ft^2, Cl_2. Usual Cl_2 and high-rate filtration not 100% effective. Slow sand filtration plus Cl_2, or conventional RSF OK. Pressure sand filtration ineffective. Also sanitation and personal hygiene.

(*continues*)

TABLE 1.4 ***(continued)***

	Disease	Specific Agent	Reservoir	Common Vehicle	Symptoms in Brief	Incubation Period	Prevention and Control
Portozoa	Giardiasis	*Giardia lamblia*	Bowel discharges of carrier and infected persons; dog, beaver	Cysts, contaminated water, food, raw fruits; also hand-to-mouth route	Prolonged diarrhea, abdominal cramps, severe weight loss, fatigue, nausea, gas; fever is unusual.	6–22 days, average 9 days	Same as amebiasis.
	Cryptos-poridiosis	*Cryptos-poridium* spp	Farm animals, man, fowl, cats, dogs, mice	Contaminated water, food, fecal-oral, person-to-person	Mild flulike symptoms, diarrhea, vomiting, nausea, stomach pain	2–21 days, average 2–10 days	Avoid untreated water, also ice, unpasteurized milk, salads in areas of poor hygiene.
	Balantidiasis	*Balantidium coli*	Swine, man, and other animals	Ingestion of cysts in infected feces	Mild diarrhea, nausea, dysentery, vomiting	Unknown, a few days	Same as cryptosporidiosis, and Shigellosis.
	Primary amebic meningoen-cephalitis (PAM)	*Naegleria fowleri*	Warm freshwater bodies and swimming pools	Nasal tissue contact with water through inhalation during swimming and diving in surface waters and swimming pools	Sudden headache, vomiting, fever, nausea, pharyngitis; late stages include confusion, lethargy, neck stiffness, coma	3–7 days	Drinking water supplies may be disinfected with chlorine or ultraviolet irradiation at proper dosage. Swimming pool water may be sand filtered and disinfected.

	Granulomatous amebic encephalitis (GME), acanthamoeba keratitis	*Acanthamoeba*	Soils, dusts, all forms of natural waters; swimming pools, spas, air conditioners	Abrasions, skin cuts, nasal passages, eyes	Eye pain, redness, blurred vision (keratitis); see symptoms for PAM (GME)	>10 days to weeks	Similar to protection against *Naegleria* spp.
Bacteria	Leptospirosis (Weil's disease)	*Leptospira* interrogans with 27 serovars	Urine and feces of rats, swine, dogs, cats, mice, foxes, sheep	Food, water, soil contaminated with excreta or urine of infected animal, contact	Fever, rigors, headaches, nausea, muscular pains, vomiting, thirst, prostration, jaundice	4–19 days, average 9 to 10 days	Destroy rats. Protect food. Avoid polluted water. Treat abrasion of hands and arms. Disinfect utensils, treat infected dogs.
	Trichinosis (Trichiniasis)	*Trichinella spiralis*	Pigs, bears, wild boars, rats, foxes, wolves	Infected pork and pork products, bear and wild boar meat	Nausea, vomiting, diarrhea, muscle pain, swelling of face and eyelids, difficulty in swallowing	2–28 days, usually 9 days	Thoroughly cook pork (150°F), pork products, bear and wild boar meat. Destroy rats. Feed hogs boiled garbage or discontinue feeding. Store meat 20 days at 5°F or 10 days at −10°F.

(*continues*)

TABLE 1.4 *(continued)*

	Disease	Specific Agent	Reservoir	Common Vehicle	Symptoms in Brief	Incubation Period	Prevention and Control
Helminths	Schistosomiasis (Bilharziasis)[a] (blood flukes)	*Schistosoma haematobium, S. mansoni, S. japonicum, S. intercalatum*	Venous circulation of man; urine, feces, dogs, cats, pigs, cattle, horses, field mice, wild rats, water buffalo	Cercariae-infested drinking and bathing water (lakes and coastal sea waters)	Dysenteric or urinary symptoms, rigors, itching on skin, dermatitis; carrier state 1 to 2 years and up to 25 years. Swimmer's itch schistosomes do not mature in man.	4–6 weeks or longer	Avoid infested water for drinking or bathing; coagulation, sedimentation, and filtration plus Cl_2 1 mg/l; boil water; impound water 48 hr, Cl_2. Slow sand filtration plus Cl_2. 1 mg/l $CuSO_4$ to kill cercariae and 20 mg/l to kill snails. Drug treatment available.
	Ascariasis (intestinal roundworm)	*Ascaris lumbricoides*	Small intestine of man, gorilla, ape	Contaminated food, water; sewage	Worm in stool, abdominal pain, skin rash, protuberant abdomen, nausea, large appetite	About 2 months	Personal hygiene, sanitation.[b] Boil drinking water in endemic areas. Sanitary excreta disposal.
	Echinococcosis (Hydatidosis)	*Echinococcus granulosus*, dog tapeworm	Dogs, sheep, wolves, dingoes, swine, horses, monkeys	Contaminated food and drink; hand to mouth; contact with infected dogs	Cysts in tissues: liver, lung, kidney, pelvis, may give no symptoms, may cause death	Variable, months to several years	Keep dogs out of abattoir and do not feed raw meat. Mass treatment of dogs. Educate children and adults in the dangers of close association with dogs.

Helminths	Taeniasis (pork tapeworm) (beef tapeworm)	*Taenia solium* (pork tapeworm), *T. saginata* (beef tapeworm)	Man, cattle, pigs, buffalo, possibly rats, mice	Infected meats eaten raw, food contaminated with feces of man, rats, or mice	Abdominal pain, diarrhea, convulsions, insomnia, excessive appetite	8–10 weeks	Thoroughly cook meat. Control flies. Properly dispose of excreta. Foodhandler hygiene. Use only inspected meat. Store meat as for trichinosis.
	Fish Tapeworm (broad tapeworm)	*Diphyllo-bothrium latum*, other	Man, frogs, dogs, cats, bears	Infected freshwater fish eaten raw	Abdominal pain, loss of weight, weakness, anemia	3–6 weeks	Thoroughly cook fish, roe, (caviar). Proper excreta disposal.
	Dracontiasis (Guinea worm disease)	*Dracunculus medinensis*, a nematode worm	Man	Water contaminated with copepods-*Cyclops*; larvae from infected persons	Blistering of feet, legs, and burning and itching of skin; fever, nausea, vomiting, diarrhea; worms from skin	About 12 months	Use only filtered or boiled water in endemic areas for drinking, or a safe well-water supply. Treat water from unsafe source with temephos, Abate®. Health education.
	Paragonimiasis (lung flukes)	*Paragonimus ringeri, P. westermani, P. kellicotti*	Respiratory and intestinal tract of man, cats, dogs, pigs, rats, wolves	Contaminated water, freshwater crabs or crayfish	Chronic cough, clubbed fingers, dull pains, diarrhea	Variable	Boil drinking water in endemic areas. Thoroughly cook freshwater crabs and crayfish.[b]
	Clonorchiasis[a] (liver flukes)	*C. sinensis, Opisthorchis felineus*	Liver of man, cats, dogs, pigs	Contaminated freshwater fish	Chronic diarrhea, night blindness	Variable	Boil drinking water in endemic areas. Thoroughly cook fish.[b]
	Fascioliasis (sheep liver flukes)	*Fasciola hepatica*	Liver of sheep	Sheep liver eaten raw	Irregular fever, pain, diarrhea	Several months	Thoroughly cook sheep liver.[b]

(*continues*)

TABLE 1.4 ***(continued)***

	Disease	Specific Agent	Reservoir	Common Vehicle	Symptoms in Brief	Incubation Period	Prevention and Control
Helminths	Trichuriasis (whipworm)	*Trichuris trichiura*	Large intestine of man	Contaminated food, soil	No special symptoms, possibly stomach pain	Long and indefinite	Sanitation, boil water, cook food well, properly dispose feces.[b]
	Oxyuriasis (pinworm, threadworm, or enterobiasis)	*Oxyuris vermicularis*, or *Enterobius vermicularis*	Large intestine of man, particularly children	Fingers, ova-laden dust, contaminated food, water, sewage; clothing, bedding	Nasal and anal itching, diarrhea	3–6 weeks; months	Wash hands after defecation. Keep fingernails short. Sleep in cotton underwear. Sanitation.
	Fasciolopsias[a] (intestinal flukes)	*Fasciolopsis buski*	Small intestine of man, dogs, pigs	Raw freshwater plants, water, food	Stomach pain, diarrhea, greenish stools, constipation, edema	6–8 weeks	Cook or dip in boiling water roots of lotus, bamboo, water chestnut, caltrop.
	Dwarf tapeworm (rat tapeworm)	*Hymenolepis nana* (*diminuta*)	Man and rodents	Food contaminated with ova, direct contact	Diarrhea or stomach pain, irritation of intestine	1 month	Sanitary excreta disposal, personal hygiene, food sanitation, rodent control. Treat cases.
	Anisakiasis	Nematodes of Anisakides family	Marine mammals and fish: rockfish, salmon, cod, tuna	Contaminated fish eaten raw or under-cooked	Stomach pain, nausea, vomiting, confused with appendicitis	Hours	Do not eat raw fish. Cook fish to 140°F or freeze to −4°F for 60 hr to kill larvae.

Poisonous Plants and Animals	Ergotism[c]	Ergot, a parasitic fungus (*Claviceps purpurea*)	Fungus of rye and occasionally other grains	Ergot-fungus contaminated meal or bread	Gangrene involving extremities, fingers, and toes; or weakness and drowsiness, headache, giddiness, painful cramps in limbs	Gradual, after prolonged use of diseased rye in food	Do not use discolored or spoiled grain (fungus grows in the grain). Meal is grayish, possibly with violet-colored specks.
	Rhubarb poisoning	Probably oxalic acid	Rhubarb	Rhubarb leaves	Intermittent cramplike pains, vomiting, convulsions, coma	2–12 hr	Do not use rhubarb leaves for food.
	Mushroom poisoning	Phalloidine and other alkaloids: also other poisons in mushroom	Mushrooms—*Amanita phalloides* and other Amanita	Poisonous mushrooms (*Amanita phalloides, Amanita muscaria*, others)	Severe abdominal pain, intense thirst, retching, vomiting, profuse watery evacuations	6–15 hr or 15 min–6 hr with muscaria	Do not eat wild mushrooms; warn others. *Amanita* are very poisonous, both when raw or cooked.
	Favism[a]	Poison from *Vicia faba* bean, pollen	*Vicia faba* Plant and bean	The bean when eaten raw, also pollen	Acute febrile anemia with jaundice, passage of blood in urine	1–24 hr	Avoid eating bean, particularly when green, or inhalation of pollen. Toxin not destroyed by cooking.
	Fish poisoning	Poison in fish, ovaries and testes, roe (heat stable)	Fish: pike, carp, sturgeon roe in breeding season	Fish: tedrodon, meletta, clupea, pickerel eggs, mukimuki	Painful cramps, dyspnea, cold sweats, dilated pupils, difficulty in swallowing and breathing	30 min–2 hr or longer	Avoid eating roe during breading season. Heed local warnings concerning edible fish.

(*continues*)

TABLE 1.4 ***(continued)***

	Disease	Specific Agent	Reservoir	Common Vehicle	Symptoms in Brief	Incubation Period	Prevention and Control
Poisonous Plants and Animals	Ciguatera poisoning	Toxin concentrated in tropical reef fish flesh, possibly from toxic dinoflagellate; also roe	Warm-water fish, possibly barracuda, snapper, grouper, amberjack, sea bass	Warm-water fish caught near shore from Pacific and Caribbean, coral reef fish	Progressive numbness, tetanuslike spasms, heavy tongue; facial stiffness; also nausea, vomiting, diarrhea, dryness of the mouth, abdominal cramps	1–8 hr, usually 3–5 hr	Avoid warm-water fish caught near shore in Pacific and Caribbean. The toxin ciguatera is not destroyed by cooking; toxin is not poisonous to fish.
	Shellfish poisoning (Paralytic)	Neurotoxin produced by *Gonyaulax catenella* and *G. tamarensis*	Clams and mussels feeding on specific dinoflagellates	Mussels and clams, associated with so-called “red tides”	Respiratory paralysis: in milder form, trembling about lips to loss of control of the extremities and neck. Fish kills and mass deaths in seabirds.	5–30 min and longer, up to 12 hr	Obtain shellfish from certified dealers and from approved areas. Monitor plankton in coastal waters. Toxin not destroyed by routine cooking.
	Scombroid fish poisoning	Scombrotoxin (histamine-like toxin)	Scombridea family primarily tuna, bluefish, amberjack	Fish that have been held at room temperature forming toxic histamine in muscle	Headache, burning mouth, nausea, vomiting, diarrhea, tingling of fingers, fever, cramps	Several minutes to 1 hr	Gut fish immediately after catch and refrigerate at 32°F or on ice. Toxin heat stable.
	Snakeroot poisoning	Trematol in snakeroot (*Eupatorium urticaefolium*)	White snakeroot jimmy weed	Milk from cows pastured on snakeroot	Weakness or prostration, vomiting, severe constipation and pain, thirst; temperature normal	Variable, repeated with use of the milk	Prevent cows from pasturing in wooded areas where snakeroot exists.

	Potato poisoning	*Solanum tuberosum*; other *Solanum*	Sprouted green potatoes	Possibly green sprouted potatoes	Vomiting, diarrhea, headache, abdominal pains, prostration	A few hours	Do not use sprouts or peel of sprouted green potatoes.
	Water-hemlock poisoning	Cicutoxin or resin from hemlock (*Cicuta maculata*)	Water hemlock	Leaves and roots of water hemlock	Nausea, vomiting, convulsions, pain in stomach, diarrhea	1–2 hr	Do not eat roots, leaves, or flowers of water hemlock.
Chemical Poisons	Antimony poisoning	Antimony	Gray-enameled cooking utensils	Foods cooked in cheap enameled pans	Vomiting, paralysis of arms	5 min–1 hour	Avoid purchase and use of poor-quality gray-enameled, chipped enamel utensils.
	Arsenic poisoning	Arsenic	Arsenic compounds	Arsenic-contaminated food or water	Vomiting, diarrhea, painful tenesmus (a cumulative poison)	10 min and longer	Keep arsenic sprays, etc., locked; wash fruits, vegetables. Avoid substances with concentrations greater than 0.05 mg/l.
	Cadmium poisoning	Cadmium	Cadmium-plated utensils	Acid food prepared in cadmium utensils	Nausea, vomiting, cramps, diarrhea	15–30 min	Watch for cadmium-plated utensils, racks, and destroy. Inform manufacturer.
	Cyanide poisoning	Cyanide, sodium	Cyanide silver polish	Cyanide-polished silver	Dizziness, giddiness, dyspnea, palpitation, unconsciousness	Rapid	Select silver polish of known composition. Prohibit sale of poisonous polish.

(*continues*)

TABLE 1.4 ***(continued)***

	Disease	Specific Agent	Reservoir	Common Vehicle	Symptoms in Brief	Incubation Period	Prevention and Control
Chemical Poisons	Fluoride or sodium fluoride poisoning	Fluoride or sodium fluoride	Roach powder	Sodium fluoride taken for baking powder, soda, flour	Acute poisoning, vomiting, abdominal pain, convulsions; paresis of eye, face, finger muscles, and lower extremities; diarrhea	Few minutes-2 hr	Keep roach powder under lock and key; mark "Poison"; color the powder, apply with care, if use is permitted.
	Lead poisoning	Lead	Lead pipe, sprays, oxides, and utensils, lead-base paints	Lead-contaminated food or acid drinks; toys, fumes, paints, drinking water	Abdominal pain, vomiting, and diarrhea (a cumulative poison), mental retardation, birth defects, fatigue, anemia	30 min and longer	Do not use lead pipe; Pb < 0.015 mg/l. Wash fruits. Label plants. Avoid using unglazed pottery. Test imported pottery. Screen child. Remove lead paint.
	Mercury poisoning	Mercury—methyl mercury and other alkyl-mercury compounds	Contaminated silt, water, aquatic life	Mercury-contaminated food, fish	Fatigue, mouth numbness, loss of vision, poor coordination and gait, tremors of hands, blindness, paralysis	2–30 min or longer	Keep mercuric compound under lock and key. Do not consume: fish with concentrations of mercury more than 0.5 ppm, water with more than 0.002 ppm, food with more than 0.05 ppm. Eliminate discharges to the environment.

Chemical Poisons	Methyl chloride poisoning	Methyl chloride	Refrigerant, methyl chloride	Food stored in refrigerator having leaking unit	Progressive drowsiness, stupor, weakness, nausea, vomiting, pain in abdomen, convulsions	Variable	Use nontoxic refrigerant, or ice, water, brine, dry ice.
	Selenium poisoning	Selenium	Selenium-bearing vegetation	Wheat from soil containing selenium, also other plants and water	Gastrointestinal, nervous, and mental disorders; dermatitis in sunlight	Variable	Avoid semiarid selenium-bearing soil for growing of wheat, or water with more than 0.05 mg/l Se.
	Zinc poisoning	Zinc	Galvanized iron	Acid food made in galvanized iron pots and utensils	Pain in mouth, throat, and abdomen followed by diarrhea	Variable, short	Do not use galvanized utensils in preparation of foods or drink, or water with more than 5.0 mg/l zinc.
	Methemo-globinemia	Nitrate nitrogen, plus nitrite	Groundwater; shallow dug wells, also drilled wells	Drinking water from wells high in nitrates	Vomiting, diarrhea, and cyanosis in infants	2–3 days	Use water with less than 45 mg/l NO_3 for drinking water and in infant formula. Properly develop and locate wells.
	Sodium nitrite poisoning	Sodium nitrite	Impure sodium nitrate and nitrite	Sodium nitrate taken for salt, cured meats	Dizziness, weakness, stomach cramps, diarrhea, vomiting, blue skin	5–30 min	Use USP sodium nitrate in curing meat. Nitrite is poisonous, keep locked.

(*continues*)

TABLE 1.4 ***(continued)***

	Disease	Specific Agent	Reservoir	Common Vehicle	Symptoms in Brief	Incubation Period	Prevention and Control
Chemical Poisons	Copper poisoning	Copper	Copper pipes and utensils	Carbonated beverages and acid foods in prolonged contact with copper	Vomiting, weakness, diarrhea	1 hr or less	Do not prepare or store acid foods or liquids or carbonated beverages in copper containers. Cu should not exceed 0.3 mg/l. Prevent CO_2 backflow into copper lines in soft drink machines.
	Reference: Material safety data sheets-Infectious substances. 2001. Public Health Agency of Canada (available at: http://www.phac-aspc.gc.ca/msds-ftss/msds106e.html); Centers for Disease Control and Prevention. 2007. Acanthamoeba infection, Department of Health and Human Services (available at http://www.cdc.gov/NCIDOD/DPD/parasites/acanthamoeba/factsht_acanthamoeba.htm); Martinez, A. J. Free-living amebas: *Naeglaria, Acanthamoeba*, and *Balamuthia*, Medmicro chapter 81 (available at http://www.gsbs.utmb.edu/microbook/ch081.htm)						

Source: This figure represents a summary of information selected from: I. G. M. Dack, *Food Poisoning*, 251 pp., University of Chicago Press, 1956. 2. C. E. Dolman, "Bacterial Food Poisoning," 46 pp., *Canad. Pub. Health J. Assoc*., 1943. 3. V. A. Getting, "Epidemiologic Aspects of Food-Borne Disease," 75 pp., *New Eng. J. Med*., 1943. 4. F. A. Korff, "Food Establishment Sanitation in a Municipality," *Am. J. Pub. Health* **32**, 740 (1952). 5. P. Manson-Bahr, *Synopsis of Tropical Medicine*, 224 pp., Williams & Wilkins Co., Baltimore, 1943. 6. New York State Department of Health, *Health News*. 7. Miscellaneous military and civilian texts and reports. 8. R. P. Strong, *Stitt's Diagnosis, Prevention and Treatment of Tropical Diseases*, 2 vols., Blakiston Co., Philadelphia, 1942. 9. *The Control of Communicable Diseases in Man*, American Public Health Association, Washington, D.C., (Sept. 1944, Revised May 1945, 1946, 1952, 1971, 1980, 1990.) Copyright 1946, Joseph A. Salvato, Jr., MCE.) More complete characteristics, preventive and control measures, and modes of transmission, other than food and water, have been omitted for brevity as has been the statement "epidemiological study" and "education of the public" opposite each disease under the heading "Prevention and Control." Milk and milk products are considered foods. Under "Specific Agent" and "Common Vehicle" above, only the more common agents are listed.

[a] Does not originate in the U.S.

[b] Take same precautions with drinking, culinary, and bathing water as in Schistosomiasis.

[c] Many other fungi that produce toxin are associated with food and feedstuffs. The mycotoxins cause illness in humans and animals; see text. For more information see F. L. Bryan, *Diseases Transmitted by Foods*. DHEW, PHS, Atlanta, Ga., 1971, 58 p., *Procedure for the Investigation of Foodborne Disease Outbreaks*, and *Procedures to Investigate Waterborne Illness*, International Association of Milk, Food, and Environmental Sanitarians, P.O. Box 701, Ames, Ia. 50010, 1988, and Morbidity and Mortality Weekly Report(s), U.S. DHHS, PHS, CDC, Atlanta, Ga.

present-day human population is the increasing number of infections caused by bacteria not normally considered highly virulent. These organisms, sometimes considered secondary pathogens, are opportunistic bacteria that, under certain conditions, can cause infections through contact in some way with water.[31] Certain groups of people notably, infants, elderly, immunocompromised, transplant recipients, and convalescents, are at greatest risk of susceptibility to infection by these organisms. A summary of some important opportunistic bacterial pathogens appears in Table 1.5. Several of the bacterial species listed in the table are relatively newly discovered and responsible for specific pathological problems. Two such organisms are *Helicobacter pylori* and *Legionella pneumophila*.

Gastrointestinal disturbances are so commonplace in the human experience in wealthy countries that they are essentially an accepted fact of life, hence, usually receive little medical attention and go unreported. However, in undeveloped lands, gastrointestinal diseases are a ravishing scourge that accounts for numerous deaths, especially, among children. Of an estimated 2.2 million deaths from diarrheal-type diseases, 1.8 million of these involve children under five years of age.[32] To grasp the importance of safe drinking water on reduction of child mortality in various countries of the world, examine the comparative data in Figure 1.2.[33] The occurrence of a large number of diarrheal cases indicates that there has been a breakdown in hygiene or in the sanitary control of water or food and may forewarn impending cases of salmonellosis, typhoid fever, dysentery, or other illness.

Bacteria are prokaryotic, microscopic organisms, typically unicellular with morphologies described as coccoidal (ovoid), bacillary (rodlike), spiral (vibroid or helical), and filamentous. Typical eubacterial single-cell dimensions average 0.5 to 1 μm in diameter by 1 to 5 μm in length. Bacterial physiologies are more varied among the species than those of any group of microorganisms that supports the notion that plant and animal life on earth as we know it would not be possible without the bacteria. Unfortunately, the typical notoriety that bacteria in general have among the uninformed is that bacteria are “germs” and, therefore, are synonymous with disease. *Rickettsias* are obligate, intracellular parasitic bacteria not cultivatable outside host cells. Unlike viruses, they are retained by the Berkefield filter.[34] Their sizes average 0.3 to 0.7 μm by 1 to 2 μm.

Viruses are submicroscopic, genetic parasitic elements consisting of a nucleic acid (DNA or RNA) core surrounded by a protein coat, fall in the size range of 10 to 100 nm, pass through filters that retain bacteria, are visible only with the aid of an electron microscope, and can replicate only following invasion of living (host) cells. Viruses responsible for diseases transmitted by the water route are all RNA viruses, and most are geometrically icosahedral (ovoid) and small (about 30 nm) in size. Virus particles (virions) maintain infectiousness outside the host. Although all viruses require a host for sustaining replication of virions, expression of a clinical disease does not always take place. Animal enteric viruses do not appear to be readily transmissible to humans, although hepatitis A virus has been shown to pass from chimpanzees to humans. There are more than 100 types of human enteric viruses excreted in large numbers from the gastrointestinal tract.

TABLE 1.5 Opportunistic and "Modern" Bacterial Pathogens Transmitted by the Water Route

Disease and /or Conditions	Specific Agent	Reservoir	Common Vehicle	Symptoms	Incubation Period	Prevention and Control
Varied infections (urinary, eye) and abscesses (lung, brain), septicemia	*Acinetobacter* spp.: *calcoaceticus-baumannii* complex	Soil, seawater, freshwater, estuarine water, wastewater, contaminated food	Finished waters withhigh bacterial levels and low disinfectant residuals	Multifactorial according to body site affected	6-12 days	Adequate water treatment; maintain chlorine residual in distribution system
Gastrointestinal maladies; septicemia	*Aeromonas* spp.: *hydrophila, sobria, caviae*	Freshwater, marine water, estuarine water, wastewater, sludges, sediments	Finished waters with high bacterial levels	Diarrhea, vomiting	1-2 days	Adequate water treatment; maintain chlorine residual in distribution system
Gastroenteritis	*Campylobacter* spp.: *jejuni, coli, upsaliensis*	Contaminated water, wastewater, wastewater effluent	Contaminated water facilitating a zoonosis especially involving poultry consumption	Diarrhea, fever, cramps, tiredness, occasional vomiting	2-5 days	Disinfect water to effectively minimize residual *E. coli* numbers
Septicemia, pneumonia, infant meningitis, endocarditis	*Flavobacterium* spp.: *meningosep-ticum, breve, odoratum*	Soil, natural and finished waters, plumbing systems, hospital water fixtures	Water supply by ingestion or bodily contact	Unavailable	Unavailable	Tight control of finished water quality and provide well maintained distribution system

Gastritis, peptic and duodenal ulcer disease, stomach adeno-carcinoma	*Helicobacter* sp.: *pylori*	Uncertain presence in water distribution system	Possible contaminated food and water	Chronic indigestion, heartburn	5-10 days	Maintain adequate disinfectant residual in finished water
Enterocolitis, urinary and respiratory infections including hypersensitivity pneumonitis	*Klebsiella* spp.: *pneumoniae, oxytoca, rhinoscleromatis, planticola, ozaenae terrigena*	Certain industrial wastes, especially of paper-making and sugar refining; fruits and vegetables, plant matter	Surface water and unprotected ground water; water filters	Diarrhea, abdominal cramps; fever, dry cough, bloody sputum	1-3 days (chronic respiratory disease)	Maintain adequate disinfectant residual in distribution system and conduct periodic flushing to eliminate biofilms
Central nervous system, bone, soft tissue infections; endocarditis (HIV/AIDS patients highly susceptible	*Mycobacterium avium* complex (*M. avium* and *M. intracell-ulare*)	All environments (soil, clean and polluted waters), animals	Water and soil by ingestion, inhalation of aerosols	Abdominal pain, fatigue, diarrhea, anemia	Typically very long and dependent on health status	Water treatment coagulation and filtration for suspended matter removal, maintain effective disinfectant residuals

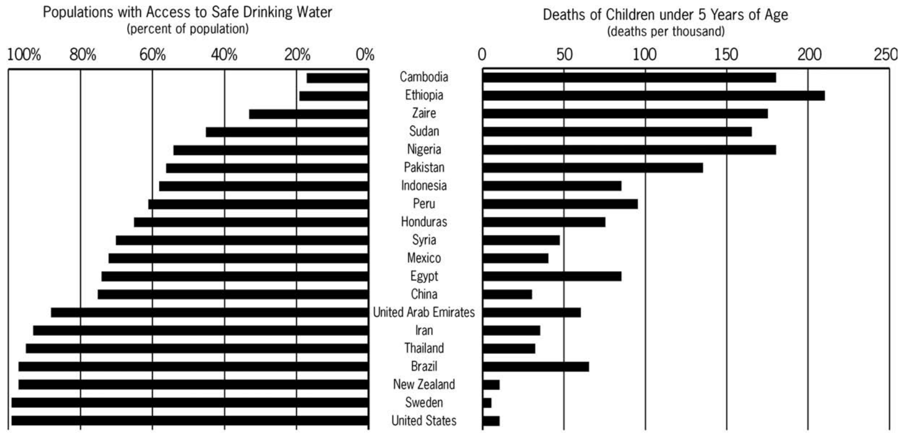
(*continues*)

TABLE 1.5 ***(continued)***

Disease and /or Conditions	Specific Agent	Reservoir	Common Vehicle	Symptoms	Incubation Period	Prevention and Control
Infant diarrhea, bacteremia, eye infections, cystic fibrosis, folli- colitis, osteo- myelitis, malig- nant external otitis	*Pseudomonas* sp.: *aeruginosa*	Surface water, groundwater, bottled water, distilled water, seawater, soils, vegetation	Water and food by ingestion, bodily contact in bathing waters and spas, hospital environments	Multifactorial; coughing, chest pain, fatigue (cystic fibrosis); pimply rash; ear ache	1-10 days (infections and rashes)	Control growth of *Pseudomonas* spp. in all phases of water treatment and in the distribution system maintaining chlorine residual of 0.5 mg/l throughout
Legionellosis, Pontiac fever	*Legionella* sp.: *pneumophila*	Surface water, cooling water towers, evaporative condensers, whirlpools, hot water tanks, fountains, water distribution systems	Inhalation of water mists emanating from cooling waters, condensers, spas	Pneumonia, anorexia, malaise, headache (legionellosis); influenza-like symptoms (Pontiac fever)	2-10 days (legionellosis); 1.5-3 days (Pontiac fever)	Clean sediments from hot water tanks and cooling towers; hold temperature range of 71–77°C in hot water tanks; maintain steady disinfectant levels in whirlpools and cooling towers

Cystitis, septicemia, central nervous system infections	*Serratia* spp.:*marcescens, odorifera, rubidaea* subgroup *liquefaciens*	Surface water, groundwater, soil, decaying vegetation, insects, decaying meat, sour milk	Hospital sump water, medical solutions, dialysis effluents	Fever, urinary discomfort; vomiting, headache	Not clearly defined; 1-7 days (dose related septicemia	Maintain adequate disinfectant residuals and reduce sediment accumulation in pipes and storage reservoirs
Skin infections, bacteremia, urinary tract infections, nosocomial infections	*Staphylococcus* spp.: *epidermis saprophyticus*	Warm-blooded animal surfaces, wastewater, stormwater	Contaminated bathing water in contact with open skin lesions, eyes, and ears	Sudden vomiting (poisoning); inflammation, boils (dermal)	1-6 hours (poisoning); 5-10 days (dermal)	Distribution system maintenance in the manner required for minimizing conditions favorable to any of the opportunistic pathogens
Gastroenteritis	*Plesiomonas* sp.: *shigelloides*	Domestic animals, fish, amphibians	Contaminated drinking and recreational water	Fever, chills, diarrhea, nausea, vomiting	1 day	Effective water disinfectant residual; proper food handling

Source: Information presented in Table 1.5 was retrieved from chapters 5, 6, 11–16, 18, 20 in ref. 30; ref. 28; R. Webber, Communicable Disease Epidemiology and *Control*, CAB International, Wallingford, UK, 1996. and Internet sources.



Sources: United Nations Children's Fund, *The State of the World's Children 1993*; Worldwatch Institute, *Worldwatch Paper 64: Investing in Children*, June 1985

FIGURE 1.2 Relationship between availability of safe drinking water and mortality of children below age five. (*Source*: T. E. Ford and R. R. Colwell, A Global Decline in Microbiological Safety of Water: A Call for Action, American Academy of Microbiology, 1996. Washington, DC.)

The following groups of enteric viruses have been implicated or suspected to be transmitted by contaminated water: enteroviruses (including polioviruses and four subsets of enterovirus [A, B, C, D]), coxsackievirus A viruses, parechoviruses [1-3], hepatitis A (HAV) virus, hepatitis E (HEV) virus, caliciviruses (Noroviruses and Sapoviruses), rotaviruses, adenoviruses, and astroviruses.

Algae are chlorophyllous microorganisms ranging from microscopic unicellular to "seaweed"-size multicellular forms. Their oxygenic capability in performing the light reaction in photosynthesis is the major source of atmospheric oxygen. Various types of algae serve as sources of food and pharmaceutical agents. Although pathogenic algae are relatively rare, certain of the marine dinoflagellates (e.g., *Gonyaulax* spp.) are producers of saxitoxin and gonyautoxin, two of the most virulent nonprotein neurotoxins of record. *Gambierdiscus toxicus* is a tropical marine, benthic dinoflagellate, that synthesizes ciguatoxin, a polycyclic ether compound that creates imbalance in sodium concentration in the axons and nerve terminals causing influx of water and swelling. Ciguatera is a foodborne illness in humans caused by eating marine species that have accumulated cells of G. toxicus by ingestion.[35]

Protozoa are aerobic or anaerobic protists having a true nucleus (eukaryotic). They reproduce usually by fission. They are classically described as simple, unicellular microorganisms, some of which feed on particulate organic matter, including bacteria, and others that utilize soluble organic matter. Motility may be by protoplasmic streaming (amoeba), flagellation, or the synchronize thrashing of cilia. Free-living forms may utilize soluble nutrients or ingest particulate matter (e.g., bacteria). Several pathogenic forms exist such as *Giardia* sp. and *Cryptosporidium* sp. species, that are responsible for waterborne, communicable diseases. Protozoa range in size from approximately 5 to 100 μm in size. Giardia cysts are 8 to 18 μm in length and 5 to 12 μm in width and Cryptosporidium 3 to 5 μm in size.

Fungi are principally aerobic, achlorophyllous microorganisms represented by single and multicellular forms. Most notable of the multicellular fungi are the filamentous varieties known as molds. Filaments (hyphae) are typically on the order of 5 to 10 μm in diameter and many millimeters in length. Molds are important as degraders of complex animal and vegetative matter in nature but become a nuisance in food spoilage and as producers of allergens via sporulation. Many fungi cause diseases in both plants and animals. Certain of the higher fungi, notably the edible mushrooms, are important foodstuffs, as are the yeasts used in bread making and the brewing of alcoholic beverages. Some of the most valuable antibiotics used for medical therapy are synthesized by fungi.

Helminths include intestinal worms and wormlike parasites: the roundworms (nematodes), tapeworms (cestodes), and flatworms or flukes (trematodes). The eggs are about 40 μm or larger in size.

Poisonous plants contain toxic substances that may cause illness or even death when consumed by humans or other animals. Poisonous animals include fish whose flesh is poisonous when eaten in a fresh and sometimes cooked state. (Poisonous flesh is not to be confused with decomposed food.) Acute toxins, such as paralytic shellfish neurotoxins, pose the threat of severe illness or, in rare occasions, death when consumed along with shellfish meats by humans, especially children and the immunocompromised, and by other animals. As already noted, the toxic substance (e.g., saxitoxin) present in some poisonous shellfish flesh results from the filtration of toxigenic marine dinoflagellates, Gonyaulax spp., and appears to be heat stable. Inorganic chemical elements of greatest concern as a seafood hazard appear to be cadmium, lead, and mercury. The long-term effects are nephropathy, anemia and central nervous system disorders, and retardation; the latter two effects associated with lead and mercury are especially dangerous to the human fetus and neonatal stages.[36] Organic contaminants of fish flesh of particular concern are polychlorinated biphenyls, doxins, chlorinated insecticides, and furans as pertains to their potential as carcinogens and teratogens.

Illnesses associated with the consumption of poisonous plants and animals, chemical poisons, and poisonous fungi are not strictly communicable diseases but more properly noninfectious or noncommunicable diseases.

Vehicle or Means by Which Waterborne Diseases Are Spread

The means by which waterborne disease agents are transmitted to individuals include drinking, bathing in swimming pools and recreational waters, showering (mists), natural aerosols, contaminated hand towels and wash cloths, contaminated water (fish and shellfish), produce irrigated or washed with contaminated water, contact with water containing invasive parasites, and bites of insects that spend at least a part of the life cycle in water. The lack of potable water for bathing, household cleanliness, and food preparation also contributes to poor personal hygiene and sanitation and to the spread of disease. In addition, contagious diseases of individuals, originally produced by contact with contaminated water, may then be passed to another person. The discussions that follow will cover the role of water as a source of disease-producing organisms and poisonous substances.

The reporting of waterborne illnesses has, with rare exceptions, been very incomplete. Various estimates have been made in the past, indicating that the number reported represented only 10 to 20 percent of the actual number.

Hauschild and Bryan,[37] in an attempt to establish a better basis for estimating the number of people affected, compared the number of cases initially reported with either the number of cases identified by thorough epidemiologic investigations or the number estimated. They found that for 51 outbreaks of bacterial, viral, and parasitic disease (excluding milk), the median ratio of estimated cases to cases initially reported to the local health authority, or cases known at the time an investigating team arrived on the scene, was 25 to 1. On this basis and other data, the annual food- and waterborne disease cases for 1974 to 1975 were estimated to be 1,400,000 to 3,400,000 in the United States and 150,000 to 300,000 in Canada. The annual estimate for the United States for 1967 to 1976 was 1,100,000 to 2,600,000.[37] The authors acknowledge that the method used to arrive at the estimates is open to criticism. However, it is believed that the estimates come closer to reality than the present CDC reporting would indicate, particularly to the nonprofessional. The estimates would also serve as a truer basis for justifying regulatory and industry program expenditures for waterborne illness prevention, including research and quality control.

Historical Waterborne Disease Background

Prior to the mid-1800s, understanding the connection between routes of disease transmission and the causes of illness was greatly hampered by the ignorance of mankind concerning the existence and role of pathogenic agents. Two centuries separated the seminal discoveries of the basic biological cell, including the existence of microbial beings, and the demonstration that certain microorganisms were at the root of disease formation and decay. Prior to the formative years of the field of microbiology, civilization regarded the onset of infections as the curse of some undefined phenomenon of fouled air (miasma), and treatments of the sick were largely relegated to the practice of quarantine or administering of harsh chemical potions. Pollution of water sources was rampant. Some chose to intuitively avoid contact with such waters, not because of any knowledge of the presence of disease-producing agents, but because of the intolerable offensive odors. Indeed, such philosophy was espounded by Dr. John Sutherland, a Scottish physician, when asked in 1854 to comment on the origins of the London Asiatic cholera epidemic of 1853 to 1854: "There is no sufficient proof that water in this state [of impurity] acts specifically in generating cholera" [but] "use of water containing organic matter in a state of decomposition is one predisposing cause of cholera.[38]

Diseases such as cholera, typhoid, typhus, and dysentery were common in the United States, Europe, and other parts of the world prior to the 20th century. Three classical waterborne disease outbreaks are summarized next.

Asiatic cholera produced two epidemics in London in the years 1849 and 1853, both of which were investigated by John Snow, a physician in the twilight of his life, who came to believe that the feces of cholera patients were the source of the disease.[28] It was the Italian physician, Filippo Pacini of Florence,[39] however, who actually observed the cholera vibrio in the intestinal tissue specimens of a deceased victim with the aid of a microscope and deduced the relationship between the bacteria and the disease. Snow noted that the Broad Street well in the SoHo district of London—specifically, St. James Parish, Westminster—served an area where 616 people had died during a 15-week period, and the death rate for St. James Parish was 220 per 10,000, compared to 9 and 33 per 10,000 in adjoining subdistricts.

Snow found that a brewery on Broad Street employing 70 workmen had no deaths. The brewery had its own well, and all the workers had a daily allotment of malt liquor. It can be reasonably assumed that these workers did not drink any water. In contrast, at a factory at 38 Broad Street, where only water from the Broad Street well was available, 18 of 200 workers died (900 per 10,000). But in a nearby workhouse, which had its own water supply in addition to the city supply, there were only 5 deaths among 535 inmates.

Snow's investigation included a follow-up on each death. He spotted the location of each on a map with relation to the Broad Street well and inquired of the work and activities of each person, their habits and customs, and source of drinking water. The one common factor was consumption of water from the Broad Street well. With this information in hand, he convinced the Board of Guardians of St. James Parish to have the handle of the pump removed, and the epidemic was brought under control.

A survey was made to determine the cause and source of the epidemic. The house at 40 Broad Street nearest the well was suspected as the source; there had been four fatal cases of cholera at the house. A privy emptying into a cesspool, which served more like a tank, overflowed to a drain passing close to the well.

On further investigation, including excavations, it was found that the Broad Street well was a brick-lined dug well with a domed brick top 3 feet, 6 inches below the street. The well was 28 feet, 10 inches deep and 6 feet in diameter, and contained 7 feet, 6 inches of water. The house drain, 12 inches wide with brick sides 12 inches high and stone slab top and bottom, passed within 2 feet, 8 inches of the brick lining of the well. The drain, on a very flat grade, was 9 feet, 2 inches above the water level in the well and led to a sewer. The mortar joints of the well lining and the drain were completely disintegrated. It was found on inspection after excavation that the drain was like a "sieve and through which house drainage water must have percolated for a considerable period" into the well, as indicated by black deposits and washout of fine sand. The drain received wastewater from 40 Broad Street in addition to the overflow from a cesspool in the basement, over which there was a privy.[40]

In another study in 1854, Snow found that a low incidence (37 per 10,000 residences) of cholera fatalities occurred in one part of London supplied by the Lamberth Company with water from the River Lea, a tributary of the River Thames, with an intake more than 38 miles upstream from London. People supplied by the Southwark & Vauxhall Company received water taken from the heavily wastewater-polluted Thames River, opposite the location of Parliament, with a very high incidence of cholera and a death rate of 315 per 10,000 residences. Snow compared the income, living conditions, work, and other characteristics of the people in the two areas and found that source of water was the main variable and, hence, the cause of the illness. The study involved approximately 300,000 people and laid the basis for future epidemiologic studies.

Today, John Snow is considered the epidemiological giant of his time. However, his views on the transmission of cholera did not go unchallenged during his active investigations. William Farr, a professional epidemiologist, was lukewarm to Snow's findings of 1849 and, although he accepted that an association existed between cholera illness and the south district water supply of London, clung to the view that the cholera epidemic of 1849 was responsible to "spread by atmospheric vapours" and the consequences of the lower elevation of water pipes in the soil carrying water from the lower Thames as opposed to that of the upstream region.[41] Farr also contended that the cholera agent was heavier than water and, therefore, would be expected to be of higher concentration in pipes of lower elevation than those of higher elevation. Interestingly, in 1866 a cholera epidemic occurred in the Whitechapel area of London that was traced to water supplied by the East London Water Company whose source was the River Lea. William Farr pronounced, “Only a very robust scientific witness would have dared to drink a glass of the waters of the [river] Lea,” on which note Farr’s notions that air, not water, was the cause of London’s infamous cholera epidemics came to an end.[42] Snow was immersed in the study of anesthesiaology in his final days and died from complications of a stroke at the age of 45; quite possibly brought on by his self-committed experimentation with chloroform, ether, and other noxious agents in the quest for useful anesthetics. Epidemics of cholera persisted in London after Snow’s death. The poor water quality of the Thames is evident from the account of a large pleasure craft that capsized on a Sunday afternoon in the mid 1800s with its passengers thrown into the river; no one drowned, but most died of cholera within a few weeks, thereafter.[43]

In still another instance, Robert Koch (1843–1910), an eminent German physician, unaware of Pacini’s earlier discovery, observed the cholera bacillus under similar pathological conditions in Alexandria, Egypt, in 1883.[44] In 1884, Koch succeeded in isolating and culturing the organism from the stools of advanced cholera patients in Calcutta, India. Closer to home in 1892, Koch investigated the incidence of cholera in two adjacent cities in Germany that pumped drinking water out of the Elbe River. Hamburg pumped water from a point upstream and Altona, a suburb, took water downstream from the city sewer outfalls, but the outbreak occurred in Hamburg upstream. However, the water in Altona was filtered through a slow sand filter, whereas the water in Hamburg was not. Koch isolated *Vibrio cholerae* from the polluted Elbe River, proving the relationship between polluted water and disease. There were 8,605 deaths in Hamburg, a death rate of 1,342 per 100,000. The death rate in Altona was 234 per 100,000.

Water treatment, specifically the application of a disinfectant, notably chlorine, has practically eliminated cholera, typhoid, and dysentery in developed areas of the world. The conquest of these and other waterborne diseases parallels the development of microbiology and sanitary engineering, as well as immunization; water treatment, including chlorination, proper excreta, and wastewater disposal; and education in hygiene and public health. However, waterborne diseases still occur with viral gastroenteritis (nonspecific gastroenteritis being more common), infectious hepatitis A, giardiasis, and cryptosporidiosis. As noted elsewhere, absence of potable water and latrines is associated with high diarrheal illness and mortality rates among children under five in developing countries. The major concerns in developed countries today are the chronic and degenerative diseases, including those associated with the ingestion of trace amounts of toxic organic and inorganic chemicals, but it is also essential that the safeguards found effective in preventing waterborne diseases be maintained and strengthened to prevent their recurrence.

Waterborne Disease Outbreaks Given the vulnerability of surface waters to pollution, it may be surprising to learn that in every decade since 1920, contaminated groundwaters in the United States have been responsible for more waterborne outbreaks than contaminated surface waters, and that during the period 1971 to 2000, waterborne outbreaks have declined in untreated ground waters, whereas disinfected groundwaters have accounted for 38 percent of the groundwater-related waterborne outbreaks during that time frame.[16] Most recently, however, a waterborne outbreak suspected to involve a *Salmonella* sp. was believed to be linked to the undisinfected, deep-well, groundwater system serving Alamosa County, Colorado, in the United States. On March 19, 2008, at least 33 confirmed cases of salmonella infections were recorded, and the Colorado Department of Health issued a "bottled water" advisory. The source of the contamination was unknown, but a cross-connection with a wastewater line or a violated storage water tank was suspected. The following day, the number of confirmed and suspected salmonella cases rose to 79. Two days later, 139 people were reported ill from salmonella infections, and the city declared a state of emergency. By Sunday, March 28, the suspected case load had reached 276, with 10 people hospitalized. Laboratory-confirmed-cases numbered 72 and a candidate pathogen, *Salmonella enterica* serotype Typhimurium, was isolated from the stools of confirmed victims.[45] The "boil order" was lifted on April 11, 2008 and Alamosa likely will be required to comply with U.S. EPA Groundwater Disinfection Rule as published in the Federal Register on November 8, 2006 concerning disinfection of groundwater public drinking water supplies. It was reported on April 20, 2008 that 411 salmonella cases, of which 112 were confirmed and 18 hospitalized, included one death not proven responsible to infection by salmonella.[46]

Waterborne outbreaks occur more frequently in noncommunity water systems than in community water systems; however, the number of cases associated with community water systems is usually larger than in noncommunity water systems. In the period 1991 to 2000, the annual average of waterborne outbreaks in noncommunity water systems was approximately eight compared to six outbreaks for community water systems. The median number of illness cases associated with the noncommunity and community outbreaks was 112 and 498, respectively.[16] Although waterborne diseases account for only a very small percentage of all human illness in the United States and other industrialized countries, this advantage can only be maintained by the continued reduction in biological and chemical pollution of our surface and groundwaters and by complete and competent treatment of drinking water. A case in point is the cryptosporidiosis outbreak that occurred in Milwaukee, Wisconsin, in 1993, resulting in an estimated 403,000 cases of watery diarrhea.[47] Although in excess of 100 deaths have been stated in various media sources, 54 deaths were *officially* reported in the 4-year post-outbreak period, of which 85 percent involved AIDS patients;[48] testimony to the ravishing effect of infectious diseases on immunocompromised individuals. The magnitude of the Milwaukee incident is such that it represented 93 percent of the total 173 waterborne disease outbreaks during the period 1991 to 2000. The total cost of the Milwaukee outbreak was estimated to be \$96.2 million (1993 U.S. dollars), with about \$31.7 million in medical expenses and about \$64.6 million in productivity losses.[49]

Between 1946 and 1980, a total of 672 waterborne disease outbreaks were reported, with 150,475 cases. Contaminated untreated groundwater accounted for 35.3 percent of the 672 outbreaks, inadequate or interrupted treatment for 27.2 percent, distribution or network problems for 20.8 percent, contaminated untreated surface water for 8.3 percent, and miscellaneous for 8.3 percent. Forty-four percent of the outbreaks involved noncommunity water systems and accounted for 19 percent of the cases.[50]

Weibel et al.[51] studied the incidence of waterborne disease in the United States from 1946 to 1960. They reported 22 outbreaks (10 percent) with 826 cases due to use of untreated surface waters; 95 outbreaks (42 percent) with 8,811 cases due to untreated groundwaters; 3 outbreaks (1 percent) with 189 cases due to contamination of reservoirs or cisterns; 35 outbreaks (15 percent) with 10,770 cases due to inadequate control of treatment; 38 outbreaks (17 percent) with 3,344 cases due to contamination of distribution system; 7 outbreaks (3 percent) with 1,194 cases due to contamination of collection or conduit system; and 28 outbreaks (12 percent) with 850 cases due to miscellaneous causes, representing a total of 228 outbreaks with 25,984 cases.

Weibel et al.[51] reported the greatest number of outbreaks and cases in communities of 10,000 population or less. Wolman and Gorman stated that the greatest number of waterborne diseases occurred among population groups of 1,000 and under and among groups from 1,000 to 5,000—that is, predominantly in the rural communities.[52] Between 1971 and 1978, 58 percent of the outbreaks occurred at small, noncommunity water systems. The need for emphasis on water supply control and sewage treatment at small existing and new communities, as well as at institutions, resorts, and rural places, is apparent and was again confirmed in the 1970 PHS study,[53] a 1978 summary,[54] and others.[50] From 1971 to 1982, a total of 399 waterborne outbreaks with 86,050 cases of illness were reported to the U.S. Public Health Service. Forty percent of the outbreaks occurred at community water systems, 48 percent at noncommunity systems, and 12 percent at individual systems. Thirty-one percent involved groundwater systems serving motels, hotels, camps, parks, resorts, restaurants, country clubs, schools, day care centers, churches, factories, offices, and stores. Thirty-one percent of the total waterborne outbreaks were caused by use of contaminated untreated groundwater (wells and springs); 20 percent by inadequate or interrupted disinfection of groundwater (wells and springs); 16 percent by distribution system deficiencies (cross-connection, storage facilities, and contamination of mains and through household plumbing); 14 percent by inadequate or interrupted disinfection of surface water; 8 percent by use of contaminated untreated surface water; 4 percent by inadequate filtration, pretreatment, or chemical feed; and 7 percent by miscellaneous deficiencies.[55] In another analysis of 484 waterborne outbreaks with 110,359 cases between 1971 and 1985, the agent was bacterial in 59, parasitic in 90, viral in 40, chemical in 51, and acute gastrointestinal in 244. Community systems, noncommunity systems, and individual systems experienced 209, 217, and 58 outbreaks, respectively. Untreated groundwater and treatment deficiencies were the major causes.[56]

Drinking water contaminated with sewage is the principal cause of waterborne diseases. The diseases that usually come to mind in this connection are bacterial and viral gastroenteritis, giardiasis, hepatitis A, shigellosis, and typhoid and paratyphoid fevers. However, nearly one-half of outbreaks involving drinking water in the United States between the years 1971 to 2002 were described as gastroenteritis of unknown origin.[18] Protozoa, bacteria, and viruses were the causative agents in 19, 14, and 8 percent of outbreaks, respectively, and chemicals were responsible for 12 percent percent. A breakdown of the various diseases of drinking water for eight decades in the United States can be found in Table 1.6.[16]

Modern day globalization presents a concern for the monitoring and control of infectious diseases. Human transport and interaction on an international scale along with transport of animals and food items enhances the threat of disease transmission. The United States must be vigilant in recognizing the risk for its citizens in contracting infectious diseases or becoming carriers as a result of travel to countries having lower standards of environmental health. [57]

Because of the supervision given public water supplies and control over a lessening number of typhoid carriers, the incidence of typhoid fever has been reduced to a low residual level. Occasional outbreaks, due mostly to carriers, remind us that the disease is still a potential threat. During the period 1967–1972, *Salmonella typhi* was isolated from 3661 individuals in the United States and, coincidentally, the number of travel-associated cases of typhoid fever rose yearly by 270%; a phenomenon believed connected in some way to Mexico.[57] Although the incidence of typhoid fever cases has decreased from approximately 1.9 per million to 1.3 per million travelers to Mexico between 1985 and 1994, of all states reporting cases of typhoid fever to the Typhoid Fever Surveillance System for the period between 1985 and 1994, California and Texas ranked one and two, respectively, with California accounting for 44% of the 2443 cases recorded.[58] United States residents with Hispanic names were found to be at higher risk of contracting typhoid fever than were others in the population.[57] In effect, globalization is likely to influence the level of endemic infectious diseases in the United States and, as noted by Mermin et al[58], will be interconnected to the incidence of infectious diseases in other countries of the world, thus underscoring the importance of achieving high standards of environmental hygiene worldwide.

The outbreaks reported below are also instructive. In 1940 some 35,000 cases of gastroenteritis and 6 cases of typhoid fever resulted when about 5 million gallons of untreated, grossly polluted Genesee River water were accidentally pumped into the Rochester, New York, public water supply distribution system. A valved cross-connection between the public water supply and the polluted Genesee River firefighting supply had been unintentionally opened. In order to maintain the proper high pressure in the fire supply, the fire pumps were placed in operation and hence river water entered the potable public water supply system. The check valve was also inoperative.

TABLE 1.6 Causes of Drinking Water Outbreaks in the United States, 1920-2000. Calderon, and M. F. Craun. 2006

Organism	Survival Time[a] In Surface Water	Survival Time[a] In Groundwater
Coliform bacteria	—	7–8 days[b]
Cryptosporidium spp. oocyst	18 + months at 4°C	2–6 months, moist[c]
Escherichia coli	—	10–45 days[b]
Entamoeba histolytica	1 month[d]	
Enteroviruses	63–91 + days[e]	
Giardia lamblia cyst	1–2 months, up to 4[f]	
Leptospira interrogans	3–9 days[g]	
Pasteurella tularensis	1–6 months[g]	
Rotaviruses and reoviruses	30 days–1 + years[e]	
Salmonella faecalis	—	15–50 days[b]
Salmonella paratyphi	—	60–70 days[b]
Salmonella typhi	1 day–2 months[g]	8–23 days[b]
Salmonella typhimurium	—	140–275 days[b]
Shigella	1–24 months[g]	10–35 days[b]
Vibrio cholerae	5–16 days[g] 34 days at 4°C[g] 21 + days frozen[g] 21 days in seawater[d]	
Viruses (polio, hepatitis, entero)	—	16–140 days[b]
Enteroviruses[h]	38 days in extended aeration sludges at 5°C, pH 6–8; 17 days in oxidation ditch sludges at 5°C, pH 6–8	
Hepatitis *A*[i]	1 + years at 4°C in mineral water, 300 + days at room temperature	
Poliovirus[i]	1 + years at 4°C in mineral water, not detected at room temperature	

[a] Approximate. See also refs. 27–30.
[b] *Guidelines for Delineation of Wellhead Protection Areas*, Office of Ground-Water Protection, U.S. Environmental Protection Agency, Washington, DC, June 22, 1987, pp. 2–18. *Source:* Matthess et al., 1985.
[c] A. S. Benenson (Ed.), *Control of Communicable Diseases in Man*, 15th ed., American Public Health Association, Washington, DC, 1990, p. 113.
[d] B. K. Boutin, J. G. Bradshaw, and W. H. Stroup, "Heat Processing of Oysters Naturally Contaminated with *Vibrio cholerae*, Serotype 01," *J. Food Protection*, **45**(2), 169–171 (February 1982).
[e] G. Joyce and H. H. Weiser, *J. Am. Water Works Assoc*., April 1967, pp. 491–501 (at 26°C and 8°C).
[f] S. D. Lin, "*Giardia lamblia* and Water Supply," *J. Am Water Works Assoc*., February 1985, pp. 40–47.
[g] A. P. Miller, *Water and Man's Health*, U. S. Administration for International Development, Washington, DC, 1961, reprinted 1967.
[h] G. Berg et al., "Low-Temperature Stability of Viruses in Sludges," *Appl. Environ. Microbiol*., **54**, 839 (1988); *J. Water Pollut. Control Fed*., June 1989, p. 1104.
[i] E. Biziagos et al., "Long-Term Survival of Hepatitis A Virus and Poliovirus Type 1 in Mineral Water," *Appl. Environ. Microbiol*., **54**, 2705 (1988); *J. Water Pollut. Control Fed*., June 1989, p. 1104.

At Manteno State Hospital in Illinois, 453 cases of typhoid fever were reported, resulting in 60 deaths in 1939.[59] It was demonstrated by dye and salt tests that sewage from the leaking vitrified clay tile hospital sewer line passing within a few feet of the drilled well-water supply seeped into the well. The hospital water supply consisted of four wells drilled in creviced limestone. The state sanitary engineer had previously called the hospital administrator's attention to the dangerously close location of the well to the sewer and made several very strong recommendations over a period of eight years, but his warning went unheeded until after the outbreak. Indictment was brought against three officials, but only the director of the Department of Public Welfare was brought to trial. Although the county court found the director guilty of omission of duty, the Illinois Supreme Court later reversed the decision.

An explosive epidemic of infectious hepatitis in Delhi, India, started during the first week of December 1955 and lasted about six weeks. About 29,300 cases of jaundice had developed in a total population of 1,700,000 people. (The authorities estimated the total number of infections at 1,000,000.) No undue incidence of typhoid or dysentery occurred. Water was treated in a conventional rapid sand filtration plant; however, raw water may have contained as much as 50 percent sewage. Inadequate chlorination (combined chlorine), apathetic operation control, and poor administration apparently contributed to the cause of the outbreak, although the treated water was reported to be well clarified and bacteriologically satisfactory.[60]

Waterborne salmonellosis in the United States is usually confined to small water systems and private wells.[61] However, an outbreak of gastroenteritis in Riverside, California, in 1965 affected an estimated 18,000 persons in a population of 130,000. Epidemiologic investigation showed that all cases harbored *Salmonella typhimurium*, serological type B and phage type II, which was isolated from the deep-well groundwater supply. There was no evidence of coliform bacteria in the distribution system, although 5 of 75 water samples were found positive for *S. typhimurium*, type B, phage II. The cause was not found in spite of an extensive investigation.[62]

Of potential for causing protozoal infections in humans are the species *Entamoeba histolytica, Giardia lamblia, Cryptosporidium parvum* and *C. hominis, Cyclospora cayetanensis, Enterocytozoon bieneusi, Isopora belli* and *I. hominis*, and *Balantidium coli*.[63] *E. histolytica, G. lamblia, C. parvum* and *C. hominis*, and *C. cayetanensis* have all been implicated in diseases of the water route. The remaining organisms stated above are intestinal parasites so there is potential for their transmission by contaminated water. Nonetheless, present-day concerns center on three genera, namely *Giardia, Cryptosporidium*, and *Cyclospora*. Also of interest are the free-living amoebae, *Naegleria* spp., especially, *N. fowleri*, the etiologic agent of an explosive disease of the central nervous system termed primary *amebic meningoencephalitis (PAM)* and *Acanthamoeba* spp., which are also free-living amoebae and causative agents of *granulomatous amebic encephalitis (GAE)* and *acanthamoeba keratitis* (see Table 1.4).

In 1974 to 1975, a waterborne outbreak of giardiasis occurred in Rome, New York.[64] About 5,357 persons out of a population of 46,000 were affected. The source of water was an upland surface supply receiving only chlorine–ammonia treatment, which confirmed the inadequacy of such treatment to inactivate the Giardia cyst. The coliform history was generally satisfactory. Other early giardiasis outbreaks in the United States occurred in Grand County (1973, 1974, 1976)[65] and near Estes Park (1976)[65], Colorado; Camas, Washington (1976) [66,67]; Portland, Oregon(presumptive, 1954-55)[68]; Unita Mountains, Utah(1974)[69]; Berlin, New Hampshire (1976)[70]; and in areas of California and Pennsylvania.[71] Between 1969 and 1976 a total of 18 outbreaks with 6,198 cases were reported. An additional 5 outbreaks with approximately 1,000 cases were reported in 1977. There were 42 outbreaks reported with 19,728 cases between 1965 and 1980.[72] A total of more than 90 outbreaks occurred through 1984. Acceptable turbidity and coliform tests are important for routine water quality control, but they do not ensure the absence of *Giardia* or enteric viruses; complete water treatment is necessary.

The reporting of outbreaks of waterborne giardiasis has become more common in the United States, Canada, and other countries of the world. The source of the *G. lamblia* cyst is humans, and possibly the beaver, muskrat, and other wild and domestic animals, probably infected from our waste. The *Giardia* stool positive rate may range from 1 to 30 percent, depending on age and the indigenous level of personal hygiene and sanitation, with the higher rate in day care centers and institutions.[73] Infected individuals may shed 10^6 cysts per gram of stool for many years. The cyst is resistant to normal chlorination, similar to the cyst of *E. histolytica*. Conventional rapid sand filtration of surface water—including coagulation, flocculation, and sedimentation, slow sand filtration, and diatomaceous earth filtration followed by disinfection—is considered effective in removing the *Giardia* cyst.[74] Prolonged protected sedimentation and a filter press using special cellulose sheets (reverse osmosis) to remove 1-μm-size particles is also reported to be effective.[75] Pressure sand filtration is not reliable and should not be used, as the cyst penetrates the filter. Experimental results show that 2.5 mg/l (free) chlorine for 10 minutes killed all cysts at pH 6 at a water temperature of 60°F (15°C), but 60 minutes was required at pH 7 and 8, and 1.5 mg/l at 77°F (25°C) in 10 minutes at pH 6, 7, and 8; at 42°F (5°C), 2 mg/l killed or inactivated all cysts in 10 minutes at pH 7 and in 30 minutes at pH 8. [76] A total chlorine residual of 6.2 mg/l after 30 minutes at pH 7.9 and 37°F (3°C) also inactivated *G. lamblia*. A temperature of 131°F (55°C) will destroy the cyst, but boiling is advised.

Cryptosporidium parvum (Type 1) and *C. hominis*, are both infectious apicoplexan protozoan parasites of humans. The first human cases of the disease were reported in 1976. [77] Infection occurs by the ingestion of oocysts that have been excreted in the feces and the disease, cryptosporidiosis, is usually spread by the fecal-oral route, but has also been implicated as the cause of food- and waterborne illness.[78] The incubation period is in the range of 2 to 14 days.[78] It is still often overlooked or not identified, contributing to the problem of underreporting of the disease. However, new molecular and clinical diagnostic tests are in use. The organism is found in the fecal discharges of humans and many wild and domestic animals, including cattle, deer, muskrats, raccoons, foxes, squirrels, turkeys, pigs, goats, lambs, cats, and dogs and zoonotic transmission to humans has been documented. The oocyst, 3 to 6 μm in diameter, survives 18 months or longer at 39°F (4°C), however, inactivation can be exacted at 45°C (20 minutes), 64.2°C (5 minutes), 72.4°C (1 minute), and −20°C (3 days).

Conventional rapid sand filtration, including coagulation, should remove 90 to 100 percent of the *Cryptosporidium*. The oocysts may be inactivated in the presence of a free chlorine residual of 2 mg/l (two days) at 20°C; 2 mg/l (one day) at 30°C, and 10 mg/l (less than six hours) at either temperature under chlorine-demand free conditions.[79] Circumstances contributing to the resistance of oocysts to chlorine in real-world conditions include presence of chlorine-consuming organic matter, protection of oocysts by clumping, and protection of oocysts by adsorption to particulate matter. Other chemicals, such as hydrogen peroxide (6 to 7.5 percent) and ammonia (5 percent), can be effective. Ultraviolet irradiation presents the interesting effect of being able to curtail infective capability in oocysts irradiated at low dosage (99 percent at 1 mWs/cm^2 at 20°C), however, prevention of excystation required 230 mWs/cm^2 at 20°C.[80] Cyclosporiasis is a diarrheal disease with symptoms closely resembling cryptosporidiosis, including watery diarrhea without blood, which may last for an extended period of up to 40 days. Other symptoms are anorexia, nausea, vomiting, pronounced flatulence, stomach cramps, and abdominal bloating. The incubation period is similar to that of cryptosporidiosis. The causative agent is *Cyclospora cayetanensis*—an intestinal parasite with many of the characteristics of *Cryptosporidium* spp. and viewed as an emerging, opportunistic waterborne pathogen.

In this vein, increased numbers of immunocompromised people in the population since the AIDS epidemic appears to be a root to the upwelling of disease incidence by organisms such as *Cyclospora* sp. and the collection of intracellular parasites making up the Microsporididea.[81] The oocysts of *C. cayetanensis* are larger (8–10 μm in diameter and approximately the size of *Giardia* spp. cysts) than those of *Cryptosporidium* spp. However, this feature has not deterred much past misdiagnosis of diseases caused by the misinterpretation of *Cyclospora* sp. for *Cryptosporidium* spp. One important difference between the cycle of cryptosporidiosis and cyclosporiasis is that the latter is not transmitted person to person, owing to the need for oocysts of *Cyclospora* sp. to spend an extended amount of time outside the human host in order to sporulate; a condition essential for the oocysts to become infectious upon transfer to another human. Detection of *Cyclospora* sp. oocysts, which autofluoresce a bright blue by epifluorescence microscopy, involves laboratory techniques similar to those described for *Cryptosporidium* spp.[82] Inactivation of the oocysts of *Cyclospora* sp. is difficult. Organisms die quickly at −70°C; at −20° and −15°C, survival is one day and two days, respectively.

Information on the effect of chemical disinfectants on the oocysts of *Cyclospora* sp. is little known. On the one hand, there is the general belief that oxidants such as chlorine are ineffective, at least at the concentrations employed in water and wastewater treatment. On the other hand, disinfection combined with secondary wastewater treatment may be sufficient to remove *Cyclospora* sp.[83] At present, there is the tendency to infer that inactivation steps effective for containment of *Cryptosporidium* spp. ought to prevail with *Cyclospora* sp. Incidence of cyclosporiasis in the United States up to the present is rare, and, when suspected, is often without the presence of the tell-tale oocysts.

Legionnaires' disease is caused by *Legionella pneumophila*. Another form is Pontiac fever, which typically has a shorter incubation period and results in mild, influenzalike symptoms. The organism has been readily isolated from surface waters and adjacent soils. Other sources are cooling towers and evaporative condensers, hospital hot-water systems, whirlpools, showerheads, domestic hot-water tanks, hot- and cold-water distribution systems, humidifiers, and open water-storage tanks. The organism is primarily spread by aerosols and, to a much lesser extent, water ingestion. It is a major problem in hospitals. Person-to-person spread has not been documented.[84] A water temperature of 68° to 114°F (20° to 45°C) or 104° to 122°F (40°to 50°C)[85] appears to be most favorable for organism survival. The critical temperature is believed to be 97°F (36°C). The organism has been found in hot-water tanks maintained at 86° to 129°F (30° to 54°C) but not at 160° to 172°F (71° to 77°C).[86] The FDA recommends a minimum temperature of 166°F (75°C).

Suggested *Legionella* control measures include 1 to 2 ppm free residual chlorine at water outlets, including daily testing; maintenance of continuous chlorination and hot water temperature; annual cleaning and disinfection of the cold-water system.[87,88] Consensus data suggests that 140°F (60°C) is the minimal temperature for thermal disinfection of hot water plumbing systems and that this temperature should be used in flushing outlets, faucets, and shower heads for a period in excess of 30 minutes and maintained to prevent reestablishment of L. *pneumophila*.[89] It should be noted that scalding is a potential hazard at the recommended thermal inactivation temperature. It has been suggested that 4 to 6 mg/l residual chlorine, maintained in the facility for 6 hours, is sufficient for disinfection, however, this level of disinfectant is difficult to maintain in hot water and may cause problems with patients having transplant surgery.[90] In view of the different findings, laboratory monitoring of the water in the distribution system for *L. pneumophila* is also suggested.

Control and Prevention of Waterborne Diseases

Many health departments, particularly on a local level, are placing greater emphasis on water quality and food protection at food-processing establishments, catering places, schools, restaurants, institutions, and the home and on the training of food management and staff personnel. An educated and observant public, a systematic inspection program with established management responsibility, coupled with a selective water- and food-quality laboratory surveillance system and program evaluation, can help greatly in making health department food protection programs more effective. It is necessary to remain continually alert because waterborne diseases have not been eliminated and other diseases, previously considered not typically transmissible or thought to be transmissible by the water route, are being discovered.

In the general sense, Lashley[91] outlines preventive measures to be taken to control waterborne disease, including the safeguard of drinking water, recreational water, and more stringent actions for the protection of immunocompromised persons. Immunocompromised individuals should not rely on tap waters without additional home treatment such as boiling for one minute or treatment with certain filters. The CDC AIDS Hotline (1-800-342-2437) is available for additional information on this subject. Immunocompromised persons should be especially careful about exposure to fecal matter, young animals—which are more apt to be carriers of infectious disease organisms that are especially difficult (e.g., *Cryptosporidium* and *Cyclospora* agents)—and travel to countries with low-grade sanitation.

Prevention of Waterborne Diseases

A primary requisite for the prevention of waterborne disease at the community level is the ready availability of an adequate supply of water that is of satisfactory sanitary quality for meeting microbiological, chemical, physical, and radiological standards. The prevailing scheme in the water treatment industry for the establishment of a reliable water purification system is the multiple-barrier concept.[92] The multiple-barrier plan for the treatment of water is, in effect, a fail-safe program for ensuring the safety of the consumer of finished water, should a step in the overall process fail. The barriers thus proposed are (1) source water protection, (2) water treatment plant processes, (3) disinfection practices, (4) distribution systems, (5) security, and (6) education. Protection of source water deals with the selection and developing of the raw water supply and safeguarding the watershed from infiltration of pollution. Water treatment plant processes entails the appropriate and proper unit operations and the necessary measures to maintain plant functions. Disinfection practices assume the maintenance of an adequate disinfectant residual throughout the distribution system for destruction of pathogenic agents arising from the untreated source water and faults within the distribution system. The distribution system includes inspection and remediation of piping and inline storage facilities. Security involves the physical watch on the treatment system against the possibility of unlawful entry, with the intent to disrupt or compromise treatment operations and goal of producing quality water. Education embraces the training of water treatment personnel and informing public officials and the public at large of any emergency measures required, owing to interruptions in operations that may affect water quality and quantity. Publicly owned water companies are preferred because they usually provide water of satisfactory quality and quantity and are under competent supervision. It is important that the finished water be convenient, attractive, and palatable to inspire public confidence in the product and dissuade alternate choices of expensive bottled waters or the selection of some other source water, such as a nearby well or spring of doubtful quality. Although excellent water service, especially in municipalities, is generally available in the United States and in many developed areas of the world, consumers and public officials must not have tended to become complacent. Many of the older water treatment facilities have distribution systems in dire need of replacement. The American Society of Civil Engineers in 2001 acknowledged the need for replacement of aged facilities in 54,000 water treatment plants in the United States at a cost of $11 billion, not including the additional cost to meet new drinking water standards.[93] Compounding the problem is the shrinking availability of revenues within the tax structure of communities such that, in some instances, funds may have to be diverted from maintenance, operation, and upgrading of the water supply system in order to cover other expenses. It is also sometimes forgotten that in developing areas of the world, a convenient, safe, and adequate water supply, in addition to affording protection against waterborne diseases, makes possible good personal hygiene, including hand washing, sanitation, household cleanliness, and clean food preparation. In addition, it obviates the need to wade in schistosome-snail-infested streams to undertake the laborious and time-consuming task of transporting water (see the section "Schistosomiasis," later in this chapter). An interesting sidelight is the controversy that emerged over the construction of the Aswan High Dam in the early 1960s. A large impoundment was formed on the Nile River to serve both as a water supply and flood control. It had been argued that the dam lowered the downstream level of the Nile River and, combined with large-scale irrigation, brought increased incidence of schistosomiasis. This may not be the case. With the improved level of sanitation, clean water, and medical facilities, schistosomiasis has actually been reduced from over 40 percent in predam years to 10.7 percent in 1991.[94]

Adequate drinking water statutes and regulations and surveillance of public water supply systems are necessary for their regulatory control. This is usually a state responsibility, which may be shared with local health or environmental regulatory agencies. The EPA recommendations for a minimum state program include [95]:

1. A drinking-water statute should define the scope of state authority and responsibility with specific statutory regulations and compliance requirements. Regulations should be adopted for drinking-water quality standards; water-supply facility design and construction criteria; submission, review, and approval of preliminary engineering studies and detailed plans and specifications; approval of a water-supply source and treatment requirements; establishment of a well construction and pump installation code; operator certification; provision for state laboratory services; and cross-connection and plumbing control regulations.
2. The surveillance of public water-supply systems should involve water quality sampling—bacteriological, chemical, and radiological, also turbidity and residual chlorine; supervision of operation, maintenance, and use of approved state, utility, and private laboratory services; cross-connection control; and bottled and bulk water safety.

3. Surveillance and disease prevention are recommended with periodic, onsite fact finding as part of a comprehensive sanitary survey of each public water-supply system, from the source to the consumer's tap, made by a qualified person to evaluate the ability of the water supply system to *continuously* produce an adequate supply of water of satisfactory sanitary quality. The qualified person may be a professionally trained public health, sanitary, or environmental engineer, or a sanitarian, to make sanitary surveys of the less complex water systems such as well-water supplies. The EPA suggests that the sanitary survey, as a minimum, cover quality and quantity of the source; protection of the source (including the watershed and wellhead drainage area); adequacy of the treatment facilities; adequacy of operation and operator certification; distribution storage; distribution system pressure; chlorine residual in the distribution system; water quality control tests and records; cross-connection control; and plans to supply water in an emergency. The WHO has similar suggestions.[96]

Details concerning water supply quality and quantity, source protection, design, and treatment are given in Chapters 1 and 2 of the water and wastewater volume *of Environmental Engineering*, *Sixth* Edition (Wiley, 2009).

Schistosomiasis

Schistosomiasis is a largely endemic disease in parts of Africa but also occurs in areas of Asia and South America. If known preventive precautions are not taken, the global prevalence of schistosomiasis, spread by freshwater snails and estimated at 300 million or more cases, is expected to increase as new impoundments and irrigation canal systems are built. Cooperation in the planning through the construction phases in endemic areas, or potentially endemic areas, between the health and water resources agencies can help reverse this trend. Water contact through swimming, wading, laundering, bathing, and collecting infested water and poor sanitation and hygiene are the major causes for the persistence and spread of schistosomiasis. Individuals who have or had schistosomiasis (bilharziasis) are more likely to have a urinary infection. Long-term schistosomiasis control would involve an appropriate combination of chemotherapy; molluscicid-ing; basic sanitation, including biological intervention and the supply of potable water at the village level; and socioeconomic development.[97] Mollusciciding is impractical where the water is used as a direct source of drinking water or where the water body and its tributaries are inaccessible or beyond control. In such cases, chemotherapy is considered the most cost-effective control *when* coupled with safe drinking water and sanitation facilities to minimize indiscriminate urination and defecation. In any case, education to prevent reinfection is necessary.[98,99] Heating water to 122°F (50°C) for 5 minutes or treating with chlorine or iodine as in drinking water and filtration through tightly woven cloth or paper (coffee) filter will remove the cercaria. Settling water for 3 days is also effective, as cercaria survives only 48 hours, but reinfestation must be prevented.

BIOTERRORISM

Bioterrorism is a disruptive and health-threating event directed at an individual, group of individuals, a community, or at-large population within a nation and is facilitated by the intentional release of a highly virulent biological agent. In this context, the term *biological agent* includes a microorganism or a biologically synthesized toxin that causes disease in man, plants, or animals or causes deteoriation of materials.[100] The use of pathogenic elements to subvert and disrupt the normal life style of innocent people has a long history.[101] As far back as the fourth century, Scythian warriors coated the tips of their arrows with human feces as a means of infecting their enemies. This is testimony to the very early suspicions about the noxious properties of excreta. In 1346, the Mongols used catapults to hurl the corpses of their dead soldiers, riddled with plague, over the walls in Kaffa, currently Theodosia. The practice of spreading infectious disease by exposure to the dead continued in the siege of the Bohemian castle at Karlstein in 1422 and the attack of the Swedes by Russians in 1710, whereupon corpses were catapulted over the city walls of Reval (Tallinn).

The selection of an agent to be used in an act of terrorism should satisfy the following properties: (1) be readily available, (2) be easy to produce on large scale, (3) be highly virulent for lethal or incapacitation purposes, (4) be of appropriate size for distribution by aerosolization and uptake by victims (penetrate defense mechanisms of the upper respiratory tract), (5) be easy to disseminate by available means, (6) be environmentally stable, and (7) be dispersible in a way that targeted individuals, but not the terrorists, suffer intended effects.[102] A list of candidate biological agents and biologically produced toxins for application in bioterroristic attacks is given in Table 1.7. The categories mainly reflect high level of priority for prepardness (category A), need for improved awareness, surveillance measures, and laboratory diagnosis (category B), and need for continued review of potential threat to the public (category C). Many of the typical vehicles and vectors of infectious disease transmission may be deployed in acts of terrorism. Several of the prominent bacterial agents high on the list of potential bioweapons are the cause of zoonotic infections.

An interesting approach has been made to quantitatively evaluate the usefulness of a biological agent as a weapon of bioterror by calculation of the agent's weapon potential (WP):

$$WP = [V_{\mathrm{BW}} SC/T] \times XD$$

where: V_{BW} = virulence of a bioweapons derived from F_{SI}/I where F_{SI} is the fraction of symptomatic infections for a given inoculum, I.

S = stability of biological agent when released

C = communicability by host to host transfer

T = time

X = terror modifier based on judgment that the agent could cause panic and social disruption

TABLE 1.7 Biological Agents Categorized According to Level of Concern as Threats to Human Welfare.

Biologic Agent	Disease(s)
Category A Agents	
Variola virus	Smallpox
Bacillus anthracis	Anthrax
Yersinia pestis	Plague
Clostridium botulinum toxin	Botulism
Francisella tularensis	Tularemia
Ebola virus	Ebola hemorrhagic fever
Marburg virus	Marburg hemorrhagic fever
Lassa virus	Lassa fever
Junin virus	Argentine hemorrhagic fever
Other arenaviruses	
Category B Agents	
Coxiella burnetti	Q fever
Brucella species	Brucellosis
Burkholderia mallei	Glanders
Venezuelan equine encephalitis virus	Venezuelan encephalomyelitis
Eastern equine encephalitis virus	Eastern equine encephalomyelitis
Western equine encephalitis virus	Western equine encephalomyelitis
Others include:	
Ricin toxin from *Ricinus communis*	*Salmonella* species
Epsilon toxin of *Clostridium perfringens*	*Shigella dysenteriae*
	Escherichia coli O157:H7
Staphylococcus enterotoxin B	*Vibrio cholerae*
	Cryptosporidium parvum (now *hominis*)
Category C Agents	
• Nipah virus • Hantaviruses • Tickborne hemorrhagic fever viruses • Tickborne encephalitis viruses • Yellow fever • Multidrug-resistant tuberculosis	

Source: Centers for Disease Control and Prevention, 2000a, pp. 5–6.
M. Cohen, "Bioterrorism in the Context of Infectious Diseases," in F. R. Lashley and J. D. Durham (Eds.), *Emerging Infectious Diseases—Trends and Issues*, Springer Publishing Company, New York, 2007, pp. 415–442

D = deliverability of the agent that is a function of technical capabilities of the user and biological characteristics of the agent

Currently, availability of essential data and the necessity to make assumptions for terms in the equation limit the applicability of the equation for its intended purpose.[103]

Natural pathogens and even normally nonpathogenic agents, earmarked as potential terror weapons, may be genetically altered to improve virulence, nullify protection of the individuals that may have been immunized against terror agent, resist chemotherapy (antibiotic or antiviral treatments) applied to attack victims, and, possibly, alter the bodily regulatory functions of victims.[103]

Following the attacks in New York and Washington on September 11, 2001, letters containing *Bacillus anthracis* (anthrax) spores were mailed to various locations in the United States. This led to 11 inhalation and 7 cutaneous cases of anthrax, resulting in the death of 5 individuals due to inhalation anthrax. DNA sequencing of the anthrax DNA has led to the conclusion that the origin of the infectious material contained in the letters was a U.S. military laboratory.As such, the possibility existed that an employee of the laboratory was involved and that the laboratory harboring anthrax was in violation of the Biologic and Toxin Weapons Convention.[104] It remains to be determined whether these terrorist attacks were related and to identify the perpetrators. As of early 2008, 9,100 persons were interviewed and the Department of Justice had not named any suspects.[105] More recently, four suspects were placed under watch by the FBI, and the source of the anthrax used in the letters of 2001 was narrowed to the U.S. Army's biological weapons research facility at Ft. Detrik, Maryland. On August 6, 2008, it was concluded by the Justice Department, based on documents provided by federal investigators, that a mentally disturbed microbiologist employed at the U.S. Army biological weapons laboratory and who committed suicide one week earlier, acted alone in the 2001 anthrax letter attacks.

Critical microbiological agents in the United States are endemic but of low incidence in disease manifestation, and each new case reported should serve as an alert for investigation, especially in areas were the disease is nonendemic.[106] Several of the major agents will be briefly discussed next. Due to the significant pathogenicity of each of these agents, individuals seeking to employ their use, especially in large amounts, would require substantial knowledge, expertise, and laboratory equipment as well as protection against accidental exposure (e.g., vaccination or antibiotics).

Smallpox

Smallpox, a disease that has killed approximately 300 million people worldwide in the twentieth century alone, and is now globally nonexistent, may have been one of the first microbial agents to be used as a weapon. During the 1800s, North American Indians were deliberately given blankets contaminated with the virus[107] by European settlers. Smallpox virus comprises two strains: variola major, a highly virulent form that produces a high mortality among cases of the disease and variola minor, which causes a milder form of the disease resulting in under 1 percent fatalities among cases. The only remaining stocks of the variola virus are currently being held in secure locations in the United States and Russia. The WHO voted to postpone a decision on the remaining variola stocks until 2002, raising the possibility of their misappropriation and use as weapons.[108] The scientific community has requested that the available virus stocks be maintained and no further action on the part of WHO has been taken. Some have questioned the grounds for maintaining smallpox stocks. The likelihood of a rebirth of a vaccination program is minimal leading to the conviction that the only purpose the stocks could serve is for bioweapons research. This raises the question of accidental release, improper disposal of hazardous materials, and laboratory mishandling.[104] Variola virus satisfies a number of the prerequisites for an ideal bioterror agent. Since immunization against smallpox was halted in 1976, following a successful worldwide eradication program that saw the last known case of smallpox in 1977, a significant number of the U.S. population would be at risk from a bioterrorism attack. Although individuals vaccinated prior to 1976 may retain immunity to smallpox, the level of protection is currently unknown. Smallpox is generally fatal in about 30 percent of infections of unvaccinated individuals.[109]

Given these uncertainties and the significant health risk of smallpox, the United States and other countries are currently increasing the production of smallpox vaccine. In the wake of concerns for the deployment of variola virus in a bioterror attack, The Advisory Committee on Immunization Practices formulated an interim smallpox release plan, guidelines and a revision of vaccine recommendations in 2001 and reiterated recommendations in 2003.[102] However, approximately 1 in 1 million people exhibit serious and potentially fatal complications following vaccination. Thus, if the entire U.S. population were to be vaccinated, we might expect 100 to 300 deaths from the vaccine. To avoid this situation, one strategy that is being considered for a bioterrorism attack is to limit vaccination to individuals who have come in contact with the initial (index case) infected individual. Vaccination and training of primary health care workers and physicians who are most likely to see the first cases in an attack will also be an important aspect for countering the use of viruses and bacteria as weapons.

Anthrax

Anthrax is a zoonotic disease caused by *Bacillus anthracis*, the facultatively anaerobic, gram positive, nonmotile, endospore-forming bacillus isolated by Robert Koch in 1877 and used by Koch to demonstrate for the first time the relationship between an infectious agent and the etiology of disease. Many domestic and wild animal species have been demonstrated to harbor the anthrax bacillus. Three forms of the disease may be expressed and each is related to the points of entry of the bacterial spores into the body: cutaneous, gastrointestinal, and pulmonary.[102] Cutaneous anthrax in humans occurs through handling of infected animal meat or hides. Anthrax spores gain entry through skin abrasions or cuts. In fact, the term *anthrax* derives from the Greek word for "coal" and reflects the blackened nature of advanced skin lesions produced by infected individuals. It is far less fatal (under 1 percent) than the gastrointestinal and pulmonary form, which may exceed 50 percent. Gastrointestinal anthrax results from the ingestion of spores and if the disease reaches the septicemia stage, fatality rates are as high as 90 percent. Pulmonary anthrax, while normally rare, poses the greatest risk to humans that have inhaled the spores. Initiating the disease requires a high infectious dose, however, the incubation period is short (on the order of two days) followed by rapidly progressing symptoms culminating in cardiovascular arrest. Fortunately, *B. anthracis* responds readily to antibiotic therapy, most notably, penicillin. Antibiotics such as amoxicillin, ciprofloxacin, and doxycycline are effective against the inhalation form of anthrax; however, they must be administered prior to spore germination, which can occur within 48 to 72 hours following exposure and must be continued for several months.

The level of naturally occurring, human anthrax in the United States is nearly nil, having fallen steadily from about 130 cases in 1920. The last reported incidence of naturally occurring anthrax was a cutaneous case in 1989; however, in 2006, a pulmonary case developed in New York City.

As already noted, anthrax poses a major concern for use in bioterrorism. The endospore stage of the organism confers longevity for the organisms in the environment and represents an advantage to its use as a bioweapon. In fact, it is believed that during World War I, Germany intentionally infected sheep to be shipped to Russia for the purpose of infecting the Russian military. Gastrointestinal anthrax has been reported in the former Soviet Union, but never in the United States. Inhalation of anthrax spores, resulting in the full-blown pulmonary disease, is highly fatal when untreated—and sometimes even with treatment. Of the 18 cases of pulmonary anthrax recorded in the United States for the entire twentieth century, greater than 75 percent of them were fatal. The anthrax bacillus synthesizes four major virulence factors: a antiphagocytic polysaccharide capsule and three separate proteins (exotoxins) that act to induce an endema in the infected localities of the body and cause macrophages to elicit tumor necrosis factor and interleukin 1, which promotes sudden death in the pulmonary disease. An anthrax vaccine is available and is generally effective, although it is currently in limited supply (and mostly dedicated to military rather than civilian use). It has also been observed to cause side effects. Animal vaccines are available, also, however, disease incidence in herds has been so meager that farmers are reluctant to have their animals vaccinated.

It will be important to be able to rapidly monitor and analyze the genetic properties of different anthrax strains and to develop new antibiotics. Another promising avenue stems from the recent identification of the receptor for anthrax lethal factor toxin[110] as well as high-resolution structural determination of lethal factor[111] and edema factor.[112] These molecules represent potential targets for rational drug design of new antibacterial compounds to combat this disease.

Plague

The etiologic agent of plague is the gram negative, facultatively anaerobic, nonmotile, coccobacillus, *Yersinia pestis*. Plague is a vectorborne disease that manifests itself in three clinical forms; bubonic, septicemic, and pneumonic. Bubonic plague has the greatest notoriety, having been the cause of great historic pandemics, such as the sixth-century pandemic that killed 100 million people and the fourteenth-century "Black Death" pandemic that claimed 40 million people.[113,102] The bubonic form of plague has a 75 percent fatality rate. No bacterial disease in history has been more devastating. *Y. pestis* is a zoonotic pathogen, and the reservoirs of *Y. pestis* are various rodents. Infected rodents transmit the pathogen to other animals, most notably domestic rats, through the bite of fleas. Domestic rats are susceptible to the plague and will die. In areas of poor sanitation and living conditions, as characterized much of Europe and Asia in the Dark and Middle Ages, domestic rat populations abounded among human squalor. As domestic rat populations dwindled, owing to loss of members to the plague, fleas carrying *Y. pestis* infected humans. The flea carries a high density of *Y. pestis* following a blood meal on an infected rat and can deposit the bacteria at the site of a human bite, both by regurgitation and fecal deposition.

The term *bubonic* comes from the word "bubo," which refers to the enlarged nodule that forms as a result of *Y. pestis* growth in lymph nodes. The human (host) defense system, through the action of polymorphonuclear leucocytes and macrophages, attack the infectious bacteria. Bacteria phagocytized by macrophages produce toxins that spare them from enzymatic destruction. Other bacteria (e.g., *Legionella pneumophila*) have similar defense strategies. The bacteria contained in the macrophages survive and grow and are delivered to lymph nodes and various organs of the body by the macrophages in the bloodstream. The hemorrhaging (gangrene) that occurs beneath the skin over various parts of the body appears dark—hence the term *Black Death* (recall a similar visible effect to the lesions developed in anthrax infections). More fatal than the bubonic form of plague is pneumonic plague; a manifestation of the disease caused by the migration of the infectious bacteria to the lungs. Untreated pneumonic plague is 100 percent fatal. Septicemic plague, which results either upon inoculation of the bacteria directly into the blood stream or as secondary complications from bubonic or pneumonic forms, progresses from the multiplication of the infectious bacteria in the bloodstream and is essentially always fatal.

As a bioweapon, it is likely that an attack would involve dissemination of the infectious bacteria in aerosol form. The respiratory consequences of inhalation would be expressed as pneumonic plague, which is the most contagious form of plague. *Assuming* the availability of swift medical attention and effective hospital care, the fatality rate from such an attack might be held to 25 percent of the infected portion of the population. First indications of an attack would be a burst in incidence of the disease, especially in places free of animal reservoirs such as a metropolitan area. The incubation period of the disease would be short, likely in the range of two to four days. Despite the high fatality rate and contagious nature of *Y. pestis*, the organism has a relatively short-lived existence in the free state, disfavoring its use as a terror agent for causing widespread panic.

Tularemia

Like *Y. pestis*, the etiologic agent of tularemia, *Franciscella tularensis*, is a gram negative, nonendospore-forming, coccobacillus. It is a strict aerobe and nonmotile, having many natural arthropod and animal reservoirs and not limited to a particular group of related species. Transmission of the infectious bacterium may occur by several routes:

- Insect bite
- Contaminated aerosols
- Contact with infected animal carcasses, hides, or fluids
- Contaminated water, food, or soil

It is not contagious; person-to-person transmission has not been demonstrated. Virulence of the organism varies among the subspecies, and type A, the North American variety, is the most virulent. There are six clinical manifestations of the disease, of which three are described here: ulceroglandular, pneumonic, and typhoidal. Ulceroglandular infection results from the bite of an insect, often a tick, or a scratch from an animal. The infectious bacteria initiate ulcer formation at the point of entry to the body and in various organs accessed through travel in the bloodstream. The pneumonic form of the disease results from inhalation of the infectious bacteria during handling of infected animals. Advanced symptoms include fatigue, malaise, atypical pneumonia signs, and, possibly respiratory failure. Pneumonic tularemia can develop in any of the other forms of tularemia. Typhoidal tularemia results from ingestion of the infectious bacteria and the symptoms resemble gastroenteritis-type diseases (i.e., vomiting, diarrhea, and abdominal pain). Typhoidal tularemia usually follows in pneumonic cases and is the most fatal form of the disease, with fatality rates as high as 35 percent in untreated cases.

The attractiveness of *F. tularensis* as a bioterror agent is its high rate of infectivity, high virulence, low infectious dose (25 to 50 percent rate of infection in exposed individuals when 10 organisms are presented by the respiratory route), and ease of dissemination by aerosolization. Incubation periods vary from 3 to 15 days, however, clinical symptoms typically appear in 3 to 5 days. There is ample evidence of the interest in *F. tularensis* as a bioweapon, having been studied by both the Japanese and United States during World War II and the Soviet Union into the 1990s.[29]

Glanders

Glanders is a disease occurring mostly in horses and rarely encountered in the United States. The disease in humans is very rare; however, one case was reported in the United States in 2000. The etioloigic agent of the disease is *Burkholderia mallei*, a gram negative, strictly aerobic, nonmotile bacillus, previously assigned to the Genus *Pseudomonas*. Several *Burkholderia* species are responsible for respiratory-type diseases including melioidosis (see Table 1.4). Glanders infection can be by the cutaneous (skin lesion), inhalation (upper respiratory and pulmonary), or bloodstream (septicemic) routes. Cutaneous infection produces swelling and sores at the site of inoculation within 1 to 5 days. Upper pulmonary invasion induces such symptoms as development of mucus and discharges from the nose and eyes. Pulmonary infection affects the lungs and the symptoms are edema, abscesses, and pneumonia. The incubation period is 10 to 14 days. Septicemia results in fevers, chills, sweating, chest pain, diarrhea, and fatigue, culminating in death within 7 to 10 days. Fatality rates as high as 95 percent occur in untreated events. Therapeutic measures are not well developed, owing to inexperience with the disease, but some recommendations on antibiotic therapy have been made. Several antibiotics are effective against the organism in vitro. Transmission by person to person is rare; however, there are documented cases of sexual transmission. Susceptible animals contract the disease through contaminated water.

Aerosolization of the bacterium is the anticipated form of bioweaponry. The glanders organism was deployed successfully by the Germans in World War I to infect enemy horses and mules. The Japanese intentionally infected both horses and humans in China during World War II.[114,115]

Botulism

The disease derives mainly from ingestion of foods containing an extremely potent neurotoxin produced by the strictly anaerobic, gram positive, endospore-forming, bacillus *Clostridium botulinum*. Spores of *C. botulinum* may gain entry to the body through wounds, ingestion, and inhalation. In these cases, neurotoxin formation would occur *in vivo* during and following spore germination. Intestinal botulism occurs in infants and adults. Inhalation is the mode of infection by intentionally dispersed, aerosolized spores, and by the snorting of spore-containing cocaine. Several forms of the toxin exist, assigned class A status by the CDC. The toxin consists of light (some number of peptides) and heavy (large quantity of proteins) chains. The mode of action of the botulinum toxin begins with the attachment of the heavy toxin chain to axon terminals. Briefly, toxin gains access to the neuron and the light chain penetrates synaptic cells. Through proteolytic action on a protein required for release of acetylcholine, muscle contraction is inhibited. Clinical manifestations of botulism may initially involve interruption in bowel functions, blurred vision, and dry mouth proceeding in advanced stages to paralysis of voluntary muscles, including those controlling the diaphragm. Respiratory arrest follows.

The lethal dose of the toxin to a 150-pound adult human being is approximately 0.15 μg, which explains its appeal as a bioweapon. It is deliverable in particulate form. Botulinum toxin is very unstable, however. In fact, several bacterial toxins are labile and would be short-lived upon release to the natural environment. Hence, if selected to inflict intentional harm to humans, the preferred delivery vehicle would be food rather than water. Although use of the toxin intentionally on mass scale is rare, such attempts by the cult Aum Shinrikyo took place in Tokyo, Japan, and at U.S. military sites in 1990 and 1995. Fortunately, the group lacked microbiological and technological expertise to deliver the bioweapon successfully.[116]

Tetanus or Lockjaw

This disease develops upon contamination of a wound or burn with soil, street dust, or animal excreta containing endospores of the bacterium, *Clostridium tetani*. Morphological characteristics of the organism are essentially similar to those of *C. botulinum*. The bacillus lives in the intestines of domestic animals. Gardens that are fertilized with manure, barnyards, farm equipment, and pastures are particular sources of danger owing to presence of endospores. The tetanus toxins are tetanolysin and tetanospasmin; the latter a neurotoxin and the known active participant in the pathology of the disease. The toxin is slightly less potent than botulinum toxin, requiring about 0.175 μg to be fatal to a 150-pound adult, but is still a powerful inhibitor of the nervous system. Fatality rates in the United States range from 18 to 25 percent; however, in lands where treatment is less effective, fatality can be 50 percent. There is a tetanus antitoxin that can be used after infection, however, preventative vaccination is much more effective. Older adults (over 50) especially should be revaccinated against tetanus.

Tetanospamin is taken up at the nerve axon, as in the case of botulinum toxin, but is delivered across the synapses to points directly on the central nervous system, as opposed to peripheral regions in the case of botulinum toxin. The effect of the toxin is to interfere with the release of neurotransmitters resulting in muscle contractions and spasms. The incubation period is 1 to 3 weeks.

In summary, use of pathogens as weapons is no longer theoretical. Strategies to counteract their use and defend against their presence are currently in place or under discussion. Research involving the synthesis of a reporter protein for use in a toxin detection system is underway at the Lawrence Livermore National Laboratories in California. Continued efforts in this arena will likely stimulate the development of improved treatments for many known and little understood infectious diseases that will likely plague mankind for the foreseeable future.

NONINFECTIOUS AND NONCOMMUNICABLE DISEASES AND CONDITIONS ASSOCIATED WITH THE WATER ENVIRONMENT

Background

The terms *noncommunicable* and *noninfectious* are used interchangeably. The noncommunicable diseases are the major causes of death in developed areas of the world, whereas the communicable diseases are the major causes of death in the developing areas of the world. The major noncommunicable disease deaths in the United States in 1988 were due to diseases of the heart, malignant neoplasms, cerebrovascular diseases, accidents, atheriosclerosis, diabetes mellitus, and chronic liver disease and cirrhosis (accounting for 73 percent of all deaths). An analysis of mortality due to noncommunicable diseases in five subregions of the Americas in 1980 showed 75 percent of the total mortality attributed to noncommunicable diseases in North America (United States and Canada); 60 percent in Temperate South American countries (Argentina, Chile, and Uruguay); 57 percent in the Caribbean area (including Cuba, the Dominican Republic, and Haiti); 45 percent in Tropical South America (including the Andean countries, Brazil, French Guiana, Guyana, Paraguay, and Suriname); and 28 percent in Continental Middle America (Central America, Mexico, and Panama).[117] The mortality can be expected to shift more to noncommunicable causes in the developing countries as social and economic conditions improve and communicable diseases are brought under control. Major diseases of developing countries are gastrointestinal, schistosomiasis, malaria, trachoma, and malnutrition.

Treatment of the environment supplements treatment of the individual but requires more effort and knowledge. The total environment is *the most important determinant of health*. A review of more than 10 years of research conducted in Buffalo, New York, showed that the overall death rate for people living in heavily polluted areas was twice as high, and the death rates for tuberculosis and stomach cancer three times as high, as the rates in less polluted areas.[118] Rene Dubos points out that "many of man's medical problems have their origin in the biological and mental adaptive responses that allowed him earlier in life to cope with environmental threats. All too often, the wisdom of the body is a shortsighted wisdom."[119]

Whereas microbiological causes of most communicable diseases are known and are under control or being brought under control in many parts of the world (with some possible exceptions such as malaria and schistosomiasis), the physiologic and toxicologic effects on human health of the presence or absence of certain chemicals in air, water, and food in trace amounts have not yet been clearly demonstrated. The cumulative body burden of all deleterious substances, especially organic and inorganic chemicals, gaining access to the body must be examined both individually and in combination. The synergistic, additive, and neutralizing effects must be learned in order that the most effective preventive measures may be applied. As noted earlier, chemicals contributed to 12 percent of drinking water outbreaks during the period 1971 to 2002, which is greater than the fraction attributed to viruses.[18] Some elements, such as fluorine for the control of tooth decay, iodine to control goiter, and iron to control iron deficiency anemia, have been recognized as being beneficial in proper amounts. But the action of trace amounts ingested individually and in combination of the pollutants shown in Figure 1.3 and other inorganic and organic chemicals is often insidious. Their probable carcinogenic, mutagenic, and teratogenic effects are extended in time, perhaps for 10, 20, or 30 years, to the point where direct causal relationships with

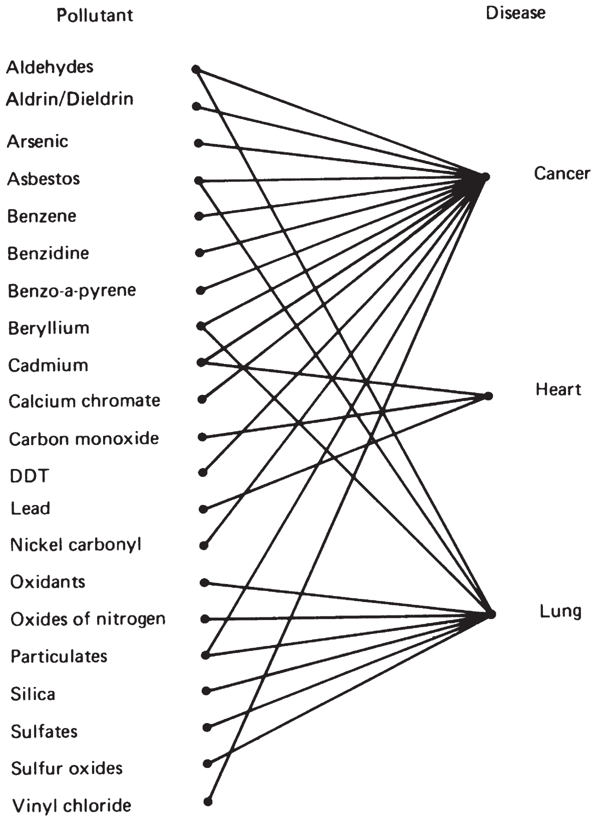


FIGURE 1.3 Known or suspected links between selected pollutants and disease. (*Source*: First Annual Report by the Task Force on Environmental Cancer and Heart and Lung Disease, Printing Management Office, U.S. Environmental Protection Agency, Washington, DC, August 7, 1978.)

morbidity and mortality are difficult, if not impossible, to conclusively prove in view of the many possible intervening and confusing factors.

There are an estimated 2 million recognized chemical compounds and more than 60,000 chemical substances in past or present commercial uses. Approximately 600 to 700 new chemicals are introduced each year, but only about 15,000 have been animal tested with published reports. Limited trained personnel and laboratory facilities for carcinogenesis testing in the United States by government and industry will permit testing of no more than 500 chemicals per year. Each animal experiment requires 3 to 6 years and a cost of more than \$300,000.[120] Another estimate is \$500,000 just to establish the carcinogenicity of one compound with the National Cancer Institute test protocol, requiring at least two species of rodents and 3 years' time.[121] A full toxicologic test, including those for carcinogenicity, can take five years and cost in excess of \$1.25 million for each compound. The chemicals are viewed by Harmison[122] as falling into four groups: (1) halogenated hydrocarbons and other organics, (2) heavy metals, (3) nonmetallic inorganics, and (4) biological contaminants, animal and human drugs, and food additives.

In group 1 may be polychlorinated biphenyls (PCBs); chlorinated organic pesticides such as DDT, Kepone, Mirex, and endrin; polybrominated biphenyls (PBBs); fluorocarbons; chloroform; and vinyl chloride. These chemicals are persistent, often bioaccumulate in food organisms, and may in small quantities cause cancer, nervous disorders, kidney and brain damage, and toxic reactions. A recently recognized undesirable role for pharmaceuticals, herbicides, and pesticides in natural waterways is as endocrine disruptors.[123] The extraordinary production and use of these compounds, coupled with their persistence through wastewater treatment processes, has resulted in long residence times of such materials in the environment. Aquatic life have been impacted through the ability of endocrine disruptor-active compounds to mimic hormonal control of reproductive systems, organ development, and sensory functions. There is concern that contaminants falling into the category of endocrine disruptors may exist in finished drinking waters. The route by which herbicides and pesticides may gain entry to natural waters is through agricultural runoff. PCBs are no longer manufactured, but their residues are still present in aquatic sediments and the tissues of aquatic vertebrates and invertebrates. Other chlorinated compounds may appear in soils and waters from leaking storage drums, uncontained industrial lagoons, and accidental landfill leachates.

Another group of nine chlorinated compounds that may appear in drinking water as a consequence of the use of chlorine as a post water treatment disinfectant is the haloacetic acids or disinfection byproducts (DBP). Trihalomethanes are a subset of the haloacetic acids that are regarded as the major carcinogens among DBP in relation to colon and rectal cancers[124] and reproductive disorders including spontaneous abortions, fetal deaths, miscarriages, and birth defects.[119] Precursors to the formation of DBP are naturally occurring organic molecules present in raw water supplies. Unlike the plethora of organic substances referred to in the AP report, DBP are regulated in the drinking water standards. However, only five of the nine DPB compounds are monitored.

Group 2 includes heavy metals such as lead, mercury, cadmium, barium, nickel, vanadium, selenium, beryllium. These metals do not degrade; they are very toxic and may build up in exposed vegetation, animals, fish, and shellfish. Some of them (e.g., lead, mercury, cadmium, and beryllium) have no role in human metabolism and are inhibitors of enzymes at very low concentrations. As poisons, they can affect the functions of various organs (e.g., kidney, liver, brain) and damage the central nervous system, cardiovascular system, and gastrointestinal tract. Children and pregnant women are especially vulnerable. The levels of heavy metals in drinking water are highly regulated. Heavy metals variably appear in many manufactured products, including metal goods and electronic devices, as well as naturally occurring minerals and coal deposits. Hence, there is ample opportunity for contamination of natural waters through runoff from insecure toxic waste containment sites, improper disposal and storage, and anthropogenic discharges such as power plant emissions.

Group 3 represents nonmetallic inorganics such as arsenic (metalloid) and asbestos, which are carcinogens.

Group 4 includes biological contaminants such as aflatoxins and pathogenic microorganisms; animal and human drugs such as diethylstilbestrol (DES) and other synthetic hormones; and food additives such as red dye No. 2. An Associated Press report released March 9, 2008 (available at http://www.metrowestdailynews.com/homepage/x1574803402), outlined the appearance of antibiotics, hormonal preparations, personal care chemicals, antidepressants, cholesterol control and cardiovascular medications, and pain relievers in ultra-small concentrations (ppb and ppt) in drinking-water samples from 24 of 28 metropolitan areas of the United States. All of these chemical substances are undetectable by the human senses.

Evaluation of the toxicity of existing and new chemicals on workers, users, and the environment and their release for use represent a monumental task, as already noted. Monitoring the total effect of a chemical pollutant on humans requires environmental monitoring and medical surveillance to determine exposure and the amount absorbed by the body. The sophisticated analytical equipment available can detect chemical contaminants in the parts-per-billion or parts-per-trillion range. Mere detection does not mean that the chemical substance is automatically toxic or hazardous. But detection does alert the observer to trends and the possible need for preventive measures. Short-term testing of chemicals, such as the microbial Ames test, is valuable to screen inexpensively for carcinogens and mutagens. The Ames test determines the mutagenic potential of a chemical based on the mutation rate of bacteria that are exposed to the chemical. However, positive results suggest the need for further testing, and negative results do not establish the safety of the agent. Other tests use mammalian cell cultures and cell transformation to determine mutagenicity.

Prevention and Control

Prevention of the major causes of death, such as diseases of the heart, malignant neoplasms, cerebrovascular disease, accidents, and other noninfectious chronic and degenerative diseases, should now receive high priority. Prevention calls for control of the source, mode of transmission, and/or susceptibles as appropriate and as noted in Figure 1.1.

The prevention and control of environmental pollutants generally involves the following three procedures:

1. *Eliminate or control of the pollutant at the source*. Minimize or prevent production and sale; substitute nontoxic or less toxic chemical; materials and process control and changes; recover and reuse; waste treatment, separation, concentration, incineration, detoxification, and neutralization.
2. *Intercept the travel or transmission of the pollutant*. Control air and water pollution and prevent leachate travel.

3. *Protect humans by eliminating or minimizing the effects of the pollutant*. This affects water treatment, air conditioning, land-use planning, and occupational protection.

At the same time, the air, sources of drinking water, food, aquatic plants, fish and other wildlife, surface runoff, leachates, precipitation, surface waters, and humans should be monitored. This should be done for potentially toxic and deleterious chemicals, as indicated by specific situations. Table 1.4 also lists characteristics of noninfectious diseases due to the ingestion of poisonous plants and animals and chemical poisons in contaminated water or food.

INVESTIGATION OF A WATER DISEASE OUTBREAK

General

The successful outcome in the investigation of any disease outbreak, no matter the source, depends on expedient execution of a preplanned process. Extensive investigations are economically burdensome to all parties involved, and the target of the study (e.g., a municipal water supply) in the end is faced with a public-relations problem in winning back the confidence of the community concerning the safety of the drinking water.

Hunter[125] delineated a nine-step "cradle to grave" program for the conduct of a waterborne outbreak study (Figure 1.4).

Each of the steps in the chronology of an investigation is elaborated on in the following sections. Although investigation of a waterborne incident is described here, the steps put forth would be applicable to a foodborne outbreak, also. Details on foodborne outbreaks are presented in Chapter 3.

Preparation Requisite to the investigation of an elevated incidence of disease, there must be in place a team of individuals having the collective expertise to handle all phases of the study. Ideally, this would include an epidemiologist, field engineer, preferably trained in matters of public health, and assistants. Each of the individuals must have an assigned role to play in the team effort to characterize an outbreak and provide suggestions to solve the problem. Responsible leadership, typically under direction of an epidemiologist, must be established in order to monitor and coordinate team activities and seek approval of the plan from pertinent pubic officials.

Detection The first stage of a potential outbreak event is the unusual level of sick individuals in the population requiring medical attention within a short time frame. Similarity in patient symptoms and results of laboratory examinations of specimens may provide preliminary evidence of the possibility of an outbreak. However, it is imperative that prompt reporting of laboratory data to public health authorities take place in order that there be an evaluation and dispensing of information to appropriate individuals to confirm the existence of an outbreak.

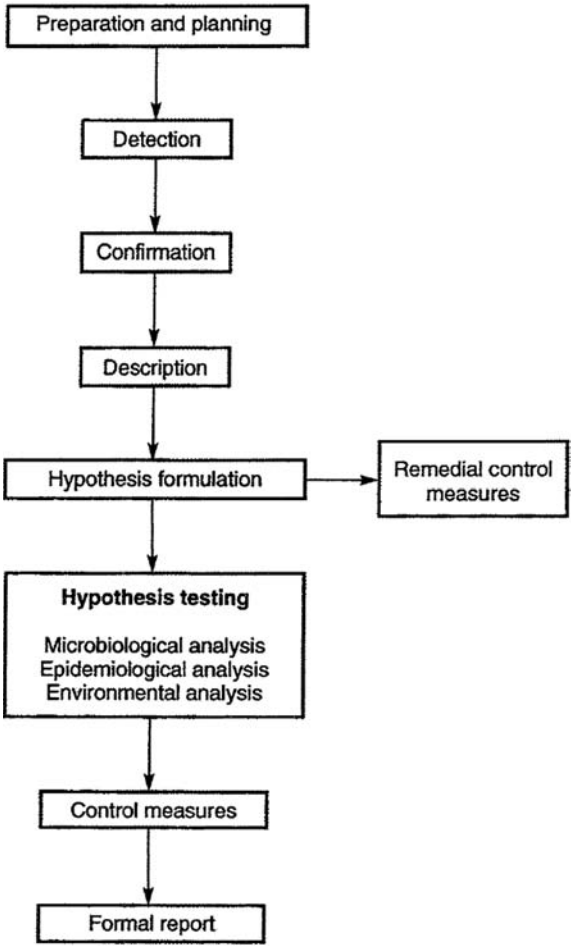


FIGURE 1.4 Flow diagram depicting the incremental steps in the investigation of a waterborne outbreak. *Source: P. R. Hunter, Waterborne Disease-Epidemiology and Ecology, John Wiley & Sons, New York, 1997*.

Hunter[125] cautions that many variables contribute to the inefficiency of identifying the existence of a waterborne disease, including difficulty in assembling patient data, proper diagnosis and laboratory testing for etiologic agents of prospective diseases, and underestimates of the number of afflicted people. For these and other reasons, much time and effort can be lost between the onset of illness in the population and the resolution of an outbreak.

Confirmation A redoubling of the effort on the part of authorities to substantiate from all information received that, indeed, an outbreak has occurred. This will involve a review of physician and laboratory records and ensuring that proper reporting of data to public health bureaus has taken place.

Description Upon confirmation that an outbreak has occurred, the investigating team should be activated and initial steps undertaken. It is not a simple matter to quickly determine the cause of illness due to water, food, or other vehicle, but a preliminary study of the symptoms, incubation periods, food and water consumed, housing, bathing area, and sanitary conditions may provide early clues and form a basis for formulating a quick response control action.

What is to be considered an outbreak case? The answer will require a preliminary set of parameters with which to define the case (e.g., limits of time regarding onset of the illness, symptoms of the illness, geographical boundaries of the affected area, and microbiological description of the disease etiology). The more rigid the definitions of parameters, the more likely it is that fewer cases will qualify for inclusion in the outbreak. However, parameter definitions should be flexible in relation to the availability of new information over time.

Following agreement on definition of a case, quantitative accounting of the number of cases involved is in order. Reliability of physician diagnoses and the collection of completed questionnaires of the type presented in Figure 1.5 are important. The information gathered from questionnaires contributes to the medical survey. If it appears that the number of completed questionnaires is insufficient, similar kinds of information can be collected and tabulated in the field when assistance is available. The tabulation horizontal headings would include the following seven categories:

1. Names of persons served food and/or water;
2. Age(s);
3. Ill—yes or no;
4. Day and time ill;
5. Incubation period in hours (time between consumption of ingestibles and first signs of illness);
6. Foods and water served at suspected meals—previous 12 to 72 hours (foods eaten are checked)
7. Symptoms—nausea, vomiting, diarrhea, blood in stool, fever, thirst, constipation, stomach ache, sweating, sore throat, headache, dizziness, cough, chills, pain in chest, weakness, cramps, other

Other analyses may include a summary of persons showing a particular symptom such as vomiting, diarrhea, and nausea, as shown in Figure 1.5, or those using a specific facility for calculation of incidence rates. For complete investigation details, consult references as appropriate.[126–129]

A common method of determining the probable offending water is a tabulation as shown in Figure 1.6, which is made from the illness questionnaire provided in Figure 1.5 or similar version. Comparison of the attack rates for each water will usually implicate or absolve a particular water. The water implicated is that showing the highest percentage difference between those who ate the specified water and became ill and those who did not eat the specified water and

Please answer the questions below to the best of your ability. This information is desired by the health department to determine the cause of the recent sickness and to prevent its recurrence. Leave this sheet, after you have completed it, at the desk on your way out. (If mailed, enclose self-addressed and stamped envelope and request return of completed questionnarie as soon as possible.)

1. Check any of the following conditions that you have had:

Nausea	Fever	Sore throat	Cough	Chills
Vomiting	Constipation	Headache	Pain in chest	Weakness
Diarrhea	Stomach ache	Dizziness	Laryngitis	Cramps
Thirst	Sweating	Paralysis	Bloody stool	Other

2. Were you ill? .... Yes ....No.
3. If ill, first became sick on: Date.............Hour............. A.M. / P.M.
4. How long did the sickness last ? ....
5. Check below (✓) the food eaten at each meal and (×) the food not eaten. Answer even though you may not have been ill.

Meal	Tuesday	Wednesday	Thursday
Breakfast	Apple juice, Corn flakes, oatmeal, fried eggs, bread, coffee, milk, water	Orange, pancakes, wheaties, syrup, coffee, milk, water	Grapefruit, Wheatina, shredded wheat, boiled egg, coffee, milk, water
Lunch	Baked salmon, creamed potatoes, corn, apple pie, lemonade, water	Roast pork, baked potatoes, peas, rice pudding, milk, water, chef salad	Swiss steak, home fried potatoes, turnips, spinach, chocolate pudding, orange drink, milk, water
Dinner	Gravy, hamburger steak, mashed potatoes, salmon salad, cookies, pears, cocoa, water	Roast veal rice, beets, peas, jello, coffee, water	Fruit cup, meatballs, spaghetti, string beans, pickled beets, sliced pineapple, tea, coffee, milk

6. Did you eat food or drink water outside? .... If so, where and when? ....
7. Name... Tel........................ Age .... Sex...............
8. Remarks (Physician's name, hospital)... .... Investigator ....

FIGURE 1.5 Questionnaire for illness from food, milk, or water.

became ill (Figure 1.6). The sanitary survey is important to the interpretation of an environmental sample and determining a sound course of action and should include a study of all environmental factors that might be the cause or may be contributing to the cause of the disease outbreak. These should include water supply, food, housing, sewage disposal, bathing, insects, rodents, pesticide use, food handlers and other workers, practices, procedures, and any other relevant factors. Each should be considered responsible for the illness until definitely ruled

DEPARTMENT OF
HEALTH AND HUMAN SERVICES
PUBLIC HEALTH SERVICE
CENTERS FOR DISEASE CONTROL
CENTER FOR INFECTIOUS DISEASES
ATLANTA, GEORGIA 30333

INVESTIGATION OF A WATERBORNE OUTBREAK

Form Approved
OMB No. 920-0004

1. Where did the outbreak occur?
______________________(1-2) City or Town _______________ Country _________

2. Date of outbreak : (Date of onset of 1st case)
__________________________________ (3-8)

3. Indicate actual (a) or estimated (a) numbers :
Persons exposed _______ (9-11)
Persons ill _____________ (12-14)
Hospitalized __________ (15-16)
Fatal cases ____________ (17)

4. History of exposed persons :
No., histories obtained _______________ (18-20)
No. persons with symptoms ___________ (21-23)
Nauses _______ (24-26) Diarrhea______ (33-35)
Vomiting ______ (27-29) Fever ________ (36-38)
Cramps _______ (30-32)
Other, specify (39) _________________________

5. Incubation period (hours):
Shortest ____ (40-42) Longest ____ (43-45)
Median _______ (46-48)

Shortest ____ (49-51) Longest ____ (52-54)
Median _______ (55-57)

7. Epidemiologic date (e.g., attack rates (number ill / number exposed) for persons who did not eat or drink specific food items or water, attack rate by quantity of water consumed, anacdotal information) * (58)

ITEMS SERVED	NUMBER OF PERSONS WHO ATE OR DRANK SPECIFIED FOOD OR WATER				NUMBER WHO DID NOT EAT OR DRINK SPECIFIED FOOD OR WATER			
	ILL	NOT ILL	TOTAL	PERCENT ILL	ILL	NOT ILL	TOTAL	PERCENT ILL

8. Vehicle responsible (item incriminated by epidemiologic evidence) : (59-60) ____

9. Water supply characteristics

(A) Type of water supply** (61)
☐ Municipal or community supply (Name ___________________)
☐ Individual household supply
☐ Semi-public water supply
☐ Institution, school, church
☐ Camp, recreational area
☐ Other, ____
☐ Botteled water

(B) Water source (*check all applicable*):

☐ Well	a	b	c	d
☐ Spring	a	b	c	d
☐ Lake, pond	a	b	c	d
☐ River, stream	a	b	c	d

(C) Treatment provided (*circle treatment of each source checked in B*):
a. no treatment
b. disinfection only
c. purification plant - coagulation, settling, filtration, disinfection (*circle those applicable*)
d. other ____

10. Point where contamination occurred: (66)
☐ Raw water source ☐ Treatment plant ☐ Distribution system

*See CDC 52.13 (Formerly 4.245) Investigation of a Foodborne Outbreak, Item 7.
**Municipal or community water supplies are public or investor owned utilites, Individual water supplies are wells or springs used by single residences. Semipublic water systems are individual-type water supplies serving a group of residences or locations where the general public is likely to have access to drinking water. These locations include schools, camps, parks, resorts, hotels, industries, subdivisions, trailer parks, etc., that do not obtain water from a municipal water system but have developed and maintain their own water supply.

CDC 52.12 (f. 4.461)
Rev. 7-81

This report is authorized by law (Public Health Service Act, 42 USC 241)
While your response is voluntary, your cooperation is necessary for the understanding and control of the disease.

FIGURE 1.6 Investigation of waterborne outbreak.

11. Water specimens examined: (67)
(*Specify by "X" wheather water examined was original (drunk at time of outbreak) or check-up (collected before or after outbreak occurred*)

ITEM	ORIGINAL	CHECK UP	DATE	FINDINGS Quantitative	FINDINGS Quantitative	BACTERIOLOGIC TECHNIQUE (e.g., fermentation tube, membrane filter)
Examples: Tap water	X		6/12/74	10 focal coliforms per 100ml.		
Examples: Raw water		X	6/2/74	23 total coliforms per 100 ml.		

12. Treatment records: (*Indicate method used to determine chlorine residual*):
Example: Chlorine residual – One sample from treatment plant effluent on 6/11/74 – trace of free chlorine
Three samples from distribution system on 6/12/74 - no residual found

13. Specimens from patients examined (stool, vomitus, etc.) (68)

SPECIMEN	NO. PERSONS	FINDINGS
Example: Stool	11	8 *Salmonella typhi*
		3 negative

14. Unusual occurrence of events :
Example: Repair of water main 6/11/74; pit contaminated with sewage, no main disinfection. Turbid water reported by consumers 6/12/74.

15. Factors contributing to outbreak (*check all applicable*):

- ☐ Overflow of sewage
- ☐ Seepage of sewage
- ☐ Flooding, heavy rains
- ☐ Use of untreated water
- ☐ Use of supplementary source
- ☐ Water inadequately treated
- ☐ Interruption of disinfection
- ☐ Inadequate disinfection
- ☐ Deficiencies in other treatment processes
- ☐ Cross-connection
- ☐ Back-siphonage
- ☐ Contamination of mains during construction or repair
- ☐ Improper construction, location of well/spring
- ☐ Use of water not intended for drinking
- ☐ Contamination of storage facility
- ☐ Contamination through creviced limestone of fissured rock
- ☐ Other (specify)

16. Etiology: (69-70)
Pathogen
Chemical
Other

(71)
Suspected 1
Confirmed .... 2 (*Circle one*)
Unknown 3

17. Remarks: *Briefly describe aspects of the investigation not covered above, such as unusual age or sex distribution; unusual circumstances leading to contamination of water; epidemic curve; control measures implemented; etc.*
(Attack additional page if necassary)

Name of reporting agency: (72)

Investigating Official: | Date of investigation:

Note: Epidemic and Laboratory assistance for the investigation of a waterborne outbreak is available upon request by the State Health Department to the Centers for Disease Control, Atlanta, Georgia 30333.
To improve national surveillance, please send a copy of this report to: Centers for Disease Control
Attn: Enteric Disease Branch, Bacterial Diseases Division
Center for Infectious Diseases
Atlanta, Georgia 30333
Submitted copies should include as much information as possible, but the completion of every item is not required.

CDC 52.12 (f. 4.461) (BACK)
7-81

FIGURE 1.6 (*continued*)

out. Other chapters in this book dealing with water and wastewater treatment, residential housing, food protection, recreational areas, and so on may be useful. Table 1.4 should be referred to for guidance and possible specific contributing causes to an outbreak and their correction.

A form for use in an environmental field investigation is presented in Figure 1.7. Water system, food service, housing, and swimming-pool sanitary survey report forms are usually available from the state or local health

Date .... Investigator ....
Name of place .... Owner ....
Population .... Manager ....
Onsets—day and hours .... Incubation period ....
Number afflicted .... Number hospitalized .... Number deaths ....
Outbreak: explosive .... gradual .... undetermined ....
Samples collected ....

Underline symptoms most commonly reported:

Diarrhea, constipation, abdominal pains, stomach cramps, muscular cramps, prostration, high temperature, painful straining at stool or in urination, sore throat, chills, thirst, sweating, vomiting, nausea, swelling of face and eyelids, laryngitis, cough, pain in chest, enlarged tonsils or adenoids, pains in joints, eye movement difficult, swallowing difficult, headache, dizziness, other ....

Water

1. Water sources and treatment ....
2. Method of serving water ....
3. Interconnections: toilet .... washbasin .... bath tubs .... tubs .... other ....
4. Recent repairs ....
5. Cross-connections, with other supplies ....
6. Changes in water taste .... color .... odor ....

Milk and food

7. Source of milk (pasteurized) ....
8. Method of handling milk ....
9. Use of leftover foods ....
10. Source of fowl, meats, ice cream, shellfish, pastries ....
11. Food refrigeration and storage ....
12. Food handling and preparation ....
13. Ice source and handling ....
14. Thawing foods protected ....
15. Dressings, sauces, etc. ....

Food handlers

16. Recent illness in food handlers ....
17. Hand-washing facilities ....
18. No. pyogenic skin infections ....
19. Personal hygiene ....

Kitchen and dining hall

20. Storage and use of insecticides .... rat poison .... roach powder .... water paint .... silver polish ....
21. Garbage storage and disposal ....
22. Prevalence of rodents and insects ....
23. Fly breeding controlled ....
24. Dish cleansing and disinfection ....
25. Premises and equipment clean ....
26. Food service well organized ....

Other

27. Housing overcrowding ....
28. Bathing beach or swimming pool operation, water source ....
29. Medical and nursing care ....
30. Other ....

Remarks (Comment on unsatisfactory items and probable cause, general impressions, etc.):

FIGURE 1.7 Outbreak investigation field summary.

department to assist in making a complete epidemiologic investigation. A WHO publication also has a water system reporting form[130,131] and the EPA has an evaluation manual.[132]

Laboratory results are the key to confirming the cause of disease cases. It may be necessary to ask physicians to obtain specimens from patients considered to be presumptive cases where such sampling had not been done. Also, a reexamination of physician records may be warranted against the possibility that certain patients were overlooked.

Once individuals are identified as cases, personal history of each of the cases must be obtained. In addition to the usual descriptors (e.g., name, age, sex, etc.), personal information relevant to the case definition is needed. Accessory data may be collected on cases (e.g., information about whereabouts and activities leading up to the occurrence of disease symptoms). Such information is useful to establish the incubation period for the disease and to compare the evaluation with published incubation periods for suspected etiologic agents. The medical survey should assist in developing a clinical picture to enable identification of the disease and its causative agent. Typical symptoms, date of onset of the first case, date of onset of last case, range of incubation periods, number of cases, number hospitalized, number of deaths, and number exposed are usually determined by the epidemiologist. To assemble this information and analyze it carefully, a questionnaire should be completed, by trained personnel if possible, for each person available or on a sufficient number of people to give reliable information (see Figure 1.5).

The importance of animal reservoirs of infection should not be overlooked where small-scale water systems are involved. Table 1.4 contains in condensed form symptoms and incubation periods of many diseases that, when compared to a typical clinical picture, may suggest the causative organism and the disease. A high attack rate, 60 to 80 percent, for example, would suggest a virus (Norovirus) as the cause of a foodborne outbreak.[133]

Finally, all data collected in the description phase of the investigation are analyzed and charted in various ways to obtain a picture of the outbreak. Visual aids will be areal maps, graphs displaying the chronology of case densities over time with subplots according to age, sex, ethnicity, and so on. A simple bar graph, with hours and days (possibly weeks) as the horizontal axis and number who are ill each hour or other suitable interval plotted on the vertical axis, can be made from the data. The time between exposure to or ingestion of water and illness or first symptoms or between peaks represents the incubation period. The average incubation period is the sum of the incubation periods of those ill (time elapsing between the initial exposure and the clinical onset of a disease), divided by the number of ill persons studied. The median, or middle, time may be preferable when incubation periods vary widely. The shape of the curve is useful in revealing the period of primary infection as may be due to point source infection vs. person-to-person contact. Extended case-time plots may be biomodal, indicating a point-source outbreak and a secondary person-to-person outbreak. Good data presentation adds to the strength of the investigation and the location of "hot spots" that may reveal points of interest in the drinking-water distribution system subject to possible contamination.

Hyothesis Formulation The data collected and analyzed in connection with the "Description" are used to formulate hypotheses concerning the events responsible for the outbreak and make preliminary recommendations for remedial control measures. More than one hypothesis is possible. The outbreak may be responsible to a point-source or person-to-person contact. Furthermore, if it is envisioned that a point-source is possible, it will be necessary to determine the point of access by disease-producing agents to the finished water. For example, an infectious agent believed responsible for a waterborne outbreak may be associated with a cross-connection somewhere in the distribution system or regrowth in an activated carbon filter at the treatment plant compounded by ineffective disinfectant residual in the finished water. Knowledge of past outbreaks and epidemiology of the suspected infectious agent, combined with the total of current data logs and analyses of the outbreak in question will serve to identify the hypothesis with greatest likelihood explaining the outbreak. Publications summarizing disease outbreak investigation procedures are very helpful.[134–137]

Remedial Control Measures During hypothesis formulation, implications as to the cause of the outbreak may emerge, justifying a simultaneous review of options for remedial control measures. Since the hypothesis advanced has not been proven at this point, any remedial actions called for must be directed at immediate protection of the public. Where a danger in the drinking water supply is envisioned, decisions are limited to disconnecting the purveyor from the users, issuing a boil order, or supplying an auxiliary source of safe drinking water. In the example of the Alamosa, Colorado, outbreak, residents were advised not to use tap water for potable uses on the day bacterial contamination was discovered and to bring large containers to obtain safe water from distribution centers located within the community. Bottled water was supplied mostly to schools. Main flushing following superchlorination took place in stages, beginning six days from the time the outbreak was announced and residents were asked to refrain from using tap water for drinking and cooking at that time. Water authorities should not be required to undertake expensive repair and retrofitting of the treatment system before it is definitely ascertained that there is a physical problem in need of attention. The mere enactment of precautionary measures will prescribe a liability, both in terms of monetary cost and public relations.

Hypothesis Testing This is the important "proof" step in the investigatory program. All parties affected and the rest of the community will anxiously await the final word on the cause of the outbreak. All evidence obtained during the investigation is evaluated in an acceptable plan for testing a particular hypothesis. The evidence presented is the sum total of microbiological, epidemiological, and environmental findings collected during the course of the investigation. The most definitive microbiological evidence is the unequivocal identification of the waterborne disease agent in case specimens and samples taken at the source of the outbreak, however, the latter may be difficult to accomplish. New methodologies are available to aid in rapid detection of suspected pathogenic agents in environmental samples including water. A brief description of the procedures is given in the following section. Epidemiological evidence arises from the results of retrospective studies conducted on known cases and randomly selected control subjects within the affected community. Environmental evidence pertains to results of a sanitary survey. The sanitary survey should cover all factors that may potentially impact on operational and quality control issues associated with the treatment and distribution of the community water supply. It is very helpful to have personnel knowledgeable about the water field involved in the environmental investigation. Upon obtaining positive identification of the etiologic agent of a communicable disease, the number of confirmed cases should be made known to the state health department and to the national Centers for Disease Control.

Control Measures These are the repairs and installation of facilities and equipment necessary to safeguard the water supply from repeated microbial violations of the system. Successful establishment of the cause and source of the waterborne outbreak pays dividends, not only in returning the community to normal use of its water supply but also easing the tensions of individuals upon which the onus for correcting defects and bearing the financial burden is leveled.

Formal Report The published written report should chronicle the essentials of the waterborne outbreak. The report should be fully detailed and include the cause, laboratory findings, transmission, incidence, case by dates of onset, average incubation period and range, typical symptoms, length of illness, age and sex distribution, deaths, secondary attack rate, and recommendations for the prevention and control of the disease, so as to be of use to various professional, political, and technical members in the community workforce. Copies of the report should be sent to the state health department and the Public Health Service. The press should be carefully briefed to avoid misinterpretation and dissemination of misinformation to the community. Effort should be made to use the report as an instructional tool for the education of students in the community and geographically dispersed parties through scientific reporting.

Samples and Specimens

The prompt collection of samples and specimens for laboratory examinations is a necessary part of the investigation of any disease outbreaks. Although not often done, isolating the incriminating organism from the persons made ill and the alleged outbreak source, producing the characteristic symptoms in laboratory animals or human volunteers, and then isolating the same organisms from human volunteers or laboratory animals will confirm the field diagnosis and implicate the responsible vehicle. In the early stages of the field investigation, it is very difficult to determine just what samples to collect. It is customary, therefore, to routinely collect samples of water from representative places and available samples of all leftover milk, drinks, and food that had been consumed and place them under seal and refrigeration. Sterile spatulas or spoons boiled for 5 minutes can be used to collect samples. Sterile wide-mouth water bottles and petri dishes make suitable containers. In all cases, aseptic technique must be used. Since examination of all the food may be unnecessary, it is advisable, after studying the questionnaires and accumulated data, to select the suspicious foods for laboratory examination and set aside the remaining food in protected sterile containers under refrigeration at a temperature of less than 40°F (4°C) for possible future use. Laboratory procedures should be followed for collection, preservation, and shipment of all specimens and samples.

Samples of water should be collected directly from the source, storage tanks, high and low points of the distribution system at times of high and low pressure, kitchens, and taps near drinking fountains for chemical and bacterial examinations. It should be remembered that the time elapsing before symptoms appear is variable and depends on the causative agent and size of dose, the resistance of individuals, and the amount and kind of food or drink consumed. For example, an explosive outbreak with a very short incubation period of a few minutes to less than an hour would suggest a chemical poisoning. Antimony, arsenic, cadmium, cyanide, mercury, sodium fluoride, sodium nitrate, or perhaps shellfish poisoning, favism, fish poisoning, and zinc poisoning are possibilities. An explosive outbreak with an incubation period of several hours would suggest botulism or fish, mushroom, potato, rhubarb-leaf, shellfish, chemical, or staphylococcus food poisoning. An incubation period of 6 to 24 hours would suggest botulism, mushroom poisoning, rhubarb poisoning, salmonella infection, or streptococcus food poisoning. An incubation period of one to five days would suggest ascariasis, botulism, diphtheria, amebic dysentery, bacillary dysentery, leptospirosis, paratyphoid fever, salmonella infection, scarlet fever, streptococcal sore throat, or trichinosis. For other diseases with more extended incubation periods, refer to Table 1.4. The laboratory examinations might be biologic, toxicologic, microscopic, or chemical, depending on the symptoms and incubation period.

The CDC[138] classifies outbreaks of unknown etiology into four subgroups by incubation period of the illnesses: less than 1 hour (probable chemical poisoning), 1 to 7 hours (probable *Staphylococcus* food poisoning), 8 to 14 hours (probable *C. perfringens* food poisoning), and more than 14 hours (other infectious or toxic agents).

The sanitary and medical surveys may involve the swimming pool or bathing beach. In that case, samples should be collected at the peak and toward the end of the bathing period for examinations.

Laboratory analyses for water samples should include the standard plate count (heterotrophic plate count), in addition to the test for coliform bacteria, since large bacterial populations may suppress the growth of coliform organisms. Where large volumes of water are needed, use 2- to 5-gallon sterile containers and store at 41°F (5°C). Sampling for recovery of viruses and *Giardia or Entamoeba* cysts may require special on-site filters and equipment.[139]

It is customary to notify the laboratory in advance that an outbreak has occurred and that samples and specimens will be delivered as soon as possible. All should be carefully identified, dated, sealed, and refrigerated. A preliminary report with the samples and specimens, including the probable cause, number ill, age spread, symptoms, incubation period, and so on, will greatly assist the laboratory in its work.

Epidemiology and Risk

In the foregoing discussion, a scheme for dealing with the orderly investigation of a waterborne disease outbreak was presented. Central to the conduct of the investigation is the team of workers appropriately trained to perform specific roles. One such team member, if available, and a likely leader of the group, is the epidemiologist. *Epidemiology* literally translated is "study of epidemics." In the broader sense, it is the science (with considerable art) of defining the causes of disease distribution within a population and the causal factors that made the disease possible. A causal factor is an event, condition, or characteristic that increases the likelihood of a disease.[4]

Environmental epidemiology is the study of environmental factors that influence the distribution and determinants of disease in human populations.[26] In the context of a waterborne outbreak, the epidemiologist is interested in learning the susceptibility of the population under the sphere of influence of a water transmitted disease, what regions or groups of people in the population are at the greatest risk, how the disease will manifest itself temporally and spatially in the population, commonalities, and differences among the individuals listed as having been symptomatically affected and not affected, and something of the risk to the population under the conditions of exposure to water.

During the course of the investigation of a waterborne outbreak, a descriptive epidemiologic study will be undertaken with the collection of data sets obtained from laboratory, hospital and physician, environmental, and residential records and field surveys. The emphasis will be put on establishing the veracity of the outbreak, containing the spread of the disease through emergency measures, and characterizing the event in support of formulating a hypothesis on the cause of the outbreak. A follow-up to the descriptive epidemiologic study would be an analytical epidemiologic exercise involving a case-control study to identify causal factors to the outbreak. A case-control study is an observational study in which a group of persons with a disease (cases) and a group of persons without the disease (controls) are identified without knowledge of prior exposure history and are compared with respect to exposure history.[140]

If the selection of control participants is truly random, some of the subjects selected to be controls may also have expressed the illness. Selection of individuals making up the control group is not a simple process and, as with the convening of any sample of people intended to be representative of a particular population, bias is inevitable. Bias impacts the strength of the study results. The object of the exercise is to analyze the behaviors of both groups prior to the outbreak so that a determination can be made about the importance of the water as a condition to developing the disease. For this, a simple approximation of the essentiality of the water to the infectious outcome is obtained by computing an odds ratio. A 2×2 square is constructed by pairing the number of people that consumed and did not consume water against the number of those people who became ill and did not become ill.

The following is a hypothetical example involving collected data on the population associated with the waterborne outbreak:

52 people drank contaminated water and became clinically ill. (a)
32 people drank contaminated water and did not become ill. (b)
21 people did not drink contaminated water and became ill. (c)
64 people did not drink contaminated water and did not become ill. (d)

The 2 × 2 table is constructed to display the data as given.

	Drank water	Did not drink water
Became ill	52	21
Did not become ill	32	64

$$\text{Calculation of the odds ratio (OR): } \frac{a/c}{b/d} = \frac{52/21}{32/64} = 4.95 = 5$$

The OR clearly establishes a strong connection between exposure (water) and the prevalence of disease.

In an actual study, there may be a number of possible sources for the disease agent including food, insects, and personal associations, to name a few. With the category of food, many subsets are possible, including salads, meats, breads, juices, milk, and so on. Each of the sources deserves consideration as a vehicle or vector, depending on the nature of the suspected disease agent. Case-control studies can be constructed to test any and all of the potential sources of the disease agent. The odds ratios can then be statistically analyzed to narrow the field of suspected sources. Usually, the statistical evaluation is performed at the 95 percent confidence level ($p < 0.05$).

In the previous example of a case-control study in connection with a waterborne outbreak, cases of the disease had been established. Now consider a situation where the town health officer released advance information to a population of people that a wastewater cross-connection was found to have leaked at some point in the distribution system. These conditions may provide the opportunity for a cohort study, which is an observational study in which two or more groups of persons who are free of disease and differ by extent of exposure to a potential cause of a disease are compared over time with respect to the incidence of the disease.[140] In our example, this would be a prospective investigation of a group (cohort) of healthy people known to have been exposed to contaminated water. The object of the study would be to follow the course of events to evaluate the appearance of illness in the exposed population and determine if consuming the contaminated drinking water posed a risk for illness. In the cohort study, it is of interest to determine the incidence of disease in the exposed group vs. the unexposed group. To do this, a 2×2 table is constructed as previously illustrated and a relative risk (RR) is determined. Relative risk cannot be established for a case-control study because members of the case-control population are not random samples of the *entire* community population.

To illustrate the calculation of RR, a hypothetical situation is presented below. The same data as for the case-control study was used for comparative purposes:

52 people drank contaminated water and became clinically ill. (a)
32 people drank contaminated water and did not become ill. (b)
21 people did not drink contaminated water and became ill. (c)
64 people did not drink contaminated water and did not become ill. (d)

The 2×2 table is constructed to display the data.

	Drank water	Did not drink water
Became ill	52	21
Did not become ill	32	64

Calculation of the RR value involves the ratio of the exposed group as a proportion of the population examined to the unexposed group as a proportion of the population examined:

$$\mathrm{RR} = \frac{a/(a+b)}{c/(c+d)} = \frac{52/(52+32)}{21/(21+64)} = \frac{0.62}{0.24} = 2.6$$

The RR establishes that the relative risk of becoming ill for the group of people exposed to contaminated water as opposed to the group of people not exposed to contaminated water is 2.6.

Two types of information regarding disease in a population that can be helpful to an epidemiological study are incidence rate and prevalence rate. Incidence rate is defined as the number of new cases per unit of person-time at risk. For example, suppose the waterborne outbreak used in the previous examples occurred in a stable community of 10,000 people. Following the outbreak, the number of new cases occurring over a five-year period was 30 per 10,000 people. These new cases might have nothing to do with consuming water, but the waterborne incident might have established some carriers of the disease within the population that could contribute to the infection of others. In this example, the incidence rate of the disease in the community would be 6 cases per 10,000 people-years; the expression *people-years* arriving from the normalization of the 30 disease cases over a five-year period.

Prevalence rate is something different from incidence rate because prevalence rate concerns the actual number of disease cases in a community. In the case of the waterborne outbreak, there were 73 cases of the disease. Supposing that secondary infections occurred among the population to add another 43 cases of the disease bringing the total to 116 cases of the disease for the year. In the community of 10,000 people, the prevalence rate of the disease for the year of the outbreak would be 1 percent.

The incidence rate can be determined for both the exposed and unexposed individuals identified with the waterborne outbreak above. Looking at the data, we find that 52 people became sick out of 84 people that drank water and 21 people became sick out of 85 people that did not drink water. The incidence rate for the two subgroups of individuals is 62 percent and 25 percent, respectively. From these data, an attributable risk can be determined by subtracting the incidence rate of nondrinkers from drinkers of the water, which would be 37 percent.

Incidence measures reflect the level of infectivity of the causative agent of the disease. They do not establish the virulence of the causative agent because virulence relates to the damage produced as a result of the infection. Damage resulting from infection of an individual can range from a few mild symptoms to life-threatening symptoms, depending on many contributing factors (e.g., health and nutrition status, age, infectious dose of the pathogen received, how the pathogen was received, genetic disposition and others). In the study of an outbreak, a case is defined not by the severity of the infection but by the fact that an infection occurred.

The subject of risk assessment has advanced considerably in the last 20 years. Mathematical models have been constructed to estimate the probability of infection using databases of human exposure. Before models could be formulated it was necessary to ascertain the variables of the infection process. In the case of microbial risk assessment, such variables might include etiologic disease agent identification, human health effects manifested through infection, dose-response data relating dose received and probability of infection/disease in the target population, physiology of host-parasite relations, and epidemiological data.[26]

Molecular Detection of Waterborne Pathogens

Water, especially drinking water, when under suspicion of the transmission of pathogens, requires laboratory examination for proof of contamination. Cultural methods may prove inadequate for the isolation of pathogens, may produce uncertain results, or may be too time-consuming to support ongoing epidemiological investigations. During the past three decades, environmental laboratories have exploited molecular-based protocols to gain insight into the presence of sundry infectious bacteria, viruses, and protozoa in aquatic environments and water supplies. These techniques can be useful to investigations of disease outbreak, especially, where no cultural evidence can be obtained to show the existence of an infectious agent. In fact, a fundamental challenge in proving the hypothesis that a disease outbreak has occurred is to establish conclusively that the suspected agent of disease existed at the suspected source of the disease. A broad range of sophisticated laboratory techniques, such as fluorescent antibody, enzyme-linked immunosorbent assay (ELISA), fluorescent *in situ* probe (FISH), flow cytometry, and the polymerase chain reaction (PCR), are available to provide answers not possible by classical measures. From these has emerged a branch of epidemiology called molecular epidemiology. Routine use of molecular tools is nonexistent in many health laboratories, however, owing to the requirement for relatively expensive equipment, need to employ technicians knowledgeable about molecular techniques, and the technical issues surrounding detection of specific genomes present in very low levels in water. Despite these apparent limitations to adopting molecular techniques for routine surveillance of pathogens in water-quality-control laboratories, molecular protocols have been used to detect a wide range of pathogenic agents in waters.

A brief introduction to molecular methods for microbiological investigation in the water environment is given based on descriptions by Rochelle and Schwab.[141]

Sample Collection Proper procedures for obtaining water samples are independent of the intended use of water. However, taking advantage of the sensitivity of molecular detection implies that the target organism is probably in very low in concentration, else it might be prudent to employ a cultural technique (assuming the target microorganism or virus is in a viable/recoverable state). Therefore, sample volumes earmarked for molecular applications are usually large and will require concentration of contents.

Sample Concentration Large water samples are processed by filtration procedures applicable to bacteria, protozoa, or viruses.

Nucleic Acid Extraction The material of interest to be assayed by molecular techniques is deoxyribonucleic acid (DNA) or ribonucleic acid (RNA). Extraction of nucleic acids from filtered/centrifuged biomass containing the target organism of interest may take place directly or following repeated elution and centrifugation steps (principally required for virus recovery). Ideally, the extraction step will be minimally time consuming, produce a high yield of intact nucleic acid, and preclude carryover of inhibitory substances inimical to the polymerase chain reaction (PCR) analysis. Special procedures can be introduced prior to nucleic acid extraction for removal of inhibitors. Published protocols and commercial kits may be used for postextraction purification of nucleic acids to eliminate inhibitors.

Methods of Detection The basic approach to assaying purified target nucleic acid is the application of PCR. The purpose of PCR is to amplify the nucleic acid of the target organism so that workable quantities of product become available for subsequent sequence analysis. It is important that the PCR procedure be sensitive and specific. PCR assays are typically operated in three cycles of temperature to accommodate three steps:

1. Denaturation of the double-stranded, target DNA (92°–94°C)
2. Annealing of specific primers to the single-strand form (denatured) of the target DNA at some prescribed or trial-and-error temperature (45°–55°C)

3. Complementary strand synthesis by primer extension of each of the single strands produced by step 1 at a temperature of 75°–80°C

The three-step procedure is repeated usually 30 to 40 times in order to obtain exponential copies of PCR product. The two important variables in successful use of PCR as a tool are primer synthesis or selection and PCR operating conditions. These two factors dictate the level of specificity and sensitivity that can be obtained by PCR and are instrumental in facilitating the detection of target nucleic acids at refined taxonomic levels.

Evaluation of PCR Products The purpose of amplifying target nucleic acids present in the environmental sample is to be able to subject a sufficient quantity of the representative material (PCR product) to a laboratory procedure for the determination of the microbial agent that it represents. Classic procedures for this purpose involve application of a series of concentrations of the PCR products to an agarose gel electrophoresis slab along with a molecular marker. Various amplified gene fragments migrate through the gels in proportion to their molecular weights. The separated gene fragments can then be confronted with an oligonucleotide probe specific for the organism of interest in relation to its possible presence in the original water sample. Oligonucleotide probes are conjugated with a reporter molecule (typically a fluorogenic compound) that under appropriate conditions (fluorescent lighting) signals hybridization with a complementary (target) nucleic acid fragment.

Two areas of interest in connection with molecular detection of specific microbial agents in environmental samples are robustness of the detection effort and the level or density of the target microbe in the representative environmental sample. In the former, since molecular detection is a gene-based exercise, it stands to reason that the more types of gene fragments that are available as probes, the more information that can be learned about the genome of the target organism. The technique that makes use of the multiple probe approach is the microarray. The microarray is a glass microscope slide that serves as a solid support for the spotting of literally thousands of genes or gene fragments—in this example, oligonucleotide probes—that serve to test hybridization potential with amplified gene fragments (PCR products) of unknown identity. The nucleotide sequence of the probe is known and representative of specific microbes. The location of each of the probes on the glass slide is carefully recorded, so when hybridization with unknown PCR products (amplicons) is indicated by reporter signals, the strain, species, and genus identity of the unknown amplicon can be learned.

Quantification of the target microbe in the environment with the aid of a PCR instrument must involve procedural modifications and special equipment in order to measure the level of production of PCR products. Fluorogenic probes and a fluorescence detection device are used to track the formation of PCR product formation. Quantitative PCR (qPCR) is still relatively new, and advances are being made to increase its utility. The following brief description is based on methodology described by Grove.[142] In the qPCR process, two fluorogenic probes anneal to the template nucleic acid between the primers. As the nucleic acid polymerase extends the primer, the probe is displaced, and the polymerase cleaves the fluorogenic dye. Released dye is freed from the quencher and a fluorescent signal is produced. The detection device consists of a multiwell thermal cycler connected to a laser and a charge-coupled optics system. A fiber optic inserted through a lens is positioned over each of the wells, and a laser beam is directed through the fiber to excite fluorochrome in the PCR fluid present in wells. Fluorescence emissions are sent through the fiber to the CCD camera, mathematically analyzed by the system software, and the data are computerized.

Obtaining quantitative data on the original sample requires construction of a calibration curve. This is done by preparing dilutions of a known quantity of nucleic acid and performing PCR. Emissions data are obtained for each dilution of the nucleic acid and plotted against thermal cycle numbers. A series of curves result, and a line is drawn through the curves parallel to the thermal cycle numbers (x axis) at a height just above the background fluorescence (Figure 1.8). Another line is drawn perpendicular to the thermal cycles (x axis) at the intersection of the parallel line and each of the curves representing the nucleic acid dilutions. The thermal cycle number corresponding to each curve is the threshold cycle (Ct). The calibration curve is a plot of each Ct value against the corresponding nucleic acid concentration in the dilution series. The Ct is inversely proportional to the copy number (concentration) of nucleic acids in the dilution series, so a straight line should result. The actual concentration of nucleic acid in the unknown sample is determined by obtaining a Ct value under identical conditions of PCR operation

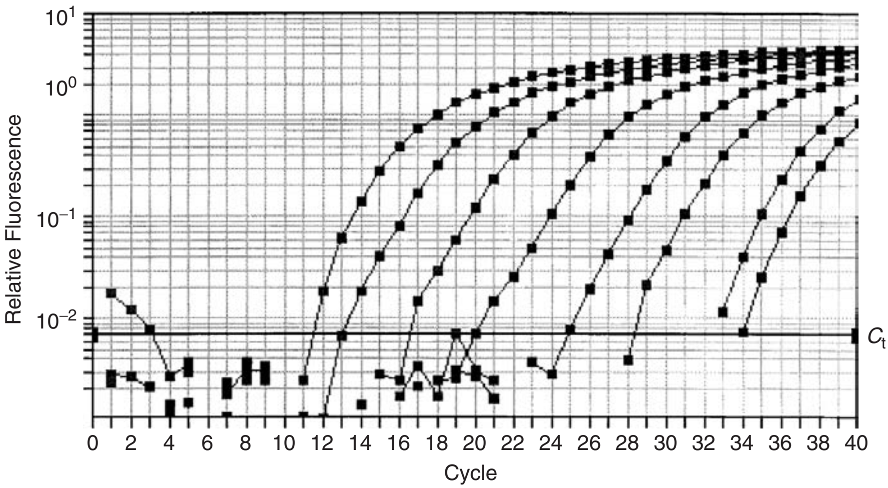


FIGURE 1.8 Family of fluorescence emission curves prepared from dilutions of nucleic acid for the determination of threshold cycle values. (*Source*: *D. S. Grove, "Quantitative Real-Time Polymerasae Chain Reaction for the Core Facility Using TaqMan and the Perkin-Elmer/Applied Biosystems Division 7700 Sequence Detector," J. Biomol. Tech, 10 (1999): 11–16.*)

as took place for the known dilution series and the nucleic acid concentration represented by the *C*t value is read from the calibration curve.

Quality control and assurance is uppermost in all phases of PCR methodology. Prospective analysts should be aware of the U.S. Environmental Protection Agency publication "Quality assurance/quality control guidance for laboratories performing PCR analyses on environmental samples," available at http://www.epa.gov/nerlc/cwww/qa_qc_pcr10_04.pdf.

Advances in molecular methods of detecting and quantifying microorganisms should be powerful assets to modern environmental epidemiology. The potential exists for analyzing samples for the presence of suspect pathogens in water supplies with far greater certainty than can occur by conventional methods.

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CHAPTER 2

CONTROL OF DISEASES OF THE AIR AND LAND

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COMMUNICABLE DISEASES

Background

Communicable diseases are illnesses due to a specific infectious agent or its toxic products. They arise through transmission of that agent or its products from an infected person, animal, or inanimate reservoir to a susceptible host, either directly or indirectly through an intermediate plant or animal host, vector, or the inanimate environment.[1] Illness may be caused by pathogenic bacteria, bacterial toxins, viruses, protozoa, spirochetes, parasitic worms (helminths), poisonous plants and animals, chemical poisons, prions (infectious proteinlike particles) rickettsias, and fungi, including yeasts and molds. In this text, vectorborne and airborne communicable diseases are discussed under arthropodborne diseases and respiratory diseases; noncommunicable diseases will also be discussed. This chapter concludes with a basic description of definitions and typical studies and measures used in epidemiology. The terms *communicable disease* and *infectious disease* are used interchangeably.

The communicable diseases (malaria, yellow fever, pneumonia, human immunodeficiency virus [HIV], tuberculosis, cholera, schistosomiasis, measles, onchocerciasis, intestinal parasites, and diarrheal diseases) and malnutrition have traditionally been considered the core health problems of developing countries, many of which are aggravated by contaminated drinking water, unhygienic housing, and poor sanitation. In developed countries, the chronic diseases (disease of the heart, cerebrovascular disease, cancer, diabetes) and injuries

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(motor vehicle accidents, suicide, poisonings) comprise the majority of causes of death. [2]

When a country shifts from predominately infectious disease mortality to chronic disease mortality, the country is said to have undergone the *epidemiologic transition*. Although this has been the view of disease burden for the latter half of the twentieth century, the burden of chronic diseases in developing countries has increased dramatically in the last two decades and has resulted in mixed patterns of mortality between different populations, even within the same country. For example, in developing countries relatively well-off urban dwellers will have a higher mortality due to chronic diseases, while poor rural residents may have greater burden of infectious disease. Therefore, it is important to remember that while communicable diseases are the focus of this chapter and the next, individuals with chronic health conditions will make up large proportions of infected populations; this has large implications for the severity of disease and managing clinical conditions, and it reiterates the importance of prevention for all.

A study by Clough[3] compares two investigations showing the impact of environmental factors on cancer mortality. The term *environment* has different meanings to the epidemiologist and to the general public. To the epidemiologist, "it refers to everything that humans encounter: everything that is eaten, drunk, and smoked; drugs, medicine, and occupational exposures; and air, water, and soil. In this context it means everything outside the body as distinct from a person's genetics."[3] Clough defined "environment" as the aggregate of all the external conditions and influences affecting the life and development of humans. Included is the air, water, land, and climate and the interrelationship that exists between them and all living things.

Social epidemiologists refer to different levels of human environment, terms that may be used differently than in other realms of environmental engineering. The *built environment* refers to manmade structures that are the setting for human activity, including buildings, bridges and planned open spaces. Influences of the built environment on mental health,[4,5] obesity,[6] nutrition,[7] sleep disturbances,[8] traffic accidents,[9] malaria-transmitting mosquitoes,[10] visceral leishmaniasis,[11] and other diseases and injuries have been documented. Although causal inference between these associations is difficult to make, we are just beginning to understand the health impact of the structures we live and work in. This is likely to be an expanding and exciting field of research in public health that can be translated into applications through environmental engineering.

Social factors not intuitively associated with health can also have significant influences. Of all the predictors of individual good health (diet, exercise, environmental factors, access to medical care, etc.), studies repeatedly show that educational attainment is highly important. More educated populations tend to be healthier, although the causal mechanism has not been clearly articulated. Although increasing the basic education level is not usually considered a public health intervention, it should be acknowledged that many of the broader societal trends that influence health are beyond the scope of any individual agency or organization. Collaborative efforts from different public welfare sectors are necessary to make meaningful improvements in public health.

It bears mentioning that many bacteria live in symbiosis (mutual benefit) with humans, with both deriving mutual benefits. The presence of natural "flora" of the intestinal tract and skin are normal and considered healthy under most circumstances; when the immune system becomes compromised (i.e., with age, HIV infection, breaks in the skin, chemotherapy, etc.) these organisms can cause pathological disease. The bacteria also provide protection against more damaging bacterial and viral organisms and can become depleted with the use of antibiotics. When we refer to "infectious diseases" for the rest of this chapter and the next, we specifically mean those infectious organisms that cause pathological disease in humans.

Life Expectancy and Mortality

The life expectancy at birth has varied with time, geography, and the extent to which available knowledge concerning disease prevention and control could be applied. Table 2.1 shows the trend in life expectancy through the ages. The gains in life expectancy in the United States between 1900 and 2000 shown in Table 2.2 have resulted in lower childhood mortality and longer life expectancy, and this is typical of the epidemiologic transition already mentioned. The life expectancy gains since 1900 are due primarily to better sanitation (water filtration and chlorination, sanitary excreta and sewage disposal, milk pasteurization, hygiene), improvements in nutrition, vaccination and the development of antibiotics, and improved medical care. These measures have led to a reduction in infant mortality, the conquest of epidemic and infectious diseases, and an improved quality of life. Many developing countries have achieved dramatic reductions in infectious disease mortality among upper and middle class populations; however, the joint burden of poverty and infectious disease remains entrenched in many areas, including in the United States. In many areas of the United States, including inner cities and Native American reservations, life expectancy is as low as in countries with much higher burdens of infectious disease. Future increase in life expectancy in the United States (and other developed countries) is dependent in part on our ability to identify the causes and control the chronic and degenerative noninfectious diseases such as cardiovascular diseases, malignant neoplasms, and cerebrovascular diseases, provided we maintain and strengthen existing barriers to infectious diseases as needed. In the United States, the top 10 causes of death in 2004 were diseases of the heart, cancer, stroke, chronic lower respiratory disease, unintentional accidents, diabetes, Alzheimer's, influenza and pneumonia, kidney disease, and septic bacterial infections.[12] See Table 2.3.

The prevention of deaths from a particular disease does not increase the life expectancy in direct proportion to its decreased mortality.[13] Keyfitz[14] gives an example showing that if a general cure for cancer were found, there would be nearly 350,000 fewer deaths per year (cancer deaths in 1970). It would seem, then, that the mortality would be lowered by one-sixth, since cancer deaths were

TABLE 2.1 Life Expectancy at Birth

Period of Year	Life Expectancy
Neanderthal (50,000 B.C.–35,000 B.C.)	29.4[a]
Upper Paleolithic (600,000 B.C.–15,000 B.C.)	32.4[a]
Mesolithic	31.5[a]
Neolithic Anatolia (12,000 B.C.–10,000 B.C.)	38.2[a]
Bronze Age, Austria	38[a]
Greek Classical (700 B.C.–460 B.C.)	35[a]
Roman Classical (700 B.C.–A.D. 200)	32[a]
Roman empire (27 B.C.–A.D. 395)	24
1000	32
England (1276)	48[a]
England (1376–1400)	38[a]
1690	33.5
1800	35
1850	40
1870	40
1880	45
1900	47.3[b]
1910	50.0[b]
1920	54.1[b]
1930	59.7[b]
1940	62.9[b]
1950	68.2[b]
1960	69.7[b]
1970	70.8[b]
1980	73.7[b]
1988	74.9[b]
1999	76.5[c]
2004	77.8[d]

Source: J. A. Salvato Jr., "Environmental Health," in *Encyclopedia of Environment Science and Engineering*, E. N. Ziegler and I. R. Pfafflin (Eds.), Gordon Breach Science, London, 1976, p. 286.

Note: The 1981–1982 average life expectancy for Japan was 77.0, Sweden 76.1, and Netherlands and Norway 76.0.

Life expectancy figures after 1690 are for the United States. The average life expectancy for the world) in 1984 was 61 years and for Africa in 1975 it was 45 years. The world population was reported by the United Nations as 4 billion in 1975 and projected to 6.25 billion in 2000. The U.S. Census Bureau in 1986 predicted 6.2 million.

[a]E. S. Deevy Jr., "The Human Population," *Sci. Am*., **203**, 3 (September 1960): 200.

[b]*Health United States 1989*, U.S. Department of Health and Human Services, Public Health Service, March 1990, p. 106.

[c]From ref. 12.

[d]National Center for Health Statistics, Centers for Disease Control and Prevention. *National Vital Statistics Report, Deaths: Final Data for 2004*, Vol. 55(9), August 2007.

TABLE 2.2 Increase in Life Expectancy between 1900 and 1990 at Selected Ages, U.S. Total Population

	Life Expectancy		
Age	1900[a]	2004[b]	Gain During 1900–2004
0	49.2	77.8	28.6
1	55.2	77.4	22.2
5	55.0	73.5	18.5
15	46.8	63.6	16.8
25	39.1	54.0	14.9
35	31.9	44.5	12.6
45	24.8	35.3	10.5
55	17.9	26.6	8.7
60	14.8	22.5	7.7
65	11.9	18.7	6.8
70	9.3	15.1	5.8
75	7.1	11.9	4.8
80	—	9.1	—
85	—	6.8	—

[a]Department of Commerce, U.S. Census Bureau, *United States Life Tables 1890, 1901, 1910, and 1901–1910*, by J. W. Glover, U.S. Government Printing Office, Washington, DC, 1921, pp. 52–53.
[b]National Center for Health Statistics, Centers for Disease Control and Prevention. *National Vital Statistics Report, Deaths: Final Data for 2004*, Vol. 55(9), August 2007.

one-sixth of all deaths, and the life expectancy increased by one-sixth. But this would hold true only for a population with homogeneous individual risks for cancer (ref. 13, p. 954): "Only in such a population would the reduction of the deaths and of the death rate by one-sixth extend the expectation of life by one-sixth. Only then could each of us expect to live 12 more years (assuming a life expectancy of 72 years) as a result of the discovery of a cure for cancer." But because the population is not homogeneous and the risk factors for cancer, and other diseases, vary with age [such as for a 20-year-old man (1: 10,000) compared to a 70-year-old man (1: 100)], the "universal elimination of cancer would increase life expectancy by only about 2 years—not the 12 years that would apply if the population were homogeneous" (ref. 13, p. 955). Keyfitz[14] goes on to say, "But even the gain so calculated (two years if cancer is eliminated) is almost certainly an overestimate of the benefit. For within any given age group, the people subject to any one ailment tend to have higher than average risks from other ailments" (p. 955). To extend average life expectancy beyond 70 years, Keyfitz feels it is necessary to focus on prevention of "deterioration and senescence of the cells of the human body" (p. 956).

Taeuber[15] estimates that the life expectancy of a 65-year-old man would be increased by 1.4 years if there were no cancer; 2.25 years would be added to the average life expectancy for 35-year-olds. Also, of the nearly 2 million deaths that

TABLE 2.3 Leading Causes of Death, 1990, 1960, and 2004 in the United States

Rank	Cause of Death	Deaths per 100,000 Population[a]	Percentage of All Deaths
	1900		
	All causes	1719	
1	Pneumonia and influenza	202.2	11.8
2	Tuberculosis (all forms)	194.4	11.3
3	Gastritis, etc.	142.7	8.3
4	Diseases of the heart	137.4	8.0
5	Vascular lesions affecting the central nervous system	106.9	6.2
6	Chronic nephritis	81.0	4.7
7	All accidents[b]	72.3	4.2
8	Malignant neoplasma (cancer)	64.0	3.7
9	Certain diseases of early infancy	62.5	3.6
10	Diphtheria	40.3	2.3
11	All other and ill-defined causes	615.3	36
	1960		
	All causes	955	
1	Diseases of the heart	366.4	38.7
2	Malignant neoplasms (cancer)	147.4	15.6
3	Vascular lesions affecting the central nervous system	107.3	11.3
4	All accidents[c]	51.9	5.5
5	Certain diseases of early infancy[d]	37.0	3.9
6	Pneumonia and influenza	36.0	3.5
7	General arteriosclerosis	20.3	2.1
8	Diabetes mellitus	17.1	1.8
9	Congenital malformations	12.0	1.3
10	Cirrhosis of the liver	11.2	1.2
11	All other and ill-defined causes	148.4	15
	2004		
	All causes	816.5	
1	Diseases of the heart	222.2	27.2
2	Malignant neoplasms	188.6	23.1
3	Cerebrovascular diseases	51.1	6.3
4	Chronic lower respiratory diseases	41.5	5.1
5	Accidents (unintentional injuries)	38.1	4.7
6	Diabetes mellitus	24.9	3.1
7	Influenza and pneumonia	22.5	2.8
8	Alzheimer's disease	20.3	2.5

(*continues*)

TABLE 2.3 (*continued*)

Rank	Cause of Death	Deaths per 100,000 Population[a]	Percentage of All Deaths
9	Nephritis, nephrotic syndrome, and nephrosis	14.5	1.8
10	Septicemia	11.4	1.4
11	All other and ill-defined causes		22.0

Sources: For 1960 data: *President's Science Advisory Committee Panel on Chemicals, Chemicals and Health*, U.S. Government Printing Office (GPO) Washington, DC, 1973, p. 152; DHEW, PHS, "Facts of Life and Death," DHEW Pub. No. (HRA) 74–1222, GPO, Washington, DC, 1974, p. 31. For 1900 and 2004 data: "National Center for Health Statistics, Centers for Disease Control and Prevention. *National Vital Statistics Report, Deaths: Final Data for 2004*, Vol. 55(9), August 2007. Cause of death is based on *International Classification of Diseases*, 10th rev. 1992, WHO, Geneva.

[a] Crude death rate. Cannot be compared among populations differing in relative age distribution. Does not reflect high percentage of older population dying of natural causes.

[b] Violence would add 1.4%; horse, vehicle, and railroad accidents provide 0.8%.

[c] Violence would add 1.5%; motor vehicle accidents provide 2.3%; railroad accidents provide less man 0.1%.

[d] Birth injuries, asphyxia, infections of newborn, ill-defined diseases, immaturity, etc.

occurred in 1973, 356,000 were attributed to cancer. Two-thirds of those saved lives, according to Taeuber, would have died of heart conditions or strokes.[15] It would seem, then, that a general improvement in the "quality of life" to slow down premature aging, together with prevention and control of the noninfectious as well as communicable diseases, will accomplish a greater increase in life expectancy than concentrating *solely* on elimination of the major causes of death; there will always be a list of the top then causes of death. This appears to be a sound approach since it is known that "mortality levels are determined by the complicated interplay of a variety of sociocultural, personal, biological, and medical factors" (ref. 14, p. 966). However, if the causes of a disease are also contributing factors to other diseases, then elimination of the cause of one disease may, at the same time, eliminate or reduce morbidity and mortality from other diseases, thereby resulting in an additional overall increase in life expectancy. For example, the ready availability of clean water can not only greatly reduce gastrointestinal diseases but also promote personal hygiene and cleanliness, prevent impetigo, reduce stress, and save time. Better nutrition can reduce mortality due to obesity, diabetes, and cardiovascular disease, but it would also improve resistance to certain infectious diseases, reduce birth defects, stunted physical growth, and subtle cognitive deficits, leading to a greater earning potential at the individual level and more productivity and economic security at the population level.

In developed countries, thousands of deaths due to preventable diseases occur each year. Some of these diseases are chronic in nature, and the incidence could be reduced through behavioral interventions (e.g., increased seat belt use, reduced cigarette smoking). Other preventable illnesses are due to infectious diseases such as influenza and pneumonia. There seems to be a consensus that further increase in life expectancy in developed countries is dependent primarily on the extent to which personal behavior will be changed—obesity, poor nutrition, lack of exercise, smoking, reduction of harm related to alcohol and drug consumption, stress—and environmental pollutants will be controlled—industrial and auto emissions, chemical discharges into our air and waters, use of pesticides and fertilizers, interaction of harmless substances forming hazardous compounds[16]—together with a reduction of accidental and violent deaths and an improvement in living and working conditions.

It must also be recognized that although life expectancy is a measure of health progress, it does not measure the morbidity levels and the quality of life.

FRAMEWORK FOR DISEASE TRANSMISSION

Sound factual information upon which to base programs for the prevention and control of morbidity and mortality is sometimes not adequate or available. Multiple causes of disease and delayed effects compound the uncertainties. Broadly speaking, interventions can be targeted at the individual level, the environment, and the infectious agent. Nevertheless, it is prudent to apply and update known health education measures, including screening for early disease detection and treatment, with the full knowledge of their limitations and without raising unreasonable expectations of the public. The environmental preventive measures for disease control are elaborated on here, but the importance of the other measures is not to be minimized.

The goal of environmental health programs is not only the prevention of disease, disability, and premature death but also the maintenance of an environment that is suited to humanity's efficient performance and the preservation of comfort and enjoyment of living today and in the future. The goal is the prevention of not only communicable diseases but also the noncommunicable diseases, the chronic and acute illnesses, and the hazards to life and health. This requires better identification and control of the contributing environmental factors in the air, water, and food at the home and the place of work and recreation, as well as changes in personal behavior and reduced individual assumption of risk. Lacking complete information, the best possible standards based on the available knowledge must be applied for the public good. Standards adoption and regulatory effort should be based on the risk that society or the individual is willing to assume and pay for, taking into consideration other risk factors and needs. At the same time, we must be conscious of limiting disruption to lifestyle and economic activity that could arise as unintended consequences of enacting disease control program. The more onerous a prevention program is, the less likely it is the many people will follow it.

The traditional epidemiologic triangle for infectious diseases has at its vertices three separate factors that influence disease transmission: host, environment, and

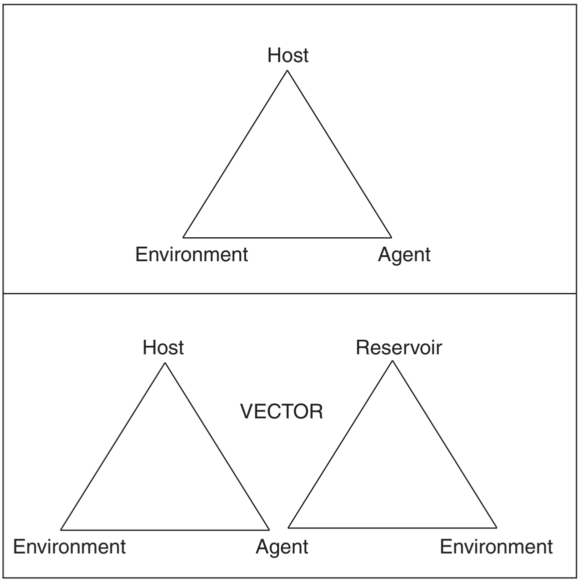

FIGURE 2.1 Epidemiologic triangle framework for infectious disease transmission. Top panel is for non–vectorborne diseases. Bottom panel shows interaction between insect and pathogen. The two "environment" vertices represent the separate milieu in which the host and reservoir reside. The vector participates in both triangles and serves as the bridge between them. Control measures should be targeted at all three/six legs for maximum effectiveness.

agent (Figure 2.1). For arthropodborne diseases, a second triangle is involved, representing the biological interactions between the vector (insect) and the environment. Host factors include genetic and behavioral susceptibility. The agent is the infectious organism. The environment is the setting in which the interaction occurs, and includes the social as well as biological environment. For most effective interruption of disease transmission, interventions must be targeted at all three legs of the triangle. More nuanced versions of this triangle or concept exist, but for our purposes, the three-point model will suffice.

Phelps called the interruption of disease at each of these three points the *principle of multiple barriers.*[17] It recognizes as axiomatic the fact that "all human efforts, no matter how well conceived or conscientiously applied, are imperfect and fallible" (ref. 16, p. 347). Sometimes it is only practical to control or break one link in the chain. Therefore, the number and type of barriers or interventions should be determined by the practicality and cost of providing the protection, the benefits to be derived, and the probable cost if the barriers are not provided. Cost is used not only in the sense of dollars but also in terms of human misery, loss of productiveness, ability to enjoy life, and loss of life. Here is a real opportunity to apply professional judgment to the problems at hand to obtain the maximum return for the effort expended.

REGULATORY AUTHORITIES IN HEALTH

Communicable and certain noninfectious diseases can usually be regulated or brought under control. In the United States, the local or municipal (often at the county level) health department is the fundamental unit of health intervention and surveillance. A health department having a complete and competent staff to prevent or control diseases that affect individuals and animals is usually established for this purpose. The preventive and control measures conducted by a municipal health department might include supervision of water supply, wastewater, and solid wastes; housing and the residential environment; milk and food production and distribution; stream pollution; recreational areas, including camps, swimming pools, and beaches; occupational health and accident prevention; insects and rodents; rural and resort sanitation; air pollution; noise; radiological hazards; hospitals, nursing homes, jails, schools, and other institutions; medical clinics, maternal and child health services, school health, dental clinics, nutrition, and medical rehabilitation; medical care; disease control, including immunizations, cancer, heart disease, tuberculosis, and venereal diseases; vital statistics; health education; epidemiology; and nursing services. In practice however, many local health departments are understaffed and not adequately funded.

The front line of emerging health concerns is often a private clinician's practice or hospital emergency department or poison centers. In the United States, health care providers and biological testing laboratories have mandatory reporting obligations for specified lists of infectious diseases. These data are to be sent to the state health department, usually within days of a presumptive diagnosis. Mandatory reporting is a prime form of disease surveillance, and has been bolstered in reaction of fears about bioterrorism. Large health care facilities, such as teaching hospitals, will have their own surveillance systems for infectious disease, and epidemiologists monitoring infections.

State health departments are involved in disease surveillance, priority setting for policy, and funding initiatives for alleviation of specific diseases. In some states, certain environmental and medical activities are combined with the activities of other agencies and vice versa, making the achievement of a comprehensive and coordinated preventive services program for environmental health more complicated. State health departments must interact closely with legislatures. Funding for disease prevention or health promotion programs can thus be tied to political considerations and public opinion.

At the federal level, the Centers for Disease Control and Prevention (CDC) has a broader mission, including but not limited to, setting national priorities, providing technical assistance, conducting multistate or rare disease outbreak investigations, and serving as an authority to policy makers and Congress. Parallel organizations fulfilling the same roles exist in all countries, with differing levels of capacity and resources. In the United States, the National Institutes of Health (NIH) fund research on diseases, the Food and Drug Administration (FDA) regulates foods, drugs, and cosmetics, the U.S. Department of Agriculture (USDA) sets standards for farming and animal husbandry, and the Environmental Protection Agency (EPA) sets standards for acceptable pollutant levels, funds research, and sets regulations for environmental exposures. Military involvement in outbreaks of infectious diseases with large-scale implications has increased over the last decade, due in part to increased fears of bioterrorism. Specialized offices for particular diseases also exist, such as for mental health and substance use and pandemic influenza. Public and private health financing agencies also have a strong interest in health promotion and may also be involved in interventions. Many infectious diseases have animal sources and veterinary regulatory agencies may also be involved in quelling an outbreak.

Also at the national level are commercial managed health care insurance organizations and public health financing authorities, such as Medicaid, Medicare and the Veterans' Administration (VA) system. These organizations exert influences on the types of diseases that are treated and what medications can be used. For example, a health plan may or may not reimburse for preventative malarial prophylaxis or particular vaccines. Insurance plans also dictate which antibiotics will be paid for, and the order in which they can be used in complicated cases. The medical records from these organizations can be a rich source of data for determining the incidence of infectious diseases that require medical attention, as well as afford details of the comorbid conditions that exist in those presenting with infectious diseases. These organizations also conduct regular review of causes of illness and can make convenient partners in disease investigations.

At the international level, the World Health Organization (WHO) is a technical organization that issues best-practice guidelines and assists member nations in disease prevention and eradication projects. The interactions between these levels of health organizations and regulators become of importance when multidimensional health interventions are proposed. Jurisdictional constraints may limit the reach a health promotion program has and will dictate which parties are involved.

EPIDEMIC CONTROL AT THE INDIVIDUAL LEVEL

Control of infections at the individual level is achieved primarily through three different measures: behavior modification, treatment with antibiotics and antivirals, and prevention through vaccination. We will describe these interventions at these three levels, followed by descriptions of environmental and infectious agent control. First, some basic terminology will be elaborated.

An infected individual goes through four basic stages: incubation period, carrier state, fulminate infection, and remission/immunity. The incubation period is the interval between exposure of a susceptible host to an agent and the establishment of the infection in the host. There are usually no clinical signs of disease in the host during this period. During this period, the person is not usually infectious to others. In the carrier state, the person or animal that harbors an infectious agent in the absence of discernible clinical disease and serves as a potential source of infection; this happens after the incubation period. The carrier state may exist in an individual with an infection that is outwardly unapparent throughout its course. The carrier state may be of short or long duration. During the third stage, fulminate infection (or convalescence), there are overt physical manifestations of disease pathology. Clinical diagnosis based on symptoms can occur at this phase.* Individuals may cycle through periods of clinically expressed disease and carrier state. This cycling can last days, weeks, months or even decades (e.g., herpes, chicken pox/shingles, tuberculosis), depending on the disease. In the fourth phase, remission (or post-convalescence), the individual will no longer express the signs of the disease, and is immune to reinfection. Immunity to reinfection is mediated by circulating antibodies, special protein-based complexes that can "remember" the identity of pathogens and serve to immediately neutralize (render harmless) an infectious organism when it reenters the body. However, in some cases, immunity can wane with age, and the individual may become susceptible to infection by the same organism again. The importance of understanding these four phases will become clear as interventions targeting all phases are discussed.

Behavioral Change

Behavioral interventions aim to control the actions of the individual. The most drastic of these measures, in a civil liberty-oriented society, is restriction of association, achieved through isolation of infected individuals showing signs of disease, quarantine of suspected carriers, and cancellation of school or mass gatherings. The basic idea is to limit the number of individuals who are exposed to the carrier or diseased persons. In order to sustain an infection in a population, a certain number of new individuals must be infected in a given time period. These numbers can be calculated and form the basis for ascertaining the length of the restriction period. Most countries have strict laws on isolation and quarantine, and these are some of the most powerful tools wielded by public health authorities. However, due to the severe interruption of lifestyle and livelihood resulting from these measures, they are rarely used. There has been a shift recently to develop protocols for more benign methods of limiting association, following a "snow day" model. In these instances, people would be encouraged (not forced) to stay home for a few days to prevent new infections.

Other forms of behavior modification for the prevention of infectious disease transmission are routinely employed. For example, in hospitals, frequent hand washing by health care professionals prevents the transmission of disease between patients.[18] Seatbelts, speed limits, driving age restrictions, and drunk driving

*For some infections, such as HIV, there may be an acute phase where mild symptoms are apparent, before progression into the carrier state. For HIV, this acute phase manifests as flulike symptoms and occurs in the week or two following infection. Not all individuals will experience this phase. After this acute phase, all outward signs of the disease subside and the person enters the carrier stage, during which he or she can be infectious (depending on the amount of circulating virus and integrity of the immune system). The acute phase infection has been used as an early surveillance system to identify those recently infected, weeks before traditional testing would have been able to detect the presence of the infection. It is hoped that early detection during the acute phase could be exploited to treat patients before the virus enters particular cell types, increasing the likelihood of clearing the infection.

prohibitions save thousands of lives each year.[19] Condom use and the availability of sterile syringes have been shown to reduce the incidence of HIV, hepatitis, and other sexually transmitted and injection-borne infections.[20] In order to reduce West Nile virus infection from mosquito bites, the use of personal insect repellent and staying indoors at dusk (when the disease carrying insects were active) is encouraged in epidemic areas.[21] Hand washing by foodservice staff also prevents transmission of foodborne diseases, as do industrial hygiene standards for food processing and inspections of facilities.[22] Protective masks are recommended for tuberculosis patients, and gain widespread public use during the outbreak of severe acute respiratory syndrome (SARS).[23]

The interventions described here involve the modification of human behaviors. In order to affect such changes, broad population-based educational campaigns are often used. Laws (such as for seatbelts) can also be enacted to require protective measures be taken for prevention or mortality and morbidity. Fear of sanction, as in the foodservice example, can also serve as a means for creating behavior change. In general, behavioral changes require a willingness on the part of the population to take protective measures to ensure the safety of themselves, but also of others. These types of interventions may take considerable public attention and concern to enact.

Antibiotics and Antivirals

Treatment of those who are showing symptoms of disease, and those who are believed to have been exposed, benefit the individual, but can also shorten the duration or severity of disease and thereby prevent infections in others.

The use of antibiotics and antivirals carry the risk of resistance developing in the infectious agent that could render the drugs useless. When these medications are used indiscriminately, bacteria and viruses that carry naturally occurring mutations that allow them to circumvent the mechanism of the drug's action will have an evolutionary advantage and are likely to become the dominant strain. Therefore, antibiotics and antivirals should be used judiciously and reserved for cases in which they are most likely to confer a medical benefit.

Every drug carries a risk of unintended side effects. In epidemic control, mass administration of antibiotics should be done carefully and limited to those who are most likely to have been exposed. It is an ethically difficult decision to give someone a medication when their level of exposure risk is unknown or low. In such cases, the antibiotic or antiviral serves little or no individual benefit, while the risks of their use to the individual remain. Therefore, mass administration of these medications should be limited to very specialized situations.

Vaccination (or Immunization)

A vaccine is a suspension of attenuated live or killed microorganisms (bacteria, viruses, or rickettsias), or purified protein or polysaccharide portions thereof, administered to induce immunity and thereby prevent infectious disease. Vaccines function by exposing the immune system to just enough of a pathogen to induce antibody formation. The important part of a vaccine is the signature proteins, which are normally expressed on the surface of bacteria or virus; these surface proteins are unique to each infectious agent and are duly recognized by immune system. Antibodies are formed that recognize these proteins, without the infection actually taking hold in the body. When the individual is subsequently exposed to the infectious agent, the antibodies neutralize the pathogen before it can enter cells and replicate. Pathogens coated with antibodies are recognized by immune system cells that destroy the virus or bacteria.

During the twentieth century, the burdens of many infectious diseases were drastically reduced due to widespread vaccination campaigns. Smallpox, the only infectious disease to have been actively eradicated by human beings, was vanquished due to diligent vaccination efforts by the World Health Organization.[24] Polio was also greatly reduced in a similar manner. Childhood vaccinations have made rare the incidence of measles, mumps, rubella, chickenpox, and other infectious diseases in all developed countries and many developing countries. Recently, a vaccine for human papilloma virus (HPV), the leading cause of cervical cancer, has been recommended for adolescent girls, with the hope of reducing mortality from this neoplasm.[25] Adult vaccines for hepatitis B, tetanus, and rabies are also routinely used. Some vaccines need to be administered repeatedly, such as tetanus, due to a decline in circulating antibodies with age. Other vaccines, such as for seasonal influenza must be administered every year since the genetic composition and signature proteins expressed on the surface of the virus changes from year to year.

Although vaccines have a storied and important place in the prevention of infectious disease, they are difficult to develop since they mimic a complex biological interaction. They have also traditionally taken decades to develop, although new advances in molecular biology are intended to reduce development time. Vaccines involve creating a less pathogenic (or “attenuated”) form of the infectious agent, often by deleting genes and structures essential for replication. While the molecular mechanisms for creating vaccine strains are well developed, when these attenuated vaccines are used in humans, they may still be capable of producing some disease. Therefore, the same ethical problems as were discussed for mass administration of antibiotics and antivirals also apply to vaccination, namely balancing the benefit to the individual with the benefit to the population. Mass vaccination after release of a bioterrorism agent has been the focus of many studies in recent years, and remains a viable option.[26]

As previously mentioned, infectious diseases need to sustain a level of incidence over time in order to remain established (endemic) in a population. Vaccines do not prevent every case of disease in a population; they reduce the number of new infections so that the infectious agent cannot establish itself and replicate continuously in the population. When an infected (and infectious) individual is placed in a population with high vaccination rates, the chances that he or she will be able to pass along the infection is low. Not every person needs to be immunized, nor does the immunization need to be effective in creating protective antibodies in every person; however, the higher the rates of immunity in the population, the lower the chances that a newly introduced infectious person will infect enough people for the pathogen to be able to become endemic. This concept is called *herd immunity*.

The United States has enjoyed high levels of vaccine coverage for most childhood vaccine preventable diseases. However, there are and will always be subpopulations who are opposed to vaccination for moral and/or religious reasons. In 2005, an outbreak of polio was reported among unvaccinated Amish residents in remote Minnesota.[27] This group had eschewed vaccination on religious grounds, and U.S. law allows for such exemptions. When one member of the group traveled abroad (it is hypothesized), he was infected with polio (and became a carrier) and brought the disease back to the other susceptible members of his community. Since few people had been vaccinated, the virus was able to pass from human to human. Sanitary measures and emergency vaccination were used to control the outbreak, but not before considerable suffering in the small community.

In summary, vaccines play an integral role in protecting the public health. The use of vaccines is problematic due to ethical, biological, and social reasons. However, in the instances that they are available, they can be a crucial tool in breaking the cycle of transmission.

Control of Infectious Agents and Vectors

Arthropods involved in the transmission of human (and animal) disease are called *vectors*. Common vectorborne (or arthropodborne) include malaria, yellow fever, plague, dengue, West Nile virus, Japanese encephalitis, Lyme disease, Chagas disease, sleeping sickness, and leishmaniasis. These diseases combined are the most common infectious diseases in the world. The infectious agent is actually a bacteria or virus, and the insect serves as a vehicle for transmitting the agent to the human host. They are transmitted through bites (and other forms of inoculation) from mosquitoes, ticks, sand fleas, and other insects. The bacteria or virus have a complex biological relationship with the insect, as well as the host. In some cases, the bacterium will cause pathology in the insect. Arthropods serve as a site of maturation for the parasite, and passage through the insect is a crucial step in the natural life cycle of the infectious agent. Referring back to Figure 2.1, controlling arthropod populations can break the cycle of transmission between human and insect. Broadly speaking, this can be achieved through interruption of the parasite life cycle within the insect, or by limiting the reproduction of the insect itself. Vector control is an aspect of environmental engineering that has tremendous impact on infectious disease transmission. The most work has been done in controlling mosquito populations, and some of these interventions will be discussed in this chapter.

The *reservoir* is source of infection, often a nonhuman animal. Reservoirs are not adversely affected by the presence of the infectious agent, and interaction between humans and the reservoir introduce the pathogen into human populations. Wild animals and farm animals can be reservoirs for human disease.

To eliminate or reduce the incidence of insectbome diseases, it is necessary to control the environment and reservoirs and the vectors. This would include control of water and food, carriers of disease agents, and the protection of persons and domestic animals from the disease (immunization). Where possible and practical, the reservoirs and vectors of disease should be destroyed and the environment made unfavorable for their propagation. Theoretically, the destruction of one link in the chain of infection should be sufficient Actually, efforts should be exerted simultaneously toward elimination and control of all the links, since complete elimination of one link is rarely possible and protection against many diseases is difficult, if not impossible, even under ideal conditions. The amount of personnel, funds, and equipment available will frequently determine the action taken to secure the maximum results or return on the investment made.

In developing countries, insecticide-treated bed nets have been distributed and shown to effectively reduce malaria transmission. Including screens on windows in the design of buildings is a relatively simple means of preventing mosquito bites and disease transmission. In addition to such structural changes, preventative anti-malarial medications are sometimes given to individual travelers venturing from areas of no or low malarial endemnicity to areas of higher risk. However, this intervention is not an option in parts of the world where malaria is endemic, due to rapidly developing resistance to the drugs. In certain regions, a sleeping adult may be bitten hundreds of times a night by mosquitoes; if even a small proportion of the insects carry the malarial parasite, the risk of transmission is high. Therefore, reducing mosquito populations can result in a decrease in malarial transmission, as well as better quality of life.

Environmental Control of Infectious Diseases

Environmental interventions for preventing the spread of infectious diseases have long been a central component of public health, with a storied history starting long before the development of medications and vaccines. Malaria eradication in North America was achieved largely through environmental interventions, such as draining swamps and spraying insecticides. Large-scale engineering projects also require public health support. The Panama Canal could not have been built without research conducted by the military on protecting workers from yellow fever.[28]

Traditionally, clean drinking water (often referred to as *potable* water, water that is clean enough, in terms of microorganisms and chemicals, that it could be used for drinking), has been the primary concern of environmental and sanitary engineering, in the realm of infectious disease transmission. Related to this is proper treatment of sewage and other hazardous wastes. Water quality is covered in great detail in Chapter 4. However, there are other areas of environmental engineering that can play a crucial role in preventing the spread of infectious diseases.

The International Rice Research Institute (IRRI), based in the Philippines, has conducted extensive research into implementable environmentally oriented practices for reducing malaria transmission in developing countries. Since mosquitoes need still, nutrient-rich water to breed, rice paddies are a prime habitat for the insect; and, rice is a staple food in many mosquito endemic regions of the world. IRRI has proposed village layout plans that optimally increase the distance to mosquito-breeding grounds by relocating rice paddies to certain distances from homes. They have also developed strains of rise that are resistant to pestilence, resulting in less use of economic chemical poisons. Other projects include reducing methane and nitrous oxide emissions from burning of rice fields at the end of the harvest season,[29] strategies for managing water scarcity in rice producing areas,[30] and plans for increasing biodiversity in agricultural settings.[31]

Commercial air circulation systems have been implicated in the spread of infectious diseases. Legionnaires' disease is caused by the bacterium *Legionella*. It was discovered when attendees at a military veterans' conference staying in the same hotel came down with pneumonia. It was later found that the infectious agent was spread via exhaled droplets that traveled through the ventilation system.[32,33] Air filtration systems that are capable of sequestering airborne infectious organisms are routinely used in developed nations, but more can be done in developing countries to expand this prevention measure.

The spread of infectious diseases within a health care setting is called *nosocomial transmission*. Transmission of infectious diseases in clinical care settings is of grave concern because many hospitalized patients have compromised immune systems, due to medications they are receiving, advanced age, or immune system disorders. A large portion of nosocomial infections can be alleviated with frequent hand washing by health care providers and proper barrier protection. However, some factors influencing nosocomial spread can be alleviated through informed design of hospitals, including air and water filtration systems and proper waste disposal. For example, the shape of sinks in hospitals has been linked to transmission of *Pseudomonas aeruginosa*, a severe respiratory infection, often resistant to drugs, that preferentially infects hospitalized patients. One study found that faucets and taps were contaminated by the bacterium when water poured out from drinking glasses splashed upward.[34] In Europe, there were reports of transmission of smallpox from hospital workers breathing in aerosolized virus particles from dirty laundry.[35] In these cases, simple engineering and process control measures were enacted to end the outbreaks, alongside vaccination (when available and appropriate).

The Centers for Disease Control and Prevention have issued four guidelines for environmental infection control in health care facilities:[36]

1. Appropriate use of cleaners and disinfectants;
2. Appropriate maintenance of medical equipment (e.g., automated endoscope reprocessors or hydrotherapy equipment);
3. Adherence to water-quality standards for hemodialysis, and to ventilation standards for specialized care environments (e.g., airborne infection isolation rooms, protective environments, or operating rooms); and
4. Prompt management of water intrusion into the facility.

Routine environmental sampling is not usually advised, except for water quality determinations in hemodialysis settings and other situations where sampling is directed by epidemiologic principles, and results can be applied directly to infection-control decisions.

In summary, environmental measures for prevention of infectious diseases are a well-acknowledged component of public health. Since air and water are common vehicles for transmission of viruses and bacteria, the scope for increased participation of the environmental engineering community is vast.

Arthropodborne Diseases

Arthropod or insectborne diseases are an important class of diseases that affect millions of people worldwide. They have a long history of causing human suffering. The bubonic plague that devastated Europe in the late medieval period was transmitted via bites from a flea. Today, malaria is an archetype mosquitoborne disease for research.

The addition of an arthropod species to the transmission cycle results in a more dynamic and complex ecological to understand, but one which offers additional avenues for intervention. Again, multilevel responses have been shown to be most effective against vectorborne diseases, just as they have been for other infectious agents.

A *host* is a person or other living animal, including birds and arthropods, that provides subsistence or lodgment to an infectious agent under natural (as opposed to experimental) conditions. Some protozoa and helminths pass successive stages in alternate hosts of different species. Hosts in which the parasite attains maturity or passes its sexual stage are *primary* or *definitive hosts*; those in which the parasite is in a larval or asexual state are *secondary* or *intermediate hosts*. A *transport host* is a carrier in which the organism remains alive but does not undergo development.[1]

The infectious agent can be a virus, bacteria, or multicellular organism. We refer to the arthropod that delivers the infectious agent to humans as the *vector*. Vectors can involve simple mechanical carriage of the infectious agent by a crawling or flying insect through soiling of its feet or proboscis, or by passage of organisms or eggs through its gastrointestinal tract. This does not require multiplication or development of the infectious agent within the arthropod. The other type of vector-agent interaction involves a more complex biological process; the pathogen will undergo transitions in its life cycle while inside the insect. The transition is required before the arthropod can transmit the infective form of the agent to humans. The *extrinsic incubation period* is the time a pathogen requires to develop or multiply in the vector before it can be transmitted to another host. The infectious agent may be passed vertically to succeeding generations of arthropod (transovarian transmission); transstadial transmission indicates its passage from one stage of life cycle to another, as nymph to adult. Transmission may be by injection of salivary gland fluid during biting or by regurgitation, or deposition on the skin of feces or other material capable of penetrating through the bite wound or through an area of trauma from scratching or rubbing.[1]

Usually, mosquitoes, lice, ticks, and other blood-sucking insects spread disease from person to person, or animal to human by biting a person or animal carrying the disease-causing organisms. By taking blood containing the disease-producing organisms, the insect is in a position to transmit the disease organism when biting another person or animal. The complete elimination of rodents and arthropods associated with disease is a practical impossibility. Humans, arthropods, and rodents, therefore, offer ready foci for the spread of infection unless controlled.

Lately, insectborne diseases that had been confined to Africa or South America are showing up in the United States. A good example of this is West Nile Virus. This virus, a flavivirus, causes encephalitis in susceptible individuals. It was formerly found in Africa, Southeast Asia, and the Middle East, but how now been detected in the United States. It is spread by *Culex* mosquitoes, and usually is not spread from person to person. However, there are documented cases of people obtaining the virus from an organ donor.[37] The donor was apparently healthy before a fatal accident and the donor's organs were transplanted into four individuals who became ill with a febrile illness progressing to encephalitis 7 to 17 days posttransplantation. Their cerebral spinal fluid was tested and found positive for West Nile Virus. The donor's serum was also tested by a PCR test and found positive for West Nile Virus.[38] This indicates that transmission routes can change, and unusual transmissions should be considered when investigating the cause of insectborne diseases.

A list of insectborne diseases together with their important reservoirs is given in Table 2.4, Table 2.5, and Table 2.6. The list is not complete but includes some of the common as well as less-known diseases.

Since many diseases are known by more than one name, other nomenclature is given to avoid confusion. As time goes on and more information is assembled, there will undoubtedly be greater standardization of terminology. In some cases there is a distinction implied in the different names that are given to very similar diseases. The names by which the same or similar diseases are referred to are presented below.

Bartonellosis includes oroya fever, Carrion's disease, and verruga peruana. Dengue is also called dandy fever, breakbone fever, bouquet, solar, or sellar fever. Endemic typhus, fleaborne typhus, and murine typhus are synonymous. Epidemic typhus is louseborne typhus, also known as classical, European, and Old-World typhus. Brill's disease is probably epidemic typhus. Plague, black death, bubonic plague, and fleaborne pneumonic plague are the same. Filariasis or mumu are infestations of *Wuchereria bancrofti* that may cause obstruction of lymph channels and cause elephantiasis. Loa loa and loiasis are the same filarial infection. Cutaneous leishmaniasis, espundia, uta, bubas and forest yaws, Aleppo/Baghdad/Delhi boil, chiclero ulcer, and oriental sore are synonyms. Visceral leishmaniasis is also known as kala azar. Malaria, marsh miasma, remittent fever, intermittent fever, ague, and jungle fever are synonymous. Blackwater fever is believed to be associated with malaria. Onchocerciasis is also known as blinding filarial disease. Sandfly fever is the same as phlebotomus fever, three-day

TABLE 2.4 Characteristics of Some Insectborne Disease

Disease	Etiologic Agent	Reservoir	Transmission	Incubation Period	Control[a]
Endemic typhus (murine) (fleaborne)[b]	*Rickettsia typhi* (*R. mouserl*) also possibly *Ctenocephalides felis*	Infected rodents, *Rattus rattus* and *Rattus norvegicus*, also fleas, possibly opossums	Bite or feces of rat flea *Xenopsylla cheopis*; also possibly ingestion or inhalation of dust contaminated with flea feces or urine.	7–14 days, usually 12 days	First elimination of rat flea by insecticide applied to rat runs, burrows, and harborages, then rat control. Spray kennels, beds, floor cracks.
Epidemic typhus (louseborne)	*Rickettsia prowazeki*	Infected persons and infected lice	Crushing infected body lice *Pediculus humanus* or feces into bite, abrasions, or eyes. Possibly louse feces in dust.	7–14 days, usually 12 days	Insecticidal treatment of clothing and bedding; personal hygiene, bathing, elimination of overcrowding, Immunization. Delousing of individuals in outbreaks.
Bubonic plague	*Pasteurella pestis*, plague bacillus (*Yersinia pestis*)	Wild rodents and infected fleas	Bite of infective flea *X, cheopis*, scratching feces into skin, handling wild animals, occasionally bedbud and human flea; pneumonic plague spread person to person.	2–6 days	Immunization, Surveys in endemic areas. Chemical destruction of flea. Community hygiene and sanitation; rat control. (Plague in wild rodents called sylvatic plague.)

Q fever	*Coxiella burneti* (*Rickettsia burneti*)	Infected wild animals (bandicoots); cattle, sheep, goats, ticks, carcasses of infected animals	Airborne rickettsias in or near premises contaminated by placental tissues; raw milk from infected cows, direct contact with infected animals or meats	2–3 weeks	Immunization of persons in close contact with rickettsias or possibly infected animals. Pasteurization of all milk at 145°F for 30 min or 161°F for 15 sec.
Rocky Mountain spotted fever	*Rickettsia rickettsii*	Infected ticks, dog ticks, wood ticks, Lone Star ticks	Bite of infected tick or crushed tick blood or feces in scratch or wound.	3–10 days	Avoid tick-infested areas and crushing tick in removal; clear harborages; insecticides.
Colorado tick	Colorado tick fever virus	Infected ticks and small animals	Bite of infected tick, *Dermacentor andersoni*	4–5 days	See Rocky Mountain spotted fever.
Tularemia	*Franciscella tularensis* (*Posteurella tularensis*)	Wild animals, rabbits, muskrats; also wood ticks	Bite of infected flies or ticks, handling infected animals. Ingestion of contaminated water or insufficiently cooked rabbit meat.	1–10 days, usually 3 days	Avoid bites of ticks, flies. Use rubber gloves in dressing wild animals; avoid contaminated water; thoroughly cook rabbit meat.

(*continues*)

TABLE 2.4 (*continued*)

Disease	Etiologic Agent	Reservoir	Transmission	Incubation Period	Control[a]
Rickettsial-pox	*Rickettsia akari*	Infected house mice; possibly mites	Bite of infective rodent mites	10–24 days	Mouse and mite control. Apply miticides to infested areas; incinerators.
Scabies	*Sarcoptes scabiei*, a mite	Persons harboring itch mite; also found in dogs, horses, swine (called mange); not reproduced in skin of humans	Contact with persons harboring mite and use of infested garments or bedding; also during sexual contact	Several days or weeks	Personal hygiene, bathing, chemical treatment, clean laundry; machine laundering. Exclude children from school until treated. Prevent crowded living.
Trypanosomiasis, American	*Trypanosoma cruzi*	Infected persons, dogs, cats, wood rats, opossums	Fecal material of infected insect vectors, conenosed bugs in eye, nose, wounds in skin	5–14 days	Screen and rat proof dwellings; destroy vectors by insecticides and on infested domestic animals.
Scrub typhus	*Rickettsia tsutsugamushi*	Infected larval mites, wild rodents	Bite of infected larval mites	10–12 days	Eliminate rodents and mites; use repellents; clear brush.
Trypanosomiasis, African (sleeping sickness)[c]	*Trypanosoma gambiense*	Humans, wild game, and cattle	Bite of infected tsetse fly	2–3 weeks	Fly control; treatment of population; clear brush; education in prevention.

Lyme disease	*Borrella burgdorferi*	White-footed field mice in eastern United States and lizards and jack-rabbits in the West; ixodid tick feeds on and survives on white-tailed deer	Bite of infected deer tick nymph and adult	3–32 days, average 7 days	Identify and post infested areas and educate public to avoid ticks. Use repellent—deet or pemethrin. Inspect for presence of ticks, also cats and dogs, and remove without crushing. Early treatment if bitten.

Source: Various sources and ref. 3.

[a]Investigation and survey usually precede preventive and control measures.

[b]"The association of seropositive opossums with human cases of murine (endemic) typhus in southern California and the heavy infestation of the animals with *Ctenocephalides felis* which readily bite man, suggest that opossums and their ectoparasites are responsible for some of the sporadic cases of typhus in man." W. H. Adams, R. W. Emmons, and J. E. Brooks, "The Changing Ecology of Murine (Endemic) Typhus in Southern California," *Am. J. Trop. Med. Hyg*. (March 1970): 311–318.

[c]African trypansomiasis, or Chagas disease, affects 16–18 million people with 90 million at risk according to the WHO, *Nation's Health* (July 1990): 9.

TABLE 2.5 Mosquitoborne Diseases

Disease	Etiologic Agent	Reservoir	Transmission	Incubation Period	Control
Dengus or Breakbone fever[a]	Viruses of dengue fever	Infected vector mosquitoes, humans, and possibly animals, including the monkey	Bite of infected *Aedes aegypti, A. albopictus, A, scutellaris* complex	3–15 days, commonly 5–6 days.	Eliminate *Aedes* vectors and breeding places; screen rooms; use mosquito repellents.
Encephalitis, anthropodborne viral	Virus of Eastern equine, Western, St. Louis, Venezuelan equine, Japanese B, Murray Valley, West Nile, and others	Possibly wild and domestic birds and infected mosquitoes, ring-necked pheasants, rodents, bats, reptiles	Bite of infected mosquito, probably *Culiseta melanura* and *Aedes* for Eastern; *Culex tarsalis* for Western; *Culex tritaeniorhynchus* for Japanese; *Culex pipiens-quinquefasciatus* for St. Louis, also *Culex nigripalpus*	Usually 5–15 days	Destruction of larvae and breeding places of *Culex* vectors. Space spraying, screening of rooms; use mosquito bed-nets where disease present. Avoid exposure during biting hours or use repellents. Public education on control of disease. Vaccination of equines.
Filariasis[a] (elephantiasis after prolonged exposure)	Nematode worms, *Wuchereria bancrofti* and *W. malayi*	Blood of infected person bearing microfiliariae, mosquito vector	Bite of infected mosquito; *Culex fatigans, C. pipiens; Aedes polynesiensis* and several species of anopheles	3 months; microfilariae do not appear in blood until at least 9 months	Antimosquito measures. Determine insect vectors, locate breeding places, and eliminate. Spray buildings. Educate public in spread and control of disease.

Malaria[a]	*Plasmodium vivax, P. malariae, P. falciparum, P. ovale*	Humans and infected mosquitoes, found between 45° N and 45° S latitude and where average summer temperature is above 70°F or the average winter temperature is above 48°F or the average winter temperature is above 48°F	Bite of certain species of infected anopheles and injection or transfusion of blood of infected person	Average of 12 days for falciparum, 14 for vivax, 30 for malariae; sometimes delayed for 8–10 months	Resudual insecticide on inside walls and places where anopheles rests. Community spraying. Screen rooms and use bed-nets in edemic areas. Apply repellents to skin and clothing. Eliminate breeding places by drainage and filling; use larvicides; oil and Paris green. Suppressive drugs, treatment, health education. *Gambusia affinis* fish for larvae control.
Rift Valley fever[b]	Virus of Rift Valley fever	Sheep, cattle, goats, monkeys, rodents	Probably through bite of infected mosquito or other blood-sucking arthropod; laboratory infections and butchering	Usually 5–6 days	Precautions in handling infected animals. Protection against mosquitoes in endemic areas. Care in laboratory.

(*continues*)

TABLE 2.5 (*continued*)

Disease	Etiologic Agent	Reservoir	Transmission	Incubation Period	Control
Yellow fever[a]	Virus of yellow fever	Infected mosquitoes, persons, monkeys, marmosets, and probably marsupials	Bite of infected *A. aegypti*. In South Africa, forest mosquitoes, *Haemagogus spegazzinii*, and others; in East Africa, *Aedes simpsoni, A. africanus*, and others; in forests of South America, by bite of several species of *Naemagogus* and *Aedes leucoceldenus; Aedes albopictus* in Asia, Pacific, also southern United States and Brazil[b]	3–6 days	Control of *Aedes* breeding places in endemic areas. Intensive vaccination in South and East Africa. Immunization of all persons exposed because of residence or occupation. In epidemic area spray interior of all homes, apply larvicide to water containers; mass vaccination, evaluation surveys.

Source: Various sources and ref. 3.

[a]Normally not found in United States, The WHO estimates that 90 million people have lymphatic filariasis, with 900 million at risk: *The Nation's Health*, (July 1990): 8–9.

[b]*PAHO Bulletin*, **21**, 3 (1987): 314.

TABLE 2.6 Some Exotic Insectborne Diseases (Not Normally Found in the United States)

Disease	Incubation Period	Reservoir	Vector
Bartonellosis	16–22 days	Man	Sandflies (*Phlebotomus*)
Leishmaniasis			
cutaneous	Days to months	Animals, dogs	Sandflies (*Phlebotomus*)
Visceral	2–4 months	Man, dogs, cats, wild rodents	Sandflies (*Phlebotomus*)
Loiasis (*Loa loa*)	Years	Man	Chrysops, blood-sucking flies
Sandfly fever	3–4 days	Man, sandfly	Sandfly (*Phlebotomus*)
Relapsing fever	5–15 days	Man, ticks, rodents	Lice, crushed in wound; ticks
Trench fever	7–30 days	Man	Lice, crushed in wound (*Pediculus humanus*)

Source: Ref. 3.

fever, and pappataci fever. Q fever is also known as nine-mile fever. Febris recurrens, spirochaetosis, spirillum fever, famine fever, and tick fever are terms used to designate relapsing fever. Rocky Mountain spotted fever, tick fever of the Rocky Mountains, tick typhus, black fever, and blue disease are the same. Tsutsugamushi disease, Japanese river fever, scrub typhus, and miteborne typhus are used synonymously. Trench fever is also known as five-day fever, Meuse fever, Wolhynian fever, and skin fever. Plaguelike diseases of rodents, deer-fly fever, and rabbit fever are some of the other terms used when referring to tularemia. Other forms of arthropodborne infectious encephalitis in the United States are the St. Louis type, the Eastern equine type, and the Western equine type; still other types are known. Nasal myiasis, aural myiasis, ocular myiasis or myiases, cutaneous myiases, and intestinal myiases are different forms of the same disease. Sleeping sickness, South American sleeping sickness, African sleeping sickness, Chagas' disease, and trypanosomiasis are similar diseases caused by different species of trypanosomes. Tick-bite fever is also known as Boutonneuse fever, Tobia fever, and Marseilles fever; Kenya typhus and South African tick fever are related. Scabies, "the itch," and the "seven-year itch" are the same disease.

Two vectorborne disease involving different types of vectors are detailed below to give the reader a sense of the different issues that arise in vector management: malaria and plague.

Malaria Nearly 40 percent of the world's population lives in regions at risk for malaria. The World Health Organization estimates that each year 500 million people become severely ill as a result of malaria.[39] The burden of disease falls disproportionately on some of the poorest countries, with most deaths due to malaria occurring in sub-Saharan Africa.

Malaria is a caused by parasites of the species *Plasmodium* that are spread from person to person through the bites of infected mosquitoes. The common first symptoms—fever, headache, chills, and vomiting—appear 10 to 15 days after a person is infected. If not treated promptly with effective medicines, malaria can cause severe illness that is often fatal. There are four types of human malaria—*Plasmodium falciparum*, *P. vivax*, *P. malariae*, and *P. ovale*. *P. falciparum* and *P. vivax* are the most common. *P. falciparum* is by far the most deadly type of malaria infection.[39]

Environmental factors directly influence malaria transmission. These include rainfall patterns, proximity of mosquito breeding sites to human settlements, the distribution and biting patterns of mosquito species, and mass application of commercial poisons. Changes in weather and climate, as well as natural disasters, can lead to epidemics of malaria, even in areas where few human cases have been reported. In the United States, most cases are a result of returning travelers from malaria-endemic areas. Cases of malaria transmitted through blood transfusions have also been reported in the United States.[40,41]

The WHO defines the main objective of malaria vector control as: "to significantly reduce both the number and rate of parasite infection and clinical malaria by controlling the malaria-bearing mosquito and thereby reducing and/or interrupting transmission".[39] The two main recommended strategies for limiting mosquito bites are indoor residual spraying of long-acting insecticide (IRS) and long-lasting insecticidal nets (LLINs). Larval control and environmental control of mosquito breeding locations is achieved through a process called Integrated Vector Management (IVM).

Plague Plague is a rare but frequently fatally zoonosis caused by the gram-negative bacterium *Yersinia pestis*. Humans are infected by the bites of infected rodent fleas, by handling infected animals, or rarely, by human-to-human transmission of pneumonic plague. Plague was first described in the United States in 1900 and is thought to have been introduced into San Francisco from plague-endemic regions of Asia.[42] Plague is now endemic in the western United States, where a median of seven human cases occur annually.[43] Plague is enzootic in wild rodent populations in rural areas of the Americas, Africa, and Asia, with occasional outbreaks among rats or other rodent hosts in villages and small towns. Wild rodent plague poses a real, although limited, risk to humans. When infection spreads to rats in urban or populated areas, persons are at markedly increased risk of exposure. In recent decades, urban outbreaks have been rare and limited in size.[44]

There are three principal clinical forms of plague: bubonic, septicemic, and pneumonic.[45] All three forms may be accompanied by fever and systemic manifestations of gram-negative sepsis and cause high mortality unless promptly diagnosed and treated. Patients with bubonic plague have a characteristic bubo (i.e. one or more enlarged, tender, regional lymph nodes, often auxiliary or inguinal). Septicemic plague may be primary when the bacteria invade and multiply in the bloodstream in the absence of an apparent bubo, or may occur secondarily to bubonic plague. Patients with pneumonic plague can have dyspnea, chest pain, and a cough that can produce bloody sputum.[46]

Plague is treatable in its early stages with appropriate antibiotics. Appropriate antibiotic treatment should be initiated immediately if plague is suspected. Drugs effective against plague include streptomycin, gentamicin, and the tetracyclines.[47] Fluroquinolone antibiotics are commonly used empirically to treat critically ill patients and have demonstrated activity against *Y. pestis in vitro, in vivo*, and in limited clinical use.[48] Penicillins and cephalosporins are not effective for plague treatment.

In the United States, most plague exposures occur in or around the home.[45,49] Plague can be prevented by year-rodent control, including rodent-proofing structures, elimination of food sources such as pet food and garage, and removal sources of rodent harborage. Additionally, persons residing in endemic areas should keep their dogs and cats free of fleas through regular use of flea treatments, and restrict pets from wandering. Persons who participate in outdoor recreational activities in areas of plague epizootic activity should use personal protective measures including use of insect repellents and protective clothing, and avoiding sick or dead animals. Public health officials should treat rodent habitats with effective insecticides and should conduct public education about plague prevention and control.[49]

Zoonoses and Their Spread

Zoonoses are infections that are transmitted from animals to humans. Many vectorborne disease are also capable of infecting other animals, with differing levels of severity. Zoonoses have garnered attention because it is recognized that many newly discovered or "emerging" infections in humans originated from animal sources. In addition, many infectious disease that were believed to be controlled or vanquished are making a resurgence as human interaction with wild animals has increased as a result of clearing and development previously uninhabited land. In this way, infectious diseases are directly linked to the environment and industrial development. Sensible environmental protection includes prevention of zoonoses.

The Pan-American Health Organization lists as the major zoonoses in the Americas encephalitis (arthropodborne), psittacosis, rabies, jungle yellow fever, Q fever, spotted fever (Rocky Mountain, Brazilian, Colombian), typhus fever, leishmaniasis, trypanosomiasis (Chagas' disease), anthrax, brucellosis, leptospirosis, plague, salmonellosis, tuberculosis (bovine), tularemia, hydatidosis, taeniasis (cysticercosis), and trichinosis. Others are ringworm, crytococcosis, toxoplasmosis, yersiniosis, cat scratch fever, tetanus, and tapeworm, hookworm, and roundworm infections;[50] as well as histoplasmosis, equine encephalitis, cryptosporidiosis, campylobacter infection, and Lyme disease. It will be recognized that some of these diseases are also classified with water-, food-, or insectborne diseases. A very comprehensive summary of zoonoses was prepared by Steele[50] and the Pan American Health Organization.[51]

The rodentborne diseases include rat-bite fever, Haverhill fever, leptospirosis, choriomeningitis, salmonellosis, tularemia, possibly amebiasis or amebic dysentery, rabies, trichinosis (indirectly), and tapeworm. Epidemic typhus, endemic or murine typhus, Rocky Mountain spotted fever, tsutsugamushi disease, hantavirus,[52] and others are sometimes included in this group. Although rodents are reservoirs of these diseases (typhus, spotted fever, etc.), the diseases themselves are actually spread by the bite of an infected flea, tick, or mite or the blood or feces of an infected flea or tick on broken skin, as previously discussed. Rats are also carriers of *S. aureus, E. coli, Y. enterocolitica*, and *Yersinia pseudotuberculosis*, as well as leptospirae and other pathogens.

Sodoku and Haverhill fevers are two types of rat-bite fever. The incubation period for both is 3 to 10 days. Contaminated milk has also been involved as the cause of Haverhill fever. The importance of controlling and destroying rats, particularly around dwellings and barns, is again emphasized.

The causative organism of leptospirosis, also known as Weil's disease, spirochetosis icterohemorrhagic, leptospiral jaundice, spirochaetal jaundice, hemorrhagic jaundice, canicola fever, mud fever, and swineherd's disease, is transmitted by the urine of infected rodents, cattle, dogs, swine, and wild animals. Direct contact or the consumption of contaminated food or water or direct contact with waters containing the leptospira may cause the infection after 4 to 19 days.

Dogs are carriers of many microorganisms and parasites that are discharged in the feces and urine and that may be transmitted to humans, particularly children. These include *G. lamblia* and *T. canis*, an ascarid roundworm (the larval stage in humans is called visceral larva migrans, a rare but serious disease if the larval stage lodges in the brain, eyes, heart, or liver). *Toxocara cati* and *Ancylostoma brazillense* are found in cats. *Ancylostoma caninum* is a canine hookworm that may affect humans. *Dipylidium caninum* and *Taenia pisiformis* are two common canine tapeworms; *Toxoplasma gondii*, a protozoa causing toxoplasmosis is also carried by cats, goats, pigs, rats, pigeons, and humans. Salmonella and campylobacter bacteria can also be transmitted to humans and from humans to dogs. Dogs are the reservoir of many other diseases. Stray and pet dogs are carriers of *Brucella canis*; stray dogs have a higher rate of infection (9 percent as compared to 1 percent for pet dogs).[53] A significant number of dogs and cats excrete the toxocara ova, and the hazard to human health is reported to be considerable.[54] General control measures include proper disposal of dog feces; avoidance of contact with the feces, such as in children's play areas; deworming of dogs; regulation of dogs in urban areas; and personal hygiene. In addition, there are the hazards associated with fleas, ticks, and rabies as well as play areas and street pollution from feces and urine. Pregnant women should exercise extreme sanitary precautions and avoid any contact.

The virus causing lymphocytic choriomeningitis (LCM) is found in the mouth and nasal secretions, urine, and feces of infected house mice, which, in turn, can infect guinea pigs and hamsters. The virus is probably spread by contact, bedding, or consumption of food contaminated by the discharges of an infected mouse. The disease occurs after an incubation period of 8 to 21 days. Precautions include destruction of infected mice, hamsters, and guinea pigs and burning their bodies and bedding. This is followed by cleansing all cages with water and detergent, disinfecting, rodent-proofing pet stores and animal rooms in laboratories and hospitals, and waiting a week before restocking with LCM-free animals

Tularemia may be transmitted by handling infected rodents with bruised or cut hands, particularly rabbits and muskrats, by the bite of infected deerflies, ticks, and other animals, and by drinking contaminated water. Freezing may not destroy the organism.

Anthrax, also known as woolsorter's disease, malignant pustule, and charbon, is an infectious disease principally of cattle, swine, sheep, and horses that is transmissible to humans (Table 2.7). Many other animals may be infected. In 2001, purified anthrax spores were implicated in an intentional release/bioterrorism event that resulted in deaths in five states, with documented transmission through postal mail sorting facilities[55,56].

Rabies is a disease of many domestic and wild animals and biting mammals, including bats. In 2001, 7,437 laboratory-confirmed cases were reported to the CDC in the United States and its territories. raccoons (37.2%; 2,767 cases), skunks (30.7%; 2,282), bats (17.2%; 1,281), foxes (5.9%; 437), cats (3.6%; 270), dogs (1.2%; 89), and cattle (1.1%; 82).[57] One human case was reported to CDC in 2001, and five in the previous year. Rabies virus is the only known infection to cause 100 percent mortality in humans.

Every sick-looking dog or other animal that becomes unusually friendly or ill-tempered and quarrelsome should be looked on with suspicion. One should not place one's hand in the mouth of a dog, cat, or cow that appears to be choking. A rabid animal may be furious or it may be listless; it may salivate heavily or have spasms, paralysis, and a hung jaw, depending on the form of the disease. A person bitten or scratched by a rabid animal, or an animal suspected of being rabid, should immediately wash and flush the wound and surrounding area thoroughly with soap and warm water, a mild detergent and water, or plain water if soap or detergent is not available and seek immediate medical attention. The physician will notify the health officer or health department of the existence of the suspected rabid animal and take the required action.

Airborne spread of the virus has been demonstrated in the laboratory and in the air of heavily bat-infested caves.

The animal (usually a pet) should be caged or tied up with a strong chain and isolated for 10 days; if any of the above symptoms appear, a veterinarian should evaluate the animal. An animal suspected of being rabid that has not been vaccinated will have to be confined for four months or be killed. A dog or cat bitten by or exposed to a rabid animal should be confined for 6 months and vaccinated 1 month before release or be destroyed. Consult the local health department. Any domestic animal that is bitten or scratched by a bat or a wild, carnivorous mammal that is not available for testing should be regarded as having been exposed to a rabid animal. A wild animal, if suspected, should be killed without unnecessary damage to the head. Gloves should be worn when handling the carcass of a suspected rabid animal, since rabies virus can be introduced

TABLE 2.7 Some Characteristics of Miscellaneous Disease

Disease	Etiologic Agent	Reservoir	Transmission	Incubation Period	Control
Ringworm of scalp (tinea capitis)	*Microsporum* and *Trichophyton*	Infected dogs, cats, cattle	Contact with contaminated barber clippers, toilet articles or clothing, dogs, cats, cattle, backs of seats in theaters, planes, and railroads	10–14 days	Survey of children with wood lamp; education about contact with dogs, cats, infected children; reporting to school and health authorities; treatment of infected children, pets, and farm animals; investigation of source.
Ringworm of body (tinea corporis)	*Epidermophyton floccosum, Microsporum, trichophyton*	Skin lesions of infected humans or animal	Direct contact with infected person or contaminated floors, shower stalls, benches, towels, etc.; lesions of infected persons or animals	4–14 days	Hot water laundering of towels; fungicidal treatment of floors, benches, mats, shower stalls with creosol or equal. exclusion of infected persons from pools and gyms. Treatment of infected persons, pets, and animals. Cleanliness, sunlight, dryness.
Ringworm of foot (tinea pedis) (athlete's foot)	*Trichophyton rubrum, T. mentagrophytes*	Skin lesions of infected humans	Contact with skin lesions of infected persons, contaminated floors, shower stalls, benches, mats, towels	Unknown	In addition to above, drying feet and between toes with individual paper towels; use of individual shower

					sandals, foot powder, and clean sterilized socks. Well-drained floors in bathhouses, pools, etc.
Ringworm of nails (tinea unguium)	Epidermophyton and *Trichophyton*	Skin or nails of infected persons, soil, animals	Probably from infected feet, contaminated floors, shower stalls	Unknown	Same as above.
Ancylostomiasis (hookworm disease)	*Necator americanus* and *Ancylostoma duodenale*	Feces of infected persons; soil containing infective larvae; cats and dogs	Larvae hatching from eggs in contaminated soil penetrate foot; larvae also swallowed	Weeks to months	Prevention of soil pollution; sanitary privies or sewage disposal systems; wearing shoes; education in method of spread; treatment of cases; sanitary water supply.
Rabies (hydrophobia)	Virus of rabies	Infected dogs, foxes, cats, squirrels, cattle, horses, swine, goats, wolves, bats, skunks, wild and domestic animals	Bite of rabid animal or its saliva on scratch or wound	2–8 weeks, as little as 5 days, or more than 1 year	Detention and observation for 10 days of animal suspected of rabies. Immediate destruction or 6 months detention of animal bitten by a rabid animal. Vaccination of cats and dogs, dogs on leashes; dogs at large confined. Education of public. Avoid killing animal; if necessary, save head intact. Reduce wildlife reservoir in cooperation with conservation agencies. If bitten, wash wound immediately and obtain medical attention.

(*continues*)

TABLE 2.7 (*continued*)

Disease	Etiologic Agent	Reservoir	Transmission	Incubation Period	Control
Tetanus	*Clostridium tetani*, tetanus bacillus	Soil, street dust, animal feces containing bacillus	Entrance of tetanus bacillus in wound, puncture wound, burn, or minor wound	3 days to 3 weeks, average of 10 days	Immunization with primary series of three doses of tetanus toxoid plus reinforcing dose and booster every 10 years. Allergic persons should carry record of sensitivity. Thorough cleansing of wounds. Safety program.
Anthrax	*Bacillus anthracis*	Cattle, sheep, goats, horses, swine, skins and hides of infected animals	Contaminated hair, wool, hides, shaving brushes, ingestion or contact with infected meats; inhalation of spores; flies possibly; laboratory accidents (Shaving brushes are under PHS regulations. Bristles soaked 4 hours in 10% formalin at a temperature of at least 110°F destroys anthrax spores.); intentional release/bioterrorism	7 days, usually less than 4 days	Isolation and treatment of suspected animals. Postmortem examination by veterinarian of animals suspected of anthrax and deep burial of carcass, blood, and contaminated soil at a depth of at least 6 feet or incineration. Spores survive a long time. Vaccination of workers handling animals, hair, hides, or meats; personal hygiene; prompt treatment of abrasions. Treatment of

					trade wastes. Disinfection of wool, hide, animal food. Dust control.
Myiasis	*Cochliomya hominivorax* fly larva (screwworm)	Humans and vertebrate animals	Fly (dipterous) infestation of humans and vertebrate animal tissue with fly larvae	Variable	Prevent fly larvae or egg infestation of wounds, skin, eye, ear, nasopharynx, food, and genitourinary tract. Manual removal of larvae. Personal hygiene, medical treatment. Release artificially sterilized male flies. Apply insecticide (dichlorvos).
Yaws	*Treponema pertenue*	Humans and possibly higher primates	Direct contact with exudates of early skin lesions of infected persons; also contamination from scratching and flies on open wounds	2 weeks to 3 months	Better sanitation, availability of clean water, personal hygiene, screening and mass treatment, including contacts.
Onchocerciasis[a] (river blindness)	*Onchocerca volvulus*, a nematode	Infected humans, gorillas rarely	Female black fly *Simulium* genus carrying *Onchocerca* bites human, causing infection with parasite: another fly bites victim	1 year or less, sometimes more	Protective clothing. Use repellent (DEET). Selected spraying of fast-flowing (oxygen) rivers harboring the larvae and treatment of individuals annually with drug invermectin,[b] which kills the microfilariae but not the worm.

(*continues*)

TABLE 2.7 (*continued*)

Disease	Etiologic Agent	Reservoir	Transmission	Incubation Period	Control
Trachoma	*Chlamydia trachomatis*	Tears, secretions, discharges of nasal mucous membranes of infected persons	Direct contact with infected persons and towels, fingers, handkerchiefs, clothing soiled with infective discharges	5–12 days	Routine inspections and examinations of school children. Elimination of common towels and toilet articles and using sanitary paper towels. Education in personal hygiene and keeping hands out of eyes.
Psittacosis (Ornithosis)	*Chlamydia psittaci*	Infected parrots, parakeets, love birds, canaries, pigeons, poultry, other birds	Contact with infected birds or inhalation of their desiccated wastes; agent is airborne	4–15 days	Importation of birds from psittacosis-free areas. Quarantine of pet shops having infected birds until thoroughly cleaned. Education of public to dangers of parrot illnesses.
Staphylococcal disease in the community	*Staphylococcus aureus*	Humans	Direct contact with infected skin lesions or articles by discharges	Usually 4–10 days	Personal hygiene, avoidance of common use of toilet articles; prompt recognition and treatment of illness. Inspection of children at camps, nurseries, institutions, schools. Frequent handwashing.

Chancroid (soft chancre)	*Haemophilus ducreyi, Ducrey bacillus*	Discharges from open lesions and pus from buboes from infected persons	Sexual contact with open lesions and pus; direct contact with infectious discharges in sexual intercourse; transfusion of infected blood	3–5 days or longer	Character guidance, health and sex education, premarital and prenatal examinations. Improvement of social and economic conditions; elimination of slums, housing rehabilitation and conservation, new housing, neighborhood renewal. Suppression of commercialized prostitution, personal prophylaxis, facilities for early diagnosis and treatment, public education concerning symptoms, modes of spread, and prevention. Case finding, patient interview, contact-tracing and serologic examination of groups known to have a high incidence of venereal disease, with follow-up. Report to local health authority.
Gonorrhea (clap, dose)	*Neisseria gonorrhoeae*, gonococcus *C. trachomatis*	Infected persons, particularly females	Sexual intercourse; contact with open lesions of infected persons	2–7 days; sometimes longer, 3–30 days	Reduce number of partners within sexual network.

(*continues*)

TABLE 2.7 (*continued*)

Disease	Etiologic Agent	Reservoir	Transmission	Incubation Period	Control
Lymphogranuloma vencreum (tropical bubo) Syphilis (pox, lues)	*Treponema pallidum*	Exudates from lesions of skin, mucous membrane, body fluids, and secretions of infected persons; exudate from mucous membranes of infected persons	Sexual intercourse, contact with mucous membranes of infected persons	10 days to 10 weeks, usually 3 weeks	Use of condom., Prophylaxis of carriers. Reduce number of partners within sexual network.
Granuloma inguinale (tropical sore)	*Donovania granulomatis*, (presumed agent)	Infected persons	Presumably by sexual intercourse, direct contact with lesions	Unknown, probably 8 days to 12 weeks	

Other sexually transmitted diseases include chlamydial infections, nongonococcal urethritis, trichomoniasis, herpes simplex (genital herpes), genital warts, viral hepatitis B, human immunodeficiency virus (HIV) infection, and acquired immunodeficiency syndrome (AIDS). Control measures are similar to above.

[a]The WHO estimates that there are 17 million cases of onchocereciasis, or river blindness, mostly in Africa, and 326,000 people have been blinded by it, About 90 million are at risk. *Nation's Health* (July 1990): 8–9.

[b]E. Eckholm, "River Blindness, Conquering an Ancient Scourge," *New York Times* magazine, Jan. 8, 1989, p. 20. For further information the reader is referred to specialized sources such as ref. 3; P. N. Acha and B. Szyfres, *Zoonoses and Communicable Diseases Common to Man and Animals*, 2nd ed., Pan American Health Organization, WHO, Washington, DC, 1987; and "Guidelines for Prevention of Transmission of Human Immunodeficiency Virus and Hepatitis B Virus to Health-Care and Public-Safety Workers," U.S. Department of Health and Human Services, PHS, CDC, Atlanta, GA, February 1989, reprinted in *MMWR*, **38**, 25, (June 30, 1989): 446.

through saliva or a cut or scratch on the hands. The dead animal should be wrapped in newspaper or other covering and taken to a veterinarian or local health department. The head should be immediately delivered or packed in ice (not frozen) and shipped to the nearest equipped health department laboratory where the brain can be examined for evidence of rabies.

Several immunization products, vaccines and globulins, are available and used for postexposure prophylaxis. If treatment has been initiated and subsequent testing of the animal shows it to be negative, treatment can be discontinued. Preexposure prophylaxis is also practical for persons in high-risk groups. These include veterinarians, animal handlers, certain laboratory workers, and persons, especially children, living or visiting countries where rabies is a constant threat. Persons whose vocational or avocational pursuit brings them into contact with potentially rabid dogs, cats, foxes, skunks, or other species at risk of having rabies should also be considered for preexposure prophylaxis. The CDC and local and state health departments provide detailed recommendations for rabies prevention and treatment including pre- and post-prophylaxis.[58]

Vaccination of dogs and cats in affected areas, stray animal control, and public information are important for a good control program. In areas where rabies exists, mass immunization of at least 70 percent of the dog and cat population in the county or similar unit within a 2- or 3-week period is indicated. Where rabies exists or where it might be introduced, a good program should include vaccination of all dogs and cats at three months of age and older. Vaccines are available for dogs, cats, and cattle; special vaccines can be used in certain animals. A booster is recommended annually or triennially, depending on the vaccine used. All animal rabies vaccines should be administered by or under the supervision of a veterinarian.

Rabid bats have been reported from every state except Hawaii and have caused human rabies infections in the United States. The vampire bat (*Desmodus rotundus*) is a rabies carrier spreading death and disease among cattle and other livestock and endangering humans in Latin America from Mexico to northern Argentina. Annual livestock production losses are estimated at $250 million. The anticoagulant diphenadione is effective against the vampire bat species. The chemical may be injected directly in cattle and is then taken by the bat when it gets its blood meal or can be spread as a petroleum jelly mixture on captured bats, which, when released, spread the chemical by contact throughout a bat colony. In either case, the diphenadione enters the bloodstream and the bats bleed to death.

DDT formally was used as a control measure but has been banned since 1972. Currently, the most effective means of bat control is to screen all openings or build them out insofar as possible. Fiberglass insulation will keep bats out of spaces so insulated.

Any person bitten or scratched by a bat should receive antirabies therapy without delay unless the bat (head) is found negative by laboratory test. Any person who has handled a bat, dead or alive, may also have to undergo antirabies therapy, as the bat saliva, containing the rabies virus, may enter a patient's body through open cuts in the skin or mucous membranes.

Infectious Respiratory Diseases

Infectious diseases affecting the lungs and respiratory tract have special implications in public health. Bacteria and viruses responsible for these diseases are transmitted between humans via droplets that are expelled from the nose or mouth. Although direct transmission can occur (e.g., coughing or recirculated air), droplets on nonporous surfaces (e.g., door knobs) can also be involved in new infections. Environmental engineering can play a key role in ensuring the safety and quality of air, particularly in the design of institutional air supply systems, which have been implicated in the transmission of respiratory infections.

Control of transmission of respiratory dropletborne infections is achieved through interventions at the individual level (protective masks, hand washing, antibiotic treatment), the population level (restrictions on congregation and movement), and environmental levels (air filtration, institutional design).

In this chapter we describe two respiratory infections and their control mechanisms, of concern to developing and develop countries: tuberculosis and influenza. Table 2.8 summarizes the major respiratory illnesses.

Tuberculosis Tuberculosis (TB) is caused by *Mycobacterium tuberculosis*, *M. africanum* or *M. bovis*. Infection in the respiratory tract can lead to *pulmonary tuberculosis*, resulting in calcified nodules in the lungs, trachea, and bronchea. Infection with the mycobacterium at sites other than the lungs can happen, although much less frequently. Only 5 to 10 percent of those infected with TB will show clinical signs of disease or become infectious.[59] In 2005, the WHO estimates that there were 1.6 million deaths due to tuberculosis worldwide, making it one of the most common causes of human mortality on the planet.[59] Two developments in the last decade and half have made the spread of TB even more worrisome. First, the rapid increase in HIV infections has revealed that those infected with HIV are at much higher risk of acquiring TB. Second, the emergence of multiple-drug-resistant strains of tuberculosis (MDR-TB) have resulted from improper use of antibiotics; these strains can no longer be treated with the commonly available antibiotics and require expensive and intensive medical care. In addition, extremely drug resistant tuberculosis (XDR-TB) has also been reported, which is difficult to cure even with the most advanced forms of antibiotics available.

The World Health Organization has a large-scale program called Stop TB. These programs has the following six components[59]:

1. *Pursue high-quality DOTS expansion and enhancement*. The standard of care for tuberculosis is daily dosing of antibiotics that is observed by a health care worker. Direct observed therapy, short course (DOTS) was created in response to the realization that many TB patients were not completing the prescribed course of antibiotics, due to the number and size of the tablets that must be swallowed daily and the duration of therapy, which can be months to a year. Patients may not show outward signs of

TABLE 2.8 Respiratory Diseases

Disease[a]	Communicability (days)[b]	Incubation Period (days)
Chickenpox (v)	−2–6	14–21
Coccidioidomycosis (f)	No direct transmission	7–28
Common cold (v)	1–5	$\frac{1}{2}$–3
Diphtheria (b)	14	2–5
German (rubella) measles (v)	−7–4+	14–23
Histoplasmosis (f)	No direct transmission	5–18
Infectious mononucleosis (v)	Prolonged	28–42
Influenza (v)	3	2–3
Legionellosis (b)	None	2–10
Measles (rubeola) (v)	2–4	8–13
Meningococcal meningitis (b)	—	2–10
Mumps (v)	−6–9	14–21
Pertussis (whooping cough) (b)	Inflammation–21	7–10
Plague, pneumonic (b)	During illness	2–6
Pneumonia, pneumococcal (b)	—	1–3
Poliomyelitis (v)	Days before and after onset	7–14
Psittacosis (r)	In illness possibly	4–15
Q fever (r)	Transmission rare	14–21
Scarlet fever and streptococcal sore throat (b)	10–21	1–3
Smallpox (v)[c]	1–21	7–17
Tuberculosis (b)	Extended	28–84

[a] Abbreviations: b, bacteria; f, fungus; r, rickettsias, airborne; v, virus. For details, see A. S. Benenson, *The Control of Communicable Diseases in Man*, 15th ed., American Public Health Association, Washington, DC, 1990.
[b] Period from onset of symptoms. Onset of symptoms is considered day zero; negative numbers indicate days prior to clinical manifestation of the disease.
[c] Declared by WHO officially "eradicated" in 1978, if no new cases discovered.

TB infection (i.e., carrier state) and yet remain infectious. This component also includes public-private partnerships to create new medications for treatment of tuberculosis.

2. *Address TB/HIV, MDR-TB and other challenges*. Patients with co-occurring TB and HIV need special attention to ensure that medications do not interact with each other and that early signs of TB progression are detected. Addressing the role of TB in special populations is also important, such as among prisoners and low-income individuals, gender inequalities, and the implications of air travel.
3. *Contribute to health system strengthening*. National TB prevention programs must be integrated with other strategies to improve health care financing and delivery. Sharing of innovations among health care systems is encouraged, and adoption of new methods to stop TB is promoted.

4. *Engage all care providers*. Tuberculosis patients seek services from many different sectors of public and private healthcare providers. Training all health care workers to identify and handle patients with TB is important to ensuring that care can be delivered at a high quality at multiple levels.
5. *Empower people with TB, and communities*. Nonmedical communities can take responsibility of some aspects of TB care and prevention. Due to the large number of persons infected with tuberculosis, treating infected individuals with respect and civility is in the best interests of all parties. Networks of civil society and community organizations are crucial to promoting and sustaining political support for control programs.
6. *Enable and promote research*. New diagnostics, medications and prevention strategies will be needed in the coming decades to continue the fight against tuberculosis.

Although the WHO plan focuses on treatment, environmental engineers have played a role in the prevention of tuberculosis. For example, the Water and Environmental Engineering Research Group at the University of Leeds in the United Kingdom have created a system for ultraviolet inactivation of *mycobacterium tuberculosis* and other airborne pathogens in hospitals. Commercial airliner environmental control systems are also being developed to prevent transmission among air travel passengers.

Influenza *Seasonal influenza* occurs annually and is caused by a virus. It is an acute respiratory infection characterized by sore throat, fever, cough, headache, body pains, and prostration; it is spread via virus-laden droplets that are expectorated from the respiratory tract by infected patients. While influenza is usually self-limiting (naturally cleared by the body in 2 to 7 days), those with weakened immune systems, such as the elderly, are at risk of death.

The difficulty in controlling influenza stems from the genetic variability that is intrinsic to the family of viruses. Influenza is characterized by two main surface glycoproteins hemagglutinin (HA) and neuraminidase (NA). Dozens of variations in these glycoproteins are known; the swapping (or "reassortment") of the genes encoding these glycoproteins gives rise to strains of differing pathogenic quality. Showing the interconnectedness of human and animal health, much of the reassortment occurs in birds and pigs, from which humans are newly infected each year. The nomenclature of the viral strains specifies which numbered variant of hemagglutinin or neuraminidase is encoded; common strains include H1N1, H1N2, and H3N2 viruses, while more virulent strains are H7N7 and H5N1.

Seasonal influenza is preventable with a vaccine, but it must be administered every year due to the constantly mutating nature of the virus.[60] Vaccination rates can vary greatly, and the supply of vaccine has been hampered due to bacterial contamination during the production process. In the United States, there are thousands of deaths annually due to influenza, mostly among the oldest and youngest segments of the population.

Pandemic influenza arises when particularly virulent strains of the influenza virus emerge as a result of genetic recombination, resulting in widespread infections. Pandemics of influenza occurred in 1889, 1918, 1957, and 1968. During these pandemics, 20 percent of the general population and 50 percent of institutionalized populations (prison, college dormitories) were affected.[1] Although seasonal influenza deaths occur in the elderly, during the 1918 pandemic, most deaths were in young adults, for reasons that are unclear. Birds can be infected with influenza, and the pandemic strains from 1918, 1957 and 1968 bore genetic similarity to avian influenza viruses. This observation drives much of the fear and speculation about avian influenza and the likelihood of it morphing into the next human pandemic.

The specter of an influenza pandemic highlights many shortcomings in global health care. It is likely that the pandemic will begin in a developing country where there is close human and bird contact and veterinary surveillance is low, most likely on a farm or a food processing facility. Crowded living conditions will exacerbate the spread, and international air travel will move the virus to new regions of the world overnight. At that point, much will depend on the international cooperation in response to the perceived threat. If active control measures are put into place, there is the potential to reduce the severity, but most of the medical literature is imbued with a sense of inevitability. Whether the pessimism is warranted will be revealed with actual experience.

The availability of medical tools (respirators, vaccines, antivirals) has been the concern of much of pandemic influenza planning. Treating severe influenza is medical-resource intensive; respirators for those with impaired lung capacity are already in short supply, and must be regularly cleaned and patients monitored. Spread of influenza in health care facilities is likely, with the potential to infect health care staff. The potential volume of patients will overwhelm most hospitals, but other disruptions will occur due to absenteeism among employees needed to keep society functioning.

Airborne, or fine-droplet transmission, may also occur. In view of this, Standard Infection Control Principles and Droplet Precautions are the principal infection control strategies that should be rigorously followed. In certain circumstances, these control measures may need to be augmented with higher levels of respiratory protection. Scrupulous attention to handwashing and containment of respiratory secretions produced by coughing and sneezing are the cornerstones of effective infection control. Other key recommendations include separation or cohorting of patients with pandemic influenza from those who have other medical conditions; prompt identification of health care workers with pandemic influenza; restriction of ill workers and visitors from health care settings; and education of staff, visitors, and patients about the transmission and prevention of influenza that is understandable and applicable to their particular situation.[61]

BIOTERRORISM

In late 2001, letters containing *Bacillus anthracis* (anthrax) spores were mailed to various locations in the United States by yet unidentified individual(s) operating under unknown motive(s). This led to the deaths of at least five individuals due to inhalation anthrax and to several other cases of the less severe cutaneous form of the disease. While it remains to be determined whether these terrorist attacks were related and to identify the perpetrators, they signaled a new era of fear and awareness of biological agents.

It should be remembered that "bioterrorism" and "biological warfare" have long histories. Plague-infected corpses were catapulted by the Tartars during their siege of Kaffa (in Crimea), resulting in the collapse of the city population due to mortality from the mycobacterium. Smallpox-infected clothing and blankets were reported given to susceptible populations by Spanish conquistadors' during campaigns in South America, by the British during the French-Indian War, and by Confederate-sympathizing manufacturers during the U.S. Civil War. Plague outbreaks were created by the Japanese army after the intentional release of infected fleas over Chinese towns in 1941. The United States military tested biological weapons against unsuspecting U.S. residents by releasing relatively harmless bacteria that could be traced *Serratia marcescens* was released in San Francisco in 1950, and *Bacillus subtilis* was released into the New York City subway system in 1966. An accidental release of anthrax from a Soviet facility in April 1979 provides us with the only known "natural experiment" of aerosolized release of the bacteria; that accident resulted in hundreds of deaths and proved beyond a doubt that biological organisms could be weaponized with lethal consequences. On a smaller scale, in 1984 a group of politically motivated individuals intentionally contaminated salad bars in Oregon with *Salmonella typhimuium*, resulting in over 750 cases. A Japanese cult released the nerve gas sarin in the Tokyo subway system in 1995, resulting in 20 deaths and thousands of injuries.

The CDC and other federal agencies currently list *Bacillus anthracis* (anthrax), *Variola major* (smallpox), *C. botulinum* toxin (botulism), *Yersinia pestis* (plague), *Franciscella tularensis* (tularemia), and viral hemorrhagic fevers (Ebola virus, lassa virus) as category A agents—those that are the most likely to be used as potentially lethal weapons. This section will briefly discuss two of the major agents, smallpox and anthrax. Due to the significant pathogenicity of each of these agents, individuals seeking to employ their use, especially in large amounts, would require substantial knowledge, expertise, and laboratory equipment, as well as protection against accidental exposure (e.g., vaccination or antibiotics).

Smallpox

Smallpox, a disease that killed approximately 300 million people worldwide in the twentieth century alone, may have been one of the first microbial agents to be used as a weapon. The only remaining stocks of smallpox are currently being held in secure locations in the United States and Russia. The WHO has recently voted to delay destruction of the remaining smallpox stocks, raising the possibility of their misappropriation and use as weapons. Because immunization against smallpox was halted in 1976 following a successful worldwide eradication program, a significant number of the U.S. population would be at risk from a bioterrorism attack. Although individuals vaccinated prior to 1976 may retain immunity to smallpox, the level of protection is currently unknown. Smallpox is generally fatal in about 30 percent of infections of unvaccinated individuals. Given these uncertainties and the significant health risk of smallpox, the United States and other countries are currently increasing the production of smallpox vaccine. However, approximately 1 in 1 million people exhibit serious and potentially fatal complications following vaccination. Thus, if the entire U.S. population were to be vaccinated, we might expect 100 to 300 deaths from the vaccine. To avoid this situation, one strategy that is being considered for a bioterrorism attack is to limit vaccination to individuals that have come in contact with the initial (index case) infected individual. Vaccination and training of primary health care workers and physicians who are most likely to see the first cases in an attack will also be an important aspect for countering the use of viruses and bacteria as weapons.

Anthrax

As already noted, anthrax is a concern for use in bioterrorism. Inhalation of anthrax spores is fatal in approximately 75 percent of untreated cases. Anthrax consists of several major virulence factors: a polysaccharide capsule and three separate proteins (toxins) that act in concert to disrupt immune defense systems. An anthrax vaccine is available and is generally effective, although it is currently in limited supply (and mostly dedicated to military rather than civilian use). It has also been observed to cause side effects. Antibiotics such as amoxicillin, ciprofloxacin, and doxycycline are effective against the inhalation form of anthrax; however, they must be administered prior to spore germination, which can occur within 48 to 72 hours following exposure and must be continued for several months. One particular concern is that terrorists may genetically alter common strains of anthrax to encode antibiotic-resistance genes, a situation that could pose significant problems for current treatment protocols. Thus, it will be important to be able to rapidly monitor and analyze the genetic properties of different anthrax strains and to develop new antibiotics. Another promising avenue stems from the recent identification of the receptor for anthrax lethal factor toxin as well as high-resolution structural determination of lethal factor and edema factor. These molecules represent potential targets for rational drug design of new antibacterial compounds to combat this disease.

NONCOMMUNICABLE DISEASES AND CONDITIONS ASSOCIATED WITH THE ENVIRONMENT

Background

The terms *noncommunicable* and *noninfectious* are used interchangeably. The major noncommunicable disease deaths in the United States in 2000 were due to diseases of the heart, malignant neoplasms, cerebrovascular diseases, accidents, atherosclerosis, diabetes mellitus, and chronic liver disease and cirrhosis.

The mortality can be expected to shift more to noncommunicable causes in the developing countries as social and economic conditions improve and communicable diseases are brought under control. This section discusses some background issues, prevention and control, legislation, and types of noncommunicable diseases associated with the environment.

Treatment of the environment complements treatment of the individual but requires more effort and knowledge. The total environment is one of the most important determinants of health. A review of more than 10 years of research conducted in Buffalo, New York, showed that the overall death rate for people living in heavily polluted areas was twice as high, and the death rates for tuberculosis and stomach cancer three times as high, as the rates in less polluted areas.[62] Rene Dubos points out that "many of man's medical problems have their origin in the biological and mental adaptive responses that allowed him earlier in life to cope with environmental threats. All too often the wisdom of the body is a shortsighted wisdom."[63] In reference to air pollution, he adds that "while the inflammatory response is protective (adaptive) at the time it occurs, it may, if continuously called into play over long periods of time, result in chronic pathological states, such as emphysema, fibrosis, and otherwise aging phenomena."[63]

Human adjustment to environmental pollutants and emotional stresses due to crowding and other factors can result in later disease and misery with reduced potential for longevity and a productive life.[64]

In an address to the Sierra Club, EPA Administrator Barbara Blum stated[65]:

> Inner-city people—white, yellow, brown and back—suffer to an alarming degree from what are euphemistically known as diseases of adaptation. These are not healthy adaptations, but diseases and chronic conditions resulting from living with bad air, polluted water, excessive noise, and continual stress. Hypertension, heart disease, chronic bronchitis, emphysema, sight and hearing impairment, cancer, and congenital anomalies are all roughly 50 percent higher (for inner-city people) than the level for suburbanites. Behavioral, neurological and mental disorders are about double.

Whereas microbiological causes of most communicable diseases are known and are under control or being brought under control in many parts of the world (with some possible exceptions such as malaria and schistosomiasis), the physiologic and toxicologic effects on human health of the presence or absence of certain chemicals in air, water, and food in trace amounts have not yet been clearly demonstrated. The cumulative body burden of all deleterious substances, especially organic and inorganic chemicals, gaining access to the body must be examined both individually and in combination. The synergistic, additive, and neutralizing effects must be learned in order that the most effective preventive measures may be applied. Some elements, such as fluorine for the control of tooth decay, iodine to control goiter, and iron to control iron deficiency anemia, have been recognized as being beneficial in proper amounts. But the action of trace amounts ingested individually and in combination of the pollutants shown

> and other inorganic and organic chemicals is often insidious. Their probable carcinogenic, mutagenic, and teratogenic effects are extended in time, perhaps for 10, 20, or 30 years, to the point where direct causal relationships with morbidity and mortality are difficult if not impossible to conclusively prove in view of the many possible intervening and confusing factors. Nevertheless, sufficient information about many noninfectious diseases, including the chronic diseases, is available to make possible the mounting of an attack to prevent or at least minimize the debilitating effects. Some will say that we do not have sufficient preventive information and should devote our attention only to screening and treatment. Where would we be today if the same philosophy prevailed in our attack on the infectious diseases?

An interesting analysis was made by Dever[66] for use in policy analysis of health program needs. He selected 13 causes of mortality and allocated a percentage of the deaths, in terms of an epidemiologic model, to four primary divisions, namely, system of health care organization, lifestyle (self-created risks), environment, and human biology. He envisioned the environment as composed of a physical, social, and psychological component. Environmental factors were considered to be associated with 9 percent of the mortality due to diseases of the heart, with the rest due to causes associated with health care, life-style, or human biology. Similarly, environmental factors were considered the cause of 24 percent of the cancer deaths, 22 percent of the cerebrovascular deaths, and 24 percent of the respiratory system deaths.

Of added interest is Dever's analysis showing that environmental factors were considered to be the cause of 49 percent of all deaths due to accidents, 20 percent of the influenza and pneumonia deaths, 41 percent of the homicides, 15 percent of the deaths due to birth injuries and other diseases peculiar to early infancy, 6 percent of the deaths due to congenital anomalies, and 35 percent of the deaths due to suicides.

There are an estimated 2 million recognized chemical compounds with more than 60,000 chemical substances in past or present commercial uses. Approximately 600 to 700 new chemicals are introduced each year, but only about 15,000 have been animal tested with published reports. Limited trained personnel and laboratory facilities for carcinogenesis testing in the United States by government and industry will permit testing of no more than 500 chemicals per year. The chemicals are viewed by Harmison[67] as falling into four groups:

1. Halogenated hydrocarbons and other organics; polychlorinated biphenyls (PCBs); chlorinated organic pesticides such as DDT, Kepone, Mirex, and endrin; polybrominated biphenyls (PBBs); fluorocarbons; chloroform; and vinyl chloride. These chemicals are persistent, often accumulate in food organisms, and may in small quantities cause cancer, nervous disorders, and toxic reactions.
2. Heavy metals: lead, mercury, cadmium, barium, nickel, vanadium, selenium, beryllium. These metals do not degrade; they are very toxic and may build up in exposed vegetation, animals, fish, and shellfish.

3. Nonmetallic inorganics: arsenic and asbestos, for example, are carcinogens.
4. Biological contaminants such as aflatoxins and pathogenic microorganisms; animal and human drugs such as diethylstilbestrol (DES) and other synthetic hormones; and food additives such as red dye No. 2.

Evaluation of the toxicity of existing and new chemicals on workers, users, and the environment and their release for use represent a monumental task, as already noted. Monitoring the total effect of a chemical pollutant on humans requires environmental monitoring and medical surveillance to determine exposure and the amount absorbed by the body. The sophisticated analytical equipment available can detect chemical contaminants in the parts-per-billion or parts-per-trillion range. However, mere detection does not mean that the chemical substance is automatically toxic or hazardous. But detection does alert the observer to trends and the possible need for preventive measures. Short-term testing of chemicals, such as the microbial Ames test, is valuable to screen inexpensively for carcinogens and mutagens. The Ames test determines the mutagenic potential of a chemical based on the mutation rate of bacteria that are exposed to the chemical. However, positive results suggest the need for further testing, and negative results do not establish the safety of the agent. Other tests use mammalian cell cultures and cell transformation to determine mutagenicity.

Prevention and Control

Prevention of the major causes of death, such as diseases of the heart, malignant neoplasms, cerebrovascular disease, accidents, and other noninfectious chronic and degenerative diseases, should now receive high priority. Prevention calls for control of the source, mode of transmission, and/or susceptibles as appropriate.

The prevention and control of environmental pollutants generally involves the following:

1. *Eliminate or control the pollutant at the source*. Minimize or prevent production and sale; substitute nontoxic or less toxic chemical; materials and process control and changes; recover and reuse; waste treatment, separation, concentration, incineration, detoxification, and neutralization.
2. *Intercept the travel or transmission of the pollutant*. Control air and water pollution and prevent leachate travel.
3. *Protect humans to eliminate or minimize the effects of the pollutant*. This includes water treatment, air conditioning, land-use planning, and occupational protection.

At the same time the air, sources of drinking water, food, aquatic plants, fish and other wildlife, surface runoff, leachates, precipitation, surface waters, and humans should be monitored. Biosensor technology can assist in determining exposure to pollutants, however for the foreseeable future, epidemiological studies collecting blood and other biological specimens, astute clinical observation, emergency department and poison center surveillance will be the most likely tools of monitoring. This should be done for potentially toxic and deleterious chemicals as indicated by specific situations.

Environmental Control Legislation

Many of the laws establishing national standards and controls for the discharge of pollutants to the environment and consumer and worker protection are listed as follows:*

- *Asbestos Hazard Emergency Response Act of October 22, 1986* (Amends Toxic Substances Control Act (TSCA).] Requires the EPA to regulate the inspection of schools, identify asbestos-containing materials, monitor the development of asbestos management plans by schools, and oversee corrective measures. The Occupational Safety and Health Administration (OSHA) is to establish asbestos regulations in the workplace and for asbestos removal. The *Asbestos School Hazard Abatement Act of 1984* authorizes the EPA to provide grants and loans if justified.
- *Atomic Energy Act of 1954* PL. 83–703 (as amended). Regulates the discharge of radioactive waste into the environment. Gives the EPA authority to set standards for the disposal of radioactive materials to be implemented by the National Research Council (NRC).
- *Clean Air Act of 1970* P.L. 91–604 (as amended 1990, 1996, 1998, 1999). To improve the quality of the nation's air, the EPA is to establish national air quality standards to protect the public health and welfare from the harmful effects of air pollution and ensure that existing clean air is protected from significant deterioration by controlling stationary and mobile sources and preventing harmful substances from entering the ambient air; also to review and regulate hazardous and toxic air pollutants.
- *Coastal Zone Management Act of 1972* P.L. 92–583 (as amended). Requires consideration of environmental and economic factors in the planning and efficient development of coastal areas. State receives financial and technical assistance.
- *Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) of 1980* P.L. 96–510 (as amended) (Superfund). Establishes a trust fund financed by taxes on oil and certain chemical compounds and authorizes federal action in cleaning up hazardous waste sites (especially soil and water contaminated sites), responds to spills of hazardous substances that present danger to public health and welfare, and prepares guidelines for coordinating federal and state responses. Short-term response may include

*A very good resource for examining public laws is the Thomas search engine of the Library of Congress web site, www.loc.gov. This is a searchable database of all laws in Congress, whether passed or not, from the 93rd Congress (1973–1974) through the current one.

provision of bottled water and temporary evacuation. Sites are ranked for priority action.

- *Consumer Product Safety Act of 1972* P.L. 92–573. The Consumer Product Safety Commission (CPSC) is responsible for reducing injuries associated with consumer products, including the development of safety standards and the investigation of product-related morbidity and mortality.
- *Emergency Planning and Community Right-to-Know Act of 1986* Also called *Superfund Amendments and Reauthorization Act (SARA) Title III*. Employers must report and advise employees of hazardous substances handled and their potential effects. The act also requires that information about toxic chemicals stored or permitted to be released during operation of commercial and manufacturing facilities be made available to the public. State and local governments and facilities using or storing hazardous chemicals must have emergency plans for notification and response. Facilities must report annually the amount and characteristics of certain toxic chemicals on premises and released to the environment.
- *Federal Food, Drug, and Cosmetic Act of 1938* (as amended). The FDA is responsible for the safety and effectiveness of foods, drugs, medical devices, and cosmetics; it is also responsible for radiologic health and toxicologic research, enforces compliance with EPA-established allowable limits for pesticides on food and feed crops, and prohibits use of any carcinogenic additives.
- *Federal Insecticide, Fungicide, and Rodenticide Act of 1972* P.L. 92–516 (as amended). Requires that all pesticides be registered and used strictly in accordance with label instructions; gives government (EPA) authority to prohibit or restrict a pesticide to special uses for application only by a person trained in an approved program; extends control to intrastate products, container storage and disposal methods, and direct or indirect discharge of pesticides to surface waters and groundwaters; also requires proof that pesticides will cause no harm to people, wildlife, crops, or livestock when used as directed.
- *Federal Water Pollution Control Acts of 1971, 1972* P.L. 83–660, P.L. 92–500, and P.L. 95–217 (*Clean Water Act of 1977* as amended by the *Water Quality Act of 1987* and further amended in 2000). Controls water pollutants and other related factors to make surface waters fishable and swimmable. Intended to restore and maintain the chemical, physical, and biological integrity of the nation's surface and groundwaters. Also water quality planning, wetlands protection, research, and regulation of toxic water pollutants.
- *Food Security Act of 1985* (as amended by the 1990 Farm Bill). To control degradation of wildlife habitat, water quality, and inland waters due to cultivation of marginal farmlands; preservation of wetlands; minimizing of agricultural pollutant releases.

- *Hazardous Materials Transportation Act of 1974* PL. 93–633. U.S. Department of Transportation regulates the transportation in commerce of hazardous materials or hazardous wastes by all means of transportation.
- *Irrigation Mitigation and Restoration Partnership Act of 2000* PL 106–502. Directs the development and implementation of projects to mitigate impacts to fisheries resulting from the construction and operation of water diversions by local governmental entities in the Pacific Ocean drainage area (areas of Washington, Oregon, Montana, and Idaho from which water drains into the Pacific Ocean).
- *Lead Contamination Control Act of 1988* Requires that lead be removed from school and day-care center drinking water supplies, especially water coolers. The CDC is authorized to provide funds to states for screening of children and their treatment and to remove sources of lead. The CPSC is required to recall drinking water coolers that are not lead free, if not repaired or replaced.
- *Low Level Radioactive Waste Policy Act of 1980*. Declares that the disposal of low-level radioactive waste is a state responsibility. Permits states to make agreements for joint use of a site if approved by Congress.
- *Marine Protection, Research, and Sanctuaries Act of 1972* P.L. 92–532 (as amended). Controls the dumping of materials, including sewage sludge and toxic substances, into the oceans, and EPA responsibility.
- *Medical Waste Tracking Act of 1988*. The EPA is to establish requirements for medical and infectious waste management, including control of waste generators, transporters, and disposal facility operators. The CDC and OSHA are also involved.
- *National Environmental Policy Act of 1969* PL. 91–190 (as amended). Encourages productive and enjoyable harmony between human and environment; promotes efforts that will prevent or eliminate danger to the environment and biosphere and stimulates the health and welfare of humans; enriches the understanding of the ecologic systems and natural resources important to the nation; and establishes a Council on Environmental Quality.
- *National Flood Insurance Act of 1968* P.L. 90–448, PL. 93–234. A program administered by the Federal Emergency Management Agency for land management in flood-prone areas. Supplies funds to states for planning and regulation, restricting certain uses in flood-prone areas, with community participation.
- *National Gas Pipeline Safety Act of 1968* (as amended 1992, 1996). Requires federal pipeline safety standards to meet the need for protection of the environment and demands corrective action when any pipeline facility is hazardous to the environment.
- *National Invasive Species Act of 1996* P.L. 104–332. Orders the prevention of the introduction and spread of aquatic nuisance species into the Great Lakes and other U.S. waters through the discharge of ballast water.

- *Noise Control Act of 1972* P.L. 92–574 (as amended). Makes the federal government responsible for setting standards for noise detrimental to the human environment from a broad range of sources.
- *Nuclear Waste Policy Act of 1982*. Requires the Department of Energy (DOE) to prepare guidelines for and select a geologic site for the storage of high-level waste by 1998 and a second site at a later date. The DOE is also responsible for waste management, including interim storage and transportation.
- *Occupational Safety and Health Act of 1970* P.L. 91–956. Prevents occupational disease and accidents and establishes workplace standards as well as national standards for significant new pollution sources and for all facilities emitting hazardous substances.
- *Ports and Waterways Safety Act of 1972* PL. 92–340. Regulates, through the Coast Guard, the bulk of shipment of oil and hazardous materials by waters, also under the authority of the *Tanker Act* and the *Dangerous Cargo Act*.
- *Public Utility Regulatory Policy Act of 1979*. Requires utilities to purchase energy produced by small power generators at a set cost.
- *Radiation Control for Health and Safety Act of 1968*. Controls performance standards for electronic products and notification of defects, also repair or replacement.
- *Resource Conservation and Recovery Act of 1976* RL. 94–580 (as amended). (Revised by the Hazardous and Solid Waste Amendments of 1984, P.L. 98–616.) Requires a regulatory system for the generation, treatment, transport, storage, and disposal of hazardous wastes—that is, hazardous to human health or to the environment, including a manifest system, from the "cradle to the grave." This conserves natural resources directly and through resource recovery from wastes. It protects groundwater from contamination and controls landfills and underground storage tanks for hazardous materials and lagoons. Land disposal, landfilling, placement in salt domes, beds, or underground mines, and injection of hazardous wastes into or above underground drinking water source are banned. Small generators, transporters, and disposers are also regulated.
- *River and Harbor Act of 1899*. Prohibits discharge of refuse to navigable waters. Also *Oil Pollution Control Act of 1924*. U.S. Army Corps of Engineers is the responsible agency.
- *Safe Drinking Water Act of 1974* PL. 93–523 (as amended 1986). Authorizes the EPA to establish regulations for drinking water in public water systems, including microbiological, radiologic, organic and inorganic chemical standards, and turbidity levels in drinking water, to protect the public's health. Also controls underground injection of hazardous waste and lead in drinking water, permits sole-source aquifer designation, and provides for water supply source and wellhead protection.

- *Solid Waste Disposal Act of 1965* PL. 89−272 (as amended 1992, 1996). Initiates and accelerates a national research and development program for new and improved methods of proper and economic solid waste disposal and to provide technical and financial assistance to appropriate agencies in the planning, development, and conduct of solid waste disposal programs. The Secretary of Health, Education, and Welfare (program transferred to the EPA) was responsible for the administration of the act with respect to solid waste problems of communities and their environments, including those solid-waste residues that result from business, agricultural, and industrial activities. The Department of the Interior was responsible for solving industrial solid-waste problems within facilities engaged in extraction, processing, or utilization of minerals and fossil fuels.
- *Surface Mining Control and Reclamation Act of 1977* PL. 95−87. The U.S. Department of the Interior sets standards to control disturbance of the land from mining and to assure reclamation afterward. The act also deals comprehensively with specific types of pollution affecting ground-waters.
- *Toxic Substances Control Act of 1976* PL. 94−569. Grants the EPA authority to control manufacture, distribution, and use of new and existing chemical substances that present an unreasonable risk of injury to health or the environment, except for pesticides, foods, drugs, cosmetics, tobacco, liquor, and several additional categories of chemicals regulated under other federal laws; develop adequate data and knowledge on the effects of chemical substances and mixtures on health and the environment; establish an inventory and selectively act on those that appear to pose potential hazard; and devise a system to examine new chemicals before they reach the marketplace.
- *Uranium Mill Tailings Radiation Control Act of 1978* (as amended). Requires the cleanup of radioactive contamination, including ground-water, remaining from inactive processing sites.

Lead Poisoning

Lead is a cumulative poison ending up in the bones, blood, and tissue. Lead is also found in the urine. It is not readily excreted by children. It may cause mental retardation, blindness, chronic kidney diseases, fatigue, anemia, gastroenteritis, muscular paralysis, behavioral changes, high blood pressure, birth defects, and other impairments. Lead poisoning is commonly associated with children living in old and substandard housing built before 1950 who eat lead-based paint on woodwork and paint that peels or flakes from walls (both inside and outside of buildings), ceilings, and other surfaces. However, other sources of lead, as discussed below, may contribute to or be the major cause of high blood lead levels.

Removal of lead-based paint requires special precautions to protect children, adults, and workers from inhaling dust and fumes. Sanding causes the release of lead-laden dust, and open-flame burning or torching releases lead fumes. A heat gun is preferred. Precautions include enclosure of the work area to prevent spread of the dust to other apartments or public areas; protection of furnishings and clothing in the apartments; worker protection, including proper respirator and clothing; complete dust removal and collection using a vacuum with a high-efficiency particle air filter; and proper disposal of the dust and debris, all in accordance with building code, the Department of Housing and Urban Development (HUD), the EPA, and related regulations. The effectiveness of dust removal and cleanup should be determined by surface sampling (floors, walls, window sills) before and after paint removal. Encapsulating the lead-based paint may be a preferred and acceptable alternative to removal if approved by the regulatory agency. Easily accessible locations, such as window sills, should be given priority.

Lead was banned from housepaint in 1978. Food canners stopped using lead solder in the manufacture of tin cans in 1991, and lead in gasoline was phased out in 1995. Thus the number of children with potentially harmful levels of lead in the blood ($>10\ \mu g/dl$) has dropped by 85 percent in the last 20 years. However, there are still many older homes with lead paint, which has further deteriorated and presents a great risk to children and adults who live in or near those homes. Lead is still in the soil, especially near major freeways and highways, at some worksites, and occasionally in drinking water, ceramics, and a number of other products.

Children two to three years old absorb 30 to 75 percent of their lead from ingesting substances, as compared to 11 percent for adults.[68] Adults excrete up to 95 percent of ingested lead, whereas children may absorb half of it. Other sources of lead are lead fumes and ashes produced in battery repair and burning lead battery casings, inadequately ventilated indoor firing ranges, emissions from industrial processes, soft corrosive water standing and flowing in lead pipe, pipe with lead-soldered joints, some bronze and brass faucets, and chrome-plated fixtures; natural or added lead in food and drink; lead in dust and soil; making lead type; handling lead scrap; lead in lead arsenate pesticides; radiator repair; pottery and ceramics manufacture; lead crystal decanters; lead-soldered cans; colored newsprint; household dust in urban areas; and lead in some household products, all of which contribute to the body burden.

On one hand, the phasing out of tetraethyl lead from gasoline has introduced a potential and unknown problem associated with manganese compounds used as a replacement for lead, which are emitted at low levels in various forms, including the toxic manganese tetroxide. On the other hand, a HUD study between 1970 and 1976 in New York City showed a drop in blood lead levels in children from 30 to 21 $\mu g/100\,ml$ (same as 30–21 $\mu g/dl$) of blood. The drop paralleled a recorded decrease of lead in the ambient air, suggesting a significant relationship.[69] A report from the National Center for Health Statistics found that 90 percent of all lead in the air came from leaded gasoline and that the blood lead level of the average U.S. resident between 1976 and 1980 dropped 38 percent, from 14.9 to 9.2 $\mu g/100\,ml$, and continued through 1986.[70] This drop in blood lead level reinforces previous findings and the relationship to greater use of unleaded gasoline.

Serious illness and death have been attributed to the use of earthenware pottery with improperly heated lead-based glaze. Such glaze dissolves in fruit juice, acid salad dressing, tomato sauce, coffee, wine, soda pop, and other soft acid drinks. Most of the glaze applied to pottery contains lead. When pottery, dinnerware, and other ceramics are not fired long enough at the correct temperature or the glaze is not properly formulated, the glaze will not fuse and seal completely and its lead (and possibly cadmium) component can be leached or released. Moonshine whiskey made in stills containing lead has also been implicated. The FDA has set a limit of 0.5 ppm lead leachate for ceramics used to store acid liquids (including large bowls) and 7.0 ppm for ceramics used for liquids or food service (dishes), with 5.0 ppm for small bowls. Commercial laboratories can analyze dishes, bowls, pitchers, and cups for improper lead glaze.

Control of lead poisoning is approached through identification and removal of lead sources and through screening of children, workers and their families where exposure has occurred. This includes residents of neighborhoods with older homes that have not been kept up.

Additional controls include identification through selective systematic inspection of housing, mostly built before 1950 or 1960, and removal of lead-based paint containing more than 0.05 percent lead by weight; prohibition of sale of toys or baby furniture containing lead paint; removal of dust from floors by wet mop or vacuum; and promotion of hygiene and handwashing by children and adults; education of parents, social workers, public health professionals, health guides, owners of old buildings, and those occupationally exposed to the hazard and its control. The X-ray fluorescence lead paint analyzer has improved hazard identification. Paint analysis by a laboratory is necessary for lead concentrations below the fluorescence analyzer sensitivity. Building codes should prohibit the use of lead solder, pipe, and fittings. The sale of drinking water coolers with lead-lined tanks or piping is also prohibited. Lead water service lines should be replaced.

The national ambient air quality standard for airborne lead is 1.5 μg/m^3 of air averaged over a 3-month period. The OSHA permissible lead exposure level averaged over an 8-hour work day is 50 μg/m^3, but if the air-borne lead concentration averages 30 μg/m^3 during a work shift, a control program and medical surveillance are required. Persons who work in lead smelters, brass foundries, storage battery–manufacturing plants, and plastic-compounding factories and persons cutting through metal structures coated with lead-based paint or who remove such paints from tanks or other structures are at high risk for lead toxicity.

It is believed that lead poisoning contributed to the decline of the Roman Empire and the associated deaths, disease, and sterility. The poisoning was due to water distribution in lead pipes and the widespread practice of cooking in lead-based utensils (old pewter), particularly the cooking of a syrup used to preserve and enhance the taste of wine.

There is evidence that there is no acceptable level of lead in humans. Even low levels (below 25 μg/dl) may cause brain damage. It is theorized “that lead, as well as other toxic pollutants may interfere with calcium flow into neurons, thereby disrupting the learning process" in children.[71]

The CDC guideline for blood lead level has been lowered to 10 μg/dl. This will increase the number of children under age 6 at risk by 10 times according to CDC estimates.

Carbon Monoxide Poisoning

Carbon monoxide poisoning is sometimes confused with food poisoning, as nausea and vomiting are common to both. In carbon monoxide poisoning, the additional symptoms include headache, drowsiness, dizziness, flushed complexion, and general weakness, and carbon monoxide is found in the blood. Excessive exposure results in reduced oxygen availability to the heart, brain, and muscles, leading to weakness, loss of consciousness, and possible death. Persons with cardiovascular diseases are very sensitive to carbon monoxide in low concentrations.

Carbon monoxide combines readily with blood hemoglobin to form carboxyhemoglobin (COHb), thereby reducing the amount of hemoglobin available to carry oxygen to other parts of the body. Hemoglobin has a greater affinity for carbon monoxide than for oxygen—about 210 to 1. Fortunately, the formation of COHb is a reversible process. Death can occur when blood contains 60 to 80 percent COHb.

Carbon monoxide is an odorless, tasteless, and colorless gas. It is a product of incomplete combustion of carbonaceous fuels. Poisoning is caused by leaks in an automobile exhaust system; running a gasoline or diesel engine indoors or while parked; unvented or defective kerosene, gas,* fuel oil, coal, or wood-burning space or water heater, gas range-oven, or gas-fired floor furnace; use of charcoal grill indoors; clogged or leaking chimney or vent; inadequate ventilation and fresh air for complete combustion; improperly operating gas refrigerator; and incomplete combustion of liquefied petroleum gas in recreational and camping units. The indoor work environment (use of a fork lift or other motorized equipment) may also be a hazardous source of carbon monoxide.

Motor vehicle exhausts are the principal source of carbon monoxide air pollution; however, federal standards and emission controls on new automobiles are reducing the ambient-air carbon monoxide levels. Room space heaters are a major potential hazard indoors. Cigarette smoke is also a significant source of carbon monoxide to the smoker.

Education of the public and medical care personnel, standards for appliances, and housing code enforcement can reduce exposure and death from this poisoning. Homes in low-socioeconomic areas can be expected to have the highest carbon monoxide levels.

Concentrations of 70 to 100 ppm carbon monoxide are not unusual in city traffic. The federal ambient-air-quality standard maximum 8-hour concentration is 10 mg/m^3 (9 ppm); the maximum 1-hour concentration is 40 mg/m^3 (35 ppm).

*Including methane, butane, and propane.

These levels can reduce mental efficiency. The standard recommended by the National Institute for Occupational Safety and Health is (NIOSH) 55 mg/m^3 (50 ppm) 8-hour time-weighted average. Carbon monoxide levels of 200 to 400 ppm may cause headache and levels of 800 to 1600 ppm unconsciousness; even 50 ppm for 120 minutes has been shown to reduce exercise tolerance in subjects with angina. Persons with cardiovascular diseases are sensitive to concentrations of 35 ppm and as low as 10 ppm for extended periods.

Mercury Poisoning

Mercury poisoning in humans has been associated with the consumption of methylmercury-contaminated fish, shellfish, bread, and pork and, in wildlife, through the consumption of contaminated seed. Fish and shellfish poisoning occurred in Japan in the Minamata River and Bay region and at Niigata between 1953 and 1964. Bread poisoning occurred as a result of the use of wheat seed treated with a mercury fungicide to make bread in West Pakistan in 1961, Central Iraq in 1960 and 1965, and Panorama, Guatemala, in 1963 and 1964. Pork poisoning took place in Alamagordo, New Mexico, when methylmercury-treated seed was fed to hogs that were eaten by a family. In Sweden, the use of methylmercury as a seed fungicide was banned in 1966 in view of the drastic reduction in the wild bird population attributed to treated seed. In Yakima, Washington, early recognition of the hazard prevented illness when 16 members of an extended family were exposed to organic mercury poisoning in 1976 by the consumption of eggs from chickens fed mercurytreated seed grain. The grain contained 15,000 ppb total mercury, an egg 596 and 1902 ppb, respectively, of organic and inorganic mercury. Blood levels in the family ranged from 0.9 to 20.2 ppb in a man who ate eight eggs per day. A whole-blood level above 20 ppb may pose a mercury poisoning hazard.

It is also reported that crops grown from seed dressed with minimal amounts of methylmercury contain enough mercury to contribute to an accumulation in the food chain reaching humans. The discovery of moderate amounts of mercury in tuna and most freshwater fish and relatively large amounts in swordfish by many investigators in 1969 and 1970 tended to further dramatize the problem.

The organic methylmercury and other alkylmercury compounds are highly toxic. Depending on the concentration and intake, they can cause fever, chills, nausea, unusual weakness, fatigue, and apathy followed by neurologic disorders. Numbness around the mouth, loss of side vision, poor coordination in speech and gait, tremors of hands, irritability, and depression are additional symptoms leading possibly to blindness, paralysis, and death. Methylmercury also attacks vital organs such as the liver and kidney. It concentrates in the fetus and can cause birth defects.

Methylmercury has an estimated biological half-life of 70 to 74 days in humans, depending on such factors as age, size, and metabolism, and is excreted mostly in the feces at the rate of about 1 percent per day. Mercury persists in large fish such as pike from 1 to 2 years.

Elemental metallic mercury volatilizes on exposure to air, especially if heated, and in that state poses a distinct hazard. Mercury spills and the mercury from broken thermometers and barometers must be meticulously cleaned and the space ventilated and isolated until the mercury vapor level is no longer detectable by a "mercury sniffer" or similar device. Metallic mercury should never be incinerated; toxic gases would be released. Mercury should normally be stored and handled in an airtight enclosure with extreme care. Laboratory use must be carefully controlled and monitored. Certain compounds of mercury may be absorbed through the skin, gastrointestinal tract, and respiratory system (up to 98 percent), although elemental mercury and inorganic mercury compounds are not absorbed to any great extent* through the digestive tract because they do not remain in the body.

Mercury is ubiquitous in the environment. The sources are both natural and manmade. Natural sources are leachings, erosion, and volatilization from mercury-containing geologic formations. Carbonaceous shales average 400 to 500 ppb Hg, up to 0.8 ppm in soil. Manmade sources are waste discharges from chlor-alkali and paper pulp manufacturing plants, mining and extraction of mercury from cinnabar, chemical manufacture and formation, the manufacture of scientific instruments, mercury seals and controls, treated seeds, combustion of fossil fuels, atmospheric deposition, and surface runoff. The mercury ends up in lakes, streams, tidal water, and the bottom mud and sludge deposits.

Microorganisms and macroorganisms in water and bottom deposits can transform metallic mercury, inorganic divalent mercury, phenylmercury, and alkoxyalkylmercury into methylmercury. The methylmercury thus formed and perhaps other types, in addition to that discharged in wastewaters, are assimilated and accumulated by aquatic and marine life such as plankton, small fish, and large fish. Alkaline waters tend to favor production of the more volatile dimethylmercury, but acid waters are believed to favor retention of the dimethyl form in the bottom deposits. Under anaerobic conditions, the inorganic mercury ions are precipitated to insoluble mercury sulfide in the presence of hydrogen sulfide. The process of methylation will continue as long as organisms are present and have access to mercury. It is a very slow process, but exposure of bottom sediment such as at low tide permits aerobic action causing methylation of the inorganic mercury.

The form of mercury in fish has been found to be practically all methylmercury, and there are indications that a significant part of the mercury found in eggs and meat is in the form of methylmercury.

The concentration of mercury in fish and other aquatic animals and in wildlife is not unusual. Examination of preserved fish collected in 1927 and 1939 from Lake Ontario and Lake Champlain in New York has shown concentrations up to 1.3 ppm mercury (wet basis). Fish from remote ponds, lakes, and reservoirs have

*Seven to 8 percent from food and 15 percent or less from water (*Guidelines for Drinking Water Quality*, Vol. 2, World Health Organization, Geneva, 1984, p. 122).

shown 0.05 to 0.7 ppm or more mercury, with the larger and older fish showing the higher concentration.

There is no evidence to show that the mercury in the current daily dietary intake has caused any harm, although this does not rule out possible nondetectable effects on brain cells or other tissues. The general population should probably not eat more than one freshwater-fish meal per week.

Since mercury comes from manmade and natural sources, every effort must be made to eliminate mercury discharges into the environment. The general preventive and control measures applicable to chemical pollutants were summarized previously under "Background," but the goal should be "zero discharge."

Habashi[72] has summarized techniques for the removal of mercury at metallurgical plants in the United States, Europe, and Japan. The author reports that "the removal and recovery of traces of mercury from SO_2 gases or from sulfuric acid has been proved to be technically and economically feasible." Insofar as water supply is concerned, approximately 98 percent of inorganic mercury may be removed by coagulation and settling at a pH of 9.5 followed by filtration through a granular activated carbon filter.

Illnesses Associated with Air Pollution — Lung Diseases

The particulate and gaseous contaminants in polluted air may irritate the eyes and respiratory system or damage the clearance mechanism of the lungs, thereby increasing susceptibility to upper respiratory diseases and aggravating existing chronic illnesses. Diseases mentioned as *also* being associated with air pollution include bronchial asthma (restriction of the smaller airways or bronchioles and increase in mucous secretions), chronic bronchitis (excessive mucus and frequent cough), pulmonary emphysema (shortness of breath), lung cancer, heart diseases, and conjunctivitis (inflammation of the lids and coatings of the eyeballs) (also with lead and carbon monoxide poisoning as previously discussed). In an example of the built environment influencing health, one study found the higher prevalence of asthma in poor neighborhoods of Hartford, Connecticut, to be due in large part to a heavy burden of dust laden with cockroach antigen.[73]

A direct single cause-and-effect relationship is often difficult to prove because of the many other causative factors and variables usually involved. Nevertheless, the higher morbidity and mortality associated with higher levels of air pollution and reported episodes are believed to show a positive relationship.

Certain air contaminants, depending on the body burden, may produce systemic effects. These include arsenic, asbestos, cadmium, beryllium compounds, mercury, manganese compounds, carbon monoxide, fluorides, hydrocarbons, mercaptans, inorganic particulates, lead, radioactive isotopes, carcinogens, and insecticides. They require attention and are being given consideration in the development of air quality criteria.

Bronchial asthma affects susceptible sensitive individuals exposed to irritant air contaminants and aeroallergens. The aeroallergens include pollens, spores, rusts, and smuts. There also appears to be a good correlation between asthmatic attacks in children and adults and air pollution levels.

Chronic bronchitis has many contributing factors, including a low socioeconomic status, occupational exposure, and population density; smoking is a major factor. Air pollution resulting in smoke, particulates, and sulfur dioxide is an additional factor.

Emphysema mortality rates in U.S. urban areas are approximately twice the rural rates, indicating an association with air pollution levels (sulfur oxides). Asthma and bronchitis often precede emphysema.

Lung cancer rates are reported to be higher among the urban populations than the rural. The dominant factor in lung cancer is smoking. Air pollution plays a small but continuous role.

Some generalized effects of common air pollutants and their possible relationship to these diseases are of interest. Sulfur dioxide and sulfuric acid in low concentrations irritate the lungs, nose, and throat. This can cause the membrane lining of the bronchial tubes to become swollen and eroded, with resultant clotting in the small arteries and veins. Children are more susceptible to coughs, colds, asthma, bronchitis, and croup. Carbon monoxide can affect the cardiovascular system; in high concentrations, the heart, brain, and physical activity can be impaired. It can reach dangerous levels where there is heavy auto traffic and little wind. Smokers are at greater risk. Acute carbon monoxide poisoning causes a lowered concentration of oxygen in the blood and body tissues. (See the discussion on carbon monoxide poisoning earlier in this chapter.) Ozone and other organic oxidants, known as photochemical oxidants, are produced by the reaction of hydrocarbons and nitrogen oxides in sunlight. Ozone is believed to be responsible for a large portion of the health problems associated with photochemical oxidants.[74] Ozone and other chemicals formed in smog irritate the eyes and air passages, causing chest pain, coughing, shortness of breath, and nausea. Ozone can cause aging and severe damage to the lung tissues and interference with normal functioning of the lungs at levels of 0.12 ppm to greater than 0.20 ppm. Nitrogen dioxide in high concentrations can result in acute obstruction of the air passages and inflammation of the smaller bronchi. Nitrogen dioxide at low levels causes eye and bronchial irritation. In the presence of strong sunlight, nitrogen dioxide breaks down into nitric oxide and atomic oxygen, and this then combines with molecular oxygen in air to form ozone. Particulate matter can cause eye and throat irritation, bronchitis, lung damage, and impaired visibility.

Benzopyrene and related compounds are known to cause some types of cancer under laboratory conditions and have been incriminated as carcinogens. Olefins have an injurious effect on certain body cells and are apt to cause eye irritation. Beryllium concern relates primarily to lung disease, although it also affects the liver, spleen, kidneys, and lymph glands. Vinyl chloride is related to lung and liver cancer. Mercury may affect several areas of the brain as well as the kidneys and bowels. Lead is associated with retardation and brain damage, especially in children (see separate discussion earlier). The EPA National Emission Standards for Hazardous Air Pollutants identify vinyl chloride, lead, benzene, asbestos, beryllium, and mercury as hazardous. Considerable evidence has been assembled linking air pollution with adverse health effects.[225, 226]

Asbestos Diseases

Asbestosis is caused by fine silicate fibers retained in the lungs. There are six grades of asbestos. The most common are crocidolite (blue asbestos), amosite (brown asbestos), and chrysotile (white asbestos), which come from serpentine, and the less common are actinolite, tremolite, and anthrophyllite. Fibers are 0.1 to 10 μm in length, a size not generally visible. Positive identification requires laboratory analysis. The crocidolite fibers, the most hazardous, are straight and stiff (crocidolite has rarely been used since World War II), the amosite are less so; the chrysotile are curly. Fibers that are stiff and elongated lodge across the bronchi and eventually pass into the lung tissue and pleural cavity. Hence, more of the crocidolite is retained in the lungs and may be the cause of most asbestosis. However, chrysotile* is as likely as crocidolite and other fine silicate fibers to induce mesotheliomas after intrapleural entry and also as likely to induce lung neoplasms after inhalation exposures, although it is of less risk than crocidolite. The four most common diseases that might result from asbestos, usually after prolonged exposure, are listed here. The disease may appear 10 to 35 years after first exposure:

1. *Asbestosis*—a diffuse interstitial nonmalignant, scarring of the lungs
2. *Bronchogenic carcinoma*—a malignancy of the interior of the lungs
3. *Mesothelioma*—a diffuse malignancy of the lining of the chest cavity (pleural mesothelioma) or of the lining of the abdomen (peritoneal mesothelioma)
4. Cancer of the stomach, colon, and rectum

A potential health risk exists when asbestos fibers become airborne, as in the deterioration and exposure of asbestos in old asbestos paper-lined air distribution ducts, acoustic plaster ceilings, decorative and textured-spray finishes or paints and fire-retardant coatings on steel beams, and the demolition of old buildings. Spackling and other patching compounds may contain asbestos, which would be released to the ambient air in mixing and sanding to prepare the surface for painting. Fireplaces that simulate live embers and ash usually contain asbestos in an inhalable form. Other sources include furnace patching compounds, old steam pipe covers, floor materials, brake linings, paints, and certain domestic appliances. Asbestos is also found in some surface waters, urban stormwaters, and soils and generally in urban areas. However, occupational exposure is the major risk.

The EPA, under authority of the Toxic Substances Control Act of 1976, ruled on July 6, 1989, that all manufacture, import, or processing of felt products, asbestos–cement sheets, floor tiles, and clothing containing asbestos be ended by August 1990 and that distribution be ended in 1992; that disc brake linings

*Chrysotile fibers are estimated to make up 90 percent of all asbestos ("The asbestos dilema," *U.S. News & World Report*, January 14, 1990, pp. 57–58).

and gaskets be ended by August 1993 and their distribution by 1994; and that the manufacture, import, or processing of asbestos–containing paper products, brake blocks and pads, and asbestos-cement pipe and shingles be ended by August 1996 and distribution ended in 1997.* The CPSC has banned the use of sprayed-on asbestos insulation, spackling compound, and fireplace logs made with asbestos.

Airborne asbestos is potentially hazardous where asbestos-containing materials are loosely bound or deteriorating (friable, crumbly, or powdery when dry), including areas subject to vibration or abrasion, permitting fibers to be released. Control measures in buildings include removal, coating, or sealing (with butyl rubber in inaccessible locations) the surface; enclosure to prevent escape of fibers; surveillance; and affirmative action when the asbestos material begins to lose its integrity. *Existing asbestos that is sound is best left undisturbed*. Schools are required to be inspected to identify both deteriorating and solid asbestos. The coating or sealer used must be flame resistant, and must not release toxic gases or smoke when burned or contain asbestos. Coating or sealing must be considered an expedient requiring continual surveillance. Removal poses added risks to renovation, demolition, and other workers and occupants; it may also cause air pollution and dangers in handling (respirators, disposable garments, showering, complete enclosure of work area, and wetting down are needed) and disposal.

Malignant Neoplasms (Cancer)

Cancer is any malignant growth in the body. It is an uncontrolled multiplication of abnormal body cells. The cause of the various types of cancer is unknown, circumstantial, or unclear except for cigarette smoking and exposure to ionizing radiation. There does not appear to be a dosage or level of exposure to cigarette smoking or ionizing radiation below which there is *no* risk. Viruses, genetic background, poor health, and exposure to various agents in our air, water, food, drugs, and cosmetics are believed to contribute to the disease. Some environmental substances become carcinogenic only after metabolism within the body, and gene-environment interactions are believed to be crucial in determining an individual's risk to developing cancer from exposure to toxins.

Cardiovascular Diseases

The following are the major cardiovascular diseases.

- Ischemic heart disease (coronary heart disease)—a deficiency of the blood supply; the principal disease of the heart.

*The EPA ban on, e.g., pipe and pads was overturned by the U.S. Court of Appeals for the 5th Circuit in New Orleans. The ban on insulation, patching, and clothing remains in effect. (P. Zurer, *C&EN, October* 28, 1991, p. 5. Also, EPA Asbestos Materials Bans: Clarification May 18, 1999, EPA Office of Pollution Prevention and Toxics Web page, http://www.epa.gov/opptintr/opptintr/asbestos/help.htm#Roles. December 2001.)

- Cerebrovascular disease (stroke)—an occlusion or rupture of an artery to the brain.
- Arteriosclerosis—a thickening or hardening of the walls of the arteries, as in old age. Atheroselerosis is the most common form; fatty substances (containing cholesterol) deposited on the inner lining restrict the flow of blood in the arteries, causing coronary thrombosis (an occlusion of arteries supplying heart muscle). Hypertension (high blood pressure) and hypertensive heart disease. Rheumatic fever and rheumatic heart disease.

The risk factors associated with cardiovascular diseases include cigarette smoking, poor nutrition, socioeconomic status, age, sedentary way of life, family history, severe stress, personality type, and high blood pressure. Cardiovascular diseases have also been linked to high amounts of total fats, saturated fats, cholesterol, and sodium in the diet. Persons with cardiovascular diseases are more sensitive to carbon monoxide in low concentrations. Obesity and excessive alcohol intake are associated with hypertension.

The Council on Environmental Quality[75] confirmed reports showing that the death rates from cardiovascular diseases tend to decrease as the hardness of drinking water increases, but the factor is not considered to be hardness per se. The direct relationship between cardiovascular death rates and the degree of softness or acidity of water, according to Schroeder, points to cadmium as the suspect.[76] Large concentrations of cadmium may also be related to hypertension in addition to kidney damage, chronic bronchitis, and emphysema. Cadmium builds up in the human body. Low levels of magnesium in soft drinking water are also linked to sudden cardiac death. The indications are that the effects of soft water on cardiovascular diseases may be relatively small. Nevertheless, the water association deserves close attention since cardiovascular disease deaths account for about one-third of all deaths in the United States.

There is also evidence associating the ingestion of sodium with heart disease as well as with kidney disease and cirrhosis of the liver. Soft waters and reused waters generally contain higher concentrations of sodium than hard waters. Incidentally, diet drinks generally contain more sodium than regular soft drinks, as do sodium-containing dried milk preparations and cream substitutes. Home drinking water supplies softened by the ion exchange process (most home softeners) contain too much sodium for persons on sodium-restricted diets.* This can be avoided by having the cold-water line bypass the softener and using only the cold water for drinking and cooking. Other sources of sodium in drinking water are road salt contamination of surface and groundwater supplies; the sodium hydroxide, sodium carbonate, and sodium hypochlorite used in water treatment; sodium in distilled and bottled water; carbonated water in soft drinks; lime–soda ash and zeolite softened municipal water supplies; and natural minerals in sources of drinking water. The total body burden including that from food and drink must

*Each grain per gallon (17.1 mg/1) of hardness removed will add 8 mg/1 sodium to the treated water.

be considered. The crude death rate has decreased from 366.4 per 100,000 population in 1960 to 314.2 in 1988. The age-adjusted rate decreased from a peak of 307.4 in 1950 to 134.6 in 1996, an overall decline of 56 percent. This decline is due to a number of factors, including a decrease in the number of adults who smoke cigarettes, better control of hypertension, less ingestion of cholesterol and control of cholesterol levels, and improvements in medical care.

Methemoglobinemia

The presence of more than 45 mg/1 nitrates (10 mg/1 as N), the standard for drinking water, appears to be the cause of methemoglobinemia, or "blue baby." The disease is largely confined to infants less than three months old but may affect children up to age 6. It is caused by the bacterial conversion of the nitrate ion ingested in water, formula, and other food to nitrite. Nitrite then converts hemoglobin, the blood pigment that carries oxygen from the lungs to the tissues, to methemoglobin. Because the altered pigment no longer can transport oxygen, the physiologic effect is oxygen deprivation, or suffocation. Methemoglobinemia is not a problem in adults, as the stomach pH is normally less than 4, whereas the pH is generally higher in infants, allowing nitrate-reducing bacteria to survive.

Dental Caries

Fluoride deficiency is associated with dental caries and osteoporosis. [77] Water containing 0.8 to 1.7 mg/1 natural or artificially added fluoride is beneficial to children during the period they are developing permanent teeth. The incidence of dental cavities, or tooth decay, is reduced by about 60 percent. The maximum fluoride concentration permissible in drinking water is 4.0 mg/1. Optimum fluoride levels in drinking water for caries control, based on the annual average of the maximum daily air temperature for the location of the community water system, are as follows:

Temperature (°F)	Fluoride Level (mg/1)
53.7 and below	1.2
53.8–58.3	1.1
58.4–63.8	1.0
63.9–70.6	0.9
70.7–79.2	0.8
79.3–90.5	0.7

An alternate to community water fluoridation is a 1-minute mouth rinse by children once a week; it is reported to reduce tooth decay by about one-third or more. The mouth rinse also appears to be beneficial to adults in the prevention of dental caries. Other alternatives include fluoridation of school water supplies if there is an onsite water supply, use of fluoride toothpaste, drops and tablets, and topical application. Milk fluoridation has been shown to be effective in the prevention of dental caries, but to be clinically effective, it must be freshly prepared and consumed immediately. The use of table salt containing fluoride has been proposed by the Pan American Health Organization in areas lacking fluoridated community water supplies. Oral hygiene, including at least daily teeth brushing, consumption of fewer sweets, followed by water rinse or drink, is also basic to caries reduction.

Hypothermia

The maintenance of a normal body temperature at or near 98.4°F (37°C) is necessary for proper body function. When the body core temperature drops to 95°F (35°C) or below, the vital organs (brain, heart, lungs, kidneys) are affected, causing what is known as hypothermia. There were 7,450 deaths from hypothermia reported between 1976 and 1985. In 2001, Montana had a death rate from hypothermia of 1.08 per 100,000, which is nearly fives time greater than the overall U.S. rate.[78] Rectal temperature measurement is necessary to get a correct reading. Special "hypothermia thermometers" for accurate reading are available. Predisposing conditions for hypothermia include old age, poor housing, inadequate clothing, poverty, lack of fuel, illness, cold weather, alcohol, and drugs.

Proper body temperature requires a balance between body heat generated and heat loss. Bald people lose a great deal of heat; fat people are better insulated and lose less heat on a weight–body surface basis. Disease and drugs, including alcohol, affect heat loss. Wind and dampness increase coldness. The maintenance of warmth and comfort is related to the prevailing temperature, building design and construction, clothing, heating and cooling facilities, and food consumed and also to air movement, radiant heat, relative humidity, the tasks performed, and the age and health status of individuals. At greater risk are babies and the elderly, particularly those already suffering from an acute or chronic illness. Provision for heating and cooling above and below that temperature is recommended. Lack of adequate housing and acute alcohol intoxication are the principal causes of death, as well as advanced age and adverse social and economic circumstances (homelessness).

Signs of hypothermia are bloated face, pale and waxy skin or pinkish color, drowsiness, low blood pressure, irregular and slow heart beat, shallow very slow breathing, trembling of leg, arm, or side of body, and stiff muscles. People should stay indoors when the windchill index is −20°F (−29°C) and below.

High Environmental Temperatures

Heat waves have been associated with marked increases in morbidity and mortality in the United States, but these deaths are largely preventable. Heat disorders include heatstroke, heat exhaustion, heat cramps, and heat rash. Heatstroke, when one's core temperature exceeds 105°F (40.5°C), is the most serious. The measures that have been shown to be effective to reduce heat stress include the following:

1. Keep as cool as possible.
   a. Avoid direct sunlight.
   b. Stay in the coolest available location (it will usually be indoors).
   c. Use air conditioning, if available.
   d. Use electric fans to promote cooling.
   e. Place wet towels or ice bags on the body or dampen clothing.
   f. Take cool baths or showers.
2. Wear lightweight, loose-fitting clothing.
3. Avoid strenuous physical activity, particularly in the sun and during the hottest part of the day.
4. Increase intake of fluids, such as water and fruit or vegetable juices. Thirst is not always a good indicator of adequacy of fluid intake. Persons for whom salt or fluid is restricted should consult their physicians for instructions on appropriate fluid and salt intake.
5. Do not take salt tablets unless so instructed by a physician.
6. Avoid alcoholic beverages (beer, wine, and liquor).
7. Stay in at least daily contact with other people.

Special precautions should be taken for certain higher-risk groups, including those occupationally exposed. Safeguards may include increased efforts to keep cool and close observation by others for early signs of heat illness. The high-risk groups are infants and children less than 4 years of age, persons over 65 years of age, alcoholics, persons who are less able to care for themselves because of mental illness or dementia, persons with chronic diseases, especially cardiovascular or kidney disease, and those taking any of the three classes of medication that reduce the ability to sweat: diuretics (water pills), tranquilizers, and drugs used for the treatment of gastrointestinal disorders. Building insulation and ventilation help control indoor temperature. Temperatures of 85°F (29°C) or less are usually no cause for worry. High humidity and temperatures near 100°F (38°C) for several days could be dangerous. Strenuous activity should be suspended when the wet bulb temperature index is 90°F (32°C) and above.[79]

Skin Damage from Sunlight

The ultraviolet light in sunlight can injure the skin and cause skin cancer (melanoma), depending on the exposure. Melanoma appears as a pigmented mole or tumor that may or may not be malignant. Melanomas are almost always curable if detected early and can be usually removed by surgery or freezing with liquid nitrogen. Cataracts can also result from too much sun.

Anyone exposed to the sun should take precautions to avoid the most intense and most hazardous rays between 11 a.m. and 3 p.m. in the United States. A hat and clothing that covers the body are advised. Bathers should use an effective sunscreen lotion. The higher the sunscreen number, the higher the protection.

The number selected should be based on skin type and expected exposure time. Individuals with light skin are especially vulnerable.

Tap Water Scalds

Residential hot-water heaters with temperature settings above 120°F (48.9°C) are the principal cause of tap water scalds. Young children, the elderly, and the handicapped are most frequently involved. Showers are another potential hazard if capable of discharging water above 120°F. Hot-water heater thermostats should be lowered to 120°F to prevent scalding accidents.

Sporotrichosis

Conifer seedlings packed in sphagnum moss can cause papules or skin ulcers and inflammation on the hands and arms, which can then spread to other parts of the body. This disease is caused by a fungus, *Sporothrix schenckii*, found in moss, hay, soil, and decaying vegetation. Protective clothing, including gloves and long-sleeved shirts, should be worn when handling sphagnum moss or seedlings.

DEFINITIONS

Certain terms with which one should become familiar are frequently used in the discussion of communicable and noninfectious or noncommunicable diseases. Some common definitions are given here.

Antigen(s) Foreign substance(s) inducing the formation of antibodies. In some vaccines, the antigen is highly defined (e.g., pneumococcal polysaccharide, hepatitis B surface antigen, tetanus, or diphtheria toxoids); in others, it is complex or incompletely defined (e.g., killed pertussis bacteria; live, attenuated viruses).[1] Antibodies are specific substances formed by the body in response to stimulation by antigens.

Body burden The total effect on the body from ingestion or exposure to a toxic chemical in the air, water, or food. Can be determined by examination of samples of human hair, tissue, blood, urine, and milk, also by measurement of the amount in air, water, and food, and then the intake from these sources, including contact.

Contact A person or animal that has been in an association with an infected person or animal or a contaminated environment that might provide an opportunity to acquire the infective agent.[3]

Contamination The presence of an infectious agent on a body surface; also on or in clothes, bedding, toys, surgical instruments or dressings, or other inanimate articles or substances, including water and food. *Pollution* is distinct from contamination and implies the presence of offensive, but not necessarily infectious, matter in the environment. Contamination on a body surface does not imply a carrier state.[3]

Disinfection The application of microbicidal chemicals to materials (surfaces as well as water), which come into contact with or are ingested by humans and animals, for the purpose of killing pathogenic microorganisms. Disinfection may not be totally effective against all pathogens.

Disinfestation Any physical or chemical process serving to destroy or remove undesired small animal forms, particularly arthropods or rodents, present upon the person or the clothing, in the environment of an individual, or on domestic animals. Disinfestation includes delousing for infestation with *Pediculus humanus*, the body louse. Synonyms include the terms *disinsection* and *disinsectization* when only insects are involved.[3]

Endemic The constant presence of a disease or infectious agent within a given geographic area; may also refer to the usual prevalence of a given disease within such area. *Hyperendemic* expresses a persistent intense transmission and *holoendemic* a high level of infection, beginning early in life and affecting most of the population (e.g., malaria in some places).

Endotoxin The toxin produced by a microorganism that is retained within the cell but is liberated when the cell disintegrates (as in the intestine) causing pathologic damage to surrounding tissue. Most known varieties of these toxins withstand autoclaving.[6]

Enterotoxin A toxin produced by certain microorganisms that is secreted in the gastrointestinal tract. It is associated with the symptoms of food poisoning and is heat stable. Examples of bacteria know to secrete this type of toxin are: *Escherichia coli* O157: H7, *Clostridium perfringens*, *Vibrio cholerae*, *Staphylococcus aureus*, and *Yersinia enterocolitica*.

Epidemic/outbreak The occurrence in a community or region of cases of an illness in excess of what would be expected during the same time period. The number of cases indicating the presence of an epidemic will vary according to the infectious agent, size and type of population exposed, previous experience or lack of exposure to the disease, and time and place of occurrence; epidemicity is thus relative to usual frequency of the disease in the same area, among the specified population, at the same season of the year. A single case of a communicable disease long absent from a population or the first invasion by a disease not previously recognized in that area requires immediate reporting and epidemiologic investigation; two cases of such a disease associated in time and place are sufficient evidence of transmission to be considered an epidemic. The terms *outbreak* and *epidemic* can technically be used interchangeably; however, the public perception of the latter is more dramatic.

Exotoxin A toxin produced by a microorganism and secreted into the surrounding medium, usually the cellular cytoplasm, blood, or other bodily fluids. Exotoxins can operate on organs and tissues different from the site of infection and can bring about pathological manifestations that are separate from the initial infection, or within the infected cell itself. Genes encoding exotoxins can be acquired by microorganisms that would otherwise cause minor or less severe disease in humans. Some strains of the following bacteria have are common causes of disease associated with exotoxins: *E. coli*, *Staphylococcus aureus*, *Streptococcus pyogenes*, *Clostridium perfringens*, *Shigella* spp., and *Clostridium botulinum*.

LC_{50} The median lethal concentration of a substance in the air, causing death in 50 percent of the animals exposed by inhalation; a measure of acute toxicity.

LD_{50} The median lethal dose, causing death in 50 percent of the animals exposed by swallowing a substance; a measure of acute toxicity.

Neurotoxin A toxin that attacks nerve cells (e.g., botulism).

Noninfectious or noncommunicable disease The chronic, degenerative, and insidious disease that usually develops over an extended period and whose cause may not be entirely clear. In its broad sense, cancer, alcoholism, mental illnesses, tooth decay, ulcers, and lead poisoning are regarded as noncommunicable or noninfectious diseases. Also included are cardiovascular diseases, pulmonary diseases, diabetes, arthritis, nutritional deficiency diseases, malignant neoplasms, kidney diseases, injuries, and illnesses associated with toxic organic and inorganic chemicals and physical agents in air, water, and food. For the purposes of this text, discussion of noninfectious diseases emphasizes the environmental media or factors serving as the vehicle for transmission of the disease. The usual environmental media are air, food, water, and land (soil, flora, fauna); other factors leading to injuries and contact may also be involved.

In contrast to communicable diseases, *chronic diseases* may be caused by a variety or combination of factors that are difficult to identify, treat, and control. The resulting illness may cause protracted or intermittent pain and disability with lengthy hospitalization. A *degenerative condition* is the result of the deterioration or breaking down of a tissue or part of the body (aging).

Pathogen An infectious agent capable of causing disease.

Pathogenic The potential for producing disease, if the organism is sufficiently virulent to enter the body and overcome the defense mechanism of the host.

Prevention, primary Prevention of an etiologic agent, substance, or action from causing disease or injury in humans; intervention; regulation of exposure to environmental hazards that cause disease or injury to decrease morbidity and mortality. Action to promote health and prevent disease or injury. Includes immunization, adequate supply of safe water and basic sanitation, prevention education, food and nutrition, and maternal and child care.

Prevention, secondary Early detection and treatment to cure or control disease. Surveillance, screening, and monitoring the environment. Also measures to protect the public (e.g., treatment of public water supplies, fluoridation for dental control).

Prevention, tertiary Amelioration of a disease to reduce disability or dependence resulting from it. Conventional medical treatment and restoration of health and well-being to the extent possible. Voluntary action by the individual.

Primary health care Application of the principles of health education, nutrition, immunization, water and sanitation, maternal and child care and family planning, control of endemic diseases, treatment of common diseases, and provision of essential drugs [World Health Organization (WHO)].

Public health "Public health is the science and art of preventing disease, prolonging life, and promoting physical and mental health and efficiency through organized community efforts for the sanitation of the environment, the control of community infections, and education of the individual in principles of personal hygiene, the organization of medical and nursing services for the early diagnosis and preventive treatment of disease, and the development of the social machinery that will ensure every individual in the community a standard of living adequate for the maintenance of health."[80]

Sanitation The effective use of measures that create and maintain healthy environmental conditions. Among these measures are the safeguarding of food and water, proper sewage and excreta disposal, and the control of disease-carrying insects and animals.

Sanitize To reduce microorganism level to an acceptable level, usually by the continuous application of heat or chemicals at suitable concentrations and times.

Sterilization The process of killing all microorganisms, including spores.

Susceptible A person or animal presumably not possessing sufficient resistance against a particular pathogenic agent to prevent contracting infection or disease if or when exposed to the agent.[3]

Teratogen An agent (radiation, virus, drug, chemical) that acts during pregnancy to produce a physical or functional defect in the developing offspring. Substances that have caused defects are methylmercury and thalidomide. Some environmental pollutants may be both carcinogenic and teratogenic.

TLV (threshold limit value) The *average* 8-hour occupational exposure limit This means that the actual exposure level may sometimes be higher, sometimes lower, but the average must not exceed the TLV. TLVs are calculated to be safe exposures for a working lifetime.

Toxicity, acute condition Adverse effects occurring shortly after the administration or intake of a single or multiple dose of a substance (oral rat LD_{50}). Conditions classified as acute include viruses, colds, flu, and other respiratory conditions; headaches, gastrointestinal disorders, and other digestive conditions; accidental injuries; genitourinary disorders; diseases of the skin; and other acute conditions. A condition that has lasted less than three months and has involved either a physician visit (medical attention) or restricted activity.

Toxicity, chronic condition An injury that persists because it is irreversible or progressive or because the rate of injury is greater than the rate of repair during a prolonged exposure period (cancer or liver damage). Conditions classified as chronic include major categories of chronic illnesses such as heart disease, hypertension, arthritis, diabetes, ulcers, bronchitis, and emphysema. Any condition lasting three months or more or one of certain conditions classified as chronic regardless of their time of onset.

Toxin A poisonous substance of animal or plant origin.

YPLL Total years of potential life lost, a measure of premature mortality from all causes over the span from age 1 to 65 years based on age-specific death rates.

USEFUL INTERNET WEB SITES

Centers for Disease Control: http://www.cdc.gov. Site includes Emerging Infectious Disease, National Vital Statistics, *MMWR* (*Morbidity and Mortality Weekly*), National Center for Environmental Health, and FoodNet.

World Health Organization: http://www.who.int/.

Environmental Protection Agency: Including National Ambient Air Quality Standards, AIRNOW and Pollution Prevention.

U.S. Dept of Health and Human Services: http://www.dhhs.gov.

Food and Drug Administration: http://www.fda.gov. Including FDA Consumer Magazine and Center for Food Safety and Applied Nutrition.

Taber's Online: http://www.tabers.com. Medical definitions and periodicals.

American Journal of Public Health: http://www.ajph.org.

Library of Congress: http://www.loc.gov/ Thomas Search Engine, which searches the database of the *Congressional Record* for any law or piece of legislation from the 93rd Congress (1973–1974) to the present Congress.

Medline/PubMed: http://www.ncbi.nlm.nih.gov/pubmed.

Powerful search engine for biomedical science literature. Use the "limits" feature to narrow your search.

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CHAPTER 3

FOODBORNE DISEASES

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INTRODUCTION

Enteric infections are the second most common cause of mortality among children less than five years of age in developing countries.[1] Poverty is a fundamental cause of the high mortality associated with enteric infections in the developing world. Issues such as a lack of safe drinking water, crowded living conditions, lack of refrigeration, and inadequate sanitation all contribute to this problem. Additionally, because of a lack of access to health care, enteric infections are more often severe or fatal setting where there are barriers to adequate medical care. In contrast, there is little mortality from enteric infections in industrialized countries. Toward the beginning of the twentieth century, similar conditions were more prevalent in North America and Europe; economic development and improved living conditions are thought to have played a large role in the decrease in deaths from diarrheal diseases and pneumonia by the 1930s.[2]

Foodborne illnesses are estimated to cause 76 million illnesses, 325,000 hospitalizations, and 5,000 deaths in the United States each year.[3] Infectious agents spread by water and food cause both sporadic cases and large outbreaks. Symptoms of these illnesses range from mild gastroenteritis to potentially life-threatening conditions that may cause disability and death. In some instances, as among the very young, the very old, and the immunocompromised, the added strain of a water- or foodborne illness can be fatal. This chapter covers major food- and waterborne diseases of public health importance, including their epidemiology and prevention. Included in this chapter as foodborne diseases are also those caused by poisonous plants and animals used for food, toxins produced by bacteria, and foods accidentally contaminated with chemical poisons. These diseases are usually, but not always, characterized by

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diarrhea, vomiting, nausea, or fever. Additionally, this chapter addresses some related diseases and conditions, including nutritional deficiencies, as well as investigation and control of disease outbreaks.

SURVIVAL OF PATHOGENS

The survival of pathogens is affected by a number of factors, including the type of organism, temperature, moisture, nutrients, pH, and sunlight. Since these factors are quite variable, the survival data in Table 3.1 should be used only as a guide. For some waterborne pathogens, the amount of clay and organic matter in the soil may affect the movement of pathogens, but porous soils, cracks, fissures, and channels in rocks permit pollution to travel long distances.

Despite variations in environmental resistance among pathogens, some generalities can be made. Soil moisture of about 10 to 20 percent of saturation

TABLE 3.1 Survival of Certain Pathogens in Soil and on Plants

Organism	Media	Survival Time (days)
Ascaris ova	Soil	Up to 7 years
	Vegetables and fruits	27–35
Coliforms	Soil surface	38, greater in soil
	Vegetables	35
	Grass and clover	6–34
Cryptosporidium oocyst[a]	Moist environment	60–180
Entamoeba histolytica cysts	Soil	6–8
	Vegetables	1–3
	Water	8–40
Enteroviruses	Soil	8 or longer[b]
	Vegetables	4–6 or longer
Salmonella	Soil	1–120
	Vegetables and fruits	1–68
Salmonella typhosa	Peat soils	Up to 85, 2 years at 0°C
Shigella	Grass (raw wastewater)	42
	Vegetables	2–10
	Water containing humus	160
Tubercle bacilli	Soil	180
	Grass	10–49

Source: D. Parsons et al., "Health Aspects of Sewage Effluent Irrigation," Pollution Control Branch, British Columbia Water Resources Services, Victoria, 1975, cited by E. Epstein and R. L. Chancy, "Land Disposal of Toxic Substances and Water-Related Problems," *J. Water Pollut. Control Fed*. (August 1978): 2037–2042.

Note: The survival of pathogens can be quite variable. [a]A. S. Benenson (Ed.), *Control of Communicable Diseases in Man*, 15th ed., American Public Health Association, Washington, DC., 1990, p. 113.

[b]One or two years at 40°F (4°C).

appears to be best for survival of pathogens; drier conditions generally decrease the ability of a pathogen to survive. Nutrients increase survival. The pH is not a major factor. For most pathogens, exposure to sunlight acts as desiccant rate. Low temperatures favor survival.[4,5] The survival of pathogens in soil, on foods, and following various wastewater unit treatment processes as reported by various investigators, is summarized by Bryan and others.[6,7] Most enteroviruses pass through sewage treatment plants, survive in surface waters, and may pass through water treatment plants providing conventional treatment. Water treatment plants maintaining a free residual chlorine and low turbidity less than 1 nephelometric turbidity unit (NTU) in the finished water, as noted under Chlorine Treatment for Operation and Microbiological Control in Chapter 3, or using other approved disinfection treatment, can accomplish satisfactory virus destruction.

INFECTIOUS DOSE

The development of illness is dependent on three basic things: the toxicity or virulence of a substance, the amount of the substance or microorganisms ingested (at one time or additively over a specified period of time), and the susceptibility of the individual. The result may be an acute or a chronic illness. Exposure to two or more substances may produce a synergistic, additive, or antagonistic effect. Persons may be exposed to a microorganism by direct ingestion of a pathogen or toxin in contaminated water or food, contact with an infected person or animal, or exposure to an aerosol containing the pathogen.

When the dose of a chemical substance administered to a series of animals is plotted against the effect produced, such as illness, if increased doses produce no increases in illnesses, the substance is said to cause “no effect.” If increased doses cause increasing illnesses, the substance has “no threshold.” If increased doses cause no apparent increases in illnesses at first but then continuing increased doses show increasing illnesses, the dose at which illnesses begin to increase is referred to as the substance *threshold*. Below that dose is the “no-observed-effect” range. Variations between animal species must be considered.

Table 3.2 lists various microorganisms and the approximate number (infectious dose) of organisms required to cause disease. Bryan[6] has summarized the work of numerous investigators giving the clinical response of adult humans to varying challenge doses of enteric pathogens. For example, a dose of 10^9 *Streptococcus faecalis* was required to cause illness in 1 to 25 percent of healthy volunteers, 10^8 *Clostridium perfringens* type A (heat resistant) bacteria caused illness in 26 to 50 percent of the volunteers, and 10^9 *C. perfringens* type A (heat sensitive) bacteria caused illness in 76 to 100 percent of the volunteers.

For some viral infections, ingestion of as few as one viral particle can infect a susceptible host. In that case, it would appear that viral infections should be readily spread through drinking water, food, shellfish, and water-contact recreational activities. Fortunately, the tremendous dilution that wastewater containing viruses usually receives on discharge to a watercourse and the chemical treatment of drinking water greatly reduce the probability of an individual receiving

TABLE 3.2 Substance Dose to Cause Illness

Microorganism	Approximate Number of Organisms (Dose) Required to Cause Disease
Campylobacter jejuni[a]	10^2 or fewer
Coxiella burneti[b]	10^7
Cryptosporidium spp.[c]	10^1–10^2 oocysts
Dracunculus, Ascaris, Schistosoma	1 cyst, egg, or larva
Entamoeba histolytica[d]	10–20 cysts, one in a susceptible host
Escherichia coli[b]	10^8
Giardia lamblia[c–f]	5–10^2 cysts
Salmonella typhi[b,g]	10^5–10^6
Salmonella typhimurium[g]	10^3–10^4
Shigella spp.[b,g]	10^1–10^2
Staphylococcus aureus[b]	10^6–10^7 viable enterotoxin-producing cells per gram of food or milliliter of milk
Vibrio cholerae[b,g]	10^6–10^9

[a]Robert V. Tauxe et al., "*Campylobacter* Isolates in the United States, 1982–1986," *MMWR CDC Surveillance Summaries*, June 1988, p. 9.
[b]H. L. Dupont and R. B. Hornick, "Infectious Disease from Food," in *Environmental Problems in Medicine*, W. C. McKee (Ed.), Charles C. Thomas, Springfield, IL, 1974.
[c]R. M. Clark et al., "Analysis of Inactivation of *Giardia lamblia* by Chlorine," *J. Environ. Eng.* (February 1989): 80–90.
[d]*Guidelines for Drinking Water Quality*, Vol. 2, World Health Organization, Geneva, 1984, p. 44.
[e]Up to 10 cysts from beaver to human and one to 10 cysts to cause human to human infection.
[f]R. C. Rendtorff, "Experimental Transmission of *Giardia lamblia,*" *Am. J. Hyg.*, **59**, 209 (1954).
[g]Eugene J. Gangarosa, "The Epidemiologic Basis of Cholera Control," *Bull. Pan Am. Health Org.*, **8**, 3 (1974).

an infectious dose. However, some viruses (and other microorganisms) do survive and present a hazard to the exposed population. Not all viruses are pathogenic. An indication of the difficulty involved in testing for the effect of chemicals is given by Kennedy[8] "A typical chronic toxicology test on compound X, done to meet a regulatory requirement with an adequate number of animals and an appropriate test protocol, costs $250,000 to 300,000," and requires two to three or more years to complete. Information concerning the *acute* effect of ingestion of toxic substances is available in toxicology texts.[9]

RESERVOIR OR SOURCE OF DISEASE AGENTS

Humans as Reservoirs

Contamination of food and drink may occur either directly with human or domestic animal feces or indirectly by contact with objects that have had contact with infected waste. Infected persons may serve as reservoirs for many of these diseases, and may shed infectious organisms in their feces. Urine is usually sterile, except for urinary schistosomiasis, typhoid, and leptospirosis carriers.[33] The prevalence of carriers differs by disease within an exposed population. For example, the prevalence of amebic dysentery varies between 10 and 25 percent and may be as high as 60 percent; shigellosis may be higher. Stoll has ventured to hazard a guess of the prevalence of helminthic infections in the world.[10] He estimates that at least 500 million persons harbor ascarids, 400 million other worms (helminthes). Actually, a person who is ill with a helminthic disease probably is infected with more than one parasite, since the conditions conducive to one infection would allow additional species to be present.

The World Health Organization (WHO) estimates that 600 million people are at risk and 300 million are afflicted by schistosomiasis (bilharziasis), usually spread by wading in cercariae-infested water[11] In addition, it is estimated that almost a quarter of the world's population suffers from one of four water-related diseases: gastroenteritis, malaria, river blindness (onchocerciasis), or schistosomiasis A survey of U.S., state, and territorial public health laboratories by the CDC in 1976 for frequency of diagnosis of intestinal parasitic infections in 414,820 stool specimens showed 15.6 percent contained one or more pathogenic or non-pathogenic intestinal parasites, 3.8 percent were positive for *Giardia lamblia*, 2.7 percent for *Trichuris trichiura*, 2.3 percent for *Ascaris lumbricoides*, 1.7 percent for *Enterobius vermicularis*, and 0.6 percent for *Entamoeba histolytica*.[12]

A study at a missionary college in east central China showed that 49 percent of the students harbored parasitic worms, and a survey in an elementary school in New Jersey found that 23 percent of the children were infected. In 1970, Lease reported on the study of day care and elementary school programs in four counties in South Carolina involving 884 children.[13] He found that 22.5 percent of black children harbored *Ascaris* intestinal roundworms and, of the 52 white children in the group, 13.5 percent had worms. Central sewage and water supply was lacking. Persons living in rural areas had higher infection rates; infected rural children also had twice the number of worms as infected children from urban areas. A study involving 203 children ranging in age from six months to six years in St. Lucia in the Caribbean showed that infection with *T. trichiura* was 84 percent, *A. lumbricoides* 62 percent, hookworm 7 percent, and *Toxocara canis* 86 percent.[14] Since parasitic infection plus poor diet may result in serious debility and perhaps death, preventive measures, including better sanitation and hygienic practices, are essential.

The mouth, nose, throat, respiratory tract, and skin of humans are also reservoirs of microorganisms that directly cause a large group of illnesses. *Staphylococci* that produce enterotoxin are also found on the skin and mucous membranes, in pus, feces, dust, and air, and in unsanitary food-processing plants. They are the principal causes of boils, pimples, and other skin infections, and are particularly abundant in the nose and throat of a person with a cold. It is no surprise, therefore, that *staphylococcus* food poisoning is one of the most common foodborne diseases. Scrupulous cleanliness in food-processing plants, in the kitchen, and among foodhandlers is essential if contamination of food with *salmonella* spp., *staphylococci*, *clostridia*, and other microorganisms is to be prevented.

Animals as Reservoirs

A number of animal species serve as reservoirs for diseases that may affect humans, including the following 13 diseases:

1. Brucellosis (undulant fever)
2. Clonorchiasis
3. Fascioliasis (intestinal fluke) and fasciolopsiasis
4. Leptospirosis
5. Paragonimiasis (lung fluke)
6. Salmonella infection (salmonellosis)
7. Schistosomiasis
8. Taeniasis (pork or beef tapeworm) and cysticercosis
9. Toxoplasmosis
10. Trichinosis (trichiniasis)
11. Trichuriasis (whipworm)
12. Tularemia
13. Yersiniosis

In 1948, the prevalence of trichinosis in grain-fed hogs was 0.95 percent and in garbage-fed hogs 5.7 percent.[15] Surveys in New England and the Mid-Atlantic States in 1985 found infection rates of 0.73 and 0.58 percent, respectively, in pigs, compared to an estimated national rate of 0.1 percent[16] Wild animals, including bears, boars, martens, wolverines, bobcats, and coyotes, are also carriers. Horsemeat has also been implicated as a source of infection.[17] The incidence of adult *Trichinella* infection in the United States has been declining, with only 129 cases reported in 1990[18] and 16 cases reported in 2005.[19]

Processed meats may be considered acceptable when stamped "U.S. inspected for wholesomeness," but this is no guarantee that the product is absolutely safe; it signifies the product was processed in accordance with U.S. Department of Agriculture (USDA) specifications. This is also true of raw meat and poultry, which frequently contain *Salmonella* and other pathogenic organisms, even though stamped "inspected." Raw meat products require hygienic handling and adequate cooking. Uncooked summer sausage (fresh ground pork, beef, and seasoning plus light smoking) and raw or partially cooked pork products should be avoided.[20]

Some organisms are excreted in the urine of mice and rats, including the following:

- Lymphocytic choriomeningitis virus
- *Escherichia coli*
- *Leptospira*
- *Salmonella*

- *Staphylococcus*
- *Yersinia*

Because of the practical difficulty of permanently eliminating all mice and rats, the threat of contaminating food with the organisms causing the foregoing diseases is ever present. This emphasizes the additional necessity of keeping all food covered and protected.

Dust, eggs, poultry, pigs, sheep, cattle and animal feed, rabbits, rats, cats, and dogs may harbor *salmonella* and other causative organisms. shelled eggs and egg powder may also contain *salmonella*. *Salmonella* food infection is common and routinely causes non-life-threatening in healthy individuals

FOOD SPOILAGE

When fresh foods are allowed to stand at room temperature, they begin to deteriorate. The changes in the composition of the food are brought about by the action of enzymes and microorganisms, including molds and yeasts. Factors such as oxygen, sunlight, warmth, dehydration, insects, and other vermin accelerate decomposition, contributing to the unpleasant appearance and taste of the food, the loss of freshness, and changes in the color and odor. Food that has been permitted to decompose loses much of its nutritive value. Atmospheric oxidation causes a reduction of the vitamin content and quality, a breakdown of the fats, then the proteins, to form hydrogen sulfide, ammonia, and other products of decay. Antioxidants are sometimes used to slow down food deterioration, rancidity, or discoloration due to oxidation. These include ascorbic acid, butylated hydroxyanisole (BHA), butylated hydroxytoluene (BHT), citric acid, and phosphates. The Food and Drug Administration (FDA) requires that ingredient labels carry and list the antioxidants as well as their carriers.[21] Contamination, which almost always accompanies putrefaction, may be dangerous. In certain instances, the microbiological activity will produce a toxin (e.g *Staphylococcus aureus* toxin) that even ordinary cooking cannot destroy. Most bacteria associated with food spoilage will grow within a wide pH range, from 3.0 or 4.0 to 8.0 or 9.3. Yeasts and molds also grow within a very wide pH range, from 1.5 to 8.5 or 11.0. Foods with pH values below 4.5 are usually not easily spoiled by bacteria but are more susceptible to spoilage by yeasts and molds.[22]

Mycotoxins are secondary meabolites produced by several groups of fungi, including those in the genera *Aspergillus, Penicillium, and Fusarium*. Mycotoxins may contaminate human or animal food, resulting in a toxic response when ingested. The toxic effects of mycotoxin ingestion depend on several factors, including the amount and type of toxin ingested and the duration of exposure to the toxin. In addition to causing acute toxicity, some mycotoxins may have teratogenic and carcinogenic effects.

High humidity and water activity (a_w) favor mycotoxin production; the amounts vary with the product. Molds and most yeasts require oxygen to grow and grow over a very wide pH range. Mycotoxins may also be resistant to heat and dessication and can survive a range of temperatures from 14° to 131°F (−10° to 55°C). Ingestion of contaminated feed by farm animals may permit carryover of toxins into meat and milk. There are about 15 types of dangerous mycotoxins. One common type, aflatoxin, is a potential human carcinogen and is produced by the mold *Aspergillus flavus* and other *Aspergillus* species generally found in feeds and food. Aflatoxin-producing mold growths occur over a wide range of temperatures from 53° to 110°F (12° to 43°C), although 92°F (33°C) is optimum. *Aspergillus* mold has been detected in peanuts and peanut butter, corn, figs, cereals (wheat, barley, millet), cottonseed products, milk and milk products, and other foods that are not properly dried and stored, thereby favoring fungus contamination and growth on the food. The *Aspergillus* species may be airborne and inhaled, causing aspergillosis. Compost piles are common reservoirs and sources of infection. Fortunately, the mere presence of a mold does not automatically mean the presence of mycotoxins. Contamination may result also before harvest. Most fungal toxins, including aflatoxins, are not destroyed by boiling and autoclaving.[23] Oven roasting artificially contaminated peanuts for 30 minutes at 302°F (150°C) or microwave roasting for 8.5 minutes can destroy 30 to 45 percent of aflatoxin B_1.[24]Properly stored leftover foods may also be a source of aflatoxins. Aflatoxins fluoresce under long-wave ultraviolet light.

Aflatoxin causes cancer in rats and is suspected to be a cause of liver cancer in humans. Mycotoxins can also damage the liver, brain, bones, and nerves with resultant internal bleeding.

A concise summary of mycotoxins and some mycotoxicoses of humans and animals is found in a report of a WHO Expert Committee, with the participation of the Food and Agriculture Organization (FAO) of the United Nations,[25] a paper by Bullerman, and a paper by Scott.[26,27] Some compounds and substances may inhibit, stimulate, or have no effect on the growth of aflatoxins.[28]

Foods (vegetables, meats, fruits, and cheeses) with abnormal mold growth should be promptly and properly discarded.[29] The exception to this is cheese from which mold has been *properly* removed (including mold filaments deeply penetrating along the holes or eyes), which is considered safe to eat. For other foods, is not safe to scrape off the mold and eat the remaining food. Mycotoxins are not effectively destroyed by cooking. Freezing food will prevent mold growth, but mold grows at refrigerator temperature, although at a slower rate. The inside of refrigerators should be washed and dried regularly to prevent mold growths and musty odors; commercial deodorants are not a substitute for cleanliness. Some cheeses, such as Roquefort, Brie, Camembert, and Blue, are processed with special species of molds, similar to those from which penicillin is made, and have been consumed with safety for hundreds of years.[30] In addition, consuming certain dairy, fruit and vegetable delicacies (e.g., cheeses and cider) made with unpasteurized raw materials may also lead to illness.

BURDEN AND COST OF FOODBORNE ILLNESS

In 1999, Mead et al.[3] reported new estimates of foodborne illnesses in the United States. They found that there are several factors that complicate surveillance for foodborne infections. First is underreporting, especially of mild or asymptomatic cases, but also of severe cases. Second, they found that because many pathogens can be spread by means other than food, their role in foodborne illness is often obscured or unknown. For example, pathogens such as *E. coli*, which may be spread by food, can also be transmitted through contact with infected animals or other infected persons, and through contact with contaminated water. Third, some illnesses are caused by pathogens that have not yet been identified and so cannot be diagnosed. Many of the pathogens that are reported today, including *Campylobacter jejuni, Escherichia coli* O157:H7, *Listeria monocytogenes*, and *Cyclospora cayetanensis*, were not recognized as causes of foodborne illness only 25 years ago. In total, Mead et al. estimated that foodborne diseases cause approximately 76 million illnesses, 325,000 hospitalizations, and 5,000 deaths in the United States each year. Of these, infections caused by known pathogens account for an estimated 14 million illnesses, 60,000 hospitalizations, and 1,800 deaths each year. Clearly, further work is needed to identify the causes of these other foodborne illnesses. *Salmonella, Listeria*, and *Toxoplasma* cause more than 75 percent of deaths by known pathogens.

The total cost of a disease outbreak is often overlooked. For example, a typhoid fever outbreak in 80 restaurant patrons consuming food contaminated by a carrier was estimated to cost $351,920. This cost includes patient-related medical expenses and costs of loss of income or productivity.[31] One estimate of the annual economic impact of foodborne disease in the United States is $1 billion to $10 billion. If there are five million cases each year, the average cost per case would range from $200 to $2000.[32] The FDA estimated in 1985 that 21 to 81 million cases of diarrhea yearly are caused by foodborne pathogens. The out-of-pocket costs were estimated to be $560 million for the quarter million hospitalized and $690 million for those who saw a doctor.[33] More recently, the 2001 FDA Food Code estimates that the annual cost of foodborne illness is $10 billion to $83 billion annually.[34] This figure is calculated considering the increased estimation of foodborne illness by Mead et al.[3]

The reporting of water- and foodborne illnesses has, with rare exceptions, been very incomplete. Various estimates have been made in the past indicating that the number reported represented only 10 to 20 percent of the actual number. Reasons for underreporting include that many infected persons do not seek medical care, and that persons who seek medical care may not have a stool sample or other confirmatory test. Mead et al. estimated, for example, that *Salmonella* infections are underreported 38-fold, while *E. coli* infections are underestimated 20-fold.

For other, more severe infections such as *Listeria*, the degree of underreporting was estimated to be much lower.[3]

Hauschild and Bryan,[35] in an attempt to establish a better basis for estimating the number of people affected, compared the number of cases initially reported with either the number of cases identified by thorough epidemiologic investigations or the number estimated. They found that for 51 outbreaks of bacterial, viral, and parasitic disease (excluding milk), the median ratio of estimated cases to cases initially reported to the local health authority, or cases known at the time an investigating team arrived on the scene, was 25 to 1. On this basis and other data, the annual food- and waterborne disease cases for 1974 to 1975 were estimated to be 1,400,000 to 3,400,000 in the United States and 150,000 to 300,000 in Canada. The annual estimate for the United States for 1967 to 1976 was 1,100,000 to 2,600,000.[35] The authors acknowledge that the method used to arrive at the estimates is open to criticism. However, it is believed that the estimates come closer to reality than the present CDC reporting would indicate, particularly to the nonprofessional. The estimates would also serve as a truer basis for justifying regulatory and industry program expenditures for water- and foodborne illness prevention, including research and quality control. The total number of foodborne illnesses in the United States has been estimated at 5˜million, with a total cost of $1 billion to $10 billion per year.[32]

FOODBORNE DISEASE OUTBREAK SURVEILLANCE

Between 1938 and 1956, 4,647 foodborne outbreaks with 179,773 cases and 439 deaths were reported to the PHS CDC. In 1967, 273 outbreaks were reported, with 22,171 cases and 15 deaths.

Another analysis of foodborne illnesses based on 1969 and 1970 CDC/Department of Health, Education, and Welfare (DHEW) information reported 737 outbreaks with 52,011 cases. It was found that 33.0 percent of the outbreaks occurred at restaurants, cafeterias, and delicatessens; 39.1 percent at homes; 8.7 percent at schools; 5.2 percent at camps, churches, and picnics; and 14 percent at other places. However, 48 percent of the *cases* were at schools and 28 percent at restaurants, cafeterias, and delicatessens.[36]

Bryan, in a summary of foodborne diseases in the United States from 1969 to 1973, reported 1,665 outbreaks with 92,465 cases.[37] During this same period it was found that food service establishments accounted for 35.2 percent of the outbreaks; homes 16.5 percent; food-processing establishments 6.0 percent; and unknown places 42.1 percent.

In 1982, 656 foodborne outbreaks with 19,380 cases and 24 deaths were reported to the U.S. PHS CDC.[38] The most frequently isolated bacterial pathogens were *Salmonella*, *Staphylococcus aureus, Clostridium perfringens, Campylobacter jejuni, Clostridium botulinum*, hepatitis A virus, and Norwalk virus. The latter two viruses accounted for 21 outbreaks and 5,325 cases. The most common contributing factors were (1) improper holding temperature, (2) food from an unsafe source, (3) inadequate cooking, (4) poor personal hygiene on the part of foodhandlers, and (5) contaminated equipment.

An analysis of 1,586 foodborne outbreaks reported to the CDC from 1977 through 1984 most frequently implicated fish and shellfish in 24.8 percent of the outbreaks; beef and pork in 23.2 percent; turkeys and chickens in 9.8 percent; potato, chicken, and other salads in 8.8 percent; and other foods in 5 percent.[39]

In the most recent summary of foodborne outbreak surveillance in the United States, a total of 6,647 outbreaks were reported during 1998 to 2002, causing 128,370 persons to become ill.[40] Atlhough this was in increase in the number of outbreaks compared to previous summaries, enhanced surveillance was likely responsible for much of the increase. Bacterial pathogens caused 55 percent of both outbreaks and cases, with *Salmonella* serotype Enteritidis accounting for the largest number of outbreaks and outbreak-related cases. During this same time period, infection with *Listeria monocytogenes* caused the most deaths. Viral pathogens caused 33 percent of outbreaks and 41 percent of cases, and the proportion of outbreaks attributed to viruses increased 26 percent from 1998 to 2002.[40] The factors most commonly associated with these outbreaks were described as follows:

> The most commonly reported contamination factor that contributed to FBDOs foodborne disease outbreaks was "bare-handed contact by handler/worker/preparer." For outbreaks caused by bacterial pathogens "raw product/ingredient contaminated by pathogens from animal or environment" was the most commonly reported contamination factor. The most commonly reported proliferation factor was "allowing foods to remain at room or warm outdoor temperature for several hours"; the most common survivability factor was "insufficient time and/or temperature during initial cooking/heat processing[40]."

Poultry

Campylobacter jejuni is a common contaminant in poultry-processing plants and is frequently found in conjunction with *Salmonella*. Contaminated chicken has been found to be the source or vehicle of over 50 percent of *C. jejuni* enteritis cases.[41] *Campylobacter* may also be also found in raw milk and contaminated water.

Salmonella outbreaks have been related to the use of raw or undercooked eggs.[42] The incidence of *Salmonella enterica* infection and the number of outbreaks has increased dramatically in the United States since the 1970s.[43] Shell eggs are the major vehicle for *Salmonella enterica* infection in humans; eggs are contaminated internally by transovarial transmission from the laying hen. The FDA now recommends that all products containing eggs are fully cooked or made with a pasteurized liquid egg product. Contaminated feed is believed to cause animal infection leading to contamination of meat and poultry products.

Between 1963 and 1975, there were 651 reported outbreaks of salmonellosis, with 38,811 cases in the United States. Poultry, meat (beef, pork), and eggs were the three most common vehicles. Eggs were not incriminated in

1974 and 1975, probably due to hygienic processing, pasteurization, and quality control,[44] but bulk and cracked eggs are a recurring problem as vehicles for foodborne salmonella.[42] Hauschild and Bryan found that for a total of 26 outbreaks of salmonellosis the median ratio of estimated cases to initial human isolations of salmonella was 29.5.[35] On this basis, the actual number of cases of human salmonellosis for the period 1969 to 1978 was estimated to be 740,000 in the United States and 150,000 in Canada annually.[35] Although estimates differ, they do show the seriousness of the problem and the need for more effective control methods. The overall national salmonellosis morbidity has remained relatively constant. The average number of isolates has actually increased since 1976 except for the years 1980 and 1984. Surveillance by the Foodborne Diseases Active Surveillance Network (FoodNet) has similarly found that despite decreases in the incidence of many foodborne pathogens, *Salmonella* infections have remained relatively constant over time. Of the six most common *Salmonella* serotypes, only one declined in 2006 from baseline levels.[45] Additionally, because *Salmonella* can be transmitted to human via many vehicles, including produce, eggs, poultry, meat, and contact with animals, efforts to control *Salmonella* must take into account many potential sources of infection. Several recent outbreaks of *Salmonella*, including one associated with peanut butter,[46] and one associated with tomatoes[47] underscore the diverse routes of infection and the need to more effectively prevent contamination of food products. Salmonellosis control involves use of salmonella-free feeds; strict hygiene in the handling and preparation of food for human consumption; education of managers, inspectors, and foodhandlers; time-temperature control in food preparation; and prohibition of antibiotics in animal feed (cattle, hogs, poultry), which may promote the growth of drug-resistant organisms that can spread to humans.

Milk and Other Dairy Products

Raw milk (including certified) or improperly pasteurized milk, poor milk-handling and processing practices, postpasteurization contamination, and improper refrigeration have been associated with outbreaks caused by contaminated milk. Soft cheeses and other dairy products have also been associated with a number of foodborne outbreaks. Raw milk and raw milk products have been associated with outbreaks of a number of pathogens, including *Salmonella* spp., *Camylobacter, Listeria, Staphylococcus aureus* (staphylococcus enterotoxin), *Streptococcus agalactiae, Mycobacterium tuberculosis, Listeria monocytogenes*, and *Yersinia enterocolitica*. A recent review found 46 raw-milk-associated outbreaks reported to CDC from 21 states during 1973 to 1992, including 57 percent caused by *Campylobacter* and 26 percent caused by *Salmonella*.[48] Several recent multistate outbreaks of *Salmonella* associated with the consumption of raw milk have been reported. [49,50]

The largest milkborne outbreak on record occurred in the Chicago area in March and April of 1985. Two brands of two percent low-fat pasteurized milk were implicated. *Salmonella typhimurium* was found in 16,284 culture-confirmed cases, resulting in at least two deaths and probably 12 related deaths. It was estimated that 183,000 or more persons were infected. The outbreak had been preceded by at least three smaller outbreaks. Evidence pointed to milk blending via a cross-connection between a pasteurized milk transfer line and a raw milk line. Other causes such as suction in a milk line that could draw raw milk past two valves could not be ruled out. The cross-connection was an in-plant modification. Outbreaks such as this emphasize the complexity of modern processing equipment, the importance of plan approval, the continual necessity for evaluation of plant piping systems and controls, education and training of personnel, and constant supervision and surveillance. According to a class-action suit reported in the *Baltimore Sun*, the milk company must offer 2,100 people who "represent about 15 percent of all those involved in the lawsuit . . . up to $1000 plus medical and employment compensation."[51]

Despite the ban on interstate sales of raw milk implemented in 1987, raw milk has continued to cause numberous outbreaks. In 1995, 54 percent of states permitted the intrastate sale of raw milk, although the estimated volume of raw milk in states where sales was legal was less than 1 percent of the total milk sold[48]. Of 46 raw-milk-associated outbreaks occurring from 1973 to 1992, 87 percent occurred in states where sales of raw milk were still legal at the time of the outbreak.[48]

Contamination of pasteurized milk has also been involved in several outbreaks, likely due to contamination of milk products after pasteurization. At least 12 outbreaks occurred in the United States during 1960 to 2000 associated with the consumption of pasteurized milk, including *Salmonella typhimurium* outbreaks in Arizona in 1978[97] and Pennsylvania in 2000.[52] One of the first outbreaks of yersiniosis associated with milk was reported in 1976, and was caused by milk to which chocolate syrup had been added after pasteurization. A *Yersinia* outbreak linked to postpasteurization contaminated milk affected 17,000 persons in Memphis in 1982.[53] Salmonellosis has also been associated with the consumption of nonfat powdered milk.[54]

In addition to outbreaks caused by raw milk, soft cheeses made from raw milk have been associated with *Listeria monocytogenes* infection.[55] *Listeria* grows at below refrigeration temperatures, making it hazardous in raw milk products (cheeses), unpasteurized milk, and pasteurized products that have been contaminated after pasteurization. A large outbreak, which included 142 cases with 48 deaths, occurred in California in 1985 and was linked to consumption of a Mexican-style cheese made with raw milk.[56] Victims filed damage claims for $100 million. The manufacturer of the cheese went out of business. A jury found the manufacturer responsible, but the supplier of raw milk was exonerated. The federal investigators could not determine whether the raw milk, improper pasteurization, or postpasteurization contamination was the cause.[57] *Listeria monocytogenes* has also been found in seafood and turkey franks. Other outbreaks have been reported in Canada, Massachusetts, Los Angeles, California, and Switzerland.

Fruits and Vegetables

A number of outbreaks of foodborne pathogens have been linked to consumption of contaminated fruits and vegetables. From 1973 to 1997, a total of 190 produce-associated outbreaks were reported in the United States and the proportion of outbreaks associated with a produce item increased from 0.7 percent to 6 percent.[58] Items frequently implicated in these outbreaks included salad, lettuce, juice, melon, sprouts, and berries. Of the 103 outbreaks with a known pathogen, 29 percent were caused by *Salmonella*.

Meat and Seafood

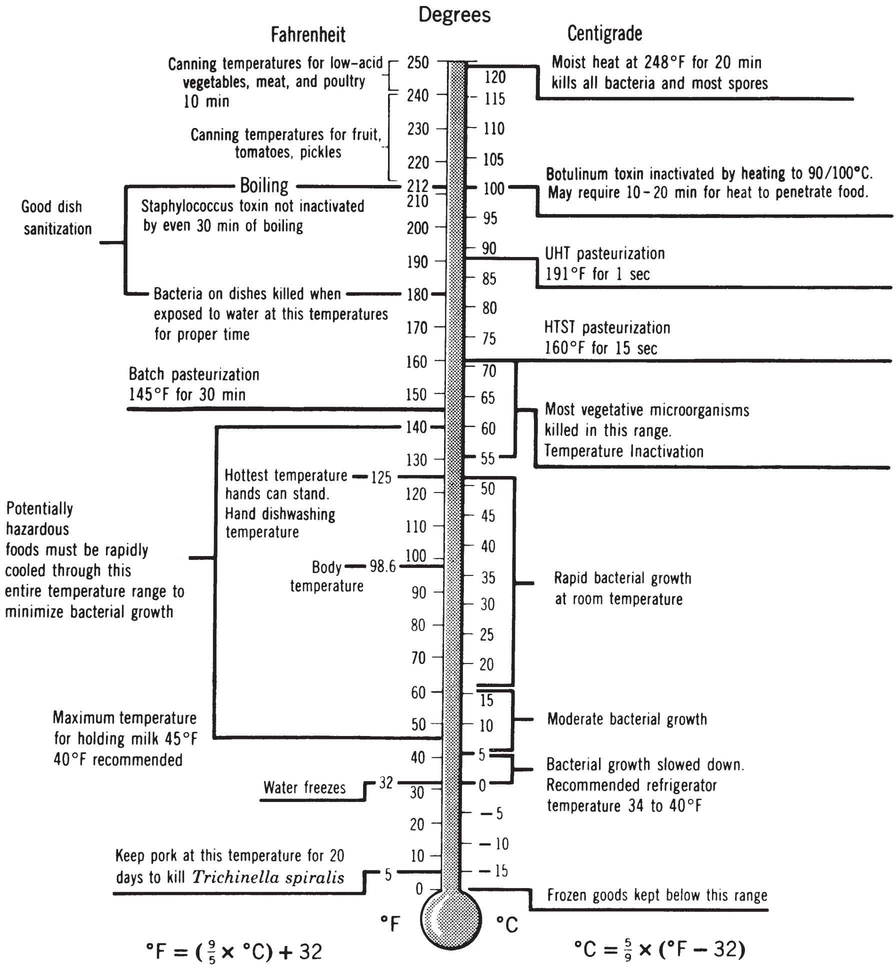
Seafood is implicated as the vehicle in 10 to 19 percent of foodborne illnesses in the United States[59] and more than 70 percent of foodborne illness in Japan.[60] In the United States, of those infections with known etiology, approximately half are caused by viruses. As with many other foodborne infections, persons with underlying immunocompromising conditions are more susceptible to infection and have worse outcomes. Consumption of raw or undercooked seafood is the factor most commonly associated with infection.[61] In one study, shellfish accounted for 64 percent of the seafood-associated outbreaks, and finfish were implicated in 31 percent.[59] Large outbreaks of norovirus have been associated with the consumption of raw oysters.[61] Oysters and other seafood are often contaminated by the discharge of human waste into harvest areas. *Vibrio* spp., including *V. parahaemolyticus* and *V vulnificus*, are also associated with human illness in the United States; consumption of oysters accounts for nearly 50 percent of *Vibrio* infections. During seasons of peak infection, as much as 100 percent of the oyster harvest may be contaminated with *Vibrio*.[62]

CONTROL AND PREVENTION OF FOODBORNE DISEASES

Many health departments, particularly on a local level, are placing greater emphasis on water quality and food protection at food-processing establishments, catering places, schools, restaurants, institutions, and the home and on the training of food management and staff personnel. An educated and observant public, a systematic inspection program with established management responsibility, coupled with a selective water and food quality laboratory surveillance system and program evaluation can help greatly in making health department food protection programs more effective. It is necessary to remain continually alert as water- and foodborne diseases have not been completely eliminated; we continue to find new ones. For a discussion of waterborne diseases, please refer to Chapter 1.

Prevention of Foodborne Diseases

The application of known and well-established microbiological and sanitary principles has been effective in keeping foodborne diseases under control, but it is apparent that more effective measures are needed. Refrigeration, hygienic practices including prevention of cross-contamination with raw foods or contaminated surfaces, food preparation planning, hot or cold holding of potentially hazardous food, identification and assurance of critical temperatures for proper cooking and reheating, and general sanitation are most important. These precautions apply also to prepared frozen dinners, reconstituted foods, and drinks. Leaving food at room temperature, inadequate cooking, and storing food in a large container account for many outbreaks. Continuous and competent surveillance is necessary to identify and eliminate procedures that might permit contamination of food or the growth of microorganisms or the accidental addition of toxic substances



Note: Increase boiling time 5 min for each 1000 ft above sea level.
H.T.S.T. = high temperature, short time. UHT = ultra high temperature.

FIGURE 3.1 Food sanitation temperature chart.

from the point of preparation to the point of consumption to prevent foodborne illnesses.

The approximate optimal temperature for growth of the principal organisms associated with foodborne illnesses are salmonella 99°F (37°C) (maximal 114°F), *Staphyhcoccus aureus* 99°F (maximal 114°F), *Clostridium perfringens* 115°F (46°C) (maximal 112°F), and enterococci (maximal 126°F). *Listeria*, in contrast, can grow at lower temperatures and is thus often associated with contaminated of refrigerated deli meats and soft cheeses.[63]

Salmonellae are widely distributed in nature and found in many raw food products, especially poultry, beef, and swine. Pets are also reservoirs of salmonellae, and outbreaks of *Salmonella* have also been associated with pet food.[64] Tables and surfaces used in preparing raw poultry and other meats can serve as vehicles for the spread of *Salmonella* and other pathogens unless they are thoroughly cleaned and sanitized between each use. *Clostridium perfringens, Campylobacter jejuni*, and *Staphylococcus aureus* are also frequently found in samples of raw beef and on workers' hands, knives, and cutting boards, as well as in soil, dust, and the intestinal tracts of humans and other warm-blooded animals. Raw meat and seafood should be separated from other food in the grocery cart or refrigerator; persons should always wash hands, cutting boards, and dishes with hot soapy water after coming in contact with raw meat, poultry, or seafood; one cutting board should be used for raw meat, poultry, and seafood and another for foods that are ready to eat; cooked food should never be place on a plate that previously held raw meat, poultry, or seafood.[63]

Salmonellae may survive up to 10 months in cheddar cheese. Aging of salmonella-infected cheese 60 days, manufactured from heat-treated (nonpasteurized) milk, is therefore ineffective to prevent human illness. The use of pasteurized milk can ensure the marketing of safe milk and milk products, including elimination of *Salmonella* spp., *Listeria, Yersinia, Campylobacter*, enterohemorrhagic *E. coli*, and other pathogens.[65] Thorough cooking 165°F (74°C) of raw shell eggs, raw meat and poultry, raw clams, and other foods of animal origin before consumption will prevent salmonellae infections, as will the use of pasteurized egg products in preparing eggnog, Caesar salad, hollandaise sauce, and homemade mayonnaise and ice cream. Eggs should not be used raw and should be cooked thoroughly before service. Flocks and eggs have been found infected.[66] Cross-contamination during food preparation should be avoided.

Fish that has been fried, baked, or broiled until it flakes when pried with a fork can be assumed to be free of viable parasites. Freezing fish at −4°F (−20°C) for three to five days will also kill most pathogens. Cooking fish to a temperature of 145°F (63°C) will kill parasites.[63]

Campylobacter jejuni is responsible for numerous foodborne outbreaks, many of which are not recognized. *Campylobacter* contamination of food products may begin during animal slaughtering and processing and may be increased by overconcentration of animals in feedlots and brooding houses. Poor food handling, storage, and sanitation facilitate *Campylobacter* transmission.

TABLE 3.3 Pathogen Time-Temperature Inactivation[a]

Organism	Temperature °C	Temperature °F	Time	Source
Ascaris lumbricoides eggs	50	122	60 min	2, 4
Brucella abortus	62–63	144–145	3 min	2
Brucella suis	61	142	3 min	3
Campylobacter jejuni	60	140	10 min	
Clostridium botulinum	100	212	5 hr	2
Spores	105	221	40 min	2
	110	230	15 min	2
	120	248	6 min	2
Toxin	70–73	158–163	10 min	2
	80	176	2 min	2
	72	162	10 min	2
	65	149	30 min	2
Clostridium burnetii				
In ice cream	66	150	30 min	5
In chocolate milk	74	165	15 sec	5
In milk	63	145	30 min	5
	72	161	15 sec	5
Clostridium perfringens				
Enterotoxin		140+	80 min	6
Spores	100	212	1 hr or more	6
Vegetative cells	65	150	A few seconds	
Corynebacteriun diphtheriae	55	131	45 min	3, 4
	60	140	20 min	2
Coxsackie viruses	71	160	15 sec	
	62	143	30 min	
Entamoeba histotytica	49	120	60 min	1
	45	113	A few minutes	4
	55	131	A few seconds	2
	68	154	10 min	3
Enteric viruses	63	145	60 min	1
	71	160	30 min	
Escherichia coli	60	140	15–20 min	3
	55	131	60 min	4
Giardia lamblia	55	131	A few minutes	
Micrococcus pyogenes var.	50	122	10 min	3, 4
Mycobacterium tuberculosis var. hominis	66	151	15–20 min	3
	60	140	20 min	2
	67	153	A few minutes	3, 4
Necator americanus	45	113	50 min	3
Salmonella spp.	60	140	15-20 min	3
	57	135	60 min	1
	55	131	60 min	4

(*continues*)

TABLE 3.3 (*continued*)

Organism	Temperature °C	°F	Time	Source
Salmonella typhosa	55–60	131–140	30 min	3, 4
	60	140	20 min	2
Shigella spp.	60	140	20 min	2
	55	131	60 min	3, 4
	58	136	60 min	1
Staphylococcus aureus	71	160	15 sec	
	60	140	30 min	
Streptococcus pyogenes	54	129	10 min	3
	60	140	5 min	2
Taenia saginata	55	131	A few minutes	2, 4
	71	160	5 min	3
	51	124	60 min	1
Toxoplasma gondii	70	158	A few seconds	
Trichinella spiralis larvae	55	131	A few minutes	2, 4
	60	140	A few seconds	2, 4
	62–70	144–158	10 min	3
Vibrio cholerae	45	113	60 min	1

Sources: 1. R. G. Feachem et al., *Sanitation and Disease: Health Aspects of Excreta and Wastewater Management*, World Bank Studies in Water Supply and Sanitation. No. 2, World Bank, Washington, DC, 1978.

2. K. F. Maxcy, *Rosenau Preventive Medicine and Hygiene*, Appleton-Century-Crofts, New York, 1951, pp. 230, 255, 874, 877, 897, 901.

3. C. G. Golueke, *Composting A Study of the Process and Its Principles*, Rodale, Emmaus, PA, 1972.

4. R. Rickles, *Pollution Control*, Noyes Development, Park Ridge, NJ, 1965, p. 143.

5. J. M. Last (Ed.), *Maxcy-Rosenau Public Health and Preventive Medicine*, 11th ed., Appleton-Century-Crofts, New York, 1980, p. 937.

6. H. S. Naik and C. L. Duncan, "Thermal Inactivation of *Clostridium perfringens* Enterotoxin," *J. Food Protection* (February 1978): 100–103.

[a]In the presence of moisture. To compensate for elevation, increase heating time 5 minutes for each 1000 ft above sea level. There is a lack of agreement among experts regarding some time—temperature relationships.

All cooked and precooked beef and beef roasts must be heated to a minimum internal temperature of 145°F (62.7°C) to comply with USDA regulations to ensure destruction of all salmonellae. At this temperature, it would not be possible to make available "rare" roast beef. However, the USDA permits other time–temperature relations for processing of water- or steam-cooked and dry-roasted beef.[67] Studies show that salmonella-free rare roast beef can be produced, for example, at internal time–temperatures ranging from 130°F (54.4°C) for 121 minutes to 136°F (58°C) for 32 minutes. The elimination of salmonella from the surface of dry oven-roasted beef (at least 10 lb. uncooked in size) requires a minimum internal temperature of 130°F (54.4°C) in an oven set at 250°F (121.0°C) or above.[63] It should be understood that these time-temperatures are under controlled laboratory conditions, which normally do not prevail in the average restaurant. The higher time–temperatures should be used in practice to prevent possible disease transmission and ensure heat penetration.

Adequate cooking of ground beef and other meats is essential to prevent infection with *E. coli* O157. Consumption of ground beef, particularly "pink" (indicating undercooked) meat, has been associated with both outbreaks and sporadic cases of *E. coli* infection.[68,69] USDA recommends cooking hamburgers and ground beef to 160°F on a meat thermometer.[63] Cooked beef roasts and turkeys, because of their size, are rarely rapidly cooled to 45°F (7°C) or less. If not consumed or sold immediately, they should be reheated as noted before use. Cooked roasts that have been rolled or punctured should be reheated to 160°F (71.1°C) (FDA recommends 165°F (73.9°C)). Cooked roasts that have been cut up into small pieces should be reheated to 165°F (73.9°C) because the handling introduces greater possibility of contamination. Cooked roasts that include solid muscle should be reheated to assure pasteurization of the surface of the roast.

There is a danger of cooking large masses of raw meat on the outside but leaving the interior of the food underdone, thereby permitting survival of salmonellae[70] spores introduced in handling, or those intrinsically present that can germinate and cause *C. perfringens* food poisoning. However, if the meat is cooked as already noted and eaten immediately after cooking, there is usually minimal risk of bacterial foodborne illness.

Incomplete cooking of stews, meats, gravies, and large cuts of meat that have been rolled or penetrated with skewers and failure to provide prompt and thorough refrigeration can lead to contamination with *C. perfringens. Clostridium perfringens* vegetative cells in food are destroyed by heat and thorough cooking, but spores are not completely destroyed by normal cooking. Therefore, foods contaminated with spores that are cooked and not promptly cooled can permit the germination of spores and the multiplication of vegetative cells with the danger of food poisoning on consumption. Heating *C. perfringens* enterotoxin at 140°F (60°C) in cooked turkey showed a gradual decrease in serologic activity with no detectable toxin being present after 80 minutes.[71]

Clostridium perfringens type A food poisoning is caused by the ingestion of foods containing large numbers of vegetative cells of enterotoxigenic strains. Many (not all) of these cells pass through the human stomach into the intestines where they are able to grow and eventually sporulate. During sporulation, the enterotoxin responsible for food-poisoning symptoms is synthesized and released. The toxin does not normally develop in the food, as in staphylococcus food poisoning and botulism, but rather, forms in the intestinal tract. Adequate cooking alone will not always prevent *C. perfringens* food poisoning because the spores are resistant to heat and may survive, multiply during slow cooling, and produce a toxin under anaerobic conditions, unless the food is eaten immediately or *promptly* cooled to 45°F (7°C) or less and reheated to 165°F (74°C) for safety to destroy the vegetative cells in the food.

The enterotoxin is produced in the intestinal tract after ingestion or in food under suitable temperatures 60° to 120°F (16° to 49°C), 110° to 117°F (43° to

47°C) for optimum growth in the absence of air. This enterotoxin is destroyed above 140°F (60°C). Bacteria in spore form are more difficult to destroy than when in vegetative form. The vegetative cell is killed at a temperature of 150°F (66°C); spores survive 212°F (100°C) for 1 hour or more. Spores are dormant, that is, inactive or not growing; they must germinate and become vegetative cells to grow. The term germination refers to the process involved when a spore changes into a vegetative cell.

Other bacterial toxins may also contaminate food, leading to food poisoning. Certain specific strains of staphylococcis (*S. aureus*) commonly found in skin infections, hands, feces, and discharges from the nose and throat are frequently associated with food poisoning. Staphylococci multiply under favorable temperature conditions, producing highly temperature and chemical resistant enterotoxins.. Common food vehicles associated with staphylococcal enterotoxins include contaminated ham, potato and chicken salads, sauces, poultry, and custard or cream-filled bakery products. Even after refrigeration and reheating, the consumption of food containing sufficient toxin, may cause food poisoning.

Botulism is caused by ingestion of a toxin produced by *Clostridium botulinum*. The *C. botulinum* in improperly canned or bottled low-acid food and in improperly cooled food will also produce a toxin (neurotoxin), but this poison is destroyed by boiling and cooking. *Clostridium botulinum* is rarely found in commercially canned foods but can be a risk in home-canned foods. During 1950 to -2005, CDC reported 405 events of foodborne botulism, of which 92 percent were linked to home-processed foods and 8 percent to commercially processed foods, including those prepared in restaurants.[72] Outbreaks associated with deficiencies in the commercial canning process are rare; in 2007, the outbreak associated with commercially canned chili sauce was the first such outbreak reported in the United States since 1974.[72] Botulism is also a hazard in prepared foods in which oxygen has been driven off in cooking and in which the food is shielded from oxygen and kept warm, permitting surviving spores to germinate and produce toxin, such as in potato salad, beef stew, meat pie, sautéed onions, and garlic in olive oil. *Clostridium botulinum* is reported not to grow at an a_w less than 0.93.

Intestinal or infant botulism can result from intraintestinal production and absorption of botulinum toxin, which is thought to result from the colonization of spores found in foods and dust and entering the gastrointestinal tract of the infant (2 to 38 weeks of age). Intestinal botulism is the most common form of human botulism in the United States (check reference list for this CDC. Botulism in the United States, 1899–1996: handbook for epidemiologists, clinicians, and laboratory workers. Atlanta, Georgia: U.S. Department of Health and Human Services, CDC, 1998), is a result of swallowing *C*. botulism spores. One source of these spores is honey. Honey should not be fed to infants less than 1 year of age.

The spread of diseases such as trichinosis, taeniasis, and salmonellosis associated with the consumption of foods of animal origin can be prevented by thorough cooking. Using only inspected meats, prohibiting the feeding of uncooked garbage or offal to hogs, and good sanitation will also help.

Storage of pork 10 days at −13°F (−25°C), or 20 days at −13°F if the meat is more than six inches thick, is adequate to kill trichina larvae. Cooking to an internal temperature of 150°F (66°C) is also adequate, although 165°F (74°C) is recommended for safety. The National Pork Producers Council recommends, and the USDA requires, that pork and pork products labeled ready to eat be frozen as noted or cooked to 170°F (76°C).[63] Fewer than 100 cases of trichinosis are being reported annually to CDC.[19] Cooking in a microwave oven does not ensure destruction of trichinae. Trichinae in polar bear meat remained viable after 24 months at 0°F (−18°C) and bear meat after 81 days at 0°.

The FDA requires that "fishery products that are not cooked throughout to 140°F (60°C) or above must have been or must, before service or sale in ready-to-eat form, be blast frozen to −31°F (−35°C) or below for 15 hours or regularly frozen to −10°F (−23°C) or below for 168 hours (7 days). Records that establish that fishery products were appropriately frozen on-site must be retained by the operator for 90 days." (FDA Code Interpretations, No. 2-403, August 21, 1987)These temperatures assure that tapeworms, roundworms, flukes, and other parasites are killed. Fish menu items that have not been fully cooked may harbor pathogenic bacteria or viruses. In summary, the 11 essential elements of health protection in food establishments are as follows:[63]

1. Cook to proper internal temperature (minimum): beef roasts 145°F (63°C), pork 165°F (74°C), eggs, fish, and lamb (145°F), poultry and all stuffed meats (165°F); holding of hot foods at 140°F (60°C), thorough reheating to 165°F of precooked or leftover (refrigerated) potentially hazardous foods, and holding potentially hazardous foods at or above 140°F or refrigerating at 45°F (7°C) or less in shallow pans (less than 4 inches food depth) until served; heating of custard and pastry filling to 165°F and cold holding at 45°F. Bring stock to a boil and keep at 140°F or above. Serve prepared foods promptly. Do not reuse leftover food that has been served. Microwave cooking of pork is not reliable, as microwave cooking can leave cold spots.
2. Ensure adequate refrigeration capacity and promptly and properly refrigerate at 45°F or less potentially hazardous leftover and prepared foods. Store in shallow pans, with food thickness or depth not greater than 4 inches. Cool foods to 45°F or less within 4 hours, but do not allow foods to remain at room temperature longer than 2 hours. A refrigeration temperature of 38 to 40°F (3° to 4°C) is recommended, and refrigerators should have indicating thermometers.
3. Plan food preparation to coincide as closely as possible with serving time. Serve food immediately after cooking.
4. Stress cleanliness and good personal hygiene habits of employees (who should be free of communicable disease or infection transmissible through food or food service). Wash hands before and after preparing each food; avoid or prevent handling of food; use utensils or plastic gloves to mix or serve food. Avoid cross-contamination; thoroughly clean and sanitize

cutting boards used for raw poultry, beef, pork, lamb, or fish before using for other foods; also clean meat grinders, knives, saws, and mixing bowls.

5. Use wholesome food and food ingredients; purchase and use of shellfish from approved safe sources. Discard swollen, leaking, deeply rusted, and seam-dented cans. Do not use raw or certified raw milk or home-canned foods. Use only pasteurized milk and milk products and commercially canned food.
6. Clean dishware, utensils, equipment, and surfaces used for food preparation; use adequate, properly constructed equipment that is easily cleaned and sanitized and is kept clean.
7. Have an adequate supply of potable water (hot and cold), detergents, and equipment for cleaning and sanitization of dishes and utensils; eliminate cross-connections or conditions that may permit backflow or back siphonage of polluted or questionable water into the water supply piping or equipment.
8. Properly store and dispose of all liquid and solid wastes.
9. Control rodents, flies, cockroaches, and other vermin, and proper use and store pesticides, sanitizers, detergents, solvents, and other toxic chemicals. Exclude dogs, cats, birds, and turtles from kitchen.
10. Protect dry food stores from flooding, sewage backup, drippage, and rodent and insect depredations. Store all foods at least 6 inches above the floor. Rotate stock—first in, first out.
11. Use structurally sound, clean facilities in good repair and adequately lighted and ventilated premises that can be properly cleaned.

According to *Food Code 2001*:

Potentially hazardous food means any food or ingredient, natural or synthetic, in a form capable of supporting (1) the rapid and progressive growth of infectious or toxigenic microorganisms or (2) the slower growth of *C. botulinum*. Included is any food of animal origin, either raw or heat-treated, and any food of plant origin which has been treated or which is raw, e.g. seed sprouts. Excluded are the following

- Air-dried hard-boiled eggs with shells intact the FDA has classified raw shell eggs as a potentially hazardous food;
- Foods with a water activity (a_w) value of 0.85 or less;
- Foods with a pH level of 4.6 or below;
- Foods, in unopened hermetically sealed containers, which have been commercially processed to achieve and maintain commercial sterility under conditions of unrefrigerated storage and distribution; and
- Foods for which laboratory evidence (acceptable to the regulatory authority) demonstrates that rapid and progressive growth of infectious and toxigenic microorganisms or the slower growth of *C. botulinum* cannot occur.[73]

Open self-service food counters, salad bars, or buffets require a physical barrier such as a canopy or guard that will effectively prevent or minimize contamination by persons assisting themselves to the displayed food. In any case, the potentially hazardous food should be held either at or above 140°F (60°C) or at or below 45°F (7°C) at all times. Displayed foods remaining should not be reused.

Since food service in private institutions, including churches and nonprofit and fraternal organizations, have been implicated in numerous foodborne outbreaks, special educational material should be developed incorporating the principles listed above and distributed to affected organizations. Caterers should be under special surveillance and permit.

Sandwiches containing potentially hazardous foods that remain unrefrigerated for more than 2 or 3 hours at room temperature can support the growth of bacteria that could lead to a foodborne disease outbreak. Prior refrigeration, or freezing where appropriate, and consumption within 4 hours will minimize the hazard. Cheese, peanut butter and jelly sandwiches, salami, bologna, and hard-boiled eggs will keep better. Canned meats and poultry also keep well. Commercial mayonnaise (pH below 4.1–4.6) will inhibit the surface growth of salmonellae and staphylococci on food, but the pH of all the ingredients or mass of the food, such as egg, meat, chicken, or potato salad, must be reduced to inhibit bacterial growth in the food. Vinegar and lemon juice can accomplish the same objective, provided the food ingredients do not neutralize the acidity of the mixture. The salads should be kept refrigerated. The guiding principles should be hygienic food preparation practices, proper cooking, and *prompt refrigeration* of potentially hazardous foods if the food is not immediately.

Mercury Poisoning

Mercury poisoning in humans has been associated with the consumption of methylmercury-contaminated fish, shellfish, bread, and pork and, in wildlife, through the consumption of contaminated seed. Exposure to mercury may also occur from household sources, including certain antique items such as clocks or thermometers.[74] Short-term exposure to high levels of mercury can cause lung damage, nausea, vomiting, diarrhea, increases in blood pressure or heart rate, skin rashes, and eye irritation. Exposures to mercury vapor at high levels can permanently damage the brain, kidneys, and developing fetuses. Mercury exposure is of particular concern for fetuses, infants, and children, and for persons with medical conditions that might be worsened by exposure to mercury, such as conditions of the nervous system, kidneys, or heart and vascular system.[74,75]

Fish and shellfish poisoning occurred in Japan in the Minamata River and Bay region and at Niigata between 1953 and 1964. Bread poisoning occurred as a result of the use of wheat seed treated with a mercury fungicide to make bread in West Pakistan in 1961, Central Iraq in 1960 and 1965, and Panorama, Guatemala, in 1963 and 1964. Pork poisoning took place in Alamagordo, New Mexico, when methylmercury-treated seed was fed to hogs that were eaten by a family. In Sweden, the use of methylmercury as a seed fungicide was banned in 1966 in view of the drastic reduction in the wild bird population attributed to treated seed. In Yakima, Washington, early recognition of the hazard prevented illness when 16 members of an extended family were exposed to organic mercury poisoning in 1976 by the consumption of eggs from chickens fed mercury-treated seed grain. The grain contained 15,000 ppb total mercury, an egg 596 and 1,902 ppb, respectively, of organic and inorganic mercury. Blood levels in the family ranged from 0.9 to 20.2 ppb in a man who ate eight eggs per day. A whole-blood level above 20 ppb may pose a mercury poisoning hazard.[66]

It is also reported that crops grown from seed dressed with minimal amounts of methylmercury contain enough mercury to contribute to an accumulation in the food chain reaching humans. The discovery of moderate amounts of mercury in tuna and most freshwater fish and relatively large amounts in swordfish by many investigators in 1969 and 1970 tended to further dramatize the problem.

Methylmercury has an estimated biological half-life of 70 to 74 days in humans, depending on such factors as age, body mass, and metabolism, and is excreted, mostly in the feces, at the rate of about 1 percent per day. Mercury persists in large fish such as pike for one to two years.

Elemental metallic mercury volatilizes on exposure to air, especially if heated, and in that state poses a distinct hazard. Mercury spills and the mercury from broken thermometers and barometers must be meticulously cleaned and the space ventilated and isolated until the mercury vapor level is no longer detectable by a "mercury sniffer" or similar device. Metallic mercury should never be incinerated; toxic gases would be released. Mercury should normally be stored and handled in an airtight enclosure with extreme care. Laboratory use must be carefully controlled and monitored.[66] Certain mercury compounds may be absorbed through the skin, gastrointestinal tract, and respiratory system (up to 98 percent), although elemental mercury and inorganic mercury compounds are not well absorbed through the digestive tract.

Mercury is ubiquitous in the environment from both natural and manmade sources. Natural sources include leachings, erosion, and volatilization from mercury-containing geologic formations. Carbonaceous shales average 400 to 500 ppb Hg, up to 0.8 ppm in soil. Manmade sources include waste discharges from chlor-alkali and paper pulp manufacturing plants, mining and extraction of mercury from cinnabar, chemical manufacture and formation, the manufacture of scientific instruments, mercury seals and controls, treated seeds, combustion of fossil fuels, atmospheric deposition, and surface runoff. As a result of these processes, mercury may end up in lakes, streams, tidal water, and the bottom mud and sludge deposits.

Microorganisms and macroorganisms in water and bottom deposits can transform metallic mercury, inorganic divalent mercury, phenylmercury, and alkoxyalkylmercury into methylmercury. The methylmercury thus formed and perhaps other types, in addition to that discharged in wastewaters, are assimilated and accumulated by aquatic and marine life such as plankton, small fish, and large fish. Alkaline waters tend to favor production of the more volatile dimethylmercury, but acid waters are believed to favor retention of the dimethyl form in the bottom deposits. Under anaerobic conditions, the inorganic mercury ions are precipitated to insoluble mercury sulfide in the presence of hydrogen sulfide. The process of methylation will continue as long as organisms are present and have access to mercury. It is a very slow process, but exposure of bottom sediment such as at low tide permits aerobic action causing methylation of the inorganic mercury.[76]

In fish, most mercury is in the form of methylmercury, and there are indications that a significant part of the mercury found in eggs and meat is also in the form of methylmercury.

The concentration of mercury in fish and other aquatic animals and in wildlife is not unusual. Examination of preserved fish collected in 1927 and 1939 from Lake Ontario and Lake Champlain in New York has shown concentrations up to 1.3 ppm mercury (wet basis). Fish from remote ponds, lakes, and reservoirs have shown 0.05 to 0.7 ppm or more mercury, with the larger and older fish showing the higher concentration.

In view of the potential hazards involved, steps have been taken to provide standards or guidelines for mercury. The maximum allowable concentration for 8-hour occupational exposure has been set at 0.05 mg metallic vapor and inorganic compounds of mercury per cubic meter of air. For organic mercury the threshold limit is 0.01 mg/m^3 of air. The suggested limit for fish is 0.5 ppm; for shellfish, it is 0.2 ppm. The primary standard for drinking water is 0.002 mg/1 (2 ppb) as total mercury. A standard of 0.05 ppm has been suggested for food.

A maximum ADI of 0.03 mg for a 70-kg (154-1b.) man would provide a safety factor of 10. If fish containing 0.5 ppm mercury were eaten daily, the limit of 0.03 mg would be reached by the daily consumption of 60 g (about 2 oz.) of fish. The safe levels would be 2 μg/100 ml for whole blood and 6 ppm for hair.

There is no evidence to show that the mercury in the current daily dietary intake has caused any harm, although this does not rule out possible nondetectable effects on brain cells or other tissues. The general population should probably not eat more than one freshwater-fish meal per week, with special concern for pregnant women.

Since mercury comes from manmade and natural sources, every effort must be made to eliminate mercury discharges into the environment.

Habashi has summarized techniques for the removal of mercury at metallurgical plants in the United States, Europe, and Japan.[77] The author reports that "the removal and recovery of traces of mercury from SO_2 gases or from sulfuric acid has been proved to be technically and economically feasible." Insofar as water supply is concerned, approximately 98 percent inorganic mercury may be removed by coagulation and settling at a pH of 9.5 followed by filtration through a granular activated carbon filter.

Methemoglobinemia

The presence of more than 45 mg/1 nitrates (10 mg/1 as N), the standard for drinking water, appears to be the cause of methemoglobinemia, or "blue baby" syndrome. The disease is largely confined to infants less than three months old but may affect children up to age six years of age. Methemoglobinemia is caused by the bacterial conversion of the nitrate ion ingested in water, formula, and other food to nitrite.[78] Nitrite then converts hemoglobin, the blood pigment that carries oxygen from the lungs to the tissues, to methemoglobin. The altered pigment no longer can transport oxygen, resulting in oxygen deprivation, or suffocation. Methemoglobinemia is not a problem in adults, as the stomach pH is normally less than four, whereas the pH is generally higher in infants, allowing nitrate-reducing bacteria to survive.

The boiling of water containing nitrates would cause the concentration of nitrates to be increased. Also, certain respiratory illnesses may in themselves cause an increase in methemoglobin levels in infants. A better epidemiologic basis for the standard is apparently needed. The inclusion of nitrite ion and nitrates ingested through food and air, in addition to those ingested through water, would give a more complete basis for evaluating dietary intake. Spinach, for example, is a high source of nitrate nitrogen.

Dental Caries

Fluoride deficiency is associated with dental caries and osteoporosis.[79] Water containing 0.8 to 1.7 mg/1 natural or artificially added fluoride is beneficial to children during the period they are developing permanent teeth. The incidence of dental cavities or tooth decay is reduced by about 60 percent. The maximum fluoride concentration permissible in drinking water is 4.0 mg/1. Optimum fluoride levels in drinking water for caries control, based on the annual average of the maximum daily air temperature for the location of the community water system, are as follows:

Temperature (°F)	Fluoride Level (mg/1)
53.7 and below	1.2
53.8–58.3	1.1
58.4–63.8	1.0
63.9–70.6	0.9
70.7–79.2	0.8
79.3–90.5	0.7

An alternate to community water fluoridation is a 1-minute mouth rinse by children once a week; it is reported to reduce tooth decay by about one-third or more. The mouth rinse also appears to be beneficial to adults in the prevention of dental caries. Other alternatives include fluoridation of school water supplies if there is an onsite water supply, use of fluoride toothpaste, drops and tablets, and topical application. Milk fluoridation has been shown to be effective in the prevention of dental caries, but to be clinically effective, it must be freshly prepared and consumed immediately.[80] The Pan American Health Organization has proposed adding fluoride to table salt in areas lacking fluoridated community water supplies.[81] Oral hygiene, including at least daily teeth brushing, consumption of fewer sweets, followed by a water rinse or drink, is also basic to caries reduction.

Studies have found that consumption of fluoridated water does not lead to adverse health effects. A federal study involving almost 1 million persons in 46 American cities showed virtually no difference in death rates, including from cancer, between 24 cities using fluoridated water and 22 without fluoridated water.[82]

The long-term consumption of water high in fluoride (8–20 mg/1) is reported to cause bone changes. On the one hand, an intake of 20 mg fluoride per day for 20 or more years may cause crippling fluorosis, and death can come from a single dose of 2,250 to 4,500 mg. On the other hand, optimal concentrations of fluoride in drinking water and food appear to be beneficial in preventing osteoporosis.

Sporotrichosis

Conifer seedlings packed in sphagnum moss can cause papules or skin ulcers and inflammation on the hands and arms, which can then spread to other parts of the body. This disease is caused by a fungus, *Sporothrix schenckii*, found in moss, hay, soil, and decaying vegetation. Protective clothing, including gloves and long-sleeved shirts, should be worn when handling sphagnum moss or seedlings.[83]

Nutritional Deficiency and Related Diseases

Severe examples of diseases caused by deficiencies in the diet are not common in the United States and other developed countries; however, they do occur.[84] These deficiencies are found much more often in less developed countries of the world. There are, however, many people whose diet is slightly deficient in one or more nutrients but who show no clinically detectable symptoms for many years. Most malnutrition takes the form of protein deficiency. Diarrheal diseases and resulting malabsorption may compound nutritional deficiencies; hence, basic environmental sanitation, including safe water, availability and use of latrines, clean food handling, hand washing, personal hygiene, and refrigeration of food, are essential elements of a comprehensive nutrition program. Deficiency of a nutrient does not by itself necessarily cause disease. Predisposing host and environmental factors as noted are also involved, and this must not be overlooked in the development of a control program.

Recommended daily dietary allowances for the maintenance of good nutrition, to be consumed in a variety of foods to provide other less defined required nutrients, are shown in Table 3.4.[85] Of the more than 60 mineral elements found in living things, nine are considered essential to human life. These are iron, iodine, fluoride, copper, manganese, zinc, selenium, chromium, and cobalt. The role of other minerals is not well established.

There has been a great deal of interest in the adoption of a balanced, healthy diet to help minimize deaths due to heart disease and cancer, which, together

TABLE 3.4 Food and Nutrition Board, National Academy of Sciences—National Research Council Recommended Dietary Allowances,[a] Revised 1989

							Fat-Soluble Vitamins			
Category	Age (years) or Condition	Weight[b] (kg)	(lb)	Height[b] (cm)	(in)	Protein (g)	Vitamin A (μg RE)[c]	Vitamin D (μg)[d]	Vitamin E (mg α-TE)[e]	Vitamin K (μg)
Infants	0.0–0.5	6	13	60	24	13	375	7.5	3	5
	0.5–1.0	9	20	71	28	14	375	10	4	10
Children	1–3	13	29	90	35	16	400	10	6	15
	4–6	20	44	112	44	24	500	10	7	20
	7–10	28	62	132	52	28	700	10	7	30
Males	11–14	45	99	157	62	45	1,000	10	10	45
	15–18	66	145	176	69	59	1,000	10	10	65
	19–24	72	160	177	70	58	1,000	10	10	70
	25–50	79	174	176	70	63	1,000	5	10	80
	51+	77	170	173	68	63	1,000	5	10	80
Females	11–14	46	101	157	62	46	800	10	8	45
	15–18	55	120	163	64	44	800	10	8	55
	19–24	58	128	164	65	46	800	10	8	60
	25–50	63	138	163	64	50	800	5	8	65
	51+	65	143	160	63	50	800	5	8	65
Pregnant						60	800	10	10	65
Lactating	1st 6 months					65	1,300	10	12	65
	2nd 6 months					62	1,200	10	11	65

Water-Soluble Vitamins							Minerals						
Vitamin C (mg)	Thiamin (mg)	Riboflavin (mg)	Niacin (mg NE)[f]	Vitamin B_6 (mg)	Folate (μg)	Vitamin B_{17} (μg)	Calcium (mg)	Phosphorus (mg)	Magnesium (mg)	Iron (mg)	Zinc (mg)	Iodine (μg)	Selenium (μg)
30	0.3	0.4	5	0.3	25	0.3	400	300	40	6	5	40	10
35	0.4	0.5	6	0.6	3.5	0.5	600	500	60	10	5	50	15
40	0.7	0.8	9	1.0	50	0.7	800	800	80	10	10	70	20
45	0.9	1.1	12	1.1	75	1.0	800	800	120	10	10	90	20
45	1.0	1.2	13	1.4	100	1.4	800	800	170	10	10	120	30
50	1.3	1.5	17	1.7	150	2.0	1,200	1,200	270	12	15	150	40
60	1.5	1.8	20	2.0	200	2.0	1,200	1,200	400	12	15	150	50
60	1.5	1.7	19	2.0	200	2.0	1,200	1,200	350	10	15	150	70
60	1.5	1.7	19	2.0	200	2.0	800	800	350	10	15	150	70
60	1.2	1.4	15	2.0	200	2.0	800	800	350	10	15	150	70
50	1.1	1.3	15	1.4	150	2.0	1,200	1,200	280	15	12	150	45
60	1.1	1.3	15	1.5	180	2.0	1,200	1,200	300	15	12	150	50
60	1.1	1.3	15	1.6	180	2.0	1,200	1,200	280	15	12	150	55
60	1.1	1.3	15	1.6	180	2.0	800	800	280	15	12	150	55
60	1.0	1.2	13	1.6	180	2.0	800	800	280	10	12	150	55
70	1.5	1.6	17	2.2	400	2.2	1,200	1,200	320	30	15	175	65
95	1.6	1.8	20	2.1	280	2.6	1,200	1,200	355	15	19	200	75
90	1.6	1.7	20	2.1	260	2.6	1,200	1,200	340	15	16	200	75

[a] The allowances, expressed as average daily intakes over time, are intended to provide for individual variations among most normal persons as they live in the United States under usual environmental stresses. Diets should be based on a variety of common foods in order to provide other nutrients for which human requirements have been less well defined. See text for detailed discussion of allowances and of nutrients not tabulated.

[b] Weights and heights of Reference Adults are actual medians for the U.S. population of the designated age, as reported by NHANES II. The median weights and heights of those under 19 years of age were taken from P. V. Hamill, T. A. Drizd, C. L. Johnson, R. B. Reed, A. F. Roche, and W. M. Moore, "Physical Growth: National Center for Health Statistics Percentiles," *Am. J. Clinical Nutrition* (March 1979): 607–629 (see pp. 616–617). The use of these figures does not imply that the height-to-weight ratios are ideal.

[c] Retinol equivalents: 1 retinol equivalent = 1 μg retinol or 6 μg β-carotene. See text for calculation of vitamin A activity of diets as retinol equivalents.

[d] As cholecalciferol; 10 μg cholecalciferol = 400 IU of vitamin D.

[e] α-Tocopherol equivalents: 1 mg D-α-tocopherol = 1 α-TE. See text for variation in allowances and calculation of vitamin E activity of the diet as α-tocopherol equivalents.

[f] 1 NE (niacin equivalent) is equal to 1 mg of niacin or 60 mg of dietary trytophan.

with stroke, were the top three causes of death in the United States in 2004.[86] Diets high in saturated fat, sugar, and sodium may promote the development of these diseases. Recommendations include greater consumption of chicken and turkey (with skin removed), fish, pasta, whole-grain products, vegetables, fruits, and vegetable oils (not palm or coconut oils), and reduced consumption of meat, dairy products, and eggs.

Scurvy Scurvy is caused by a deficiency of vitamin C or ascorbic acid. Vitamin C is found in citrus fruit, fresh strawberries, tomatoes, raw peppers, broccoli, kale, potatoes, and raw cabbage. Common symptoms of scurvy include weakness, anemia, spongy and swollen gums that bleed easily, and tender joints. Vitamin C also strengthens body cells and blood vessels and aids in absorption of iron and in healing wounds and broken bones.[87]

Pellagra Pellagra is caused by a prolonged deficiency of niacin (nicotinic acid) or tryptophan (amino acid). Niacin is found in eggs, lean meats, liver, whole-grain cereals, milk, leafy green vegetables, fruits, and dried yeast. Recurring redness of the tongue or ulcerations in the mouth are primary symptoms, sometimes followed by digestive disturbances, headache, and psychiatric depressive disorders.[87]

Rickets Rickets is most common in children less than two years old and is caused by the absence of vitamin D, which is associated with proper utilization of calcium and phosphorus. Vitamin D is found in liver, fortified milk, butter, eggs, and fish of high-body-oil content such as sardines, salmon, and tuna. An inadequate supply of vitamin D in the diet will probably show in knock-knees or bowed legs, crooked arms, soft teeth, potbelly, and faulty bone growth. Sunshine is a good source of Vitamin D, as are vitamin D-fortified foods. Vitamin D helps build strong bones and teeth.[87]

Beriberi A prolonged deficiency of thiamin or vitamin B_1, found in whole-grain cereals, dried beans, peas, peanuts, pork, fish, poultry, and liver, may cause changes in the nervous system, muscle weakness, loss of appetite, and interference with digestion. Change from unpolished to polished rice in the diet can cause the disease in some countries where the diet is not varied.[87]

Ariboflavinosis This disease is due to a deficiency of riboflavin, known also as vitamin B_2 or G. Riboflavin is found in liver, milk, eggs, dried yeast, enriched white flour, and leafy green vegetables. An inadequate amount of this vitamin may cause greasy scales on the ear, forehead, and other parts of the body, drying of the skin, cracks in the corners of the mouth, anemia, and sometimes partial blindness. Riboflavin is essential for many enzyme systems.[88]

Vitamin A Deficiency A deficiency of Vitamin A causes night blindness, skin and mucous membrane changes, and dryness of the skin and eyes. It is believed to increase susceptibility to colds. In severe deficiencies, Vitamin A deficiency may lead to blindness and death. Vitamin A is also needed for bone growth. The diet should be adjusted to include foods rich in vitamin A or carotene, such as dry whole milk and cheese, butter, margarine, eggs, liver, carrots, dandelion, kale, and sweet potatoes.[89]

Iron Deficiency Anemia Lack of vitamin B_{12} or folic acid, repeated loss of blood, and increased iron need during pregnancy cause weakness, irritability, brittle fingernails, cuts and sores on the face at the mouth, and other debility. Prevention of blood loss and treatment with iron salts are suggested. Iron combines with protein to make the hemoglobin of the red blood cells that distribute oxygen from the lungs to body tissues. Consumption of liver, lean meats, poultry, shellfish, eggs, oysters, dried fruits, dark green leafy vegetables, iron-fortified flour, and cereal foods will contribute iron to the diet.[90]

Goiter Goiter is a thyroid disorder usually caused by deficient iodine content in food and water and inadequate iodine absorption. The WHO estimated that nearly 2 billion people worldwide have insufficient iodine intake, with the greatest burdens in Europe, the Middle East and Africa.[91] Widespread use of iodized salt in the Americas has led this region of the world to have the lowest prevalences of insufficient iodine intake. Seafood and ocean mist are good sources of iodine.[88]

Kwashiorkor Kwashiorkor is one of a group of diseases caused by protein deficiency and common among children less than six years of age living in underdeveloped areas of the world. Related diseases include marasmus and protein energy malnutrition (PEM). The term *kwashiorkor* means “the disease of the displaced child” and often occurs in children affected by manmade or natural disasters. Signs and symptoms include changes in the color and texture of the hair, diarrhea, and scaling sores. A diet rich in animal proteins, including dry skim milk, meat, eggs, fish, and cheese, and vegetables can control the disease. Because of the scarcity or lack of these foods in some developing countries, special formulations have been prepared to provide the necessary nutrients. These include Incaparina,[92] a mixture of cornmeal, ground sorghum, cottonseed flour, torula yeast, and leaf meal, blended and fortified with calcium and vitamins; WSDM, consisting of 41.5 percent sweet whey, 36.5 percent full-fat soy flour, 12.2 percent soybean oil, nine percent corn syrup, and vitamins and minerals; and CSM, corn soy-milk.

Marasmus Marasmus is a form of malnutrition that causes a progressive wasting of the body. Marasmus occurs primarily in young children and is associated with insufficient intake or malabsorption of food.[93] Marasmus is usually associated with diarrheal diseases and weight loss in young children. An inadequate diversified food intake can contribute to the problem. A gradual increase in food intake, including protein, carbohydrates, and fat, is the suggested treatment.

Dehydration Dehydration is the leading cause of diarrheal illness–associated morbidity and mortality. Oral rehydration therapy (ORT) with oral rehydration salts (ORS) began as the use of oral rehydration salt packets dissolved in water[94] on the basic premise that fluid replacement can be achieved by providing patients with diarrheal illness an oral supplement comprised of sugar, salt, and water. More recently, the term *ORT* has expanded to include the use of ORS, as well as recommend home fluids which are composed of NaC and a source of carbohydrate ranging from rice water to cereal-based solutions and traditional soups.[95] Newer formulations of oral rehydration salts under development will also help to promote intestinal healing. In order to be most effective, oral rehydration salts must be used early in the course of illness and maintained or replaced by early resumption of feeding.[96]

Important to note is that the use of ORT does not prevent recurrence of the diarrheal disease, and affected children may require ORT many times during their first five years. The causes must be removed. Safe drinking water, environmental sanitation, and hygiene are essential to provide long-term protection against the causes of diarrheal diseases. Safe drinking water will also promote sanitary food preparation, personal hygiene and household cleanliness, improved housing, a better quality of life, and more.[97]

Osteoporosis Osteoporosis is defined as a decrease in bone mass and bone density and an increased risk or incidence of fracture. In osteoporosis, bone is decalcified and becomes porous and brittle, particularly in women after menopause. Because estrogen has an important role in the maintenance of structure and calcification of bone, the drop in estrogen at menopause is, in part, responsible for osteoporosis, although lifestyle, nutritional, and environmental factors have also been found to play a role in the development of osteoporosis. Maintenance of an adequate level of calcium and vitamin D may help to offset the disease and fluorides in proper amounts in drinking water and food also appear to help prevent osteoporosis. Major dietary sources of calcium include milk, cheese, and other dairy products, and dark green leafy vegetables. The use of hormone replacement therapies to offset the decrease in estrogen has been used with some success, but because of the increased risk of certain cancers and heart disease, the use of hormone replacement therapy is generally not recommended.

Obesity *Overweight* is classified as having a body mass index (BMI is weight kg/height m^2) of ≥ 25.0, *obesity* is defined as having a BMI ≥ 30.0, and *extreme* (class III) *obesity* is defined as having a BMI $\geq 40.0\,kg/m^2$. Obesity is associated with increased risk for hypertension, dyslipidemia, type 2 diabetes, coronary heart disease, stroke, and certain cancers.[98] The prevalence of obesity has increased dramatically in the United States in the past decades. In 1999-2002, 65 percent of adults surveyed in the National Health and Nutrition Examination Survey (NHANES) were either overweight or obese, a 5 percent increase over the previous survey (NHANES III, 1988–1994). Of these, half (30% of total) were obese. In the 2003–2004 NHANES, the prevalence of obesity was 32.2 percent.[99]

Given the continued increases in the prevalence of obesity in the United States, there is a clear need for programs to educate and motivate persons to make healthier lifestyle choices and to establish environments which support these choices.[100] Effective public health programs to reduce obesity should combine policies, programs, and supportive environments created through the combined activities of health-care agencies, government, media, business and industry, communities, schools, families, and individuals.[100]

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CHAPTER 4

APPROPRIATE TECHNOLOGY FOR DEVELOPING COUNTRIES

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ABBREVIATIONS

AAEE	American Academy of Environmental Engineers
ADB	Asian Development Bank
AEESP	Association of Environmental Engineering and Science Professors
AESs	Appropriate environmental standards
APHA	American Public Health Association
ASCE	American Society of Civil Engineers
ASEP	Asian Society for Environmental Protection
AWWA	American Water Works Association
BMR	Bangkok Metropolitan Region
CC	Construction Contractor
CECI	Chief Environmental Construction Inspector
CP	Cleaner production
DC	Developing country
DIW	Department of Industrial Works
E1	Economics parameter
E1-c-E2 (E-c-E)	Economics-cum-Environmental
E2	Environment parameter
ED	Environmental degradation
EE	Environmental engineering
EIA	Environmental impact assessment
EMO	Environmental management office
EMP	Environmental management plan
EPM	Environmental protection measure
EPU	Economic Planning Unit (Malaysia)
ES	Executive summary

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ESA	Environmental study area
ET	Environmental technology
FCF	Fixed capital formation
FS	Feasibility study
GDP	Gross domestic product
HFL	Harvey F. Ludwig
HW	Hazardous waste
HWMP	Hazardous waste management project
IAA	International assistance agency
IC	Industrialized (developed) country
IEE	Initial environmental examination
IEEDP	Integrated Economic-cum-Environmental Development Planning
IT	Information technology
IUCN	International Union for Conservation of Nature
IWA	International Water Association
KIP	Kampung improvement project
KVEIP	Klang Valley Environmental Improvement Project
LACSD	Los Angeles County Sanitation Districts
LW	Liquid waste
MDB	Multilateral development bank
MSL	Municipal sanitary landfill
MSS	Municipal sewerage system
NEB	National Environment Board (Thailand)
NEcPA	National economic planning agency
NEnPA	National environmental protection agency
O&M	Operation and Maintenance
PB	Palmer-Bowlus (flumes)
PCD	Pollution Control Department (Thai government)
PEA	Project economic analysis
PrPr	Project proponent
R&D	Research and development
SEIs	Significant environmental issues
SLF	Sanitary landfill
STP	Sewage treatment plant
SW	Solid waste
TDS	Total dissolved solids
THMs	Trihalomethanes
TOR	Terms of reference
TT	Technology transfer
UNDP	United Nations Development Program
UNEP	UN Environment Program
USAID	U.S. Agency for International Development
USEM	Urban sewerage and excreta management
U.S. EPA	U.S. Environmental Protection Agency

USWM	Urban solid waste management
UWSS	Urban water supply system
VEO	Village Environmental Officer
WB	World Bank
WEF	Water Environment Federation
WHO	World Health Organization
WPC	Water pollution control
WQ	Water quality
WTO	World Trade Organization
WWF	World Wildlife Fund
YC	Young coyote

INTRODUCTION

Background

Examination of publications in the field of engineering shows that practically all of the technologies utilized for protecting environmental resources and preventing environmental degradation have been developed in the affluent industrialized countries (ICs) without significant contributions from the developing countries areas and regions of the world. This is because their advanced economic status has enabled the ICs to reach levels of understanding on the need for protecting environment, and has given them the funds to study and develop the feasible technologies needed for controlling environmental degradation and the funds to finance design/construction/operation of the protection control facilities.

History

By the mid-twentieth century, the ICs had progressed sufficiently to begin implementation of the desired control programs, especially in the basic sanitary engineering fields of urban water supply, wastewater management, and food sanitation, plus beginning efforts for tackling other key problems including solid wastage management, air pollution control, noise control, and radioactive emissions control. Then came the impact of World War II, which initiated a great increase in research and development (R&D) in all aspects of environmental engineering, so much so that of the total arena of information on environmental engineering technology, it is estimated that more than 90 percent has been generated in the second half of the twentieth century. Moreover, while this environmental technology developed by the ICs was relatively simple and labor-intensive before World War II, the emphasis of the subsequent R&D has focused on minimization of labor by replacing this with hi-tech equipment that is readily operated only by trained professionals. And the overall IC effort has included progressively improving programs for furnishing the needed training. In the U.S. the U.S. Environmental Protection Agency (U.S. EPA) established in the 1960s (built on the earlier federal environmental engineering program operated by the U.S. Public Health Service) had a leadership role in the "U.S. Environmental Movement" with a budget believed to exceed the governmental budgets of all other countries combined, and this remarkable effort has been further enhanced by very significant extra investments by U.S. state and local agencies and by the U.S. private sector. The result is, in the United States (and somewhat similarly in other ICs) the approach to resolving environmental degradation problems has become very hi-tech, with the level of technology continuing to increase.

Problem of Developing Countries

What is the situation in the DCs, as related to the context of environmental technology development in the ICs, keeping in mind that the bulk of the world's population, land area, and environmental resources are located in the DC regions? An important point here is that the IC developments were essentially focused as would be expected on IC problems, with little, if any, attention to the fate of environment in the DCs. However, development of the U.S. environmental movement in the years immediately following World War II (stemming from the new role of the United States as a truly rich country) led to the UN/Stockholm/1972 Conference, which established a global effort funded by the ICs for assisting the DCs for protecting DC environments, including establishment of UNEP, and led to establishment of National Environmental Protection Agencies (NEnPAs) in virtually all DCs, either as an environmental ministry or branch or affiliate of existing ministries, intended to function together with existing National Economic Planning Agencies (NEcPAs) (already established with World Bank assistance) to promote continuing assistance to DCs to promote economic development (E1 development), but without sufficient attention to protecting environmental resources (E2 protection) as needed to promote sustainable development.

Examination of what has actually happened to the DC environments since the beginning of the "International Global Environmental Movement" in 1972 shows that the expectations for protection of DC environmental resources have not happened. Indeed, as shown by the UN Brundtland Report of 1987[141], DC environmental degradation over the period 1972 to 1987 actually exceeded the total of all historically previous degradation. This was due to (1) rapid growth of population and industries in the ICs resulting in increasing demands for import timber and other environmental resources from the DCs, (2) rapid development of new technologies, making it increasingly much easier to extract and export these resources, and (3) matching realization by DC decision makers that allowing such rapid extraction and export furnished much money for their immediate goals of remaining in office[72,82,83]. In this context the newly established DC/NEnPAs found that achieving meaningful environmental protection could not be done in emulation of role models like U.S. EPA, because of lack of basic will by DC governments to resolve the degradation problem[58]. Hence, the NEnPAs had, compared to say, U.S. EPA, relatively very low budgets and staff without experience in how to proceed to protect environment under DC conditions. Moreover, their efforts were undermined by the lack of will by the governments to enforce the recommendation of the NEnPAs for environmental protection (e.g., the environmental protection measures specified in a project's Environmental Impact Assessment.

Summary of DC Problem

A summarization of the typical DC situation is given in the paper, "How Asian Development Bank can Improve Their Technology Transfer Operations for Water/Sanitation Projects in Developing Countries"[94], which is quoted here as follows

> (a) Require post-construction monitoring of performance of the systems which are built. This is basic standard engineering practice which together with periodic performance monitoring is routine in the ICs, to determine how effective the investment is, and what needs to be done to improve planning/design practices so the system will become more effective. Despite this fundamental fact, the MDBs have persistently refused to require performance monitoring, hence the MDB staff have not found out how to improve their practices in guiding DC project planning/design. Such monitoring will reveal deficiencies in design and in provisions for O&M, so that practices can be progressively improved[73].
>
> (b) For each type of sector investment (water supply, sewerage, air pollution control, etc.), discontinue common MDB practice of allowing systems to be designed which follow IC design criteria and matching environmental standards, and figure out for each sector for the particular DC what the appropriate/affordable environmental standards and matching design criteria should be, in recognition that the monies available to the DC will be only a fraction of that spent in the ICs for managing the same problem. This is crucial but cannot be done by "Environmental Generalists" or "Engineer Generalists" but can be done only by skilled sanitary engineers knowledgeable both in IC practices and how to modify these to suit DC conditions. Many of the MDB project staff with whom the author has worked have not had the needed skills in appropriate IC vs. DC practices.
>
> (c) Ensure that the recommended system is realistic with respect to the O&M limitations in the DCs. Most IAA projects have not done this but have pretended to do it. The Feasibility Study reports commonly include a chapter on O&M which simulates IC practices, even though the writers know the DCs cannot/will not implement it. This practice is not only counterproductive but is grossly unprofessional. The reason for the malfunctioning and wastage mentioned above sometimes is poor design, but even with good design the system often will not function effectively due to lack of adequate O&M. Usually the DC governments (and the IAA sponsors) are not aware of this because of the lack of performance monitoring. Sometimes the DC officials involved may insist on including components in the project which shouldn't be there (such as a highly mechanized sewage treatment plant). Never mind, their "money need" must be accommodated, but they take only a part of the total project budget. The goal is to see to it that the remaining money isn't frittered away but will produce a useful project. The existing syndrome is that "corruption" takes a sizeable slice, but the DC can live with that. The need is not to let the rest of the money get frittered away.

(d) The MDBs and other IAA sponsors have done a very poor job in technology transfer to DC personnel. The best/cheapest way to achieve effective TT (technology transfer) is to utilize the actual project for this purpose. But the way the MDBs et al. structure the budget, while the overall project team includes both expat experts and DC participants as assistants, the project budget has no funds for enabling the expat experts to use the project for TT purposes[45]. So the expats use the DC-ers to do tasks without explanation of the "why" of the tasks. The MDBs et al assume the TT will "rub off" on the DC participates in the project implementation process, but this doesn't happen—It's not that easy. The need is to increase the project budget for the expats by about 10 percent to enable the expat experts to have the time to utilize the project for training purposes.

(e) The MDBs should recognize that Environmental Technology has been developed primarily in the ICs, but in the DCs, because of the non-money making nature of most environmental/sanitary infrastructures, the DC governments/universities are generally not knowledgeable on appropriate sanitary engineering design technology. Often the practitioners and university professors have only academic backgrounds in affluent IC practices and are not at all capable of doing the judgment thinking needed for making the IC to DC changes. This applies also to most MDB/IAA staff and most DC staff because they have not had the needed apprenticeship[72]. The result is the poor design noted in Items (b)(c) above. How to correct this very basic problem? Several approaches are feasible:

(e.1) Incorporate technology transfer into the investment project program as noted in Item (d) above.

(e.2) Prepare textbooks or manuals on appropriate DC design criteria (and matching environmental standards), which can guide DC/IAA designers to produce a project which works, such as done by H. Ludwig et al. for the Municipal Sewerage Sector[105], which to the author's knowledge, is the only environmental engineering design textbook yet produced which is actually appropriate for DC application. As noted in its Preface, this Sewerage textbook is "just for starters," to illustrate this approach. Similar textbooks are needed for all sectors (municipal water supply, highways, ports, etc.) so that projects in all sectors will be economically-cum-environmentally sound.

(e.3) Established graduate training programs on IC versus DC design practices for all types of investment, to ensure appropriate design practices (and matching environmental standards) for all types of environmentally-sensitive projects, leading to university graduate degrees in Economic-cum-Environmental (E-c-E) Development in the DCs, to be attended by both DC and IAA personnel[99]. This approach is the most basic—to give attention to the need for E1-cum-E2 project design for all sector projects as part of the graduate education program. The MDBs should take the lead to establish at least one such university program, somewhere in a qualified university. No existing graduate university now does this, not even the Asian Institute of Technology in Bangkok nor the UN university program in Japan.

(e.4) Promote establishment of an Environmental Engineering Journal, i.e., a professional magazine in which each issue will feature projects that discuss specific examples or case studies of illustrative DC projects which explain how IC practices were modified to suit DC conditions.

(e.5) Furnish copies of selected IC textbooks/manuals, which, despite their IC origins, nevertheless can be very useful to DC practitioners (who with rare exceptions cannot afford to buy them), translated into the local DC language[163]. One example is the American text, "Standard Methods for Analysis of Water and Wastewaters"[2], which is a virtual "bible" on this subject, which is useful per se in both ICs and DCs. If done this simple stop alone should greatly improve water and wastewater management technology in the DCs, hence remarkably high benefits at low cost.

(e.6) Send DC staff for training, not "observing," with U.S./IC organizations. Most MDB-sponsored projects of this type amount to what may be called "observation junkets." What is needed (and the author has used this approach repeatedly) is to assign the DC individual to be an additional working team member in an organization doing what he wants to learn to do. For example, if the DC-er wants to learn about regulatory permit systems for WPC (water pollution control), assign him to be a temporary extra member of the WPC permit section staff of one of the California State Regional Water Quality Control Boards. This not only achieves real world training but doesn't require the organization to whom the individual is assigned to make any special preparations. The best agencies for this purpose in my view in the environmental engineering field are the California Regional Boards for regulation procedures, and the Los Angeles County Sanitation Districts for management of liquid and solid wastes.

(e.7) Plan Technology Transfer projects, not in the usual way as a single event operation, but spread this over a period of training series with enough time between to permit the student to absorb the lessons from each session[45]. The IAAs like the single-event approach because it "saves" travel costs, without realizing that their approach is not effective. Might as well cancel the project and save all of its cost.

(e.8) Use retired expat experts to give hands-on training, where a single expert, say in community water supply systems, visits each of say 10 systems every month. The big advantage of this approach is that the expert catches the DC-er at the moments when he has a serious problem, hence listens carefully to the expert's advice. This is far superior to use of academic classroom textures.

Make much more effective use of the Private Sector, both by means of turnkey projects and by use of contracts limited to O&M, especially for projects in water supply and sanitation. This subject is discussed in some detail in the section on Urban Water Supply Systems (UWSSs).

Purpose of This Chapter

This chapter is devoted to Item e.2, namely the furnishing of design guidelines, with matching environmental standards, which are appropriate for design of DC environmental engineering systems. Experience over the past several decades on many DC projects has shown[72] that the lack of such guidelines is often the major reason for failure of investments in DC environmental engineering systems. This experience shows that if the project is designed so that it is not suitable for DC/O&M, it is doomed to failure at the outset—and a large percentage of IAA-sponsored projects are in this category. However, if the project is designed to suit DC conditions, there is a good chance that it will actually be operated and effectively utilized, despite the many problems already noted. What the DC practitioner critically needs (the same for his IAA adviser) is a "cookbook" type of manual that can be copied (despite the practitioner's lack of training/experience), just as a novice cook can make an edible cake using a cookbook, and environmental lab technicians can do acceptable BOD testing of wastewaters even with limited training.

To sum up, the essential purpose of this chapter is to illustrate how the design information given in the other chapters, which is essentially IC-oriented, can be properly modified to be applicable for use in DCs. The objective is to enable DC (and IAA) practitioners to make valuable use of this sixth edition of *Environmental Engineering*. Note not only that almost all existing textbooks/manuals are intended for IC use, but also, the same applies to the articles in the magazines/journals published by professional organizations such as ASCE, AWWA, and WEF. The technologies described in these articles are much beyond the affordability of most DCs now and in the foreseeable future[112].

Specific Subjects Included in This Chapter

Of the various technological fields discussed in the sixth edition of *Environmental Engineering*, this chapter includes discussion of the major sanitary/environmental engineering fields of urban water supply, urban sewage management, industrial waste management, urban solid waste management, urban hazardous waste management, urban air pollution control, megacities, urban slums, urban sanitation, rural sanitation, public health, and water resources, together with discussion of the related subjects of environmental governance, environmental impact assessment, emergencies management, environmental technology transfer, development planning, global warming, and the future of global environmental issues.

Key Constraints in Environmental Engineering Practice in DCs The purpose of this section is to illustrate the key constraints involved in applying environmental engineering technology in DCs (as distinguished from ICs).

Limited DC Expertise in Environmental Technology This problem is illustrated in Figure 4.1, which shows that many, if not most, DC/ET professionals have limited actual apprenticeship experienced in working under the guidance of ET experts, and moreover their academic training is often IC-oriented[72]. This explains the need for "cookbook" versions of design textbooks/manuals for use by DC practitioners (and their counterparts in the IAAs).

Appropriate DC Design Criteria/Environmental Standards This problem is illustrated in Figures 4.2 and 4.3. Review of the development of environmental engineering design criteria (and matching environmental standards) in the ICs shows that these have steadily increased over the decades along with increasing

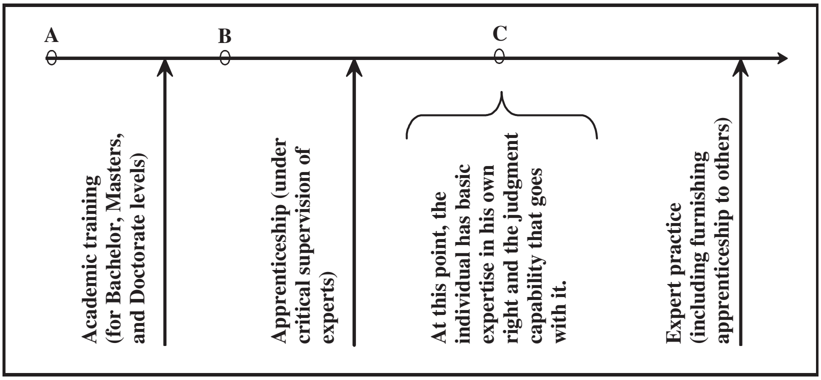


FIGURE 4.1 Role of apprenticeship in development of expertise[66].

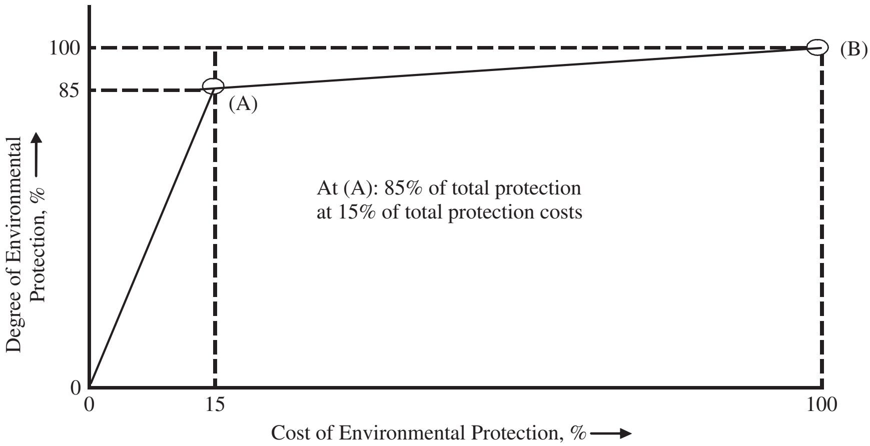


FIGURE 4.2 Appropriate project design criteria for DCs[82].

IC affluence. These criteria/standards are simply not affordable or appropriate for use in DCs; hence, the criteria/standards that are appropriate represent lesser levels as shown in the figures. However, as shown in Figure 4.2, even at a much lower percentage of cost, the bulk of the environmental protection can still be achieved. The problem is in modifying IC criteria/standards to reduce them to appropriate DC levels, which takes truly expert judgment. This is another reason for the need for "cookbook" textbooks/manuals.

(a) Figure 4.3 also illustrates the influence of costs in differentiating between IC and DC design criteria. While Point C represents the target in current U.S. practice, Point B is the appropriate target for DCs.

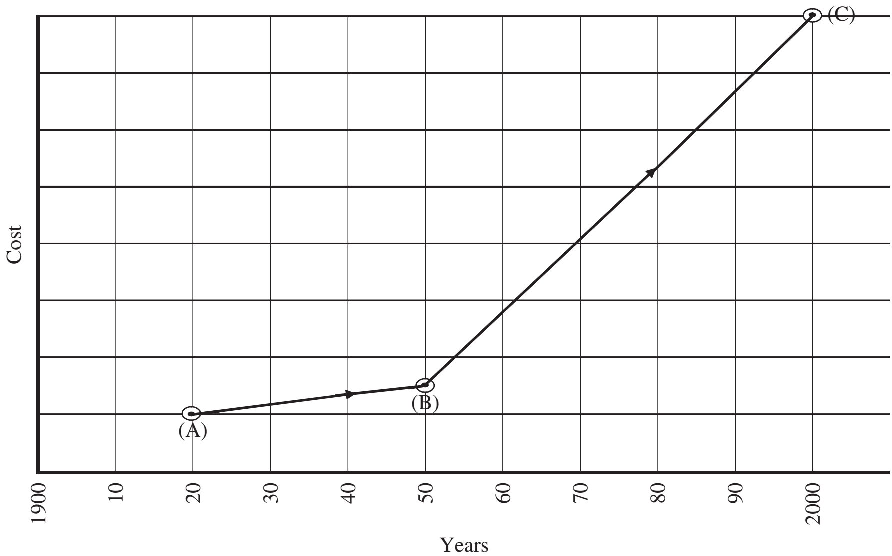


FIGURE 4.3 Levels of U.S. requirements for treatment of water supply and sewage. Source: H. Ludwig/2007.

Lack of Enforcement of Environmental Laws/Regulations This problem is illustrated in Figure 4.4. The ICs clearly understand that laws/regulations are not meaningful unless their requirements are enforced using monitoring to detect noncompliance with penalties for noncompliance sufficient to encourage compliance. Sad to say, no DC has as yet have applied this principle so that, while the DCs do often have excellent laws/regulations for environmental protection, including use of the EIA process, generally the monitoring of performance and use of serious penalties is low, which, of course, encourages evasion rather than compliance[82]. However, as noted earlier, experience in the DCs shows that if an EE facility is properly designed so it can be feasibly operated within the DC system, there is a good chance that the plant will be made to perform by its management despite the lack of monitoring/enforcement.

Use of Private Sector As already noted, much more effective use of the private sector is recommended, especially for water and sanitation systems. How to achieve this is discussed in the section on “Urban Water Supply.”

Protection of Precious Ecosystems A serious deficiency in conventional economic analyses of proposed development project is to ignore the real value of precious ecosystems that will be impaired by the project simply because of lack of mechanics for expressing this value in the money terms used for such analyses. This issue is discussed in the section on “Development Planning.”

(1) Environmental Protection Action (EPA) = Laws/Regulations (L/Rs) x Enforcement (E)

(2) Enforcement (E) = Effective Monitoring (EM) x Stiff Penalties (SPs)

(3) Effective Monitoring (EM)

(3.1) Review of project feasibility study to ensure inclusion of EIA constraints including use of appropriate environmental standards (AESs).
(3.2) Review of project's final design, to ensure inclusion of EIA constraints including environmental controls to be followed by construction contractor.
(3.3) Monitoring of construction contractor's operations to ensure compliance with environmental controls.
(3.4) Inspection of final construction to ensure compliance with environmental construction (before releasing contractor).
(3.5) Periodic monitoring of project operations to ensure implementation of prescribed EPMs, including sampling and analyses, to evaluate project's actual environmental impacts, with follow-up to obtain needed corrections.

FIGURE 4.4 Environmental protection action versus enforcement.[120].

ENVIRONMENTAL GOVERNANCE

Introduction

The previous section on "Introduction" includes preliminary discussion of the issue of environmental governance in the DCs (i.e., the degree to which attention is given in the country by the government, by industries, and by environmental engineering practitioners to the needs for protecting environmental resources from unnecessary degradation). This section gives additional details.

Situation in DCs versus United States/ICs

As noted in Figure 4.4 the situation in environmental governance in the DCs is vastly different from that in the ICs, simply because the U.S./IC system embodies effective monitoring/enforcement to ensure that the project proponent for any proposed project, both public and private, will actually comply with the requirements for EPMs that are specified in the approved EIA (part of the feasibility study) in the subsequent project implementation stages of final design, construction, and operation. Usually, the administration of this process in the ICs involves use of the "permit system" in which the project regulating agency issues a permit to the project proponent that spells out all of the EIA's EPMs to be carried out by the proponent, including periodic self-monitoring with periodic reporting, with public surveillance visits to the regulating agency to check actual environmental performance (i.e., to check the reliability of the self-monitoring reports). The project proponent complies simply because the cost of compliance is less than the cost of penalties for noncompliance. This system has evolved in the ICs in recognition that effective monitoring/enforcement is essential to gain compliance.

Unfortunately, the situation in the DCs is vastly difference because none of the DCs has yet to establish effective monitoring/enforcement operations. Although the DCs do use the EIA process (with limited success), which do specify the needed EPMs, the follow-up provisions for monitoring/enforcement are generally so weak that it is much less costly to evade rather than to comply with the specified EPMs. It seems that the decision makers of the DCs have not wanted to implement effective monitoring/enforcement because this conflicts with their interest in immediate financial gains, rather than in optimal long-term economics (See section on “Environmental Economics and Financing”).

What DC and IAA Practitioners Can Do to Correct This Problem

There are several approaches that can be utilized to encourage use by the DCs of effective monitoring/enforcement.

World Bank and Other IAAs: Project Monitoring and Enforcement The best opportunity for improving DC environmental performance is the leverage available to the World Bank and other IAAs that help finance DC projects, for requiring project monitoring/enforcement as a loan codicil. There have been some projects where the loan codicil did include this requirement, including World Bank/Gunaratnam projects[81,161,162,163]. But these have been very few and, in general, the World Bank and others seem to have assiduously avoided this requirement. (They have preferred the “diplomatic approach,” no doubt because such effective monitoring would clearly conflict with political wishes, including the very serious problem of wastage of project money by corruption.) Also, the monitoring would clearly indicate the wastage that takes place and which parties are the “culprits,” and both the IAAs and DCs have preferred not to push this approach. Only in recent years has the World Bank begun overt evaluation of the corruption problem, and this is a major issue now facing new World Bank president appointed in 2007. The job of the IAAs is to get all parties involved in project investments to understand that only by competent monitoring can deficiencies in project performance be evaluated, leading to progressive improvement in planning/design criteria to get best results for these investments.

Guidelines Design Manuals Another boat missed by the IAAs is their lack of understanding of the need for producing guidelines manuals on how to design DC projects that will suit the DC system, which will actually produce the desired objectives. With very few exceptions, all manuals and virtually all university teaching (even at AIT in Bangkok) utilize the affluent IC approach, including design criteria and matching environmental standards. If the project planning/design practitioners (in both DCs and IAAs) had the proper manuals, they could greatly improve their performance. When projects are properly designed to match DC conditions, the chances that these will actually be built and operated will be greatly improved. See the section on “Technology Transfer” for details.

Role of the Private Sector

Private Consulting Firms that Design Projects, including EIA As already noted, if appropriate manuals were made available to these DC practitioners, their chances of preparing appropriate designs should be greatly improved.

Industry This same principle applies to the investments in pollution control systems by industries. Properly planned, many industry plant managers will operate the systems instead of practicing evasion. Industry plant managers are generally not anti-environmentalists, but they can hardly be expected to use funds for operating systems that cannot be operated with available local skills or that produce no significant environmental improvement.

Another promising governance role for industry is for several industries to form their own industry/environment associations that develop practices to be utilized by all association members[92]. Still another example of industry cooperation utilized in Thailand is the establishment of an effective joint enterprise for managing oil spills from oil tankers operating in the open seas and in harbors (See section on “Industrial Wastewater Management.”)

URBAN WATER SUPPLY

Situation in United States/ICs

One of the greatest engineering achievements of the twentieth century, which is included in the listing of these achievements by the U.S. National Academy of Engineering (NAE), is the advent of chlorination of community water supplies early in the century, which by mid-century had become the well established practice of practically all U.S. cities, to chlorinate the water delivered to the distribution system, plus rechlorination along the way, to ensure that the water delivered at the household tap had a measurable chlorine residual. This chlorination, together with the provision of superior water supply distribution system piping to obtain “watertight” piping, plus pressures sufficient to maintain a significant positive pressure in the distribution system at all times, served to deliver water at the taps that was safe to drink at all times. And this, together with steadily improving management of excreta and other sanitary wastes, resulted in reduction in enteric disease rates from their high levels at the beginning of the century, to very low levels by mid-century, representing a great public health achievement, especially so for infants and preschool children, who are especially vulnerable to enteric diseases.

Following World War II, urban water supply practice in the United States and other ICs became increasingly more sophisticated in design and equipment and materials, particularly in relation to the hazards of other communicable diseases that can be transmitted by water, including those transmitted by cysts of *Cryptosporidium* and *Giardia*, which has resulted in a great deal of attention to utilization of other methods of disinfection including use of ozone and ultraviolet light. Moreover these alternative methods, while more expensive, have the added advantage of not generating trihalomethanes (THMs), which are a byproduct of chlorination and which, if ingested in drinking water over a period of decades, can result in some increase in THM-induced cancer. Hence, the international waterworks literature of today (which is IC-oriented) gives major of attention to use of these alternative disinfection methods.

Another important aspect of urban water supply systems in the United States is that in the earlier decades many of these systems were privately owned, but by the end of the twentieth century, most of these had shifted to municipal ownership. Even so, the municipally owned systems have been well designed and managed—and hence, profitable, including financing of return on investment plus O&M plus profit. A basic reason for this success is that the municipal and higher-level public health authorities had the real power to require effective monitoring for the safety of drinking of water delivered to the tap and to enforce the requirement that the routine testing of the tap water for coliforms meet the prescribed safety levels.

A key question here is, what do these progressive improvements in U.S. urban water supply systems (WSSs) mean for DCs?

Situation in Typical DCs

Sad to say, the urban municipal water supply systems for almost all cities in DCs, with the exception of the capital cities, very much resemble the situation in U.S. cities in the early 1900s. The typical DC systems maybe characterized as follows:

- Little if any attention to protecting the source of supply (the raw water supply) from pollution contamination.
- Focus of interest of WSS managers is on delivering an adequate quantity of water, with little, if any, attention paid to the safety of the water delivered to the tap for drinking. Some attention is given to selected water quality parameters including hardness or excessive color or turbidity, which would result in massive complaints from householders.
- Use of treatment plants (usually rapid sand filters) designed to suit IC conditions requiring sophisticated O&M. Hence, these plants (the most expensive component in the overall WSS) function poorly, commonly producing effluents with turbidities in the range of 5 to 10 ppm, which are hardly amendable to disinfection. This is due primarily to the fact that the plant design is by IAA engineers not familiar with DC needs, and to the fact that IC governments in their programs for helping DCs often try to do so by furnishing/selling them the type of design/equipment utilized in the ICs, without realizing the consequences.
- Although the treatment plant effluent is usually chlorinated, so the water is safe to drink when leaving the plant, the WSS managers rarely have training in sanitary engineering, so they often don't understand that the

key issue is safety of drinking water delivered at the household tap. Often, the distribution-system piping uses materials and equipment that do not result in watertight piping but have "holes" that tend to soak up excreta in the vicinity (which is often there do to lack of excreta management). This soaking up is intensified by the fact that many of the WSSs are not able to maintain pressures 24 hours day, resulting in marked pressure fluctuations.

- There is a lack of any monitoring of water safety for drinking at household taps, due primarily to the fact that most the DC health authorities, unlike those in the ICs, have thus far not given significant attention to this need.
- The sad fact that the people customers believe they should be furnished with water at low cost, and this practice has been going on for so long that the UWSSs are unable to collect enough tariffs to finance costs. Often, the total revenue is barely sufficient to pay for O&M costs, with nothing for return on investment (and nothing for profit).

In most DCs, the only city that does sometimes receive adequate attention with competent WSSs is the country capital city, which, because of its political importance, does receive special attention, including extraordinary financial assistance plus use of expat consultants. However, this kind of assistance is rarely ever furnished to secondary cities (most of which do not have sufficient taxing powers to afford this level of attention).

An example of a problem facing DCs relates to the Provincial Waterworks Authority (PWA) of Thailand, which has responsibility for all community UWSSs in the country except the capital (Bangkok), including use of rapid sand filter plants throughout the country, which commonly produce effluents with turbidities—not of 0.1 ppm as per the design, but in range of 5 to 10 ppm, because of the lack of adequate budgets for financing competent O&M operators. Although the IAAs have given many grants for funding programs for training of these operators, these programs do not deal with the "root" O&M problem, which is the low pay for these workers. Such training programs per se cannot correct this problem. In fact, such programs commonly result in causing the workers who have potential talents to leave their jobs to take better-paying jobs, which they are able to get because of the training. Use of the private sector has not been able to solve this problem, as has been the experience of many DCs including DCs in Latin America[30,32], because the private sector companies, to operate efficiently with profits, must charge much higher water use rates, which infuriates the public (so the governments tend to back down).

Suggested Approach for Improving IAA Assistance to DCs

What can be feasibly done in a typical DC to improve its UWSSs, taking into account the constraints already noted? The experience of the World Bank on projects in

China[161,165] indicates that the following measures are feasible (and can be made as requirements through codicils in the financing loan agreement):

(a) Insist on use of chlorination sufficient to produce a measurable residual at the household taps, including weekly monitoring of a selected number of taps (which is easily done using simple colorimetric instruments) (Measure coliforms much less frequently, say at 3-month intervals). To this end, promote use of elevated storage tanks in the UWSS for maintaining pressure in the distribution system, instead of pressure pumping, so that the storage tank can be used for easy chlorination of the supply, preferably by use of sodium hypochlorite powders. If gaseous chlorine must be used, utilize safety protection systems as specified in publications of the American Water Works Association, to prevent injury to O&M personnel.
  (a.1) People in some DCs, especially in Asia, commonly boil their drinking water; hence, the argument may be made that chlorine disinfection is not needed. It is nevertheless needed, especially because children, when away from the home, are prone to drink water from any available tap, regardless of instructions from parents.
  (a.2) Some UWSS officials are confused by the attention in the international media on THMs in chlorinated water and use of disinfection by methods other than chlorination. The reality in the DCs is quite different from that in the ICs. In the DCs, a person's chances for growing old will be greatly diminished if he or she drinks nondisinfected water, and the only disinfection method feasible for almost all DC cities is chlorination.
  (a.3) Encourage local organizations, like the Boy Scouts, to do the routine chlorine residual testing, as a public service, in recognition that most DC municipalities will be reluctant to fund this service.

(b) Insist on a salary level sufficient to attract and keep and a competent UWSS manager and furnish him with adequate staff and training materials and training opportunities, and require meaningful periodic reports on system performance (including management of complaints).

(c) Encourage use of quality materials and equipment in order to minimize "holes" in the distribution system.

(d) Try to achieve a design for the overall UWSS that will maintain positive pressures in the system at all times.

(e) Encourage addition to the UWSS staff of an engineer trained in sanitary/public health engineering as the most practical way for incorporating the sanitary/public health engineering parameter into the "mindset" of the UWSS organization, including establishment of a reliable water quality testing laboratory. The need and value for this is illustrated in the paper on this subject as presented in Box 4.1 in the Subsection, "Water Quality Analyses."

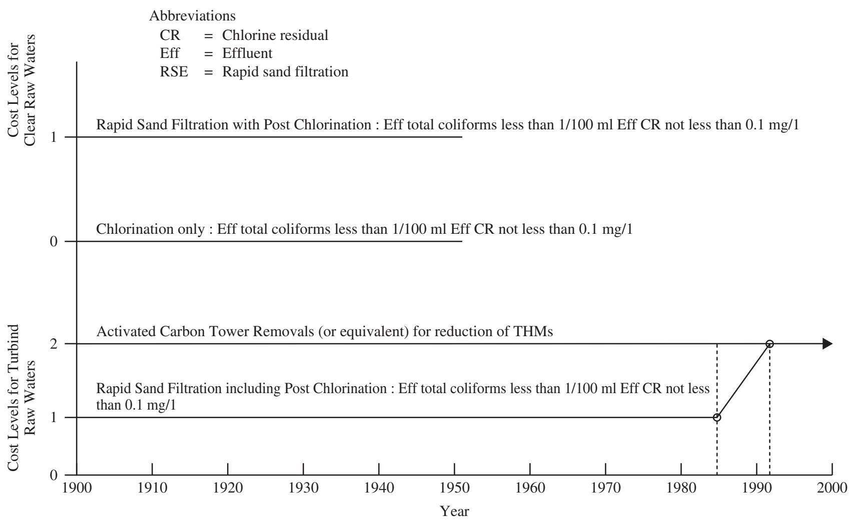
(f) Make effective use of private sector, either for turnkey projects or only for O&M, with feasible attention to use of water charge rates acceptable to public. This means the private company should start with a rate low enough to be acceptable, with subsidies from government to comply, with progressive increase in rates (with lesser subsidies) over a period of years.

Appropriate Water Quality Standards

Maintaining a measurable chlorine residual in the delivered tap water is the water quality parameter that should be given greatest attention in designing and operating DC/UWWSs. It is illustrated by Figure 4.5, taken from a report of the Asian Development Bank published in 1988[112].

Water and Sewer Pipes in Same Trench

Situation in ICs Many U.S. state health authorities have persistently prohibited placing water supply and sewers in the same trench, setting limits requiring specified distance between the two types of conduits. However, there



NOTES

U.S. Practices:

- Turbid raw water: "Zero health risk" syndrome will require activated carbon tower or equivalent treatment to remove THMs and other toxic substances.
- Clear raw waters (initial turbidity <10 units): whereas previously only chlorination required, now full-scale rapid sand filtration with post chlorination to be required.
- In addition to chlorination of filter effluent, it has been necessary in states like California to maintain a positive chlorine residual in the water supply distribution system, which sometimes requires rechlorinaization within the distribution system. Generally, DCs have no such requirement, and often there is no residual in the distribution system, but the DCs really need this (far more than ICs) because of leaky distribution systems, fluctuating pressures, and lack of sanitation.

RecommendationS for DCs:

- Clear waters: Chlorination only.
- Turbid water: RSF/Chlorination only, no activated carbon treatment. Maintain positive chlorine residual in distribution system.

Source: ADB[112]

FIGURE 4.5 Schematic drawing showing drinking water standards for U.S. chlorine residuals, coliforms, and THM toxicity parameters with recommendations for DCs.

are exceptions—for example, in Washington, D.C. In some Western Europe countries (e.g., Sweden), such dual use of the trench is permitted under specified conditions because of the resulting considerable savings in total trending costs.

Situation in DCs The DCs have followed the WHO guidelines, which do not permit dual use of the same trench following general U.S. practice. However, a study sponsored by USAID completed in 1984 at the request of the Jordan government evaluated dual use considering both economic and public health parameters[60]. The conclusions of this study (endorsed by Dr. Abel Wolman, then a chief consultant to WHO), are summarized as follows:

- A review of UWSS experience in the United States and elsewhere, which included consultation with the U.S. and international agencies carrying out evaluations and research on water supply contamination hazards, has clearly indicated that dual use of the trenches is regarded as an acceptable practice in many localities, without the use of special encasement of the sewer pipe and/or the use of pressure pipe for the sewer, provided (1) the sewer pipe is of first-class quality (can withstand low head pressures with rubber ring joints or the equivalent); (2) the vertical separation between the two pipes is at least 18 inches; and (3) the water main is located on a side-bench so that the sewer main may be repaired without disturbing the water main. This practice is commonly used in Western Europe, and in the United States, it is generally allowed whenever the physical or right-of-way constraints make it necessary to utilize a single trench for both mains. It is commonly used in Washington, D.C.
- In Amman, dual use of the trenches has resulted in a reduction in the cost of the water supply system of about 15 percent. Where excreta disposal depends on the use of subsurface leaching areas, as is the case in the urban areas of many developing countries, dual use on wide as well as narrow streets, would be a relatively cheap way of providing health protection. The alternative (i.e., the use of separate trenches) or of dual use with rigid sewer requirements (i.e., the use of pressure pipe and/or encasement), will often be too expensive for developing countries to afford. However, such dual use assumes that the quality of construction for both water and sewer pipes will meet minimum international standards, and the construction records of municipal agencies in many developing countries may show that they do not meet this requirement.
- This is one of the main reasons for recommending that the DC/USSS should establish a Division of Water Quality (DWQ), one of whose functions would be to monitor and exercise surveillance over the planning, design, and construction of future water supply and sewer mains, including dual use, to ensure that construction practice do in fact meet the minimum international standards. The DWQ would, of course, work closely with the Ministry of Health to keep the Ministry of Health appraised of its activities and progress. Assuming that this is done, it would be good practice to allow use in Jordan

and other DCs (1) where separate trenches are not feasible (due to physical constraints or right-of-way constraints), and (2) in wider streets where the savings would result in enhancing the overall health protection obtainable with limited funds.

Reuse of Treated Wastewater

Situation in ICs Ever since human activities reached levels that caused significant pollution of streams, urban water supply system (UWSSs) have, in effect, been producing the water supply delivered to the distribution system by treating polluted stream waters—representing a kind of reuse. In the 1940s, USPHS studies concluded the stream waters, to be suitable as raw water to be treated, must not be polluted beyond specified limits, but since then these limits have steadily risen as the removals achieved by rapid sand filtration progressively improved with the development of superior additives for improving the coagulation/flocculation/filtration processes included in rapid sand filtration plants—so much so that even badly polluted raw waters can be utilized. Despite this, U.S. public health officials have persisted in not being willing to authorize direct reuse of sewage for urban drinking water supply purposes (the treated sewage could be utilized for irrigation of selected types of crops). For urban water supply purposes, first the sewage must be released into a stream, then the raw water removed at a downstream location. As a result, the only systems acceptable to U.S. health authorities have been those where the wastewater, after treatment (conventional complete treatment followed by reverse osmosis if salinity must be reduced) is infiltrated into the ground to become part of the natural groundwater supply, then can be pumped out for acceptable use as raw water supply. This system was pioneered in Southern California in the 1950s to 1960s by the Los Angeles County Sanitation Districts and the Eastern Riverside Municipal Water District[34] and since has been utilized in many other communities in Southern California including the Orange County Water District[144]. However, the City of San Diego's Water District has since implemented partial direct reuse, approved by the health authorities, by which treated wastewater is mixed with natural fresh water in an impounding reservoir used for raw water supply.

Situation in DCs The current situation in the DCs resembles that in the United States prior to the interest in projects for direct reuse beginning in the 1950s. However, some initial studies are being made in recent years for exploring the potentials for recharging groundwater in desert type regions, as in Pakistan[151] and in regions with ample water in the rainy season but with negligible rainfall for the remainder of the year (prolonged dry season)—for example, in the Bangkok region of Thailand[138].

IAA-Sponsored Community Water Supply Programs

WHO/UN Program A primary effort of WHO has been the development of the UN's "Water and Sanitation Decade" program and follow-up efforts carried out in recent decades, with the objective of furnishing everybody in the DCs, including the poor, with clean water safe for drinking together with basic provisions for management of excreta. Although this program has achieved only partial success, it has done much good and the effort continues. An evaluation of the program's achievements made in 2004 by the *Economist* magazine[31] showed there have been many problems that have hampered progress in the UN program. One problem is that governments have persisted in delivering water at much too low charge rates, so those with taps in their homes (typically the better-off) have no incentive to conserve it. Because the UWSS has not been self-funding, it has not been extended to the poorest areas, so the poorest have ended up paying inflated prices to black-market water sellers.

In towns, private firms can work wonders if they are allowed to charge reasonable prices. In rural areas, where the poorest of the poor live, the most progress has been made by concentrating on small (and usually publicly funded) projects, such as boreholes, rather than trying to follow urban water supply practice. The locals should be trained to maintain their own boreholes. Pumps can be designed to double as children's round-abouts, so that children pump water as they play. Tanks to catch rain are simple and efficient. In one African village, for example, the poorest residents pay a few cents each week for water and a communal shower block. Better-off families pay extra for taps in their homes. The sums raised pay for an engineer to live in the village and fix its pipes.

U.S. Agency for International Development (USAID) Legislation was enacted ("Water for Poor Act") by the U.S. Congress in 2006 for authorizing USAID to establish a program for assisting DC populations to have access to clean water and basic sanitation, which is an example of efforts by bilateral countries to supplement the UN project[145]. But it remains to be seen whether the U.S. Congress will actually furnish funds to support this program.

Other Considerations

Desalinization Desalinization technology and costs have steadily decreased in the past several decades resulting in increasing use in the United States and other affluent countries like the oil-rich Middle East countries. But little use has been made of desalinization in the DCs because the costs are still beyond their means. There are only special exceptions, such as in Baja California, in Mexico, where use of "shelf" desalinization units has made it feasible to operate beach resorts catering to affluent visitors.

Dual Water Supply Distribution Systems Advocates of the use of dual urban water supply systems in the ICs, including Dan Okun[126], argue that (1) the established UWSS practice is to design the systems so then can accommodate the flows required for firefighting (which are very large compared to the needs for domestic and other municipal purposes), which results in large resident time in the distribution system piping leading to growth of biofilms on the pipe walls, which depreciate water quality, and (2) it would make much more sense, cost-wise and water-quality-wise, to switch to use of separate systems. This would permit use of much-smaller-diameter piping in the distribution system for delivering potable water, and resulting in much reduced residence time—hence much lesser organic growths—and making it feasible to utilize stainless steel for the drinking water piping, which would greatly reduce the problem of pipe leakage due to corrosion. It would also permit unrestricted use of reclaimed water for firefighting purposes. Despite these arguments, little interest in such systems has been expressed in the ICs and virtually none in the DCs. Some DC cities such as Calcutta still utilize dual systems, but, unfortunately, the water for the firefighting mains is untreated water drawn from the local river, which is replete with cholera virus, and these mains have been commonly tapped to furnish drinking water for the plentiful urban poor, who often have no place to sleep except on the city streets[146]. Hopefully, the recent ADB-sponsored project for improving this situation in Calcutta will ensure continuing disinfection of the water in the firefighting mains.

Overdrafting of Groundwater and Ground Subsidence Overpumping of groundwater is an all-too-common practice in many DCs where the UWSSs systems depend on use of groundwater as a major source and where the demands by increasing population and industry have resulted in very serious damages. This includes deterioration of the groundwater quality due to infiltration into the fresh groundwater basin from adjacent salinity groundwater basins, and very serious subsidence of ground levels. Outstanding examples are the situations in the Bangkok metropolitan area[17] and at Taiyuan in China[164]. The only solution is for the DC governments to sponsor much better use of the local freshwater plus importing freshwater, thus enabling elimination of groundwater overdrafting.

The situation of the "too little/too late" approach is the situation at Bangkok, where the seriousness of the subsidence become obvious in the 1970s, but even now the government's importation program has enabled closing of wells only in limited areas. Hence, subsidence (now more than 2 meters in some areas) continues in much larger (and heavily industrialized) areas. And at Taiyuan, the situation is almost comical in that the Chinese government, with World Bank support, recently completed an importation system (300 km of aqueducts, tunnels, pumping plants) that does bring in the needed extra water, but without provision of firm administrative mechanics (i.e., without establishing a local "water czar" with power to control all water uses in the municipal area, including wastewater treatment/reuse), and as a result, industries continue with more overdrafting to avoid paying the extra costs for buying the expensive imported water[166].

Water Hyacinths

Situation in ICs Water hyacinth growth in waterways has been a serious problem in virtually all tropical regions, including the tropical areas in the United

States such as southern Florida and Puerto Rico and the Virgin Islands in the Caribbean. Because of the seriousness if this problem in Florida, the U.S. Corps of Engineers has carried out a comprehensive studies on control of such growths, including use of physical, chemical, and biological methods of control, which show that mechanical cutting/removal is expensive and yet the most feasible control method[123].

Situation in DCs A study of this problem in southern Nigeria in 1988[157], where the problem is very serious, led to a review of other potentials for control, including a comprehensive review by the Asian Institute of Technology in 1984[133]. This again did not come up with any noncostly control methods, although some potential for harvesting hyacinths for making wood furniture which was followed by limited use of this method in Thailand[22] and in Japan for limited commercial making of fiber baskets[18]. Still another potential being tested in Argentina uses Amazonian flies as a means of biological control[123]. For reservoirs suffering from heavy hyacinth growth, it may be necessary to utilize log booms to prevent the hyacinths from entering water intakes.

The survival hardiness of this plant is well shown by observations of its growth in a major *klong* (waterway) in Bangkok, Klong Samrong, which in 1970 was relatively free of hyacinth, with the klong used for major boat traffic. However, progressive pollution by degradable organics resulted in such heavy growth that the boat traffic had to cease; then came pollution from toxics discharged by industries, which caused the growth to fade away. Another example is the experience in Laguna Lake in the Philippines, Manila[148] where little growth occurred when the lake, normally freshwater, was affected by serious periodic seawater intrusions; then building of a gate to minimize the intrusion resulted in great increase in the hyacinth prevalence.

Water Quality Analyses

Problem in DCs A very common problem with WQ testing by DC practitioners, both in the laboratory and in the field, is the lack of review of the test data by WQ testing experts to ensure its reliability. This is due, usually, to the common belief that the practitioner with a graduate degree is bound to be correct—hence, no need for such review[66]. As a result, much of the data are misleading and counterproductive. This problem is illustrated by Box 4.1, which reviews a practitioner's nonreviewed report to indicate errors with explanations[61]. The IAAs commonly give grants of testing equipment to the DCs but do not finance the training that is needed to enable good use of the equipment.

An additional example is the testing of well waters by the laboratory of the national water supply agency of the Philippines (very well furnished with donor grants, with ample equipment and ample staff with ample graduate training), with the laboratory reports showing that the well waters were negative by presumptive coliform (agar testing), but with positive coliform counts in the follow-up confirmation test[57]. In another situation at Bali (Indonesia), a Korean testing team headed by a doctorate engineer scientist reported that the river waters there were unfit for irrigation of rice because the soil would be clogged by the excessive sodium in the river waters, despite the fact that these waters had been successfully used for a thousand years without clogging[3]. The problem was that the reported sodium analysis concentration was 10 times too high (wrong decimal point).

Correction Measures As already noted, the IAAs should recognize the need for training in WQ monitoring, including distribution of free (or cheap) copies of Standard Methods (translated into the local language), as recommended in the section on "Water Resources Management." Another good measure is to advise the DC practitioners to use checking methods to check the validity of the laboratory results by using more than one laboratory to do the same testing, and by having the same laboratory do the testing for the same sample submitted as two separate samples (one say the actual water and the other, say a 50–50 mix with distilled water).

BOX 4.1 EXERCISE IN CHECKING VALIDITY AND RELIABILITY OF TYPICAL WATER QUALITY ANALYSIS FOR A NATURAL WATER, SEPTEMBER 1985

By Dr. H. F. Ludwig, Advisor to NEB

An exercise has been developed for training professional staff of NEB on the significance of quality control in making and reporting upon analyses for determining water quality. All too often the results of water analyses reported in developing countries, while they look to be adequate at first glance, actually contain numerous errors and omissions and scarcely give a competent picture of the water quality. The problem stems from lack of critical review of such reports, which are often accepted as submitted on the assumption, because these doing the analyses are presumably qualified, that no such review is necessary. Actually such reviewing is an essential element of quality control for all fields of environmental monitoring.

The exercise described here comprises three attachments. Exhibit A is a laboratory report on results of a mineral analysis for a natural water (in this case a surface water). Please review these data and prepare your comments on the validity and reliability of the data in this report. (There are at least 11 aspects of this report that are either incorrect "suspicious," or improperly stated.) When you have completed your comments, compare them with Exhibit B and C.

Exhibit A

Laboratory Report on Mineral Analysis for Surface Water

	Constituent	Unit	Value
(1)	pH	-	7.35
(2)	Total alkalinity (as $CaCO_3$)	mg/l	52.14
	(a) Carbonate alkalinity (as $CaCO_3$)	”	2.02
	(b) Bicarbonate alkalinity (as $CaCO_3$)	”	50.12
(3)	Bicarbonate (HCO_3)	”	82.24
(4)	Sulfate (SO_4)	”	32.33
(5)	Chloride (Cl)	”	35.05
(6)	Nitrate (NO_3)	”	17.14
(7)	Silica (SiO_2)	”	8.01
(8)	Sodium (Na)	”	15.27
(9)	Potassium (K)	”	8.13
(10)	Calcium (Ca)	”	30.19
(11)	Magnesium (Mg)	”	20.52
(12)	Hardness (as $CaCO_3$)	”	93.14
(13)	Silica (SiO_2)	”	16.67
(14)	Iron (Fe)	”	8.03
(15)	Manganese (Mn)	”	7.14
(16)	Boron (B)	”	3.56
(17)	Turbidity	ppm	15.36
(18)	Suspended Solids	mg/l	40.25
(19)	Total Dissolved Solids (TDS)	”	523.10
(20)	Electrical Conductivity	mm/cm	106.0

Exhibit B

Errors/Irregularities/Inadequacies in Report

Most of values shown in Exhibit A are not realistic in terms of significant figures. Most of these analyses are reproducible only within a few percent. Thus, to report the results to hundredths of a mg/l is actually silly. A suitable presentation of these values is shown in the revised tabulation, Exhibit C.

At pH of 7.35, no carbonate alkalinity is possible (to have carbonate alkalinity, (pH must be 8.3 or more).

If the bicarbonate alkalinity is 82.24 mg/l, then its equivalent in me/l would be 1.35 me/l or 67 mg/l as $CaCO_3$.

In terms of me/l, the total major cations must be approximately equal to the total major anions, which is not at all the case here. Hence, one or more of the major anion and major cation determinations must be in error.

The total of Ca plus Mg in me/l must equal the total hardness in me/l, which is not the case here (the total of Ca and MG is 3.22 me/l, whereas the total hardness is only 1.86 me/l, which is impossible).

An iron value of 8.0 mg/l would be extremely high if not impossible for a natural surface water, hence this value appears to be wrong. Maybe it was misrecorded and should be 0.8 or 0.08 mg/l. Also, surface water with this much iron would likely be highly colored (hence the color could not be 0.1 units as reported).

Manganese levels in natural waters are very low, rarely over 1 mg/l and usually much less. Values as high as 7.5 mg/l do not occur in natural waters (if they did, the water would be very red and the color (Item 21) would not be 0.1 units are recorded.)

Boron values over 2 mg/l are extremely rare.

If the turbidity is 15 ppm, then the suspended solids should be of the same magnitude, not three times as much.

The TDS of 523 mg/l is much too high, i.e., is not consistent with the reported values for major anions and cations (which indicate a TDS of about half as much).

It the TDS is 523 mg/l, the electrical conductivity would be in the range of 600, not 106.

Exhibit C

Revised Tabulation

	Constituent	Unit	Value	me/1[1/]
pH and Alkalinity (1, 2)				
(1)	pH	-	7.35	-
(2)	Total alkalinity (as $CaCO_3$)	mg/l	52.	1.04
	(a) Carbonate alkalinity (as $CaCO_3$)	”	2.0	-
	(b) Bicarbonate alkalinity (as $CaCO_3$)	”	50.1	1.00
Major Anions (3 to 7)				
(3)	Bicarbonate (HCO_3)	”	82.	1.34
(4)	Sulfate (SOV)	”	32.	0.67
(5)	Chloride (Cl)	”	35.	0.99
(6)	Nitrate (NO_3)	”	17.	0.54
(7)	Total major anions	-	-	3.54
Major Cations (8 to 12)				
(8)	Sodium (Na)	”	15.3	0.67
(9)	Potassium (K)	”	8.1	0.21
(10)	Calcium (Ca)	”	30.2	1.51
(11)	Magnesium	”	20.5	1.71
(12)	Total major cations	-	-	4.10

	Constituent	Unit	Value	me/1[1/]
Other Parameters (13 to 22)				
(13)	Silica (SiO_2)	”	17.	-
(14)	Hardness (as $CaCO_3$)	”	93.	1.84
(15)	Iron (Fe)	”	8.0	-
(16)	Manganese (Mn)	”	0.07	-
(17)	Boron (B)	”	3.6	-
(18)	Turbidity	ppm	15.	-
(19)	Suspended Solids	mg/l	45.	-
(20)	Total dissolved solids (TDS)	”	520.	-
(21)	Electrical conductivity	mm/cm	106.	-
(22)	Color	color units	0.1	

Water Quality Monitoring

One of the most confusing issues for DC water quality (WQ) monitoring practicioners is selection of appropriate WQ monitoring parameters to suit the particular situation, and thus to spend money only to obtain valuable needed information and not to obtain information that is not needed. A common mistake in many DCs is to set up a monitoring system with a group of parameters deemed at the time to be needed, then to continue on with this same system year after year. The need is for critical review on an annual basis to (1) fill gaps for valuable data not being obtained, and (2) delete parameters where it is found that the data are not serving any useful purpose. In China, for example, the river basin agencies commonly set up monitoring problems to include a long list of parameters, as specified by national governmental guidelines (which include “everything in the book”), then continue this indefinitely (at no small expense) when a critical review would show than a sizable portion of the data do not contribute in any way to assisting river basin development planning[160].

Figure 4.6 is a matrix that indicates the appropriate parameters to use for various particular situations[163].

Role of Private Sector

As already mentioned, use of the private sector for receiving DC problems in UWSSs and USEMs has not yet been successful because, while the private sector firm has the necessary skills, the firm must make a profit. Thus, it must increase water use rates from the low rates commonly used in the DCs (which have commonly subsidized UWSSs believing that this is a government obligation) to

FUNCTION	PARAMETERS																									
	1. BOD/COD	2. Suspended Solids (inflow and outflow)	3. Floatables (including grease, oils) (in and out)	4. Settleable Solids (in and out)	5. Toxicity in effluent or stream	5.1 Gross toxicity (if applicable)	5.2 Toxic heavy metals (if applicable)	5.3 Toxic inorganics (if applicable)	5.4 Toxic synthetic organics (if applicable)	6. Ammonia in effluent	7. Total phosphorus (P) in (effluent) (if applicable)	8. Total nitrogen (N) in (effluent) (if applicable)	9. TDS and/or conductivity (effluent) or stream)	10. Major ions	10.1 Chlorides (Cl)	10.2 Bicarbonate (HCO_3)	10.3 Sulfate (SO_4)	10.4 Nitrates (NO_3)	10.5 Sodium	10.6 Potassium	10.7 Calcium	10.8 Magnesium	11. Bottom Salients (See note)	12. Temperature	13. Quality of flow when sampling	14. Turbidity
1. Sewage Treatment Plants (MSS/STPs) 1.1 Sewage treatment Plant design (for expected inflow including industrial wastes)	A	A	A																							
1.2 Sewage treatment plant operations (inflow, outflow)	D	D	D	D	M					W	M	M	M	M										D	D	
2. Industrial Wastewater Discharges: 2.1 Food/organics processing	D	D	D	D									W											D	D	
2.2 Industries using toxics	D	D	D	D	D								W											D	D	
2.3 Animal farms	D	D	D	D	W					W	W	W	W	W										W	W	
3. Anbient WQ Monitoring	W	W	W		M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	Y	M	M	M

NOTES:

1. A = Average, D = Daily, W = Weekly, Y= Annually, S = Sesonally
2. Nutrients (5,6) = When downstream eutrophication may be a problem. Not a single such situation to date in Asian DCs. (This is problem sometimes in U.S. and often in European Union)
3. Item (9): Total anions in me/1 must equal total cations in me/1.
4. Item (10): Includes toxic substances (toxic heavy metals, toxic synthetic organics, petroleum substances, and particle size distribution).
5. Samples for Items 1.2 and 2 to be composited (not grab) samples.
6. On Items 5: Select applicable parameters on situation. For example, mining operations involve toxic heavy metals and toxic inorganics but not toxic synthetic organics, and if put factory involve then toxic synthetic organics is pertinent.
7. Source: Ref. 163.

FIGURE 4.6 Water quality monitoring parameters.

markedly higher rates, resulting in massive public protests and consequent backing down of the government's commitment to permit the private firm to change proper rates. Examples are described in[32], which reviews the very unsuccessful experiences of the three major European private-sector firms in this field of business as of August 2006, and in[37], which reviews a similar recent experience in the city of Cochabamba in Bolivia.

The suggestion here is that the private-sector firms can be valuably utilized for filling the skills gap, both for turnkey projects, which may include financing as well as design/construction and for only O&M, but with provision for continuing subsidization by the government but at a level that progressively decreases over a period of years with a corresponding gradual increase in rates.

Integrated Economic-cum-Environmental Development Planning (IEEDP)

The programs already noted for making optimal use of water resources, valuable as those are, may be criticized for planning for effective water resource utilization independently of other precious environmental resources—"obviously" the best approach would be use of planning mechanics in which the target is optimum utilization of all precious environmental resources including freshwater resources. Information on how to do this is given later in this chapter on "Development Planning for DCs."

WATER RESOURCES MANAGEMENT

Circa mid-the twentieth century, it was still practical in most countries to design and build dams/reservoirs on streams for intended single-purpose uses such as UWSSs, but over the next half-century, it become increasingly necessary, because of increasing growth of population and industry, to design the reservoirs for multipurpose uses (i.e., for all beneficial water uses in the project's service area). But also by year 2000, water resources experts were beginning to realize that continuing further growth was resulting in serious water shortages conflicts between provinces (or states) of individual countries and between different countries. Hence, the problem now facing the world in water shortage regions is how to resolve these conflicts by (1) making much more effective use of the limited water resources, and (2) reaching agreements between countries utilizing the some limited resources on fair allocation of the limited resources. In the DC regions, initial steps are underway on how to reach agreements on fair allocation, including especially regions in the Middle East and in the semiarid regions in Asia (such as the region of India/Pakistan/Bangladesh). Excellent evaluation of this problem on a global scale includes surveys made by *Resources for the Future* in 1996[129], by *Economist* magazine in 2003[30], and by the *International Herald Tribune*[39]. The Asian

Development Bank has carried out a comprehensive survey limited to the Asian region[10].

Reducing Water Irrigation Requirement

Virtually all of the studies on how to make much more efficient use of the limited resources in water shortage regions, including those in California[85], show that the single most important inefficiency is in use of water for irrigation. Hence, a priority in both ICs and DCs is to develop practicable mechanics for resolving this problem. One approach is that used by Israel, where the severity of the problem has led to development of a new approach to agriculture called *drip irrigation*, in which the water is fed directly into the plant roots rather than into the soil around the plant. In due time, it is expected that many DCs will have to adapt to use of this approach.

China Studies Sponsored by World Bank

One of the most serious immediate water shortage problems for Asian DCs is the situation in the northern coastal provinces in China, where about half of the countries population and industry are located, and which is continuing to grow despite the fact that most of this region has been desperately short of fresh water for some 20 years, resulting in very severe impairment of both economics and public health, including increasing problems for industries to continue to operate efficiently, very severe water pollution, and massive land subsidence in many areas.

A comprehensive evaluation of this situation was conducted by the "Water Agenda Study for North China" sponsored by the World Bank together with AusAid. It was completed in 2000[163], and included detailed analyses of all water uses and of their relative efficiencies and importance for contributing to continuing economic-cum-environmental development, with recommendations for making marked changes in the existing water use system, in order to achieve maximum beneficial use of the limited local natural fresh water resources and hence to minimize the need for expensive importing of the plentiful water available in the Yangtze River in southern China to resolve the water crisis in the north. This massive water transfer program is being planned in detail, with its initial project, the Wanjiazhai Water Transfer Project[164], already constructed. When completed, the overall importation project will be by far the world's largest mass water transfer project, dwarfing even the existing mass massive transfer system in California.

The Water Agenda emphasized that efficient use of the limited local water can be achieved only by establishing River Basin Control Agencies, which (unlike existing river basin agencies) will have the needed real power to manage the limited resource. This means there will be changes in the existing system where power is divided (and hence not integrated and not effective) between the national and local governments. The study recommended that this new approach be demonstrated by first applying it to the Yellow River basin in north China, resulting in a follow-up World Bank sponsored study for this demonstration for the Yellow River basin completed in 2005[165]. This included provisions for authorizing this new basin agency for achieving effective water pollution control throughout the basin, following the same approach developed by U.S. EPA in the 1960s, which has been proven to be very successful. Actual achievement of the recommended effective river basin authorizes will, of course, not be easy for China to achieve, but this must be done because the existing ineffective system is no longer viable. And this same approach (use of real basin authorities) is critically needed in most DCs, including Indonesia[156].

Watershed Management

Watershed management represents a complex specialized technology in the field of environmental engineering, especially on the need for maintaining forest cover to prevent massive erosion runoff and loss of infiltration of rainwater into the soil to maintain groundwater that furnishes the dry weather flow of streams. Such management is most important in water shortage regions.

Particular references that discuss pertinent projects applicable to DC conditions include the following:

- "Supplemental EIA Manual for Watershed Projects," prepared for the Thailand National Environment Board in 1997[69].
- Ludwig, H., "Engineering-Cum-Environmentalism: Case Study of Tarim River Basin of China" (Region of the Silk Road), ASEP Newsletter, September 1992[76].
- Ludwig, H., and Castro, L., "Sharing of Project Benefits for Hydropower Projects in Upland Regions of Philippines," *ASEP Newsletter*, September 1992[103].
- Ludwig, H., "Wastewater Management and Water Quality Control, Experience in California as Applicable for Helping Resolve Water Shortage Problem for North China," for World Bank/Beijing, April 2001[85].
- World Bank, "Water Agenda Study for North China," D. Gunaratnam, 2000[163].

URBAN SEWERAGE AND EXCRETA MANAGEMENT (USEM)

Regarding urban (or municipal) sewage and excreta management (USEM), this is believed to be one of the very few subjects (if not the only subject) of environmental engineering technology for which a textbook has been written specifically for use by DC practitioners (and their IAA counterparts). This textbook, *Appropriate Sewerage Technology for Developing Countries* by H. Ludwig et al., was published in 2006[105]. Its Preface and Table of Contents are as shown in Box 4.2.

The textbook includes comprehensive coverage of all aspects of USEM in detail. This chapter, because of space limitations, includes only brief discussion of the most salient points.

Situation in ICs

Sewerage technology evolved essentially from the experiences of the Western European countries, then the United States, and this evolution developed in three stages:

1. Construction of sewers in the community to collect excreta and to export the collected wastewater for discharge into a nearby river or stream or drainage channel. This removes the excreta from the immediate community environment where, if unmanaged, it poses great hazards for transmission of enteric diseases. Although disposal of the untreated wastewater into the waterways involves some disease hazard, this is small compared to the hazard from the presence of unmanaged excreta in the community.
2. Treatment of the collected wastewater, primarily to protect stream ecology but also for public health protection purposes. The target is achievement of complete treatment (primary plus secondary) of the collected wastewater.
3. Use of advanced waste treatment methods for removal of nutrients, together with effective control of point sources for control of toxics.

The resulting situation is that the typical IC city does have an effective wastewater management system, including sewers, interceptors, transmission liens, pumping stations, and treatment facilities, together with point source control and effective use of on-site septic tank/leaching units for buildings not connected to the sewers, including effective periodic monitoring of overall system performance.

BOX 4.2 PREFACE OF TEXTBOOK OF APPROPRIATE SEWERAGE TECHNOLOGY FOR DEVELOPING COUNTRIES

H. Ludwig, B. Fennerty, S. K. Leng, and K. Mohit

"Practically all existing textbooks on planning/design of municipal sewerage systems (MSSs) are written by Westerners and tend to emulate the environmental standards and matching design criteria utilized in the affluent industrialized countries (ICs), and because these same standards and design criteria have been used for planning/design of MSSs in the developing countries (DCs), most of the MSSs built in the DCs have been dysfunctional and have not achieved their intended objectives. The new textbook is believed to be the first that is written to be appropriate for DC use, featuring use of simple rather than sophisticated approaches, thus greatly simplifying problems of O&M. The textbook of 400 pages covers all aspects of MSSs systems including institutional, economic, financing, and environmental as well as technical engineering aspects for both sanitary and industrial wastewaters. It also recognizes the need to give attention to not only the affluent urban sectors which case afford sanitary sewers but also to the problem of ensuring adequate management of excreta from buildings not connected to sewers but utilize individual on-site disposal units. It covers all components of MSSs, including the collection component (collecting sewers, interceptors, and pumping to collect and deliver the sewage to the treatment plants, plus treatment and disposal. Dr. Harvey F. Ludwig of Bangkok is Chief Author, assisted by the three co-authors. Their combined experience in MSS technology is estimated 60 man-years, about one-third in IC and two-thirds in DC systems. Dr. Ludwig is a member of the National Academy of Engineering of the U.S.

If you wish to purchase a book, please contact Mr. Kumar Vinod, South Asian Publishers at New Delhi, India. His e-mail address is <sapub@del2.vsnl.net.in>. Cost for persons in Industrialized Countries and International Agencies is US$32.00 (hardcover version) including surface mailing. Extra postage of US$3.00 required for airmail shipping, totaling US$35.00. A softcover version at lower price is applicable for nationals of Developing Countries. Postal address of South Asian Publishers is 50 Sidharth Enclave, P.O. Jangpura, New Delhi 110014, India."

The chapters included in this textbook is as follows:

Introduction
Urban Sewerage and Excreta Management
Sewage Characteristics and Flow Measurements
Sewerage System Collection Component
Onsite Sewage Disposal
Sewage Treatment and Disposal
Industrial Wastewater
Operation and Maintenance
Monitoring and Enforcement
Appropriate Standards
Environmental Impact Assessment
Sewerage Institutions
Sewerage Economics
Sewerage Financing
Other Considerations
Summary and Conclusions

Situation in Typical DCs

In contrast with the United States/ICs, the typical DC city, including even many capital cities, has yet to achieve satisfactory management of community excreta and other wastes posing public health/environmental hazards, including industrial wastewaters discharged to municipal sewers. However, in recent decades the IAAs have made many grants/loans intended to help the DCs to get a handle on this problem, but with generally ineffective results and wastage of investments. The first (and almost remarkable) finding in reviewing DC/USEM experience to date shows a lack of understanding of the three components of a comprehensive municipal sewerage system as previously described. It especially fails to recognize that the most important component is use of sewers to collect/export the sewage, not the subsequent treatment. A large number of IAA-sponsored projects of the past several decades have been formulated on the assumption that provision of treatment per se is the answer to the problem, without recognition that treatment plants are not effective without sewers to collect and transport the waste to the treatment plant.

The most comprehensive analysis of the USEM problem in the DCs known to the author is the study on “Sewerage Prioritization” in Thailand completed in 1995[135]. This evaluated the ongoing situation in all of the larger cities in the country (more than 100), with the key findings. These who plan/design/manage urban sewerage systems must recognize that the DC approach must be quite different from the IC approach, as follows:

- A common notion (already noted) in both the IAAs and the DCs is that urban sewage problems can be solved simply by building a treatment plant, which receives only a portion of the area’s excreta, with much of the remainder reaching the waterway without adequate treatment, without recognizing that such plants may do little good for protecting either public health or receiving water quality.
- In the ICs, virtually all buildings in the sewerage service areas are served by sanitary or combined sewers. When the public sewer system is built, all buildings connect up and existing on-site units are abandoned. Generally in the DCs, only the affluent areas (which can afford them) are served and the bulk of the population continues to depend on on-site units. Many of these on-site units do not function satisfactorily due to inadequate design and lack of periodic servicing, resulting in frequent excreta overflows into the community environment, which pose very serious disease transmission risk hazards, not only to the nonaffluent subareas but to the entire service area. Hence, the argument that is often made by IAAs that improving service to the affluent subareas can be justified in terms of protecting overall community health is hardly correct. If the planners are really interested in overall community public health protection, the project plan must include “equal attention” to the nonaffluent subareas (the same is true for provisions of improved urban water supply) if these are to be justified in terms of public health).

- Another common misconception is that treatment plants can be operated and maintained with a very low O&M budget, usually about one-third of the minimum need[51], so that, even if well designed, the plant cannot be expected to function. Monitoring and acting on this problem, which is mandatory in the ICs, does not exist in the DCs. DC officials and practitioners have paid such little attention to O&M because of lack of performance monitoring and because the project feasibility studies often do not include adequate allowance in the economic analysis for O&M costs.
- A typical example is the proposed expansion in 1992 of the municipal sewage treatment plant of Chittagong (Bangladesh)[8], justified on the basis of public health protection and of correcting water pollution in the river receiving the plant effluent. An evaluation showed that (1) the plant, even when enlarged, would not receive the bulk of the city's excreta, (2) the existing plant (built earlier by the British) had long since ceased to be operated properly, and, hence, was doing little if any good, and this problem was scarcely recognized in the project feasibility study, and (3) even if the old and new plants were to be properly operated, the resulting benefit both to public health and water pollution control would likely not be very meaningful. All such proposed projects need to include an EIA, which will call attention to such deficiencies and misconceptions.
- An additional finding from the USEM experience in the DCs so far is the need for standardization in design of facilities for the USEM system, to standardize practices for all system components, but especially for treatment plants. As it has been, individual designers use a variety of treatment systems that are in the same ballpark in terms of costs[135] but that, because of their differences in terms of parts replacement, go unrepaired for months or even years. Replacement parts often takes months or even a year or two to get, and finding people who are trained to make the repairs is another problem. With standardization, parts replacement can be readily managed and training requirements greatly simplified. Unfortunately, few if any DCs have as yet adopted such standardization and, accordingly, O&M is usually very inadequate.
- Infiltration into sewers in the ICs used to be a serious problem but this has been virtually eliminated over the past half-century by use of new pipe jointing methodology. But jointing in existing DC sewers is often old-style (bell and spigot pipes), which can result in significant infiltration, which must be taken into account in the design.
- Selection of treatment/disposal design criteria depends on the environmental standards to be met, and the appropriate standards suited to the DC use may be quite different from the IC standards. Care must be given to selecting treatment levels that are appropriate/affordable.
- Attention must be given in the project feasibility study to the institutional and financial aspects—that is, the relationship between the central, provincial, and local governments and their relative responsibilities. Common

practice in many DCs has been for the central government to build the plant, then "abandon" it to the local government to be managed without provision for funding of O&M. The ADB study of 1990[7] on "Economic Policies for Sustainable Development" stresses the need to decentralize so that the local governments have both responsibility and authority for planning/building/operating, with ability to raise their own funds, with the central government in an assisting role.

- The role of the EIA in the project feasibility report is very important for helping ensure attention to all of the issues already noted. The manual on EIA for USEM prepared for use in Thailand in 1997[6] serves this need and, as such, can be very helpful to all parties concerned including project proponents, regulatory officials, and design engineers.

Brief discussions some of the problems already noted are given next. Details are given in[135].

Sewerage-cum-Sanitation Systems for 100 Percent Excreta Management

The first effort to plan and implement a comprehensive USEM system that provides for management of all excreta in the study area, so that its public health protection target will actually be achieved, is the World Bank–sponsored Jakarta Sewerage and Sanitation Project, which was constructed in the 1980s[152]. It covers one selected area in the overall Jakarta region. The project includes both (1) a system for collecting and treating sewage from those portions of the area capable of paying for this service (the affluent portion), with the interceptors planned for ready expansion eventually to cover all areas, and (2) provisions for satisfactory use of on-site disposal units for buildings not connected to the sewerage system.

The recommended on-site disposal is provided by use of dual leaching pits, which receive the discharges from pour-flush toilets, including establishment by the municipality of a special pit desludging service dedicated to servicing only these nonaffluent areas, with use of special desludging trucks designed to be narrow enough to enable access to buildings on narrow streets/lanes, with long desludging hoses. These units give satisfactory service for most of the premises for which the ground permeability and groundwater levels enable them to function as designed, and for these desludging is needed only every several years, with the premise owner paying for this service. For the relatively small percentage of the houses/buildings where permeability is not adequate and/or groundwater levels are too high, more frequent desludging is needed, with these extra costs subsidized by the municipality.

Sewage Treatment Systems

Evaluation of the accumulated experience in numerous DCs showed that the tendency is for each municipal system to be designed on its own, employing a wide variety of treatment systems, each costing about the same to construct but each posing separate needs for parts replacement (which may take many months in many cases) and for O&M training. The economic answer is for each DC to standardize the design of treatment units so that one of several parts depots can readily service all plants in the country and so that O&M training is greatly simplified. The recommended procedure is to utilize a system of four types of plants, proceeding from the first to the fourth progressively as land prices increase, as shown in Figure 4.7. Note that three options (A, B, C) are indicated for System (i) and 2 options (A, B) for System (iii). The selection depends on the particular situation. For example, for System (iii), Option B will often be adequate for very small plants, as for schools in rural areas and for large plants discharging to open (unconfined) ocean water. See[105] for details on the selection process.

Experience indicates that the IAAs will generally be quite willing to give grants to international DCs who wish to follow these guidelines to prepare a national sewerage system plan, including provisions for collection as well as treatment, to be progressively implemented as the country's urbanization and industrialization continue to grow and land prices correspondingly increase. The same study can also examine potentials for achieving regional pollution control systems for protecting affected waterways.

Sewage Collection (Including Interceptors, Pumping, Transmission)

The most important design consideration here is to recognize that many DC municipalities will not be able to afford immediate construction of sanitary sewers for servicing the entire community area, which will have to be achieved progressively with a series of stages, so that use is made of the existing storm drainage conduits for the collection role on an interim basis. Again, the national agency responsible for sewerage facilities should standardize use of materials and equipment for simplifying parts replacement and O&M training, including sewer-cleaning equipment.

Pumping Stations An especially difficult problem is design of pumping plants (which have always been a headache in sewerage history everywhere), but fortunately a design manual produced by Robert Sanks et al.[130] is available that is invaluable for helping the designer with this problem. Another important design aspect for collecting sewers is to utilize not the old-fashioned bell and spigot pipe lengths, which generally result in entry into the sewers of large amounts of unwanted groundwater, but instead the modern type of joint (now generally available) using rubber rings, which virtually eliminate groundwater infiltration.

Curved Sewers Another valuable change in design of sewers applicable to both ICs and DCs was development in the United States following World War II of curvilinear sewer alignments, thus greatly reducing sewer construction costs,

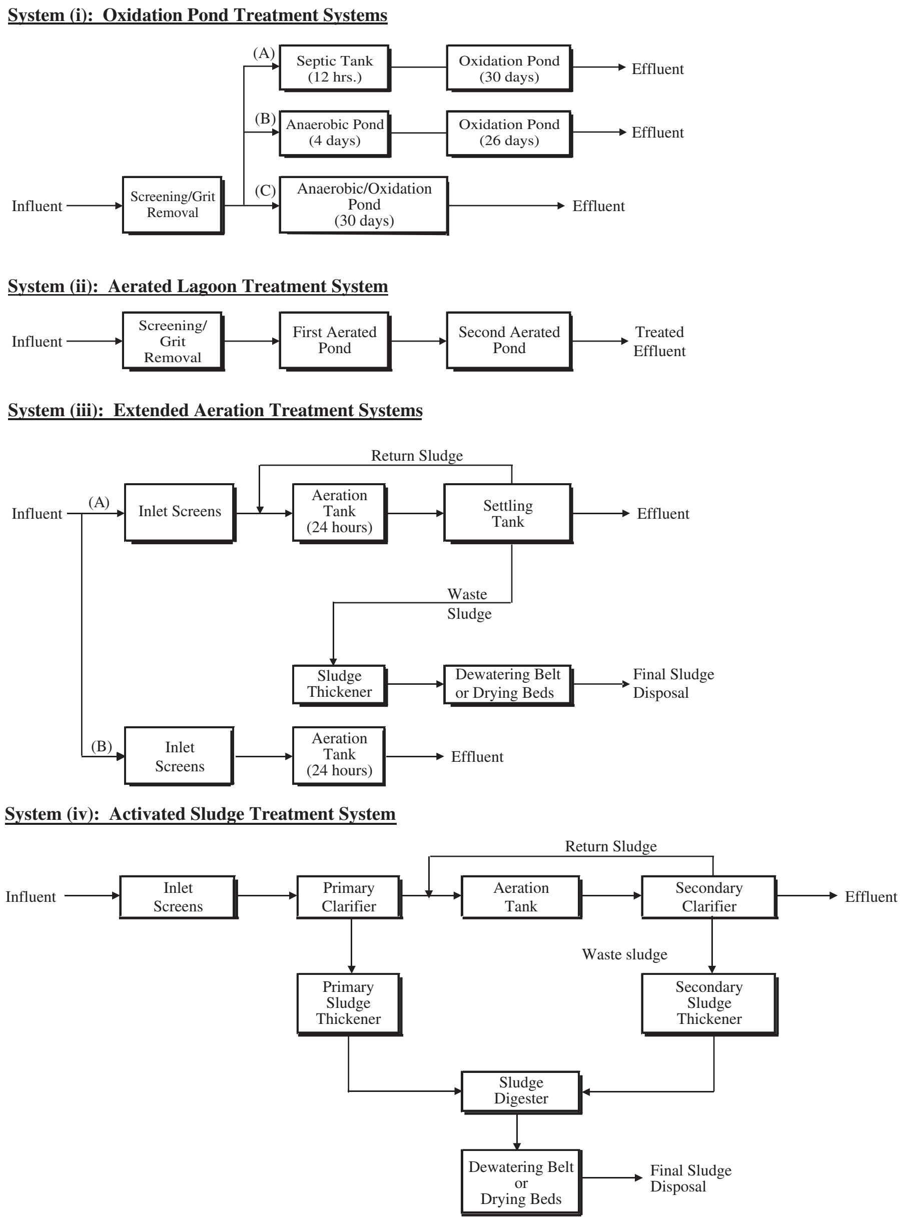


FIGURE 4.7 Recommended standard sewage treatment systems[105].

which became practical because of availability of sewer cleaning equipment which can readily clean curved sewers. Previously, standard practice was to allow only straight sewer alignments, requiring a much larger number of costly manholes[105].

Sewage Characteristics and Needs for Treatment and Point Source Control

Unfortunately, the international literature on sewage treatment places such emphasis on removal of BOD that many design engineers tend to forget which are the parameters that are most important for design of sewage treatment systems:

- Floatable materials, which, if not removed, form surface mats on receiving waters
- Settleable solids, which, if not removal, form sludge banks in receiving waters
- BOD (together with suspended solids), which if not removed, will be harmful to stream ecology (as well as making it more costly to use the river waters as raw water supply)
- Nutrients, which, if not removed, can induce eutrophication
- Toxics and other hazardous substances, which, if not removed, can disturb biological treatment processes and harm aquatic ecology (and impair raw water quality for community water supply)

Primary treatment will remove floatable materials and settleable solids, and complete treatment (primary plus secondary) is required to removal of BOD. Advanced treatment is required for removal of nutrients, and point source control is needed for control of toxics and other hazardous substances. For many DC communities, primary treatment will suffice for the foreseeable future, but for others, complete treatment should be the target. Rarely in DCs will there be need for removal of nutrients. Thus far, many DCs have not made sufficient progress on point source control due to weakness in the enforcement mechanics of most DC governments.

Sewage Flow Measurement

Measurement of sewage flows used to be a difficult problem, but the development of the Palmer-Bowlus ("PB") flume[105] greatly simplifies the problem by use of the PB flume placed in the sewer, which does not restrict the sewage flow. Beginning in the 1960s, such flumes became commercially available as shelf items. They can be readily fitted into a sewer of specified size.

Unfortunately, many DC practitioners are not familiar with the use of these "PB" meters.

Appropriate Standards

As shown in Figure 4.3, the target for DC sewage systems should be not the IC target of point C, but point B. This is all that is needed for environmental protection in the DCs, and it will require several decades to achieve this. Unfortunately, the international media releases nowadays feature point C concerns, leading to confusion rather than help to DC practitioners.

A few years ago the IWA sponsored a major international conference at Bangkok on the subject of controlling eutrophication in rivers and lakes and other waterways in DCs by removal of nutrients. But this is quite expensive and hardly ever needed in DCs, where problems of eutrophication are scarcely a priority issue.

Some examples relating to appropriate standards for sewage treatment developed by ADB[112] are included here as Figures 4.8, 4.9, and 4.10.

Marine Sewage Disposal

As indicated by Figure 4.10, treatment/disposal of municipal sewage for discharge to marine waters can be categorized into two types, (1) disposal to confined marine waters (bays, shallow nearshore waters) for which DO is the controlling parameter, hence treatment requirements are the same as for inland waterways, and (2) disposal to open ocean waters, which requires use of a submarine outfall extending far enough offshore to reach unconfined open ocean water, for which removal only of floatables is really required, together with point source controls to prevent discharge of toxics/hazardous substances into sewer systems.

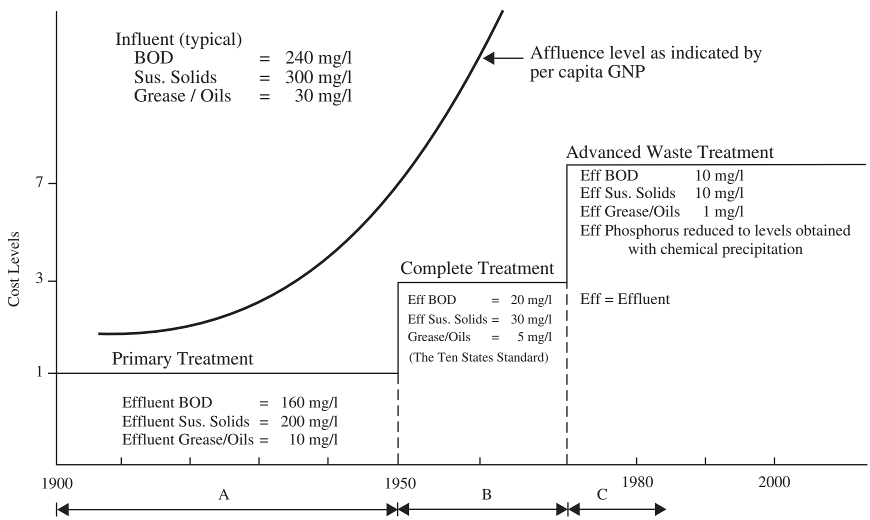


FIGURE 4.8 Drawing showing effluent standards requirements for disposal of municipal sewage to receiving waters where DO is a salient ambient parameter (inland waters and confined coastal waters including estuaries and semi-enclosed bays).

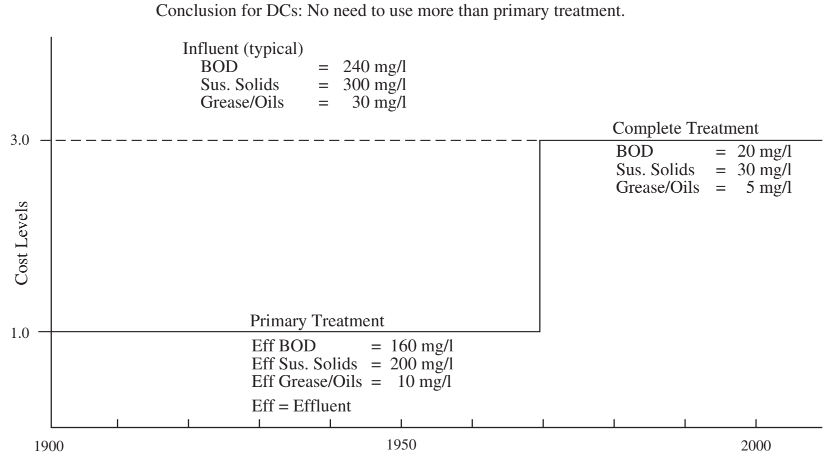


FIGURE 4.9 Schematic drawing showing effluent standards requirements for disposal of municipal sewage to inland/confined coastal waters where DO is not and significant ambient parameter.

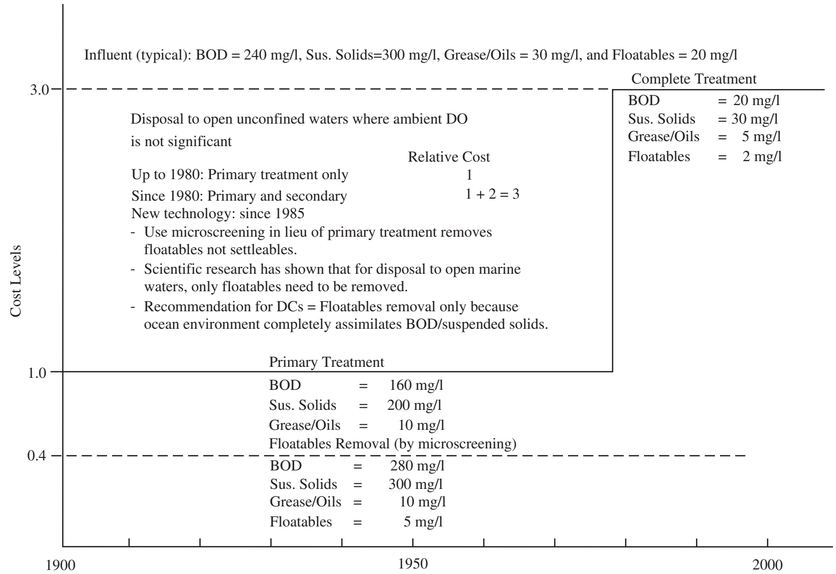


FIGURE 4.10 Schematic drawing showing effluent standards requirements for disposal of municipal sewage to unconfined marine waters (where access to open ocean is feasible and DO is not a significant parameter).

An economic analysis is needed to compare costs for the submarine outfall plus floatables removal, versus a short outfall with complete treatment.

Disposal to open ocean waters also can greatly simplify disposal of industrial wastewaters, which may contain numerous substance (such as salt, degradable organics, inorganic chemicals, etc.) that cannot be discharged to inland waterways without treatment to remove substances that impair confined water quality but that need not be removed for disposal to open seawater[105].

Buffer Area Requirements around Treatment/Pumping Plants

Recommendations that are considered appropriate for DCs are given in a paper by R. Bradley[24]. His recommendations are summarized in Figure 4.11.

Regional Water Pollution Control

Few DCs have yet developed regional water pollution control systems, which can cover the needs for a group of municipalities, but beginning efforts to do this are the Samutprakarn regional system in Thailand[107], the proposed regional plan for Abidjan in the Ivory Coast[67], and the regional systems for the coastal provinces in north China[163].

INDUSTRIAL WASTEWATER MANAGEMENT

Situation in ICs versus DCs

Management of industrial wastewaters is a very complex subject because of the great variety (ever increasing) of pollutant constituents contained in these wastewaters. One way or another, by treatment, by use of cleaner production technology, or by point source control, the levels of these pollutants must be controlled to reduce concentration to levels acceptable to receiving waters. Fortunately, U.S. EPA, with its ample financial resources, has been able to produce a series of excellent manuals, one for each type of industry (now available on the Internet), which give excellent basic data for each industry including quantification of all raw materials utilized, the steps involved in manufacture, and the various types of wastes produced by each step, including needs for treatment of these either singularly or combined. The online manuals include illustrative schematic drawings. These basic data are equally useful for IC and DC purposes. The U.S. EPA manuals include a final chapter which includes environmental standards applicable in the U.S. together with the matching treatment requirements. Unfortunately, these manuals do not include an additional chapter on standards and matching treatment requirements that are appropriate for DCs. It would be greatly helpful to the DCs if U.S. EPA would do this.

The job of the DC designer is to devise environmental standards and matching treatment requirements that are appropriate for the particular DC. The target for DCs should be point B in Figure 4.3 of the Introduction section, not the point C

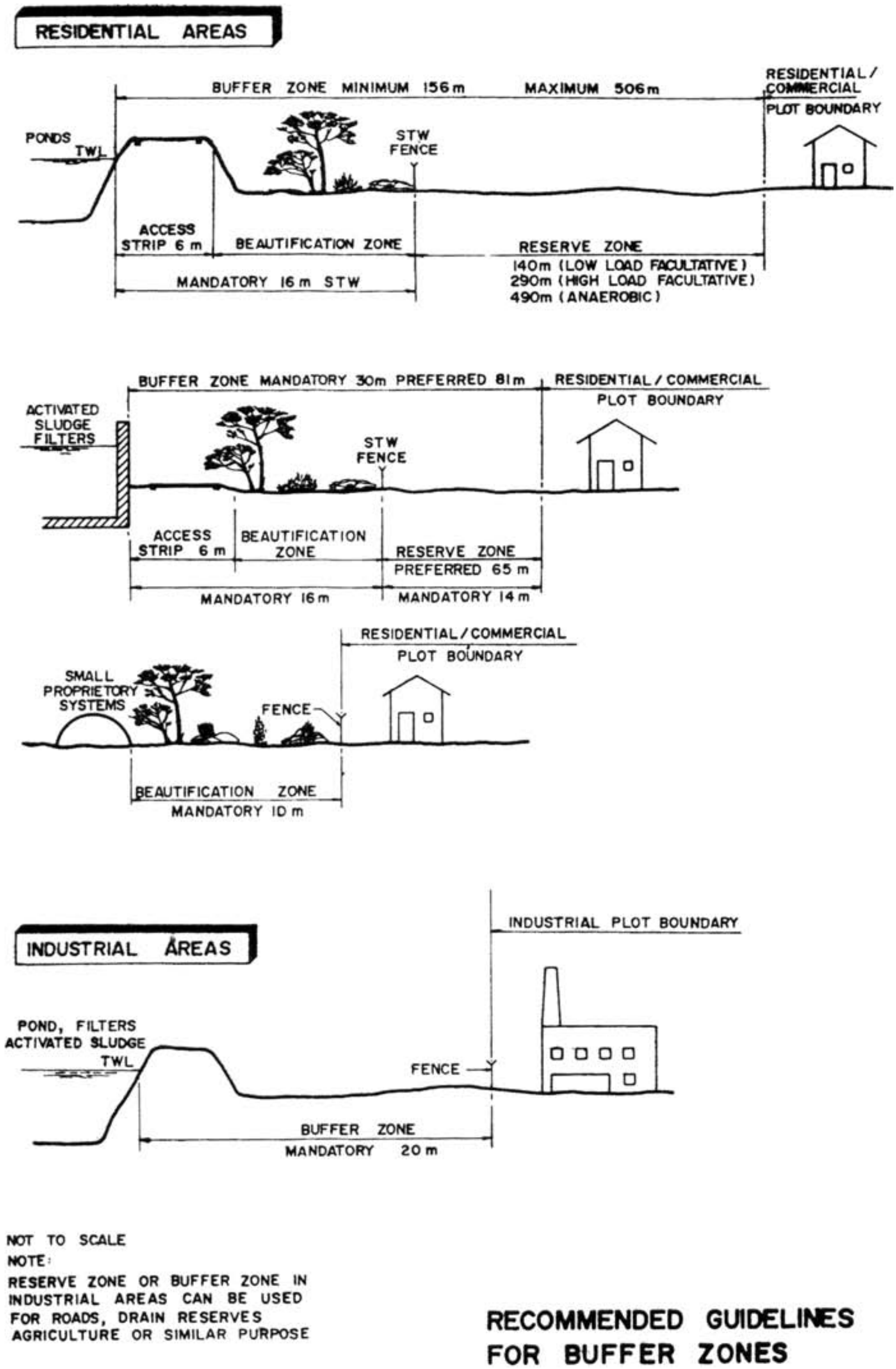


FIGURE 4.11 Recommended guidelines for buffer zones.

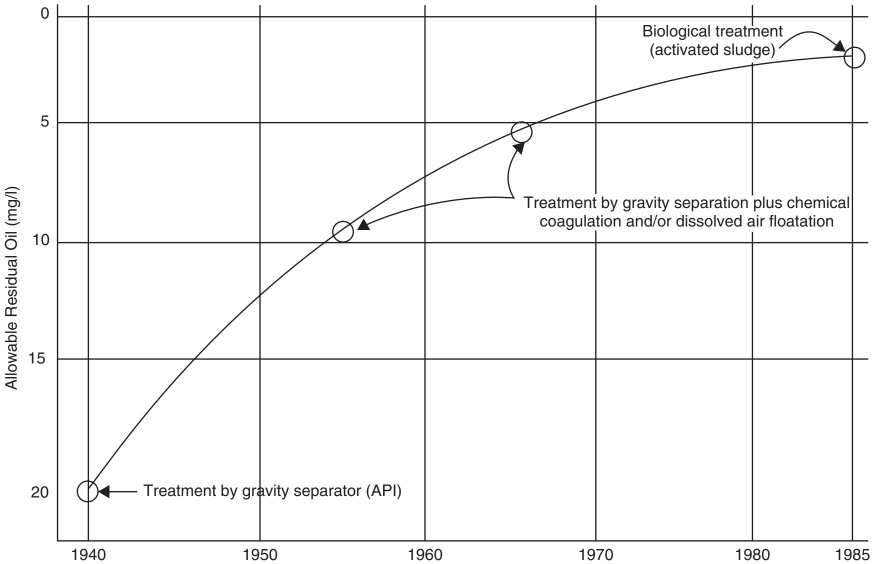


FIGURE 4.12 Schematic drawing illustrating requirements in U.S. over Past 50 years for removal of oil from refinery effluents.

target used in the ICs. An example of this approach is illustrated here from ADB sources[112] for petroleum refinery wastewaters, as shown here in Figures 4.12 and 4.13. Figures 4.14 show recommendations for control of industrial wastes disposal of by infiltration into groundwaters for the parameter of total dissolved solids (TDS).

Discharge into Municipal Sewerage Systems (MSSs)

Box 4.3 describes preparation of a municipal ordinance that encourages industries to make use of the MSS (municipal sewerage system), which can greatly assist in financing the overall MSS, but with a system of controls that protects the MSS and the receiving water environment. The salient control items are the following:

- Restrictions to prohibit discharge into the MSS of any industrial wastewaters that cannot be received by the municipal system because of hazards of damage to the system, or to receiving waters or land areas to which the STP effluent is discharged
- In-house pretreatment by industries for removing unacceptable constituents from industrial wastewaters so effluents will be acceptable for discharge to MSS (or directly to the environment)

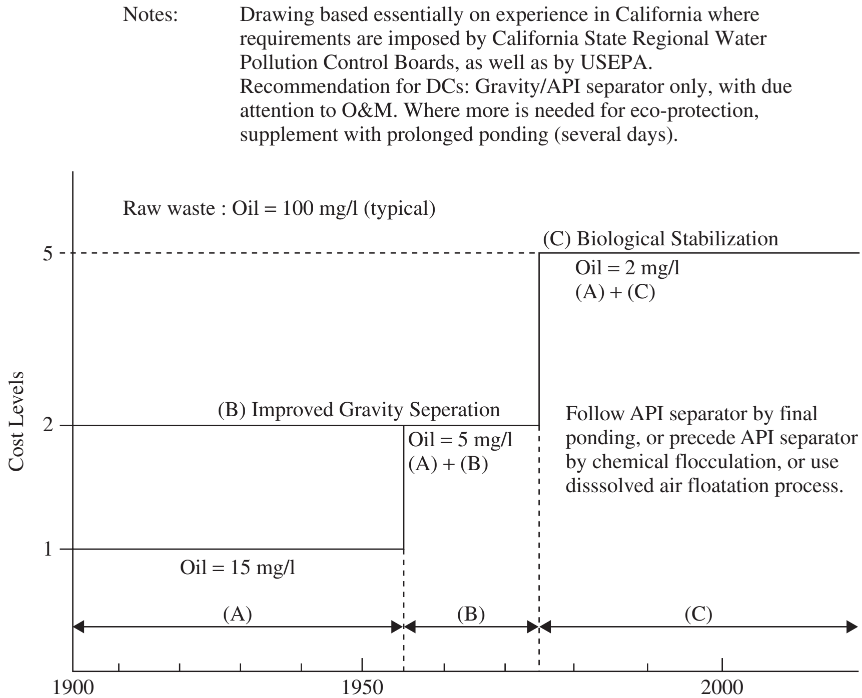


FIGURE 4.13 Schematic drawing showing effluent standards removal of oil from petroleum refinery waste.

- Permit system to be established by MSS that authorizes industries to discharge into MSS, including provisions for fees to be paid by the participating industry

Note that this recommended system is patterned after that used by the Los Angeles Country Satiation Districts (LACSD) circa 1970, which is considered to be practicable for DC use. The current system utilized by LACSD, as now required by the U.S. EPA, is much too sophisticated/expensive for DC use[105].

Discharge Directly to Environment

These discharges must be controlled in the DCs by use of the permit system already described, administered by the local authority with this power (which may be the MSS for industries within the municipal boundaries). In most DCs, the permit system is administered by the NEnPA, which requires preparation by the industry of an approved EIA before the Ministry of Industry can issue its permit that allows the industry to be built and operated. The EPMs specified in the approved EIA are included in the Ministry of Industry permit.

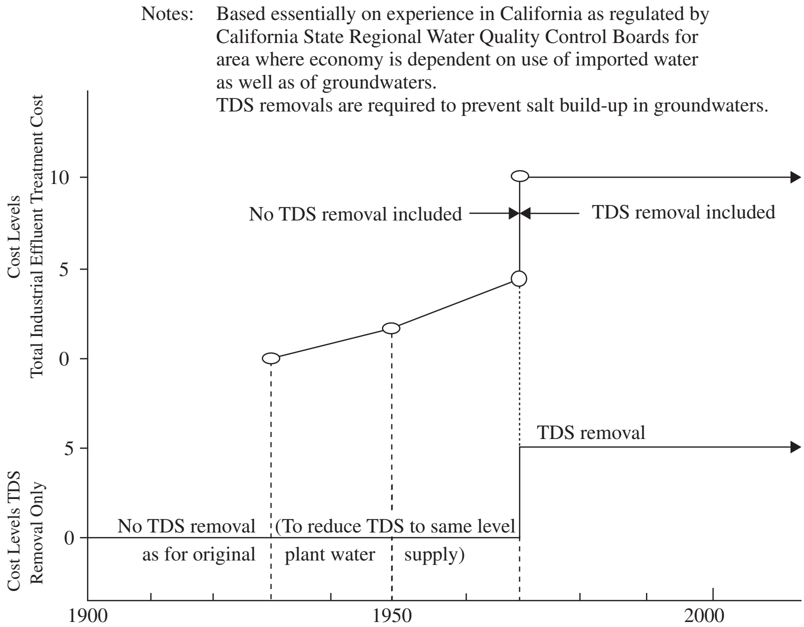


FIGURE 4.14 Schematic drawing showing effluent standards requirement for disposal of industrial wastes by soil infiltration affecting valuable groundwaters in semi-arid regions for parameter of total dissolved solids (TDs).

The weakness in this system is the lack of firm monitoring of actual industry performance and lack of fines for nonperformance, which are sufficiently high to encourage performance.

Appropriate Standards

As already noted, the U.S. EPA point source publications, which are available for almost all types of industries, are excellent sources of background information needed for designing the appropriate wastewater management system for a particular industry. But in using these manuals, care must be taken (as already noted) to adjust the control system to be practical for use in the DC (if not, performance will be evaded)—that is, to utilize appropriate environmental standards. This adjustment requires skilled expertise and virtually all DCs need IAA assistance for this task.

Some examples of use of appropriate environmental standards are given in Figures 4.12, 4.13, and 4.14.

Cleaner Production (CP)

In the 1990s, the IAAs initiated a program for getting DC industries to utilize cleaner production technologies developed in the ICs for minimizing production of wastewater pollutants by modifying the various process steps utilized by industries, thus not only simplifying treatment needs but also saving raw materials, making the industrial operation more economic. The experience thus far in DCs[108] indicates three things:

1. The NEnPAs/industry ministries have not established sufficient regulatory mechanics to enforce use of CP; hence, use of CP to date has been limited because of the required upfront investment in reorienting the industrial processing methods, and the time required (3 years or more) before these costs can be recovered, together with the pressures prevailing in most DCs for realizing immediate financial gains, and the continuing lack of regulatory enforcement for controlling pollution discharge requirements.
2. The best success in use of CP in the DCs has been in industries that are branches of international companies that can afford the upfront investments and, moreover, have the goal of increasing overall long-term profits.
3. The best approach is for the DC to gain support from the country's industrial/trade associations to encourage industries to use CP[87].

Industrial Estates

Usually, the most practical approach for controlling industrial pollution in DCs is the use of industrial estates where polluting industries are required to locate, as illustrated by the Industrial Estates Authority of Thailand. These estates offer economic advantages in furnishing a central treatment plant for managing pollutants treatable by the central plant, and with the estate administering the permit system including performance monitoring and enforcement. The administrative costs of proper control of pollutants with these estates are vastly simpler and inexpensive compared to the situation when the industries are in separate locations.

Marine Disposal

As noted in the section on "Urban Sewerage and Excreta Management," when disposal to unconfined offshore ocean waters is feasible, the costs for treatment/disposal can be greatly reduced because of open ocean's virtually unlimited supply of oxygen for stabilizing BOD, and because the ocean waters can receive many types of inorganic compounds without damage which cannot be accepted by confined receiving waters. Selenium, for example, is a serious toxic substance for receiving waters used for irrigation but of no special significance when discharged to the open seas.

Figure 4.15 illustrates this capability of the open seas for accepting many types of inorganic compounds. One example of this advantage of open ocean disposal is the World Bank's project for metropolitan sewerage planning at Abidjan (Ivory Coast), where such disposal is vastly less costly and much more practical than a previous proposal, which attempted to require in-house treatment by the many industries in the metropolitan region[157]. Another is the recommendation

INDUSTRY \ TREAEMENT PARAMETER		pH	Acidity/Alkalinity	TSS	TDS	BOD	COD	TOC	Temperature	Color	Grease/Oil	Phosphorus	Nitrogen	Surfactants	Chromium	Lead	Copper	Mercury	Arsenic	Manganese	Zinc	Potassium	Aluminium	Heavy Metals	Cyanide	Phenols	Fluoride	Sulfate	Coliforms (Fecal)
Inorganic Chemicals		●		●			●	●							●	●		●							●				
Organic Chemicals		●	●	●	●	●	●	●		●	●	●	●												●	●			
	Bauxite Refining	●	●	●	●																							●	
Aluminium	Primary Smelting	●		●																							●		
	Secondary Smelting	●		●			●						●				●						●				●		
Feedlots				●	●	●	●					●	●																●
Fruit/Vegetable Canning		●		●		●																							●
Plywood		●	●	●	●	●	●		●		●	●	●		●		●		●		●						●		
Iron Smelting		●		●											●					●					●	●			
Cement		●	●	●	●				●													●						●	
Asbestos Building Materials		●		●	●	●	●	●	●			●	●											●		●			
Cane Sugar Refining		●	●	●	●	●	●		●			●	●																
Fiberglass Insulation		●		●	●	●	●		●	●	●		●														●		
Meat Processing		●	●	●	●	●	●		●		●	●	●																●
Grain Processing		●	●	●	●	●	●		●			●	●																
Soap and Detergents		●	●	●		●	●				●			●															
Synthetic Resins		●			●	●	●					●			●						●								
Steam Power									●																				
Pulp and Paper		●		●		●	●			●																			
Brewery				●		●																							
Copper Wire		●		●	●										●		●				●								

FIGURE 4.15 Significant parameters for treating wastewaters from various industries for discharge to confined waters (but not significant for discharge to open ocean waters) (after point source publications of U.S. EPA).

for disposing of huge amounts of polluting coal dust from power generation in India by discharge to the open seas[131].

See section on "Emergencies Management" for discussion of Thailand's system for managing oil spills.

BOX 4.3 GUIDELINES FOR PREPARATION OF ORDINANCES FOR REGULATING AND INDUSTRIAL WASTE DISCHARGES FOR MUNICIPALITIES IN INDONESIA

by H. Ludwig for UNDP/UNOTC, 1978[44]

Abstract

Interest in environmental protection in Indonesia, including protection of the quality of the water resources of the country, has progressed greatly over the past decade. There is now considerable interest in formulating and establishing a national program for protecting the quality of these water resources, including rivers, lakes, estuaries, and marine waters.

An important aspect of a national water quality control program relates to the management of public sewerage systems in urban areas, so that the system will fulfil its primary objective of collecting and disposing of sanitary wastes, while at the same type furnishing reasonable service for receiving and disposing of industrial wastes. Thus, a municipality having a public sewerage system needs to enact ordinances which will provide for the proper controls for protecting both (1) the public sewerage system including treatment plants, and (2) the environment in waterways that received the treated wastewater.

A preliminary step toward formulation of such guidelines for municipal sewerage systems was carried out as part of the Jakarta Sewerage and Sanitation Project completed in 1978 by the Ministry of Public works in cooperation with the United Nations Development Program and the World Health Organization. The Jakarta Project report includes sections, prepared by Dr. Harvey F. Ludwig as the Project's Consultant on Environmental Technology, on a recommended municipal ordinance for control of industrial wastes discharged to municipal sewers, which were adapted from the requirements utilized by the Los Angeles County Sanitation Districts circa 1970.

The information in the current report includes the salient aspects of municipal ordinances that are needed to control discharges to the public sewerage system, both for sanitary and industrial wastes. A glossary is also included to define the technical terms and abbreviations used in the report. Although the information presented in this report was initially prepared for consideration for use at Jakarta, it has been edited to make it generally useful by all municipalities in Indonesia.

URBAN SOLID WASTE MANAGEMENT

Situation in United States versus DCs

Solid waste disposal in the United States has mostly made use of landfills. Pursuant to U.S. EPA regulations, design and operation of urban solid waste landfills is now a highly sophistical hi-tech business, which, while expensive is affordable in the United States and desirable to protect environment, particularly to prevent pollution of groundwaters[142]. In most DCs, however, most solid wastes continue to be disposed of by piling into open dumps, resulting in serious environmental hazards including (1) exposure of workers and other site visitors to disease hazards from flies and rodents that are attracted to the site, (2) production of odor and smoke nuisances from uncontrolled burning, (3) hazard of polluting groundwater, and (4) hazard of polluting nearby areas by flood runoff. In addition the systems for collection and transport of the wastes to the site are generally not protected and often are contacted by children.

The history of urban solid waste management (USWM) in the United States has involved three stages: (1) use of open dumps, (2) use of sanitary landfills beginning in the 1930s, then (3) improvement of landfilling technology to its current hi-tech state. The costs for Stage 3 are prohibitively expensive for DCs; in fact, the Stage 3 costs for performance monitoring alone may exceed the funds available in many DCs for the entire landfilling system. The realistic target for DCs at this time is to aim for switching from open dumping to use of sanitary landfilling as practiced in the United States prior to U.S. EPA involvement (Stage 2).

Over the past two decades, the DCs with IAA assistance, have begun the process of utilizing sanitary landfill in selected cities, so the technology for designing and operating these to suit the criteria is gradually being developed.

It should be noted that many DC/USWM practitioners are not aware that solid wastes typically are replete with disease pathogens (much like sanitary sewage); hence the need for attention to collection/handling/disposal practices to protect people from exposure/contact with the wastes.

Practical Sanitary Landfilling Technology for DCs

As already noted, the target for DC/SWMSs is use of sanitary land-filling technology as used in the United States up to mid-twentieth century, without use of plastic liners/recirculation of waters seeping through the fill and without elaborate monitoring, but with adequate attention to (1) use of storage collection containers and/or storage areas which are protected from access by children, (2) use of collection trucks that can transport the wastes without spilling, and (3) locating the landfill site at places with little if any potential for polluting groundwater (no groundwater or deep groundwater aquifers that are covered with deep layers of impermeable clays), (4) protection against flood runoff from the site, and (5) provision of buffer areas around the landfill sufficient to prevent complaints from neighbors (see section on "Urban Sewerage and Excreta Management," subsection on "Buffer Area").

Following these guidelines, an ADB-sponsored project in 1997 produced and EIA manual on the requirements for designing and operating an acceptable DC sanitary landfill[136].

Experience in Asian DCs

Thailand Most Thailand cities are located in the flat lowland regions where the major groundwater resources are at deep depths covered by deep layers of impermeable clays, so it is feasible to find sites where use of expensive liners is not necessary. In about 1990, there were only a few municipal sanitary landfills (MSLs) in the country, and these came about at local initiative (usually by city officials who happened to observe SLF operations in the United States). Beginning in the 1990s, Thailand's Pollution Control Department (branch of the country's environmental ministry), in response to development of serious SWM problems in several municipal areas, undertook studies to plan SLF operations on a provincial basis so that a single MSL could provide economic service to several municipalities in its region. However, while these plans appear excellent from the technical/economic points of view, progress in implementing these schemes has been slow because it has been difficult to obtain political approval from the municipalities involved[134].

Malaysia Solid waste disposal problems in cities in the Klang Valley region the country's primary population/industrial region with a number of cities (including the capital city of Kuala Lumpur) had become especially serious by about 1970, due to the legal situation where each city is responsible for managing its own disposal, but usable disposal sites within the city boundaries had become all used up, and the cities had no authority to utilize areas outside their boundaries. As part of an ADB-sponsored project for improving economic-cum-environmental development in the region, called the "Klang Valley Environmental Improvement Project"[5], a plan was prepared in 1987 for a single regional SWL system serving all these cities, including trucks for picking up the wastes collected by each city, hauling these to the SWL site (using transfer stations as needed along the way), with the SLF well located for economic hauling form the cities to be serviced. The essence of this plan is shown in Figure 4.16. At the same time, the capital city of Kuala Lumpur had proposed to proceed with an incineration plan that would cost seven times as much per ton of solid waste incinerated, compared to the regional plan, and even the incineration scheme would dispose of only 80 percent of the waste with 20 percent remaining as residue to be disposed of by hauling to a landfill.

Philippines In most DCs, a serious public health hazard is the practice of the urban poor to find employment by visiting SLF sites to pick them over to recover plastics and other resalable. In the Philippines, the Ministry of Human

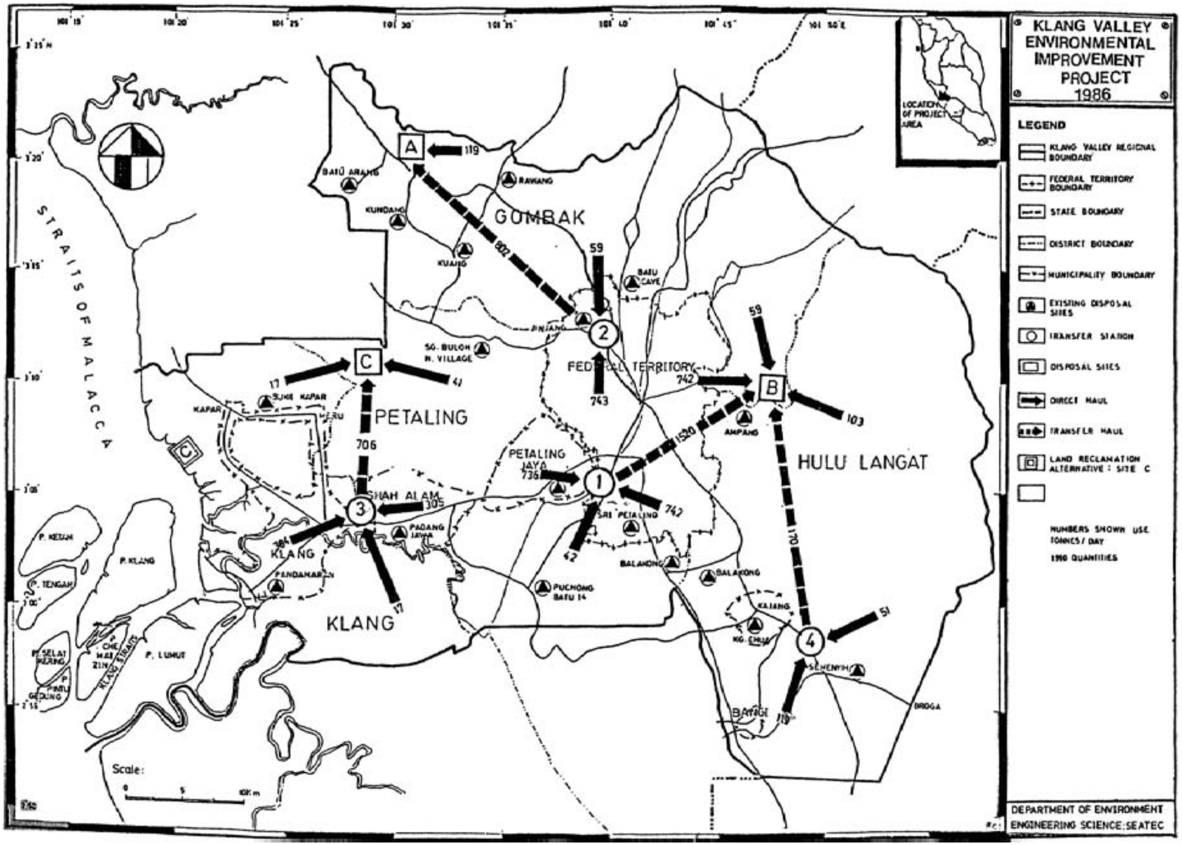


FIGURE 4.16 Recommended plan for solid waste management in Klang Valley.

Settlements in 1980 attempted to "sanitize" the landfill recovery operations in the Metro Manila region with public employees doing the picking over, using protective clothing and picking gear, but it was found that the costs of this was greater than the value of the recovered materials[49].

Indonesia A World Bank–sponsored project in the 1980s[150] developed a plan for markedly increasing the life of the available SLF sites by use of equipment for compacting the waste into bales before disposal, thus greatly decreasing the waste disposal volume.

China The World Bank's project for resettlement for the major Xiaolanddi dam/reservoir project on the Yellow River included provisions for adequate SWM in the resettlement cities, including use of appropriate vehicles for picking up and hauling wastes to transfer stations fenced off to prevent access by children, then hauling to SLF sites including fencing off of the sites to prevent public access[160]. Hence, these resettlement cities are blessed with USWM facilities much better than those in the cities in which the resettlers previously lived.

Alternative Disposal Methods

The DCs cannot consider use of incineration because of the unaffordable high costs. Several attempts have been made for use of composting (as practiced in Europe), including construction in Bangkok in the 1960s of several major composting plants presumed to be useful as a general disposal alternative. These have been abandoned except for one plant, which produces only a small amount of compost sold to nearby fruit orchard farmers[46].

Reclamation of Swamp Lowlands by Refuse Landfilling

Project Concept It was observed in the Jakarta region of Indonesia in the 1970s[150] that valuable land was being reclaimed from uninhabited swamp areas by filling of the swamps with solid wastes by private-sector operators. This practice would be prohibited by U.S. health authorities, but examination of this practice in Jakarta indicated that it was essentially sound.

The solid waste materials, under water-saturated conditions, quickly consolidated and degraded to form good land. This led to a World Bank–sponsored R&D project conducted at Bangkok for evaluating the feasibility of reclaiming swamp areas by filling with refuse[104]. The study examined core samples in Bangkok areas that had been filled by refuse. Half of the city of Bangkok is built on former swampland filled with refuse, but the other half on areas filled with dirt or sand.

Stabilization Phenomena The study evaluated the available literature on research studies of landfilling with solid wastes, on gas production and degree of stabilization of the fill materials, to obtain appropriate guidelines or criteria

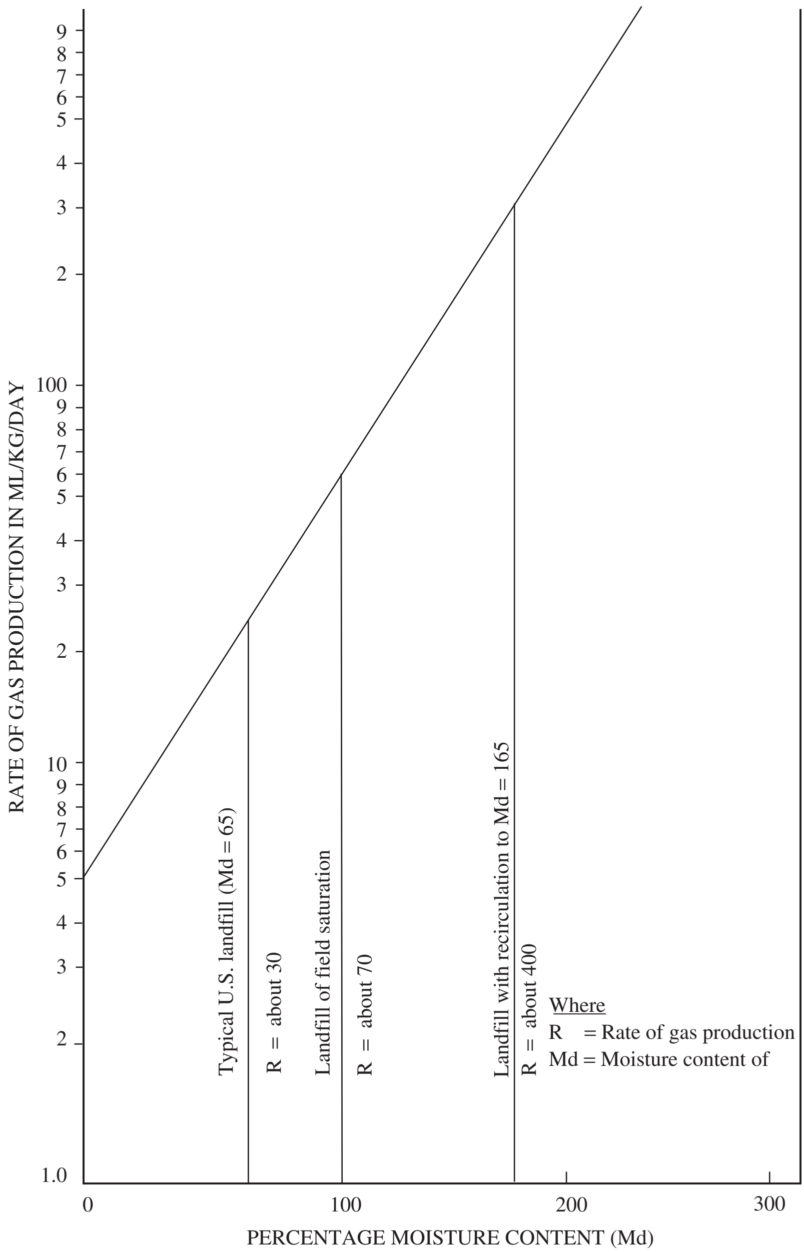


FIGURE 4.17 Illustrates this relationship between rate of gas production and percentage moisture content in landfills for different sets of conditions.

that could be used for estimating the degree of stabilization obtained within fills under the saturated or submerged conditions prevalent at Bangkok during the six-month rainy season Figure 4.17 illustrates the relationship between the rate of gas production and the percentage moisture content in landfills. Information was also gathered on problems in utilizing completed fill sites as related to degree of stabilization and/or compaction. To supplement the review and literature available at Bangkok, a canvass was made of past and ongoing research on refuse landfilling stabilization phenomena. The results of the review are as follows:

- There are several types of stabilization/gas production phenomena going on in a fill including aerobic, facultative, and anaerobic, with the anaerobic phase representing the main mechanics for achieving gas-production (both methane and carbon dioxide) and hence stabilization. These various phenomena into be classified in five stages: (1) initial adjustment, (2) transition, (3) acid formation, (4) methane fermentation, and (5) final maturation[127].
- In a typical U.S. fill, a total of about 600 days is required to complete stabilization under usual conditions in practice. However, various studies show that the stabilization can be speeded up by increased temperature (up to 41°C), and especially by increasing moisture content, because the unsaturated portions of the fill tend to remain within the acid formation phase, whereas when the materials become saturated, methogenesis develops very rapidly. Under Bangkok conditions, saturation would be the norm during the rainy season (about 6 months).
- While the data are limited, the available data indicate that the rate of gas production (total gas) may be roughly expressed by the equation:

  $$\log R = 0.0125\text{Md} + 0.5$$

  where R = gas production in ml/kg/day and M_d is the moisture content of the fill on a dry weight basis.

Study Conclusions Because of the fact that practically all research studies on refuse landfilling have been conducted in the Western countries, there is a well-meaning tendency in the Western technology against the concept of depositing organic refuse at ground elevations below groundwater levels. Western technology requires that all filling be at levels above groundwater, and moreover, a great deal of research and development over the past two decades has been focused on developing practicable methods for preventing leachate percolating from fills downward into the groundwater strata. The objectives are to protect the groundwater quality from pollution because, in many situations, the groundwater, including strata near the surface, are used as a source of water supply for community and industrial purposes. In other words, under normal conditions, without use of planned refuse filling, the groundwater is not generally polluted and it is desired to keep it clean.

The situation in urbanizing swamp (formerly paddy) areas in tropical monsoon countries is entirely different. Under these conditions, the normal situation involves routine deposition of community refuse into the vacant lands by householders all year around, because the municipal refuse collecting system gives only partial service. Thus, a great deal of refuse is disposed of by the householders, commercial establishments, and others on a local basis, by throwing it into the swamp/paddy area or by trucking it there (usually done during the night hours so the operations are not observed by most people). As a result, the swamp areas are routinely very heavily polluted with these materials. The groundwater level during the rainy season is above the surface and often close to the surface during the dry season. In other words, the surface and shallow groundwaters in these urbanizing areas are routinely polluted to a high degree by uncontrolled deposition of refuse.

In addition, excreta also heavily pollute the surface and shallow groundwaters because excreta disposal is generally by use of subsurface leaching pits, or by septic tanks with subsurface leaching systems. At Bangkok, because the soils are generally tight clays, the subsurface leaching systems hardly leach at all; hence their effluents tend to ooze to the ground surface. At Jakarta, many of them in the northern city area function poorly because of either tight soils or high ground water. The result is that even under normal conditions, the surface and shallow ground waters are very heavily polluted. This situation continues until the low-lying areas become filled. Usually, this requires a period of years, ranging from a few years to much longer periods of a decade or several decades. There is little prospect in the foreseeable future that this situation will change. Even when the municipal refuse collection system can expand its services, new areas of building development spring up in the fringe areas on the city outskirts.

Because of the situation just described, the first conclusion, in making the environmental analysis, is that the "Western rules" are inappropriate for evaluating the situation on refuse landfilling in low-lying tropical monsoon regions, and that the analysis, to be appropriate, must be based on the actual local situation.

Parameters for Analysis Review of the literature on refuse filling practices in developing countries indicates that the significant parameters involved in evaluating the environmental effects of the proposed scheme for systematic swamp reclamation by refuse landfilling are: (1) sanitation/public health, (2) community aesthetics, and (3) economics including savings in reclaiming land by the proposed method (with credits for its value for waste disposal) and suitability of the completed fill for building purposes. Other meaningful considerations applicable at Bangkok include the impact on local flooding and on the local refuse scavenger industry.

Sanitation/Public Health/Aesthetics Under current conditions, the swamp areas in urbanizing zones arc characterized by very heavy pollution of the shallow groundwater, and of surface waters existing during the rainy season, due to uncontrolled dumping of refuse into these areas and due to excreta waste residuals from subsurface disposal units, which are unable to function effectively.

These problems persist so long as the areas are undergoing filling, which may take many years or even decades.

The only practicable solution to the problem is to fill these areas as promptly as possible, because there is little hope in the foreseeable future that waste management practices will be much improved. The proposed refuse landfilling reclamation scheme will achieve the objective of prompt filling. This will include planned filling of sites so that the refuse hauling distances will be decreased. In these selected areas filling will be as rapid as possible (as permitted by biological degradation and consolidation constraints), thus minimizing the period of unacceptable sanitation/public health/aesthetic conditions.

Structural Suitability of Completed Fill Much of the literature on sanitary landfilling in the industrialized countries is concerned with the suitability of the completed fill for use for sites for buildings. Such use has involved serious problems because methane gas generation in the fill results in explosion hazards beneath the building, with settling of the building due to settling/consolidation of the fill, and with the difficulties in driving structural piling through the completed fill.

In the proposed refuse landfilling reclamation scheme for DCs, the problems of methane gas and of fill settling appear to be eliminated due to the virtually total biological degradation and total physical consolidation taking place in the reclamation period because of the wetted condition in the fill during the rainy seasons.

With respect to driving of piles, this should pose no significant problem because of the limited depth of the fill, usually less than 2 meters. In addition, where footings are used for foundations, because the fills are shallow, usually it should be possible to place the footings to rest on the natural soil underlying the fill.

No problems of the types described here arc known to have been reported in Bangkok, despite the fact that much of the city (all built on former swamp/paddy areas) has been filled with refuse to a depth of about 1.5 meters.

Overall Study Conclusions The conclusions on economics are as follows:

- The stabilized waste is suitable for fill material, which will be used for developments such as parks, playing fields, light surface improvements, one-story buildings with footings in soil below the fill, or structures on piles. This is based on the study soils laboratory analyses that show that the decomposed solid waste is similar in nature to inert fill material used in Bangkok and based on experiences in Thailand and elsewhere where swamps reclaimed with solid waste have been widely utilized for decades for building development, with no known reported settling or structural damage.
- Degradation of solid wastes deposited in low-lying areas with tropical monsoon climatic conditions probably occurs within two rainy seasons, and

maybe even more rapidly if swamp conditions prevail year-round. Problems of methane gas and fill settling are believed to be eliminated through virtually total biological degradation and total physical consolidation due to the wetted conditions.

- The proposed scheme of refuse filling should be quite beneficial in terms of environmental impacts, primarily because the only known way to solve "sanitation mess" problems in low-lying areas is to fill them in, and use of refuse is often the only affordable approach.
- The solid waste disposal/swamp reclamation scheme could reduce overall municipal solid waste management costs by a significant reduction in hauling costs and reduction in expansion requirements for the existing series of landfill operations.

URBAN AIR POLLUTION CONTROL

Background

In the United States, the regulatory control system established by U.S. EPA for point source control (industries) is effective because its regulations are enforced, so it is cheaper to comply than to evade, and the major remaining problem is control of pollution emission from vehicles. The regulations for vehicles (use of exhaust emission controls, requirements for better mileage) have made significant progress, but the eventual solution will probably be switching the fuel from gasoline to hydrogen.

The problem in most DCs is relatively very poor; hence, many of the major DC cities suffer from severe air pollution. The DCs have appropriate laws/regulations, but enforcement is generally very weak, and in addition to the major sources from industries and vehicles, uncontrolled burning of forests, especially in Indonesia, now is a major pollutant. The pollution from the annual burning in Indonesia now causes prolonged pollution every year in the nearby countries of Singapore and Malaysia, and despite a major effort by ADB to help the Indonesian government to resolve this problem, significant progress has not been made.

Air pollution is now horribly severe in many of the major cities of China, due primarily to China's dependence on burning of coal as the primary energy source, and it seems unlikely that China will get around to use of sequestering of CO_2 from coal burning in the foreseeable future. And this problem, already so severe, is now being compounded by the recent great increase in vehicle traffic in China cities now underway.

Thailand: General Situation

One of the better (less bad) situations on air pollution control in Asian DCs is that in Thailand where the government's Pollution Control Department has achieved significant reductions in reducing vehicle pollution by enforcement for reducing emission with periodic inspections, ban on use of leaded gasoline, and requirements for switching from two-stroke to three-stroke motorcycle engines. The control program of the Ministry of Industry's Department of Industrial Works, which has jurisdiction for industry control suffers from inadequate enforcement measures, and tends to enforce correction measures only in situations with very severe public complaints. The worst single major air pollution problem in Thai history resulted in massive emissions of SO_2 from a major power generating facility (Mae Moh) in northern Thailand, which generates power by burning of peat with high sulfur content, resulting in a major control effort by the Pollution Control Department (assisted by U.S. EPA), but even with this, plentiful public complaints continue. This record has given fossil fuel power production in Thailand a very bad image, and made it difficult to gain acceptance of proposed new plants, even for plants burning clean coal with proper controls. It is the public's belief that these will be "more Mae Mohs."

Thailand: Sharing of Controls for Multiple Industries

Study Objectives The Department of Industrial Works (DIW) sponsored a study completed in 2001[139] for evaluating the situation in industrial zones where emissions come from multiple industries, to develop a system that can fairly distribute/divide responsibility for controls among the various industries.

Study Work Plan and Strategy Figure 4.18 shows the Work Plan tasks, and Figure 4.19 shows the study strategy for evaluating the pertinent collected data.

Organization of Study Report The report consists of seven chapters and appendices as follows:

- Chapter 1: Introduction.
- Chapter 2: Industrial area management. This section contains reviewing of related documents and data, summary of necessary data, industrial area management data in Thailand and related international experience.
- Chapter 3: Methodology for conducting assimilative capacity both overall, detailed for each step, including limitations.
- Chapter 4: Detailed applications of assimilative capacity evaluation method and appropriate management methods for the two main industrial study zones.
- Chapter 5: Environmental management conditions and implementing organization, which present detailed environmental management conditions for the project developers.
- Chapter 6: Training, meetings, and seminars for project outcome presentations.
- Chapter 7: Conclusions and recommendations.
- Appendices: References and detailed related information, which are grouped for each chapter for convenient use.

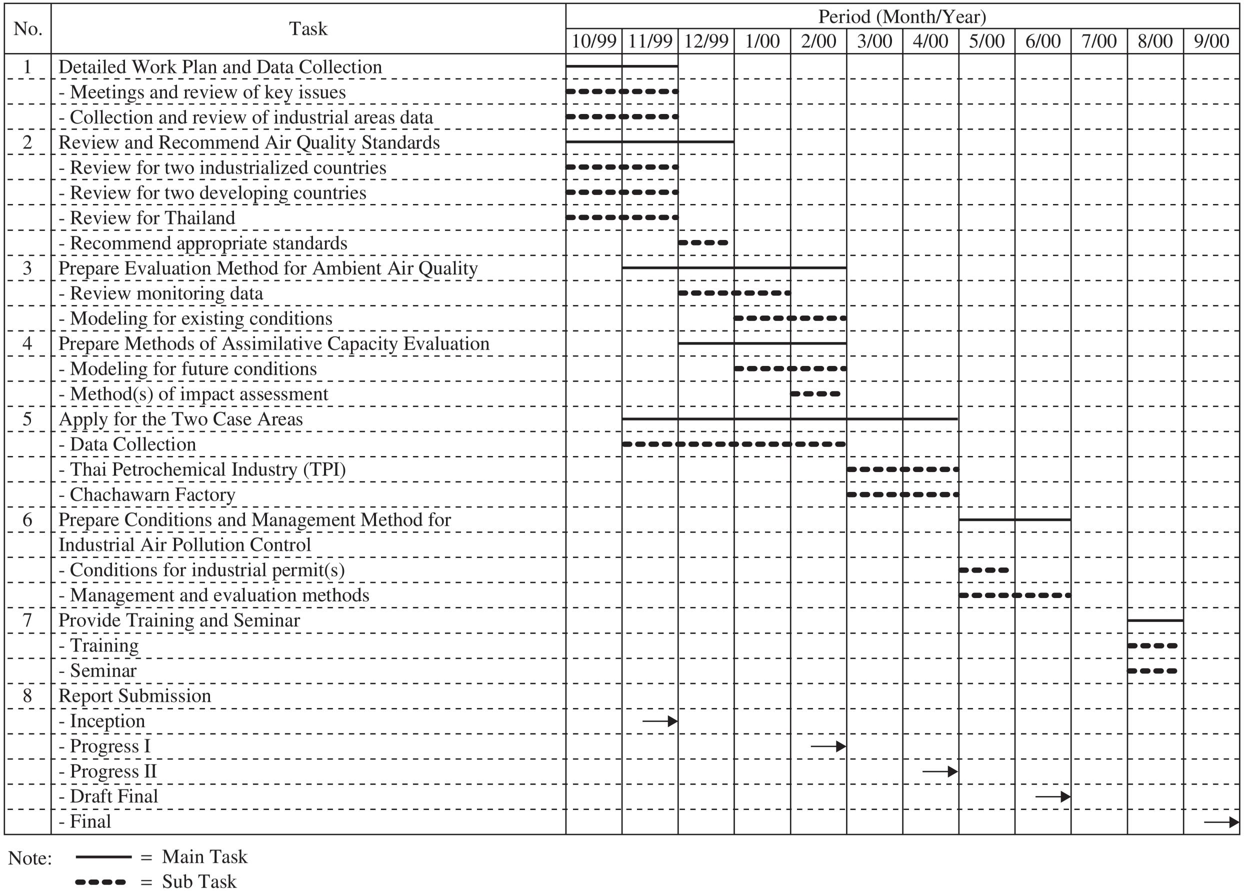


FIGURE 4.18 Work plan for study for controlling air pollution in zones receiving emissions from multiple industries.

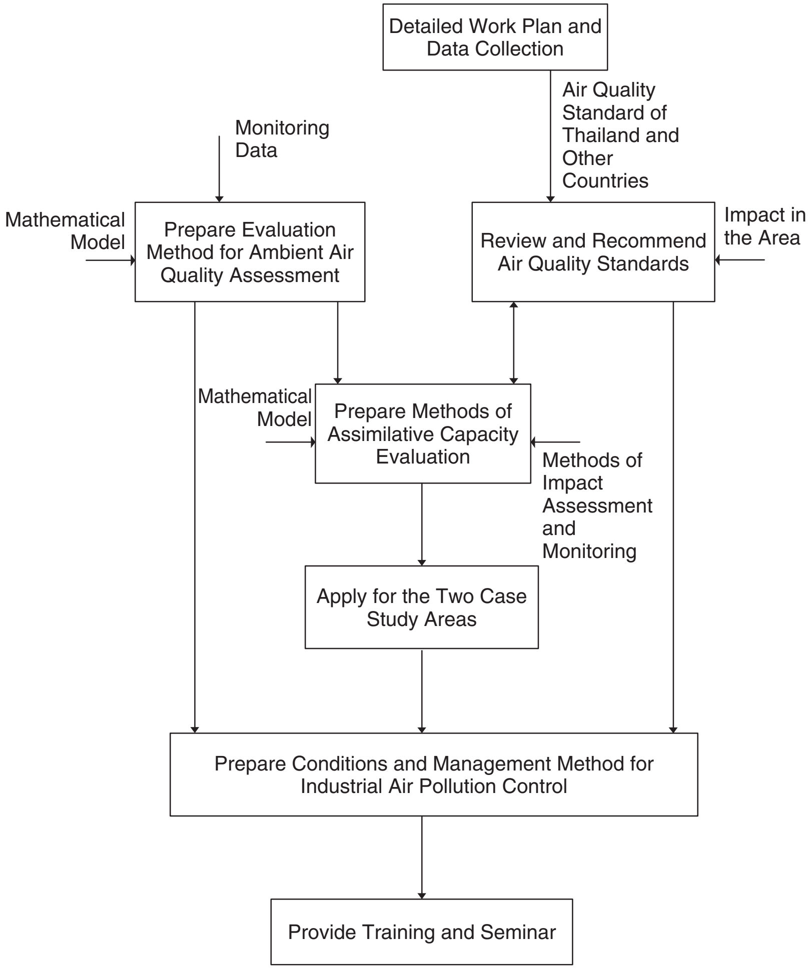


FIGURE 4.19 Assimilative capacity evaluation of air pollution.

Conclusions and Recommendations A mathematical modeling procedure is presented that enables determination of the reductions to be required for each industry operating in dense industrial zones where the ambient conditions exceed prescribed standards. The essential aspect of the recommended procedure is to require continuing competent monitoring of key parameters and reporting of the monitoring data, in sufficient frequency and detail as needed for proper modeling purposes

Air Pollution Control Experience in India

This summarizes information on a review of air pollution control experience in India reported in 2003[1].

Standards and Procedures for Industrial Air Pollution Control

- *Ambient air quality standards:* These standards for India are shown in Table 4.1. These differentiate between air quality requirements for industrial areas, residential areas, and "sensitive" areas. Sensitive areas are intended to include health resorts, national parks, bio-reserves, sanctuaries, declared archaeological monuments (e.g., Taj Mahal, Ajanta, Khajuraho) and other declared sensitive areas. However, industrial and residential areas are often mixed and overlapping, and because there are large differences between the limits for the two uses, this often creates a lot of confusion and controversy. Obviously in all such circumstances the more stringent value should prevail. To utilize relaxed requirements, strict land-use zoning would be necessary, which is hardly possible in most developing countries, including India. Also, due to lack of recording/monitoring instrumentation, regular frequent monitoring, and long-term data collection, annual average values are used, but these have only limited relevance. Pollution control based on 24-hour values seems to be easily complied with at almost all places for all pollutants, except for particulates.
- *Emission standards:* Prescribed emission limits for a few selected categories of industries are given in the report. The limits are essentially based on what is expected to be achieved by the best available/practical technology

TABLE 4.1 Ambient Air Quality Standards (National) In India

Pollutants	Time Weighted Average	Concentration in Ambient Air		
		Sensitive Areas	Industrial Areas	Residential Areas
1	2	3	4	5
Sulphur dioxide (SO_2)	Annual average[(a)]	15 mg/m^3 30 mg/m^3	20 mg/m^3 120 mg/m^3	60 mg/m^3 80 mg/m^3
Oxide of nitrogen as NO_2	24 hours[(b)]	15 mg/m^3 30 mg/m^3	80 mg/m^3 120 mg/m^3	15 mg/m^3 80 mg/m^3
Suspended particulate matter (SPM)	Annual[(a)] 24 hours[(b)]	70 mg/m^3 100 mg/m^3	360 mg/m^3 500 mg/m^3	140 mg/m^3 200 mg/m^3
Suspended particulate matter (SPM) size less than 10m	Annual[(a)] 24 hours[(b)]	50 mg/m^3 75 mg/m^3	120 mg/m^3 150 mg/m^3	60 mg/m^3 100 mg/m^3
Lead (Pb)	Annual[(a)] 24 hours[(b)]	0.50 mg/m^3 0.75 mg/m^3	1.0 mg/m^3 1.5 mg/m^3	0.75 mg/m^3 1.0 mg/m^3
Carbon monoxide (CO)				

[(a)]*Annual arithmetic mean of minimum of 104 measurements in a year taken twice a week 24 hours at uniform interval.
[(b)]24 hours/8 hourly values should be met 98 percent of the time in a year. However, 2 percent of the time, it may exceed but not on two consecutive days.

and not on any relationship to ambient air quality on assimilative capacity of the atmosphere. In the absence of recording instruments for emission monitoring, limits specifying pollutant loads per unit of production have little meaning. Concentration monitoring is on grab samples and is rather infrequent, and hence, enforcement is rather lax.

- *Assimilative capacity of atmosphere:* Prediction of expected increments in pollutant concentrations due to proposed major industries, using modeling dispersions of the likely emissions, has become an integrated part of EIAs and environmental clearances for the last 15 years. However, this does not appear to have contributed very much to air quality management due to doubtful meteorological data and models that have never been validated for local conditions. Modeling is done on a case-by-case basis, and in the absence of firm meteorological or background air quality data; there is unlimited scope to manipulate to get projects cleared. A few regional EIA studies (or what are called "carrying capacity" studies) have been carried out (e.g., for Doon Valley, National Capital Region at Delhi, and the Jamshedpur Region), but so far, these have not been used for planning or granting clearance for industrial units. Thus, assimilative capacity of the atmosphere is a new concept and the greatest difficulty in its use is the lack of appropriate meteorological data. The first competent effort in this field appears to be that underway at Patna in Bihar State since August 1999 by Envirotech Instruments Pvt. Ltd. of New Delhi, which is collecting primary meteorological data at the site (including wind and temperature profiles and mixing heights).
- *Pollution load trading:* This concept has so far not arrived in India, and each project is treated as an individual case. In the highly dusty and politicized Indian scenario, pollutant load trading may not be easy, even in years to come.

Evaluation of Performance It is wrong to say that there have been no significant improvements in the air quality scenario in India during the previous 10 years. The most noticeable improvements have been in the levels of SO_2 in urban areas, primarily due to a switch from using sulphur-free liquid petroleum gas instead of other locally available fossil fuels. A recent reduction in sulphur content of diesel (from around 1 percent to below 0.1 percent) is bound to further improve the situation. The introduction of lead-free gasoline and of catalytic converters on all new cars has drastically brought down concentrations of lead in ambient air of the metro cities. However, the levels of particulates have not abated, and concentrations of nitrogen oxides are rising. All these changes have essentially resulted from reductions in vehicular and other nonindustrial emissions under court directions. Although a lot of emission control systems have been installed and commissioned in industries, and industrial units and regulatory agencies claim large improvements in compliance of emission standards, it would be a rare case that reports even the slightest improvement in the ambient air quality due to the better management of industrial emissions. The situation in all such pockets suffering air quality deterioration due to industrial emissions, especially particulates, continues to be as bad as ever. Compliance with emission limits has been easier to manage in cases of large industries, especially multinational and/or private sector units. Much greater attention needs to be given to regulating the emissions from medium and small-scale units, which often cause much greater adverse impacts due to their location in or near densely populated or other sensitive and critical areas.

Lessons Learned from Indian Experience

- *Experience to date:* The Indian experience shows that people's support and pressure, either overt or at least covert, is necessary to obtain any level of significant success in pollution control. Shortcomings in enforcement mechanisms may render the efforts of regulatory agencies ineffective unless public concern and public activism enter into the picture to require improved regulatory action. Public agitations and public interest litigation can activate and energize even weak/corrupt/inefficient bureaucratic machinery. People's concern and interest are much more easily roused when impacts of the environmental pollution are easily seen, such as loss of crops, health damage, offensive odors or visibility loss, or risks to sensitive structures like the Taj Mahal. Subtle and distant impacts such as greenhouse effect or climate change are not readily perceived and do not attract public pressure without long and arduous mass-education and sensitization. Proper selection of siting and technology for new industrial units appears to be the most cost-effective method for industrial air pollution control, together with requirements for continuing self-monitoring. These requirements should be the responsibility of the government's industry control agency, as part of its permit system.
- *Future:* The government's environmental agency should reinforce the role of the industry agency by the effective use of the EIA process, which should spell out in detail the requirements for emissions control as already noted, including routine periodic monitoring to be done by the industry as a prerequisite for application for a permit from the industry agency. Also, the environmental agency should conduct its own periodic monitoring of industrial emissions as a check to ensure that the industry agency's requirements are being observed.

It should be noted that while affluent Western industrialized countries understand that effective regulatory monitoring with enforcement is essential for achieving successful performance by emitters, and do practice such monitoring/enforcement effectively, the authors (who have worked in more than 40 developing countries) do not know of any developing country where this has yet happened—no doubt because of the traditional "top-down" nature of the governments. However, the situation is gradually changing in most developing countries (like India and Thailand) due to the continuing efforts of dedicated working-level professionals who persistently push for establishing meaningful monitoring and enforcement. Meaningful monitoring/enforcement is expected to be introduced in many developing countries within the next few decades, and the lessons learned in India should be valuable in helping guide for such introduction.

HAZARDOUS WASTES MANAGEMENT

Background

Attention to management of hazardous wastes/substances in the DCs has been woefully lacking. The main problems have been (1) lack of adequate point source control at factories that produce these wastes, including both wastewaters and solid wastes, and (2) inadequate attention to this problem in the design of wastewaters management systems (insufficient attention to excluding intakes of these materials), (3) use of open dumps for solid waste disposal that accept delivery of anything and everything, and (4) inattention to management of hazardous substances that enter the country.

The first three problems are discussed in the sections on "Urban Sewage and Excreta Management" and "Urban Solid Waste Management." Especially serious is the common practice of accepting used batteries and electronic gear, which include plentiful amounts of toxic metals/substances that will be released sooner or later to contaminate groundwaters—for example, the use of such a landfill in Tonga located above the groundwater, which is the country's only freshwater source[48].

A typical example of the fourth problem is the experience in Thailand in the 1990s, when dangerous radioactive cobalt materials were found along public streets[21]. Investigation of this problem showed that the Thai government's agency responsible for keeping track of imports of radioactive materials had a very inadequate budget, with staff not sufficiently trained for their jobs.

The answer is that the IAAs who guide the DCs need to get a much better handle on this problem. Moreover, the attention must be "DC-oriented," not the publication and distribution to the DCs of manuals for control, which are essentially IC-oriented (as has often been the general practice of UNIDO). The manuals must suit the guidelines shown in Figure 4.2 of the section on "Introduction."

Guidelines Manual for DCs

An ADB project for strengthening EIA practice in Thailand[11] produced a series of guideline manuals, including one on management of hazardous wastes/substances[12]. Boxes 4.4 and 4.5 give the table of contents and the text for this manual, without its numerous annexes.

BOX 4.4 SUPPLEMENTAL EIA SECTOR MANUAL FOR HAZARDOUS WASTE MANAGEMENT PROJECTS (HWMPS)

Table of Contents

BOX 4.5 SUPPLEMENTAL EIA SECTOR MANUAL FOR HAZARDOUS WASTE MANAGEMENT PROJECTS (HWMPS)

1. Introduction

1.1 Purpose of Present Manual The purpose of the present manual of guidelines is to advise participants in the EIA process on the specific requirements for EIA for projects in the Hazardous Waste Management Sector. Figures 1.1-1 is a drawing showing the group of manuals utilized by DEIE, including (a) the Primary EIA Process Manual (and supplements to this), which applies to all types of projects, and (b) EIA Sector Manuals for particular categories or types of projects. The present document is the sector manual for Hazardous Waste Management Projects (HWMPs).

The EIA for HWMP projects is to comply with the requirements specified in the Primary Process Manual and in the present HWMPs sector manual. An EIA for a HWMP project must comply with the requirements of both manuals.

1.2 Types of HWMPs This manual classifies HWMPs in two categories, (i) LWs (Liquid wastes) and SWs (Solid wastes). HWMP/SWs are assumed to utilize landfills. Hospital wastes are covered in the Sector Manual for Large Buildings.

1.3 Toxic Wastes For purpose of the present manual, the term HWs includes toxic wastes which are in liquid or solid form.

1.4 Steps in Applying EIA Process The initial step for the EIA team is to carry put an IEE which will prepare the detailed TOR the follow-up EIA, including identification of Significant Environmental Issues (SEIs) and their prioritization, as specified in Chapter 2 of the Primary Manual. Following approval of the IEE, when a follow-up full-scale EIA is needed, the EIA team is to proceed to prepare the full-scale EIA report.

1.5 Reference Utilized Annex I list of references utilized in preparing the present manual. The primary reference utilized for LWs is Reference 1, "Preliminary Data Summary for the Hazardous Waste Treatment Industry," U.S. EPA, Sept. 1989, and Reference 2, "Requirements for Hazardous Waste

Landfill Design, Construction, and Closure." This information has been adapted to suit present conditions in Thailand.

1.6 Laws and Regulations Pertinent laws and regulations are discussed in Annex II.

2. IEE for HWMPs

2.1 Importance of IEE Any HWMP, if not properly designed and operated, can result in very significant adverse environmental impacts, even for very small projects employing only a few people. Hence, submittal of an IEE is required for all commercial HWMPs projects, regardless of size. Assuming full-scale will be needed, the IEE should include preparation of the Work Plan for the full-scale EIA including the tentative detailed Table of Contents for the final EIA report.

2.2 Basic Planning Requirements Basic guidelines for planning and conducting the IEE for a project are given in the Primary Manual. For HWMP/EIA, the SEIs will usually include the following:

(i) Delineation and quantification of wastes can be expected to be discharged from the project, both for (a) conditions assuming the project control plan is properly designed and operated, and (b) conditions in event of breakdown in operation of the control facilities.
(ii) Delineation and quantification of all beneficial uses of land/water/air in the project vicinity which could be affected by the plant discharges under conditions as noted in (i), and delineation of these in an appropriate Environmental Base Map.
(iii) Need for design of an effective control system with matching O&M skills.
(iv) Need for incorporating into the project provisions for ensuring delivery of HW inputs to the plant (no dumping elsewhere to avoid costs), and evaluation of affordability of charges to the interested customers.
(v) Preparation of an effective Environmental Management Plan (EMP) and Environmental Management Office (EMO) including implementation of competent monitoring, especially of the plant operations phase and for corrections of any inadequacies discovered by the monitoring.

3. Full-Scale EIA Tasks for HWMP/LWs

3.1 Project Description

3.1.1 General Description Annex III.1 gives information on the nature and scope of HWMP/LWs, which will be useful for preparing parts of Task 2.

3.1.2 Waste Characteristics and Treatment Annex III.2 gives background information on waste characterization and Annex III.3 on feasible methods for treating and disposing of the wastes. This will be useful for Task 2.2.

As noted in Annex III.3, the types of LHWs (liquid HWs) include three general categories, corresponding to ongoing practices in the U.S.

Recently a new approach has been under development at the University of Texas (Austin) for treatment and disposal of LHWs by "supercritical water oxidation" which sues very high temperature/pressures which break the HW substances down into harmless simple substances (Reference 6 and Annex III.5). It is anticipated that this type of treatment will come into commercial use within the next few years.

3.1.3 Project Alternatives Because of the "not in my backyard" feeling of most of public, it is important to present a convincing case for the proposed selected location, together with adequate attention to Public Participation (See Item 3.5).

3.2 Environmental Study Area (ESA) The ESA must be very carefully delineated and explained (See Comment 2.2/ii).

3.3 Environmental Impacts and EPMs Information from the Reference 1 and Reference 2 sources is summarized in Annex III and IV.

3.4 Environmental Monitoring Because of the sensitivity of all HWMP operations, preparation of the Environmental Monitoring programs is essential, especially for the Operations stage. This is to cover all items noted in Comment 2.2 and Annex III.4.

3.5 Public Participation Because of the "not in my backyard" feeling of many people, they will tend to oppose any waste treatment/ disposal facility to be located in their neighborhood, no matter how well it may be planned, because of apprehensions that the system will not be properly designed/operated/monitored. For this reason a public participation program, including provision of amenities, will usually be very important, to convince the localities that they will be properly protected. T his may include provisions for allowing local representatives to participate in the project planning and especially in the continuing project monitoring, with agreement that the system will be shutdown if not giving satisfactory performance. This approach has been very successfully utilized for example, by the Los Angeles County Sanitation Districts in gaining neighborhood acceptance of proposals for new waste landfilling operations. For further details please refer to DEIE's Supplemental Process Manual on Public Participation.

Reference 8 is an example of such public concern for a proposed HWMP in Thailand.

3.6 Compliance with Environmental Laws The pertinent laws and regulations are discussed in Annex II.

4. Full-Scale EIA Tasks for HWMP/SWs

4.1 Introduction Sections 3.1.1, 3.1.3, 3.2, 3.4, 3.5, and 3.6 for LWs also apply to SW systems.

4.2 Use of Reference 2 As already noted, reference 2 from U.S. EPA, "Requirements for Hazardous Waste Landfill Design, Construction, and Closure," which is available in the DEIE Library. This presents the basic information for planning and monitoring HWMP/SW systems. Included here in Annex IV is the Table of Contents of Reference 2 and section 1 which summarizes the salient findings of this publication.

Information of Task 4 (SEIs and treatment methodology) is given in Annex IV section 2 to 9, including closure systems and provision for emergency response in event of spills/failures. Information on monitoring is given in Annex IV, sections 4, 6, 7, 9, 10.

4.3 Special Situation on Clays in BMR In the BMR, much of the area is covered with very thick layers of very tight impermeable clay layers of thickness of 100 meters or more, and the usable groundwater resources are below this layer. Where this is the case, this greatly simplifies the design of landfill systems both for solid wastes (including solid hazardous wastes), especially use of liners. Linear technology has been developed primarily in the United States where the soils are permeable and where leakage from the fill can contaminate valuable groundwater. In BMR (and similar coastal areas of Thailand) the clay layers are often impermeable so that leachate hazards are minimized, and if sufficiently impermeable the liners may not be needed. This potential in BMR is reviewed in Reference 10.

5. Summary and Conclusions

The technology on management of HWs as its won specialty is relatively new, beginning essentially in the 1980s as part of U.S. EPA's focusing on this issue including its Superfund program. The technology is still evolving and it is estimated that about another decade will be required before this specialized field becomes conventional and standardized.

Annex I: References

1. "Preliminary Data Summary of Hazardous Waste Treatment Industry," Document EIA-440/1-89/100, U.S. EPA, Sept. 1989.
2. "Requirements for Hazardous Waste Landfill Design, Construction, and Closure," Publication EPA/625/4-89/622, U.S. EPA, Cincinnati, Ohio, 1989.

3. "Manual for Preventing Spills of Hazardous Substances at Fixed Facilities," Document EPA/600/52-87/068, U.S. EPA, Feb. 1988.
4. "Quality Assurance for Hazardous Waste Projects," N. Shashidhara Civil Engineering (ASCE), Dec. 1994.
5. "Redefining Hazardous Waste," P. Puglionesi, Environmental Engineer (American Academy of Environmental Engineers), 1996.
6. "Integrated Approaches to Management of Toxic Chemicals and Hazardous Waste," J. Hay and N. Thom, University of Auckland, New Zealand, 1996.
7. "Supercritical Water Oxidation and Related Processes." Consulting Engineering Studies, University of Texas (Austin), 1996 (Annex III.5).
8. "Traffic Disrupts As Villagers Protect Plant," Nation Newspaper, Oct. 1996.
9. "Laws and Standards on Pollution Control in Thailand, 3rd Edition," PCD, Sept. 1994.
10. Techniques for Assessing Industrial Hazards," by Technica for World Bank, 1990.

MEGACITIES: RURAL TO URBAN MIGRATION

Background

One of the major development of the past several decades is the accelerating migration from the rural areas to urban cities (and even to urban cities in other countries), due to realization by rural farmers for the first time in history, resulting from the new IT technologies, that the cities offer opportunities for a better quality of life[9,25,29,124]. In 1950 two-thirds of the world's population lived in rural areas, but by 2030 an estimated two-thirds will be urbanites. From 1975 to 2015, the number of world megacities (over 10 million people) will have grown from 5 to an estimated 26, all but 4 in the DCs, which are the least prepared to provide the essential services of transportation, housing, water supply, sewerage, and drainage systems. This corresponds to the equivalent of a new Bangkok every 2 months. And everybody agrees that this migration in unstoppable, and there is no precedent in history for this phenomenon.

Economic Policies for Sustainable Development (ADB)

Primary Study The UN/Brundtland report of 1987 emphasized the need for studying the mass immigration phenomenon in order to gain information fro guiding Asian DCs on how to proceed to get better prepared for accepting the massive immigration. In response to this the ADB, together with financial assistance from the Scandinavian countries, carried out a major in-depth evaluation in seven selected Asian DCs (Indonesia, Malaysia, Nepal, Pakistan, Philippines, Sri Lanka, and South Korea), completed in 1990[7]. The findings of the study, with respect to need in megacities for environmental infrastructure, are evaluated in a follow-up paper[111] presented at a WEF-sponsored seminar at Singapore in 1993.

Existing Situation in the DCs

Infrastructure In all six DCs (excluding South Korea as a semi-industrialized country), the existing urban infrastructure and housing are severely overtaxed, and this will get progressively worse unless, somehow, a marked increase in investment funding can be realized. Even South Korea is suffering from similar problems. The primary sector problems are as follows:

- *Water supply:* Quantity of supply is usually "Acceptable," but generally the water as delivered to house taps is not safe, and generally there are very high unaccounted-for water losses. Also, major cities like Jakarta, Surabaya, and Manila (and Bangkok) are having increasing difficulty in obtaining raw water supplies sufficient to keep up with increasing urban/industrial growth due to the lack of coordinated river basin planning and control needed to achieve a proper balance in water use, and especially to reduce large wastages in traditional irrigation practices.
- *Sewerage and excreta management:* Service generally is not bad in affluent urban areas in the six DCs, either by sewers or by on-site subsurface disposal; but the excreta in nonaffluent areas including slums, except for some urban areas in Indonesia, is more or less uncontrollable, resulting in very serious enteric communicable disease hazards. South Korea, following the Japanese pattern, is proceeding to provide sewers to all urban areas (South Korea now has the affluence to afford this).
- *Sewage treatment for water pollution control:* There has been little if any meaningful investment in most urban cities in the six DCs, except for Malaysia, where municipal sewerage practices introduced by the British are still followed to a limited extent, no doubt because of the relatively favorable position of Malaysia municipalities with respect to local financing. The resulting massive river and coastal water pollution in most DC urban areas, and of course uncontrolled industrial wastes, intensify this problem. South Korea, with its new affluence, is just now embarking on a massive national sewage treatment program covering 100 major cities.
- *Flooding and drainage:* This is a serious problem in all six DCs in the poor people areas, which are generally located at the lowest elevations. It has not received much attention precisely because it is the poor people who are suffering. This problem is increasingly intensified by the development of more infrastructure (like highways), which results in increasing flood runoff into the low areas, without regard by the planners for this impact.

- *Solid wastes:* In most of the DCs the problem is already very serious, with adequate collection services generally limited to affluent areas, and lesser and quite unsatisfactory collection services elsewhere, and generally with disposal from all areas by dumping, resulting in plenty of land and water pollution. It also poses serious public health hazards, since municipal garbage is almost as replete with pathogens as is municipal sewage. In Malaysia, disposal previously had been managed fairly well using landfilling by individual cities, but in heavily urbanizing and industrializing regions like the Klang Valley, no more land is available for individual city use because of prohibitive haul distances, and hence the need is for regional solid waste management systems.
- *Slum improvements:* Of the six DCs, only Indonesia has given meaningful attention to this problem through its "KIP" (Kampung Improvement Program) for upgrading the slum area infrastructure (leaving the homes alone), which has been remarkably successful[155]. This is a massive problem in the other five DCs, except in Nepal where it is expected to develop soon, and in three of them (Malaysia, Pakistan Philippines) the governments continue to insist that the slum inhabitants (mostly illegal squatters) do not belong there, and hence can be neglected despite the huge hazard to public health thus imposed on the entire community. Attempts to solve the problem by use of public housing in the city and by relocation to condominiums out in the country have failed due to the high expense, and due to the relative scarcity of jobs in the country. The Indonesian KIP program represents an innovative practicable solution. It is slum infrastructure upgrading, including legalization of squatters. One of the innovative findings of the Indonesian KIP experience is that on-site leaching pits for excreta disposal, considered by most as not suited for concentrated urban areas because of failure of some of the units (posing health hazards to all), can be made to give overall acceptable service simply by furnishing special subsidized desludging service for the poorly functioning units, which are usually a small percentage of the total. Another interesting finding is that, where piped water service is not feasible, many slum homes utilize shallow tube wells for domestic water supply, and while this water is invariably polluted, the people diligently boil all water before drinking. This boiling practice is used even in affluent areas of Jakarta, where the main municipal water treatment plant has never been operated "as designed" and routinely produces unsafe water.

Institutional Aspects

- *Laws and regulations:* There are ample laws, but they are generally uncoordinated and overlapping in all seven countries, and in the six DCs there is little meaningful enforcement. The study of the Klang Valley region in Malaysia, where the capital of Kuala Lumpur is located, indicated about 20 to 30 percent enforcement, and Malaysia is relatively quite advanced in enforcement compared to the other DCs. The need is for each country to prepare a consolidated law with clear delineation of responsibilities, which is enforceable, and to enforce it.

- *Central versus municipal government roles:* In practically all of the DCs to some extent, the central government agencies have practically all the authority, expertise, and control of funds (limited as they are); while the municipal governments are assigned the bulk of the responsibilities but have very little authority, expertise, and funds.
- *Status of national policies, strategies and planning:* In all six DCs there is negligible or little attention to formulating or implementing a coordinated policy/strategy/planning so that the limited funds available for municipal infrastructure can be wisely used. The pattern continues to be a piecemeal process, with each implementing agency operating as its own "fiefdom." There is little if any attention in most of the DCs to formulating appropriate standards of minimum acceptable infrastructure/services to serve as the basis for optimal cost effectiveness for future investment, and many projects continue to incorporate Western practices, which are often inappropriate for DC use. South Korea is now planning to implement a massive national sewerage program.
- *Better use of informal and private sectors:* The findings here are that (1) the informal sector can create jobs at greatly reduce investment capital per job created, hence attention should be give to planned and systematic use of this potential, and (2) the private sector potentials need to be utilized in a systematic way to assist not only in financing but in furnishing skills that the government sector can hardly do because of salary constraints, such as for operating and maintaining water supply and sewerage systems.
- *Dearth of planning:* There is a great dearth of meaningful national/subnational planning on needs for E-c-E infrastructure services in all the DCs, which is essential for guiding continuing investment and to get away from the syndrome of uncoordinated piecemeal investments (often with inappropriate components). A carefully thought-through strategy/plan is needed so that the limited funds can get optima1 returns, with decent attention to the urban poor, including use of appropriate design technologies to reduce ineffectiveness and to reduce needs for sophisticated O&M skills. This is an overriding highest priority need in all the DCs.
- *IAA involvement:* All of the poor DCs stress the need for increased assistance from the IAAs, both for funding and for expert guidance on planning and on appropriate use of the EIA process.

Urban Growth Management/Action Strategy

National Strategy The critical need in all six DCs is to prepare a national industrial expansion plan, based on E-c-E principles, to furnish the needed employment in the urban sector, including selective use of the subnational E-c-E planning process that can produce detailed guidelines on how to meet minimal infrastructure requirements in the most cost-effective manner for accommodating continuing urban/industrial development. This would include (1) establishing a reliable matching economic/environmental database, (2) establishing appropriate standards for urban infrastructure, with attention to the urban poor and urban slums (poorest of the poor) as well as the urban affluent, for guiding development of matching infrastructure design technologies, (3) fair distribution of total infrastructure investment funds, both within the individual urban areas and between the capital region and other urban areas, and (4) clear delineation of urbanizing/industrializing areas versus rural areas. Some beginning efforts in this direction have been made in South Korea and the partially industrialized DCs.

Local Municipal Planning The critical need everywhere is to replace the conventional discoordinated piecemeal approach, carried out by essentially independent local government "fiefdoms," with integrated planning that achieves optimal cost-effective progress within the constraint of limited funds, including use of appropriate standards/technologies and including fair distribution of benefits between urban affluent/urban poor/urban slum areas, and including effective use of the EIA and subcountry E-c-E planning processes.

River Basin Planning In the partially industrialized DCs (as well as South Korea), it is becoming recognized that sooner or later, it will be necessary to establish River Basin Authorities to solve the increasingly severe problem of managing the water resources in a river basin, so this limited resource can be optimally used with minimum wastage to meet all development needs (rural and urban). Although worldwide experience in the ICs has shown this to be the only practicable solution, it is never easy to make the change because of conflict with established government authorities. However, it must be done, and both the national governments and the IAAs should give persistent effort to achieve this in basins where the problem is acute. From the urban development point of view, the problem is becoming more and more serious in that the capital and other major cities are usually coastal cities with their surface water river supplies being "dried up" by upstream irrigation development using excessive amounts of water.

Decentralization/Taxation In virtually all DCs, the message is clear that the only feasible solution to the problem of obtaining the needed additional funding for urban infrastructure must come from municipal property taxes and service charges, and moreover, that the taxing power must be decentralized so that the municipalities will not only have responsibility for municipal infrastructure but will also have the authority/funds resources to manage this. This would encourage local authorities to give attention to problems of environmental degradation through effective use of EIA and Regional E-c-E planning as valuable planning tools. Also, the IAAs need to contribute their influences for helping to achieve this transition.

Slum/Squatter Areas As already noted, in all the seven countries these areas must be given a fair share of the total municipal infrastructural/services investment, and in addition the planning of all municipal infrastructure/services projects must be reoriented, through use of EIA process, so that these projects give due attention to poor people problems. Virtually all conventional (Western) infrastructure/service design criteria, which were developed for use in essentially urban affluent areas, are not applicable to DCs in that the resulting projects almost invariably advantage the affluent and disadvantage the poor (for example, urban highways invariably create serious poor people severance problems that are only partially offset, and they compound poor people/low area drainage problems with no offsetting).

There is increasing recognition by most DCs that the only practical solution to the squatter areas (instead of doing away with them because they are "illegal") is by upgrading the slum community infrastructure/services and letting the individual householder attend to his housing, which is a far cheaper solution than public housing or relocation to remote condominiums. Indonesia has made impressive progress in this, and South Korea, Pakistan, and Sri Lanka are beginning to believe it. The trend is certainly in this direction.

Better Use of Informal and Private Sectors There is increasing recognition in the DCs of the need to make much more effective use of the informal sector for helping to create jobs (at relatively very low capital investment cost per job), of the private sector for helping solve infrastructure/services problems, not only through financing taking on O&M assignments which can hardly be handled by government agencies because of low salaries, and of NGOs for aiding/abetting the government agencies to get action on urgent critical problems.

Economic Instruments As already noted, while NEcPAs have tended to ignore environmental degradation in the past (i.e., to give it only a kind of add-on-attention), there is beginning recognition in all DCs that deregulation alone can hardly be expected to solve problems of environmental degradation. Rather, the need is for optimal use of reoriented economic policies. This includes adjustments not only in investment policy but in virtually all economic policies involved in DC development, including trade policies, energy policies, access to resource policies, and so on. There is urgent need, also, for preparation of a new "Manual of Appropriate Economic Analysis for DC Project Development," for use both by DCs and IAAs to ensure due consideration of the sustainable/E-c-E approach in future project planning.

Effective Control of Environmental Degradation

The NEcPAs must give No. 1 priority to seeing to it that E-c-E principles become an integral part of all governmental operations, including its own operations, including giving guidance/support to the NEnPA and NEcPA to enable them to develop and work effectively, including establishment of meaningful environmental units in the planning divisions of the major governmental implementing agencies, including insistence on appropriate use of the EIA to be an integral project feasibility planning, and selected use of the subcountry E-c-E planning process. Without strong NEcPA support, the NEnPA cannot be successful.

Strengthen the NEnPA (at least in its components relating to urban development, looking at this from the urban point of view) so that the NEnPA capabilities/resources are sufficient to do a meaningful job, which has not been yet the case in any of the seven countries. In the poorer DCs, the situation is pathetic, but some meaningful progress is now being made in Indonesia, which is now launching an innovative large-scale program including establishing of an "NEnPA affiliate" for proceeding with local action on such issues as industrial pollution control and pollution cleanup in river basins experiencing heavy growth. In Thailand, a similar approach is envisioned under a new environmental law, by delegating environmental responsibilities to the provincial governors, together with resources to enable them to act.

In general, the budget resources available to the NEnPAs are very low compared to the situation in the United States (and extremely low in the poorer DCs); hence, a critical study is needed for developing guidelines on minimum "bottom 1ine" budget/staffing levels appropriate for DCs. This does not suggest matching U.S. levels, but certainly more than one percent or a few percentages of U.S. levels.

Follow-up Evaluation of ADB Study

Purpose of Study The report on "Economic Policies for Sustainable Development," published by the Asian Development Bank in September 1990, was based on detailed case studies of national development problems in seven selected Asian countries, namely Indonesia, Malaysia, Philippines, Pakistan, Sri Lanka, Nepal, and South Korea. The country reports considered the present and projected future conditions involved in continuing economic development of the countries, considering all environmental sectors, especially as related to the problem of relentless population growth and accelerating rural to urban migration. A follow-up study was carried out by the ADB in 1993[111] to make an analysis of the detailed information in the country reports with respect to the mushrooming needs for urban infrastructure and services. This appears to be perhaps the paramount environmental problem to be faced up to by the DCs over the next several decades.

Methodology Based on preliminary review of the country reports, a "standard format" (four pages) was prepared that lists the various items discussed in the reports in a systematic manner, as related to urban environmental development. The main items of this listing (each of which has a number of sublistings) are the following:

Urban Growth Management Existing Situation
- Urban population growth
- Employment and incomes
- Poverty and slums

Infrastructure/housing facilities
Infrastructure/institutional aspects
Extent of environmental degradation (ED)
Control of environmental degradation
Urban Growth Management Proposed Action Strategy
Planning
Decentralization
Greater policy focus on poor people
Better use of nongovernmental sectors
Financing
Establish meaningful EPC in near future
Industrial Growth Management Existing Situation
Background
Economic aspects affecting ED
Adverse environmental effects
Adequacy of waste management
Planning needs
Industrial Growth Management/Proposed Environmental Action Strategy
Planning
Economic policies reorientation
Establishing effective regulatory control of pollution

Results of Study The detailed study findings are summarized in a series of matrices, including each of the items just listed, each with various subheadings, and a judgment evaluation for each of the seven countries the seriousness of the problem.

Conclusions The inevitable acceleration of urbanization and industrialization in the DCs poses unprecedented problems to the DC governments, not only in nature but in magnitude, and the No. 1 task facing the governments is to change their economic development behavioral patterns, and to do this promptly, in order (1) to create the needed jobs to support the massive population influx, (2) to furnish urban the infrastructure/housing to accommodate the growth needs, including obtaining a much higher level of financing for this purpose by use of taxation and service charges and including innovative use of planning so that the available funds can be wisely invested in an integrated urban development approach, including decentralization of authority/resources for urban infrastructure/housing problems to the municipal level where it belongs, and (3) to accomplish this in an E-c-E manner that reduces urban environmental degradation problems to acceptable levels.

To accomplish this, a huge increase in technical assistance investment is needed for developing the needed appropriate technology for guiding future planning and project implementation. For example, it is clear that manuals of appropriate technology are urgently needed, as follows:

- For setting appropriate minimum acceptable standards for urban infrastructure/services, for all categories of developments, with "equal attention" to affluent, poor, and poorest municipal areas
- For design of urban infrastructure systems (including water supply and waste management) that are appropriate (which give acceptable levels of service at affordable cost), with special attention to ensuring adequate O&M, for all categories of development
- For conducting EIAs, including follow-up monitoring for all categories of urban/industrial projects, in sufficient detail to facilitate wide-scale use and application of the EIA process (similar to engineering design handbooks)
- For planning and conducting appropriate environmental monitoring programs, including all aspects of community environment including quality-of-life and socioeconomic aspects, including institutional and financing aspects, including periodic evaluation of the monitoring data for use in planning needed improvements, and including establishment of an appropriate national environmental database adequate for assessing environmental quality in quantified terms suitable for use by both environmentalists and economists

Essay on Urban Population Growth in DCs

The rural to urban influx is increasing not only because of the economic pressure but also because of the impact of modern communications (especially TV, the internet, and cell phone) in alerting the rural people to realize that life in the urban sector, even if one has no job, will generally be much better than in the rural in terms of both earnings and quality of life. A World Bank officer who worked in Calcutta (India) in the 1960s remarked that the homeless people who slept on the streets (a million at least) were actually "bankable" people. By doing odd jobs, their income was much higher than their rural cousins, and the sidewalk-urbanites were sending appreciable monies to their rural relatives every month.

The term *quality life* reminds me of the author's work in the Belgian Congo (now the Congo Republic) in the 1950s, to assist the Congo's chief engineer and deputy governor general, on urban sanitary engineering planning. He noted one day that the black natives who made up most of the population of the capital (then Leopoldville, now Kinshasa) had immigrated to the city from the "bush" (the rural areas), attracted by the urban employment opportunities, and that to his knowledge, not a single one had since returned to the bush. Once the native tasted the "Wine, Women, and Song" readily available in the urban sector (and almost nonexistent in the bush), nobody ever left. Later on, working with a Belgian who was chief engineer for Katanga Province, a visit was made to the province's maximum-security prison (for hardened criminals) to observe pipe manufacturing with prison labor. The prison guards were mostly asleep, and the chief engineer noted that nobody ever tried to escape because life in prison was far better than in the bush. Nowadays, the rural peasant almost everywhere can see on TV that his urban cousin is enjoying a much higher quality of life, and the ruralite often abandons the farm (even if his situation there is viable) to head for the city.

One illustration of this situation is experience in East Java in Indonesia on a World Bank irrigation project in the 1980s[152], namely, a Sunday tour to talk to typical farmers. It was found that while most farmers worked essentially to grow rice, a few had invested in chicken raising to produce eggs to sell to the provincial capital market at Surabaya and thus realize some cash income all year round. Only a few had the investment resources to do this. One of these explained, when asked if he/his family ever ate any of the eggs, that the eggs were much too expensive for them to consume, but his two younger brothers, who had been forced off the farm to become urbanites (typical family of three sons, but only enough land for one), and who had become taxi drivers, yes, they often ate eggs.

Another final illustration of the rural to urban scenario is a TV cartoon movie, which features a young coyote ("YC") who lives in the uninhabited open bush areas of eastern Riverside Country in Southern California (one drives through this region in going from Los Angeles to Las Vegas). He's happy there, including working at hunting 10 to 12 hours per day (mostly chasing rabbits) to get enough to eat. It's all he knows. One day, while chasing a rabbit in the northern part of his hunting territory, which borders on the highway, it happened that a big truck/van stopped there, and the driver opened the back to take out a package for delivery to a local gas station, leaving the door open. The rabbit ran in, the YC after him, and the driver returned, closed the door, and took off. When the truck stopped and the door was opened, the YC got out and found himself in the foothills residential area of Hollywood/Beverly Hills (populated mainly by very wealthy people). He promptly ran up into the mountainous hills that overlook the L.A. basin, where he soon found a pack of coyotes who took him in. These guys were living in the lap of luxury. They spent less than an hour per day having a banquet, in the early morning, by feeding on a deluxe variety of delicious foods contained in the house garbage cans that they overturned. Instead of eating only rabbits all the time, and not very much of that, he enjoyed choices of beef, pork, veal, whatnot, even rabbit, plus all sorts of desserts. Our YC soon became sleek (no longer skinny) and with his ample time soon found a girlfriend and had endless recreational fun with her, howling together especially in the evenings. It was too good to be true, for long. The women organizations of Los Angeles County, who believed that the "Hollywood Way of Life" was not good for the coyotes and that they should be caught and returned to wilderness areas, forced the county to set up a governmental unit to do this. Yes, our YC got caught, and it happened he was returned to the very place where he had come from. At first, he was very glad to be "home," to see his friends again; however, after a few weeks of all work and no recreation, the story ends when the YC stations himself near the highway, waiting for another truck to stop and leave the rear open. It happens; the YC runs in, the driver returns, closes the door, and drives off.

URBAN SLUMS

Background

As noted in the section on “Megacities,” a massive immigration of rural farmers to urban cities has been underway for several decades, which is “unstoppable,” and the existing cities being enlarged have been able to furnish the infrastructure and housing sufficient to accommodate only part of the immigrants, leading to formation of large slum areas with very inadequate housing and community facilities including environmental infrastructure/facilities (water supply, excreta management, solid waste management, drainage, roads/access lanes). This section on Urban Slums describes the experience and findings of two major slum management studies/projects, one in Indonesia and the other in Malaysia.

Indonesia Kampung Improvement Projects (KIPs)

New Approach to Slum Management In the 1990s, the governor of Jakarta “invented” a new approach to handling the urban slum problem in which abandoned than the conventional approach of tearing down slum housing and moving the families to new housing outside the city, which hardly solved the problem because of lack of employment in the new housing areas, requiring the workers to travel back to the city to be employed, through wasting both time and travel costs. In the new approach the city furnished these facilities to the slum areas with the expectation (which did happen) that the families would then upgrade their homes to match their new environmental situation. An evaluation of this in 1976 for a WHO sponsored project for planning a metropolitan sewerage system for Jakarta, showed that the governor’s project, to be really effective, needed improvements, and these were subsequently planned and implemented with World Bank support[43]. The success of this effort led to expansion of the “KIP” (kampung improvement program) approach to many other cities throughout Indonesia.

The sanitation facilities furnished in this program[154] included provisions for (1) piped water supply including delivery to homes that could afford individual house connection changes, with public taps (operated by a paid tap manager) for other users, (2) use of pour-flush toilets with excreta disposal using dual leaching pits, (3) periodic pickup of refuse, (4) pathways for enabling access to homes above flood levels, (5) adequate drainage (with the KIP dwellers themselves furnishing the labor to keep the drains clean and functioning), and (6) public centers with toilets, washing facilities, and bathing facilities, including payment by users at low charge levels.

The dual pit leaching system for disposal recognized the need for (1) two pits so that one would be in use while the other was being desludged, (2) a special desludging unit of the municipal government for desludging service to the homes designed to work effectively in narrow access[154].

A very important aspect of the KIP program was recognition that, while many if not most of the slum residents were squatters who had come to the cities "illegally," hence previously not considered eligible for assistance, but in fact these people were citizens who were there to stay hence deserving of assistance.

Quantification of Impacts of Jakarta KIP A paper prepared for presentation at a UNEP conference on slum management at Bangkok in 1976[43] evaluated the information derived from the KIP projects in Indonesia cities with the objective of quantifying the actual impact of the water supply and sanitation improvements furnished by the KIP projects. The Jakarta KIP in 1969 to 1972 covered 88 villages with 2 million people. Some key findings are the following:

1. *Definition of KIP sanitation component:* This was defined as including the following components:

   Water supply: Facilities for making water of acceptable (good and safe) quality and of sufficient quantity available to village residents.

   Public hygiene: Facilities for enhancing use of this water for promotion of community sanitation, especially toilets, plus washing and bathing facilities, usually in the form of "MCK's" (public hygiene stations located at strategic points in the village), available at low rates (costs partially subsidized by government).

   Excreta management: Sanitary sewerage system when affordable. For homes not connected to sewers, use of pour-flush toilets with dual leaching pits, with availability of a community pit desludging service with affordable service rates.

   Surface drainage: Provision of minimum surface drains to maintain a reasonably dry community environment most of the time.

   Access ways: These are pathways high enough to enable villagers to reach their homes form the roads in the rainy season without traveling in water.

   Solid wastes: Minimum facilities for collection, hauling, storage, and disposal of solid wastes.

2. *Water supply* The basic problem is the cost for individual homes to afford individual house connections. One solution is to permit on several houses to be served together as a single unit (up to 10 houses), with a single meter and single connection fee, and moreover to permit this fee to be paid in easy monthly installments rather than requiring payment in advance. It is estimated this reduces the average per house cost for installing connections to houses by about 50 percent. Where public taps are used, the key problem is to ensure it is properly operated/maintained. The usual solution is to assign management rights to the individual homeowner who allows a portion of his land to be used for the tap, with authority to charge for the water at established rates.

Expansion of KIP Program to Cover Entire Country The success of the initial Jakarta project, including the World Bank sponsored improvements to the original Jakarta KIP implemented by Jakarta on its own, resulted in subsequent expansion of the program to include many major secondary cities throughout the country.

A significant "political" problem occurred at Jakarta where some of the tap franchise holders built water storage tanks plus pumping to enable them to "suck up" the water supply in the surrounding distribution system (their authority legally permitted them to serve only a fixed number of families); thus, enabling them to go into business on their own, due to the lack of adequate governmental controls, stemming mostly from the diverse ethnic groups in the city. No such problem occurred with the KIP project at Surabaya where the city has no ethic divisions and the city government did establish effective controls.

Urban Slum Sanitation Planning Manual The Jakarta KIP experience led to a project for preparing a World Bank design manual on how to plan/design KIP facilities including provisions for management, financing, and O&M[154]. This manual is one of the Bank's "Kalbermattan" series of manuals on Low Cost Sanitation Manuals for use by DCs prepared in the 1980s. Home sewage disposal utilizes pour-flush toilets with dual leaching pits, with special desludging service operated by the municipal government, which is equipped with special trucks, and pumping to gain access to homes located on narrow lanes.

Klang Valley Environmental Improvement Project (KVEIP) An ADB sponsored project, the "Klang Valley Environmental Improvement Project" (KVEIP) completed in 1987[5], prepared a master plan for recommended environmental improvement in the Klang Valley region of Malaysia, which includes the capital (Kuala Lumpur) and many other cities and is the major industrial region in the country. And, of course, this region had been a "magnet" for attracting immigration from rural areas, resulting in formation of large-scale slum areas in the region. One of the components of the overall environmental planning was the task on what to do about these slum areas, mostly inhabited by "illegal" people who entered the region without government permit to change their place of residence. Hence, they were legally classified as "squatters" without any obligation by the government to provide for them.

Because of their legal policy, the government established a governmental unit, equipped with bulldozers, with the job of destroying the squatter homes. At the time, the costs of housing had increased to levels no longer affordable even to some nonsquatter people, and some of these moved to live in the illegal but cheap slum housing, including the chief of the slum bulldozing operations. Discussions with him showed that the home destruction approach was not working because the squatters promptly rebuilt the homes within a period of days.

The problems of the slum areas were very similar to those of the kampungs in Indonesia. Based on the success of the Indonesia KIP experience, the KVEIP study prepared a recommended project following the same KIP approach, including provision of a project for upgrading the community service facilities in these slum areas following the KIP guidelines. This included an economic analysis that showed that if these areas were upgraded as proposed, the value of the land in the surrounding neighborhood would be increased more than enough to offset the cost of the slum improvements. However, while ADB welcomed this proposal, Malaysia's Economic Planning Unit (EPU) (the NEcPA of Malaysia), which was in top-level charge of the KVEIP project, vetoed the proposal in apprehension that this would further increase the illegal immigration problem.

URBAN SANITATION

Although many aspects of urban sanitation are discussed in other sections of this chapter, some additional information on selected subjects is provided here.

Ports and Harbors

A common problem in DCs is that design of ports and harbors generally pays little attention to furnishing adequate provisions for sanitation/water pollution control. Guidelines for helping resolve this problem were prepared for use in Thailand in 1980[50].

One of the findings of the major programs in water pollution control in the industrialized countries over the past two decades is that ports/harbors, as conventionally designed, built, and operated, tend to become "sanitation messes," with much lower sanitation levels than the rest of the urbanizing zone in which the port/harbor is located. It was found that this occurred because sanitation facilities in port/harbor areas had been planned the same as for urbanizing areas in general, without recognizing that special provisions must be made in the design of the port/harbor complex if acceptable sanitation conditions are to be maintained. In addition, it was found that it is relatively inexpensive to solve this problem for new ports/harbors if appropriate special sanitation measures are incorporated into the system from the outset, and that if this not done, it will be very expensive (and perhaps unaffordable) to correct the situation later.

The evaluations made of actual sanitation mess situations in the United States and elsewhere have shown that the following measures must be incorporated into the planning/design of the port/harbor complex in both ICs and DCs if it is expected to be able to maintain an acceptable level of sanitation in the port/harbor area, including consideration both of shipping and of shore installations:

1. Provision of an adequate water supply distribution system recognizing the extraordinary water supply demands in port/harbour complexes (usually considerably higher than for other urban zones), including pier installations for hose connections for furnishing fresh water to ships.
2. Provision of an adequate sewage collection, treatment, and disposal system serving the entire complex, including a shoreline interceptor for receiving liquid wastes from all shoreline installations. (In conventional practice such an interceptor is usually not provided because it is expected that slips will discharge treated sewage directly into the harbor waters.)

3. This includes provision of special hose connections so ships can readily connect to them and discharge their sewage, bilge water, and other liquid wastes into the sewage collection system. (Without these, it can be expected that most ships will discharge raw sewage and bilge waters directly into the harbor waters.)
4. Provision of a comprehensive solid waste management system for the entire complex including provisions so that ships can readily be serviced by the system, otherwise the ships will likely dump the wastes into the harbor.
5. Where the port/harbor is to be used for importing or exporting petroleum oil or products from refining of oil, additional special measures must be provided to control the hazard of oil spills.

Coastal City of Chonburi in Thailand

Many of the homes in the coastal area of this city are built on stilts over shallow coastal water areas that, in earlier years, were regularly cleaned by tidal flushing, but because of coastal development the sewage discharged from the homes remains under them—hence, these areas are a "sanitation mess." A study done in 1984[132] recommended that the city correct this problem by filling the space under the homes with city refuse, which will promptly be consolidated and stabilized because of its water content (see section "Urban Solid Waste Management"). The initial work would be done by the city with no cost to the homeowner. The work would involve filling the sites with refuse in a systematic manner up to the desired ground elevation, covering if with a thin layer of soil to eliminate problems from rats, odors, and so on, and periodically continuing the process as the refuse degrades and settles until a stable fill to the desired depth is achieved. Once the homeowners are confident that the filling enhances sanitation and increases property values, it is anticipated they will want and even demand the service and may be willing to pay for it.

Public Water Supply Taps

While public water supply taps are widely used for improving environment in urban slum areas, these are also valuable for use in other municipal areas where house connections are generally unaffordable. A review of this usage on Asian DCs, made for the World Bank in the 1980s[71], resulted in the following eight findings:

1. While the construction cost of the public tap varies widely (in the range of \$100 to \$1,000), the indicated usual cost is about \$400 for an installation sufficient to serve about 30 families (average of seven persons) with an average consumption of about 30 lcd (or about 6 m^3/d per tap). The price of water delivered to the tap (paid to the municipal water agency) is in the order of US\$0.10, or 10 cents/m^3, and the price to the family getting water directly from the tap is about 40 cents/m^3. Where vendors are used, the price to the public is usually three times as much.

2. The cost for one house connection in the same slum area is about 0.3 of that for a public tap, or as much as \$120. Consumption is much higher, around 150 lcd or five times as much, with the price to the householder about the same per m^3 as paid by the public tap manager. Thus, the investment cost per family for the house connection is more than 10 times as much as for using a public tap. However, the unit water charge is considerably higher for public tap water in order to gain sufficient revenues to pay for tap management, including operation and maintenance.
3. The percentage of homes in a slum area that use public taps varies widely. The average is about 50 percent each for use of public taps and for use of house connections (including sharing of one house connection by several families). This indicates that most urban slum areas are populated by families of diverse income ranges.
4. Most public taps installed are being utilized more-or-less as planned, but little feedback information is available to permit reorientation of the planning/design criteria to obtain a much higher percentage of success. Very few urban slum improvement projects include budgets for post-construction usage monitoring which would furnish the needed feedback. This represents a gap in the planning of urban tap systems that, hopefully, International Assistance Agencies will take into account in the future. Moreover, periodic usage monitoring can be effectively combined with monitoring for evaluating O&M needs, another serious gap in conventional public tap planning.
5. Continuing tap management is essential if the facility is to remain intact and be wisely operated with efficient use of water. For the reason, taps may best be located on private home property, with an agreement with the homeowner to be responsible for tap security and management, including collection of fees established by mutual agreement between the homeowner and the municipality.
6. A typical slum area includes a wide range of family incomes. The source of supply varies accordingly, from (1) individual home wells (using a hand pump), to (2) public taps with self-service, to (3) public taps with vendor service, (4) shared house connections, and (5) individual house connections. The tendency is to progress upward in the series as family income increases.
7. With effective tap management, the municipal water authority can be reasonably reimbursed for its actual costs for furnishing water to public taps. Where the municipal agency cannot exercise controls, some of the taps are likely to be converted to local private-sector water supply businesses, with only a part of the delivered water being paid for. Hence, arranging for competent management is essential for a financially viable program.
8. The results of this study indicate that it should be very worthwhile for an interested International Assistance Agency to sponsor a project to obtain much more detailed information on experiences in using public taps in urban poor people areas; to analyze these data; and to prepare a manual of guidelines to assist in planning public tap programs in DCs. The proposed

study should include consideration of all parameters that significantly affect the planning and implementation of public tap projects, including (1) technical design criteria, (2) institutional aspects, including procurement of land, and provisions for management, (3) operation and maintenance, (4) financial aspects, (5) economic and socioeconomic aspects, and (6) provisions for continuing monitoring and feedback.

RURAL SANITATION

Very Low Priority for Attention

Rural sanitation is a major problem in most DCs because of the simple fact that governments are very sensitive to the urban centers (which have the potential for serious revolts) and are generally quite insensitive to rural areas (which have little such potential and are "out-of-sight, out-of-mind"). A typical situation is government responsibility for provision of rural town water supply in Thailand, which used to be the responsibility of the Public Health Ministry, where it received little attention for the reason already noted. Then in the 1980s, this was transferred to the Provincial Waterworks Authority in order to have water supply responsibility for all communities in the country (excepting the capital city of Bangkok) in a single agency, where it seems to be again receiving very little attention for the same reason[159].

WHO Manuals

WHO has produced a series of manuals covering virtually all aspects of rural sanitation, and these contain a great deal of pertinent basic sanitation. However, it is good to keep in mind that the standards utilized by these manuals sometimes are a bit too idealistic and too expensive for use in DCs, so some adjustments may need to be made. In the 1970s to 1980s, the World Bank decided to produce its own series of rural sanitation manuals titled "Low Cost Sanitation Manuals" (the "John Kalbermatten series"), which were planned to suit poor DC financing limitations. An example is[154] on use of pour flush toilets with leaching pits at Jakarta (Indonesia).

Xiaolangdi Resettlement

Sanitation Improvements The World Bank project for resettlement of families displaced by the major Xiaolangdi dam on the Yellow River completed in year 2001[160] gave careful attention to provisions of (1) use of wells for water supply, with protection from surface contamination, for all homes in the more than 60 resettlement villages, together with use of elevated water storage tanks, which served the very useful purpose of enabling ready disinfection of the supply using hypochlorite powder, plus periodic monitoring of chlorine residuals in selected house/public building taps, (2) provisions for handwashing by students leaving toilets (See see “School Sanitation”), (3) managing solid wastes from houses by furnishing routine pickup, storage in protected storage sites (to prevent public access, especially by children), transfer to landfill sites using sanitary landfill techniques, again fenced off from the public, (4) careful attention to provision of adequate town drainage plus planning for discharge of the drainage outside the town without flooding downstream areas. Unfortunately, the Chinese resettlement authority opted for use of dry toilets in the homes, instead of use of pour-flush toilets (to enable washing on exit), which could have been used, considering that all homes received piped water supply. Otherwise, these homes actually had sanitation facilities at the “semiurban” level, far better than those in the towns that the resettlers come from.

Household Excreta Management The World Bank project of the late 1990s for resettling villagers displaced by the Xiaolangdi dam on the Yellow River[160] included an estimate of the relative values of household excreta management systems for protecting public health, which is summarized in Figure 4.20. This compares the performance of (1) dry latrine toilet systems,

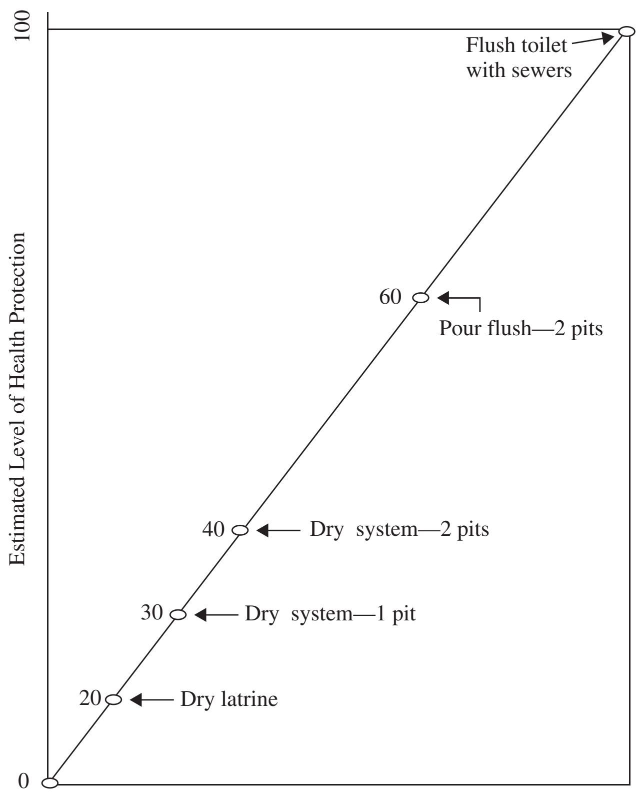


FIGURE 4.20 Health Protection Levels for Different Methods of Excreta Management.

(2) dry toilets with one receiving pit, (3) dry toilets with two pits, and (4) pour-flush toilets with two receiving pits, and shows that the pour-flush systems should be utilized whenever feasible. The pour-flush/two-pit systems not only permits washing before leaving the toilet, but also the water content in the receiving pit greatly speeds up sludge stabilization, so that the sludge removed (usually taken for use as fertilizer for crops), is very much safer for handling than dry pit sludge.

Village Environmental Officers (VEOs) The overall environmental program already noted for Xiaolandgi resettlement towns included attention not only to the water/sanitation facilities but also attention to all other significant village environmental issues including adequacy of roads, electricity service, clinics, and even the need for planting of trees to furnish aesthetically attractive green areas. To ensure continuing adequate attention to all of these the local governments for all of the resettlement towns, at the World Bank's recommendation, appointed a village environmental officer (VEO) for continuing monitoring of all the various environmental protection activities, with monthly reporting following a standardized format including recommendations to the resettlement program's director on needed improvements[81]. These officers are included in the upper echelon of the village governmental hierarchy and are paid for their services. An interesting finding is that all of the village chiefs expressed real enthusiasm for using the VEO, and at time of completion of the resettlement construction program, the VEO program was going very well.

Farm Animal Manures

The World Bank–sponsored Water Agenda study for north China's coastal provinces[163] found the bulk of river pollution caused by animal farms was due to drainage of unmanaged animal manures, and that this problem could readily be solved by requiring the farmers to utilize simple stabilization ponds with retention periods of 20 or more days. These ponds remove about 90 percent of the BOD.

Handwashing

The importance of handwashing can scarcely be overemphasized. Studies by the London School of Hygiene and Tropical Medicine reported in 2002[28] indicate that diarrhea alone kills more children than malaria, and the most effective preventive measure is to persuading people to wash their hands with soap after going to the toilet, cleaning a dirty baby, and so on, which will reduce disease incidence in their children by some 43 percent. The problem is to get DC governments together with private-sector soap companies to develop programs suited to particular countries. The World Bank has initiated a program in Ghana with plans to extend it to many other DCs.

School Sanitation

Review of design of school facilities in DCs showed that these designs often need improvement in two important aspects:

1. Provision of a handwashing basin at the exit from the school toilets, especially when dry latrine–type toilets are used, arranged (with monitoring supervision by a school staff member) so that the exiting students must pass this basin and use it to wash their hands, so that their excreta is not passed on to others, especially during periods of recess playing[160].
2. Location of school toilets as far as possible from school dining rooms. In the Philippines in the 1980s, it was found that school design manuals often placed dry latrine toilets next to the dining areas[49].

Hazard of Flies

The *Bangkok Post* newspaper published on article on February 2, 1991[19] that has proven to be of value in getting DC officials to understand the need for control of flies. The article reads as follows:

> Our Gulf war correspondent faxed us an ad for a pest control firm published in an English-language newspaper in Saudi Arabia. It says: "This is what happens when a fly lands on your food. Flies can't eat solid food, so to soften it up they vomit on it. Then they stamp the vomit in until it's a liquid, usually stamping in a few germs for good measure. Then when its' good and runny they suck it all back again, probably dropping some excrement at the same time. And then, when they've finished eating, it's your turn. Had your breakfast yet?"

Septic Tanks for Coastal Homes on Stilts

A common pollution problem in DCs with homes built on stilts over nearshore coastal waters (e.g., in Malaysia) is how to manage pollution from sewage discharged from these homes. The recommended solution is to install a septic tank under the home, with a 24-hour retention period, which removes the waste components that if discharged are really objectionable, namely floatable and settleable materials[35]. The net discharge contains only soluble/colloidal pollutants, which generally are readily absorbed by the coastal waters. Provision must be made for a desludging service to be available for periodic tank dislodging (average about every 10 years).

Water Treatment for Homes Using Surface Waters

One of the suggestions prepared for assisting the National Environment Board of Thailand in the 1970s for improving the health of villagers who take their water supply from ponds or klongs (canals), which is common practice for many rural villages in the country, is for distribution to these homes (free or at low prices) of pill packages, containing sodium hypochlorite powder and alum, with instructions to the villager to flocculate the raw water in large jars, allow the flocs to settle, then add the hypochlorite powder, to be done in the evening, and by the following morning the supernatant water is safe for drinking.

PUBLIC HEALTH

Many of the other sections in this chapter deal with public health issues, especially the sections on urban and rural sanitation. In addition, an important parameter in evaluating public health benefits is the ongoing market value of a human life. This is discussed in the section "Environmental Economics and Financing."

Assessment by Asian Development Bank

A good summary of public health conditions in Asian DCs is given in ADB's 1999 report, "Policy for the Health Sector"[13]. This shows that health conditions in Asian DCs have much improved over the previous 3 decades for the general population, but of course the level of improvement has been much less in the poverty poor social sector. The IAA projects have focused on furnishing primary care clinics in the rural villages. However, the book *The White Man's Burden* by W. Easterly (2006)[27] shows that the poor sector is disadvantaged in the IAA-sponsored health improvement programs for the usual reasons, for example, the situation on malaria control in Africa where more than 300 million people per year are infected with malaria, with more than 70 million deaths per year, mostly infants and preschool children. Insecticide- treated mosquito nets, which cost a few dollars, can prevent most infections and another few dollars for medicine give effective treatment. Easterly notes that when the IAA projects handed out free mosquito nets in poor DCs, many of the nets are diverted to the black market and wind up being used as fishing nets or wedding veils, and a similar story for the medicines.

Water Supply and Sanitation

"The Truth about Public Health Protection and Community Water Supply/Sewerage in DCs" (2003), reviewed the author's experience on this subject[115]. This paper notes that since the establishment by the affluent ICs of the "Global System" for assisting the developing countries following World War II, the affluent ICs, operating through various IAAs, have carried out a vast array of assistance projects, including both technical assistance grants and attractive loans. In practically, all cases the control of the planning and design of these projects have been in the hands of the IAAs using planners and engineers who are experts in planning and design of facilities that suit the needs of the affluent ICs, but unfortunately, only a few of these officials are competent in understanding that the DCs cannot afford such systems because their state of economic development requires management of the problems with budgets that are only a fraction of those available in the ICs. The resulting systems that are built are often not suitable for DC use; hence, they do not function adequately, and the losses are very large. Unfortunately, the IAAs have chosen not to invest in post-construction monitoring of actual project performance (because it is much easier to assume satisfactory performance, and to collect facts to the contrary would be politically disturbing), and none of the DC governments have as yet invested in meaningful performance monitoring (such monitoring is routine in the ICs, but as yet is absent in the DCs).

With respect to the projects for sewerage and excreta management and for community water supply, the true picture is very unsatisfactory, particularly due to the utilization of IC designs/standards, which depend on skilled operation and maintenance (when it is known in advance that these will not be available). The result is that the investments furnish only a small fraction of the services and health protection that are assumed, with these assumptions are used to justify the investments. About the only beneficiaries from the projects are the community's affluent: "The rich get richer."

It is time to recognize this reality. What is needed is a project (financed, say, by the Global Environment Fund) that will make a critical evaluation of the actual performance of these water supply and sanitation systems, and then reorient the planning procedures to be realistic. This will include manuals of design and of operation and maintenance that match the DC realities, using systems that require the simplest levels of operation and maintenance skills, recognizing that the existing texts and manuals, with only a very few exceptions, represent use of conventional IC systems. Use of the private sector for operation and maintenance is another feasible option.

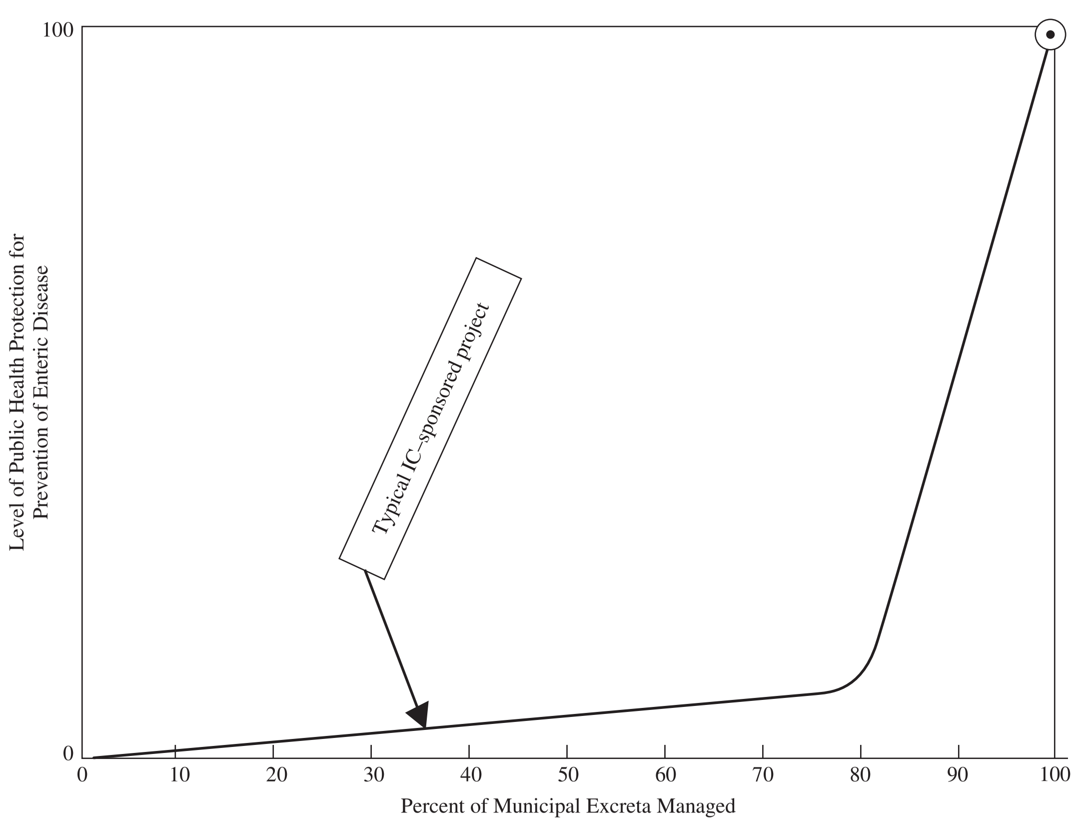
Figure 4.21 shows the author's estimate of the relationship of percent of excreta managed versus degree of community public health protection provided.

To summarize the United States/IC versus DC current situations on control of water-related diseases, the ICs have reduced the major diseases (cholera, typhoid, etc.) to negligible levels, and their emphasis today is on control of relatively minor water-related disease such as control of "crypto" and reduction/elimination of THMs in urban water supply systems, whereas these issues are hardly pertinent in the DCs, which have yet to achieve control of the major diseases. It is the author's estimate that current U.S. expenditures on the nonmajor diseases probably exceed the total expenditures of all DCs on the major diseases.

Disease Reporting

Philippines Reporting of disease cases is usually poorly managed in the DCs due to low budgets for this function. A study of this problem in the Philippines[57] in 1983 showed that the data reported by provinces varied a lot from the information in the annual reports of the Ministry of Health, and discussions with the responsible reporting doctors in the provinces showed they were employed only on a part-time basis with inadequate time for this task.

Resettlement Villages in China It was found, as part of the resettlement program for China's Yellow River Xiaolangdi dam, in most Chinese rural villages



Notes:

1. Even if only 10% of excreta is left unmanaged, the overall hazard is not much reduced.
2. Most municipal sewerage projects pronoted by World Bank, ADB, USAID, UNEP, etc. manage sewage only for affluent city areas. Hence, they provide little public health protection, yet these projects are often *justified* as overall community health protection projects.
3. In U.S., *everybody* in service area is sewererd.
4. In DC cities, only the affluent areas are sewered. Other areas use individual building on-site subsurface disposal units, which often function very inadequately.
5. To get real public health protection, need 100% excreta management = sewers for affluent areas *plus* *effective* sub surface disposal systems individual systems for each nonsewered areas.

FIGURE 4.21 Estimate of protection against enteric disease furnished by excreta management in urban areas in developing countries.

in the Yellow River basin the local pharmacies not only sell medicines but keep a careful record of the names/addresses of the villagers who buy them[160]. Every village had at least one pharmacy, all with competent pharmacists, who kept detailed daily records of names/addresses of all persons who purchased pills/drugs, including which kinds were bought and how much. These pharmacists' records clearly showed that the sale of pills/drugs relating to various diseases sometimes increased to much higher levels for a period of time, indicating an outbreak of a related disease. However, most of these illnesses were never reported to the local health offices. The project recommended that these data could be utilized as a very valuable supplement to the health officer's official records on disease morbidities, so the health officers could be on the alert whenever they notice any marked increase in the use of pills/drugs.

Jordan: Cholera Outbreak During the author's assignment on a USAID project in Jordan in 1984[60], the water resources ministry noted that, when a cholera outbreak had occurred in one of the country's cities, the government responded by putting the city's sewage treatment plant operator in jail—an indication of their level of knowledge on enteric disease epidemiology at the time.

Syria: Endemic Cholera at Damascus A WHO-sponsored project for planning of sewage treatment at Damascus in 1980 had the target of solving the existing problem of endemic cholera due to discharge of raw sewage into the river running through the city which was subsequently used for irrigating vegetable crops below the city, with the vegetables (with the cholera virus) then sold for consumption in the city[149]. The study proposed intercepting the raw sewage discharges on both sides of the river, treating the intercepting flows at a station below the city, then pumping the treated flow back for return to the river at a point above the city (to maintain steady river flow).

India: Enteric Cholera at Calcutta A WHO-sponsored project for improving water supply waste management, and drainage at Calcutta in the 1960s[146] included provision for chlorinating the river water that was used, separately from the city's drinking water system, for the city's firefighting mains, but this river water was also used as drinking water by about one million illegal squatters living in the city, as the logical and practical step to resolving the endemic cholera problem. However, after several years of such chlorination, the city council discontinued this chlorination with the argument that public health savings applied mostly to the illegal squatters who were not entitled to this expenditure.

ENVIRONMENTAL IMPACT ASSESSMENT (EIA)

Difficulties in Application of EIA Process to DCs

The advent of the EIA process in the United States in the late 1960s (called the Environmental Impact Statement) was the initial step leading to the UN/Stockholm/1972

Conference that established UNEP and led to establishment of National Environmental Protection Agencies (NEnPAs) in the DCs around the world. This was a moment of great expectations, when it was generally assumed that the DC/NEnPAs would be able, like the U.S. EPA (the role model at the time), to make effective use of the EIA process to achieve control of all proposed development projects (as well as existing projects) so that their potentials for causing significant environmental damage would be brought under control. However, by the end of the 1970s and early 1980s, it became apparent that the DC/NEnPAs were not able to achieve effective control, primarily because of the lack of governmental will to permit this, including (1) lack of provision of effective monitoring/enforcement mechanics for ensuring project compliance for implementing the environmental protection measures specified in the project's EIA report, and (2) insufficient budgets for the NEnPAs to attract, train, and keep personnel skilled in administering the EIA process. This problem became painfully recognized in 1987 with publication of the UN/Brundtland report, which made a comprehension evaluation of environmental resource degradation in the DCs. It showed that the DC degradation that occurred in the 15-year period 1972 to 1987 actually exceeded all known historical degradation up to 1972[141].

For the reason already noted, the EIA has not yet been effectively utilized by the DCs, despite numerous IAA-sponsored training projects to try to help, but that didn't help much because of the low budget problem already noted and because many of the IAA/EIA trainers were not themselves knowledgeable in how to adapt the IC-oriented approaches to suit DC conditions. An important breakthrough on this problem was the publication by the Asian Development Bank in 1988 of a series of EIA guideline manuals, one for some 12 different types of developed projects, which were the first such manuals designed to suit DC conditions[6]. This series became an ADB best seller and was widely distributed and used by DC practitioners. These manuals were especially valuable in enabling DC/EIA practitioners, including both NEnPA staff and the private sector and other agencies doing EIA studies, to produce EIAs that are realistic in specifying environmental protection measures (EPMs) that are suited to DC conditions and thus have a realistic chance for actually being implemented.

Effective Use of EIA Process in DCs

The most effective use of the EIA process for DC projects has been (1) for projects built by major international private-sector companies to require preparation of a competent EIA and competent implementation of the EPMs specified in the EIA as a matter of the environmental protection policy set by the company headquarters, and (2) for projects with financing by IAAs such as the World Bank similar EIA requirements in order to get IAA project approval. Example of such World Bank projects are given in[160,162,164]. An important step by the World Bank, followed by the other MDBs, was the Bank's requirement that the Executive Summary of the EIA for a proposed project be made available to the public 6 months prior to the time for the Bank's loan approval, thereby giving NGOs and others interested an invitation to submit comments to be considered. This procedure is illustrated in Box 4.6, "Recommended DC/EIA Report Table of Contents".

BOX 4.6 RECOMMENDED DC/EIA REPORT TABLE OF CONTENTS

PREFACE

General Table of Contents
Abbreviations Utilized in Report

EXECUTIVE SUMMARY (ES)

CHAPTERS

1. INTRODUCTION
    1.1. Project Background
    1.2. Purpose of EIA Report
    1.3. EIA Methodology
    1.4. Environmental Study Area (ESA)
    1.5. Relation to Project Feasibility Study
    1.6. EIA Team
    1.7. Pertinent Reference
    1.8. Work Plan/Tesks
    1.9. Task Scheduling
    1.10. Report Preparation
    1.11. Summary
2. PROJECT DESCRIPTION
    2.1. Introduction
    2.2. Project Production Components
    2.3. Environmental Production Components
    2.4. Project Time Frame
    2.5. Required Permits from Governmental Agencies
    2.6. Due Diligence
    2.7. Training Program
    2.8. Use of Local Personal
    2.9. Special Amenities
    2.10. Summary

3. ENVIRONMENTAL SETING
   - 3.1. Environmental Study Area (ESA)
   - 3.2. Environmental Resources in ESA
   - 3.3. Summary
4. INSTITUTIONAL SETTING
   - 4.1. Environmental Lews/Regulations
   - 4.2. Country Agencies for Managing Environmental Protection
   - 4.3. Environmental Standards
   - 4.4. Permits
   - 4.5. Summary
5. ENVIRONMENTAL IMPACTS AND RECOMMENDED EPMs
   - 5.1. Introduction
   - 5.2. Identification of Significant SEIs
   - 5.3. Management of SEIs
   - 5.4. Constraints for Contract for CCs
   - 5.5. Summary
6. ENVIRONMENTAL MONITORING
   - 6.1. Introduction
   - 6.2. Monitoring for Individual EMPs
   - 6.3. Consolidated Monitoring Programs
   - 6.4. Summary
7. OTHER SIGNIFICANT ISSUES
   - 7.1. Public Participation
   - 7.2. Compliance with Environmental Lews
   - 7.3. Attention to Poverty Poor
   - 7.4. Risk Management
   - 7.5. Training
   - 7.6. Summary
8. ENVIRONMENTAL MANAGEMENT PLAN (EMP) AND ENVIRONMENTAL MANAGEMENT OFFICE (EMO)
   - 8.1. Introduction
   - 8.2. Compilation of EPMs
   - 8.3. Functions of EMO
   - 8.4. EMO Organization/Staffing/Budget
   - 8.5. Reporting
   - 8.6. Surveillance by Government
   - 8.7. Summary

The EIA reports sponsored by the international companies and by the MDBs have proven to be very valuable for training of DC/EIA practitioners, who prepare the reports with supervision by consulting experts furnished by the IAA. Each such report has been, in effect, valuable as a demonstration on how to understand the essence of the EIA concept and, accordingly, to prepare a competent EIA report. Preparation of the reports has been especially valuable in developing *team mechanics* by which the various expert disciplines included in the IEA team, including environmental engineers, economists, ecologists, and sociologists, learn how to function together to produce an integrated EIA report.

The methodology for using the EIA process in the DCs has evolved to maximize its usefulness, especially the development of the requirement beginning in the 1990s for a final chapter in the EIA report, which requires established of an Environmental Management Office (staffing/offices/equipment/budget) by the project owner as a part of the overall project management system[140]. Experience had shown that establishment of the EMO is essential if it is to be expected that the EPMs specified in the EIA report will actually be implemented.

Recommended EIA Report Components

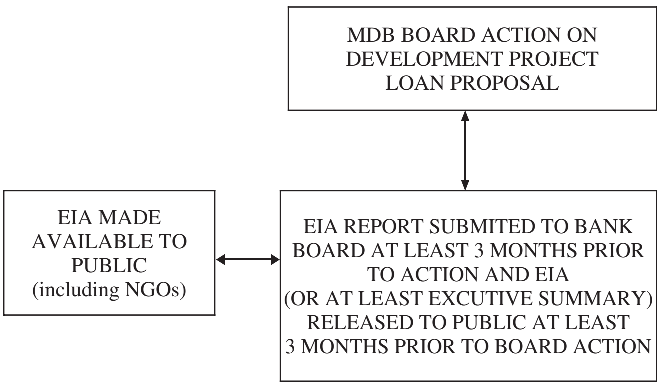
For DE/EIA reports, the recommended EIA report TOR, designed to meet World Bank, ADB, and other IAA requirements, is shown in Box 4.7, “Procedure for Approval of EIA Reports for New Projects to be Financed by Multilateral Development Books”[110]. Explanatory notes are as follows:

- *Summaries:* Each chapter’s final section is a summary of the findings and conclusions of the chapter. The Executive Summary is readily prepared by combining these summaries.
- *Item 2.6 (Due Diligence):* This is to ensure that there are no “hidden” aspects that could be later found to the detriment of the project. The primary concern is whether the project site soils contain toxic/hazardous substances from previous uses of the site.
- *Item 7.1 (Public Participation):* This has become a major requirement beginning in the 1990s. It requires (1) consultations with concerned governmental agencies (all levels) and with local “people leaders” and NGOs, and (2) making the EIA report draft available for public inspection at selected local libraries, to obtain public comments (with radio/television announcements on where to find the draft).
- *Item 7.3 (Poverty Poor):* The intention here is to ensure that the project gives fair consideration to the needs of the general public and, especially, the poverty poor.
- *Item 2.8 (Use of Local Staff):* Provisions for use of local people for project staffing (including training) (to extent feasible).
- *Item 2.9 (Special Amenities):* To gain local approval, it may be necessary for the project to furnish some special amenities (e.g., schools, water wells, roads, etc.) to the affected communities.

- *Item 3.1 (ESA):* This includes the project area, plus all surrounding areas that may be significantly affected by the project.
- *Item 3.2 (Environmental Resources in ESA):* Detailed description of physical, biological, economic, and quality-of-life resources in ESA.
- *Item 8.2 (Compilation of EPMs):* This compilation represents the Environmental Management Plan.

BOX 4.7

PROCEDURE FOR APPROVAL OF EIA REPORTS FOR LOANS FOR NEW PROJECTS TO BE FINANCED BY MULTILATERAL DEVELOPMENT BANKS
(Effective 19 Dec. 1991 for World Bank)



NOTES: PREVIOUSLY, THE EIA REPORTS WERE AVAILABLE TO MDBs AND TO THE GOVERNMENT, BUT THERE WAS NO REQUIREMENT FOR RELEASE OF THE EIA TO THE PUBLIC. THE SIGNIFICANCE OF THIS CHANGE IS THAT BOARD MEMBERS GIVE MUCH GREATER ATTENTION TO EIAs THAN PREVIOUSLY

Source: HFL/1992.

Constraints for Construction Contractors

Experience in use of the EIA process in DCs has shown that the EIA must include special detailed provisions to ensure that the EPMs specified in the approved EIA will be actually observed by the construction contractors (CCs) who build the project. While the CCs agree in their contracts to comply with the EIA/EPMs assigned to the CC, the CC commonly does not intend to do so. Therefore, the CC does not include in his bid price the cost for proper compliance because his own experience has shown that the usual project has no provisions for forcing compliance. A good example is the experience of the World Bank with the major Xiaolangdi Dam Project on the Yellow River in China[160], which was built by three international contractors who had signed contracts for compliance without intending to do so.The Bank's loan codicils provided for routine monitoring/enforcement, but it was not easy to get the CCs to understand they would have to set up their own competent EMOs. Under Bank pressure, they all came around to satisfactory compliance, including preparation of detailed monthly reports giving compliance details including management of all complaints by people and agencies affected.

Box 4.8 "Illustration of Requirements to be included in Construction Contracts to Ensure Compliance by Construction Contractor for Implementing Environmental Protection Measures Specified in Approved EIA" illustrates the types of requirements that need to be included in the CC's contract, including specific details for each EPM so the CC understands clearly what must be done to gain performance approval. Note that a special system is needed for management of the monitoring of the CC's performance on EPMs, which is carried out by a chief environmental construction inspector, but this inspector must work through and in collaboration with the project's chief supervisor of construction, because it is essential that the CC will report only to a single construction supervisor boss.

BOX 4.8 ILLUSTRATION OF REQUIREMENTS TO BE INCLUDED IN CONSTRUCTION CONTRACTS TO ENSURE COMPLIANCE BY CONSTRUCTION CONTRACTOR (CC) FOR IMPLEMENTING ENVIRONMENTAL PROTECTION MEASURES SPECIFIED IN APPROVED EIA

Purpose of These Instructions to CCs
Environmental Responsibilities of CCs

Monthly and Yearly Reports

Areas Involved in CC's Reporting

Base Drawings

Specific Issues Involved and to be Reported Upon by CC

- Water Supply
- Sanitary Sewage Management
- Industrial Wastewater Management
- Housing for Chinese Villages/Camps
- Solid Waste Management
- Drainage
- Erosion Control

- Air Pollution Control
- Noise Control
- Occupation Health and Safety in Construction Zones
- Communicable Disease Control
- Cultural Relics
- Natural Resources Protection
- Other Issues Relating to Environment Protection

Format for CC Reporting

Work by Chief Environmental Construction Inspector (CECI)

Work and Reporting by CECI
Environmental Supervision Daily Log Book
Monthly Environmental Supervision Report
Six-Monthly Environmental Supervision Report

Notes

1. Only main headings are given here.
2. Source: [160].

Need for Effective Training

A primary lesson in DC use of the EIA process is that the NEnPAs could make much better utilization of the process if the training efforts sponsored by IAAs were planned to be much more realistic. EIA technology and its adaptation to suit DC conditions is a complex subject[110], and most of the IAA-sponsored projects have made the mistake in assuming that the needed technology can be effectively transferred to the DC practitioner in a short-term period—say, for one year, and often the trainer himself is not "DC-oriented." The need is for a different approach where consulting EIA expertise is furnished to the NEnPA on a continuing basis over a period of, say, 5 to 10 years. This can be part time, so the same expert can give service to more than a single EIA agency—say, 1 week per month to each of four agencies[51,110].

Another way for improving EIA technology transfer is for the IAAs to modify their plan for financing of technical assistance to DC projects, which virtually always includes financing only for expat experts to carry out their work, assisted by DC staff assigned to them, without provision for meetings with the staff to explain their "thinking" for carrying out the project. The expert uses the assistants, but without explaining to them the "why" of what they are doing.[45] details the author's experience in this, for an EIA report prepared by an expat expert for a major World Bank dam/reservoir project in Indonesia, with assistance of professionals from the Government's Institute of Water Resources Research. For this purpose, an extra work session was scheduled for 4 hours on Saturday mornings, during which the expert did the necessary explanations, but this was "freebee" work by both the expert and the trainees.

ENVIRONMENTAL ECONOMICS AND FINANCING

Inclusion of Environmental Values in Project Economic Analysis (PEA)

Prior to use of EIA, PEAs commonly were limited to values of interest to the Project Proponent (PrPr). The "Economic Study Area" was often considered to exclude the *project externalities*, meaning that these are not to be considered in the economic analysis. Examples include (1) downstream flooding damages due to deforestation in timber logging projects, (2) flooding damages due to hydrology changes by highway projects, (3) loss of capture fisheries due to hydrology changes, and so on. A proper "economic study area" must include all areas that are significantly affected by the project, with attention given to all environmental values that are impaired (and to any gains that may occur)[136].

Another aspect of this issue is the value assigned to existing natural resources that are utilized for economic gain, such as trees that are logged for timber. The fair value would seem to be its replacement values (cost for regrowing)[9].

Effect of EPMs on Project Economic and Financial Analyses

The EIA should evaluate the impact of including EPMs on the PEA (i.e., to compare the benefit/cost and financing both with and without the EPMs). This may be needed to offset arguments that the costs of EPMs will ruin the project economics. These evaluations invariably show that provision of EPMs will actually increase overall benefit/cost in the project's life term, and that for some of the amenities that may be included, the benefit/cost ratio may be much greater than for the main project production objective.

Unfortunately, however, the DC decision makers, for political reasons, were more interested in immediate financial gains[88], and the use of the EPMs requires provision of significantly more upfront financing money, which conflicts with the immediate gains goal. This *immediate gains goal* is the primary reason why so many DC projects do not achieve their intended objectives and are very wasteful.

Human Greed Parameter

The *human greed parameter* has a very considerable effect on project development. This is well explained in "Radical Birthday Thoughts" featured in the June 28, 2003 issue of the *Economist* on the occasion of this magazine's 160th birthday[168]. This includes a statement by Alan Greenspan that man hasn't become more greedy; rather, the new technologies including IT have made it possible for the same greed-level to steal much more (e.g., Enron et al.).

Application of this principle to the field of environment gives a gloomy picture. Although the new technologies have created enormous new wealth, so it's much more feasible now to care for the poor and to protect environmental values—the money is there—there seems to be little hope for environment because human greed will continue to give its primary attention to using the technologies to making the rich richer, with environment going down the drain. The world will wake up to the environmental problem and face up to it only when the "roof falls in." However, even then it may not be too late; for example, even it jillions of species are lost, Man may well be able to do very well with what's left in terms of tending to human economy (health and welfare), using ever new technologies to fill the gaps.

Economic-cum-Environmental Development Planning

The need to incorporate the environmental (E2) parameter into economic (E1) development planning, as the only way for the DC to affair sustainable development, has been long recognized, but an acceptable methodology for this is now available as discussed in the section "Development Planning."

Value of Human Life

A key parameter to be taken into account when modifying IC environmental design criteria and matching standards is the DC's situation on the value of a human life. The author moved from the United States to live in Bangkok in 1973, and at that time had a public liability policy for auto driving that included provision of $1 million in case of causing accidental death (today this is many times higher). He asked his Bangkok insurance agent to furnish a similar policy for Bangkok. The provision for accidental death was only $10,000, and this because the author was a foreigner—The normal Thai policy amount was $1,000. This, of course, doesn't mean that an American life is worth 1,000 times more than a Thai life, but it does mean that the actual market value of a life must be taken into account in modifying IC design criteria to suit DC conditions.

At that same time, the author's brother's firm engaged in heavy engineering construction. He noted that the cost in the United States for building a dam, which in 1950 was, say, $100 million, by 1970 had increased to $200 million due to stiffer safety construction regulations which reduced the average construction death rate from three to one—at a cost of $50 million per person. Obviously, most DCs can hardly afford the original $100 million. The same problem applies to modifying construction requires for setting design criteria for protection against earthquakes for dams and superhighways.

Protecting Precious Eco-Resources

Another need for economic analyses DC project planning is to assign some appropriate money values representing the value for sustainable development of preserving precious Eco-Resources. This is discussed in the section, "Development Planning."

EMERGENCIES MANAGEMENT

Little progress has been made in most DCs in formulating for management of environmental emergencies, with only a few exceptions. The recent huge tsunami in Asia made the DCs painfully aware of the need for establishing a competent Asian regional emergency warning system for tsunamis, which likely will bring about expansion of the existing tsunami warning center in Honolulu in order to fill this role for the entire Asia-Pacific region. Even so, each DC involved needs to improve its own tsunami warning service to receive and give attention to warnings from Honolulu. At present, most DC meteorological agencies do give good warnings on impending flooding hazards. In most DCs, about the only agency able to offer prompt assistance for assisting the DC people/properties affected by emergencies (including damages from earthquakes, floods, hurricanes, landslides, oil spills, etc.) is the military. A World Conference on National Disaster Reduction was held in Japan at Yokohama in May 1944, which indicated the need for each DC to establish its own National Emergency Management Agency. The recent earthquakes in china and massive flooding in Myanmar also emphasize this need.

An example of a rare exception-to-the-rule is the system established in Thailand in the 1970s by a consortium of the country's major petroleum companies, for managing major oil spills from tankers or other sources, including a standing management committee (with the director rotated among the participating companies)[77,128]. This includes (1) enforcement of regulations to prohibit illegal discharge of oil laden wastes both at sea and in harbors, (2) provision of standby equipment ready to get into action when needed for managing the spills, including use of log booms, mechanical removal of the oil, and use of chemicals for negating oil damage, (3) planning for use of equipment in emergencies, and (4) actual emergency operations. This is operated under the jurisdiction of the Thai government, and has proven quite effective for handling the several major spills that have occurred. Some efforts were made to expand this operation into a joint operation of the Southeast Asian countries in the same region (Thailand, Malaysia, Singapore, Indonesia), but with no success as yet.

TECHNOLOGY TRANSFER (TT)

Problem

All IAAs recognize the need for transfer of environmental technology to DC practitioners; hence, there have been hundreds of IAA sponsored project since the 1970s for such TT to assist them in their planning efforts. Many, if not most, of these projects have not been successful for a variety of reasons that are summarized as follows:

- Lack of experience by many IAA staff actually working/living in DCs such that they understand the DC problem. For example, the World Bank staff at

Bangkok work in what is essentially a branch of World Bank/Washington, a luxury office with luxury equipment, and the World Bank staff contacts are mostly with high-level country officials. Rarely are these staff exposed to actual working-level conditions in the country. Yet these are the persons who plan the TT projects.

- Lack of understanding that almost all environmental protection technology has been developed in the affluent ICs and is not directly applicable to DCs but must be modified to suit DC conditions (see Figure 4.3), and lack of sufficient training in how to make the modifications.
- Use of consultants for conducting TT projects who have the same backgrounds and the same deficiencies as just noted.
- Assumption that TT can be achieved with "slug type" projects (e.g., assignment of an EIA technology expert or a team of experts to the country for one year). But TT/EIA is not that easy. What is needed is for continuing expat inputs (can be on a part-time basis) for a prolonged period. For EIA/TT, the best approach is for continuing inputs over a period of several years. For one of the author's projects to train the staff of the Institute of Water Resources Development of the Ministry of Public Works of Indonesia at Bandung on environmental technology, the original plan of the sponsoring agency (UNDP) was for the expert to spend 3 months at Bandung full-time, but the UNDP agreed at the author's suggestion to change the plan to four visits each of 3 weeks, covering a period of a year. This kind of teaching is like university teaching, where a typical approach includes a number of lectures (usually 20) spread over a period of one half-year semester. Trying to achieve the TT on a slug basis is not the way, but the IAAs almost always use it because it "saves" travel time. For the case under discussion, the author advised the UNDP that its original plan would not be successful—hence, UNDP should use the "prolonged approach" or cancel the entire project and save all the money[45,94].
- Planning the TT course must be DC oriented, using appropriate standards affordable in the DCs. One of the IAA/TT projects in Thailand for protecting marine beaches utilized experts from California to do the teaching. Their lectures were about the state of California's program for beach protection, where the standards for protection are hugely high and not affordable in DCs. The lectures were all about the California practices[82].
- Another nonproductive approach in IAA planning of TT projects is that the project target is production of training manuals by the expat experts, and for such a project for the Provincial Waterworks Authority (PWA) in Thailand sponsored by World Bank, the manuals produced were actually appropriate, but the project budget did not permit the expert team to produce the manuals in close association with the PWA staff, or to explain them to the PWA staff. Therefore, the manuals were rarely "accepted" and used by the PWA staff[159].

- For many training needs, the best approach is not provision of an academic type course, but to include in the planning of a major development project sufficient budget to enable the expat team to give lecturers as the project continues for explaining to the DC team members the "why and how" of the tasks being managed by the expats[94]. But this is almost never done. The IAAs still haven't grasped this basic concept; they still think the TT occurs simply by "rub-off."
- Another good approach for O&M training, for example, for water supply and/or sewage treatment plants, is to use experts on O&M from the ICs who make periodic visits (like a circuit judges in early Western U.S. history) to a number of plants. Retired IC experts are often willing to accept these assignments. This system is much more effective than academic training because, when the expat arrives at the plant, the plant O&M manager is very happy to get guidance from the expat on immediate urgent O&M problems. At that time, he the manager is keenly interested in learning, but at an academic course (where the manager has no immediate urgent problems), he often is not very keen to learn.

Recommendation

The author's recommendations are discussed in the 2006 publication, "How the Asian Development Bank Can Improve Their Technology Transfer Operations fro Water/Sanitation Projects in Developing Countries"[93]. These recommendations are summarized in this chapter in the section on "Introduction" (and also in the section on "Urban Water Supply").

DEVELOPMENT PLANNING FOR DCS

This section summarizes efforts by the IAA/DC practitioners for regional development planning in the DCs, with the goal of selecting development projects that can best contribute to continuing DC sustainable development. The section includes subsections on (1) the need to give much more attention to providing for the rural poverty poor, (2) the need to assign money values to represent (in project economic analyses) the intrinsic value of precious eco-resources, (3) development of a practical methodology for achieving integrated economic-cum-environmental planning methodology so that project investments will best contribute to sustainable development, and (4) role of women for alleviating poverty.

Social Parameters: Attention to Rural Poverty Poor

Background Over the last decade, the affluent ICs, represented by the Group of 8, and the IAAs, including the U.N., have increasingly recognized that, while new technologies are improving the overall economics of DCs, nevertheless the gap between family income for urbanites and ruralites has generally been steadily increasing, and the IAAs (including WTO) and some DC are now undertaking numerous projects/programs to try to help resolve this problem, but as yet without much improvement. It is proving to be very difficult to close this gap.

ADB's report of 1990 on "Economic Policies for Sustainable Development"[7] represents ADB's initial recognition of the seriousness of rural poverty and outlines development policies, which need to be followed, including giving the rural sector its fair share of attention in the country's overall investment program, especially for provision of rural town amenities and development of local agro-industries. The report's Executive Summary stresses the urgency of this need.

ADB's report of 2000, "The Environment Program, Recent Achievements and a New Agenda for the Poor"[14] was prepared in response to new and emerging directions in ADB's overall operation. ADB has recently embarked on a reformulation of its environment program. In particular, the adoption of poverty reduction as ADB's overarching objective in November 1999 offers challenges and opportunities for ADB to adjust the focus of its assistance in sustainable management of environmental resources to improve the plight of Asia's rural and urban poor.

All of the studies/projects already noted concur that attention to the rural poverty sector is a major urgent problem in most DCs. Feasible ways for resolving the problem include the following:

- Provision of decent amenities (facilities), including water supply and sanitation, primary health care facilities, and schools
- Land distribution so the "landless poor" have opportunity to manage farming to help themselves
- Promotion of local handicraft industries
- Promotion of local factories using trained local labor to produce items for sale to global manufacturers
- Promotion of off-farm job opportunities

Illustrative Projects Two of the ADB projects over the past several years, which were designed with the twin objectives of environmental protection and poverty reduction, are the following:

1. Sulawesi Rainfed Agriculture Development, Indonesia ($34 million project loan), is directly benefiting about 50,000 households scattered over 235 villages and representing about 10 percent of the total population. The project has increased the productivity and farm incomes of rainfed farmers; protected and improved the fragile environment; created employment in the rural areas; reduced poverty; and improved the socioeconomic condition of women beneficiaries.
2. The Philippines received a $35.2 million loan for fisheries resource management, aiming to reverse the trend of fisheries resources depletion in

municipal waters. It will achieve this objective by implementing three components: (1) fisheries data management, and coastal resource management and planning; (2) income diversification; and (3) capacity building for relevant public agencies. By controlling destructive fishing, reducing overfishing, and rehabilitating fish habitats, the project will benefit municipal fisherfolk in about 100 municipalities in 18 of the country's 6 priority bays.

Role of Women Virtually all socioeconomic analyses of development on the DC have shown that the potentials for utilization of the talents of women have generally been given very inadequate attention in development project planning. That is, the traditional role of women in DC socioeconomic should be reoriented to make much better efficient use of these talents. Guidelines for achieving this in project planning developed in recent years have been prepared by the World Bank and ADB and other IAAs.[83], A guide to "womenomics,[168]" from the April 25, 2006 issue of the Economist magazine, gives a good summary of this subject. It notes, "The future world economy lies increasingly in female hands."

Eco-Resources Protection

Problem in DCs A major problem in DCs has been the lack of environmental engineering expertise needed for planning projects for protecting natural eco-resources (and modifying the planning of projects which utilize natural resources), especially forests, eco-swamps, river aquatic life, and aquatic life in nearshore marine waters, due to increasing encroachment into the eco-areas by cities, industries, and agriculture, extraction of the resources for export for the DCs, and lack of government monitoring/enforcement needed to protect established national parks and other eco-resources areas from poaching of animals and "looting" of precious plants and animals for sale in urban markets. In the author's view, this is a major problem of the World Wildlife Fund and International Union for Conservation of Nature, which are staffed essentially by wildlife scientists (foresters, fisheries, etc.) are seriously lacking in environmental engineers[52].

Protection of National Parks/Eco-Resource Areas A key problem has been the inability of DC governments to protect national/eco-resource areas so there is actual protection. Many DCs have officially established many such parks/resources, but very few are actually protected, so the official proclamations amount to delineating these areas on a map and pretending their bio-resources are indeed being protected. The most serious single problem of natural resources destruction in the DCs is the loss of natural forests, which has reached unprecedented high rates in the past several decades. It seems that this degradation will continue with little forest left by mid-twenty-first century because of inability of DCs governments to impose controls. This results in very serious problems of loss of wildlife habitat, and in watershed areas heavy loss of soils by rain runoff and seriously diminished water infiltration to sustain the groundwater levels that furnish the dry season flow in streams. The author's recommendation for saving the world's tropical rainforests are given in Box 4.9.

One approach that appears to be feasible and meaningful for DC/forestry protection agencies was developed in preparing the EIA for a proposal hydroelectric plant in Ecuador to be located in the Amazon portion of the country[53]. The study made three findings:

1. The national environmental protection agency of the government, located at Quito, near the Pacific Ocean, had very limited budget hence was not able to protect its proclaimed national resources even in the western region of the country, let alone for the Amazon portion on the other side of the Andes.
2. One of the most precious wildlife regions in the country was located next to the hydropower operations area.
3. Financial resources of the hydropower protect were very large compared to those of the NEnPA.

The recommendation (to which the hydropower agency expressed interest) was for the NEnPA to arrange for the hydropower agency to protect/manage the precious habitat region as part of its overall project tasks, which the hydropower agency could do readily as a contribution to helping preserve the nation's eco-resources (as well as using these areas for hydropower generation).

Segara Anakarn Lagoon Preservation in Indonesia Studies sponsored by the ADB for promoting irrigation in the huge Citanduy River basin in Java, beginning in 1990[90], included attention to what should be done about protecting the lower end of the basin where the Citanduy River discharges (along with some smaller rivers) into the Segara Anakarn lagoon, located just next to and discharging to the sea (like Jamaica Bay in New York City). This wonderful eco-swamp, the last remaining large eco-swamp in Java, has over the past several decades been filling up with silt runoff resulting from continuing development in the Citanduy River basin. This attracted the interest of environmentalists in developing a feasible plan for saving the swamp while a major portion of it still exists. A number of studies concluded that the best feasible plan would be to reroute the Citanduy River to discharge directly into the sea (bypass the lagoon), and ADB offered a loan for doing this, but this plan is yet to be implemented, apparently due to differences between the bureaucracies of the two provinces in which the lagoon location is shared.

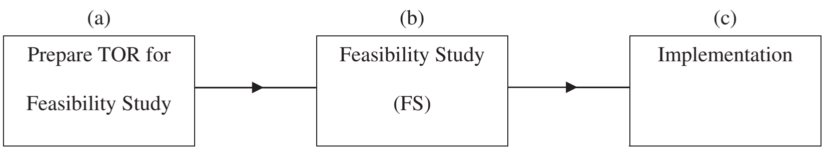
Assigning Money Values for DC Eco-Resources The Segara Anakarn project brought out need for recognizing that saving precious eco-resources (like Segara Anakarn)deserves to be assigned money values representing the economic-cum-environmental development value of these resources, and for revising conventional project economic evaluations to include these money values[97]. The conventional methodology gives zero money value for eco-resources in the area/region affected by a proposed project. The argument is that ICs spent very large amounts of real money for this purpose, for many projects—for example, restoring the eco-systems of the Florida Everglades in Florida. The proposal recognizes that DCs cannot afford the IC approach, but notes that even so, the eco-resources do have some intrinsic value for sound development value in the DCs. The proposed approach is to evaluate the budgets spent for the many cases of eco-preservation in the United States (and other ICs) in order to devise a "formula" for quantifying these values, then to have these IC values reduced to match, say, the relative GDPs of the ICs versus the DCs, with the value for a particular eco-resource set by a high-level DC committee comprising both distinguished economists and environmentalists in the country.

Recommendations A basic recommendation is for the WWF, IUCN, and other interested IAAs is to give much more attention to this problem, and in doing so to do a much better job in adapting or modifying protection technologies developed in the United States (much to expensive for DC use), including use of the engineering approach for planning of proposed eco-protection projects, including use of the methodology discussed in subsection "Economic-cum-Environmental Development Planning." The author's review of the IUCN's proposed plan for protecting Thailand's wildlife habitat in 1980[52] is an example of the need for environmental engineering expertise in developing such plans, including development and use of the methodology already noted for assigning many values for precious DC eco-systems.

Another critical need is for preparing the tropical forests preservation plan shown in Box 4.9.

BOX 4.9 RECOMMENDED PROGRAM FOR SAVING WORLD'S TROPICAL RAIN FORESTS

by H. Ludwig[94]



(a) This cost estimated at two professional man-months = about \$50,000 to \$100,000. Report will describe FS job, its components, FS team, schedule, costs, and proposed financing plan.
(b) This will evaluate all remaining precious tropical rainforests in the world and delineate the described minimum combination of

pieces/components which are to be purchased and protected, including (1) skills and support needed for implementing plan, (2) estimated costs for acquisition and for true protection (total and annual over period of, say, 50 years), (3) financing plan, (4) management plan, with each component area to be established as International Treaty Organization Nature Reserve (ITONR), and (5) overall global management system. Estimated cost of FS is about $20 million.

(c) Present implementation program, to be spelled out in FS, is in the range of about $1 trillion (to be spread out over period of 50 years). The FS will include such cost estimating and suggested financing (to be paid by ICs).

Affordability of Environmental Improvements

Prior to the 1990s, it was common practice, in project economic analysis (PEA), to look upon proposed environmental improvement projects as a kind of "add on" to economic development, and economic decision makers expressed willingness to approve proposal environmental improvements, provided these were a small percentage of all project investments. Figure 4.22 is a typical situation for ADB's 1987 proposed Klang Valley Improvement Project for Malaysia[5]. This shows the capital cost of the proposed environmental improvement represents from one to three percent from about 2 percent of total fixed capital formation (FCF). This represents approximately 0.4 percent of the Klang Valley GDP.

Integrated Economic-cum-Environmental Development Planning (IEEDP)

Sustainable Development The term *sustainable development* means a development program that takes care of society's current needs, by utilization-cum-protection of environmental resources (natural and human) so that sufficient resources will be maintained so that future societies can take care of their needs.

IEEDP Methodology Most development planning in the DCs has not been able to focus on sustainable development per se because of lack of a suitable planning methodology. As shown in Figure 4.23, the need for developing a practical IEEDP methodology began to be recognized in the 1990s. An ADB-sponsored project carried out by Dr. Daniel G. Gunaratnam in 2000 did produce a practicable methodology for IEEDP for the region of northeast Thailand[15]. This has been followed up by a second ADB-sponsored project for preparation by Dr. Gunaratnam of a textbook/guidelines manual to be released in 2008, for use by IAA/DC practitioners for general application for any DC or sub-DC region or for regions that include areas in two or more adjoining DCs[16].

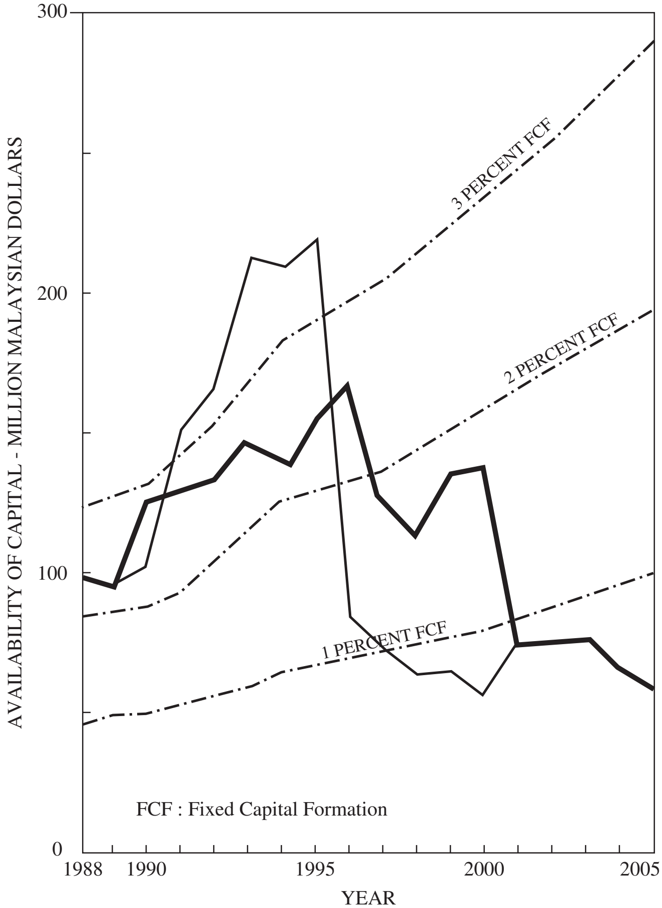


FIGURE 4.22 Comparison of in capital requirements to capital availability for environmental improvement Klang Valley.

GLOBAL WARMING

Problem

Most climate scientists believe that serious global warming due to man-induced emissions of CO_2 and methane gases is underway and that, if this is not soon controlled, it can be expected there will be dire consequences throughout the world, including flooding of coastal areas and of low-lying islands. Agricultural changes will also take place, in that crop choices will need to be shifted to correspond with the new climatic patterns. It is also recognized that while the damages will be felt globally, the greatest damages will be in the DCs, which can least afford to cope with them. While the United States and China are now is in the lead in contributing emissions, India is expected also to become

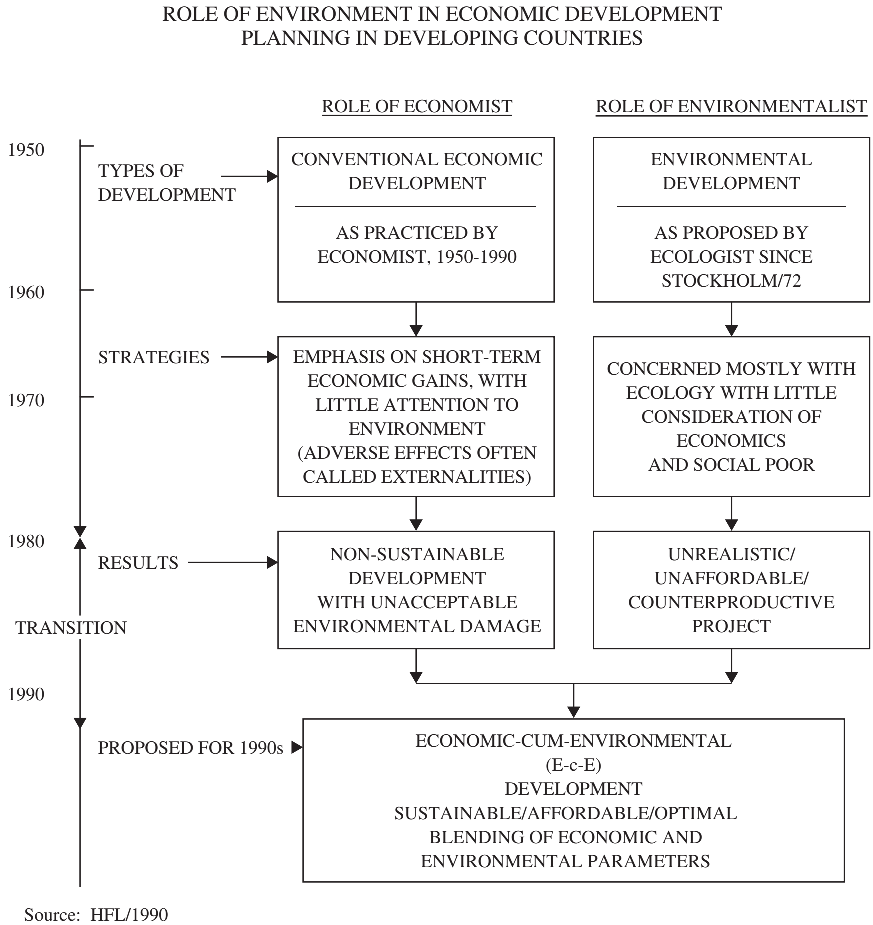


FIGURE 4.23 Role of environment in economic development planning in developing countries.

"one of the big three." The protocols now being proposed, to replace Kyoto, even if totally implemented, seem far "too little too late," and the cost of achieving adequate global control will be hugely expensive. It will be very difficult to get the key countries to agree on a comprehensive plan of corrective action.

What seems not to be sufficiently recognized is that the timeframe for achieving sufficient emissions reductions is very short, probably only a few decades, which further increases the problem of reaching agreement on an effective global action plan. The basic problem is lack of any definitive proposal so far as to the specifics on what needs to be done together with the applicable timeframe, task assignments for each country, and how to finance the costs. Without this, country leaders do not have a good picture on what their country should do.

Efforts have been made to prepare a feasibility study for climate warming control which would furnish the answers needed by country division makers, but it has not yet been possible to do this because of a multitude of complexities. Even if a proper comprehensive global correction program could be formulated, it's very unlikely China and India (2 of the 3 major "culprits") would be willing to participate. What is clear is that the most appropriate approach at this time is (a) to reduce energy wastage, and (b) to development energy sources as alternatives to burning of fossil fuels.

FUTURE OF ENVIRONMENT IN DEVELOPING COUNTRIES

Problem of DCs

The world's ICs with their power/financial resources have had the role of formulating the program of the ICs for assisting the DCs on how to protect (as well as use) environmental resources as needed for sustainable development in the DCs. The global assistance program started with the UN/Stockholm/1972 Conference, with great expectations at the time that the new NEnPAs being established by the DCs, with assistance from the ICs (via the IAAs including MDBs, UN agencies, bilaterals, others), would be able to simulate the progress made in the United States with establishment of U.S. EPA. Unfortunately for the DCs, this target has not been achieved, because (1) it is the ICs themselves who are the primary problem by getting the DCs to export their raw resource materials (export of timber for making pulp and paper in the DCs is a classic example) to meet rapidly increasing IC demand for these materials, (2) the DC capabilities for developing skills/procedures for environmental management had been quite limited, and very dependent on IAA assistance to help the DCs develop the needed expertise, and (3) the interest of the ICs has been focused on how to make money by utilizing the DC resources, with quite limited interest in helping the DCs to develop their own capabilities, hence the assistance programs of the IAA have not been very effective.

However, the past several years have witnessed growing discontent by people of both ICs and DCs in the way the IC-assistance system has failed to bring about the needed results in the DCs including both protection of human resources, that is meeting the needs of the several billion DC peoples living with incomes at one dollar per day per person or less, and reducing the high ongoing rates of degradation of natural resources in the DCs, including forests, eco-swamps, nearshore marine areas, and so on.

Changes in Environmental Policy in the ICs

A promising sign in recent years is numerous media items showing a distinct change in IC policy makers in both the public and private sectors, and also in individual persons, resulting in many improvement in environmental performance—for example, in design of big buildings and in conduct of business operations[33]. However, little of this has taken place in the DCs.

Glimpse of Future

The present indicators are that the affluent ICs will be able to maintain fairly good environments in their countries. They have the money and the popular will to require public and private agencies to do this. But the situation in the DCs, which have the major share of land, environmental resources, and people in the world, does not look good. Most DCs have neither the needed financial resources nor the will to manage even the ongoing problems of environmental pollution and accommodating the massive immigration of people from the rural sector. The situation will be intensified by global warming and, again, the DCs have much lower capabilities for coping. Hopefully, the ICs will give much more attention to helping resolve the environmental problems of the DCs, as is happening now—for example, by the 2007 pledge of the Group of 8 for increased major reduction of poverty in Africa.

Recommendations

Some of the author's recommendations for consideration by the IAAs are given in[94], "How the Asian Development Bank Can Improve Their Technology Transfer Operations for Water/Sanitation Projects in Developing Countries" (2005). These recommendations are summarized in the sections on "Introduction" and on the "Urban Water Supply." Hopefully the IAAs will come around to giving serious attention to these recommendations.

As noted in the subsection on "Eco-Resources Protection," in the section on "Development Planning for DCs," the most serious single problem of natural resources destruction in the DCs is their losses of natural forests, which has reached unprecedented high levels in the past several decades, and it seems that this degradation will continue, with little forest left by the mid-twenty-first century, because of the inability of DC governments to impose controls. The author's recommendations for saving the world's tropical forests are given in Box 4.9. As for the problem on how to control global warming, the indicated best approach is to reduce wastage of energy and to develop alternative energy sources not dependent on the use of fossil fuels.

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CHAPTER 5

ENVIRONMENTAL EMERGENCIES AND EMERGENCY PREPAREDNESS

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INTRODUCTION

The objective of this chapter is to present the basic concepts associated with emergency preparedness and the preparation of emergency response plans for industrial contingencies, which can result in toxic releases of contaminants in air, water and soil, as well as, more generally, in other industrial emergency situations such as fire and explosions. Emergency preparedness is not only limited to the prevention, contingency planning, and emergency activities within the boundary of an industrial facility, but it may extend to the federal government, state and local officials, as well as local communities, especially if the release of hazardous materials is involved, or if it involves transportation emergencies. Therefore, the scope of this chapter is to examine the main aspects of emergency preparedness first at the facility level (i.e., concerning the industrial plant) and then at the local level (i.e., within the community but outside the facilities).

The impact of the release of hazardous and toxic materials may be different depending not only on the type and physical state of the material being released, but also on the medium in which the material is released. In general, toxic gaseous or vapor emissions have the potential for causing more acute, and possibly catastrophic, effects, especially on humans and animal populations, but are typically less severe on the environment. If the materials being released as well as the receiving medium are denser (e.g., an oil spill in a waterway or in soil), the consequences are typically less potentially lethal for human populations, because

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of the limited risk for acute toxic exposure, but the immediate and especially long-term consequences, especially for the environment, can be more severe. In all cases, the basic approach to contingency planning and emergency preparedness is similar, although the remedial actions may not be. Therefore, in this chapter a unified approach was used to discuss emergency preparedness, planning, and response in general, without distinctions between different emergency scenarios.

Currently, and for the foreseeable future, the focus of emergency preparedness and industrial emergencies will likely be in two areas: protecting public health and safety as well as environmental media from the potential effects of releases of hazardous substances and protecting vital services from possible terrorist attacks, natural disasters or similar catastrophic events.

Before the toxic release catastrophe of Bhopal, India, in 1984, emergency planning was the exception rather than the rule for facilities, organizations, and agencies other than those associated with the nuclear industry, since there was no regulatory incentive for them to do otherwise. However, the federal government had already begun to legislate as early as 1968 on emergency preparedness, primarily for those events associated with the release of petroleum hydrocarbons (oil spills). The impetus for this action at the federal level originated from another calamitous incident, i.e., massive oil spill from the oil tanker *Torrey Canyon* off the coast of England in 1967. More than 37 million gallons of crude oil spilled into the water, causing extensive environmental damage. To avoid the problems faced by response officials involved in this incident, U.S. officials developed a coordinated approach to cope with potential spills in U.S. waters. This resulted in the National Oil and Hazardous Substances Pollution Contingency Plan, more commonly called the National Contingency Plan or NCP, which was promulgated in 1968. The NCP is the federal government's blueprint for responding to both oil spills and hazardous substance releases. The 1968 plan provided the first comprehensive system of emergency event reporting, spill containment, and cleanup, and it established response headquarters, a national reaction team, and regional reaction teams.

Initially, the NCP's focus was primarily on emergency response to oil spills. Since 1968, Congress has broadened the scope of the NCP. This first amendment came in 1973 in response to the Clean Water Act of 1972. This revision provided the framework for responding to hazardous substance spills in addition to oil discharges. In 1980, the NCP was again revised in response to the Superfund legislation. This revision broadened the NCP to include response and clean-up of hazardous waste sites in the form of emergency removal actions. The current version of the NCP was revised in 1994 to reflect oil spill provisions of the Oil Pollution Act of 1990 (CFR Title 40, Volume 20, Parts 300 to 390). The NCP establishes the fundamental aspects of the federal government's organizational structure and procedures for preparing for, and responding to, discharges of oil and hazardous substances, pollutants, and contaminants. It includes provision for the development of response teams, the definition of the role of the federal on-scene coordinators (OSC), National Response Center (NRC), the coordination among federal agencies, the preparation of Federal Contingency Plans. The NCP also establishes the authority of the federal government to initiate removal actions at hazardous waste sites.

When the Bhopal disaster occurred in India in 1984, and some 3,800 people died as a result of the toxic release of methyl isocyanate gas, it became quickly apparent that no contingency plans existed in the United States to deal with similar emergencies, and that this type of extreme events involving an industrial toxic gas release had not been not considered in the NCP at the time. In the wake of the Bhopal tragedy and other accidental chemical releases, public concern escalated dramatically. This became even more acute with the advent of environmental regulations that sought to identify the magnitude of the release of hazardous substances to the environment. As a result, the public continued to demand protection, and the Emergency Planning and Community Right-to-Know Act (EPCRA), Title III of the Superfund Amendments and Reauthorization Act (SARA) of October 1986, was the outcome.[1] The onus of Title III is on states and local communities to develop plans for responding to hazardous materials emergencies. Although legislation such as EPCRA is intended to protect the public, others are focused on the protection of workers in the workplace. The Occupational Safety and Health Administration's (OSHA) Hazard Communication Standard, or Worker Right-to-Know, became fully effective in May 1986 and amended as of February 13, 1996.[2] Its purpose is to ensure that employees are aware of hazards in the workplace. Additional federal regulation, that is, OSHA 1910.120–Hazardous Waste Operations and Emergency Response, often referred to as HAZWOPER, became effective in March 1990.[3] It mandates emergency response and preparedness programs for industry, including required interface activities with off-site agencies and prompt notification to them of an emergency situation. It also requires health and safety training for all individuals involved with emergency response and investigation and remediation of hazardous waste sites and spills. HAZWOPER applies to five distinct groups of employees and their employers, which are clean-up operations, corrective actions at RCRA facilities, voluntary clean-up at any site covered by a federal, state, or local environmental action, operations involved with treatment, storage, and disposal of hazardous waste, and emergency response actions. Companies must have a written emergency action plan in place to comply with 29 CFR 1910.38,[4] and an employee alarm plan per 29 CFR 1910.165.[5]

Some states have even more prescriptive regulations. New Jersey's and Delaware's Toxic Catastrophe Prevention Acts (TCPA)[6] are examples. In addition to the sudden release of a substance, environmental emergencies can take on other forms. The discovery of a leaking underground tank or a number of buried drums requires a response that seeks to protect human health or the environment, particularly when the release threatens a water supply or a fragile ecosystem. The response to these situations involves equally important planning activities among federal, state, and local groups.

The planning process is the key to successful emergency preparedness. Relationships among the plant, local government, and the community are often complex. Planning promotes interaction among participants. The planners become aware of one another's strengths and weaknesses, which are factored into the response mechanism. Therefore, the planning process should not be circumvented by reworking a document prepared by others because this diminishes the importance of the planning process and the interaction of those responsible for implementing it.

The planning process can take many forms. Normally, emergency response planning is thought of as being undertaken for unpredictable but anticipated sudden events, such as a spill or gas release. However, planning is critical to the response to any environmental event as well. For example, a concern about the indoor air quality at a school or office building requires detailed planning with regard to sample collection, instrumentation, and analytical procedures if the data are to be meaningful and useful to design a remedial approach.

Normally, one of the most important outcomes of the planning process is the preparation of an Emergency Response Plan. This document covers the many different aspects of emergency response, from establishing procedures for mobilizing resources and communicating with site specific first responders and off-site emergency response personnel to describing levels of emergency situations and providing a description of the conditions associated with each level. The plan is designed to promote effective response with minimal confusion and disruption to site activities. It also defines responsibilities and establishes priorities for essential activities.

The following sections describe the two basic aspects of emergency action response. The first is associated with emergency planning at industrial facilities, and the other is related to emergency response at the community level. It is well known that industrial facilities use and manufacture a wide variety of hazardous chemicals contained in vessels, tanks, pipelines, and other storage containers. All industrial facilities need some form of emergency response planning that establishes the procedures and actions that the facility will follow in the case of emergency. The section on industrial facilities discusses a number of the key aspects associated with emergency preparedness at the facility level, such as the planning process, emergency action levels, the facility response organization, the resources needed to cope with the most probable emergency events, the establishment of an emergency operations center, how to interact with the media, communication equipment and alarm systems needed, personnel protective equipment and protectiveness levels, spill/vapor release control equipment, medical facilities, security and access control, environmental media sampling and testing, recovery and reentry, and training exercises.

The emergency response at the local level is covered in the second part of this chapter, where emergency management and leadership commitment, the community planning team, interaction between various levels of government, local hazard analysis, resources needed on the local level, development of a basic community emergency response plan and the development and distribution of public information and education are discussed.

EMERGENCY PLANNING FOR INDUSTRIAL FACILITIES

One of the reasons for having an emergency preparedness plan is that the stress induced by a crisis severely limits cognitive ability. In plain language, when people become frightened or anxious, their ability to process information and make judgments appropriate to the circumstances is severely degraded. This happens to everyone to some degree. By planning for emergencies, one can make decisions while in a calm state, unaffected by stress, and outline rational response activities commensurate with the events that have been defined and prepared for in advance.

Initially, the emergency planning process focuses on analysis of the situation. Members of the planning team use analytical skills to approach the problem. They will, for example, analyze the hazards associated with the facility, assess the resources currently available to control a potential emergency event, determine the facility command structure, determine what external resources exist, collect information on applicable codes and regulations, and analyze existing plans and assess their validity.

Once this initial work has been completed and relevant material has been collected, emphasis switches toward the preparation of the actual plan document. This includes allocation of the resources needed to control emergency events, procedures to raise the alarm and assess the severity of the situation, establishment of a chain of command and emergency response structure and definition of response strategies to protect people, the environment, and property while mitigating an event. These activities lead to synthesis of the previously accumulated information into a cohesive emergency response organization and structure.

An effective emergency response plan should include the following:

- Pre-emergency planning and off-site coordination
- Identification of roles and responsibilities of assigned personnel
- Training programs
- Communication structure
- Emergency recognition and prevention
- Identification of safe distances
- Places of refuge and evacuation routes
- Decontamination procedures
- Emergency medical treatment and first-aid training
- Locations, emergency alerting and response procedures
- Identification of personal protective equipment (PPE), and emergency equipment

RESOURCES

Facility response teams typically comprise specially trained personnel normally operating the plant itself and therefore familiar with it and its hazards. However, as part of the planning process, a resource assessment should be performed. Figure 5.1 presents a sample format for performing a resource assessment. The list is not necessarily totally exhaustive, but facilities should nevertheless select only those resources appropriate for their anticipated response activities.

The resource assessment should consider not only facility resources but also those available in local municipalities and at neighboring industrial facilities. The local fire department, however, may be trained to cope only with the most common emergencies, such as structural fires and rescue, or perhaps for hazardous material transportation accidents. Thus, they may only support the primary response actions that plant personnel must implement in a serious emergency. Local resources will, however, become essential if the emergency spreads beyond the plant boundary or is the result of a transportation accident.

Resource Assessment			
Resources	*Current*	*Required*	*To Be Acquired (Acquisition Date)*
Emergency Control/Operations Center			
Media Center			
Site Notification System			
Offsite Notification System			
Communications Equipment			
Personal Protective Equipment			
Meteorological Equipment			
Firefighting Equipment			
Spill Control Equipment			
Monitoring Equipment			
First Aid Capability			
Security and Access Control Equipment			
Auxiliary Power			
Trained Employees			

FIGURE 5.1 Resource assessment chart.

Emergency Operations Centers (EOCs)

An EOC is the physical location where a predefined team of responders assembles and operates from during an emergency to coordinate response and recovery actions and resources. These centers may alternatively be called command centers, situation rooms, war rooms, crisis management centers, or other similar terms. Regardless of the term, this is where the coordination of information and resources takes place. The EOC is not an incident command post; rather, it is the operations center where coordination and management decisions are facilitated.[7]

All but very small plants should establish an EOC from which response activities can be directed and coordinated whenever a major emergency is declared or anticipated. Upon declaration of an emergency, the emergency management staff, including the highest-ranking person in charge of the operation, will activate the EOC. The EOC should be equipped with adequate communication systems such as telephones, radios, and other equipment to allow unhampered communication with the site response teams, external agencies, and other response organizations.

A properly designed EOC should serve as an effective and efficient facility for coordinating emergency response efforts. An EOC may serve a number of uses, including operations, training, and meetings. The EOC can optimize communication and coordination by effective information management and presentation.

The EOC should be located where the risk of exposure to accidental releases is minimal. When possible, it should also be located close to routes easily reached by response personnel. Only a limited and prearranged number of people should be admitted to the EOC. This eliminates unnecessary interference and reduces confusion.

The EOC should be designed to protect its occupants against releases, especially against infiltration of toxic vapors. A small meteorological station (or at least a wind sock) should be located nearby to monitor wind direction and velocity. The EOC should have an uninterruptible power supply or at least backup power for lighting and electric communication system operation. The EOC should always be ready for operation. It need not be a single-purpose room; a conference room can be easily adapted for this purpose, provided it is maintained for EOC operations as well.

Media Center

A media center is a designated room located on or near plant property where representatives of the various news media would be admitted during an emergency. This center should be located near the plant entrance and be the only area accessible to news reporters. This limits access to the facility for all nonessential personnel.

The public affairs officer should ensure that the necessary media material is stored at or near the media center. Such material should include a fact sheet on the facility describing the number of employees, annual payroll, taxes paid to the community, a simple description of the plant processes, consumer products that are produced either at the facility or ultimately from its operations, and a facility map.

Communication Equipment and Alarm Systems

Communication equipment and alarm systems are essential to notify plant personnel, to notify external agencies, and to coordinate response operations. Initial notification equipment and procedures are especially important because their effectiveness determines how rapidly the response actions can be initiated. Communication equipment must be available to each function within the response organization to prevent communication breakdowns.

Horns, Sirens, and Public Address Systems Audible alarm systems are commonly used in many industrial facilities. Horns and sirens rely on different types and lengths of tones to convey messages. An alarm should not just warn but also instruct people to perform specific assignments. However, horns and sirens can convey only a very few simple messages. Public address systems are limited in areas of excess external noise. In high-noise areas, it is appropriate to install a visual signal (e.g., a flashing light) as well as an audible alarm system. Systems that use belt-worn vibrators as alarm signals are also used.

Telephones Telephones are often the preferred means of communication for reporting emergencies and for communicating between different areas of the plant. The EOC should be equipped with enough telephone lines to enable all the members of the response teams to communicate effectively. Some lines should be equipped for outgoing-only capability. Cellular phones are also very useful in emergencies. They can be used to notify response personnel who are away from the plant, by emergency management to direct operations while on the way to the site, and even to coordinate the entire response effort.

Portable Radios Radios are most effective for communicating with emergency response teams operating in the field. In addition, they can be a backup system in case of telephone communication breakdown. Emergency response radios should operate on a frequency dedicated for emergency communications only.

Mobile Phone/Text Messaging/Email In recent years, new technology has allowed the contact of many people simultaneously. Computer command centers based at EOCs can now distribute, with just a few commands on a computer, messages to people via phone, pager, fax, e-mail, and text message. Contact information is inserted in a computer calling system. Messages can then be distributed to a predetermined list of personnel based on the alert level and complexity of the event. To reach a wider group, text messages can now be sent to cell phones over a broad-based contact system. Personnel must register to receive the messages and agree to follow emergency response protocol.

Personal Protective Equipment (PPE) The main function of PPE is to protect personnel from a hazard while performing rescue or emergency control operations. Protective clothing for protection against heat radiation or those having high resistance to chemical assault (acid suits) are typically used by response personnel. The most important pieces of protective equipment in both fire and toxic release events are the self-contained breathing apparatus (SCBA).

Personnel performing tasks that require prolonged exposure to a toxic environment such as smoke or toxic vapors typically use SCBA. The use of SCBA requires training. It is also important to remember that personnel performing any such containment or control operations must be trained in accordance with the appropriate levels of emergency response mandated by 29 CFR 1910.120 (q).[3] The PPE and SCBA should be stored in strategic locations throughout the plant, for example in control rooms, EOCs, the firehouse, special plant units, and the emergency supply storage area. A compressor is required for refilling the cylinders. The SCBA should be inspected and serviced periodically through a preventive maintenance program.

In addition to protective clothing, there are a variety of instruments available to monitor the conditions surrounding emergency response personnel. Portable gas detectors that are intrinsically safe for service in hazardous environments are available. These devices can be supplied with sensors that can monitor methane, lower explosive limits, toxic gases, chlorine gas, hydrogen sulfide, carbon monoxide, oxygen deficiency and other hazardous concentrations. Also, portable gas chromatographs are available that can provide compound-specific data on the concentrations of gases in the breathing zone as well as preliminary information on contaminated soil or water.

Other important PPE items are personnel respirators and escape hoods. Both can selectively reduce exposure to toxic gases or particles. All require training to be properly used. There are several different types of respirators and escape hoods, including the following:

- Escape respirators for quickly leaving a dangerous area to a safe one
- Particulate respirators that only protect against particles but not against gases or vapors
- Chemical cartridge or air purifying respirators that trap chemical gases and possibly particles from the breath air
- Powered air purifying respirators use a fan to blow air through the filter to the user

There are some important questions one should ask about any respirator or escape hood:8

- What protection (which chemicals and particles, and at what levels) does the respirator or escape hood provide?
- Is there more than one size?

- How does one know if the gas mask or escape hood will fit the user?
- What type of training is needed?
- Has the respirator or escape hood been tested against claims for protection such as biological agents, chemical warfare agents, toxic industrial chemicals, and radioactive dust particles?
- Who performed the testing, what were the tested levels, and test durations?
- Is the respirator or escape hood certified by an independent laboratory or government agency?
- Are there any special maintenance or storage conditions?
- Will the user be able to talk while wearing the respirator?
- Does the hood restrict vision or head movement in any way?
- Can one carry the device in the trunk of an automobile?
- Is a training respirator available?
- Can one use the same device more than one time?
- Can children wear the respirator or escape hood and get the expected protection?

Finally, EPA identifies four levels of PPE ensembles for responding to chemical spills:[8]

- **Level A** protection is used when contaminants are present that require the highest possible degree of both respiratory and skin protection. Includes the use of an atmosphere supplying respirator such as a self-contained breathing apparatus (SCBA) and a totally encapsulating chemical protective (TECP) suit.
- **Level B** is used when contaminants are present that require the same degree of respiratory protection as Level A, but require a lesser degree of skin protection, such as a splash suit that is not totally encapsulating or gas tight.
- **Level C** involves the same degree of skin protection as Level B, but a lesser degree of respiratory protection. Oxygen levels and chemical concentration levels must be known in order to use the air-purifying respirators in the Level C ensemble.
- **Level D** provides protection only against "normal" workplace hazards and is not designed to protect against chemical hazards. Includes safety glasses, hard hats, steel-toe boots, and leather work gloves.

Firefighting Facilities, Equipment, and Supplies

Medium-sized and large plants usually have some type of firefighting capability. Fire pumper trucks are the most important units. National Fire Protection Association (NFPA) standards provide details on the equipment to be carried on pumpers and on ladder trucks. For example, NFPA provides guidelines for the use, maintenance, and service testing of fire department ground ladders.[9] A firewater distribution system is common to many industrial facilities. Arrangements should be made to access water tank trucks to supply additional water if the need arises.

Specialized firefighting equipment is often necessary at industrial sites because of the unusual chemical process. For example, dry chemical units carrying large quantities of dry extinguishing material such as potassium bicarbonate (purple K) may be necessary where water cannot be used as extinguishing agent.[10] Fire-extinguishing foam is probably the most frequently used nonaqueous medium.

New innovations are assisting firefighters in responding to chemical fires and complex situations. Thermal imaging equipment is now available that allows firefighters to "see" in areas with dense smoke. GPS equipment allows firefighters to locate one another in complex situations where multiple activities are occurring.

Spill and Vapor Release Control Equipment

Few methods are available to control a vapor release after it has occurred. Fixed abatement systems (e.g., water curtains) spraying an absorbent such as water into the dispersed cloud of a soluble vapor such as ammonia and hydrogen chloride or fluoride are occasionally used.[11,12] Sometimes, dispersion of gases in air below their flammability point can be achieved using water streams.

Special tools may be required to perform some response operations to control the leak or vapor release, such as plugging a leak or shutting off jammed isolation valves. Equipment for stopping and containing a liquid spill is also necessary. Emergency containment systems for liquid spills, such as booms and portable dikes, can be built to limit the leaching of spilled material into the ground and to nearby sensitive areas. Quick-setting foams can be applied to create an impermeable barrier to limit leaching of spills into the ground. These foams can also be used to temporarily plug a leak.[13] Also, emergency spill containment barriers designed for rapid deployment are available. These units are manufactured from chemical-resistant flexible membranes and have self-supporting perimeter chambers. Vacuum trucks are another useful type of spill response equipment. These trucks can quickly collect surface liquids for transport to appropriate disposal facility.

Many facilities have spill containment trailers equipped with a variety of spill control equipment and supplies. Usually these trailers are outfitted with sorbent products, acid neutralizers, spill containment berm, pumps and tanks, and various types of PPE. Universal sorbents are available that can control pesticides, acids, hydrocarbons, and chlorinated compounds. Also available are products that rapidly neutralize and solidify low pH fluids such as hydrochloric acid, nitric acid, and sulfuric acid.

Medical Facilities, Equipment, and Supplies

Most industrial facilities have a medical center. This facility should be equipped to deal with the most likely medical emergencies at the particular site and contain a file of material data safety sheets (MSDSs) on site-specific chemicals. Additionally, the plant response team personnel should be trained in cardiopulmonary resuscitation and should be equipped with the most common types of rescue equipment.

Meteorological Equipment

During toxic gaseous release emergencies, meteorological conditions greatly affect migration speed and direction. The most important of these parameters are wind direction and speed. A facility should have one or more meteorological stations where this key information is constantly monitored. The station needs not be complex. Care should be taken to avoid locations where the presence of buildings and other structures may result in faulty readings. In addition to mounting windsocks on the highest point for optimum visibility, windsocks should also be located close to the ground so that people leaving a building in an emergency know in which direction to run to avoid a toxic plume.

Security and Access Control Equipment

In an emergency, it is likely that traffic flow around the plant may have to be redirected, especially if toxic material has contaminated nearby areas. Equipment such as flares, emergency lighting, road barriers, reflective vests, reflective tape, and traffic control cones should be available to security personnel.

Environmental Testing Systems

Although initially the emphasis of the emergency response will focus on containment and control of the situation, it will quickly shift to evaluation of the potential impacts to the environment. Thus, planning should also include methods to quickly assess the degree of potential environmental impacts. While it is not normal for a facility to own a drill rig or soil-testing apparatus, planning should include mechanisms to acquire these services rapidly, if needed. By quickly assessing the magnitude of potential impacts, an effective remedial response that will control potential threats can be developed. Hydraulic push soil-sampling machines are very useful to collect near surface soil and groundwater samples, and a variety of instruments are available to do field analysis of the samples. Also, arrangements should be made with a nearby environmental testing laboratory to provide rapid turnaround analysis of samples.

Mobile laboratories and field test kits for various types of chemicals are available. For example, portable GC/MS units are available that can provide high quality chemical testing in the field on a fast turnaround basis. The ability to have field-based testing is critical when trying to assess the magnitude of the impact and the extent of threats to human health and the environment. GPS systems are available that allow real-time location and plotting of sample locations so that the finding from rapid testing equipment can be interpreted in a dynamic fashion. This allows managers to determine the next sampling locations as the investigation unfolds.

EMERGENCY ACTION LEVELS

A practical way to classify the seriousness of an incident and quickly convey this information to other personnel is to use emergency action levels (EALs), which may be designated by code names or numbers associated with situations of different intensities. The higher the number, the more serious the problem. A four-level classification system is typically adequate:[14]

Level 1: Minor building incident. This can be resolved by the responding service unit. No other entities are involved.

Level 2: Building incident. This can be resolved with existing facility resources or limited outside help. These incidents are usually one-dimensional events having a limited duration and little impact, except those using the space/building in which the incident occurs.

Level 3: Major emergency impacting a sizable portion of the facility and/or outside community. Level 3 emergencies may be single or multi-hazard situations, and often require considerable coordination, both within and outside the facility. These emergencies include projected events on the facility or in the general community that may develop into a major crisis or a full disaster.

Level 4: Catastrophic emergency involving the entire facility and surrounding community. Immediate resolution of the disaster, generally multihazard, is beyond the emergency response capabilities of the facility and local resources.

The use of EALs has the advantage of standardizing response to different classes of events in terms of the resources mobilized to cope with the emergency. It also improves communications during critical times.

EMERGENCY RESPONSE ORGANIZATION

A major objective of contingency planning is the creation of a response organization structure capable of being deployed in the shortest time possible during an emergency. For this purpose, the following questions must be answered:

- What will be the command structure and who will be in command of emergency operations?
- Will the command structure change as more response personnel reach the event site?
- How will the command structure evolve if the emergency worsens?
- Who will decide what company resources to allocate to mitigate the consequences of the event?
- Who maintains communication with whom during an emergency?

- Which emergency functions (e.g., firefighting, engineering, medical) should be deployed?
- Who will be in charge of each specific emergency response function?
- Where should the command post(s) be located?
- Who decides which protective actions to recommend?
- Will environmental testing be required?
- Who decides when the emergency is over?
- Who is responsible for recovery operations?

A response organization, complete with command structure, should be developed. One method of arriving at this is to first develop a responsibility matrix of emergency organization functions versus the departments or positions that will have primary and support responsibilities for performing them. An example of such a matrix is presented in Figure 5.2.

Initial-Response Organization

The timely implementation of appropriate initial response actions may significantly mitigate the consequences of an emergency. One person should be designated to be in charge of the initial response. Usually, responsibility for coordinating these early emergency response actions is assigned to the shift supervisor. The shift supervisor assumes the function of emergency director and assesses the level of severity of the emergency event using the emergency action

Function **Department/ Individual**										

FIGURE 5.2 Emergency responsibility matrix.

level classification system; notifies the appropriate personnel, departments and agencies; and directs the response activities.

Other plant personnel are also assigned the task of covering the other key functions in the initial emergency response organization until the predestinated personnel arrive to relieve them. Initially, the production or operations manager, who could also act as the field operations coordinator, takes the post of response operations coordinator. Alternatively, the production supervisor of the unit where the emergency occurs could take the latter position. These two coordinators are in charge of organizing response activities and directing response operations at the actual emergency scene.

Full Emergency Response Organization

The deployment of the full emergency organization is required only in the case of severe emergencies. An example of a full emergency organization chart is given in Figure 5.3. Multiple personnel are assigned to all emergency functions in the event that the principal person is unavailable to cover that position. The personnel assigned to each of the different functions shown in Figure 5.3 play key roles in implementing the decisions made by the emergency director. They decide what appropriate response actions to take, such as shutting down the plant, fighting fires, evacuating plant personnel, recommending that the public be evacuated from certain areas, carrying out emergency repair work, arranging for supplies or equipment, and coordinating actions with local off-site agencies.

Emergency Director (Site Emergency Coordinator)

The emergency director responsibility includes those actions necessary to bring the emergency under control and the overall supervision of the protective actions recommended for the public, employees, and the environment. It is recommended to the degree possible that the same hierarchical structure used during normal operation should be maintained during an emergency. Thus, the plant manager should be assigned the emergency director position, if possible.

Response Operations Coordinator

The response operations coordinator operates in the EOC and is responsible for coordinating the activities. The response operations coordinator performs the following functions:[14]

- Assists the emergency director in organizing and directing emergency activities
- Formulates strategies on actions to be taken to mitigate consequences of the event
- Maintains direct communication with the on-scene incident commander
- Establishes a journal/log for recording activities
- Evaluate operational information and determines priorities
- Requests additional personnel and equipment resources

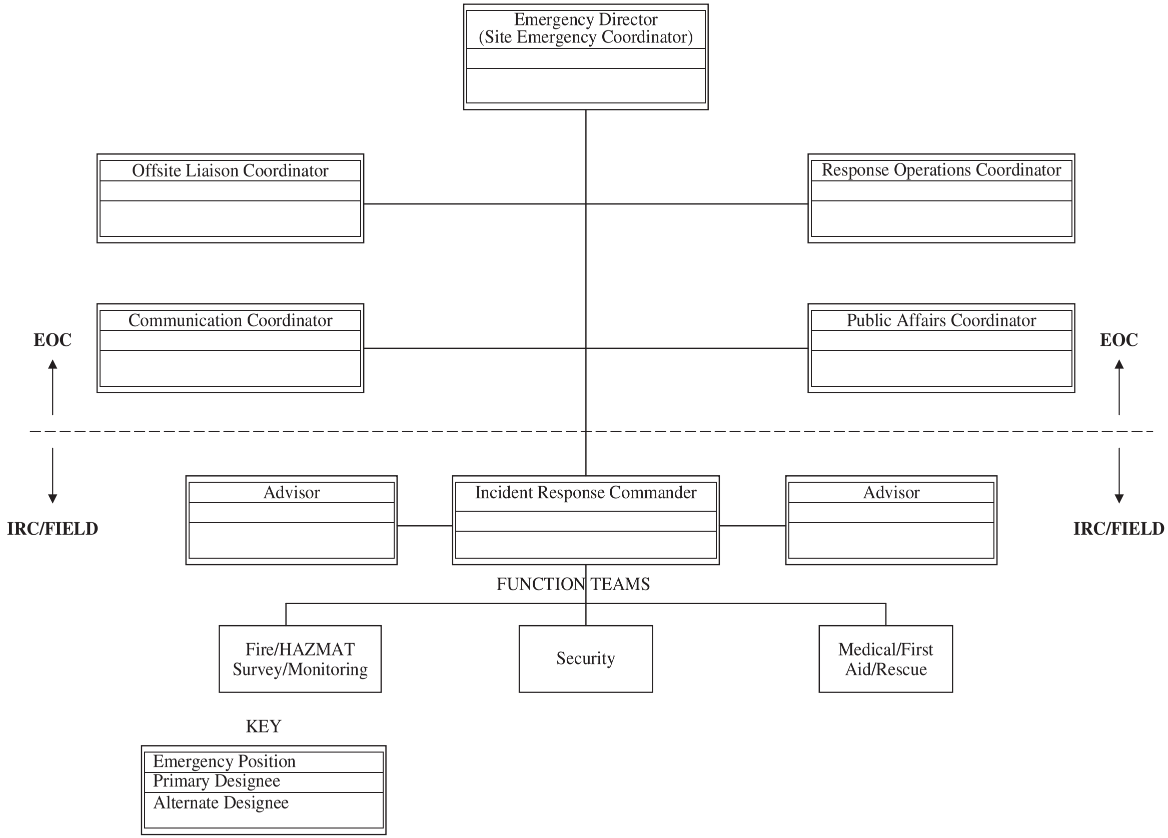

FIGURE 5.3 Emergency response organization.

The response operations coordinator should be very knowledgeable of the plant and its response plan and organization. In small plants, this position may coincide with the emergency director function. In other cases, the plant manager may assume the emergency director function, mainly because of the responsibilities associated with this role and his or her overall responsibility for the safety of the facility. The response operations coordinator may perform the bulk of the coordination activities.

Incident Response Commander (IRC, Field Operations Coordinator)

The incident response commander or field operations coordinator is the highest ranking officer at the scene of an emergency event. The command post from which that person directs the emergency response should be located as close as possible to the emergency field operations. The main responsibilities associated with this position are as follows:

- Direction and coordination of all field operations
- Assessment of severity of the incident
- Recommendation of on-site protective actions
- Implementation of response actions at the scene of the event
- Coordination of these actions with the emergency preparedness coordinator

The incident response commander must also be very familiar with the facility and have solid technical expertise.

Incident Response Team

These are the group of persons directly involved, and prepared for, an emergency event. Typically, there are two types of teams: specific member teams and volunteer or ad-hoc teams.

Specific member teams are trained and are on standby all the time during scheduled hours. They are normally paid by the state or local municipality or agency and therefore outside the facility operations. Sometimes, plants are large enough to support a specific member team. They are usually organized by rank and have a clearly defined chain of command and response structure. Examples are SWAT and municipal fire department HAZMAT response teams.

Volunteer or ad-hoc teams are composed of willing volunteers who get special training focused on emergency response. These teams undergo specialized training for various aspects of the response and are prepared to fulfill the roles required by the specific situation. They normally have unrelated jobs at the facility, but in an emergency respond as a member of the team. Example would be a member of the engineering department trained in confined space emergency response.

EMERGENCY FUNCTIONS

Implementation of an emergency response plan relies on a number of functions that deal with different aspects of the emergency. The most important emergency functions are as follows:

- *Communications*. Ensures that the flow of communications among the response personnel within the on-site response is effective and uninterrupted.
- *Fire and rescue*. Most facilities have an emergency response team, primarily trained to handle fires and rescue operations and typically composed of personnel from the different plant units or departments. These teams usually have some basic training in the handling of other types of emergencies (such as spills) to control the situation before more specialized teams arrive at the scene. Team members are trained in comprehensive first aid, search-and-rescue procedures, and emergency equipment handling.
- *Special hazard (HAZMAT) or spill control*. This function is associated with personnel specially trained in dealing with any emergency caused by the presence of special hazards such as releases of toxic or hazardous materials. The handling of these emergencies depends on the physical state of the material released, type of hazardous material (e.g., poisonous gas, explosive, flammable liquid), type of facility from which the material is released (e.g., storage tank or reactor), and type of event (e.g., vessel rupture, overfilling, spill, fire, toxic vapor release).
- *Process/utilities*. Controls the process during the emergency and ensures that the necessary facility units are shut down. This function is also responsible for generating the necessary utilities during the emergency and isolating the impacted portions of the manufacturing process.
- *Engineering/technical assistance*. Provides the technical support for strategies to isolate damaged process equipment, designs emergency transfer of materials to safe vessels, and is responsible for all other process-related emergency management.
- *Environmental and field survey*. This function is responsible for reducing the impact of an emergency on the environment. This function develops programs to monitor potential migration of the release and assesses impacts.
- *Medical*. This function is responsible for providing first aid to the victims and arranging for their prompt transportation to an appropriate hospital and also for providing information on the nature and properties of the chemical and identifies the most appropriate emergency treatment of injured or exposed personnel.
- *Security*. This function is responsible for ensuring that plant security is maintained, making sure that unauthorized persons are not admitted to the plant, and controlling the entry and exit of contractor and other appropriate response personnel.

- *Off-site liaison*. This function coordinates actions between the on-site response organization and the various external response teams, departments, local representatives, agencies, and neighboring industries.
- *Public affairs/legal counsel*. The function is responsible for providing news releases and legal counsel during an emergency.
- *Resources/supplies* This function ensures that the necessary supplies are available to the emergency response teams and organizes and maintains the staging area where emergency material and equipment is temporarily stored.

All the persons in charge of each of these functions report to the emergency director or to the incident response commander. A team is established, the size and composition of which depends on the task to be performed and the size of the facility. This team operates according to instructions provided by the emergency director's staff and utilizes preformatted, written procedures to accomplish their tasks.

EMERGENCY RESPONSE ACTIONS

One critical aspect of emergency preparedness is the identification of the actions to be implemented by the various response functions. Although the emergency response plan includes generic descriptions of the functions, specific details are incorporated in the annexes to the plan. For simplicity and user friendliness, these are best formatted as checklists.

Concept of Operations

An outline of the response sequence should be included in the emergency plan. This plan should include a brief description of the following points:

- Brief description of plant operations and chemicals handled
- Warning upon discovery of an abnormal event
- Event evaluation and classification
- Emergency declaration and response team activation
- Notification of off-site response teams
- Implementation of on-site response actions
- Identification of protective actions
- Coordination of response actions with external resources
- Completion of the response and plant reentry

Emergency Response Implementing Procedures

Emergency response organization implementation is organized according to the type of hazard. Different manufacturing facilities use varying types of chemicals in their processes, which require customizing the response to the situation. For each hazard, a set of procedures is developed, which includes checklists of detailed steps, to be followed by the response teams for the release situation.

Environmental Considerations

An environmental emergency such as a hazardous substance spill or gas release requires not only notification and mobilization of containment and control response teams but also an understanding of the potential migration pattern of the material in the environment. Basic site information, such as geology, soil types, proximity to water bodies, and general meteorological conditions, needs to be available so that this information can be used to design a sampling program. It is important to quickly obtain data on soil, air, or water impacts in order to assess risk and define the magnitude of the affected area. For example, if a facility has a shallow water table, a surface spill could impact groundwater quality. This situation would require groundwater as well as soil sampling. Conversely, if the water table is deep or separated from the surface by a low permeable layer, then groundwater sampling may not be necessary and the focus of sampling may be toward soil and surface-water impacts.

Another important need for sampling media at the time of the emergency is to establish a database that can be used to protect the responsible party from unjustified damage claims. Environmental damage lawsuits are common in today's world and in many cases are driven by emotional issues. Hard data, acquired at the time of the incident, can be very useful in controlling damage claims and establishing a factual representation of the impacts from the event.

Finally, it is important to understand the local, state, and federal regulatory community. A spill or other emergency event that causes a release of a chemical to the environment will involve reporting this incident to the appropriate regulators. They will want to understand the extent of the impacts and whether any human health or sensitive environmental systems are threatened. Usually, any sampling data generated by studying the effects of the event will need to be submitted to the regulators. In some cases, an environmental consultant or engineer will needed to be hired to oversee the investigation and determine if clean-up is necessary and to what degree. He/she would also be responsible for preparing a report of clean-up. It is useful to document activities taken to minimize environmental impact in light of the sensitivity of this issue and the public concern.

Recovery, Reentry, and Restoration

One area typically neglected in the emergency plan is postemergency activities. Specific procedures for recovering from an emergency and reentering a facility must be determined on a case-by-case basis. However, guidelines for response team activities following termination should be included.

Once the critical phase of the emergency is concluded, an inspection team appointed by the emergency director should enter the damaged area and ensure that it is safe for recovery operations.

The impact of an emergency event may be felt throughout the plant even if only a relatively minor emergency has occurred. If toxic or flammable materials have been involved in the event, the area must be decontaminated and the procedures used should be discussed in the plan. It will be important to collect samples of the impacted area after clean up in order to document the restored condition and provide evidence of a clean work space. The main objective of the recovery phase is to restore the plant to its initial condition so that normal plant operating conditions can be established as quickly as possible. After the emergency is concluded, the emergency response should be reviewed and the plan adjusted accordingly.

TRAINING, EXERCISES, AND PLAN MAINTENANCE

An emergency plan, no matter how carefully prepared, cannot be effective unless accompanied by a training program. The objectives of training and drills are to accomplish the following:

- Familiarize personnel with the content of the plan
- Train new or existing personnel
- Train specific response personnel in certain special skills
- Introduce personnel to new equipment and techniques
- Keep personnel informed of changes
- Test the preparedness of response personnel
- Test the validity, effectiveness, and timing of the plan
- Test emergency equipment preparedness
- Maintain cooperative capability with other response organizations

Anyone assigned to a position within the emergency response organization needs initial training. Members of off-site emergency response organizations should participate in training exercises because it strengthens the cooperation among response groups and improves communication procedures. Drills and exercises are vital to emergency preparedness. Both involve enactment of the implementation of the response actions performed during an emergency.

There are three types of training: tabletop drills, functional drills, and full-scale exercises. Tabletop drills are useful for orientation purposes, while functional drills are designed to test a limited aspect of the response capability (e.g., a fire drill). Full-scale exercises are more comprehensive and test the entire response organization up to and including communication with off-site response organizations. An important benefit of training exercises is that the response plan is reviewed during these activities, a process referred to as *plan maintenance*.

The two main benefits of the training are individual training and system improvement. Individual training exercises enable people to practice their roles and gain experience in these roles, while the exercises improve the organizations system for managing incidents and emergencies. Exercises only have value when they lead to improvement.

EMERGENCY PLANNING AT THE LOCAL LEVEL

Regulatory requirements exist under OSHA and the Environmental Protection Agency (EPA) for interaction with local, state, and, in some cases, federal agencies[1,2,3] and require the development of hazardous materials emergency response plans for local communities. For communities to develop these plans, they need to be aware of the hazards presented by facilities within their planning district. Those facilities that fall within the planning district must, by law, provide a representative to assist the community with its planning.

Emergency Management

Effective emergency planning at the local level provides assurance to a community as to how citizens and the environment will be protected in a disaster. Emergency response plans on the local level have the following objectives:

- Create an ensured level of preparedness
- Ensure an orderly and timely decision-making process
- Ensure the availability of necessary services, equipment, supplies, and personnel
- Ensure a consistent, preplanned response

The optimum emergency management plan delineates actions that may be required for any hazard.[14] Such broadly applicable functions as direction and control, warning, communications, and public protective actions are generic to the management of events.

A multihazard emergency operations or contingency plan consists of a basic plan, generic functional annexes, and hazard-specific appendices.[15] The basic plan provides an overview of the local entities' approach to emergency management, while the generic functional annexes address the specific activities required in all emergency response on the local level. Hazard-specific appendices provide response direction for special problems identified during the hazards analysis process. They detail the tasks to be performed by preassigned organizational elements at projected places under specific circumstances, based on plan-defined objectives and a realistic assessment of response capabilities.

Leadership Commitment

Management commitment to emergency preparedness is essential to an effective response at the local level. The motivation for leadership commitment to effective emergency preparedness comes from the concerns of the citizens in the community. Citizen awareness of the potential threats to safety, health, and the environment from hazardous materials is growing. Local government officials have the authority and access to resources necessary to develop the plan that will allay their fears. They also have the credibility to interact effectively with industry leaders and other government jurisdictions.

Management of a crisis and authority to direct the response must be vested in an individual who is responsible and accountable. At the local level, this is usually the elected chief official. Alternates should be named for each defined position in the local emergency organization. Alternates must have the same responsibility and accountability. The question of direction and control must be confronted directly before an emergency occurs because it is impossible to establish a line of command and control while a crisis is in progress. The chain of command needs to be clearly laid down and accepted within an organization long before an incident occurs.

This is particularly important with regard to the interaction between the local level officials and others within the state, county and federal government. The planning document should address the different levels of government and their roles and responsibilities during emergency response. Local jurisdictions have the primary duty to save lives, protect property, protect the economic base of the community, and preserve the environment. However, there will come a time when an emergency requires resources beyond those available at the local level, and additional agencies and departments need to assist. The interaction between all these parties must be prearranged in order to allow for the effective command structure. Normally, federal resources in the form of FEMA have to be acquired through a formal request made by the governor of the affected state.

The chief executive of a community is charged with coordinating the functions of the local fire and police departments and any other agencies involved in aspects of local emergency response. These groups may have differing views about their roles in managing an incident. It is up to the community leader to resolve these differences before an emergency situation arises. It is important to note that the responsibility for assuring proper local incident response is assigned to the appropriate office and not the individual. Ideally, there should be written agreements in place that define the roles and responsibilities of all the appropriate entities before the emergency. These agreements can be obtained through the planning process.

Planning Team

Successful planning requires community involvement and support throughout the process. When a community participates in the planning process, then it will accept the plan. Cooperative interaction among responders and the community begins with the planning process. Most important in the development a community emergency preparedness plan is a leader who has the respect of the organizations involved in the local emergency response. Management and communication skills are essential for gaining the cooperation of all concerned parties.

The team should be staffed with individuals with expertise in many areas. Representatives of industrial facilities in the community that could be potential sources of hazardous substance releases should be included, as well as knowledgeable officials from transportation, community resources, and utilities.

The group should represent all elements of the community and be able to work cooperatively.

A component of the community emergency response planning is the Local Emergency Planning Committee, or LEPC. This is a voluntary organization established to meet the requirements of the federal Emergency Planning arid Community Right-to-Know Act (EPCRA), also known as the Superfund Amendment and Reauthorization Act (SARA Title III), for emergency response planning. EPCRA contains four major provisions:

1. Emergency planning
2. Emergency release notification
3. Hazardous chemical storage reporting requirements
4. Toxic chemical release inventory

Each one of these components is associated with specific reporting requirements, which will not be discussed here. Instead, the following sections briefly touch upon the planning process, the key steps in the development of the response plan, the content of the plan and procedures, and the integration of the plan with other response plans.

PLANNING PROCESS

As discussed in previous sections, the planning process is the key to success. Agreeing to use a document prepared by others substantially reduces the value of the planning process and diminishes the commitment of those who must prepare the plan. The relationships of the industry, government, and the local community are often fragile. The process itself provides an opportunity to interact with the participants so they become aware of their strengths and weaknesses.

Hazards Analysis

The planning team is responsible for several key components. Hazards identification, vulnerability analysis, and risk analysis together make up the hazards analysis task. Help with this process is available. The EPA has developed a publication jointly with the Federal Emergency Management Agency (FEMA) and U.S. Department of Transportation (DOT) to assess the hazards related to potential airborne releases of extremely hazardous substances ["Technical Guidance for Hazards Analysis" ("Green Book")]. Information on this and other relevant publications is available elsewhere.[16]

Hazards Identification Identification of the hazards determines whether a plan is really needed. High-priority hazards should be addressed first. For facilities or transportation routes where the identified hazard is toxic or flammable material, the identity, location, and quantity must be precisely determined. The facility that manufactures, processes, stores, or uses such material is the logical source of this information.

Vulnerability Analysis The vulnerability analysis, sometimes called a consequence analysis, involves determination of the areas, populations, and facilities that may be at risk if a release occurs. A list summarizing those critical facilities in the county or municipal area whose loss would severely hamper emergency operations or increase the potential for loss of life or property should be included in the plan.

Risk Analysis The purpose of the risk analysis task is to determine the potential and severity of a possible incident. Methodologies are available for calculating estimates of the quantity of a release, the rate of dispersion, and possible concentrations that could affect human health. The previously identified EPA document[16] lists a number of publications and computer programs available from federal agencies, such as the *Handbook of Chemical Hazards Analysis Procedure* ("Brown Book"), which provide fairly detailed information useful for estimating the size of zones considered vulnerable to toxic effects from accidental releases. These documents give additional information on suggested levels of concern. When completed, a local risk and vulnerability analysis should provide the following:

- Geographic description of the areas deemed vulnerable to the identified hazard
- Size and type of populations expected to be in the defined vulnerable zones
- Property and essential utilities services that may be affected
- Environmental media that may be affected

Examples of emergency planning information that result from this process include needs for facilities and equipment; identification of safe zones for conducting response coordination and the type of equipment needed for event mitigation, emergency worker protection, and spill clean-up. Also, criteria for determining the extent of emergency response required can be established.

Additional information that should be included in the risk analysis is identification of important community resources. Sources of water are particularly vulnerable to environmental emergencies. Groundwater supply wells or surface-water reservoirs should be located on maps. Water supply distribution systems, important transportation routes, electrical supply substations, and wastewater treatment plants are examples of community resources that should be factored into risk analysis. Recently, geographic information systems (GISs)—computer systems capable of assembling, storing, manipulating, and displaying geographically referenced information—have become widely used to electronically map community resources, thus enabling risk planners who must respond to emergency situations to have access to relevant data identified according to their geographic locations, such as population densities, wetlands, groundwater resources, or critical conservation areas.[17]

Emergency action levels (EALs) or an incident classification system should be included in the planning process because they are preestablished conditions that can be used to trigger a desired response. The definition of EALs during the planning removes the ambiguity of uncertainty attitude when a problem emerges.

Damage Assessment and Recovery Operations

During the early phase of an event, the initial damage is only estimated. Plans should include procedures for conducting more detailed surveys. The procedures should include safety concerns, structural damage, clean-up activities, reentry controls, and hazard assessment. Recovery operations include informing and briefing local officials, issuing public information releases, restoring medical and government functions, removing debris, restoring utilities, providing emergency shelter, and providing building and public safety inspections.

Resources

Resources, in terms of people as well as facilities and equipment, are necessary for the contingency plan to work. Questionnaires should be developed in order to identify available resources. The questionnaires should be provided to the sources of identified hazards (facilities, transporters) and to local response and government agencies. The National Response Team's *Hazardous Materials Planning Guide* (NRT-1, 2001 update) contains a list of questions.[18]

Personnel The people available to implement the contingency plan must be identified. The specific community points of contact should be identified by position and title, along with their areas of responsibility. A list of the individuals who hold these positions and their alternates should be developed separately. Since positions stay constant, the plan should identify position titles only, with names of responsible individuals and 24-hour phone numbers in a separate, easily updated document. Once the personnel resources and areas of responsibility are identified, a matrix of groups versus functions is readily constructed.

Facilities In most cases, local governments already have facilities in place to handle the types of emergency situations they are likely to face. To the degree possible, the facilities should be integrated into the plan and augmented as necessary for industrial emergency response. In order to develop mutual understanding, letters of agreement or memoranda of understanding must be executed between government leaders and the organizations responsible for buildings that may be needed during an emergency. Normally a section of the town hall or police or fire department headquarters is established to store the equipment necessary to set up a center from which to direct emergency response.

The public receives most of its information about emergency situations through the media. For this reason, a media center should be available, staffed by spokespersons from industry as well as from local government and response agencies. Other facilities that may be needed in local response to an emergency depend on what has been identified during the hazards analysis phase. A government inventory survey (GIS) can be very useful in quickly identifying available resources. For example, if emergency response personnel may be exposed to toxic or radioactive materials, a decontamination center may be required. Portable, inflatable tents have been designed for this purpose. Whatever means are employed, procedures should be in place for their use. Additional consideration should also be given to the possible need for vehicle decontamination. For example, some commercial car washes recycle their wastewater, and agreements could be made with them.

The planning team should make arrangements assuring that emergency medical treatment will be available. The plan should consider the placement of a triage area near the scene of an event. Agreements should be established with local ambulance companies who will be directed to this area to transport the severely injured to area hospitals or treatment centers. The planning team should ensure that medical personnel at the designated centers are aware of the potential health hazards.

Sheltering in place is the most desirable mode of public protection in fast-moving industrial emergency events. However, evacuation of areas near the scene may be necessary. The planning team should develop an evacuation plan that describes optimal routes and identifies relocation centers. Public schools are often designated as relocation centers because they have cafeterias, adequate sanitary facilities, and large open gymnasiums.

Equipment The equipment needed for emergency operations at the local level is, to some degree, generic, yet also hazard specific. Emergency operations centers are equipped to handle any kind of major emergency. Communications equipment will be essentially the same in all cases, as will public warning systems and notification methods, traffic and access control, public works, law enforcement, and health and medical services. Computers connected to the Internet and copy and fax equipment should be available for electronic/hard-copy transmission and reception of data and messages.

Large-scale maps of the planning area should be prominently displayed in the local EOC. Major transportation and evacuation routes, as well as identified hazard locations with their vulnerable zones, are provided on the base map. Airborne dispersion plume projection overlays or templates are useful additions, especially for transportation accidents involving toxic releases or spills, with known wind speed and direction and populations at risk identified promptly for protective action. Specialized equipment for response to industrial plant emergencies depends on the nature of the identified hazards. Much of this necessary planning information comes from the hazards analysis process. Here, again, a GIS is useful because it allows a large amount of information to be stored electronically and then integrated with other relevant information to evaluate relationships.

Content of the Plan and Procedures

The best local-level contingency plan attempts to consider all potential hazards and is adaptable enough to accommodate those identified in the future. However, it is overly optimistic to consider that all hazards can be planned for; thus, a better term for the plan is a multihazard emergency operations plan (EOP). The EOP includes (1) a basic plan, an overview of the general approach to emergency management; (2) functional annexes in support of the basic plan to address specific activities critical to emergency response and recovery; and (3) hazard-specific appendices to the plan that address specified emergency situations. Dealing with the aspects common to all hazards first and then examining hazard-specific characteristics unique to the planning district is both efficient and economical.

Basic Plan The basic EOP is an umbrella plan that contains a substantial amount of the generally applicable organizational and operational detail. The basic plan cites the legal authority for the plan, summarizes the situations addressed, explains the concept of operations, and describes the organization and responsibilities for emergency planning and operations. The basic plan should also include maps, organization charts, and the emergency responsibility matrix. The plan should also identify critical environmental resources and environmentally vulnerable areas within the planning area.

Functional Annexes The generic functional annexes define and describe the policies, procedures, roles, and responsibilities that are inherent in the functions before, during, and after an emergency. These should include standard operating procedures, which are user friendly, checklist-type instructions for the various segments of the emergency response organization to execute the functions defined in the annexes. A telephone roster listing the names and phone numbers of key members of the emergency response organization (and their alternates) should be provided. Additional information that should be contained in the annexes is local environmental data. This would include critical habitat areas, water supply information, groundwater resources, and potentially sensitive receptors such as hospitals and schools.

One area too often overlooked in the local planning process is the step taken to return to normal conditions following an emergency. It is suggested that the planning team visit a community where an emergency event has previously occurred to learn from them what recovery problems they faced and how they resolved them.

Hazard-Specific Appendices The unique characteristics of hazards identified specific to the local planning district are included as appendices to the functional plan. A single appendix should address all response function requirements related to a particular hazard.

Plan Integration

Coordination of contingency planning between industry and community is necessary to develop mutually acceptable solutions to anticipated events. Should an actual emergency response be necessary, cooperation and commitment supply the means for orderly, timely decision making. It takes time to lay the groundwork among the members to establish an approach to cooperative problem solving. Industry should provide personnel to local planning teams and community planners should be invited to industry planning meetings.

PUBLIC INFORMATION

Public information has two roles in contingency planning: education about the plan itself and notification of an emergency condition. The first is a public relations function and the second a necessary part of the plan itself.

Public Education

Residents and businesses in industrial areas are increasingly aware of potential threats to their well being from industrial and transportation emergencies. The more information citizens have about environmental conditions and potential threats in their communities, the better equipped they are to participate in measures for their own protection. The hazards in a community and what both industry and the jurisdiction are doing to minimize the risks must be made known clearly and explicitly to the public. Perception and truth can be the same in the public eye.

People react differently to the same risk, depending on their backgrounds and their level of risk acceptance. Voluntary risks such as smoking and not wearing a seat belt are usually accepted, whereas the involuntary risks of exposure to asbestos, contaminated drinking water, or a toxic plume are not. Health risks, especially long term, are of primary concern to those who resent risks not of their own choosing. While risk comparisons may be valid, it is better to focus discussion on preventive measures, emergency preparedness, and containment and remediation procedures. The public gets most of its information through the media, which can sometimes oversimplify complex situations. The key is to present essential factual information in readily understandable terms.

When the first round of planning is complete and the plan is initially approved by the planning committee, a familiarization program should be undertaken so that citizens will understand their expected actions. Presentations to community groups are good, but they may not reach all that could be affected. Experience has shown that readily accessible emergency information presented positively and in an attractive format is remembered and used. For example, one possible method is the creation of an attractive calendar distributed annually to households and commercial establishments that contains simple instructions for citizens to follow. Another option is to provide the information on one- or two-page inserts in local telephone directories. Public confidence is enhanced when citizens have the factual information needed to make intelligent decisions.

Public Emergency Notification

When an emergency does occur, the local emergency response team must be promptly notified, and a public warning must be issued to all who may be affected. A standardized notification message form should be available to both sender and receiver of the initial information. How the media are treated while an emergency is in progress determines, to a large extent, public perception and reaction. Establishment of a media-briefing center or public information center is important. Here the local designated spokesperson can coordinate the timely provision of accurate, detailed, and meaningful information to media representatives.

CONCLUSION

Industrial emergencies are a byproduct of many of the technologies that permeate any industrialized society. Since the risk associated with them, like the risk associated with any other human activity, can never be completely reduced to zero, society has to learn to live with the finite possibility that industrial emergency situations can occur if it wants to benefit from the technologies that can generate them. What one can do, however, is to learn how to reduce the frequency with which such events can occur, learn how to cope with them, and minimize their consequences on people, environment, and property once they have occurred. Emergency preparedness and emergency planning are the tools that can be effectively used to do just that.

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Doctors Agardy and Sullivan would like to dedicate this sixth edition of *Environmental Engineering* to Nelson L. Nemerow who passed away in December of 2006. Dr. Nemerow was born on April 16, 1923 and spent most of his productive years as an educator and prolific author. He spent many years teaching at Syracuse University, the University of Miami, North Carolina State, Florida International, and Florida Atlantic University. He authored some 25 books dedicated to advancing the art of waste disposal and utilization. His passion was waste minimization and the title of one of his most recent publications, *Zero Pollution for Industry*, summed up more than fifty years of teaching and consulting. A devoted husband and father, he divided his time between residences in Florida and Southern California. Nelson served in the United States Merchant Marine during World War II. His commitment to excellence was second to none.

CONTENTS

PREFACE

Today's scientists, engineers, public health workers and physicians face challenges which were predicted, but certainly not expected to emerge this soon and to the magnitude presently occurring. The problems and proposed solutions in this volume cover a broad spectrum of issues including industrial and domestic solid wastes, air pollution and associated global warming, noise pollution and housing.

Many engineering elements go into developing solutions to these problems including the need for more detailed mapping and surveying, developing improved housing codes, including the development of more eco-friendly building materials and greater emphasis on conservation. Issues such as site planning and associated environmental assessments now play a major role in virtually all proposed developments.

New technologies and approaches are constantly evolving and are being implemented in greater scale that ever before. Old landfills are being mined for fuel (gasses), new landfills are designed to prevent waste materials from migrating to groundwater, and new approaches to waste incineration focus on energy recovery and conversion of waste materials into usable materials.

In many developed communities, noise pollution has been identified as a major problem and one sees more and more barriers constructed to suppress noise. Going a step further, home construction codes have lead to the development of materials for construction which are not only more eco-friendly but act as a much improved barrier to both noise and heat transfer.

As the earth's population grows, problems of food, water, land, housing, sanitation, medical care and global warming, to name a few, continue to place new challenges on the engineering community. The question always uppermost in our minds is "Are we able to cope?" The answer lies in the knowledge of engineers and the resources necessary to not only meet these challenges, but to address them head on and develop appropriate solutions. This text should help engineers and scientists meet these challenges.

Franklin J. Agardy
Patrick Sullivan
Nelson Nemerow

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CHAPTER 1

INDUSTRIAL SOLID WASTES UTILIZATION AND DISPOSAL

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INTRODUCTION

There are a lot of definitions for the word *industry*. The most generic definition is, “An organized manmade activity that provides goods and services essential for maintaining and developing human life.” As much as there is diversity in human needs and activities, there is also a great diversity in industry. North America Industrial Classification System (NAICS) has classified industries into the following industrial sectors according to their activities:

- Agriculture, forestry, fishing, and hunting
- Mining
- Utilities
- Construction
- Manufacturing
- Wholesale trade
- Retail trade
- Transportation and warehousing
- Information
- Finance and insurance
- Real estate and rental and leasing
- Professional, scientific, and technical services
- Management of companies and enterprises

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- Administrative and support and waste management and remediation Services
- Educational services
- Health care and social assistance
- Arts, entertainment, and recreation
- Accommodation and food services
- Other services (except public administration)
- Public administration

Another approach to classifying industries in different Asian and African countries is by their potential environmental impact according to three different categories. The three main categories are white-list industries, "category A," gray-list industries, "category B," and black-list industries, "category C."

White-list industries/projects/establishments have minor environmental impacts. They include the following:

- Textile factories, excluding dying unit and located in approved industrial sites
- Leather and shoe factories situated in approved industrial sites without tanneries
- Rubber and plastic factories situated in approved industrial sites
- Smokehouses producing small quantities (500 Kg or less) of foodstuff per day
- Very small wastewater treatment plants with a capacity of 1,000 person equivalent or less
- The expansion or modification of an existing road that would be immediately carried out to lengthen the road or widen it by 15 percent or less
- Breweries, malt houses, and mineral-water factories situated in approved industrial sites

Gray-list projects or industries for establishments might result in substantial environmental impacts. They include the following:

- Iron foundries and nonferrous metal foundries
- Engine works and machine shops
- Manufacture and assembly of motor vehicles
- Cleaning establishments and commercial operated laundries
- Tanneries with a production of 1 million square feet/year or less
- Pharmaceutical and chemical factories
- Small wastewater treatment plants with a capacity ranging from 1,000 person equivalent to 1 million person equivalent, etc.

Black-list projects or industries for establishments have severe potential impacts. These include the following:

- Iron and steel works with production greater than 150 metric tons/day
- Cement works using dry process and lime works with high capacity (100 metric tons/hour and above)
- Mining minerals in new areas where the mining excesses a total area of 1,500 acre land
- Pesticide manufacturing plants
- Pulp and paper production
- Lead smelters
- Oil and gas fields development, production, and exploration

A third approach to classify industries into two major sectors: the primary sector and the secondary sector. The primary sector of industry is responsible for converting the natural resources into primary products. The major types of industries that are considered to be primary industry are agricultural industry, mining, fishing, and forestry. Those types of industry prepare the raw material for other industries. The secondary industries take the output of the primary industries and, through processing, manufacturing, and construction provide a finished product ready to be used by the consumer. The secondary sector can be further classified into heavy industries and light industries. Heavy industries include iron and steel industries, marble and granite industries, petroleum and petrochemical industries, industrial equipments, and cement industry. Light industries include textile, clothing, food (including sugar and dairy), oil and soap, chemical and pharmaceutical, pulp and paper, metal finishing, furniture, fertilizers, tanning, electronics, and telecommunication industries.

Whatever the methodology utilized to classify industries within the industrial sector, the most important concern here is that these classifications are usually done to assemble companies into common groups that reflect shared markets and products or to reflect their degree of impact on the environment so that more control or waste utilization could be achieved.

Industry has been an open system of materials flow. People transformed natural materials such as plants, animals, and minerals into tools, clothing, and other products. When these materials were worn out, they were dumped or discarded, and when the refuse buildup bothered the habitants, they simply relocated it, which was easy to do at the time due to the small number of habitants and the vast areas of land.

An open industrial system—one that takes in materials, energy and water, creates products and waste materials and then throws most of these—will probably not continue indefinitely and will have to be replaced by a different system. This system would involve, among other things, paying more attention to where materials end up, and choosing materials and manufacturing processes that generate a more circular flow through recycling concept. Until today, industrial societies have attempted to deal with pollution and other forms of waste largely through pollution control, treatment, or disposal regulations according to life cycle assessment (LCA), following the concept of cradle-to-grave shown

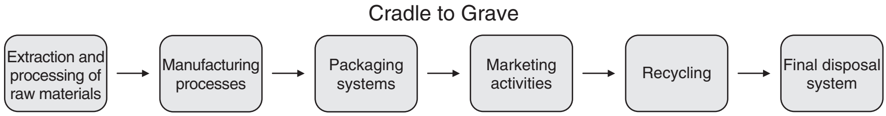

FIGURE 1.1 Traditional life cycle assessment.

in Figure 1.1. Although the "depletion of natural resources" strategy has been partially successful, the high capital and running costs, as well as the depletion of natural resources, cause it to be "unsustainable." Consequently, LCA should be based on the cradle-to-cradle concept, not cradle-to-grave concept, for industrial activities for conservation of natural resources.[1] The goals of any industry must include the preservation and improvement of the environment, as well as the conservation of natural resources. With industrial activities increasing all over the world today, new ways must be developed to make large improvements in our industrial interactions with the environment.

Industrial development/modernization is characterized by two main trends. The first is the establishment of new technologically competitive industries, and the second is the expansion and renovation of existing industries to increase their productivity. Industrial modernization is characterized by implementing cleaner production techniques to approach industrial ecology and reach cradle-to-cradle concept.[1] Industrial development and industrial modernization require establishing a good management system within an existing establishment such as an environmental management system or ISO 14001 to be able to approach cradle-to-cradle.

The new strategy for conservation of natural resources according to the cradle-to-cradle concept discussed in this chapter will help the developing countries to develop new job opportunities and reduce the cost of products as well as protecting the environment without any further burden to the investors. As for developed countries, this will help them conserve the natural resources so they can stop searching for more and more suitable sites for landfills. According to the Japan Environmental Agency, Japan currently consumes 1,950 million metric tons/year of natural resources and imports 700 million metric tons/year from overseas.[2] A total of 450 million metric tons of waste (industrial and municipal) are generated per year. Over 60 percent of this waste is either incinerated or landfilled. Current estimates predict that remaining landfill capacity will be exhausted by 2007. As a result, Japan's government has created a comprehensive program for achieving a *recycling economy* through a series of laws such as the Basic Law for Promoting the Creation of a Recycling Oriented Society and the law for the Promotion of Effective Utilization of Recycled Resources.

LIFE CYCLE ASSESSMENT AND CRADLE-TO-CRADLE CONCEPT

Life cycle assessment (LCA) is one of the very important tools to evaluate the environmental impacts associated with any given industrial activity, from the initial gathering of raw materials from the earth to the point at which all residuals are returned back to the earth, or cradle-to-grave. LCA results will not be promising for industrial activities that are based on a cradle-to-grave flow of materials. Unfortunately, most manufacturing processes since the Industrial Revolution began are based on a one way, cradle-to-grave flow of materials—starting with the extraction of raw materials, followed by processing, producing, and marketing of the goods, then utilization by consumers, and finally, disposal of waste generation, as shown in Figure 1.1.[3] The technological advancements in manufacturing processes and the constantly increasing variety of materials and products have led to a continuous rise in the amounts of waste generated. The cradle-to-grave flow of materials has proven to be just enough to protect the environment if proper and efficient disposal facilities are used. In developing countries, however, improper environmental design and operation of the disposal facility usually cause severe ecological impact as well as depletion of natural resources.

LCA helps identify the impact of the product on the environment throughout its life cycle. The main components of LCA should include the identification and quantification of not only the waste generated through the entire life cycle but also the raw materials and energy requirements throughout the entire life cycle and their environmental impacts.

A lot of work has been done to develop methodologies, guidelines, and benefits for LCA according to the cradle-to-grave concept to protect the environment throughout the life cycle of the product. The International Organization for Standardization (ISO) has develop a series of international standards to cover LCA in a more global sense, such as ISO14040 (LCA—Principles and Guidelines), ISO14041 (LCA—Life Inventory Analysis), ISO14042 (LCA—Impact Assessment), and ISO14043 (LCA—Interpretation). All ISO 1404Xs that are related to LCA are based on cradle-to-grave approach for environmental protection. It is time now to change the LCA-ISO standard from cradle-to-grave to cradle-to-cradle to protect not only the environment but also the natural resources.

LCA is a very important tool to guarantee that there are no harmful impacts on the environment, starting from extracting the raw material (cradle) all the way to the final disposal in a landfill (grave). In other words, the product's design should be selected, in part, according to safe disposal process. This process protects the environment but will deplete the natural resources. By contrast, under a cradle-to-cradle concept, the product's design would be such that materials could be reused or recycled, no wastes would get produced or would be recycled, and accordingly, no negative impacts on the environment would get generated within the closed loop of life cycle of the product, as shown in Figure 1.2. This can be achieved by having industries change their products from a cradle-to-grave design, where the product will eventually get disposed of in a landfill at the end of its life, to a cradle-to-cradle design, where the materials are circulated in a closed loop without losing any natural resources. The environmental and health impacts—as well as the consequences of depleting the natural resources as a result of using traditional treatment, incineration and/or final disposal through

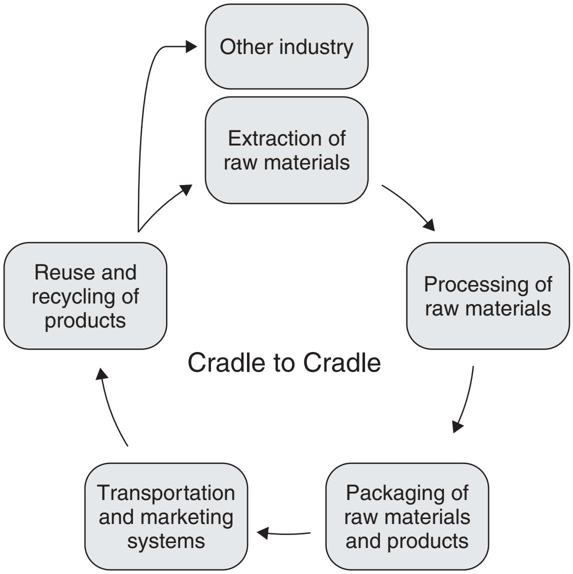

FIGURE 1.2 New life cycle analysis based on the cradle-to-cradle concept.

landfill—are becoming more dangerous, and making sustainable development a more urgent need. Establishing or approaching a new LCA based on the concept of cradle to cradle instead of cradle to grave by a full utilization of raw material, water, and energy is a must for sustainable development.[4]

Braungart and McDonough [2002] proposed a shift from a cradle-to-grave approach where waste products are disposed of in a landfill to a cradle-to-cradle approach, where waste can be used for the production of other products. They recommended the "eco-effective" recycling approach to enable material reuse with high quality. They added that combining different materials in one product prevents the products from being fully recycled. Accordingly, product designers need to plan for the reuse of their products in order to prevent waste generation. This shift in a product's design approach will require an added responsibility to the producer—extended producer responsibility, or EPR—to be able to recycle the products after its lifetime.

The cradle-to-cradle concept promotes sustainable development in a practical approach, as will be discussed throughout this chapter. It is a system of thinking based on the belief that human endeavors can emulate nature's elegant system of safe and regenerative productivity, by transforming industries to sustainable enterprises and eliminating the concept of waste.

Natural ecosystems are based on principles that can be adopted by humans in industry. For example, no waste generation—in natural ecosystems, an organism's waste is consumed by others. This can be applied in industry such that one industry's wastes are another's raw material. *Industrial ecology* will be discussed later in this chapter. This is the fundamental concept of eco-industrial parks, where industries are grouped together to have a continuous flow of material and no waste generation, as in the case of eco-industrial park in Kalundborg, Denmark, and other places worldwide.

Adopting cradle-to-cradle principles creates a cyclical flow of materials, as opposed to the one-way cradle-to-grave concept. The materials consumed in industry resemble the nutrients that flow cyclically in natural ecosystems and can circulate in one of two metabolisms, biological or technical.

According to the cradle-to-cradle concept, products would be made of materials that can be safely manufactured, used, recovered, and reused, while still maintaining their high value throughout their life cycle. This way, valuable used material can be continuously cycled in closed loops and transformed for reuse as other products. By applying the principle of cradle-to-cradle design and transforming industrial systems to a closed-loop system of material flow, not only will this design save the environment from waste generation and negative impacts, but industries can even benefit from the continuous availability of products made of high-value material even after the end of the product's lifetime.

INDUSTRIAL WASTE

The most common industrial wastes generated from industrial sectors are packaging materials using plastic and paper from almost all industrial sectors, organic wastes from food and other industries, dust from the cement industry and the marble and granite industries, glass culets from almost all industries, slag and foundry sand wastes from smelters or foundries, and waste from iron and steel industries.

Closing the loop for sustainable industrial waste management (SIWM) is very important for national development. SIWM means all components within the industrial wastes should be recycled in order to reach the cradle-to-cradle ideal for industrial waste management. This might require development of innovative recycling techniques through universities or research centers or added regulations on producers, such as extended producer responsibility (EPR) to design the products for recyclability. The cradle-to-cradle approach is new worldwide but has been implemented with success at The American University in Cairo (AUC) for most types of wastes, as will be discussed in this chapter.[1]

PLASTICS INDUSTRY

Plastics have played a very significant role in industrial development since their invention. If we take a look around us, we will discover that most tools, accessories, packaging, and equipment are made out of plastic, as shown in Figure 1.3. Some of these products have a very short life cycle and are highly consumable. Others might have longer life cycle. These products are used frequently and, in most cases, are then discarded and turned to wastes. Recycling of plastics has become a great industry throughout the world because of its effectiveness and high profits.

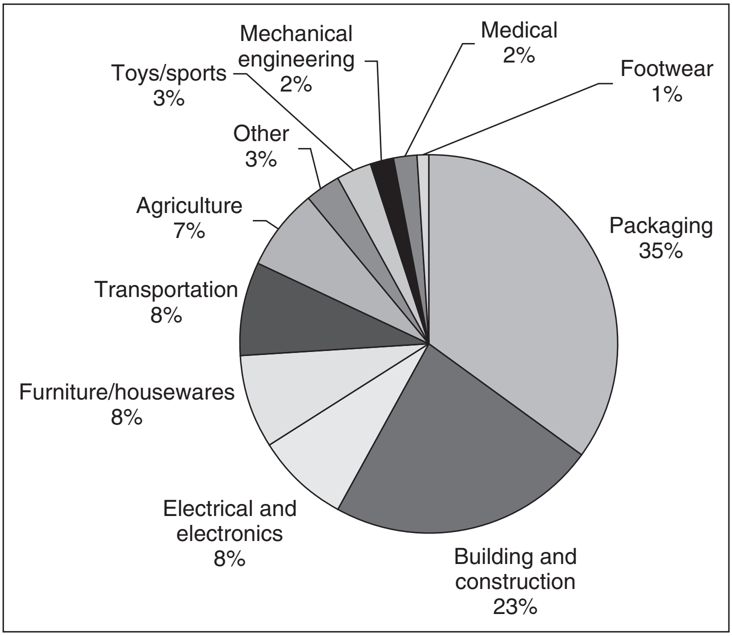

FIGURE 1.3 Uses of plastics by industry. (*Source:* R. J. Crawford, *Plastics Engineering*, 3rd ed. (Oxford: Butterworth–Heinemann, 1998).)

Even though plastics have a variety of benefits, they are detrimental to the environment. Many of the environmental impacts associated with the production and manufacturing of plastics include the fact that plastic production consumes a large amount of energy and materials, primarily fossil fuel, which, when combusted, emits toxins into the air. It is estimated that 4 percent of the world's annual oil production is used as a feedstock for plastics production and an additional 3-4 percent is used during manufacture.[5] Plastics production also involves the use of potentially harmful chemicals, which are added as stabilizers or colorants. Many of these have not undergone environmental risk assessment, and their impact on human health and the environment is currently uncertain.[5] An example of this is phthalates, which are used in the manufacture of polyvinylchloride (PVC). PVC has in the past been used in toys for young children, and there has been concern that phthalates may be released when these toys come into contact with saliva, if the toy is placed in the child's mouth or chewed by the child. Risk assessments of the effects of phthalates on the environment are currently being carried out.[5] Other environmental impacts of plastics include the extensive amount of water that is needed in manufacturing. Also, the numerous plastic bags that are dispersed as litter in urban areas have also become a plaguing concern. Due to the magnitude of the problem associated with plastic waste, this section focuses on methods and mechanisms to reduce this problem for the betterment of the environment and our lifestyles. A different study concluded that 1.8 metric tons of oil are saved for every metric ton of recycled polythene produced.[5] The benefits of recycling plastics are numerous, and thus should be investigated and utilized to the fullest extent.

There are numerous benefits to the recycling of plastics:

- Reduce water usage by 90 percent.
- Reduce CO_2 emissions by two and a half times.
- Reduce energy consumption by two-thirds.[5]

Plastic is divided mainly into two types: thermo plastics and thermo sets. Each type has its own manufacturing processes and its own characteristics. Most of the plastics are considered thermo plastics and can be recycled easily without any problems such as polypropylene (PP), Polyethylene terephthalate (PET), high-density polyethylene (HDPE), low-density polyethylene (LDPE), and polyvinyl chloride (PVC). The other type of plastics is called thermo sets. This type is difficult to recycle due to its chemical composition. As a result, products from this type of plastics are discarded. These include melamine, epoxy, phenolics, and alkyds. It is worth mentioning that most thermo sets have excellent mechanical properties rather than thermo plastics. Thus, it is considered a total loss and waste of energy if these wastes are not recycled.

Thermo Plastics

Most thermo plastics can be recycled; however, there are four types of thermo plastics that are commonly recycled due to their high percentage of usage. Figure 1.4 shows the distribution and the amount of the plastic materials to be

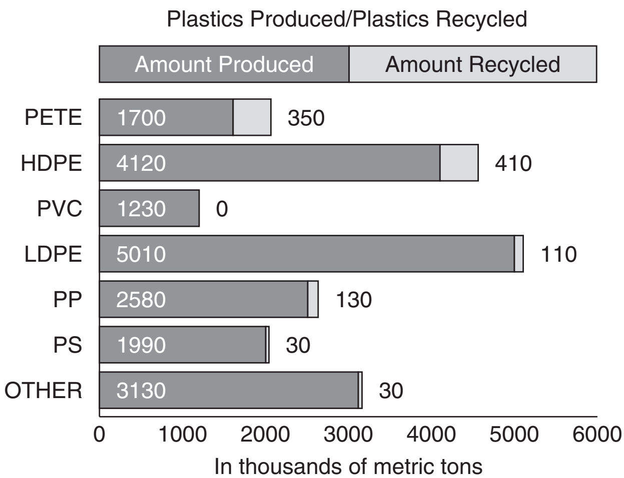

FIGURE 1.4 Amount of thermo plastics produced and recycled in the United States.

recycled every year in the United States. These recyclable materials are arranged from the most frequently used to the least frequently used as follows:

- Polyethylene (PE): it includes high and low density polyethylene
- Polypropylene (PP)
- Polystyrene (PS)
- Polyvinyl chloride (PVC)

Plastic recycling is still a relatively new and developing field of recycling. The postconsumer items made from PET and HDPE resins have found reliable markets within the United States, Asia, and Africa. Applications for recycled plastics are growing every day. Plastic waste can be blended with a certain percentage to virgin plastic to reduce cost without sacrificing properties. Recycled plastics are used to make polymeric timbers for use in picnic tables, fences, and outdoor toys, thus saving natural resources.

About 35 to 50 percent of the total volume of plastic wastes is in the form of packaging wastes, as shown in Figure 1.3. Once rejected, plastics packages gets contaminated and reuse creates a more serious problem, which is the so-called commingled plastics, affecting, in return, the properties of the new recycled products.[6]

The recycling of thermoplastics, or plastics, can be accomplished easily with high revenue. Each type of plastic must go through a different process before being recycled. Hundreds of different types of plastics exist, but 80 to 90 percent of the plastics used in consumer products are (1) PET (polyethylene terephthalate), (2) HDPE (high-density polyethylene), (3) PVC (polyvinyl chloride), (4) LDPE (low-density polyethylene), (5) PP (polypropylene), (6) PS (polystyrene), and (7) others (such as vinyl), as shown in Figure 1.5.

Plastics can be recycled mechanically or chemically. Chemical recycling can solve the problem of composites better than mechanical recycling.[7] Each one has its own pros and cons for recycling plastics. So, it is very important to decide which techniques will be selected according to the type of waste and the product(s) produced. Mechanical recycling is the most famous recycling technique because of its simplicity to use and ability to be handled by anyone. Mechanical recycling involve a number of processes such as cleaning, sorting, cutting, shredding, agglomeration, pelletizing, and finally reprocessing by injection molding, blowing, or extrusion according to the required products. A simplified schematic diagram for plastic recycling process is shown in Figure 1.6.

Recycled PET has many uses, and there are well-established markets for this useful resin. By far, the largest usage is in textiles. Carpet manufacturing companies can often use 100 percent recycled resin to manufacture polyester carpets in a variety of colors and textures. PET is also spun like cotton candy to make fiber filling for pillows, quilts, and jackets. PET can also be rolled into clear sheets or ribbon for audiocassettes. In addition, a substantial quantity goes back into the bottle market. China is currently using it in the manufacturing process of fiberoptics.

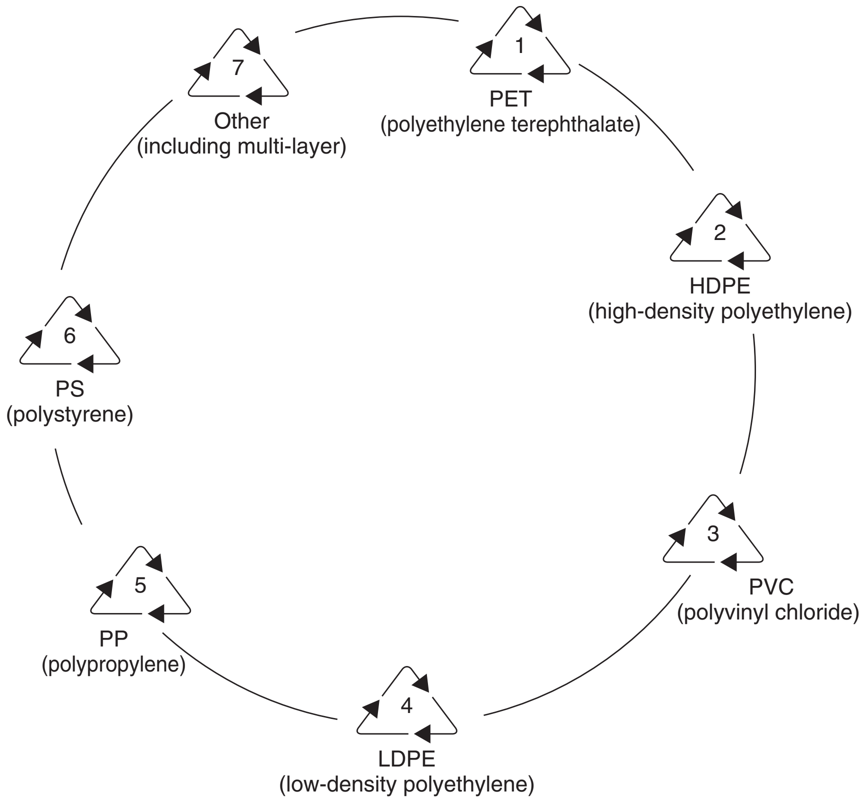

FIGURE 1.5 Coding of thermoplastics.

Some common end uses for recycled HDPE are plastic pipes, lumber, flowerpots, trashcans, or nonfood application bottles. Some end uses for recycled LDPE are plastic trash bags and grocery sacks, plastic tubing, agricultural film, and plastic lumber.

There are mainly three stages needed to recycle plastics. The initial stage, where the wastes are collected, sorted, separated, and cleaned, is labor intensive, requiring little capital investment and relatively no technical skills. Automating this stage requires high capital and might not be economically visible to be able to continue with recycling. Careful attention of this process is very important to guarantee the economics of recycling. It is always recommended to use plastic coding system shown in Figure 1.5 to sort plastic easily and to enhance the properties of recycled plastic. The second-stage, preprocessing, is where the collected wastes are being prepared for processing. In this stage, the wastes are reduced in size by undergoing cutting, shredding, and agglomeration. The final stage is the processing stage, where mixing, extrusion, blowing, injection, and product manufacturing takes place. All types of thermo plastics can be recycled if they are sorted and properly cleaned, as shown in Figure 1.6.[8]

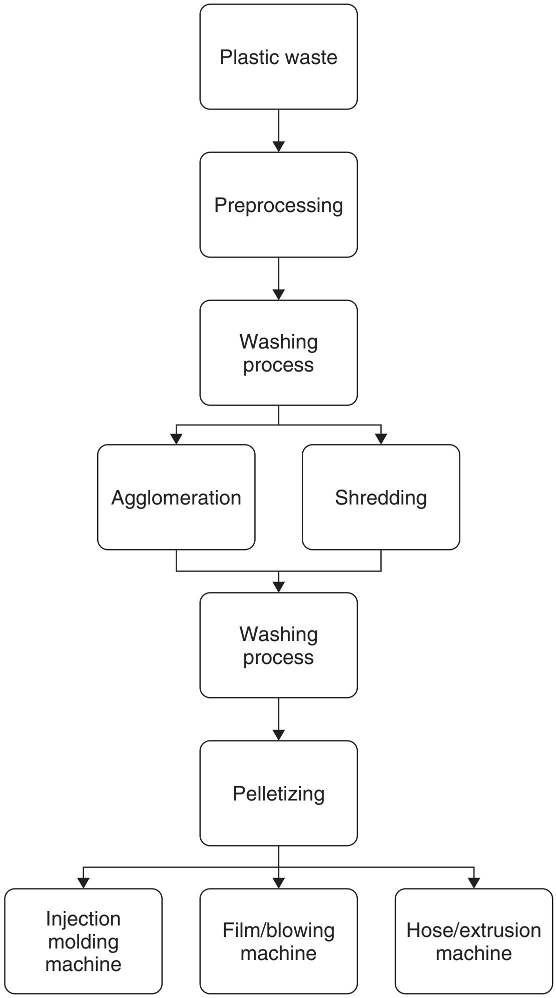

FIGURE 1.6 Process flow diagram for plastic recycling.

Thermosets

Thermosets are the second type of plastic products. Thermosets are formed by aid of the thermo plastics polymers when they covalently bonded to form chains that are interconnected and cross-linked to each other, and they differ from thermo plastics in that once they are formed with the aid of heat or pressure, they cannot be shaped or remelted again. The chain or the cross-link that forms the thermo sets occurs by the aid of some chemical reactions or due to heating or adding of a catalyst. The chemical reactions that are involved in producing the product are not reversible, and that's why it is so hard to reform it again. Once the product is converted from a liquid state to a solid state, it will be referred to as *cure*.

TABLE 1.1 Mechanical Properties for Thermosetting Plastics

Material	Tensile Strength 10^3 PSI	Tensile Modulus 10^5 PSI	Compressive Strength 10^3 PSI	Yield Strength 10^3 PSI
Epoxy	1–3	30–35	25–40	10–60
Unsaturated Polyester	4–50	7–9	15–50	10–80
Phenolics	4–9	16–20	10–40	5–12
Urea formaldehyde	5–13	10–15	25–40	10–18
Melamine	5–13	11–24	20–45	9–23
Alkyds	3–9	5–30	12–38	6–20

It is considered the last step in polymerization. The structure of all thermo sets looks like a network. All the molecules are permanently cross-linked together in a 3D network. This structure makes all thermo sets products maintain their high strength and hardness in relatively high temperatures. In addition, they have high chemical and creep resistance. Table 1.1 shows some of the mechanical properties of thermo sets materials.

Mixed Plastic Wastes

The unrecyclable mixed "different types" plastic waste "plastic rejects" can be collected and sorted into three groups (according to the technology used for size reduction): rigid thermoplastics, thin film thermoplastics, and thermo sets, as shown in Figure 1.7. The plastic rejects can be produced as a result of sorting and screening of mixed solid waste to separate organics from inorganic waste.

FIGURE 1.7 Mixed plastic waste.

The rejects might have some nonplastic waste, such as glass culets. The first step to recycle plastic rejects is to reduce the size so it can be mixed with other additives and produce a homogeneous mixture.

The size of rigid plastic can be reduced using horizontal axis shredders shown in Figure 1.8, while thin film plastics such as black plastic bags used for trash can be agglomerated using a vertical axis agglomerator machine shown in Figure 1.9 to reduce their sizes. Thermo sets can be crushed using a ball mill, shown in Figure 1.10.

Melamine, the most common type of thermo sets, will be used as an example of thermo set. It is usually found in a form of plates, cups, and other products. In order to recycle Melamine, it must be changed from the rigid forms into a powder form as to be mixed with the thermo plastics. Changing the Melamine into powder can be done through the ball mill machine shown in Figure 1.10.

The rigid thermo plastic waste is fed into a shredder shown in Figure 1.8 for size reduction and then cleaning with caustic soda in a warm-water bath after shredding. The shredder consists of a horizontal drum with four rotating blades opposite to stationary blades shown in Figure 1.8. The shredded plastics pass through a grid into a collecting tray. The sizes of shredded plastics range between 5 to 10 mm in size according to the grid used. The shredded plastics are collected in bags or containers to be further reprocessed or sold. The end products of shredding are irregularly shaped pieces of plastic, depending on the required final product and the type of industry that will use it.

FIGURE 1.8 Shredding "crushing" machine.

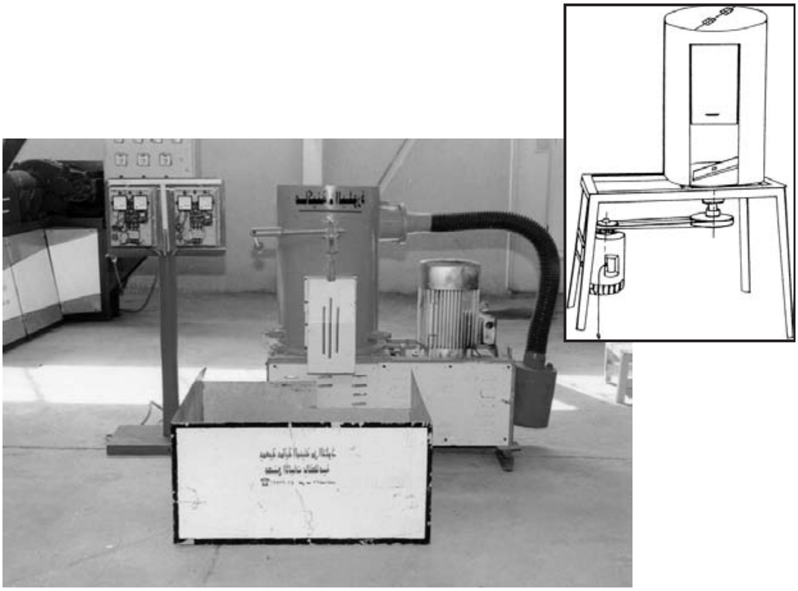

FIGURE 1.9 Agglomeration machine.

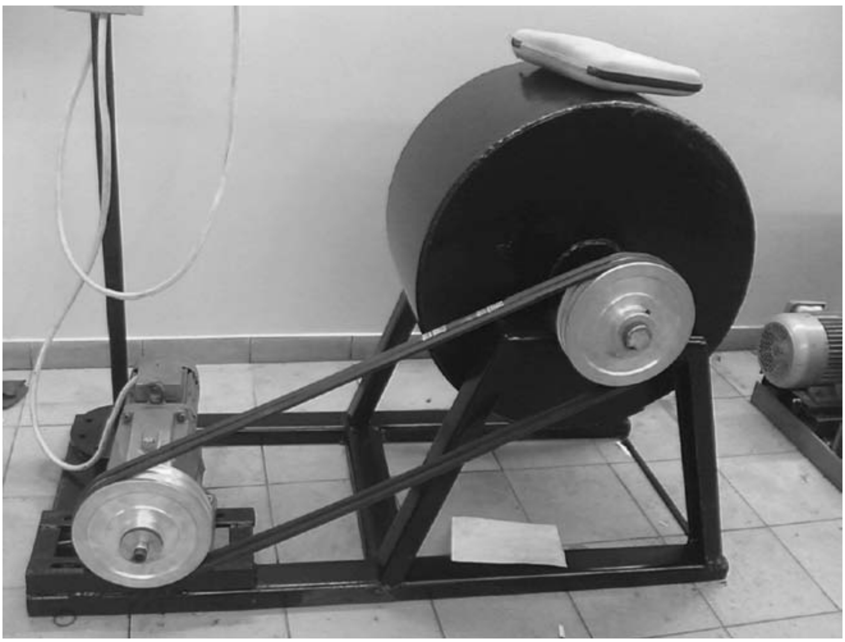

FIGURE 1.10 Ball mill machine.

Shredders can also be used for plastics films, bags, and sheets to be shredded into small pieces, but the energy consumption is more and the produced capacity is less. So, it is recommended to use an agglomerator that cuts, preheat, and dry the plastics into granules. The agglomerator will increase the material's density and quality, which will end up with a continuous flow in the extruder and hence better efficiency. In the process of agglomeration, heat is added indirectly through friction between plastic film and the rotating blade located at the bottom of the agglomerator, shown in Figure 1.9. It is therefore important to rapidly cool the plastic film to obtain the crumb shape desired. This is achieved through adding a small cup of water.

The ball mill machine used to crush thermo sets consists of an electric motor with a gearbox to make speed reduction down to 40 revolutions per minute. The motor is connected with a pulley to translate the motion through a belt to another pulley, which is connected to the shaft. The shaft carries a cylindrical drum in which the melamine or other form of thermo sets is inserted. The drum is welded to the shaft and the shaft is carried by two bearings at both ends of the shaft as shown in Figure 1.10. The balls within the ball mill machine will convert the thermo sets into powder by the gravitational force of the balls. Therefore, the particle size of the powder can be controlled through the number of balls, ball shape, and the time the machine will operate.

The recycling system for mixing plastic wastes as shown in Figure 1.11 consists of a volume-reduction step to reduce the size using agglomerator to cut the plastic bags into small pieces (granules), shredder to cut the rigid plastic into small pieces, and/or ball mill to crush the thermo sets. After the volume-reduction step, a mixture of the three with a certain percentage will be used with some additives to adjust the properties and appearance and heated indirectly to 140° to 240°C depends on the mixture and required applications. The indirect heating process occurs in an indirect heating furnace shown in Figures 1.12 and 1.13. Figure 1.12 demonstrates the vertical axis mixing and heating furnace. Figure 1.13 illustrates the horizontal axis mixing and heating furnace. Both designs guarantee a good mixing of the wastes and additives with indirect heating to produce a homogeneous hot paste for further processing.

The hot paste is then transferred to the mold according to the required shapes and applications. The mold will be placed in a hydraulic press to be pressed into the required shape shown in Figure 1.14. The mold will be cooled for 20 to 30 minutes according to the product.

Product development from mix plastic waste recycling, in general, is a must to maximize the benefits. This leads to a number of economic opportunities to remanufacture products with the recovered material. Just as market forces cannot be ignored when introducing a new product, they must also be taken into account when introducing remanufactured products. The product development from recycling mix plastic waste is more important and challenging than the product development of recycling of one type of plastic because the properties of products from mix plastic waste might change according to the product and required properties. Therefore, continual checking is a must for appropriate

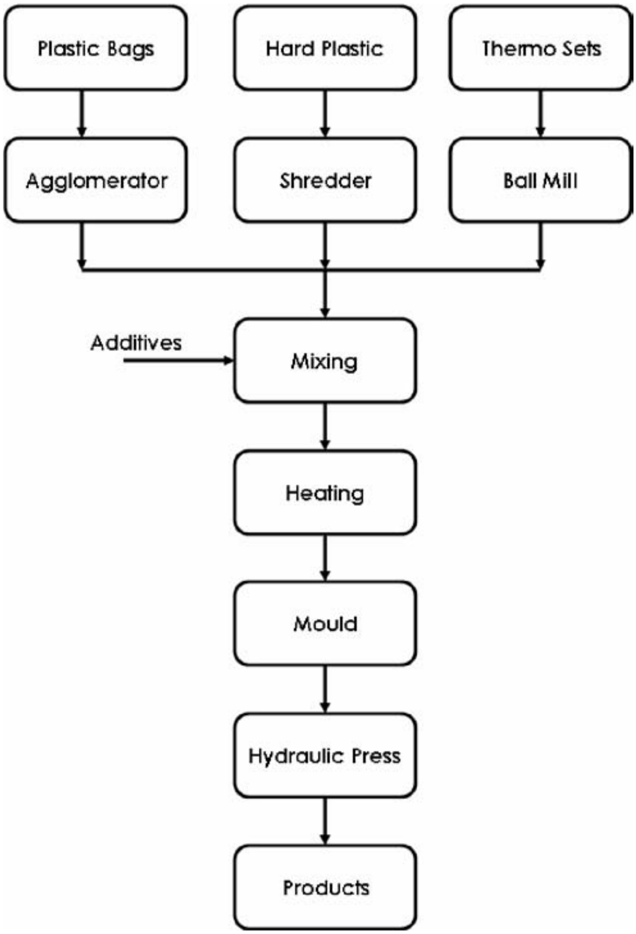

FIGURE 1.11 Process flow diagram for recycling plastic mix.

quality control and quality assurance. A number of products were produced with very good success according to the standard, such as bricks, interlocks, table toppings, wheels, manholes, road ramps, and sheets.

Figure 1.15 show the development of bricks from the solid brick (left) to bricks with holes to facilitate the assembly and disassembly of walls because bricks were made out of plastics with additives and cannot accept mortar to adhere bricks together. Any adhesive materials other than mortar are very expensive, which adds to the cost of the brick. Therefore, it is much more cheaper to bind them together using pins fitted in holes, as shown in Figure 1.15, for easy assembly and disassembly. Another problem of bricks made out of plastic rejects is the weight or density of the brick. The weight of the brick from plastic rejects is heavy compared with ordinary bricks. Thus, the bricks are not economically

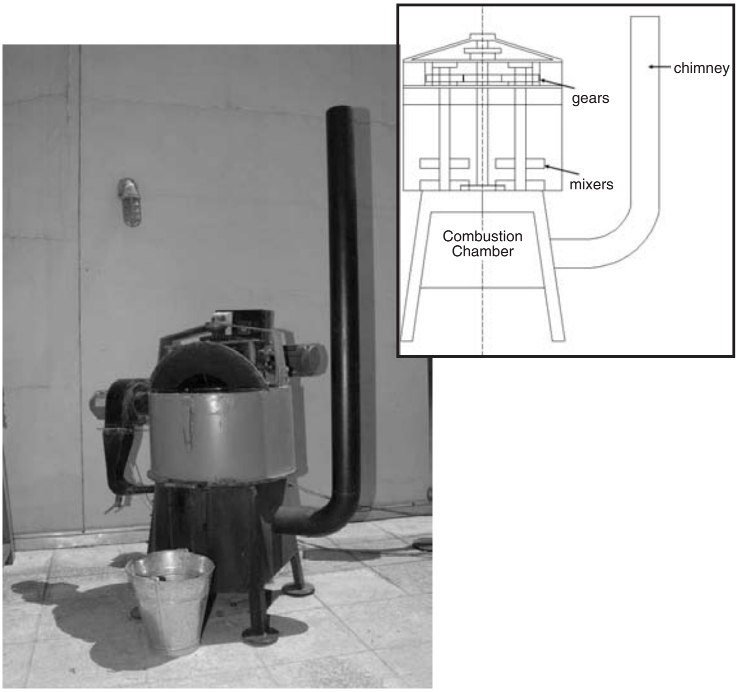

FIGURE 1.12 Vertical axis mixing and heating furnace.

FIGURE 1.13 Horizontal axis mixing and heating furnace.

FIGURE 1.14 Hydraulic press.

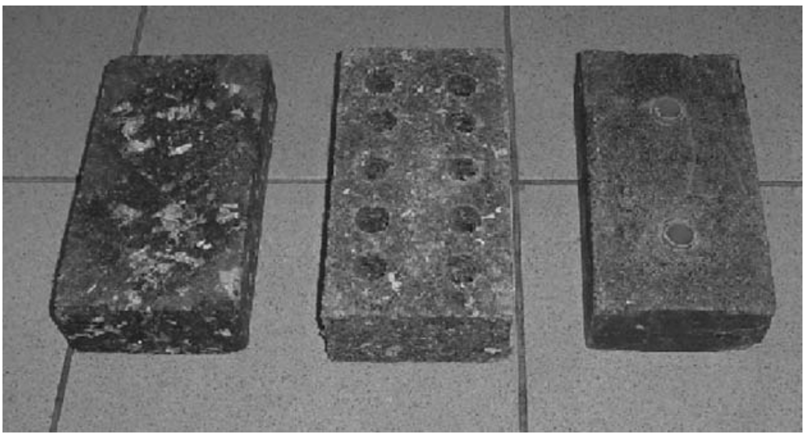

FIGURE 1.15 Development of bricks.

profitable when compared to the ordinary bricks, including the cost of adhesives. This type of bricks might have special application other than ordinary walls for construction applications.

Figures 1.16a and 1.16b show another application for plastic rejects that is much more profitable than bricks because it doesn't need adhesives. This new product is interlocks that can be used in pavements of roads, pedestrian gardens,

FIGURE 1.16a Development of interlock.

FIGURE 1.16b Application of interlocks.

FIGURE 1.17 Manhole cover and base.

factory floors, backyards, and so on. The interlocks made out of plastic rejects with additives proved to have higher strength according to ASTM standard than the normal interlock made out of cement, aggregate, and sand.[9] Figure 1.17 shows another very important application (manhole cover and base) that is much more profitable than interlock. A manhole or maintenance hole (sometimes called an inspection cover) is the top opening to an underground vault used to house an access point for making connections or performing maintenance on underground and buried public utility and other services including sewers, telephone, electricity, storm drains, and gas. The manhole cover is designed to prevent accidental or unauthorized access to the manhole. Manhole bases and covers are usually made out of case iron or reinforced fiber plastic (RFP), or can be produced out of plastic rejects. The main advantages of manholes made out of plastic rejects are less cost, less energy consumption, durability, and being acid proof. The weight can be adjusted by adding sand to the mix. Sand will increase the required specific weight up to a certain percentage (28 percent) to avoid any strength impact. The carrying load for 40 cm manhole is 1.8 metric tons, which is slightly higher than fiber-reinforced plastic (FRP) manholes and can be increased by adding steel bars.

Manhole covers are round because manholes are round; they could also designed with any geometry according to the required dimensions. Round tubes are the strongest and most material-efficient shape against the compression of the earth around them. A circle is the simplest shape whereby the lid cannot fall into the hole. Circular covers can be moved around by rolling. And they need not be aligned to be replaced.

Manholes are one of the very important applications to be produced from rejects. They can be used instead of ordinary cast-iron manholes and can be

FIGURE 1.18 Partitions made out of rejects.

made with different geometry and dimensions. Manhole bases and covers proved to be an excellent product out of rejects from social, economical and technical points of view.

Another application made out of rejects is sheets with any dimension and thickness, according to demand and needs. The partition shown in Figure 1.18 is 120 cm by 120 cm with 10 mm thickness to replace corrugated sheets or plywood. The sheets made out of rejects are much cheaper and more durable than corrugated sheets or plywood. These sheets can replace MDF (medium fiber boards) as well in many applications. Also, they can handle all weather conditions such as high/low temperatures, wind speed, and humidity.

PLASTIC AND CORK INDUSTRY

The objective of this case study is to recycle the PVC plastic offcuts from slippers production to produce new slippers from scrap PVC plastics and approach cradle-to-cradle design. This case study was implemented in a company located in Sohag, Egypt (upper Egypt), which produces around 1,500 metric tons/year of PVC sheets, cut to make footwear. The cutting and printing process used around 70 percent of the PVC sheet with the remaining 30 percent being discarded as scrap. In total, 450 metric tons of scrap PVC were sent to the local landfill each year.

This case study was prepared and implemented in cooperation between El–Ameer for plastic and Cork Company and Egyptian Environmental Affairs Agency (EEAA) SEAM project. The company produces 1,050 metric tons of products every year from 1,500 metric tons of raw material. This case study led to the recycling of 450 metric tons of scrap plastic to produce slippers. Capital investment was $100,000 and resulted in annual savings of $560,000, providing a payback in two months.

The process flow diagram to produce final product from raw material, as well as final product from recycled waste, is shown in Figure 1.19. A number of trials were undertaken to develop the optimum recipe, as shown in Table 1.2. Table 1.2 shows the recipes used for producing PVC sheets using new PVC and that for recycling scrap PVC.

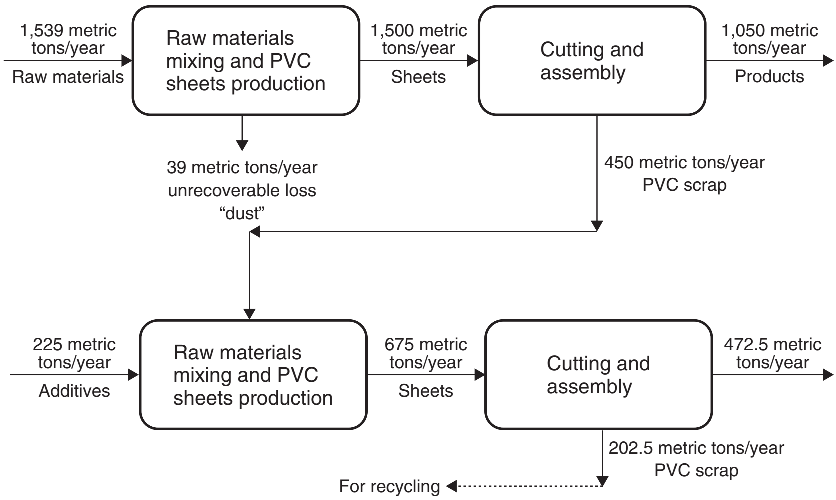

FIGURE 1.19 Process flow diagram for plastic and cork industry according to cradle-to-cradle concept.

TABLE 1.2 Raw Material Recipes Using Raw Material and Scrap PVC

No.	Raw Material	Using New PVC kg/batch	Using Scrap PVC kg/batch
1	PVC	45	–
2	Scrap PVC	–	50
3	Calcium carbonate	45	10
4	Rubber (NBR)	10	12
5	Zinc stearate	2.5	1.5
6	Fillers	1	–
7	Polyzar	1.5	–
8	Compor (azodicarbonamide)	1.5	1.5
9	DOP oil	2	–
10	Color	1	0.6
11	Sulfur, agriculture grade	0.35	0.05

The sheet-making process had to be modified to account for use of scrap plastic. In the case of new plastic, sheets formed are required to be cooled before imprinting and cutting. When scrap plastic is used in the recipe, the viscosity of sheets requires that hot sheets are directly subjected to imprinting and cutting. To cater for this, a new mechanical press was installed that could imprint and cut directly on the hot sheet.

A comparison of the costs of batch processing for raw PVC and recycled plastic scrap is given in Table 1.3. Average costs using new PVC is \$0.95 per Kg against \$0.46 per Kg using the scrap plastic. Figure 1.20 shows two slippers, one made from raw PVC and another one made from recycled PVC.

TABLE 1.3 Cost Comparison between Production with New and Scrap PVC

No.	Raw Material	Using New PVC		Using Scrap PVC	
		kg/batch	\$/batch	kg/batch	\$/batch
1	PVC	45	63	–	–
2	Scrap PVC	–	–	50	–
3	Calcium carbonate	45	2	10	0.4
4	Rubber (NBR)	10	17.5	12	21
5	Zinc stearate	2.5	3.5	1.5	2.1
6	Fillers	1	0.35	–	–
7	Polyzar	1.5	0.66	–	–
8	Compor (azodicarbonamide)	1.5	5	1.5	5
9	DOP oil	2.0	3.2	–	–
10	Color	1	6.32	0.6	3.8
11	Sulfur, agriculture grade	0.35	0.37	0.05	0.05
12	Electricity		0.1		0.1
13	Water		0.1		0.1
14	Labour		1.75		1.75
15	Fuel		1		1
Total Cost / Batch		**110 Kg**	**104.85**	**76 Kg**	**35.3**

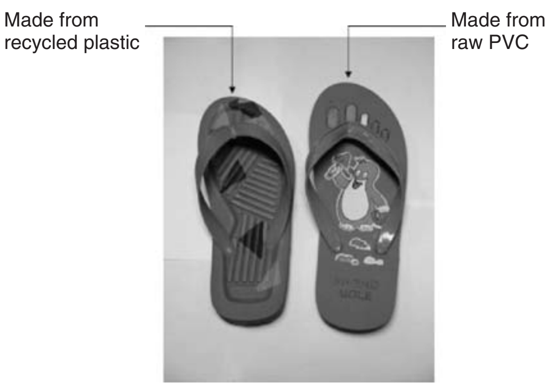

FIGURE 1.20 Slippers made from raw PVC and recycled plastic.

FOOD INDUSTRY

Food industry can be classified into a number of industries such as fruit and vegetable industry, vegetable oil industry, dairy industry, canning industry, beverage industry, meat industry, and so on. Most of these industries typically generate large volumes of effluents and solid waste. The main solid wastes generated from food industry are organic wastes, including discarded seeds, fruits, and vegetables. Odor problems can occur with poor management of solid wastes and effluents, when onions are processed, and when ready-to-serve meals are prepared, for example. So, it is very important to deal with such organic waste with full understanding of the processes, requirements, and hygiene.

Food waste recycling can take place through aerobic fermentation (composting) or anaerobic fermentation (biogas) processing. Composting is a process that involves biological decomposition of organic matter, under controlled conditions, into soil conditioner or organic fertilizer through aerobic fermentation.[10] While anaerobic fermentation process involves biological decomposition of organic waste under controlled conditions to produce fertilizer and biogas.[11]

Aerobic Fermentation Process

Aerobic fermentation is the decomposition of organic material in the presence of air. During the composting process, microorganisms consume oxygen, while CO_2, water, and heat are released as result of microbial activity, as shown in Figure 1.21. Four main factors control the composting process: moisture content, nutrition (carbon: nitrogen ratio), temperature, and oxygen (aeration).

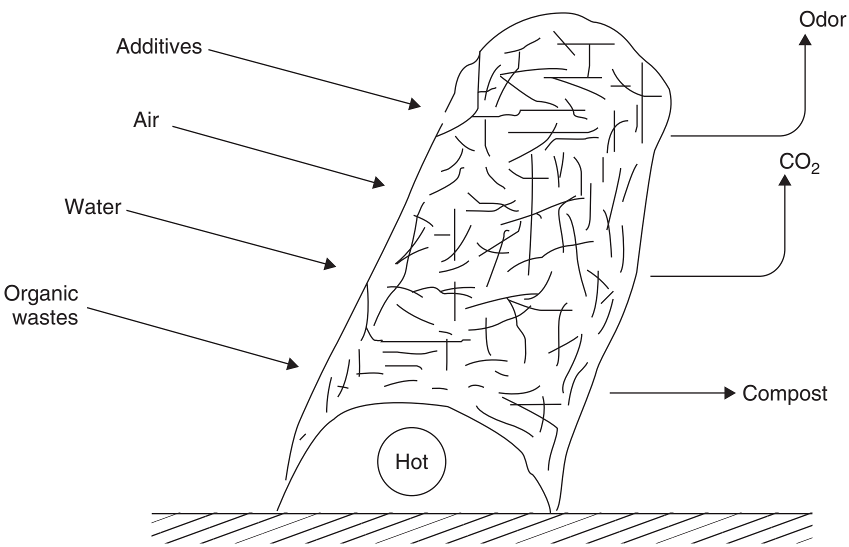

FIGURE 1.21 Composting process.

1. *Moisture content.* The ideal percentage of the moisture content is 60 percent.[10] The initial moisture content should range from 40 to 60 percent, depending on the components of the mixture. If the moisture content decreases less than 40 percent, microbial activity slows down and became dormant. If the moisture content increases above 60 percent, decomposition slows down and odor from anaerobic decomposition is emitted.
2. *Carbon to nitrogen ratio.* Microorganisms responsible for the decomposition of organic matter require carbon and nitrogen as a nutrient to grow and reproduce. Microbes work actively if carbon to nitrogen ratio is 30:1. If the carbon to nitrogen ratio exceeds 30, the rate of composting decreases. Decomposition of the organic waste material will slow down if C:N ratios are as low as 10:1 or as high as 50:1.

   However, in order to compensate the low nitrogen content of organic waste, nitrogen should be added to obtain more effective compost. To increase the C:N ratio in rice straw as an agricultural waste, for example, these techniques may be implemented:

   - *Chemical additives:* This method could be done by the addition of either uric acid, or urea or ammonia.
   - *Natural additives (manure):* In this technique, nitrogen is obtained from animal or poultry manure.
3. *Temperature.* The activity of bacteria and other microorganisms produce heat while decomposing (oxidize) organic material. The ideal temperature range within the compost to be efficient varies from 32°C to 60°C. If the temperature is outside this range, the activity of the microorganisms slows down, or might be destroyed. A temperature above 55°C while composting kills the weeds, ailing microbes, and diseases, including shengella and salmonella; this help to reduce the risk of diseases' transmission from infected and contaminated organic wastes.
4. *Oxygen (aeration).* A continuous supply of oxygen through aeration is a must to guarantee aerobic fermentation (decomposition). Proper aeration is needed to control the environment required for biological reactions and to achieve the optimum efficiency. Different techniques can be used to perform the required aeration according to the composting techniques. The most common types of composting techniques are natural composting, passive composting, forced composting, and vermi composting.

Natural Composting Piles of compost are formed along parallel rows, as shown in Figure 1.22 and are continuously moisturized and turned. The distance between rows can be determined according to the type and dimension of the turning machine.[12] Piles should be turned about three times a week at summer and once a week at winter to aerate the pile and achieve homogenous temperature and aeration throughout the pile. This method needs large surfaces of lands, many workers, and running cost.

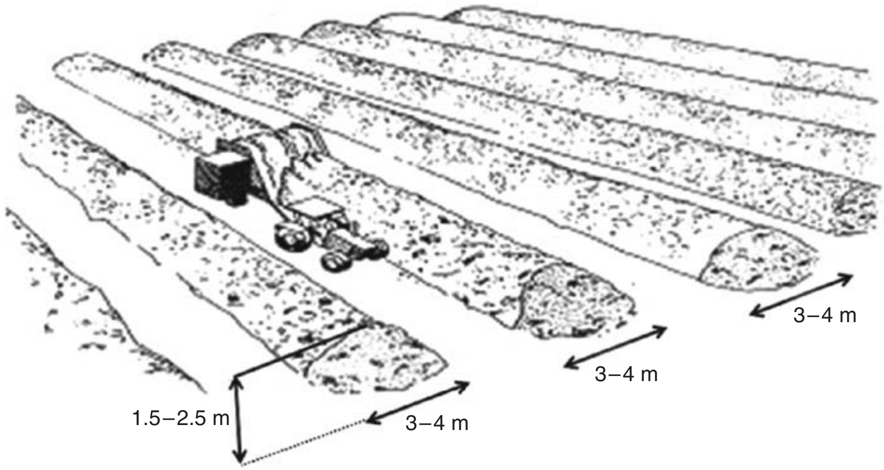

FIGURE 1.22 Natural composting process. (*Source:* F.R. Gouin et al., “On-Farm Composting,” Northeast Regional Agricultural Engineering Services, NRAES-54, Cooperative Extension, 1993.)

Passive Composting Parallel rows of perforated high-pressure PVC piping are placed at the bottom, on which compost is added above it. The pipes are perforated with 10 cm holes to allow air to enter the composting piles, as shown in Figure 1.23. The pipe manifold helps in distributing the air uniformly. Air flows through the ends of the pipes to the compost. This system is better than the natural system because of the limited flow rates induced by the natural ventilation. This method needs limited surfaces of lands, less running cost, and does not need skilled workers. This method is recommended for cost effectiveness; it is the most economic aeration method. Therefore, it is the most suitable method for developing communities that want to achieve maximum benefit from the food recycling with the minimum capital investment and a good-quality soil conditioner. The soil conditioner can be converted into organic fertilizer by adjusting the NPK ratio (nitrogen: phosphorous: potassium) through additives.[13,14]

Forced Aeration Forced aeration works like the previous system except that the ends of plastic pipes are connected to blowers that force (or suck) the air through the compost with a specific rate and velocity. Otherwise, if the air rate exceeded a certain limit, the temperature inside the compost pile would decrease, affecting the microbial activity. Also, the air velocity during the day should always be higher than at night. This system needs higher technology with air velocity control and more energy consumption. That is why it is less economic compared to the other two systems and it is not recommended for rural or developing countries that want to make profit out of all recycling processes. This method needs capital investment, skilled workers, and running cost.

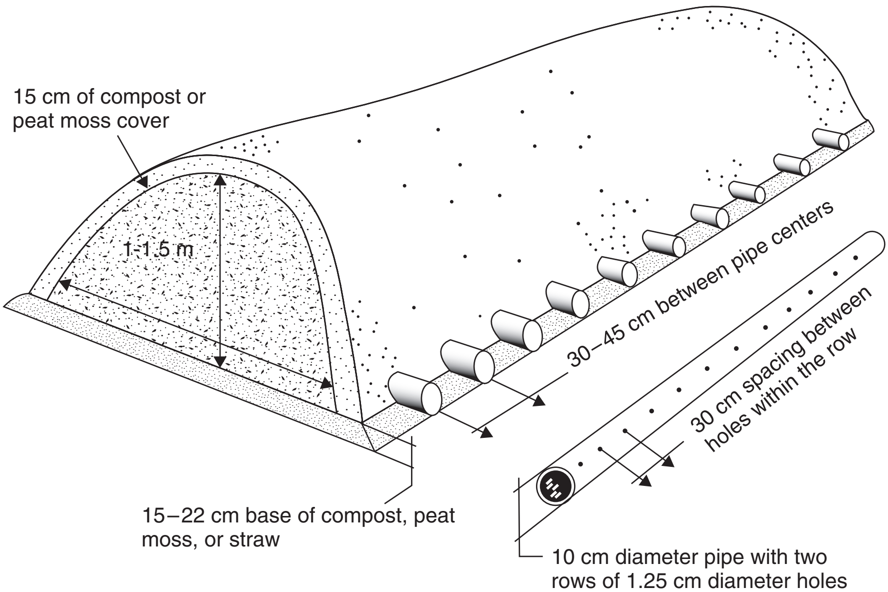

FIGURE 1.23 Passive aeration process. (*Source:* F.R. Gouin et al., "On-Farm Composting," Northeast Regional Agricultural Engineering Services, NRAES-54, Cooperative Extension, 1993.)

Vermi Composting It is an ecologically safe and economic method that depends on the worms' characteristic of transforming the organic wastes to fertilizers that are extremely beneficial to earth. There are two types of earthworms that are used due to their insensitivity to environmental changes:

1. The red wiggler (*Eisensia Foetida*)
2. The red worm (*Lumbricus Rebellus*)

Under suitable aeration, humidity, and temperature, worms feed on organic wastes and expel their manure (worm castings) that breaks up the soil, providing it with aeration and drainage. It also creates an organic soil conditioner as well as a natural fertilizer. Worm castings have more nutrients than soil conditioner in terms of nitrogen and phosphorous.

A mature worm will produce a cocoon every 8 to 10 days that contains an average of eight baby worms that mature in approximately 70 days, and in one year each 1,000 worms produce 1,000,000 worms.[15]

Vermi composting can be used in houses easily by using a special container (worm bin) that can be placed anywhere that is not subjected to light such as kitchen, garage, and basement. The organic waste is put in this container, and the worms with them. The worms are odorless and free from disease.

Anaerobic Fermentation Process

Biogas conversion is the anaerobic fermentation of organic matter (organic waste) by microbiological organisms under controlled conditions. The aim of fermentation is to produce methane (biogas) that can be used as an energy source. The fermentation process is done anaerobically—that is, without the presence of air—to allow the bacteria to perform the breakdown. The byproduct of fermentation consists of about 60 percent CH_4 and 40 percent CO_2, along with traces of H_2, N_2, and H_2S. Biogas is produced by means of a digester, which is a device used to process organic waste and produce methane. There are many types of digesters available; however, the two most famous designs are the Chinese fixed dome (constant volume) and the Indian floating cover (constant pressure). A combination of both could also be designed.

Chinese Fixed Dome The Chinese fixed-dome design is one of the oldest digester designs dating back to the 1930s. It consists of an underground fermentation chamber made of bricks and a dome-shaped tank on top of the chamber. The biomass mixture is entered through the inlet and fermentation occurs, with the gas rising to fill the tank and the slurry exiting through the outlet. This design combines the digester with the holding tank where the gas is stored. The gas then passes through an outlet pipe at the top, as shown in Figure 1.24.

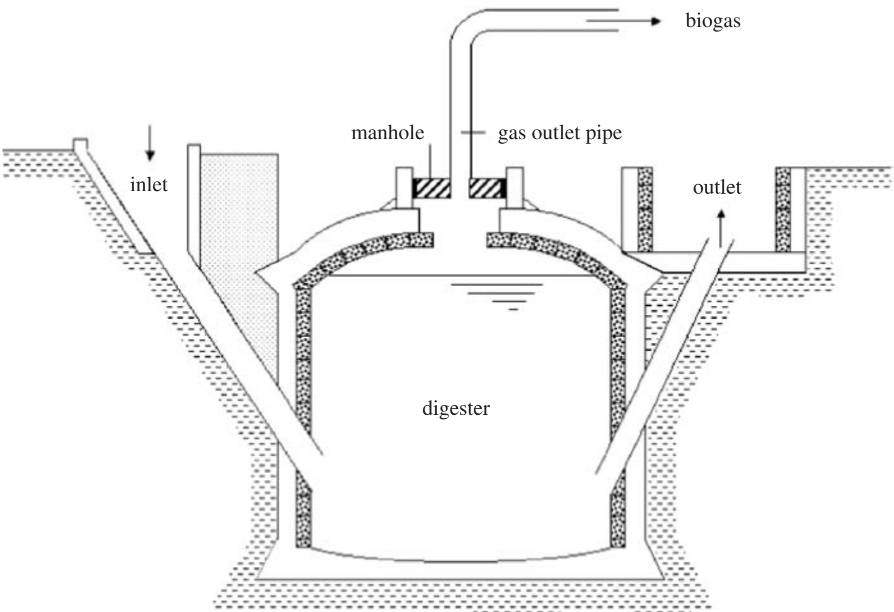

FIGURE 1.24 Chinese fixed-dome digester. (*Source:* Matthias Plöchl and Monika Heiermann, “Biogas Farming in Central and Northern Europe: A Strategy for Developing Countries?” 2006, cigr–ejournal.tamu.edu/submissions/volume8/Invited27Feb2006.pdf.)

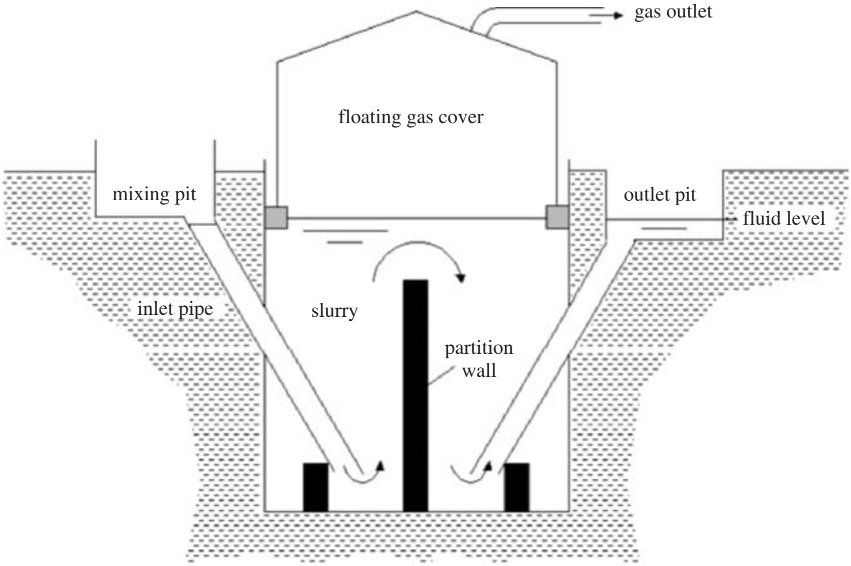

FIGURE 1.25 Indian floating cover. (*Source:* Matthias Plöchl and Monika Heiermann, "Biogas Farming in Central and Northern Europe: A Strategy for Developing Countries?" 2006, http://cigr–ejournal.tamu.edu/submissions/volume8/Invited27Feb2006.pdf.)

Indian Floating Cover The Indian floating-cover design is shown in Figure 1.25. This design was first presented as the Janata design but was further developed in 1984 to the Deenbandhu model, with both models based on the Chinese dome design. This model employs the same principles as the Chinese fixed-dome digester, with the biomass mix entering through the inlet and decomposed in the underground brick chamber. However, in this design the cylindrical gas tank is a floating cover that is separate from the mixing tank. The slurry left from the fermentation process is used as a fertilizer. The mixing process should occur at a high temperature range (30° to 40° or 50° to 60°C), and could take up to two months, depending on the quantity of biomass processed.[16]

TABLE 1.4 Uses of Biogas as Energy Sources

Applications	1 m^3 Biogas Equivalent
Lighting	Equal to 60 to 100 W bulb for 6 hours
Cooking	Can cook 3 meals for a family of 5 to 6
Fuel replacement	0.7 kg of petrol
Shaft power	Can run a 1 horsepower motor for 2 hours
Electricity generation	Can generate 1.25 kilowatt hours of electricity

Source: Practical Action, "Biogas And Liquid Biofuels," 2006, www.itdg.org/docs/technical_information_service/biogas_liquid_fuels.pdf.

Biogas can be used in several applications as an energy source, ranging from light bulbs to internal combustion engines. It has an energy content of about 5,000 Kcal/m^3. Some of the uses of biogas as an energy source are shown in Table 1.4.

CEMENT INDUSTRY

The cement industry is an important resource for development, and it is an intensive energy-consuming industry. It produces significant releases to the environment, primarily as airborne emissions such as dust emissions (cement bypass dust) and gaseous emissions of NO_x, SO_x, CO_x. It plays an essential role in the international market because cement, which is the most important ingredient of concrete, is one of the most dynamic products that directly contribute to the construction industry. Therefore, the cement industry is necessary for sustainable development in any country and can be considered the backbone for development.

Cement is a controlled chemical combination of calcium, silicon, aluminum, iron, and small amounts of other ingredients.[17] Lime, which can be extracted from limestone, shells, or chalk, constitutes 60 to 67 percent, and silica constitutes 17 to 25 percent, while alumina and iron oxide constitute the remaining small percentage.[17] According to Van Oss and Padovani, the chemical composition of a typical Portland cement clinker is mainly four oxides: calcium oxide or lime (CaO), about 65 percent; silica (SiO_2), about 22 percent; alumina (Al_2O_3), about 6 percent; and iron oxide (Fe_2O_3), about 3 percent.[18]

These elements are found in a wide variety of raw materials, and they are also found in byproducts of different industries such as blast-furnace slag from the iron and steel industry and fly ash from the electric power industry. From 115 operating plants reporting in the Portland Cement Association, 45 plants used blast furnace or iron slag as a raw material and over 40 plants used fly ash or bottom ash from electric power plants as an alternative raw material.[17]

Input materials for the cement industry are natural resources that are extracted from earth and have no negative effects on the environment. These materials are limestone, clay, and sand. Meanwhile, the final product is also an environmentally friendly product that is composed primarily of calcium silicate.[17] This means that the environmental impacts of the cement industry is associated with the process rather than with the materials themselves.

A closer look into the production process of cement will provide us with an insight of how the production system works; further, this will enable us to determine and identify potential sources of emissions and wastes. There are four main process routes in the manufacturing of cement: the dry, semi-dry, semi-wet, and wet process.[19] According to World Business Council for Sustainable development, common to all four processes are the following subprocesses:[20]

- Substances containing lime are quarried or shipped in.
- The raw materials are crushed into a fine powder to facilitate mixing and blending.

- The fine mixture is heated up to a temperature of 1430^o to 1650^oC in large rotating cylinders known as *cement kilns* to produce clinker.
- Then the clinker is cooled down and gypsum is added to it. The mixture is then ground into fine powder to form Portland cement.
- A large percentage of the final powder cement is stored in silos to be further transported or shipped, while a small percentage is packaged in 50 kg sacks.

Within the production process of cement, there are two different types of process methods, referred to as *wet* and *dry*. The major difference between the two types is the medium used to mix the powdered raw materials prior to heating, and the amount of moisture content in the materials entering the kiln. Karstensen added that between these two ends of the spectrum, there are semi-wet and semi-dry processes.[19] In the wet method, water is added to the raw materials after milling to facilitate thorough mixing, and the mixture is added to the kiln as slurry containing 30 to 40 percent water.[17] In the dry method, the powders are generally blended in a silo using compressed air. If the material entering the kiln is wet or has a high moisture content, this will require more energy and more time for driving off water. The wet process was the dominant older technology, because, in the age of abundant cheap energy, it was cheaper to burn more fuel and add length to the kiln than to add extra devices.[17]

Nowadays, kilns use the dry method. The dry method provides substantial energy savings, as well as a higher throughput. However, the energy advantages of the dry process were more fully realized with the addition of pretreatment equipment to condition the powdered raw materials before their introduction into the kiln.[17,20] A further development, called a *precalciner*, pumps more heat into the pretreatment phase, often combining some additional fuel with air from the clinker cooling stage, which has thus been preheated. The precalciner system is the most energy-efficient arrangement, and also has the highest throughput, with the shortest kiln (PCA).

Emissions may come from different stages during cement production processes, depending on the raw materials, preparation procedures, kiln type, and emissions control systems used.[20] The largest volume substances emitted during the production of cement are carbon dioxide, particulate matter (dust), oxides of nitrogen, and sulfur dioxide.

Dust and *particulate matter* include emissions of coarse dust, fine dust, soot, particles, and aerosols.[17] The emission of dust, particularly from kiln stacks, has been the main environmental concern in cement manufacture.[19] During the manufacturing steps of cement, exhaust gas passes through the fine material, resulting in a dispersed mixture of gas and particulates. According to PCA, the product is a fine powder, and various process steps involving grinding, both of the input materials and the final product, have the tendency to emit fugitive dust. Therefore, particulate control systems on exhaust air from the clinker cooling and grinding processes produce a waste material known as *cement kiln dust* (CKD).

Reduction and control of dust emissions in a modern cement plant requires investments and adequate management practices. Dust emissions from cement kilns have been reduced dramatically over the last two to three decades due to regular improvements in design and operation, including increased use of modern dedusting equipment such as electrostatic precipitators or bag filters.

Kiln dust collected from the gas cleaning devices is highly alkaline and may contain trace elements such as heavy metals corresponding to the contents in the source materials.[19,20] Usually, kiln dust is completely returned to the process either to the kiln system or to the cement mill, only in rare cases, it is not possible to recycle kiln dust or bypass dust completely in the process.[19] This residual dust is disposed of on a controlled landfills or is treated and sold to other industries as additive for waste stabilization or as fertilizer.[20]

The most popular way of disposal of the cement bypass dust is landfilling, which—to be done properly with all the required lining and covering—costs a lot of money and still pollutes the environment and depletes the natural resources. That is why proper and effective disposal or reuse of cement bypass dust is always one of the main concerns for both the cement industry and environmental protection. The chemical analysis for the bypass dust is shown in Table 1.5.

Utilization through Cleaner Production Techniques

Treatment or proper disposal of wastes to be able to comply with environmental protection regulations has always been considered as an additional cost that has no return to industry or community, which will also have a bad effect on the environment one way or another—its cost sometimes represents a significant portion of the total cost of the produced product, which is passed on to consumers or deduced from the profits of the industry resulting—either way—in an indirect waste of money.

The core element of cleaner production techniques is prevention versus clean-up or end-of-pipe solutions to environmental problems. In other words, its core element is the establishment of a safe sustainable environment yet doing

TABLE 1.5 Chemical Analysis of Cement Bypass Dust

Chemical Formula	Percentage
SiO_2	9.0–13.0
Al_2O_3	3.0–4.0
Fe_2O_3	2.0–2.5
CaO	45.0–48.0
MgO	1.7–1.9
SO_3	4.0–11.0
Na_2O	3.0–8.0
K_2O	2.0–6.0
Cl	4.0–13.0

it the most efficient way to avoid any unnecessary cost. It is considered a new and creative approach toward products and production processes.

Cleaner production focuses on reducing the use of natural resources, thus minimizing the waste generated from the process. It also stresses preventing these wastes at the source by the use of cleaner production techniques, which does not mean changing processes, as a process may be made "cleaner" without necessarily replacing process equipment with cleaner components. It can simply be done by changing the way a process is operated. Some people might suggest changing the technology or process from dry technology to wet technology to reduce the amount of cement bypass dust as one of the cleaner production techniques. This is true from the bypass dust point of view only, but wet process will increase the energy consumption and the amount of fuel consumed. This will lead to more consumption of natural resources, more air pollutant emitted to the atmosphere, more air pollution control devices installed, and more money spent in terms of capital cost and running cost. Others might think of recycling the bypass dust as one of the cleaner production technique options. This option might be cost effective if the product from the recycling process is competitive with similar product in the market from the quality and price point of views.

Therefore, cleaner production has many benefits if managed properly; it can reduce waste disposal cost, raw material cost, and the environmental impact of the business, and improve profitability and worker safety. It can also improve the public relations and image, thus also improving the local and international market competitiveness. It is simply a win–win concept, and the challenge that rises here is how to achieve cleaner production in an appropriate manner. The proper approach to tackle this challenge is: (1) source inventory (Where are wastes and emissions generated?), (2) cause evaluation (Why are wastes and emissions generated?), (3) option generation (How can these causes be eliminated?). Knowing the answer of these questions and achieving a proper cleaner production can be made using the six-step organized approach:

1. Simply getting started and taking action toward the issue
2. Analyzing process steps, inputs, outputs (flows and emissions)
3. Generating cleaner production opportunities
4. Selecting cleaner production solutions that fit your environment and that you're capable of doing
5. Implementing cleaner production solutions
6. Sustaining cleaner productions

Following this simple, logical approach, one can simply help alleviate the problems of environmental pollution with significant economical benefits.

Industrial Ecology Approach

Under what we may call the same umbrella of cleaner production, a philosophy/strategy/framework of industrial ecology came to life.[21] However, most definitions of industrial ecology include similar attributes with different emphases, and these attributes include the following:

- A systems view of the interactions between industrial and ecological systems
- The study of material and energy flows and transformations
- A multidisciplinary approach
- An orientation toward the future
- An effort to reduce the industrial systems' environmental impacts on ecological systems
- An emphasis on harmoniously integrating industrial activity into ecological systems
- The idea of making industrial systems emulate more efficient and sustainable natural systems

The concept of industrial ecology beyond already existing practices is to reduce negative impacts of industrial using a systems-oriented approach and linking with natural ecosystems in a twofold manner:

1. *Analogy:* Natural systems are seen as a "... model of highly efficient use of resources, energy, and waste," which industrial systems should try to adopt.[22] This is the same idea that had been introduced and discussed in the cleaner production approach.
2. *Integration:* Industrial systems are viewed as only one part of the surrounding systems, with which they must be in concert,[23] which is—to a limit—a new point that can be further studied.

Using the industrial ecology concept, many benefits would be provided, other than the same gains that are provided by the cleaner production, which are reduction in the use of virgin materials, reduction in pollution, increased energy efficiency, and reduction in the volume of waste products requiring disposal, many other benefits of great importance are to be gained such as increase in the amount and types of process outputs that have market value,[24] and the birth of new industries which means more work chances and high economic benefits, also like hidden resource productivity gains, synergies between production and distribution beyond production chain: closed loop, and the creation of eco-industrial parks and interfirm relations.

This takes us to the recognition of what eco-industrial parks are all about. Eco-industrial parks actually represent the form that every industrial community should be according to industrial ecology. In these parks, every single waste is either reused or retreated in a certain way that sustainability of resources and environment is assured. Most industrial ecologists believe that Kalundborg, a small city on the island of Seeland, 75 miles west of Copenhagen, is the first recycling network in history.[25] The four main Industries and a few smaller businesses feed on each other's wastes in transforming them into useful inputs.

As Gertler explains, the basis for the Kalundborg system is "creative business sense and deep-seated environmental awareness," and "while the participating companies herald the environmental benefits of the symbiosis, it is economics that drives or thwarts its development."[24]

The same idea and approach to reaching a sustainable environment is what the—cradle-to-cradle concept calls for compared with the—cradle-to-grave approach. The cradle-to-grave concept means that the raw materials of a certain industry are being used only once and then are dumped in a landfill, which is a one-way stream of materials. As explained earlier, this has been happening all over the world one way or another since the Industrial Revolution. But now to realize environmental reform in the cement industry, the cradle-to-cradle concept has to get into place, where every material is considered as a nutrient either to the environment or to the product itself. In order to form a community to cope with such concept and action, according to Braungart and McDonough, there are four steps to be made:[26]

"Phase 1—Creating Community: identification of willing industrial partners with a common interest in replacing hazardous chemicals with natural one or less hazardous, targeting of toxic chemicals for replacement;

Phase 2—Utilizing Market Strength: sharing list of materials targeted for elimination, development of a positive purchasing and procurement list of preferred intelligent chemicals;

Phase 3—Defining Material Flows: development of specifications and designs for preferred materials, creation of a common materials bank, design of a technical metabolism for preferred materials;

Phase 4—Ongoing Support: preferred business partner agreements amongst community members, sharing of information gained from research and material use, co-branding strategies."

Recycling Opportunities

According to cleaner production techniques and industrial ecology concept, a number of alternatives can be demonstrated to utilize the cement bypass dust as a raw material in another industry or another process or within the same process, such as the following:

- Recycling within the cement production process (most efficient in wet process) and requiring more research to optimize the percentage of bypass dust to be recycled without affecting the cement properties
- Production of tiles/bricks/interlocks blended cements
- Production of glass and ceramic glass
- Production of safe organic compost (soil conditioner) by stabilizing municipal wastewater sludge
- Enhancing the production of road pavement layers

Recycling through Tiles/Bricks/Interlocks By pressing the cement bypass dust in molds under a certain pressure force, bricks/interlock/tiles can be formed with a breaking strength directly proportional to the pressure used to form it, and sometimes the breaking strength is even higher than the pressure used to form it. In Cement Turah factory in Egypt, experiments were conducted on the following:

- Using 100 percent cement bypass dust with pressure force of 200 kg to form a cylindrical cross-section bricks of 50 cm^2 area where the breaking pressure of these bricks reached 120 kg/cm^2. In addition, chemical treatment of these bricks during the hydraulic molding can achieve a breaking pressure of 360 to 460 kg/cm^2 for the 100 percent cement dust bricks.
- Using 15 to 20 percent cement dust with clay and sand along with pressure thermal treatment to reach breaking pressure of 530 to 940 kg/cm^2.
- Using 50 percent cement dust with sand along with thermal treatment only to reach breaking pressure of 1,300 kg/cm^2

Using cement bypass dust with clay to produce bricks has proven to reduce the weight of the bricks along with reducing the total linear drying shrinkage. In addition, this opportunity can utilize very high percentages of the bypass dust. However, this will still depend on the market needs and the availability of easily transported bypass dust.

Recycling through Glass and Ceramic Glass Using bypass dust as a main raw material (45 to 50 percent) along with silica and sand stone and melting the mix at temperatures ranging 1,250° to 1,450°C, glass materials were obtained. The glass product has a dark green color with high durability due to the high calcium oxide (CaO) content in cement bypass dust. It can be used for bottle production for chemicals containers. This step was then followed by treatment for 15 to 30 minutes at temperatures ranging from 750° to 900°C to form what is known as ceramic glass. This new product, unlike glass, has a very high strength, is unbrittle, is untransparent, and looks like marble. The produced ceramic glass is highly durable and can resist chemical and atmospheric effects. Consequently, this new product opens the way for utilizing huge quantities of bypass dust in producing architectural fronts buildings, prefabricated walls, interlocks for sidewalks and many other engineering applications.

Recycling through Composting of Sewage Sludge Because of the high alkalinity and pH value of cement kiln dust (11–12), it can be used in stabilizing municipal sewage sludge. Municipal sludge contains bacteria and parasites. Therefore, if used directly as a soil conditioner, it will cause severe contamination to the soil and the environment and may be very hazardous to health.

Two types of sludge from sewage treatment plants can be used. The first one is from a rural area where no heavy metals were included and the second is from an urban area where heavy metals might exist, depending on the level of awareness and industrial compliance.

Due to the high alkalinity of cement bypass dust, when it is mixed with municipal sludge, it enhances the quality of sludge by killing the bacteria and viruses.[27] Also, it will fix the heavy metals (if they exist) in the compost and convert them into insoluble metal hydroxides, thus reducing flowing of metals in the leachate. Agricultural waste such as rice straw, corn stalk, and so on, which is considered a major environmental problem in most countries, can be added to the sludge for composting process to adjust the carbon to nitrogen ratio and enhance the fermentation process. Agricultural waste will also act as a bulking agent to improve the chemical and physical characteristics of the compost and help reduce the heavy metals from the sludge.

The uniqueness of this process is related to the treatment of municipal solid waste sludge, which is heavily polluted with ascaris eggs (most persistent species of parasites) using passive composting technique. This technique is very powerful and very efficient, with much less cost (capital cost and running cost) than other techniques, as explained before. First, primary sludge will be mixed with 5 percent cement dust for 24 hours. Second, agricultural waste as a bulking agent will be mixed for passive composting treatment. Passive composting piles will be formed from sludge mixed with agricultural waste (bulking agent) and cement dust with continuous monitoring of the temperatures and CO_2 generated within the pile. Both parameters are good indicators of the performance and digestion process undertaken within the pile.

Passive composting technique explained before have shown very promising results, especially by adding cement dust and agricultural wastes. Results show that ascaris has not been detected after 24 hours of composting, mainly due to the high temperature elevations reaching 70° to 75°C for prolonged periods, as well as the high pH from cement dust. Also, the heavy metal contents were way beyond the allowable limits for both urban sludge, as well as rural sludge.[27]

As a result of previous discussion, three major wastes (cement bypass dust, municipal wastewater sludge MWWS from sewage treatment plants, and agricultural waste) can be used as byproducts to produce a valuable material instead of dumping them in the landfill or burning them in the field. This technique will protect the environment and establish a new business where cement bypass dust exists. If cement bypass dust does not exist, quick lime can be used to treat the MWW sludge. Sludge has a very high nutritional value but is heavily polluted with ascaris and other pollutants, depending on location. Direct application of sludge for land reclamation has negative environmental impacts and is health hazardous. Cement bypass dust is always considered a hazardous waste because of high alkalinity. The safe disposal of cement dust costs a lot of money and still pollutes the environment because it is very fine dust with high pH (above 11) and has no cementing action. Agricultural waste has no heavy metals and contains some nutrients, which will be used as a bulking agent. The bulking agent can influence the physical and chemical characteristics of the final product.

It will also reduce the heavy metal content of the sludge and control C/N ratio for composting.

Recycling through Road Pavement Layers Cement bypass dust can be used in three ways in road pavement layers. The first application deals with subgrade layer. The second application deals with base layer, while the third application deals with asphalt mixtures.

Subgrade Layer Adding 5 to 10 percent of cement bypass dust to the soil improves its characteristics and makes it more homogenous and stiff to maintain loads.

Base Layer Limestone is used in the base layer for road paving in general. Also, good binding and absence of voids in this layer are crucial to maintain strength and to prevent settlement and cracking of this layer, which is located right below the asphalt layer. Therefore, adding cement bypass dust as filler material to the base layer eliminates the voids formed between rocks and each other due to its softness. Consequently, it increases the density (weight/volume) of this layer due to increase of weight and fixation of volume, which improves the overall characteristics of binding, especially if base layers of thickness more than 25 cm is required in the design using the same paving equipment. Also, the absence of voids in the base layer provides protection against the negative impact of acidic sewage water and underground water, which work on cracking and settling the base layer.

Asphalt Mixtures The asphalt mixture is a mix of sand, gravel, broken stones, and soft materials, along with the asphalt. In Marshal's standard test for designing asphalt mixtures, it has been found that the percentage of asphalt required can be reduced as the density of the mixture increases. Therefore, adding cement bypass dust, which has very fine and soft particles, improves the mixture efficiency by filling the voids. Also, the bypass dust contains high percentages of dry limestone powder and some basic salts that, in nature, decrease the creeping percent of the asphalt concrete, enhance the binding process, and reduce the asphalt material required, which is very desired in hot climates.

This process was implemented in the road joining the stone mill of Helwan Portland Cement Company and the company's factory in Egypt. The results from binding the base and subgrade layers assured that adding the cement bypass dust to the layers improved the overall characteristics of the road. The road is still operating in perfect condition, after 12 years of trucks using the road with a load capacity not less than 100 metric tons.

Final Remarks

The environmental and socioeconomic benefits as a result of utilizing cement bypass dust can be summarized as follows:

- Reducing air pollution problems
- Utilizing high percent of bypass dust, if not all
- Improving the pavement layer characteristics with very low cost
- Reducing the asphalt percent required in the design for the same performance asphalt mixture
- Providing more job opportunities
- Using low-price product with high quality and strength
- Developing new business opportunities
- Preventing biomass field burning to get rid of the agricultural waste in sludge treatment process
- Reducing greenhouse gas emissions
- Killing microbes and parasites in sludge, forming a high-quality soil conditioner, as well as improving land reclamation and public health

MARBLE AND GRANITE INDUSTRY

Marble and granite industry is considered one of the oldest and largest industries in the world. Marble and granite have been used in Egypt since the time of the ancient Egyptians. Historically, the industry moved from labor-intensive to capital-intensive with the advent of technological advancement, including development of automated production tools such as cranes and diamond-cutting wires. Marble consists mainly of calcite or dolomite, or a combination of these carbonate minerals. Marble is a type of metamorphic rock formed from limestone. It is formed from limestone by heat and pressure in the earth's crust that causes the limestone to change in texture and makeup (recrystallization process). Impurities present in the limestone during recrystallization affect the mineral composition of the marble that forms. The minerals that result from impurities give marble wide variety of colors. The purest calcite marble is white. Marble containing hematite has a reddish color. Marble that has limonite is yellow, and marble with serpentine is green.[28] The specific gravity of marble usually ranges from 2.5 to 3, while granite has a very high specific gravity and can go up to 9.

Marble consists of soluble residue (0.89 percent), Fe_2O_3 (0.28 percent), $CaCO_3$ (97.74 percent), $MgCO_3$ (1.22 percent), phosphoric acid –(0.04 percent), along with the impurities: SiO_2, Fe_2O_3, limonite, manganese, Al_2O_3, and FeS_2 (pyrite).[29] Granite, the hard natural igneous rock having visible crystalline texture, is formed essentially of quartz and orthoclase or microcline. It is formed from volcanic lava. The principal constituents of granite are feldspar, quartz, and biotite. However, the percentage composition of each varies and accordingly imparts different color and texture to the final product. The percentage composition of feldspar varies between 65 and 90 percent, of quartz can extend from 10 to 60 percent and that of biotite lies between 10 and 15 percent.[30] Granite consists of silica (SiO_2), 70 to 77 percent; alumina (Al_2O_3), 11 to 14 percent; potassium oxide (P_2O_5), 3 to 5 percent; soda (Na_2O), 3 to 5 percent; lime, 1 percent; iron (Fe_2O_3), 1 to 2 percent; iron (FeO), 1 to 3 percent; magnesia (MgO), 0.5 to 1 percent; titina, less than 1 percent (.38 percent); and water (H_2O), 0.03 percent.[30]

Nature has gifted Egypt with large deposits of high-quality marble and granite. Since 2700 B.C., the Ancient Egyptians used granite to build their important temples and buildings. Ancient Romans, as early as the third century B.C., acquired the Egyptian knowledge in quarrying and cutting the ornamental stones, especially granite. This technology was transferred back to Italy and, due to the natural endowment of Italy coupled with the acquired technical knowledge, the marble industry flourished and the Italians became world leaders in the production of marble. The production of marble passes through several stages.[31] The main stages are demonstrated in Figure 1.26:

1. *Exploration and identification of a quarry location.* The locations are identified, followed by testing and verification of characteristics of the marble quarry.
2. *Extraction of marble from the quarries.* Extraction of the marble stone happens in several ways, depending on the technology owned by the quarrymen. Marble does not split easily into sheets of equal size and must be mined carefully.

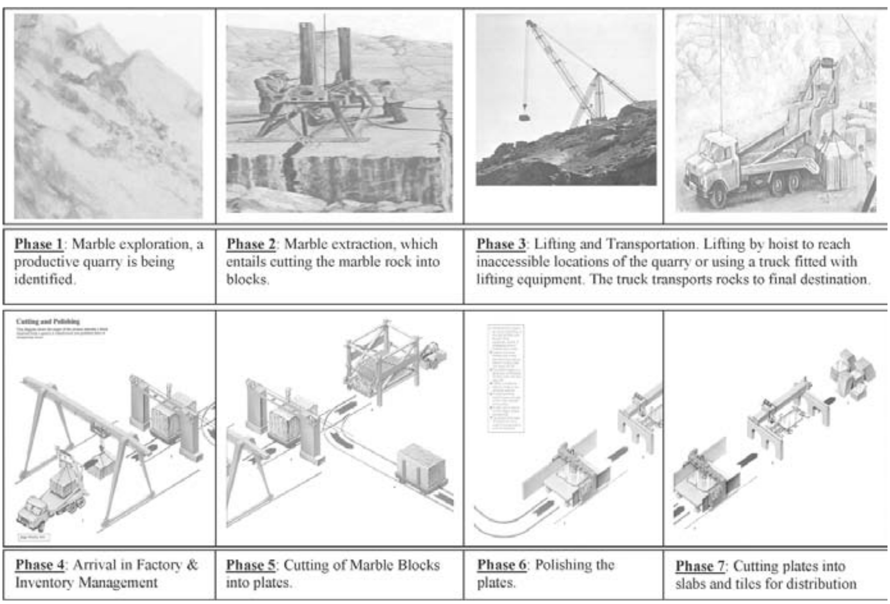

FIGURE 1.26 Marble production process (*Source:* Azza Kandil and Tarek Selim, "Characteristics of the Marble Industry in Egypt," www.aucegypt.edu/academic/economics/papers/wk6.pdf, Accessed July 5, 2007.)

3. *Lifting and transportation.* After cutting the rocks of marble, marble blocks need to be lifted to a truck for transportation to the factories.
4. *Inventory management.* The inventory of raw stone blocks is very bulky and requires a very spacious area.
5. *Cutting the stone into slabs and tiles.* When a certain order is placed, the raw stone block is transported to the factory to be cut as demanded, either into tiles or slabs of various thicknesses (usually 2 cm or 4 cm). Stone cutting is a lengthy process that can take more than a continuous 12 to 16 hours of operation, depending on the model of the cutting machine, as well as the status of its diamond wire or diamond blades.
6. *Polishing.* After the stone has been cut to the specific dimensions, there are different techniques towards reaching a "finished" product. The most known of these techniques is polishing. The polishing operation is fully automated, with the use of powdered abrasives that keeps on scrubbing the surface of the marble until it becomes smooth and shiny. The smoother the abrasive used, the shinier and smoother is the surface of the marble. Here, water showers are essential to prevent overheating.
7. *Distribution to end users.* The distribution channels depend very much on the end product produced by the factory. If the factory produces finished tiles and slabs, then this is a finished order, processed according to the customer requirements, and a customer delivery takes place. Distribution often goes to workshops that are usually the middleman between the supplier and the end user. These workshops receive the cut plates of marble and store them in their shops for the end user to choose from.

Marble and Granite Waste

Nearly 70 percent of this precious mineral resource gets wasted due to mining, processing, and polishing, as shown in Table 1.6. The processing waste being dumped on the riverbeds is threatening the porosity of aquifer zones.[32] However, for each marble or granite slab of 20 mm produced, a minimum of 5 mm is crushed into powder during the cutting process. This powder flows along with the water, forming marble slurry. In other words, a minimum of 20 percent marble/granite produced results in powder in the form of slurry. This slurry has approximately 35 to 40 percent water content. In India, about 30 percent weight

TABLE 1.6 Waste Distribution among Different Phases

Process	Marble Production	Mine Waste	Processing Waste	Polishing Waste	Total Waste	Mine Out Reserve
Quantity	30 percent	50 percent	15 percent	5 percent	70 percent	100 percent

Source: Siddharth Pareek, "Gainful Utilization of Marble Waste: An Effort towards Protection of Ecology and Environment," 2007, www.cdos-india.com/papers/18%20-%20Gainful%20Utilization%20of%20Marble%20Wast%20-%20Siddharth%20Pareek.doc.

of marble blocks are converted into powder, and it is about 1.5 million metric tons per annum. Requirement of water in the processing plants is about 2,750,000 liters per hour.[32]

Therefore, there are mainly two types of wastes solid wastes and semisolid or slurry that can be produced from marble and granite processing. Solid waste consists of stone rubble with inadequate dimension for use in any application. This rubble is of low commercial value and is usually disposed of in landfills. Natural stone slurry occurs during physical processes such as extraction, sawing, and polishing. The equipments used in these activities necessitate the use of large amounts of water, for cooling, lubrication and cleaning. This mixture of water and very small particles produces a semiliquid substance that is generally known as '*natural stone slurry*', due to its appearance.[33] Thus, a "filter press" is a key component in the eco-friendly technology for marble processing. The amount of water saved can be recirculated as a coolant from the settling tank to the saw nozzle after collecting the slurry for possible utilization as tiles or bricks, or to be used in cement industry or paving roads.

Another type of waste can be generated during quarrying. The quarrying waste disposal practices are as follows:[32]

- The waste generated during the quarrying operations is mainly in the form of rock fragments.
- The generated waste by the quarries are usually dumped in empty pits in the nearby area, thereby creating huge mounds of waste.
- The waste and overburden is dumped on roads, riverbeds, and agriculture fields, leading to widespread environmental degradation.
- The quarry operators express their inability in proper segregated and disposal of waste due to the small sizes of the quarry.

Physical and Chemical Properties of Slurry

The dimension of slurry particles was therefore compatible with the filling and densing of the transition zone (measuring between 10 and 50 μm) and of the capillary pores (which range from 50 nm to 10 μm of diameter), thus acting as a microfiller. According to parallel specific testing, it was concluded that the used slurry had no hydraulic or pozzolanic activity.

The average dimension of the slurry particles was inferior to 74 μm (which would exclude its use as an aggregate for concrete production, according to the conventional concrete technology approach). Their chemical nature was exclusively dependent on the original material (without clay or other deleterious materials), and the test results showed that the slurry was fit to be used in concrete mixtures.

The chemical analysis of marble slurry is shown in Table 1.7. The high content of CaO confirmed that the original stones were marble and limestone. It was also verified that the slurry did not contain any organic matter, thus confirming that it could be used in concrete mixtures.

TABLE 1.7 Chemical Analysis of Marble Slurry

Test Carried Out	Test Value (in percent)
Loss on ignition	43.46
Silica	1.69
Alumina	1.04
Iron oxide	0.21
Lime	49.07
Magnesia	4.46
Soda	Less than 0.01
Potash	Less than 0.01

Source: Sanjay Singh and V. Vijayalakshmi, "Marble Slurry—A New Building Material," *Technology Information*, Forecasting, and Assessment Council, 2006, http://www.tifac.org.in/news/marble.htm

The tested slurry had a specific density of 2.72 g/cm^3. Furthermore, by using an easy particle sizer M6.10 equipment, it was possible to compare both grading curves of cement and slurry particles. The specific surface area of the slurry particles was 7128 cm^2/g and its average size was 5.0 μm (smaller than cement particles).

Scrapes

Another waste is marble/granite scrapes (small pieces), which represent nearly 10 to 15 percent. These are usually dumped into landfills without any precaution. There are two types of scrapes: bulk stone and polished scrapes. Bulk stone scrapes are the huge masses produced at the mine when large blocks are cut out of their natural environment. These masses are usually crushed to small aggregates with a crusher, and ultimately used in tiles. Polished scrapes are normally 2 to 4 cm thick. Both types of scrapes have the following in common:

- They consume space.
- When piled up, they form hills of scrape that can house harmful animals like snakes and rats.
- They are not self-degrading materials.

Environmental Impacts and Mitigation

The environmental impacts and mitigation of both marble slurry and scrapes will be discussed in this section. As a result of disposal of the marble slurry generated during the processing of marble and granite, the following environmental damage might occur:

- The porosity and permeability for the topsoil is reduced tremendously, and in due course of time it results in waterlogging problems at the surface, which does not allow the water to percolate down.

- The fine marble particles with high pH reduce the fertility of the soil by increasing its alkalinity. The high pH of the dry slurry makes it corrosive material that is harmful to the lungs, and may cause eyesores.
- Dry slurry diffuses in the atmosphere, causing air pollution to human and possible pollution to nearby water. It settles down on crops and vegetation, thus severely threatening the ecology of the marble clusters.
- It may corrode nearby machinery.
- It depletes natural resources in terms of wastewater, marble, and granite powder, small pieces of marble, and granite.

The solid larger pieces can be easily incorporated in concrete or in sculptures, as in bonded marble. As for the slurry, it has much potential—from pavement filler material to agricultural fertilizers. Almedia et al. produced a paper that briefly describes many of the applications of marble and stone waste:[33]

- Cement industry
- Tiles
- Red ceramic bricks and tiles
- Mortars and concrete
- Polymer concrete
- Other cement-based products
- Pavement
- Embankment
- Agglomerate marble

Cement Industry Recent research studies concluded that there is technical viability to incorporate massive quantities of natural stone slurry as "raw material" in the production of clinker, without any previous complex treatments.

As an example, the Portuguese cement industry is responsible for the consumption of 12 million metric tons of raw materials each year, about 10 million metric tons of which is limestone. The Portuguese natural stone slurry produced annually represents 3.5 percent of the total limestone raw material needed by the national cement industry.

Tiles India also presents successful cases related to the production of tiles containing 90 percent of stone slurry bonded by 10 percent of resin.

Red Ceramic Bricks and Tiles A European research project concluded that it is possible to incorporate large amounts of natural stone slurry by substituting conventional calcium carbonate used in the production of red ceramic bricks, without compromising the behavior of the obtained final product.

The presence of this slurry in a 2 to 3 percent ratio solved the expansion problems usually associated with structural ceramic materials. Furthermore, depending on the kind of basic raw material used, it is possible to use up to 25 percent of slurry.

Confirmation on the behavior of this kind of recycled material was also obtained from similar research done in Brazil and India, where red ceramic tiles are produced with 20 percent of stone slurry input.[33]

Generally speaking, the bricks and floor tiles are heterogeneous because they consist of natural clays with a very wide-ranging overall composition. Consequently, they can tolerate the presence of different types of wastes, even in considerable percentages.

The raw materials that will be used in brick type compositions are plastic red clay (PRC) and low-grade clay (LGC). While in floor tile formulations, in addition to the PRC, shale clay (SC) is added and the granite sludge is added to both. Regarding the chemical composition of these three types of clay, (the PRC is based on illite, kaolinite, montmorilonite and some quartz and feldspar, while the LGC clay is mainly based on quartz and illite. The SC consists essentially of a mixture of quartz, mica (muscovite), kaolinite, illite, and montmorilonite.[34]

The sludge in general has relatively fine particle size distribution, and this means that it doesn't require any further grinding step and can replace the low-grade clay components used in the fabrication of brick type products or the feldspar in floor tiles compositions.

There were tests conducted regarding adding the sludge to the bricks and floor tiles as in the case of incorporating the cutting sludge in industrial porcelain tiles. The tests were conducted on granite sludge as a trial. The clay materials, together with the sludge, were mixed at different weight percentages regarding both the brick type and the floor tiles type, as shown in Table 1.8.

Regarding both compositions, the brick type were fired at 950°C in an industrial furnace and then followed by a long cycle of about 9 hours. The floor tile type were fired at 1100°C in an electrical laboratory furnace with a holding time of 1 hour at the maximum temperature.[34] The results were satisfactory concerning the tests, but focused more on the linear shrinkage, the water absorption, and the flexural strength. The results are shown in Table 1.9.

TABLE 1.8 Tested Brick and Floor Tiles Compositions

	Brick-type composition (wt percent)				
	1	2	3	4	5
PRC	30	35	35	40	45
LGC	70	30	15	0	5
Granite sludge	0	35	50	60	50
	Floor tile–type compositions (wt percent)				
	6	4	7	8	9
PRC	30	40	50	0	0
SC	0	0	0	40	50
Granite sludge	70	60	50	60	50

Source: J. M. F. Ferreira et al. "Recycling of Granite Sludges in Brick-Type and Floor Tile-Type Ceramic Formulations," University of Aveiro, 2007.

TABLE 1.9 The Properties of the Fired Products

Temperature	Composition	Fired Properties		
		Linear Shrinkage (percent)	Water absorption (percent)	Flexural Strength (Mpa)
	1	0.15	13.02	13.4
950°C	2	0.18	12.97	12.3
(BT)	3	0.16	12.92	10.3
	4	0.21	13.00	11.8
	5	0.29	13.01	11.7
	6	0.17	6.04	39.8
1100°C	4	0.19	1.60	53.8
(FTT)	7	0.28	0.43	57.4
	8	0.26	0.10	68.2
	9	0.30	0.00	74.6

* BT = Brick type
* FTT = Floor tiles type

Source: J. M. F. Ferreira et al. "Recycling of Granite Sludges in Brick-Type and Floor Tile-Type Ceramic Formulations," University of Aveiro, 2007.

Focusing on the results that were achieved after conducting the tests, it was found that the granite sludge that is derived from the cutting processes of this natural stone can be considered and reused to be an interesting raw material for the brick type and floor tile formulations. The results shown above clarify that there is a wide range of results regarding all the tests. For instance, focusing on the results of samples 4 and 5, the granite sludge represents approximately 50 percent of the total weight and the results of these samples regarding the linear shrinkage, water absorption, and the flexural strength are acceptable. Also from the results, it is obvious that PRC is beneficial because it enhances the overall performance and its absence will negatively affect the properties of the end product.

In the final analysis, "the granite sludge in brick type compositions can be as high as 60 percent. For floor tile type products, the incorporation of the sludge can be used in the range of 50 to 60 percent when combined with the SC, or it can be limited to a maximum of 50 percent in the case of PRC."[34] Therefore, since the brick type and floor tile type industry requires several tons of raw materials, it will be economical and environmental to consume the marble and granite sludge.

Mortars and Concrete Technical possibilities of producing concretes and mortars containing stone slurry have been studied with positive results in several countries. Research works in Portugal led to similar conclusions, demonstrating improvements in several properties. Tests were performed by Almeida et al. in order to investigate the maximum percentage of marble slurry that can be incorporated in concrete.[33] The mixes used for the tests are shown in Table 1.10.

TABLE 1.10 Concrete Mix Properties

Mixture	Sand Substitution	Compressive Strength 7 days (MPa)	Compressive Strength 28 days (MPa)	Spitting Tensile Strength (MPa)	Modulus of Elasticity (GPa)
CMSSO	0	60.3	85.1	4.2	40.5
CMSS5	5	66.5	91.1	4.8	43
CMSS10	10	55.3	79.4	4.2	41.4
CMSS15	15	58.1	79.5	4.3	38.8
CMSS20	20	53.9	77.5	4	36.9
CMSS34	34	41.1	60.8	3.3	33.5
CMSS67	67	36.4	58.2	3.2	30.7
CMSS100	100	30.1	50.3	3	26.7

Source: Nuno Almeida, Fernando Branco, and José Roberto Santos "Recycling of Stone Slurry in Industrial Activities: Application to Concrete Mixtures," (2005), http://www.sciencedirect.com/science.

Different concrete mix proportions were tested for compressive strength, tensile strength and modulus of elasticity as shown in Table 1.10.

Compressive Strength When 5 percent of the initial sand content was replaced by stone slurry (CMSS5), 10.3 percent higher compressive strength after 7 days, and 7.1 percent higher compressive strength after 28 days were detected, when compared with CMSS0. This increase can be related to the higher concentration of hydrated cement compounds within the available space for them to occupy. Furthermore, by acting as micro filler, the stone slurry promoted an accelerated formation of hydrated compounds, thus resulting in a significant improvement of compressive strength at earlier ages (7 days).[33]

In fact, the amount of slurry present in CMSS5 enabled the very fine particles of it to act as nucleation points. This is related to an effect of physical nature that ensures effective packing and larger dispersion of cement particles, thus fomenting better hydration conditions. Moreover, the slurry particles completed the matrix interstices (transition zone and capillary pores) and reduced space-free water. The combination of these phenomena resulted in a better bonding among the concrete components.[33]

CMSS10, CMSS15, and CMSS20 presented a reduction of compressive strength ranging from 3.6 percent to 10.6 percent at 7 days of age, and from 6.7 percent to 8.9 percent at 28 days of age (when compared to CMSS0). Lower performance of CMSS10 could seem improbable, taking into account its water/cement ratio. However, for this extremely low water/cement ratio, the available space for accommodating hydrated products was insufficient, thus inhibiting chemical reactions.[33]

Regarding higher contents of stone slurry (substitution of more than 20 percent of sand), the decrease of compressive strength values was significant. The incorporation of such amounts of very fine material did not permit the microfiller effect to prevail, which, in addition to a rather inappropriate grading, caused lower results.[33]

When substituting all the sand for stone slurry (CMSS100), test results showed 50.3 MPa at 28 days and 30.1 MPa at 7 days. Although these results were acceptable by comparison with conventional concrete, the relative reduction amounted to 40.9 percent for 28 days and 50.1 percent for 7 days. Therefore, it is possible to conclude that full substitution of fine aggregate for stone slurry is not reliable when compressive strength is a critical aspect to take in consideration.[33]

Tensile Strength The benefits obtained in compressive strength property due to the microfiller effect induced by stone-slurry particles was even further important regarding the splitting tensile strength tests (relative increase of 14.3 percent detected for CMSS5). These are coherent results, in light of the explanation advanced regarding the compressive strength variation of CMSS5.[33]

As for the compressive strength, when the substitution level of sand surpassed 20 percent, the tensile splitting strength was significantly reduced. Nevertheless, test results show that tensile splitting strength is less sensitive to high content of very fine particles than compressive strength. CMSS100 presented a result of 3 MPa, correspondent to a quite acceptable reduction of 28.6 percent relatively to CMSS0.[33]

Modulus of Elasticity In accordance with the analysis made concerning the other mechanical properties, CMSS5 test results determined that this was the concrete mixture with better behavior in terms of modulus of elasticity (6.2 percent higher than CMSS0) and that all mixtures containing less than 20 percent of stone slurry obtained acceptable results. CMSS10 also presented a slight improvement of 2.2 percent in behavior. In the extreme case of slurry incorporation (CMSS100), the average of test results for the modulus of elasticity was 26.7 GPa (34.1 percent less than the reference concrete mixture CMSS0).[33]

It is known that cement paste modulus of elasticity is generally half the modulus of elasticity of aggregates. Therefore, when introducing stone slurry (very fine particles, with slightly inferior size than cement particles), the paste could be considered as increased, thus promoting a negative effect on the modulus of elasticity of the hardened concretes. This fact, in addition to the higher water/cement ratio, could explain the lower modulus of elasticity attained for more than 15 percent substitution (inclusively).[33]

Another reason that might explain the negative behavior detected for more than 15 percent of aggregate replacement for slurry, apart from the higher water/cement ratio, might be associated with a possible volumetric expansion occurring among the different materials, withdrawing aggregates (which better contributes to a higher modulus of elasticity) from one another, thus losing some ability to restrain deformations (further dependent on the paste).[33] In light of this, better behavior of CMSS5 and CMSS10 can be explained by better grading and packing of hardened concrete mixture, attained by reduced space among the different particles.[33]

The results showed that the substitution of 5 percent of the sand content by stone slurry induced higher compressive strength, higher splitting tensile strength, and higher modulus of elasticity. The feasibility of incorporating up to 20 percent stone slurry in detriment of the respective amount of fine aggregate without prejudicing mechanical properties in a serious manner was also determined.

Polymer Concrete (PC) Marble and granite waste, in addition to organic binders, can be utilized in many different applications. Less-expensive recycled polymer binders have been used with marble, basalt, and quartz, as well as rice straw, bagasse, and cotton stalk fibers in polymer concrete (PC) production. Reasonable cost, durability under anticipated exposure conditions, adhesion to aggregate, handling properties, and ease of curing are the most important considerations in the choice of the resin used. The high cost of the traditional resins used in the preparation of PC makes it relatively expensive compared to the cement-based materials and is limiting the growth of PC-based products. Therefore, recycling of plastic polymers has received a great deal of attention to reduce the cost of resin production; in addition, it is an acceptable, convenient solution to some ecological problems resulting from the accumulation of these wastes.

Other Cement-based Products Applications include cement-based products such as structural blocks, lightweight blocks, soil–cement bricks, pavement coatings, and even acoustic panels developed at an experimental level that contained granite slurry, limestone aggregates, cement, and cork industry waste.[33]

Pavement Stone slurry was not considered as suitable for pavement use, but some laboratory tests demonstrated that it is possible to incorporate this byproduct in asphalt mixtures as a commercial filler substitute. The use of slurry in road works is not common. In fact, some researchers attest that it is possible to use marble slurry in roadwork layers that account for 25 to 35 percent of the total pavement thickness.

In Turkey, limestone dust was generally used in asphalt mixtures as filler material. However, in recent years, many quarries were closed off because of the environmental protection rules put into use. Therefore, highway authorities and municipalities have difficulties for finding suitable filler material. As a result, using the waste material as filler should be investigated for road construction. For this reason, Almeida et al. has investigated using marble dust in asphalt mixtures as filler material.[33]

Embankment As with pavements, opinions about the use of stone slurry in embankments are not unanimous. Despite the existence of bibliography referring to the possibility of using stone slurry in embankments (taking advantage of the insulation capability of the slurry) or mixed in a 25 percent ratio with soil, there are also several studies referring to environmental impacts related with the presence of this industrial waste in soil.[33]

Agglomerate Marble Agglomerate marble is the designation for products that bind pieces of natural marble together with specially formulated polyester resin. This process allows the reconstruction of large recycled “marble” blocks, similar to the ones extracted from quarries, both in quality and visual aspects, which can be submitted to the same processing activities as natural stone. Research concerning the reutilization of marble slurry as a substitute of calcium carbonate was developed for agglomerate marble fabrication. For a total amount of slurry that reached up to 6 percent of the total compounds, it was technically possible to adopt this procedure.[33]

This is sometimes called *cast marble*. It is a manmade product consisting of marble dust (calcium carbonate) and polyester resin. The type of resin used in bonded marble products is crystal clear and sometimes referred to as *casting resin*. This type of resin is costly to produce, thus adding more to the cost of the finished product. The calcium carbonate in the bonded marble creates a semiporous surface that has a very unique look and feel. The calcium carbonate also makes the piece pure white and allows for a very high degree of detail. Most bonded marble products are made in Italy, which has the whitest marble in the world. Other names for bonded marble are cast marble, cultured marble, and bonded Carrara marble.[35]

Natural Carrara marble powder is mixed with a resin. The mixture is then poured into a mold of the statue design. The resin gives the marble powder an added strength superior to the natural stone. The finished product bears a near identical resemblance to the original hand-carved statue. The texture and features are duplicated and the color is a consistent ivory white. Because of the characteristics of the resin material, these bonded marble statues shown in Figures 1.27 are waterproof, and can be washed and cleaned with most agents. Water and weather will not harm the material, and it is very strong. It will not yellow over time, can handle high detail, doesn’t have bubbles, and will not crack.[36]

METAL FOUNDRY INDUSTRY

The metal foundry industry can be divided into two sectors: ferrous and nonferrous. Ferrous foundries cast iron and steel products, while nonferrous foundries cast a variety of other metals such as aluminum, copper, zinc, lead, tin, and nickel. More than 75 percent of products by volume are ferrous. Although nonferrous industries use the same basic molding and casting techniques, byproducts can be different from those produced from ferrous industries.

The casting of metal in foundries is one of the oldest and largest recycling industries in the world. Metal foundries exist everywhere worldwide to produce different products such as valves, pipe fittings, pipe accessories used in water, and wastewater networks made out of cast iron, copper, or aluminum through metal foundry using sand-molding technology. Many other components in engines, pumps, blowers, compressors, and so on can also be produced in metal foundries. The sand molding technology consists of the following processes:

FIGURE 1.27 Bonded marble with antique stone finish 10 inches H (25 cm) (*Source:* www.goddessgift.net/page20.html.)

1. *Sand and mold preparation.* The sand is first mixed with a hardening material, like bentonite slurry for example, inside the sand preparation mixers. After that the sand molds are formed and are placed on the production line
2. *Melting.* The main types of metals are used in metal foundry: iron, aluminum, and copper. Other metal can also be used according to requests, such as zinc, aluminum alloy, copper alloy, and so on. A large quantity of slag, which is about 20 to 25 percent of the melted material, comes out from the melting process. The utilization of slag will be discussed with details in the next section.

3. *Pouring*. The end metal product is then poured into the moulds and left to cool and gain its strength. Then the moulds are untied to get the product from.
4. *Cleaning and Inspection.* All the products are gathered for inspection and quality assurance. Some of those are rejected and sent back to the furnace for remelting, and others are approved and cleaned. However, there is a huge quantity of wasted sand that creates a disaster to the company and surrounding environment, if it is left without use.
5. *Product final preparation phase.* The products are sent to workshops for cutting, making holes, and trimming. This process results in many metal wastes that are then delivered again to the furnaces for remelting.
6. *Assembly and examination phase.* After all the products are prepared, they are assembled according to the specifications, and then their mechanical properties are tested.
7. *Finishing and storage phase.* The final product is then painted by spraying it either with bitumen or epoxy in a controlled outdoor area. After the product is painted, it is stored in its final shape.

Foundry Sand

Foundry sand is a byproduct waste sand from a foundry or factory that produces castings of metal. Iron is the most common element used in foundries, but other heavy metals have been known to be used, including aluminum, copper, lead, and zinc.[37] Foundry sand is essentially uniformly sized sand with high-quality silica content. It is used as a mold to cast the metals into the desired product. The sand mold is bonded together using organic binders. The sand-casting system is the most commonly found system in the metal-molding industry. The foundry sand is generally clean before it is used in the casting process, but once it has been used, it may be hazardous.[38] The used or spent material often contains residues of the heavy metals and binder that may act as leachable contaminants. The residual sand is routinely screened and returned to the system for reuse. As the sands are repeatedly used, the particles eventually become too fine for the molding process and, combined with heat degradation from repeated pourings, requires periodic replacement of "spent" foundry sand with fresh foundry sand. This *spent sand* is black in color and contains a large amount of fines (particles of 100 sieve size or less).[39] Most of the sand-cast molds used for iron castings are of a type of foundry sand called *green sand*, which consists of high-quality silica, bentonite clay, sea coal, and water. The green sand is not actually green in color, but refers to the fact that it is used in the wet state. In the past, once the casting has been done, the spent foundry sand was often no longer used due to fears of environmental concerns and contamination. However, an article in *Civil Engineering* magazine stated, "Fears of environmental contamination have recently been laid to rest with new studies indicating that certain types of waste foundry sand are not only ecologically safe but literally cheaper than dirt in some cases."[40] According to a study done by the U.S. National Transportation Board, "the annual generation of foundry waste, including dust and spend foundry sand, in the United States is believed to range from 9 to 13.6 million tons. Typically, about 1 ton of foundry sand is required for each ton of iron or steel casting produced."[41] Most of this waste is landfilled, sometimes even being a cover material at landfill sites. It has been shown that spent foundry sand may be used in a multitude of applications without environmental considerations. A study done by Oakland–Berkeley Recycling Market Development Zone shows that spent foundry sand may be used as an addition to asphalt mixes and in the design of decorative tiles with the sand.[42] The physical and chemical properties of spent foundry sand are shown in Tables 1.11 and 1.12, respectively.

Uses of Foundry Sand

According to a technology brief done by the Clean Washington Center in Seattle, the uses for spent foundry sand in different applications include the following.[43]

Agricultural Products

- Amendments
- Commercial soil blends
- Compost
- Top dressing

Geotechnical Applications

- Barriers
- Embankments
- Highway construction
- Landfills
- Road bases
- Structural fills

TABLE 1.11 Physical Properties of Spent Green Foundry Sand

Property	Results	Test Method
Specific Gravity	2.39–2.55	ASTM D854
Bulk Relative Density, kg/m^3 (lb/ft^3)	2590 (160)	ASTM C48/AASHTO T84
Absorption, percent	0.45	ASTM C128
Moisture Content, percent	0.1–10.1	ASTM D2216
Clay Lumps and Friable Particles	1–44	ASTM C142/AASHTO T112
Coefficient of Permeability (cm/sec)	10^{-3}–10^{-6}	AASHTO T215/ASTM D2434
Plastic limit/plastic index	Nonplastic	AASHTO T90/ASTM D4318

Source: Highway Research Center, U.S Department of Transportation: Federal Highway Administration, "Foundry Sand," American Foundrymen's Society, Inc., http://www.tfhrc.gov/hnr20/recycle/waste/fs1.htm, Oct. 2, 2006.

TABLE 1.12 Chemical Composition of Foundry Sand

Constituent	Value (in percent)
SiO_2	87.91
Al_2O_3	4.70
Fe_2O_3	0.94
CaO	0.14
MgO	0.30
SO_3	0.09
Na_2O	0.19
K_2O	0.25
TiO_2	0.15
P_2O_5	0.00
Mn_2O_3	0.02
SrO	0.03
LOI	5.15
TOTAL	99.87

Source: Highway Research Center, U.S Department of Transportation: Federal Highway Administration, "Foundry Sand," American Foundrymen's Society, Inc., http://www.tfhrc.gov/hnr20/recycle/waste/fs1.htm, Oct. 2, 2006.

Manufactured Products

- Asphalt
- Concrete products
- Flowable fill
- Portland cement

A detailed case study to utilize spent foundry sand as a reinforcement material to mixed polymeric waste will be discussed later in this chapter.

IRON AND STEEL INDUSTRY

The iron and steel industry is considered one of the most important industries for the sustainable development. It is considered the base for numerous industries that could not have been established without the steel industry, such as construction, automotive, and steel structure industries. There are three basic routes to obtain finished steel products:

1. Integrated steel production
2. Secondary processing
3. Direct reduction

Integrated steel production involves transforming coal to coke in coke ovens, while iron ore is sintered or belletized prior to being fed into the blast furnace (BF). The ore is reduced in the blast furnace to obtain hot metal containing some 4 percent carbon and smaller quantities of other alloying elements. Next the hot metal is converted to steel in the basic oxygen furnace (BOF). Then, it is continuously cast to obtain semifinished products, such as blooms, bars or slabs. These semifinished products are rolled to the finished shapes of bars, sheet, rail, and H or I beams.

The secondary processing, often called minimills, starts with steel scrap that is melted in an electrical arc furnace (EAF). The molten steel produced is possibly treated in a ladle furnace and then continuously cast and finished in a rolling operation. Originally, minimills provided only lower grade products, especially reinforcing bars. But, they recently have been able to capture a growing segment of the steel market.

In the direct reduction method, production starts with high-grade iron ore pellets that are reduced with natural gas to sponge pellets. Then, the sponge iron pellets are fed into an electrical arc furnace. The resulting steel is continuously cast and rolled into a final shape.

There is a huge amount of solid waste "slag" generated from the iron and steel industry as a result of the impurities. Usually, slag is collected from the process and left in a nearby area occupying millions of square meters of land. Slag is not only hindering the use of millions of square meters of land for more useful purposes but also contaminating it with heavy metals such as barium, titanium, and lead. Also, it is well known that toxic substances tend to concentrate in slag that floats at the top of the furnace. Health hazards of heavy metals and toxic substances are well known. Based on the concentration levels of heavy metals, slags may be classified as hazardous waste materials. Furthermore, groundwater, as well as surface water, is susceptible to serious pollution problems due to the likely leaching of these waste materials.

Another type of solid waste generated from the secondary processing is the iron dust produced at the beginning of the process during feeding the scrap to the electrical arc furnace (EAF) for melting. Small quantity of sludge might also be produced during the process of iron in blast furnace.

This section describes the different types of solid waste materials generated from the iron and steel industry and the associated environmental problems. Different techniques of managing these waste materials are presented with a focus on utilizing slag, dust, and sludge in construction engineering applications. Test results of many research efforts in this area are summarized. In addition, numerous ideas to mitigate the environmental impacts of this problem are suggested.

Environmental Impacts

Iron making in the BF produces a slag that amounts to 20 to 40 percent of hot metal production. BF slag is considered environmentally unfriendly when fresh because it gives off sulfur dioxide and, in the presence of water, hydrogen sulfide and sulphoric acid are generated. These are at least a nuisance and, at worst, are potentially dangerous. Fortunately, the material stabilizes rapidly when cooled and the potential for obnoxious leachate diminishes rapidly. However, the generation of sulphoric acid causes considerable corrosion damage in the vicinity of blast furnaces. In Western Europe and Japan, virtually all slag produced is utilized either in cement production or as road filling. In Egypt, almost two-thirds of the BF slag generated is utilized in cement production. Some 50 to 220 kg of BOF slag is produced for every metric ton of steel made in the basic oxygen furnace, with an average value of 120 kg/metric ton. At present, about 50 percent of BOF slag is being utilized worldwide, particularly for road construction and as an addition to cement kilns.[44]

Recycling of slags has become common only since the early 1900s. The first documented use of BF slag was in England in 1903;[45] slag aggregates were used in making asphalt concrete. Today, almost all BF slag is used either as aggregate or in cement production. Steel for making slag is generally considered unstable for use in concrete but has been commercially used as road aggregates for over 90 years and as asphalt aggregates since 1937. Steel-making slag can contain valuable metal and typical processing plants are designed to recover this metal electromagnetically. These plants often include crushing units that can increase the metal recovery yield and also produce materials suitable as construction aggregates. Although BF slag is known to be widely used in different civil engineering purposes, the use of steel slag has been given much less encouragement.

BF dust and sludge are generated from the processing and cleaning, either by wet or dry means. The dust and sludge typically are 1 to 4 percent of hot metal production.[46] These materials are less effectively utilized than BF slag. In some cases, they are recycled through the sinter plant, but, in most cases, they are dumped and landfilled. Finding better solutions for the effective utilization of BF dust and sludge is an important problem. BOF dust and sludge are generated during the cleaning of gases emitted from the basic oxygen furnace. The actual production rate depends on the operation circumstances. It may range from about 4 to 31 kg/metric ton of steel produced, and has a mean value of about 18 kg/metric ton.[44] The disposal or utilization of BOF dust and sludge is one of the critical environmental problems in some countries.

Electrical arc furnace produces about 116 kg of slag for every metric ton of molten steel. Worldwide, about 77 percent of the slag produced in EAFs is reused or recycled.[44] The remainder is landfilled or dumped. Due to the relatively high iron content in EAF slag, screens, and electromagnetic conveyors are used to separate the iron to be reused as raw material. The EAF slag remaining is normally aged for at least six months before being reused or recycled in different applications such as road building. All efforts in Egypt have focused on separating the iron from EAF slag without paying enough attention to the slag itself. However, pilot research work conducted at Alexandria University in Egypt has investigated the possibility of utilizing such slag.[47] The test results proved that slag asphalt concrete could, in general, fulfill the requirements of the road-paving design criteria.

EAF dust contains appreciable quantities of zinc, typically 10 to 36 percent. In addition, EAF dust holds much smaller quantities of lead, cadmium, and chromium. EAF dust has been classified as a hazardous waste (K061) by the U.S. Environmental Protection Agency, and therefore its safe disposal represents a major problem. Although there are several technologies available for processing this dust, they are all quite expensive, on the order of US$150 to US$250 per ton of dust.

The Problem in Egypt

Apart from the granulated BF slag used in producing slag cement, all types of waste from any steel plant in Egypt were simply dumped in the neighboring desert. Based on the production figures of the major steel plants in Egypt and the generation rates of different waste materials per each metric ton of steel produced, the annual waste materials generated in Egypt was estimated and summarized in Table 1.13 over and above the accumulated stock pile in the near by area. There are stockpiles of 10 million metric tons of air-cooled BF slag and another 10 million metric tons of BOF slag laying in the near by area.

Obviously, waste generators will be required to pay a certain fee per metric ton disposed. In 1993, the cost of disposing one ton of steel plant wastes in the United States was $15.[48] Today, it goes up to $100. Large tonnage of iron and steel slags are increasingly produced in Egypt, and the huge space needed to dump them has become a real challenge. To have an idea about the considerable area needed for disposal, it is quite enough to know that the 20 million metric tons of BF and BOF slags currently available are estimated to occupy 2.5 million square meters.

Potential Utilization of Slag

Many of the environmental problems of solid waste materials generated from the iron and steel industry have been known for some time, and attempts have been made to tackle them with varying degrees of success. During the past few years, the iron and steel industry has been able to produce some creative

TABLE 1.13 Waste Materials Generated from Iron and Steel Industry in Egypt

Type of Waste	Annual Amount Generated (metric tons)
Blast furnace slag	600,000
Basic oxygen furnace slag	200,000
Electrical arc furnace slag	300,000
Blast furnace dust	20,000
Electrical arc furnace dust	15,000
Rolling mill scales and sludge	25,000

solutions to some of these environmental problems. It is highly probable that many other creative solutions also could emerge as a result of well-thought-out and well-supported research programs.

Processing of slag is a very important step in managing such waste material. Proper processing can provide slag with high market value and open new fields of application. Cooper et al. discussed the recent technologies of slag granulation.[49] The main steps of the granulation process were addressed with schematic drawings, including verification, filtering, and denaturing systems. The most recent continuous granulation technology at that time was introduced in detail with the help of many illustrative figures, as shown in Figure 1.28.

Foster addressed the high cost of disposing wastes generated from the steel industry and discusses an innovative idea from South Africa to manage BOF slag, which has a limited usage.[48] He came up with a new idea for processing BOF slag. This process starts with preparing the slag by grinding it, mixing it with a reductant such as sawdust or charcoal, and feeding it into a modified cyclone-type preheater. This reduction process removes iron oxide from iron. The slag is then passed over a magnet, which removes the iron particles. The low-iron slag is then mixed with other materials, such as clay, to produce an acceptable type of cement kiln feed.

Featherstone and Holliday introduced the idea of dry slag granulation shown in Figure 1.29.[45] The existing slag treatment methods, the new dry granulation method, and the value of granulated slag products were reviewed. The development, application, and advantages of the dry method of granulating molten slags were described. The dry granulated slag was proved to have many environmental

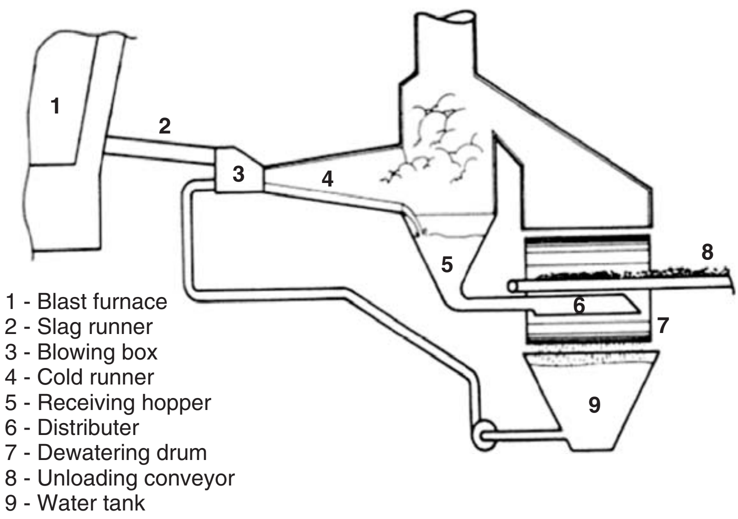

FIGURE 1.28 Continuous slag granulation system. (*Source:* A.W. Cooper, M. Solvi, and M. Calmes, "Blast Furnace Slag Granulation," *Iron and Steel Engineer*, 63, (July 1986): 46–52.)

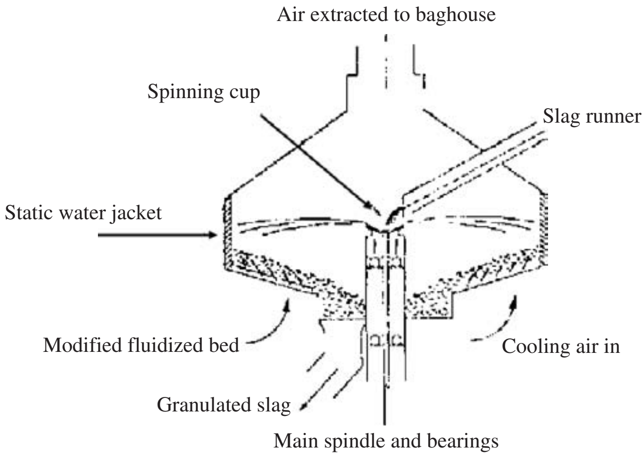

FIGURE 1.29 Dry slag granulation. (*Source:* W. B. Featherstone and K.A. Holliday, "Slag Treatment Improvement by Dry Granulation," *Iron and Steel Engineer* (July 1998): 42–46.)

advantages over conventional processes, while generating a product of equal quality in addition to its low cost and simplicity.

Swamy presented an extensive and critical examination of the use of ground granulated BF slag in concrete.[50] It was shown that the use of BF slag as aggregate in concrete can lead to high strength concrete with excellent durability. Apart from its ability to reduce the temperature rise due to hydration, test results showed that BF slag has a hidden potential to contribute high early age strength, excellent durability and very good chemical resistance. A mix proportioning method was advanced that assured the development of early strength for slags of normal surface area of 350 to 450 m^2/kg. Table 1.14 summarizes the compressive strength development up to 180 days age for mixes with 50 percent (A) and 65 percent (B) slag replacement of coarse aggregates. Curing was shown to be a critical factor that affects early age strength, continued strength development, and fine pore structure responsible for durability. It was also shown that with a well-defined curing period, the mineralogy and chemistry of slag could be mobilized to develop a very fine pore structure that is far superior to that of Portland cement concrete. Such a fine pore structure can impart a very high resistance to concrete to the transport of sulfate and chloride ions and water.

Nagao et al. proposed a new composite pavement base material made of steel-making slag and BF slag. When the new composite base material was prepared by mixing steel-making slag, air-cooled slag, and granulated blast furnace slag in proportions of 65 percent, 20 percent and 15 percent, respectively, it was found to have material properties and placeability similar to those of conventional hydraulic and mechanically stabilized slags.[51] Also, it was found feasible to quickly and economically suppress the swelling of steel-making slag by the hot water immersion that involves hydration reaction at 70° to 90°C, under which

TABLE 1.14 Compressive Strength Development of Slag Concrete

Mix	Age, Days	Compressive Strength, (MPa)
A	1	7.20
B	1	4.10
A	3	28.90
B	3	19.00
A	7	39.00
B	7	27.40
A	28	46.80
B	28	34.20
A	90	54.90
B	90	38.20
A	180	57.10
B	180	36.47

Source: R. N. Swamy, "Concrete with Slag: High Performance and Durability without Tears," 4th International Conference on Structural Failure Durability and Retrofitting, Singapore (1993), pp. 206–236.

slag can be stabilized in 24 hours at an expansion coefficient of 1.5 percent or less, as proposed by Japan Iron and Steel Federation.

One of the interesting research efforts in Egypt to find fields of application for iron and steel slags among other waste materials is the project carried out by Morsy and Saleh from 1994 to 1996.[52] This project was funded by the Scientific Research and Technology Academy to investigate the technically sound and feasible utilization of two solid-waste materials, iron and steel slags, and cement dust, in addition to some other different liquid wastes. The study dealt with BF slag, both air-cooled and water-cooled, and BOF slag. The use of such slags in road paving as a base, subbase, and surface layers was examined through laboratory and pilot field tests. The results proved that these slags are suitable for use in all paving layers. Better performance and higher California bearing ratio were obtained for slags compared to conventional stones. The Egyptian standards for ballast require that the weight of cubic meter of ballast not be less than 1.1 metric tons, and that Los Angeles abrasion ratio does not exceed 30 percent. Test results showed that the properties of iron and steel slags surpassed the requirements of these standards and can be used as ballast provided that suitable grading is maintained.

Another study performed in Egypt in 1997,[47] by the Institute of Graduate Studies and Research at Alexandria University in conjunction with Alexandria National Iron and Steel Company, was aimed at investigating the use of EAF slag as road-paving base material and as coarse aggregate for producing concrete suitable for applications such as wave breakers, sidewalk blocks and profiles, and manhole covers. The physical and chemical properties of EAF slags

TABLE 1.15 Marshall Test for Asphalt Concrete Containing Slag

Asphalt Content, percent	Unit Weight (Ib/ft^3)	Stability (Ib)	Flow/ inch	Voids in Agg., percent	Voids in Total Mix
3.5	2.62	2279	10.2	14.8	9.2
4.5	2.72	2726	11.7	14.3	5.9
5.5	2.77	2550	12.4	14.5	3.5
6.5	2.73	2100	15.9	15.6	1.5
Design criteria	–	>1800	8–18	>13	3–8

Source: M. El-Raey, "Utilization of Slag Produced by Electric Arc Furnace at Alexandria National Iron and Steel Company," Institute of Graduate Studies and Research, Alexandria University—Egypt, 1997.

of different ages were determined. EAF slag was crushed to the desired size and the applicability of slag in producing asphalt concrete was tested laboratory by the Marshall test. Table 1.15 shows some of the results obtained for asphalt concrete containing slag. The test results proved that slag asphalt concrete could, in general, fulfill the requirements of the road-paving design criteria. EAF slag was successfully used as a coarse material for the base layer in a field-scale test.

The study also covered the use of EAF slag as coarse aggregate for concrete, and the obtained results revealed that slump values for slag concrete were lower than those of gravel concrete by 33 percent for the same water/cement ratio. The unit weight of slag concrete was found to be 2.6 to 2.7 t/m^3. It ranged from 2.35 to 2.38 t/m^3 for gravel concrete. The higher unit weight is attributed to the higher specific gravity of slag compared to gravel, 3.5 and 2.65, respectively. For the same cement content and water/cement ratio, and at both early and later ages, slag concrete exhibited higher compressive strength than gravel concrete, with an average increase of 20 percent at 7 days age and 10 percent at 28 days age. The same classical effects of water/cement ratio, aggregate/cement ratio, and curing on gravel concrete were observed for slag concrete. From a durability point of view, no sign of self-deterioration was noticed for slag concrete. Slag concrete has been successfully applied in manufacturing sidewalk blocks and profiles, manhole covers, and balance weights.

Korany and El-Haggar investigated the utilization of different slag types as coarse aggregate replacements in producing building materials, such as cement masonry units and paving stone interlock.[53] Cement masonry specimens were tested for density, water absorption, and compression and flexural strengths. The paving stone interlocks were tested for bulk density, water absorption, compressive strength, and abrasion resistance. They also studied the likely health hazards of the proposed applications. The test results proved in general the technical soundness and suitability of the introduced ideas. Most of the slag solid brick units showed lower bulk density values than the commercial bricks used for comparison. All slag units exhibited absorption percentages well below the ASTM limit of 13 percent. A substantially higher compressive strength results

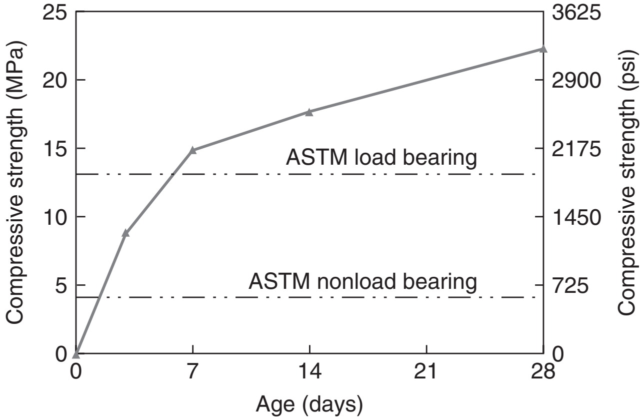

FIGURE 1.30 Development of compressive strength with age for solid brick groups at 100 percent slag replacement levels. (*Source:* Y. Kourany and S. M. El-Haggar, "Utilizing Slag Generated from Iron and Steel Industry in Producing Masonry Units and Paving Interlocks," 28th CSCE annual conference, June 7–10, 2000, London, Ontario, Canada.)

were reached for all masonry groups at 28-day age compared to the control and commercial bricks as seen in Figure 1.30. All test groups showed higher compressive strength than the ASTM limit of 4.14 MPa for nonload-bearing units. At slag replacement levels higher than 67 percent, all groups resulted in compressive strength higher than the ASTM requirement of 13.1 MPa for load-bearing units. All slag types resulted in paving stone interlocks having water-absorption values far below the ASTM limit, as shown in Figure 1.31. All slag paving stone interlocks showed higher compressive strength and abrasion resistance than the control specimens made of dolomite. Moreover, the proposed fields of application were found to be safe to the environment and have no drawbacks based on the heavy metals content and water-leaching test results.

Szekely proposed a comprehensive research program to reduce fume formation in the BOF and EAF, find an effective approach to reduce and utilize steel-making slag, and to effectively use the oily sludge produced in rolling mills.[44] Related environmental problem areas were discussed and preliminary solutions were identified. From Szekely's viewpoint, although several technologies are available for treating EAF dust, they are quite expensive, and satisfactory solutions for the EAF dust problem have not yet been produced. He suggested some possible solutions worthy of exploration, such as modifying the charging, blowing, and waste gas exhaustion system to minimize dust formation. Another proposed solution is to examine the composition of the dust produced during different phases of furnace operation and, if appropriate, segregates the recovered dust.

Some of the methods used to turn steel plant dust into a valuable raw material were described by one of the solid waste processing companies in its article published 1997.[54] One of the commonly used methods is micropelletizing, where dust is mixed with lime as a binder and is pelletized to produce a fine granular

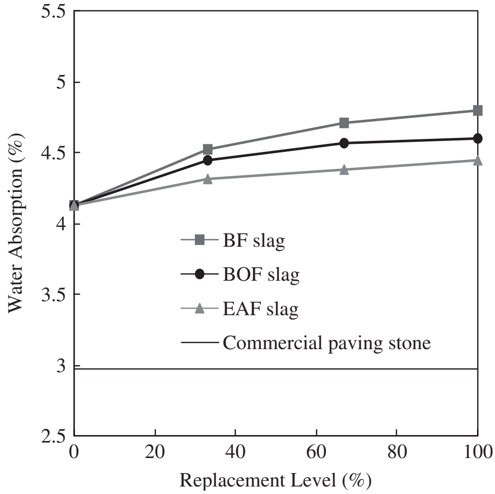

FIGURE 1.31 Comparison between absorption ratios of the different slag types with replacement level. (*Source:* Y. Kourany and S. M. El-Haggar, "Utilizing Slag Generated from Iron and Steel Industry in Producing Masonry Units and Paving Interlocks," 28th CSCE annual conference, June 7–10, 2000, London, Ontario, Canada.)

form, the major proportion being in the size range of 2 to 3 mm with a total size range of 1 to 10 mm. The water content is adjusted to 12 percent during mixing and the pellets are air-cured for a minimum of three days before charging to the sinter plant, where they account for 3 percent of the total charge. The article also addressed the direct injection process currently on trial in Germany and the United Kingdom, where injection is used to pass fine dust into the liquid metal in the furnace. Fine dust is blended with hydrating dusts such as burnt lime and carbon. The metal oxide content of the material is about 70 percent and has a particle size range of 0 to 8 mm, making it ideal for direct injection into a range of furnaces.

Final Remarks

Besides the economic and technical importance of utilizing waste materials generated from the iron and steel industry, this activity is of great importance from the environmental protection point of view, as well as conservation of natural resources. The first environmental impact is the useful consumption of the huge stockpiles of these waste materials. When these waste materials are used as replacements for other products such as cement, the natural resources that serve as raw materials are preserved. Also, air pollution levels will be reduced due to the reduction in fuel consumption. All slag types should be treated as byproducts rather than waste materials. All existing and new steel plants should have a slag-processing unit within the factory property to extract steel from slag and to crush the slag and sieve it to the desired grading for ease of promotion.

WASTE INDUSTRY

This is a new industrial sector, and the most challenging industrial sector to be addressed all over the world. The challenging part came from the nature of the waste industry because it is a multi-industrial activity containing all types of wastes, including hazardous wastes. This sector will utilize the wastes as a byproduct in order to conserve the natural resources through the cradle-to-cradle concept and reach sustainability. Sustainability or sustainable development will never be achieved without conservation of natural resources. Therefore, the main indicator for sustainability is life cycle assessment (LCA), based on the cradle-to-cradle concept, not cradle-to-grave concept, as discussed before. In other words, *cradle to cradle* is the indicator for sustainability. The degree to which cradle to cradle is achieved will give an indication of how close the industry or any manmade activity is to sustainability.[1]

Waste industrial sector can be classified into four categories: (1) direct waste recycling industry, (2) multiple waste recycling industry, (3) waste exchange network industry, and (4) environmentally balanced industrial complexes (EBICs). Direct waste industry that can relay on specific type of waste to be recycled on-site or off-site. This category is the most common type of waste industry to convert waste into products. Some additives might enhance the quality of products.

Multiple waste-recycling industries integrate more than one type of waste as a raw material in order to enhance the properties of the products. For example, use of spent foundry sand, which is hazardous waste from metal foundry industries, to enhance the properties of recycled mixed plastics from the plastics industry will be discussed next section (Multiple Waste Recycling Industry). Each waste stream represents an environmental problem for their related industry. Combining each waste together with a certain percentage will enhance the properties of new products. Some additives might be added according to product's specifications. Another example, discussed in Cement Industry section, is adding cement kiln dust (CKD) with agricultural waste to municipal sludge to produce soil conditioner. CKD will treat the sludge by killing all parasites including Ascaris eggs through high PH of CKD. Agricultural waste will act as a bulking agent to convert this mixture into a soil conditioner suitable for land reclamation.

The third category is the waste exchange network industry by integrating a new waste-related industry (based on waste generated from the current industry) into the current industry to recycle their waste, such as different new industries initiated in Kalunbourg industrial estate in Denmark located 75 miles west of Copenhagen based on waste generated from the current industries, as will be discussed later. This category can also be called *industrial symbiosis* or *byproduct exchange* (bpx) network.

The fourth category is environmentally balanced industrial complexes (EBICs), developed by Professor Nelson Nemerow to approach zero pollution.[55] EBICs can be defined as a selective collection of compatible industrial plants located together in one area "complex" to minimize both environmental impact and industrial production costs.

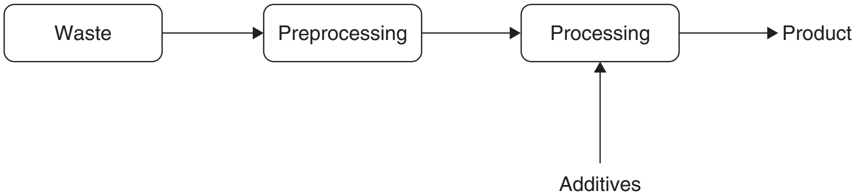

FIGURE 1.32 Direct waste recycling industry.

Direct Waste Recycling Industry

This category is commonly used within the industrial process (on-site recycling) to recycle the waste from within the process, or it could be off-site recycling within small microenterprises (SMEs) to recycle a certain type of waste, as shown schematically in Figure 1.32.

On-site recycling involves returning the waste material either to the original process as an input material or to another process as input material (inside the same factory). In other words, on-site recycling means re-entering the waste into the process as a substitute for an input material or sent as useful by products or raw material for other processes within the same factory. For example, in the plastic industry, any plastic waste from the industrial process can be added with a certain percentage to the virgin raw material to control the mechanical properties and costs. Another example in the pulp and paper industry, the fiber recovery from white paper, the surplus pulp fiber, paper mill off cuts and damaged paper rolls are recycled back into the pulping process. A third example, in oil and soap industry, the gravity oil separator (GOS) will separate the oil from the industrial wastewater stream by gravity and return it back to the industrial process.

Off-site recycling implies that the recycling process takes place by another party that recycles the industrial wastes or at the postconsumer stage such as municipal solid waste. There are companies that specialize in recycling the specific wastes. They buy certain types of wastes, recycle them, and then sell them back to other industries or direct to consumers.

Advanced direct waste recycling industry could also be included within this category such as converting recycled polypropylene (PP) into the properties of polycarbonate (PC) blends by adding some additives such as fire-retardant, impact modifier, ultraviolet stabilizer and antioxidant.[56] This additives will modify the properties of recycled PP into the properties of PC. This new material can replace the PC blends in some applications such as garden spotlights (outdoor lighting) and three-phase circuit breaker boxes. This new material based on recycled PP will maintain a good quality for the product with less cost.

Multiple Waste Recycling Industry

This category can include different wastes together to enhance the properties of a product and reach a certain specification. The famous waste exchange mechanism applied in different countries can help developing this category, such as:

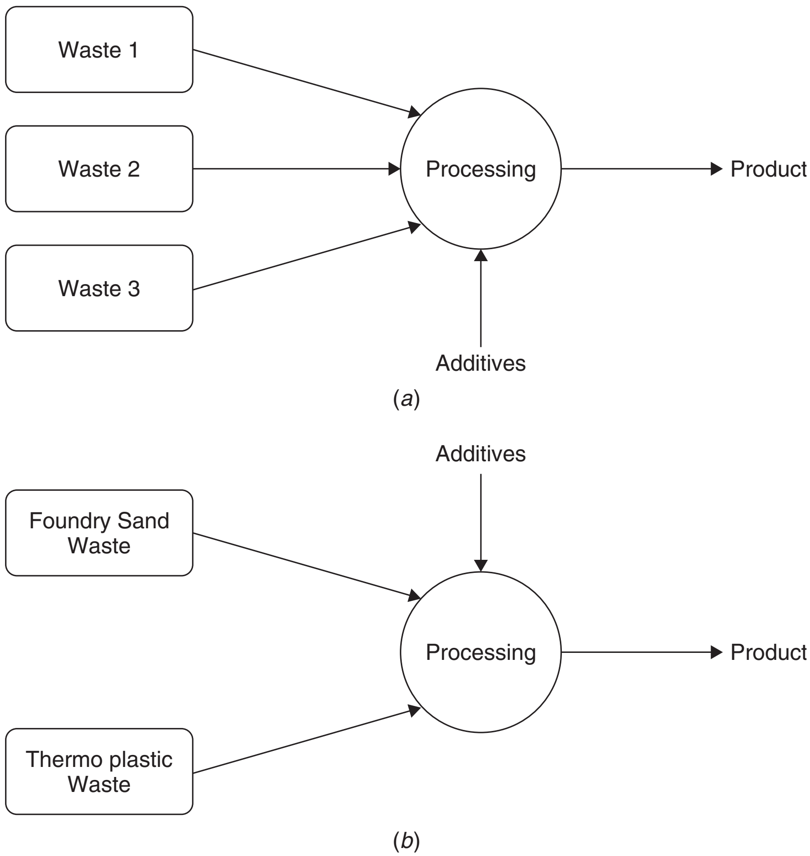

FIGURE 1.33 Multiple waste recycling industry (a) general (b) specific

- Use of foundry sand as a reinforcement to enhance the properties of plastics in different applications as will be discussed in the next section and represented schematically in Figure 1.33.
- Thermosets such as Milamean cannot be recycled directly by direct waste recycling method. Adding thermoset waste into thermoplastic waste will enhance the properties of the products as discussed before.
- Polystyrene foam can be recycled by crushing through shredding machine, and then melted. The melted product can be crushes again and mixed with PP to give the product some ductility and recycle the produced mixture.

Waste Exchange Network Recycling Industry

This is the most important category within the waste sector to develop a new industry within the existing industries and should be developed in *cooperation* with the mother industries to guarantee sustainability. Promoting this category will enhance not only the conservation of natural resources to approach cradle-to-cradle concept and the protection of the environment, but also will disseminate the culture of waste industry within the industrial communities and decision makers. This promotion will lead to the end of construction of any new disposal facilities such as landfills or incinerators. The italicized word *cooperation* mentioned before is very important to guarantee a continuous supply of raw materials (wastes) and reach sustainable development. This industrial category should be located any where between the waste generators to minimize the transportation cost. The most famous examples of waste integration category are the new industries established within Kalundborg industrial estate in Denmark. New industries joined Kalunbork Industrial Estate (eco-industrial park) based on the waste of the core industries as a byproduct as shown in Figure 1.34. They ended up with the following added new industries:

- *Gyproc—plasterboard production:* Asnaes power station "mother company" installed a desulfurization unit to remove sulfur from its flue gases, which allows it to produce calcium sulfate (gypsum). This is the main raw material in manufacturing of plasterboard at Gyproc. By purchasing synthetic "waste" gypsum from Asnaes power station, Gyproc has been able to replace the natural gypsum that is imported from Spain.

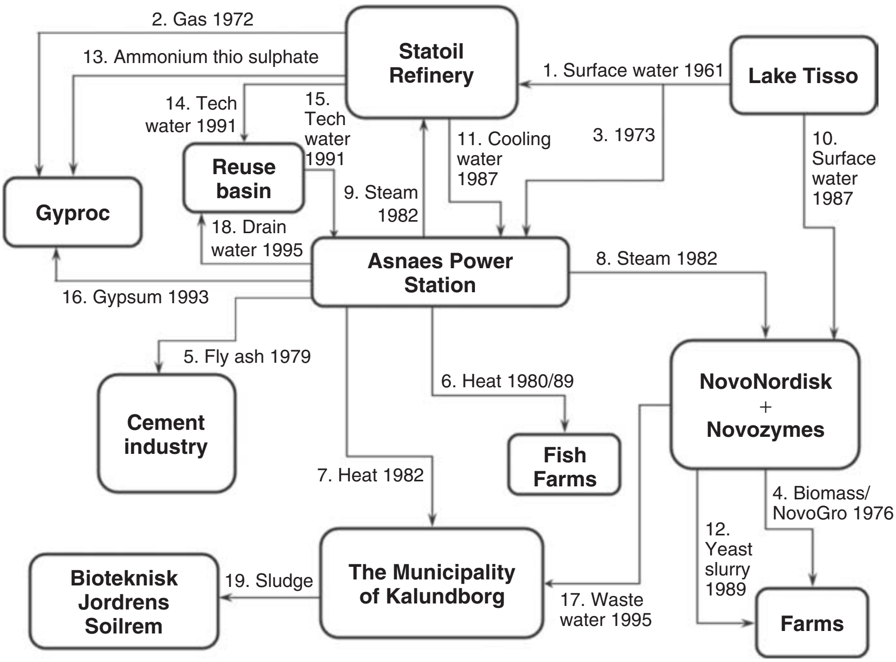

FIGURE 1.34 Waste exchange network recycling industry, Kalundborg Industrial symbiosis in 2000. (*Source:* Laura Saikkuu, "Eco–Industrial Parks: A Background Report for the Eco-Industrial Park Project at Rantasalmi," Finland: Publications of Regional Council of Etela–Savo, 2006.)

- *Fish farm—consists of 57 fish ponds*: Asnaes Power Station started fish farming to solve the problem of thermal pollution generated from the cooling water. The seawater used to cool the condenser of the thermal power plant was utilized to develop an artificial fish farm; the fish grew faster in such a warm temperature.
- *Fertilizer*: Regulation in Denmark placed significant restriction on the discharge of organics into the sea. Since Novo Nordisk (main company) used to mix the industrial sludge (organic) with wastewater and discharge it to the sea, it found out the most cost-effective way for sludge disposal is to convert it into fertilizer and give it to the nearby farmers.
- *Cement company—Aalborg Portland and road paving*: Asnaes Power Station (main company) using coal as a fuel source and produced a huge quantity of ash to be landfilled. Asnaes Power Station started to sell fly ash to cement factories to reduce the cost of waste disposal in landfill and gain money for further development. They built Ash silo with an unloading facility to accomplish this duty.
- *Kemira—a sulfuric acid producer*: Statoil refinery process the oil and separate the sulfur from the oil to produce high quality fuel. Statoil refinery begins selling sulfur to Kemira in Jutland. Excess gas from the operations at the Statoil refinery is treated to remove sulfur, which is sold as raw material for the manufacturing of sulfuric acid at Kemira.

Another subcategory can also be fitted within this category to use the waste of one plant as one of the raw material to be replaced for another plant. The waste generated from iron and steel industry, such as water-cooled slag and air-cooled slag, can be used to replace natural resources as:

- Grinding water-cooled slag produced from iron and steel industry discussed before to be mixed with raw cement to produce a special type of cement
- Cutting air-cooled slag produced from iron and steel industry discussed before to be used as an aggregate in flexible pavement or interlocks to enhance the properties and reduce the use of natural resources

Environmentally Balanced Industrial Complexes

Environmentally balanced industrial complexes are a selective collection of compatible industrial plants located together in one area "complex" to utilize the waste of one plant as the raw materials for another plant with minimum transportation and storage facilities. This category will reduce the overall production cost significantly because it eliminates waste treatment cost, reduces raw material cost "substituted by waste," minimizes storage facility and transportation cost as well as reducing pollution and protects the environment. A number of EBICs were investigated and proposed to produce zero waste out of such complexes, such as sugarcane complexes, tannery complexes, textile complexes, pulp and paper mill complexes, fertilizer–cement complexes, fossil fuel power plant complexes, steel mill fertilizer–cement complexes, cementlime, and power plant complexes.[55]

MULTIPLE WASTE RECYCLING INDUSTRY

Thermoplastics bags generally may be recycled under the condition that they are not contaminated as discussed before in plastic industry section. If they are contaminated, then usually they are burned or landfilled. They are often referred to as *plastic rejects*, such as black garbage bags. This is basically due to the fact that it is too expensive to recycle these plastics. They require immense amounts of water, chemicals, and energy in order to clean them, which defeats the purpose of conservation in the first place. At this point, it is noteworthy to mention that the objective of this case study is to use rejected plastic waste that is no longer usable. Hence, the product that will be produced will naturally have lower physical and mechanical properties than that of virgin plastic material. It may be used as a basis of comparison, but the properties of the products can be improved by using foundry sand waste (hazardous waste) as a reinforcing material for thermoplastics.

The objective of this case study is to investigate the reinforcement of contaminated thermoplastic rejects discussed under “Unrecyclable Plastics” with foundry sand waste as a reinforcing material. Rejected plastics are either burned, producing harmful emissions into the air causing pollution; landfilled, causing the inefficient use of land that could otherwise be used for more beneficial purposes; or left on the streets, causing visual pollution and potential health hazards, as well as depleting the natural resources. The mechanism of utilizing rejected plastics would be by heating the rejects indirectly at high temperatures (150° to 250°C) and then reinforcing it with foundry sand waste and regular sand to enhance its strength. The case study investigates the mechanical and environmental properties of this new material. Each of these reinforcing materials will be used in combination with the rejected plastics in varying quantities. Through this, not only will this material be able to eliminate the pollution of air, water, and land, but will also be able to utilize a certain waste as a new material, and thus not deplete the earth’s natural resources. It will also be able to save energy through the means of conserving a certain waste, thus conserving material and energy, and it will be able to save costs of waste material by using it as a raw material for another product. This will not only save the cost of the waste material, but also make a profit from the new product made of this new recycled of unrecyclable material. It will be a tool in approaching the concept of cradle to cradle and will ultimately protect the environment by producing zero waste through this mechanism of efficient use.

Seven different samples were used in this case study to mix plastic rejects with different percentages of foundry sand waste and regular sand. The two reinforcing agents that were added to the plastic rejects were added in varying percentages to determine the most efficient combination. The percentages of each material are relative to the total weight of the mix. For simplicity and ease, each mix had a total weight of 1 kg. The seven mixes and their designated percentages are shown in Table 1.16.

As shown in Table 1.16, there were a total of seven mixes, including the control mix with 100 percent plastic rejects and no reinforcing agent. All the other

TABLE 1.16 Combination of Mixes with Designated Percentages

Sample No.	Plastic Rejects (percent)	Foundry Sand Waste (percent)	Regular Sand (percent)
1	100	0	0
2	90	10	0
3	80	20	0
4	70	30	0
5	90	0	10
6	80	0	20
7	70	0	30

Source: S. M. El-Haggar and L. El-Hatow, "Reinforcing Thermoplastics Rejects with Foundry Sand Waste," Submitted for publication to ASCE (2007).

variable mixes are compared to this control mix. The percentage reinforcements are a percentage of the total weight of the sample.

Mechanical Tests

Tensile strength and flexural strength were investigated for different sand contents to determine their impacts as a reinforcement material on the mechanical properties of plastic rejects.

Tensile Strength Test To determine the properties of tensile strength of the specimens, tests were done in accordance with ASTM D3039–00.[57] Tensile strength test was performed in order to determine the ultimate tensile strength. Specimens were machined to dimensions of 25 by 250 by 2.5 mm in accordance with ASTM D3039–00. Gauge length was 100 mm, with the grips firmly holding the tabs. The tensile test occurs on a universal testing machine (UTS). Standard ribbed grips were used to hold the specimen in place. A constant head speed of 5 mm/min was used to allow for failure anywhere between 1 and 10 minutes.

The tensile properties for the different reinforcing elements showed great significance in the way the material behaves, as shown in Figure 1.35. In terms of foundry sand reinforcement of the plastic rejects, the results show that 10 percent reinforcement was the most suitable percentage that gave the highest tensile strength of 19.13 MPa. As for regular sand, 10 percent reinforcement was also the most suitable percentage that gave the highest tensile strength of 19.11 MPa. However the trend of foundry sand reinforcement curve in comparison to the regular sand reinforcement curve shown in Figure 1.34, shows that both sands reached a highest tensile strength of 19 MPa at 10 percent reinforcement and then declined with 20 percent and 30 percent, however the degree of decline of the regular sand in comparison to the foundry sand was much steeper. The regular sand declined much worse than the foundry sand, indicating the possibility that the heavy metals within the foundry sand, in fact, have a promising effect on the tensile strength. Foundry sand was shown to be a better reinforcing

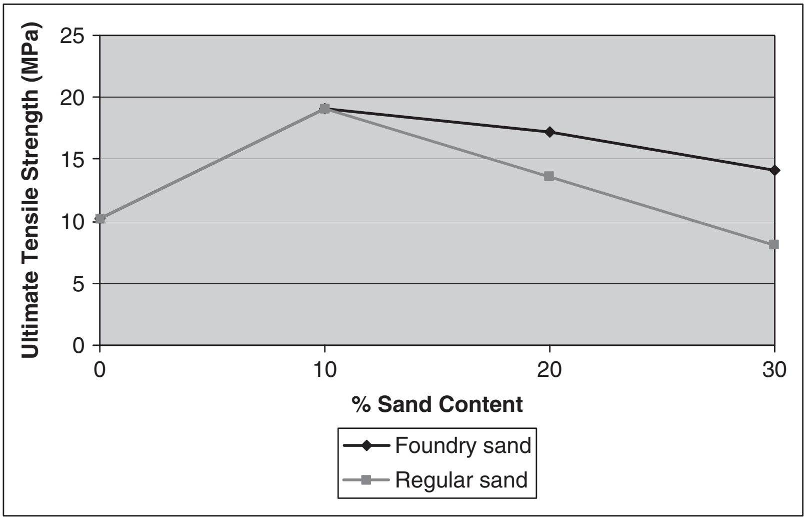

FIGURE 1.35 Tensile strengths of Composite material with foundry sand and regular sand. (*Source:* S. M. El-Haggar and L. El-Hatow, "Reinforcing Thermoplastics Rejects with Foundry Sand Waste," Submitted for publication to ASCE (2007).)

element in plastic rejects than regular sand, which is an optimistic observation considering the fact that foundry sand is also a hazardous waste.

When the best percentages of both reinforcing elements were selected and compared, many observations can be seen. First, it can be noted that both reinforcing elements showed improvement from the 0 percent no-reinforcement specimens. Second, the highest tensile strength resulted from reinforcement with foundry sand waste with 10 percent reinforcement, followed by regular sand with 10 percent reinforcement.

Flexural Test To determine the properties of flexural strength of the specimens, tests were done in accordance with ASTM D 790-03 [2003]. The flexural test was performed on the specimens in order to determine the ductility of the specimens as well as their flexural strength. Specimens were machined to dimensions of 127 by 12.7 by 4.5 mm in accordance with ASTM D790-03. Gauge length was 70 mm, with a span to depth ratio of 16. The flexural test occurs on a universal testing machine (UTS). A flexural apparatus was constructed to hold the specimen in place and allows for a three-point bending test. The apparatus was placed and aligned on the UTS machine with two concentric compression plates below and above the apparatus to allow it to function properly. A constant head speed of 2 mm/min was used to allow for failure anywhere between 1 to 10 minutes. The flexural strength for the different reinforcing elements showed varying results. The maximum flexural load of the composite material, reinforced with foundry sand waste and regular sand, are shown in Figure 1.36.

The foundry sand reinforcement of the plastic rejects, the 10 percent reinforcement shown to have the highest flexural strength with a maximum flexural

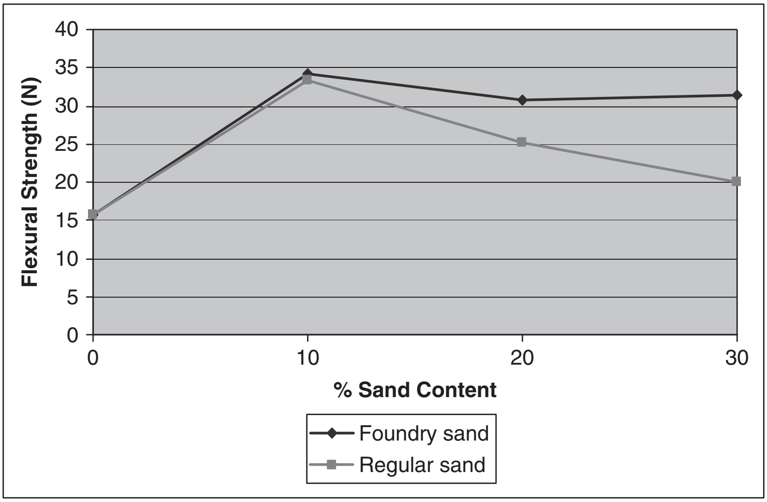

FIGURE 1.36 Maximum flexural load of composite material with foundry sand and regular sand. (*Source:* S. M. El-Haggar and L. El-Hatow, "Reinforcing Thermoplastics Rejects with Foundry Sand Waste," Submitted for publication to ASCE (2007).)

load of 34.3 N, which is higher than the 0 percent no-reinforcement value. The regular sand reinforcement of the plastic rejects proved that the 10 percent reinforcement was the best percentage of regular sand reinforcement, with a 33.3 N maximum flexural load. This value was significantly greater than the 0 percent no-reinforcement value. All the regular sand and foundry sand percentage reinforcements were significantly higher than the 0 percent no-reinforcement specimens and thus showed that their addition was enhancing the flexural strength of the specimen by reinforcing it with either regular sand or foundry sand. From Figure 1.36, it is evident that 10 percent foundry sand reinforcement was the best reinforcement in terms of flexural strength and gave the highest value that superseded all other values. The 10 percent regular sand value came in second best.

Environmental Tests

Chemical Resistance Test To determine the properties of chemical resistance of the specimens, tests were done in accordance with ASTM D543-95.[58] Thus, the specimens were tested toward their resistance to an acidic solution. Sulfuric acid with a pH of 3 was chosen, due to the fact that it plays a dual role of examining the effect of its high acidity and its sulfates content. Sulfates may also be corrosive and thus must be investigated. The specimens were measured for dimensions and weight prior to immersion into the acid. They then remain immersed for seven days in the acid and are then removed and are measured for dimensions and weight. The difference is recorded, and the differences in the specimens are examined and analyzed. It is expected that the acid should not affect the plastic specimens and that they should be able to withstand chemical resistance quite well. From this it can be assumed that the specimens will be quite resilient to chemicals.

The specimens were immersed in sulfuric acid for a week to determine their resistance to high acidic solutions of pH 3. The specimens' weight and dimensions were measured before and after the immersion. The results indicated that the specimens' dimensions did not change. Thus, it can be said that the composite material has high chemical resistance to acids and to sulfates, and will thus be useful in many applications such as manhole covers and bases.

Leachate of Heavy Metals The leachate test is necessary due to the heavy metals existing in the reinforcing element of foundry sand. According to both Abou Khatwa et al.[9] and Ibrahim,[59] the recycled plastic rejects did not leach any heavy metals that were worth noting, and thus were deemed safe. The existence of heavy metals in these specimens with the foundry sand reinforcement is minimal. The leachate test is done in accordance with ASTM D3987-85.[60] The foundry sand waste was tested separately for heavy metals, as well as the mixed composite specimen in two separate containers. The specimen and the foundry sand waste were immersed in distilled water for 18 hours, and then tested for pH, total hardness, and heavy metals of magnesium and silicon. A MACH DR/2000 direct reading spectrophotometer was used to analyze the heavy metals in the composition.

The solid specimen and the foundry sand were separately immersed in distilled water for 18 hours with continuous shaking to allow for any leachate material to be extracted from the designated samples. The liquid was then filtered. When this was complete, the pH and total hardness were analyzed, upon which the Mg hardness and thus the Mg concentration were calculated. In order to determine the silicon concentration, however, the two samples were heated at 90°C until the liquid evaporated to 10 ml. This is done in order to separate any organic material from the liquid. The samples are then tested on the spectrophotometer for silicon concentration. Table 1.17 shows the results of the leachate test; it can be seen that the foundry sand as a separate entity contained a significant composition of heavy metals of Mg and Si, while the solid specimen of recycled plastic with reinforced foundry sand contained no leachate material with these

TABLE 1.17 Results of Leachate Test

Sample	pH	Total Hardness (mg/L)	Mg Hardness (mg/L)	Mg Concentration (mg/L)	Si Concentration (mg/L)
Specimen	6.45	0.0	0.0	0.000	0.001
Foundry Sand	9.58	1.6	1.6	0.384	41.11

Source: S. M. El-Haggar and L. El-Hatow, "Reinforcing Thermoplastics Rejects with Foundry Sand Waste," Submitted for publication to ASCE (2007).

heavy metals composition. The pH of the solid specimen is quite close to that of distilled water, although that of the foundry sand waste was quite alkaline with a pH of 9.58. From these results it can be inferred that foundry sand waste as an entity contains the heavy metals of Mg and Si; however, when it is used as a reinforcing element in plastic rejects, the melting and thus solidification process enables these heavy metals to dissolve and thus does not pose a threat to the final recycled plastic specimen in terms of leachate material.

Final Remarks

It was shown from the data within the case study that contaminated plastic rejects combined with hazardous waste as a reinforcing elements proved to have durable and environmentally friendly properties that allow this new material to be used as an application in different products such as manhole cover and base. Through analysis of the material with difference percentage reinforcements, it was shown that foundry sand waste at 10 percent reinforcement showed the most promising results.

The environmental-related tests proved to show that material is highly resistant to acidity and thus will not corrode away in many applications of highly acidic applications such as sewer systems. The environmental-related tests also showed that the material does not produce any harmful leachate that may be toxic to the waters or surrounding areas, even though the leachate of the foundry sand contained heavy metals and thus might contaminate the soil and surface water as a result of land disposal. The heavy metals in the foundry sand dissolved upon the solidification process with the plastic rejects to become the new paste, and thus no longer became a problem.

In terms of economics, this new material made out of two hazardous waste will have a lot of benefits, such as saving the disposal cost and saving the natural resources, as well as protecting the environment. In order to recycle contaminated plastic rejects, the plastic first must be washed and cleaned with water in order to be deemed recyclable. This has often been very costly, and consumes a lot of water, energy, and labor. However, by recycling this contaminated material as is, we are not only saving water, energy, and labor, but also using a waste that previously had been incinerated, causing harmful emissions. This case study has shown that the mechanical properties of this new recycled material in no way match the properties of virgin plastic; however, when reinforced with different reinforcing elements such as foundry sand waste (a potential health hazard and waste), the properties of this material increase to an extent that enables it to be used in many applications. Foundry sand waste is in fact a waste material, and thus generally has no cost. Regular sand has also shown promising results in terms of durability; however, regular sand may be considered a natural resource of considerable use and thus might not be the more suitable material. Through this analysis, it can be seen that the benefits outweigh the costs incurred to produce a product out of this new composite material to alleviate the environmental hazards associated with this product.

DISPOSAL OF INDUSTRIAL WASTES

Disposal of industrial waste can be done according to a cradle-to-grave system through incineration and/or landfill. Incineration will convert the industrial solid wastes (hazardous or nonhazardous) into ash that requires landfill for final disposal. According to international regulations, industrial hazardous wastes should be treated first before landfill.

Incineration is the process of thermally combusting solid waste and converting it into ash or briefly incinerating it in a thermal treatment process. There are various types of incinerators. The type used depends on the type of waste to be burnt. Conceptually, incinerators for solid wastes can be classified into (1) rotary kiln incinerator, (2) grate type incinerator, and (3) fluidized bed incinerator. Rotary kiln incinerator can handle both liquid wastes as well as solid wastes. Grate type incinerators are used for large, irregular-shaped solid waste to allow air to pass through the grate from below into the wastes. The fluidized-bed type incinerator is used for liquid, sludge, or uniformly sized solid waste.

The main advantage of the incineration process is to reduce the amount of solid waste into 10 percent (ash). Energy may be recovered from the incineration process. But, the cost of energy produced from waste is higher than the traditional system of energy conversion system. The main disadvantages of incineration are (1) high capital cost, (2) high running cost for operation and management, and (3) disposal of ash resulting from incineration is another added cost. The mismanagement of incineration process may cause severe damage to the environment.

Industrial solid waste and/or ash produced from the incineration process should be landfilled. A landfill is a very complicated structure, very carefully designed either into or on top of the ground in which industrial solid waste is isolated from the surrounding environment. There are many steps before starting to construct a landfill. The first step is to choose a suitable site. Site location is one of the very important steps to avoid any impacts on the surrounding environment. After choosing the appropriate location for a landfill, the designing process starts. Beside the design of the lining and coverage of the landfill, a leachate collection system, biogas collection system and a stormwater drainage system should also be designed and planned for implementation during operation. The bottom liner isolates the industrial solid waste from the soil preventing the groundwater contamination. The liner is usually some type of durable, puncture-resistant synthetic plastic (polyethylene, high-density polyethylene, polyvinyl chloride). In landfills constructed below surface level, a side-liner system is used in mechanical resistance to water pressure, drainage of leachate, and prevention of lateral migration of biogas.

> The main disadvantage of landfill is high capital cost for construction as well as high operation cost for compaction, daily cover, leachate treatment, and so on. The mismanagement of landfill may cause a severe impact on the environment. The major disadvantage of both incineration and landfill, over and above the previously

mentioned disadvantages, is depletion of natural resources that lead to unsustainable solid waste management system.

Thus, one can see the tragedy of depleting the natural resources under the title "waste disposal," through incineration or landfill. For example, 60 percent of our precious stone resource is wasted in the marble and granite industry, our environment is polluted, and our health is put at risk. We need to put an end to this disaster by conserving the natural resources through cradle-to-cradle concepts as discussed before. We need to close our material and energy cycles, and apply cradle-to-cradle concepts. Industrial sectors should be approached as discussed throughout this chapter. All parties should cooperate to reduce wastes and emissions. The governments should issue strict rules controlling or prohibiting the use of landfills and/or incinerators and providing alternatives. *Alternatives* is the key word for sustainable industrial waste management to be able to develop a full utilization of natural resources and cradle-to-cradle approaches. Utilization of the waste needs to be researched through academic institutions and research centers to add value not only to individuals but also to the globe.

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CHAPTER 2

RESIDENTIAL AND INSTITUTIONAL ENVIRONMENT

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The World Health Organization (WHO) Expert Committee on the Public Health Aspects of Housing defined housing (residential environment) as

> the physical structure that man uses for shelter and the environs of that structure including all necessary services, facilities, equipment and devices needed or desired for the physical and mental health and social well-being of the family and individual.[1]

Every family and individual has a basic right to a *decent home* and a *suitable living environment*. However, large segments of the population in urban and rural areas throughout the world do not enjoy one or both of these fundamental needs. Therefore, housing must be considered within the context of and relative to the total environment in which it is situated, together with the structure, supplied facilities and services, and conditions of occupancy.

The realization of a decent home in a suitable living environment requires clean air, pure water and food, adequate shelter, and unpolluted land. Also required are freedom from excessive noise and odors, adequate recreational and neighborhood facilities, and convenient community services in an environment that provides safety, comfort, and privacy. These objectives are not achieved by accident but require careful planning of new communities and conservation, maintenance, and redevelopment of existing communities to ensure that the public does not inherit conditions that are impossible or very costly to correct. In so doing, that which is good or sound, be it a structure or a natural condition, should be retained, restored, and reused.

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SUBSTANDARD HOUSING AND ITS EFFECTS

Growth of the Problem

Practically all urban and rural areas contain substandard, slum, and blighted areas.* The causes are numerous; they are not easily detected in the early stages or, for that matter, easily controlled.

In the United States there has been a rapid growth in population in the suburbs. Many of the older cities have not enlarged their boundaries and are no longer experiencing a population increase.† Many have shown decline. The population trend graphs (see Figure 2.1) of the city of Buffalo and Erie County, New York, are typical of population shifts in older cities and metropolitan areas.

Between 1800 and 1910, a very rapid growth took place in the cities of the United States due to the mass movement of people from rural to urban areas and heavy immigration from outside the United States. Many of the newer immigrants

		Population	
Year	Buffalo	Erie Co.	Total
1900	352,387	81,399	433,686
1910	423,715		
1920	506,775	127,913	634,688
1930	573,076	189,332	762,408
1940	575,901	222,476	798,377
1950	580,132	319,106	899,238
1960	532,759	530,931	1,064,688
1970	462,768	650,723	1,113,491
1980	357,381	657,545	1,014,926
1990	328,123	640,409	968,532
2000	292,648	657,617	950,265

FIGURE 2.1 Population trends in city of Buffalo and in Erie County, New York.

*Substandard housing is said to exist when there are 1.51 or more persons per room in a dwelling unit, when the dwelling unit has no private bath or is dilapidated, or when the dwelling unit has no running water. Other bases used are described under "Appraisal of Quality of Living." An extensive definition of substandard buildings is given in the *Uniform Housing Code* (International Conference of Building Officials, 5360 South Workman Mill Road, Whittier, CA 90601, 1997 edition, pp. 22–24).

A slum is "a highly congested, usually urban, residential area characterized by deteriorated unsanitary buildings, poverty, and social disorganization" (*Webster's Third International Dictionary*, 1966). A slum is a neighborhood in which dwellings lack private inside toilet and bath facilities, hot and cold running water, and adequate light, heat, ventilation, quiet, clean air, and space for the number of persons housed. It is also a heavily populated area in which housing and other living conditions are extremely poor.

To blight is to "prevent the growth and fertility of; hence to ruin; frustrate" (*Webster's*). A blighted area is an area of no growth in which buildings are permitted to deteriorate.

†The 1980 U.S. Census of Housing showed a general population increase in the "Sun Belt" states in the South and the Southwest, but a decline or stabilizing in many other states. The U.S. Department of Commerce, Bureau of the Census, in *Patterns of Metropolitan Area and County Population Growth: 1980 to 1987*, shows continuation of this trend in the South and West but a stabilization or decline in the Northeast and Midwest regions. Between 1950 and 1986, the percent of the total population in the suburbs outside metropolitan statistical areas increased from 23.30 to 45.05.

sought out their relatives and compatriots, who usually lived in cities, thereby straining the available housing resources.

With the movement of large numbers of people to cities, urban areas became congested, and desirable housing became unobtainable. Inadequate facilities for transporting people rapidly and cheaply to and from work made it necessary for many people to accept less-desirable housing in the cities, close to their work. The inability of the ordinary wage earner to economically afford satisfactory housing left little choice but to accept what housing was available. Some landlords and speculators took advantage of the situation by breaking up large apartments into smaller dwelling units, by minimizing maintenance, and by constructing "cheap" housing.

Unfortunately, assistance or leadership from local government units to control potential problems is slow; there is usually a lag between the creation of housing evils and the enactment of suitable corrective legislation and enforcement. Obsolescence is another factor that causes the growth of slums. Land and property used for purposes for which they may have been well suited in the first place may no longer be suitable for that purpose. An example is the slum frequently found on the rim of a central business area—originally a good residential district convenient to work and business. This may start with the expansion or spillover of business into the contiguous residential areas, thereby making the housing less desirable. People next door or in the same building, desiring quiet and privacy, move. Owners are hesitant to continue maintenance work, causing buildings to deteriorate. The landlord, to maintain income, must either convert the entire building to commercial use or lower rents to attract lower-income tenants. If the landlord converts, more people leave. If the landlord lowers the rents, maintenance of the building is reduced still further, and overcrowding of apartments frequently follows. The progressive degradation from blight to slum is almost inevitable. As blight spreads, so do crime, delinquency, disease, fire, housing decay, and welfare payments.

There are areas that are slums from the start. The absence of or failure to enforce suitable zoning, building, sanitary, and health regulations leads to the development of *shanty towns*, or poor housing areas. Add to this small lots and cheap, new, and converted dwellings and tenements that are poorly located, designed, and constructed, just barely meeting what minimum requirements may exist, and a basis for future slums is assured.

An indifferent or uninformed public can permit the slums to develop. The absence of immediate and long-range planning and zoning, lack of parks and playgrounds, poor street layout, weak laws, inadequately trained personnel to enforce laws, pressure groups, lack of leadership from public officials, and local key citizens, and poor support from the courts and press make the development of slums and other social problems only a matter of time.

Population growth has been taking place outside the major older cities (Figure 2.1), but the rate of housing construction and rehabilitation has not kept pace with its growing needs. Federal grants and loans encouraging low-cost housing and rehabilitation of sound housing; the high cost of new housing, facilities, and services; and the high cost of gasoline have slowed down the migration of people from the cities to the suburbs. The loss of housing due to obsolescence, abandonment, decay, vandalism, and demolition further compounds the problem. The National Association of Home Builders estimated that more than 2 million new housing units were needed each year in the 1980s, but costs are high and construction is not keeping pace.

According to a 1974 housing survey, lack of plumbing, leaking roofs, inadequate heating, and generally bad housing repair—common problems in the late 1940s—have almost been eliminated. In 1987, only 2.4 percent of the housing units lacked complete, private plumbing, compared to 45 percent in 1940.[2] Generally, however, low-income families still occupy homes with defects, and housing and neighborhoods in some sections of U.S. cities show obvious signs of deterioration.[3] In 1983, 8.9 percent of all occupied housing units were considered physically substandard.[4]

It is apparent that unless the rate of new home construction is accelerated, the rehabilitation of sound substandard dwelling units strongly encouraged, and the conservation and maintenance of existing housing required, a decent home for every American family will never be realized. Added to this is the continued need to provide public housing and financial assistance to the low-income family.

Critical Period

There comes a time in the ownership of income property, particularly multiple dwellings, when the return begins to drop off. This may be due to obsolescence and reduced rents or an increase in operation and maintenance costs, including utilities, fuel, and taxes. At this point, the property may be sold (unloaded); repairs may be made to prevent further deterioration of the property; the property may be abandoned, sold, or demolished for a more appropriate use; or a minimum of repairs may be made consistent with a maximum return and tax payments delayed. This is a critical time and will determine the subsequent character of a neighborhood. In situations where repairs are not made or where a property is sold and repairs are not made and taxes are not paid, the annual rental from substandard property may equal or exceed the assessed valuation of the property. A complete return on one's investment in five to seven years is not considered unusual in view of the so-called risks involved.

Because of this, housing ordinances should be diligently enforced and owners required to reinvest a reasonable part of the income from a property in its conservation and rehabilitation, *at the first signs of deterioration*. This would tend to prevent rapid deterioration, the "milking" of a property, and nonpayment of taxes. The burden on the community to acquire and demolish a worthless structure for nonpayment of taxes or to maintain an eyesore and fire and accident hazard would be lessened. Shortening the time, from the usual five years to one or two years, required for the initiation of *in rem** proceedings to foreclose for real estate

*Legal actions or judgments to seize property.

FIGURE 2.2 Run-down, filthy, vermin-infested backyards present many real health hazards.

tax delinquencies, while the property still has value, would reduce abandonment if coupled with firm but reasonable code enforcement. Cause for further property devaluation and extension of the blighting influence would also be reduced. See Figures 2.2 and 2.3. In New York City, *in rem* proceedings on one- and two-family dwellings can be taken only after three years, but after one year for multiple dwellings. An owner can redeem a building after four months and may, at the city's discretion, within two years if all back taxes and repair costs are repaid.[5]

It is an unfortunate practical fact, because of the complexity of the problem, that effective code enforcement for housing conservation and rehabilitation is in many places not being accomplished. Efforts suffer from frustration and lack of support, aided and abetted by government apathy or sympathy and marginal financial assistance through welfare payments. A greater return can be realized by giving greater assistance to those communities and property owners demonstrating a sincere desire to conserve and renew basically sound areas. Evidence of actual maintenance and improvement of the existing housing supply, code enforcement, encouragement of private building, low-interest mortgages, and provision of low- and middle-income housing are some of the facts that should guide the extent and amount of assistance a community receives.

Rent controls, however, can place the owners of rental properties in poor neighborhoods in a financially untenable position. An inadequate return on an investment usually leads to reduced services and maintenance and to property

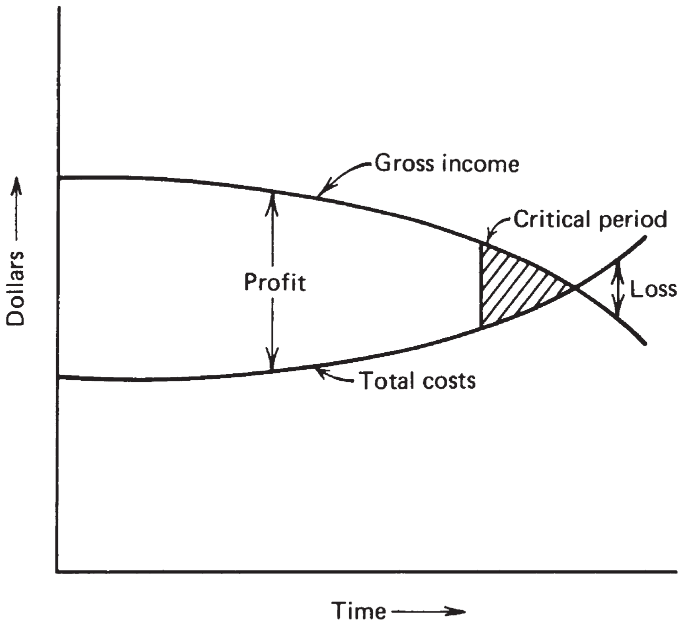


FIGURE 2.3 Rental housing gross income versus total costs with time, showing critical period. Gross income tends to go down and total costs up as property ages.

deterioration. Since a significant number of renters in poor neighborhoods may be on welfare, it would appear sound to provide higher welfare rent allowances and rent subsidies tied to property maintenance and housing code compliance. But an adequate return or profit may be distorted by the sale and resale of property by speculators to dummy corporations at increasing cost. Hence, fairness and caution are necessary.

Another factor may add to the housing problem. When there is a shortage of dwelling units and rentals are high, there is pressure to purchase rather than rent. There is also an incentive to purchase since an income-tax deduction can be taken as a homeowner, which is not available to a renter. However, there is likely to be a concurrent rise in property values when this occurs because of the shortage of rental units at a moderate price. These factors favor the conversion of existing multifamily units to condominiums and construction of new condominiums, thereby excluding from the housing market many who are poor or not sufficiently affluent and those on fixed incomes who cannot afford the higher cost of a condominium. If not protected, those displaced may be forced into less desirable housing and possible exploitation, thus contributing to the spread of slums.

Health, Economic, and Social Effects

The interrelationship of housing and health is complex and not subject to exact statistical analysis. For example, poverty, malnutrition, and lack of education and medical care also have important effects on health. These may mean long hours of work with resultant fatigue, improper food, and lack of knowledge relating to disease prevention, sanitation, and personal hygiene. The problem is compounded by poor job and income opportunities and by the slum itself, through the feelings of inferiority and resentment of the residents against others who are in a better position. In addition, slums are characterized as having high delinquency, prostitution, broken homes, and other social problems. Who can say if people are sick because they are poor or poor because they are sick. Although a real association is perceived to exist between poor health and substandard housing, it has not been possible to definitely incriminate housing as *the* cause of a specific illness. Many factors contribute to the physical and mental health and social well being of the family and individual, of which housing or the housing environment is one.[6,7] Studies show that as a matter of practical fact, many factors associated with substandard housing are profoundly detrimental to the life, health, and welfare of a community. The results of a few early studies and reports are summarized in Table 2.1.

The higher morbidity and mortality rates and the lower life expectancy associated with bad housing are also believed to be the cumulative effect or result of continual pressures on the human body. Dubos[8] points out in a related discussion that many medical problems have their origin in the biological and mental adaptive responses that allowed a person earlier in life to cope with environmental threats. He adds:

> The delayed results of tolerance to air pollutants symbolize the indirect dangers inherent in many forms of adaptation, encompassing adaptation to toxic substances, microbial pathogens, the various forms of malnutrition, noise, or other excessive stimuli, crowding or isolation, the tensions of competitive life, the disturbances of physiological cycles, and all other uncontrolled deleterious agencies typical of urbanized and technicized societies. Under normal circumstances, the modern environment rarely destroys human life, but frequently it spoils its later years.

Emphasis must be on preventive sanitation, medicine, architecture, and engineering to avoid some of the contributory causes of early and late disability and premature death. This avoidance includes the insidious, cumulative, long-term insults to the human body and spirit, as well as maintenance and improvement of those factors in the environment that enhance the well being and aspirations of people.

Although this discussion concentrates on the environmental health aspects of housing, it is extremely important that concurrent emphasis be placed on the elimination of poverty and on improved education for those living in poor housing and neighborhoods. It is essential that the causes of poverty and low income be attacked at the source, that usable skills be taught, and that educational levels be raised. In this way, more individuals can become more productive and self-sufficient and develop greater pride in themselves and their communities.

TABLE 2.1 Effects Associated with Substandard Housing

Diseases	Tuberculosis	Health and Other	Police	City Costs
CD rate 65% higher, VD rate 13 times higher, CD death rate as high as 50 years ago[a]	Half of cases from one-fourth of population[a]	Source of 40% of mentally ill in state institutions[a]	Juvenile delinquency twice as high[a]	20% of area in city brings in 6% of real estate tax[f]
	Tuberculosis rate 8 times higher[b]	Infant death rate 5 times higher[a]	20% of area in city accounts for 50% of arrests, 45% of major crimes, 50% of juvenile delinquency[f]	Contributes 5.5% of real estate tax but takes 53% of city service[f]
Intestinal disease rate 100% higher in homes lacking priv. flush toilet[b]	Secondary attack rate 200%[e] Death rate 8.6 times higher[c] 20% of area in city accounts	Infant mortality as high as 50 years ago[a] Life expectancy 6.7 years less[d]	2.6 times more arrests, 1.9 times more police calls, 2.9 times more criminal cases, 3.7 times more juvenile delinquents[i]	Slums cost $88 more per person than they yield; good areas yield $108[j]
Meningococcis rate 5.5 times higher[c] Infective and parasitic disease death rate 6.6 times higher[d]	for 60% of cases[f]	64% of out-of-wedlock cases[g]		20% of area in city accounts for 45% of city service costs, 35% of fires[f]
Pneumonia and influenza death rate 2 times higher[c]		Interest rate for mortgages higher in blighted areas Fire insurance rates higher	50% of murders, 60% of manslaughters, 49% of robberies[g]	1.5 times more fires, 15.7 times more families on welfare, 4 times more nursing visits[i]

TABLE 2.1 **(*continued*)**

Diseases	Tuberculosis	Health and Other	Police	City Costs
Lead poisoning in children higher.		Accidental death rate 2.3 times higher[d]		Account for most of the welfare benefits.
Rat and roach infestation higher. Carbon monoxide poisoning.		Injuries, burns, and accidental poisoning 5–8 times the national average[h]		Slums yielded one-half of cost of services required[k]

[a]Release by Dr. L. Scheele, Surgeon General, PHS Pub. 27, 1949, regarding six cities having slums.
[b]National Health Survey by U.S. Health Service, 1935–1936.
[c]B. Blum, *J. Am. Pub. Health Assoc*., **39**, 1571–1577 (December 1949).
[d]Erie County Health Department, NY, 1953 Annual Report.
[e]Paper on housing and progress in public health by W. P. Dearing, M.D., presented at the University of North Carolina, April 16, 1950.
[f]Miscellaneous city studies.
[g]The Twenty-seventh Annual Report of the Buffalo Urban League, Inc., NY.
[h]A. H. Stevenson, Airlie House Conference, Department of Health, Education, and Welfare, Washington, DC, March 17–19, 1970.
[i]Report from City of Louisville, Kentucky.
[j]R. M. Foley, "To Eradicate our Vast Slum Blight," *New York Times*, Magazine section, November 27, 1949.
[k]J. P. Callahan, "Local Units Fight Problem of Slums," *New York Times*, July 22, 1956.

APPRAISAL OF QUALITY OF LIVING

APHA Appraisal Method

The American Public Health Association (APHA) appraisal method for measuring the quality of housing was developed by the Committee on the Hygiene of Housing between 1944 and 1950. This method attempts to eliminate or minimize individual opinion to arrive at a numerical value of the quality of housing that may be compared with results in other cities and may be reproduced in the same city by different evaluators using the same system. It is also of value to measure the quality of housing in a selected area, say at five-year intervals, and to evaluate the effects of an enforcement program or lack of an enforcement program. The appraisal method measures the quality of the dwellings and dwelling units, as well as the environment in which they are located.

The items included in the APHA dwelling appraisal (see Tables 2.2 and 2.3) are grouped under "Facilities," "Maintenance," and "Occupancy." Additional information obtained includes rent, income of family, number of lodgers, race, type of structure, number of dwelling units, and commercial or business use. The environmental survey (see Table 2.4) reflects the proximity and effects of industry,

TABLE 2.2 Appraisal Items and Maximum Standard Penalty Scores (APHA)

Item		Maximum Score
A. Facilities		
Structure:		
1.	Main access[a]	6
2.	Water supply[a] (source)	25
3.	Sewer connection[a]	25
4.	Daylight obstruction	20
5.	Stairs and fire escapes	30
6.	Public hall lighting	18
Unit:		
7.	Location in structure	8
8.	Kitchen facilities	24
9.	Toilet[a] (location, type, sharing)[b]	45
10.	Bath[a] (location, type, sharing)[b]	20
11.	Water supply[a] (location and type)	15
12.	Washing facilities	8
13.	Dual egress[a]	30
14.	Electric lighting[a]	15
15.	Central heating	3
16.	Rooms lacking installed heat[a]	20
17.	Rooms lacking window[a]	30
18.	Rooms lacking closet	8
19.	Rooms of substandard area	10
20.	Combined room facilities[c]	
B. Maintenance		
21.	Toilet condition index	12
22.	Deterioration index[a] (structure, unit)[b]	50
23.	Infestation index (structure, unit)[d]	15
24.	Sanitary index (structure, unit)[d]	30
25.	Basement condition index	13
C. Occupancy		
26.	Room crowding: persons per room[a]	30
27.	Room crowding: persons per sleeping room[a]	25
28.	Area crowding: sleeping area per person[a]	30
29.	Area crowding: nonsleeping area per person	25
30.	Doubling of basic families	10

[a]Condition constituting a basic deficiency.
[b]Item score is total of subscores for location, type, and sharing of toilet or bath facilities.
[c]Item score is total of scores for items 16–19, inclusive. This duplicate score is not included in the total for a dwelling but is recorded for analysis.
[d]Item score is total of subscores for structure and unit.
Notes: (1) Maximum theoretical total dwelling score is 600, broken down as facilities, 360; maintenance, 120; and occupancy, 120. (2) Housing total = Dwelling total + Environmental total.

Source: An Appraisal Method for Measuring the Quality of Housing, Part II, Vol. A, "Appraisal of Dwelling Conditions," American Public Health Association, Washington, DC, 1946. Copyright by the American Public Health Association. Reprinted with permission.

TABLE 2.3 Basic Deficiencies of Dwellings (APHA)

Item[a]	Condition Constituting a Basic Deficiency[b]
	A. Facilities
2.	Source of water supply specifically disapproved by local health department
3.	Means of sewage disposal specifically disapproved by local health department
9.	Toilet shared with other dwelling unit, outside structure, or of disapproved type (flush hopper or nonstandard privy)
10.	Installed bath lacking, shared with other dwelling unit, or outside structure
11.	Water supply outside dwelling unit
13.	Dual egress from unit lacking
14.	No electric lighting installed in unit
16.	Three-fourths or more of rooms in unit lacking installed heater[c]
17.	Outside window lacking in any room unit[c]
	B. Maintenance
22.	Deterioration of class 2 or 3 (penalty score, by composite index, of 15 points or over)
	C. Occupancy
26.	Room crowding: over 1.5 persons/room
27.	Room crowding: number of occupants equals or exceeds 2 times the number of sleeping rooms plus 2
28.	Area crowding: less than 40 ft^2 of sleeping area/person

[a]Numbers refer to items in Table 2.2.
[b]Of the 13 defects that can be designated basic deficiencies, 11 are so classified when the item penalty score equals or exceeds 10 points. Bath (item 10) becomes a basic deficiency at 8 points for reasons involving comparability to the U.S. Housing Census, deterioration (item 22) at 15 points for reasons internal to that item.
[c]The criterion of basic deficiency for this item is adjusted for number of rooms in a unit.
Note: Some authorities include as a basic deficiency unvented gas space heater, unvented gas hot water heater, open gas burner for heating, and lack of hot and cold running water.

Source: An Appraisal Method for Measuring the Quality of Housing, Part II, "Appraisal of Dwelling Conditions," American Public Health Association, Washington, DC, 1946. Copyright by the American Public Health Association. Reprinted with permission.

heavy traffic, recreational facilities, schools, churches, business and shopping centers, smoke, noise, dust, and other factors that determine the suitability of an area for residential use.

The rating of housing quality is based on a penalty scoring system, shown in Table 2.2. A theoretical maximum penalty score is 600. The practical maximum is 300; the median is around 75. A score of zero would indicate that all standards are met. An interpretation of the dwelling and environmental scores is shown in Table 2.5. It is apparent, therefore, according to this scoring system, that either the sum of dwelling and environmental scores or a dwelling or environmental score of 200 or greater would classify the housing as unfit.

TABLE 2.4 Environmental Survey—Standard Penalty Scores (APHA)

Item		Maximum[a] Penalty Score
	A. Land Crowding	
1.	Coverage by structures—70% or more of block area covered	24
2.	Residential building density—ratio of residential floor area to total = 4 or more	20
3.	Population density—gross residential floor area per person 150 ft^2 or less	10
4.	Residential yard areas—less than 20 ft wide and 625 ft^2 in 70% of residences	16
	B. Nonresidential Land Areas	
5.	Areal incidence of nonresidential land use—50% or more nonresidential	13
6.	Linear incidence of nonresidential land use—50% or more nonresidential	13
7.	Specific nonresidential nuisances and hazards—noise and vibration, objectionable odors, fire or explosion, vermin, rodents, insects, smoke or dust, night glare, dilapidated structure, unsanitary lot	30
8.	Hazards to morals and the public peace—poolrooms, gambling places, bars, prostitution, liquor stores, nightclubs	10
9.	Smoke incidence—industries, docks, railroad yards, soft coal use[b]	6
	C. Hazards and Nuisances from Transportation System	
10.	Street traffic—type of traffic, dwelling setback, width of streets	20
11.	Railroads or switchyards—amount of noise, vibration, smoke, trains	24
12.	Airports or airlines—location of dwelling with respect to runways and approaches	20
	D. Hazards and Nuisances from Natural Causes	
13.	Surface flooding—rivers, streams, tide, groundwater, drainage, annual, or more	20
14.	Swamps or marshes—within 1,000 yd, malarial mosquitoes	24
15.	Topography—pits, rock outcrops, steep slopes, slides	16
	E. Inadequate Utilities and Sanitation	
16.	Sanitary sewage system—available (within 300 ft.), adequate	24
17.	Public water supply—available, adequate pressure, and quantity	20
18.	Streets and walks—grade, pavement, curbs, grass, sidewalks	10
	F. Inadequate Basic Community Facilities	
19.	Elementary public schools—beyond 2/3 mi, 3 or more dangerous crossings	10
20.	Public playgrounds—less than 0.75 acres/1,000 persons	8

TABLE 2.4 (*continued*)

Item		Maximum[a] Penalty Score
21.	Public playfields—less than 1.25 acres/1,000 persons	4
22.	Other public parks—less than 1.00 acres/1,000 persons	8
23.	Public transportation—beyond 2/3 mi, less than 2 buses/hr	12
24.	Food stores—dairy, vegetable, meat, grocery, bread, more than 1/3 mi	6

[a]Maximum environment total = 368.
[b]Include other sources of air pollution.

Source: An Appraisal Method for Measuring the Quality of Housing, Part III, "Appraisal of Neighborhood Environment," American Public Health Association, Washington, DC, 1950. Copyright by the American Public Health Association. Reprinted with permission.

TABLE 2.5 Housing Quality Scores (APHA)

Factor	Good (A)	Acceptable (B)	Borderline (C)	Substandard (D)	Unfit (E)
Dwelling score	0–29	30–59	60–89	90–119	120 or greater
Environmental score	0–19	20–39	40–59	60–79	80 or greater
Sum of dwelling and environmental scores	0–49	50–99	100–149	150–199	200 or greater

Source: An Appraisal Method for Measuring the Quality of Housing, Part III, "Appraisal of Neighborhood Environment," American Public Health Association, Washington, DC, 1950. Copyright by the American Public Health Association. Reprinted with permission.

Application of the APHA appraisal method requires trained personnel and experienced supervision.* The survey staff should be divorced from other routine work to concentrate on the job at hand and to produce information that can be put to use before it becomes out of date. In practice, it is desirable to select a limited area(s) for pilot study. The information thus obtained can be used as a basis for determining the need for extension of the survey, need for new or revised minimum housing standards, extent of the housing problem, development of coordination between existing official and voluntary agencies, the part private enterprise and public works can play, public information needs, and so on.

*A trained sanitarian can inspect about 10 dwelling units per day. For every four inspectors, there should be one trained field supervisor, three office clerks, and one office supervisor.

Census Data

Much valuable information is collected and summarized by the U.S. Bureau of the Census. The census data* include the number of one family and multifamily dwelling units, trailers and mobile homes, and condominiums; the population per owner- and renter-occupied unit†; the number of dwelling units with private bath, including hot and cold piped water as well as flush toilet and bathtub or shower and the number lacking some or all these facilities; the number of dwelling units occupied by persons of Spanish/Hispanic origin or descent; the number of rooms and bedrooms per dwelling unit; the number on public water supply, drilled well, dug well, spring or other; the number on public sewerage, septic tank or cesspool, or other system; the type of heating and fuel used; size of plot; information on occupation and income; the monthly rental; and the value or sale price of owner-occupied one-family homes. Other statistics on selected population characteristics for areas with 2,500 or more inhabitants and for counties are available. This information, if not too old, can be used as additional criteria to supplement reasons for specific program planning. Plotting the data on maps or overlays will show concentrations sometimes not discernible by other means.

The accuracy of census data for measuring housing quality has been questioned and, hence, should be checked locally, particularly if it is to be used for appraisal or redevelopment purposes. Nevertheless, it is a good tool in the absence of a better one.

Health, Economic, and Social Factors

It is frequently possible to obtain morbidity and mortality data for specific diseases or causes by census tracts or selected areas. Also available may be the location of cases of juvenile delinquency, public and private assistance, and probation cases. Sources of fires, nuisances, and rodent infestation and areas of social unrest give additional information. Health, fire, police, and welfare departments and social agencies should have this information readily available. See Table 2.1. Tabulation and plotting of these data and overlays will be useful in establishing priorities for action programs.

Planning

The location of existing and proposed recreational areas, business districts, shopping centers, churches, schools, parkways and thruways, housing projects, residential areas, zoning restrictions, redevelopment areas, airports, railroads, industries, lakes, rivers, and other natural boundaries help to determine the

*The latest published census data are *Census 2000*.

†The average number of persons per housing unit was 3.28 in 1940, 3.33 in 1960, 3.14 in 1970, 2.76 in 1980, 2.69 in 1985, and 2.62 in 1989.

best usage of property. Where planning agencies are established and are active, maps giving this, as well as additional information, are usually well developed. Analysis and comprehensive planning on a continuing basis are essential to the proper development of cities, villages, towns, counties, and metropolitan areas. The availability of state and federal aid for communitywide planning should be investigated. Plans for urban development, housing code enforcement, rehabilitation, and conservation should be carefully integrated with other community and state plans before decisions are made. These subjects are discussed in greater detail in Chapter 5.

Environmental Sanitation and Hygiene Indices

Most modern city and county health departments can carry on a housing inspection program based on minimum housing standards, provided competent personnel are assigned. Where housing inspections are made on a routine basis and records are kept on a computer, data processing punch-card system, visible card file, or by combination methods, problem streets and areas can be detected with little difficulty. A survey and follow-up form based on a modern housing ordinance are shown in Figure 2.4. The form should list recommendations for correction based on what is practical from field observation so as to serve as the basis for an accurate confirmatory letter to the owner. The type of deficiencies found, such as the lack of a private bath and toilet, dwelling in disrepair, or lack of hot and cold running water, can give a wealth of information to guide program planning. Usually the origin of complaints—which, if plotted on a map will give a visual picture of the heavy workload areas—can be added to the survey. Reliable cost estimates for complete rehabilitation of selected buildings and a simple foot survey should be made to confirm administrative judgment and decisions before any major action is taken. Many apparently well-thought-out plans have fallen down under this simple test. For example, deterioration may have proceeded to the point where rehabilitation is no longer economically or structurally feasible under existing market conditions. Other criteria are tax delinquency, welfare clients, vandalism, age, ownership turnover, housing vacancy, property value, illnesses, rodent and insect infestation, and the amount of housing demolished.

Other Survey Methods

These include aerial surveys, external ground-level surveys, and the Public Health Service Neighborhood Environmental Evaluation and Decision System (NEEDS).[9] The selection of a small number of significant environmental variables can also provide a basis for a rapid survey if checked against a more comprehensive survey system.

NEEDS This is a five-stage systems technique designed to provide a rapid and reliable measure of neighborhood environmental quality. The data collected are adapted for electronic data processing to reduce the time lapse between data collection, analysis, program planning, and implementation.

Dates inspected ______________

Address ______________ Type of Structure and Occupancy ______________

(frame, stucco, brick veneer, solid brick; residential, factory, store)

Owner and Address ______________

No.	Item	Yes	No	CM
1.	Water supply in each apt. satisfact. quality and quantity (no X-conn).			
2.	Private in each apt.			
	(*a*) water closet			
	(*b*) washbasin			
	(*c*) shower/tub			
	(*d*) kitchen sink			
	(*e*) cabinets and counter			
	(*f*) refrig. and stove			
3.	Piped hot water for			
	(*a*) washbasin			
	(*b*) shower/tub			
	(*c*) kitchen			
4.	Plumbing, heating, electricity, and fixtures are properly installed and maintained.			
5.	Water-repellent floor and base in toilet room and bathroom.			
6.	Window $\frac{1}{10}$ floor area in every room; openable, adequate light and air or induced ventilation for bath.			
7.	Dwelling unit provides 150 ft^2 for one and 100 ft^2 area for each additional occupant.			
8.	Dwelling can be heated to 68°F.			
9.	Sleeping rooms provide 70 ft^2 for one person and 50 ft^2 for each additional person.			
10.	Every habitable room has 2 electric outlets; bathroom, w.c. stall, laundry, and hall have a min. 10ft-c on floor.			
11.	Occupant keeps dwelling unit and fixtures clean and sanitary.			
12.	Space and water heaters adequate, properly connected, and vented to outer air; back-draft guard; smoke alarm.			
13.	Premises free of rodent and vermin infestation; rodent-proof.			
14.	Refuse, garbage, and trash storage proper and adequate.			
15.	One or more apartments above 2nd floor have 2 means of egress.			
16.	Public halls and stairs lighted, daylight and artificial in MD.			
17.	Property and dwelling are properly drained and sewered.			
18.	Owner keeps public areas of building and premises clean.			
19.	Living in cellar prohibited.			
20.	Dwelling in good repair, safe, sanitary, and weatherproof (handrails, stairs, walls, wiring, floors, siding, doors, frames, plaster, porch, eaves, roof, foundation beams firm and sound).			
21.	Lodging house has one washbasin, shower or tub, and water closet per 6 persons.			
22.	Lodging house supplies clean linen and towels prior to letting and weekly.			
23.	Cooking in lodging house done in approved and lawful kitchen or kitchenette only.			

NOTE: Explain each "No" item on back by item number and follow with recommendation for correction. "CM" is checked or dated when correction is made. "MD" denotes three or more dwelling units.

Floor	Apt.	Total Hab. Area	Total Hab. Rooms	Bedrooms No.	Bedrooms Area	Persons	Shelter monthly rental

Remarks: (tenant names, agent, change in ownership)

Inspected by: ______________

EH-49,5

FIGURE 2.4 Dwelling survey.

Stage I An exterior sidewalk survey is made of 10 to 20 blocks in each problem neighborhood of a city to determine those in greatest need of upgrading. The conditions analyzed include structural overcrowding, population crowding, premises conditions, structural condition of housing and other buildings, environmental stresses, condition of streets and utilities, natural deficiencies, public transportation, natural hazards and deficiencies, shopping facilities, parks and playgrounds, and airport noise. (Time: 1 person-hour per block.)

Stage II The neighborhood(s) selected are surveyed in some depth to determine the physical and social environmental problems facing the residents. About 300 dwelling units and families are sampled in the study area. This phase includes interviews to determine demographic characteristics, health problems, health services, interior housing conditions, and resident attitudes.

Stage III The data collected in stage II are computer processed and analyzed with local government and community leaders. Problems are identified and priorities for action are established.

Stage IV Programs are developed to carry out the decisions made in stage III. The community participates and is kept aware of the study results and action proposed.

Stage V The decisions made and programs developed are implemented. Federal fiscal assistance is also solicited, and the information and support made possible by this technique are used to strengthen applications for grants.[9]

Health Principles

The APHA Committee on the Hygiene of Housing has listed the criteria to be met for the promotion of physical, mental, and social health. Thirty basic principles, with specific requirements and suggested methods of attainment for each, are reported in *Basic Principles of Healthful Housing*, originally published by the APHA in 1938.

The "basic principles" have been expanded to reflect progress made and present-day aspirations of people to help achieve total health goals such as defined by the World Health Organization (WHO). The APHA Program Area Committee on Housing and Health prepared a comprehensive statement of principles available to guide public policy and goal formulation.[10] These can also serve as a basis for performance standards to replace specification standards for building construction, living conditions, and community development. The major headings, or objectives, of the committee report are quoted as follows.

*Basic Health Principles of Housing and Its Environment**

I. **Living Unit and Structure** "Housing" includes the living unit for man and family, the immediate surroundings, and the related community services

*From *Housing: Basic Health Principles & Recommended Ordinance* (ref. 10). Copyright by the American Public Health Association. Reprinted with permission.

and facilities; the total is referred to as the "residential environment." The following are basic health principles for the residential environment, together with summaries of factors that relate to the importance and applicability of each principle.

A. Human Factors
   1. Shelter against the elements.
   2. Maintenance of a thermal environment that will avoid undue but permit adequate heat loss from the human body.
   3. Indoor air of acceptable quality.
   4. Daylight, sunlight, and artificial illumination.
   5. In family units, facilities for sanitary storage, refrigeration, preparation, and service of nutritional and satisfactory foods and meals.
   6. Adequate space, privacy, and facilities for the individual and arrangement and separation for normal family living.
   7. Opportunities and facilities for home recreational and social life.
   8. Protection from noise from without, other units, and certain other rooms and control of reverberation noises within housing structures.
   9. Design, materials, and equipment that facilitate performance of household tasks and functions without undue physical and mental fatigue.
   10. Design, facilities, surroundings, and maintenance to produce a sense of mental wellbeing.
   11. Control of health aspects of materials.

B. Sanitation and Maintenance
   1. Design, materials, and equipment to facilitate clean, orderly, and sanitary maintenance of the dwelling and personal hygiene of the occupants.
   2. Water piping of approved, safe materials with installed and supplied fixtures that avoid introducing contamination.
   3. Adequate private sanitary toilet facilities within family units.
   4. Plumbing and drainage system designed, installed, and maintained to protect against leakage, stoppage, or overflow and escape of odors.
   5. Facilities for sanitary disposal of food waste, storage of refuse, and sanitary maintenance of premises to reduce the hazard of vermin and nuisances.
   6. Design and arrangement to properly drain roofs, yards, and premises and conduct such drainage from the buildings and premises.
   7. Design and maintenance to exclude and facilitate control of rodents and insects.
   8. Facilities for the suitable storage of belongings.

9. Program to ensure maintenance of the structure, facilities, and premises in good repair and in a safe and sanitary condition.

C. Safety and Injury Prevention

1. Construction, design, and materials of a quality necessary to withstand all anticipated forces that affect structural stability.
2. Construction, installation materials, arrangement, facilities, and maintenance to minimize danger of explosions and fires or their spread.
3. Design, arrangement, and maintenance to facilitate ready escape in case of fire or other emergency.
4. Protection against all electrical hazards, including shocks and burns.
5. Design, installation, and maintenance of fuel-burning and heating equipment to minimize exposure to hazardous or undesirable products of combustion, fires, or explosions and to protect persons against being burned.
6. Design, maintenance, and arrangement of facilities, including lighting, to minimize hazards of falls, slipping, and tripping.
7. Facilities for safe and proper storage of drugs, insecticides, poisons, detergents, and deleterious substances.
8. Facilities and arrangements to promote security of the person and belongings.

II. **Residential Environment** The community facilities and services and the environment in which the living unit is located are essential elements in healthy housing and are part of the total residential environment.

A. Community or Individual Facilities

1. An approved community water supply or, where not possible, an approved individual water supply system.
2. An approved sanitary sewerage system or, where not possible, an approved individual sewage disposal system.
3. An approved community refuse collection and disposal system or, where not possible, arrangements for its sanitary storage and disposal.
4. Avoidance of building on land subject to periodic flooding and adequate provision for surface drainage to protect against flooding and prevent mosquito breeding.
5. Provision for vehicular and pedestrian circulation for freedom of movement and contact with community residents while adequately separating pedestrians from vehicular traffic.
6. Street and through-highway location and traffic arrangements to minimize accidents, noise, and air pollution.
7. Provision of such other services and facilities as may be applicable to the particular area, including public transportation, schools,

police, fire protection, and electric power, health, community, and emergency services.

8. Community housekeeping and maintenance services, like street cleaning, tree and parkway maintenance, weed and rubbish control, and other services requisite to a clean and aesthetically satisfactory environment.

B. Quality of the Environment
   1. Development controls and incentives to protect and enhance the residential environment.
   2. Arrangement, orientation, and spacing of buildings to provide for adequate light, ventilation, and admission of sunlight.
   3. Provision of conveniently located space and facilities for off-street storage of vehicles.
   4. Provision of useful, well-designed, properly located space for play, relaxation, and community activities for daytime and evening use in all seasons.
   5. Provision for grass and trees.
   6. Improved streets, gutters, walks, and access ways.
   7. Suitable lighting facilities for streets, walks, and public areas.

C. Environmental Control Programs
   Maintenance of a healthy environment necessitates an educational and enforcement program to accomplish the following.
   1. Control sources of air and water pollution and local sources of ionizing radiation.
   2. Control rodent and insect propagation, pests, domestic animals, and livestock.
   3. Inspect, educate, and enforce so that premises and structures are maintained in such condition and appearance as not to be a blighting influence on the neighborhood.
   4. Community noise control and abatement.
   5. Building and development regulations.

In an article based on a working paper prepared for the WHO consultation on housing and implications for health, Schaefer[11] listed the following principles of health need and action to be taken to increase the health potential of housing internationally:

Principles of Health Needs

1. Communicable diseases can be reduced if housing provides for safe water supply, sanitary excreta and garbage disposal, adequate drainage of surface waters, and necessary facilities for domestic hygiene and safe food storage and preparation.

2. Housing should protect against avoidable injuries, poisonings, and exposure that contributes to chronic diseases and malignancies.
3. Housing may promote mental well-being; since prehistoric times, the home has been a place of refuge from danger and stress.
4. The neighborhood and community, as well as the dwelling itself, affect health.
5. Health depends also on how residents use their housing.
6. The dwelling conditions of certain groups put them at special health risk, leaving them especially vulnerable to multiple health hazards.

Principles of Health Action

1. Health advocacy in housing decisions should be strongly emphasized by health authorities, in alliance with other concerned groups, at all levels of administration and through multiple channels and media.
2. In the government sphere, health advocacy should be directed at a broad range of policies.
3. To implement socially desirable policies, health advocacy should be intersectoral in its orientation; moreover, it should be integrated into the technical and social processes that countries use to develop and maintain community resources.
4. For policies and standards to be effective, extensive public and professional education is required to promote the provision and use of housing in ways that improve health status.
5. Finally and emphatically, community involvement at all levels should support self-help, neighbor-help, and communal cooperative action in dealing with the needs and problems of the human habitat.

Minimum Standards Housing Ordinance

Building divisions of local governments have traditional responsibility over the construction of new buildings and their structural, fire, and other safety provisions as specified in a building code. Fire departments have responsibility for fire safety. The health department and such other agencies with an interest and responsibility are concerned with the supplied utilities and facilities, their maintenance, and the occupancy of dwellings and dwelling units for more healthy living. This latter responsibility is best carried out by the adoption and enforcement of a housing ordinance.

In an enforcement program, major problems of structural safety or alterations involving structural changes for which plans are required would be referred to the building division. Serious problems of fire safety would be referred to the fire department. Interdepartmental agreements and understanding can be mutually beneficial and make possible the best use of the available expertise. This requires competent staffing and day-to-day cooperation.

Housing and Health APHA-CDC Recommended Minimum Housing Standards has been prepared for local adoption.[12] Other model ordinances are also available.[13] The standards should apply to *all* existing, altered, and new housing. These standards give the conditions to be complied with before and during occupancy. They are minimum standards and in many instances should be exceeded.

A housing code or ordinance should reflect the need for safety devices and the hazards associated with new construction materials. Provision should also be made for compliance assistance and enforcement flexibility.

Smoke detectors have been found to be effective safety devices that belong in all dwellings and dwelling units. These devices afford major protection to life and property, particularly when coupled with alarms and sprinklers in multiple dwellings.

Energy conservation concerns have emphasized the importance of insulation materials to prevent heat losses from buildings. It is necessary to ensure that such materials are not flammable and do not release toxic fumes or materials when installed or subjected to high temperatures.

The administrative section of a housing code should permit the phased improvement of sound dwellings and dwelling units first in selected areas having identifiable grossly substandard living conditions. The expected level of compliance would be consistent with the intent of the housing code regulations and the achievable environmental quality of the neighborhood. Low-interest loans, fiscal and technical guidance, limited grants, craftsmen and labor assistance, tax relief, and other inducements are essential to encourage rehabilitation, stem the tide of deterioration and blight, and make possible compliance with the housing code. Concurrently, community services and facilities would need to be improved and maintained at an adequate level.

HOUSING PROGRAM

Approach

Housing can be a complex human, social, and economic problem that awakens the emotions and interests of a multitude of agencies and people within a community. Government agencies must decide in what way they can most effectively produce action; that is, whether in addition to their own efforts it is necessary to give leadership, encouragement, and support to other agencies that also have a job to do in housing.

Resolution of the housing problem involves just about all official and non-official groups or agencies. Organization begins with the housing coordinator, as representative of the mayor or community executive officer. The groups involved include an interagency coordinating committee; citizens advisory committee; health, building, public works, law, and fire departments; urban development agency; housing authority; financing clinic; planning board; air pollution control agency; office of community relations; public library; rent control office; universities and technical institutes; welfare department; council of social agencies; neighborhood and community improvement associations; banking institutions; real estate groups; consulting engineers and architects; general contractors; builders and subcontractors; press; and service organizations.

Components of a Good Housing Program

Good housing does not just happen. It is the result of far-sighted thinking by individuals in many walks of life. In some cases, a few houses are built here and there and areas grow with no apparent thought given to the future pattern being established. This is typical of small subdivisions of land and developments where there is no planning. In other instances, typical of large-scale developments, construction proceeds in accordance with a well-defined plan. The growth of existing communities, the quality of service and facilities provided, and the condition in which they are maintained usually depend on the leadership and coordination provided by the chief executive officer and legislative body and the controls or guides followed. The more common support activities are described later in this chapter.

Planning Board A planning board can define the area under control and, by means of maps, locate existing facilities and utilities. Included, for example, are highways, railroads, streams, recreational areas, schools, churches, shopping centers, residential areas, commercial areas, industrial areas, water lines, and sewer lines. In addition, plans are made for future revisions or expansion for maximum benefit to the community. A zoning plan is needed to delineate and enforce the use to which land will be put, such as for residential, farm, industrial, and commercial purposes. This also provides for protection of land values. Subdivision regulations defining the minimum size of lots, width and grading of roads, drainage, and utilities to be provided may also be adopted. New roads or developments would not be accepted unless in compliance with the subdivision standards. The planning board, if supported, can guide community changes and, if established early, direct the growth of a community, all in the best interest of the people.

Department of Public Works A public works department usually has jurisdiction over building, water, sewers, streets, refuse, and, if not a separate department, fire prevention and protection.

The building division's traditional responsibility is regulation of all types of building construction through the enforcement of a building code. A building code includes regulations pertaining to structural and architectural features, plumbing, heating, ventilation and air conditioning, electricity, elevators, sprinklers, and related items. Fire structural regulations are usually incorporated in a building code, although a separate or supplementary fire prevention code may also be prepared. Certain health and sanitary regulations, such as minimum room sizes, plumbing fixtures, and hot- and cold-water connections, should, of course, be an integral part of a building code. This ensures that new construction and alterations will comply with the health department's housing code minimum standards regulating occupancy, maintenance, and supplied facilities.

The water and sewer division would have the fundamental responsibility of making available and maintaining public water supply and sewerage services where these sanitary facilities are accessible. In new subdivisions of land, the provision of these facilities, particularly when located outside the corporate limits of a city or village, is usually the responsibility of the developer.

The division of streets would maintain streets, including snowplowing, cleaning, rebuilding old roads, and ensuring the proper drainage of surface water. In unincorporated communities the highway department assumes these functions. New roads would not be maintained unless dedicated to the city, village, or township and of acceptable design and construction.

Refuse collection would include garbage, rubbish, and trash. This function may be handled by the municipality, by contract, or by the individual.

Public Housing and Urban Development In existing urban communities, the housing authority is generally responsible for the construction and operation of dwellings for low-income families and for the rehousing of families displaced by slum clearance. The urban development agency assembles and clears land for reuse in the best interest of the community and rehouses persons displaced as a result of its actions. In basically good neighborhoods, unsalvable housing is demolished, good housing is protected, and sound substandard housing is rehabilitated. In general, large-scale demolition involving the destruction of viable neighborhoods having structurally sound housing should be avoided.

Health Department State and local health departments have the fundamental responsibility of protecting the life, health, and welfare of the people. Although most cities have health departments, many areas outside of cities do not have the services of a completely staffed county or city–county health department. However, where provided, the health department responsibilities are given in a public health law and sanitary code. In addition to communicable disease control, maternal and child health care, clinics, nursing services, and environmental sanitation, the health department should have supervision over housing occupancy, maintenance and facilities, food sanitation, water supply, sewage and solid waste disposal, pollution abatement, air pollution control, recreation, sanitation, control, radiation hazards, and the sanitary engineering phases of land subdivision. The environmental sanitation activities, being related to the planning, public works, housing, and redevelopment activities, should be integrated with the other municipal functions. For maximum effectiveness and in the interest of the people, it is also equally proper that the services and talents available in the modern health department be consulted and utilized by the other municipal and private agencies.

Health departments have the ideal opportunity to redirect and guide nuisance and complaint investigations; lead-poisoning elimination; carbon monoxide poisoning prevention; and insect, rodent, and refuse control activities into a planned and systematic community sanitation and housing hygiene program. By coordination with nursing, medical care, and epidemiological activities, as well as with those of other agencies, the department is in a position to constructively participate in the elimination of the causes contributing to the conditions associated with slums and substandard housing. The health department should also assist in the training of building, sanitation, welfare, and fire inspectors and others who have a responsibility or interest in the maintenance and improvement of living conditions.

Private Construction New construction and rehabilitation of housing in accordance with a good building and housing code are essential to meet the normal needs of people. Private construction and rehabilitation of sound structures should be encouraged and controlled to meet community goals and objectives in accordance with an adopted plan. In complete rehabilitation of a sound structure, the supporting walls, facade, and floor beams are preserved and new kitchens, bathrooms, bedrooms, living rooms, public areas, and utilities are installed. The availability of streets, water, sewers, and other utilities minimizes the total cost of providing "new" rental units, particularly if supported by some federal grant and low-interest loans. This could be accompanied by the establishment of cooperative ownership by qualified families and by self-help programs (Habitat for Humanity).

Rehabilitation is sometimes discouraged by contractors and architects because it can be full of surprises, depending on the extent of the preliminary investigation and the completeness of plans and specifications.

Loan Insurance Mortgage loan insurance by the government to stimulate homeownership has been fundamental to the construction and preservation of good housing. However, private financial institutions also have a major function and obligation. The reluctance or refusal of some lending institutions to make loans in certain urban areas for housing rehabilitation or purchase, known as *redlining*, and the similar practice by insurance companies for fire and property insurance, confound efforts to upgrade neighborhoods. Such practices should be reviewed.

Outline of a Housing Program

Several approaches have been suggested and used in the development of a housing program. They all have several things in common and generally include most of the following steps.[14]

1. Establishment of a committee or committees with representation from official agencies, voluntary groups, the business community, and outstanding individuals as previously described.
2. Identification of the problem—the physical, social, and economic aspects and development of a plan to attack each.
3. Informing the community of survey results, housing needs, and the recommended action.

4. Designation of a board or commission to coordinate and delegate specific functions to be carried out by the appropriate agency—for example, urban renewal, redevelopment, public housing, code enforcement, rehousing, rehabilitation, and refinancing.
5. Appropriation of adequate funds to support staffing and training of personnel.
6. Appraisal of housing and neighborhoods and designation of urban, suburban, and rural areas for (a) clearance and redevelopment, (b) rehabilitation, and (c) conservation and maintenance. This involves identification of structures and sites selected for preservation, interim code enforcement, rehabilitation of basically sound structures not up to code standards, spot clearance, provision or upgrading of public facilities and services, and land-use control.
7. Preparation and adoption of an enforceable housing code and other regulations that will upgrade the living conditions and provide a decent home in a suitable living environment.
8. Institution of a systematic and planned code enforcement program, including education of tenants and landlords, *prompt* encouragement and *requirement* of housing maintenance, improvement, and rehabilitation where indicated.
9. Concurrent provision and upgrading of public facilities and services where needed.
10. Provision of new and rehabilitated housing units through public housing, private enterprise, nonprofit organizations, individual owners, and other means.
11. Aid in securing financial and technical assistance for homeowners.
12. Liaison with federal, state, and local housing agencies, associations, and organizations.
13. Requirement that payments to welfare recipients not be used to subsidize housing that does not meet minimum health standards.
14. Evaluation of progress made and continual adjustment of methods and techniques as may be indicated to achieve the housing program goals and objectives.

These efforts need to be supplemented by control of new building construction, land subdivision, and mobile home parks. Also to be included are migrant-labor camps, camp and resort housing, commercial properties, and housing for the aged, chronically ill, handicapped, and those on public assistance.

Solutions to the Problem

The more obvious solutions to the housing problem are production of new housing, rehabilitation of sound housing, redevelopment, slum clearance, and public housing for low-income families. Increasing emphasis is being placed on cooperative ownership and on the conservation and rehabilitation of existing sound housing to prevent or slow down blight.* It is probably the most economical way of providing additional, healthier dwelling units and at the same time protecting the existing surrounding supply of good housing. Privately financed housing, redevelopment, and public housing cannot reach their full usefulness unless the neighborhood in which they are carried out is also brought up to a satisfactory minimum standard and is protected against degradation.

Federal, state, and local governments have an essential role in providing leadership and support. Federal programs usually make assistance available to finance housing for low- and moderate-income families, for urban development of programs including rehabilitation and conservation, and for redevelopment of urban communities. The federal programs include community development block grants, urban development action grants, low-income housing assistance, loan guarantees, and rehabilitation loans to eligible communities. Their implementation varies with the availability of federal funds. A local legally constituted agency is necessary to represent the municipality.

For example, eligibility for urban redevelopment funds may require formulation of a program to effectively deal with the problem of urban slums and blight within the community and to establish and preserve a well-planned community with well-organized residential neighborhoods of decent homes and suitable living environment for family life. The program can also make a municipality eligible for assistance for concentrated code enforcement, special help to blighted areas, demolition grants, rehabilitation grants and loans, and neighborhood facilities improvement and development. A workable program would require the following:

1. Adoption of adequate minimum standards of health, sanitation, and safety through a comprehensive system of codes and ordinances effectively enforced.
2. Formulation of a “comprehensive community plan” or a “general plan”—implying long-range concepts—and including land use, thoroughfare, and community facilities plans; a public improvement program; and zoning and subdivision regulations. See Chapter 5.
3. Identification of blighted neighborhoods and analysis for extent and intensity of blight and causes of deterioration to aid in delineation for clearance or other remedial action.
4. Establishment of an adequate administrative organization, including legal authority, to carry on the urban renewal program.
5. Development of means for meeting the financial obligations and requirements for carrying out the program.

*Careful analysis is advised, as the hidden costs and problems associated with major building rehabilitation cannot as a rule be fully anticipated. (M. Federman, “Building Rehabilitation: The Last Resort,” *Civil Eng., ASCE* (July 1, 1981), pp. 72–73.)

6. Provision of decent, sanitary housing for all families displaced by urban renewal or other government activities.
7. Development of active citizen support and understanding of the urban renewal program.

The restoration of a substandard housing area in an otherwise sound and healthy neighborhood must include removal of the blighting influences to the extent feasible and where indicated. These include heavy traffic, air pollution, poor streets, lack of parks and trees, poor lighting, dirty streets and spaces, inadequate refuse storage and collection, inadequate water supply and sewerage, unpainted buildings, noisy businesses and industries, and tax increases for housing maintenance and improvement.

Further explanations and specifics to carry out some of these program functions are given in the sections that follow.

Selection of Work Areas

A housing program must keep in proper perspective community short- and long-term plans, special surveys and reports, area studies, pilot block enforcement, and the routine inspection work to enforce a minimum standards housing ordinance. Continual evaluation of the program is necessary to ensure that the control of blight and deterioration of buildings and neighborhoods, as well as the rehabilitation of substandard dwellings, is being carried out where encountered. When indicated and possible, such action should be carried out on a planned block or area basis. This makes accomplishments more apparent and also awakens community pride, which can become "infectious." A blighted block does not always have a neon sign at the head of the street. The very insidiousness of blight makes it difficult to recognize and will have to be deliberately sought out and attacked. It may be only one or two houses in a block, which are recognized by a dilapidated outward appearance, by the inspector's intimate knowledge of the neighborhood and people, by office records showing a history of violations, or by routine survey reports. Signs of deterioration and dilapidation should be attacked immediately before decay and blight take over and incentive to make and support repairs becomes an almost impossible task.

The selection of conservation, rehabilitation, clearance, and redevelopment areas should take into consideration and adapt the following nine criteria:

1. The grading of socioeconomic areas using a weighted composite consisting of overcrowding, lack of or dilapidated private bath, lack of running water, and other measurable factors reported by the Bureau of the Census, including income and education.
2. The grading of areas using health indices and mortality and morbidity data.
3. The grading of areas on the basis of social problems, juvenile delinquency, welfare and private agency case load, adult probation, early venereal diseases, social unrest, and so on.

4. The areas having the high, average, and low assessed valuation, dilapidation, and overcrowding.
5. The grading of neighborhoods using the APHA or equal appraisal system, health and building department surveys, and plotted data. A sampling of 20 percent of the dwellings can give fairly good information.
6. Results of surveys and plans made by planning boards, housing authorities, and redevelopment boards.
7. Selection of work areas with reference to these criteria, as well as existing and planned housing projects, parks, redevelopment areas, parkways or thruways, railroads, and industrial or commercial areas; also existing barriers such as streams or lakes, good housing areas, swamps, and mountains.
8. Health department environmental sanitation and nursing division office records and personal knowledge of staff.
9. Visual foot surveys and combinations of items 1 through 8.

The superimposition of map overlays showing these characteristics will bring out areas having the most problems.

Enforcement Program

Enforcement of a housing conservation and rehabilitation ordinance involves use of the same procedures and techniques that have been effective in carrying out other environmental sanitation programs. The development of a proper attitude and philosophy of the intent of the law and its fair enforcement should be the fundamental theme in a continuing in-service training program. A housing enforcement program can proceed along the following lines:

1. Inspection of a pilot area to develop and perfect inspection techniques and learn of problems and practical solutions to obtain rehabilitation of substandard areas.
2. Routine inspection of all hotels and rooming and boarding houses for compliance with minimum standards housing ordinance. A satisfactory report could be a condition to the issuance of a permit and a license to operate.
3. Routine inspection of multiple dwellings. An initial inspection on a two-or three-year plan will reveal places requiring reinspection.
4. Inspections throughout a city, village, or town on an individual structure, block, and area basis to obtain rehabilitation and conservation of sound housing or demolition of unsalvable structures. This may be made a requirement by local ordinance before a dwelling or multiple dwelling can be resold. It could also apply before rerental.
5. Concentration of inspection in and around salvable areas to spread the border of improved housing so that it will merge with a satisfactory area.
6. Redirection of complaint inspections to complete housing surveys when practical. This can make available a large reservoir of personnel for more productive work.

7. Continuing in-service training with emphasis on law enforcement through education and persuasion, alteration and reconstruction, letter reporting, and financing to obtain substantial rehabilitation, not patchwork.
8. Close liaison with all city departments, especially city planning and building divisions, urban renewal agency, welfare, and the courts.
9. Continuing public education, including involvement of community and neighborhood organizations, to support the housing program and help or guide owners to conserve and rehabilitate their homes.

The enforcement program should take into consideration the problems, attitudes, and behavior of the people living in the dwelling units and the changes that need to be effected with the help of other agencies. The enforcement program must also recognize that, to be effective, subsidies and other forms of assistance to low-income families will usually be necessary to support needed alterations and rehabilitation.

Staffing Patterns Various staffing patterns have been suggested to administer a housing code enforcement program. One basis is a program director supported by one assistant to supervise up to eight inspectors, each making an estimated 1,000 inspections per year. Slavet and Levin suggest the following seven ratios[15]:

1. One inspector per 10,000 population or one inspector per 1,000 substandard dwelling units (this assumes inspection and reinspection to secure compliance at an average of 200 substandard dwelling units per year over a five-year period)
2. One inspector per 3,000 standard dwelling units, assuming inspection of 600 units per year over a five-year period, in addition to the staff needed to handle complaints
3. One financial specialist for every three or four housing inspectors
4. One community relations specialist for every three or four housing inspectors
5. One rehabilitation specialist for every two or three inspectors
6. One clerk for every three or four inspectors
7. One supervisor for every six to eight inspectors

Some Contradictions An enforcement program will reveal many contradictory facts relating to human nature. These only serve to emphasize that the housing problem is a complex one. The social scientist and anthropologist could study the problems and assist in their solution, provided he or she works in the field with the sanitarians and engineers:

> For example, it has been found that a person or family living in a substandard housing area may be very reluctant to move away from friends and relatives to a good housing area where the customs, religion, race, and very environment are different.

A housing survey may show that a structure is not worth repairing, and the expert construction engineer or architect may be able to easily prove that conclusion. But the owner of a one-, two-, or three-family building will rarely agree. He will go on to make certain minimum repairs or even extensive repairs to approach the standards established in the housing ordinance, leaving you wondering if there really is any such thing as a nonsalvable dwelling.

There is the not-infrequent situation where two old structures are located on the same lot, one facing the street and the other one the rear-lot line. If one structure is demolished, another cannot be built on the same lot because zoning ordinances usually prohibit such intensive lot usage by new structures. Therefore, the owner, rather than lose the vested right due to prior existence of the structure, with respect to the zoning ordinance, may choose to practically rebuild the dwelling at great cost rather than tear it down.

Another common occurrence is the tendency for some landlords to seize upon health or building department letters recommending improvements to bring the building into compliance with the housing ordinance as the opportunity to evict tenants and charge higher rentals. This is not to say that the owner is not entitled to a fair return on an investment, but the intent is that no one should profit from human misery. (A fair return on one's investment has been given as 10 percent of the assessed valuation or purchase price of the property.) Since the department's objective is to improve the living conditions of the people, it should not become a party to such actions. As a matter of fact, it is the unusual situation where needed housing improvements cannot be made with the tenant living in the dwelling unit, even though some temporary inconvenience may result. Hence, in such situations, it is proper for the department to opine that the needed repairs can be made without evicting tenants, thereby leaving the final determination in the exceptional cases with the owner and the courts.

A rather unexpected development may be the situation where an owner agrees to make repairs and improvements, such as new kitchen sink and provision of a three-piece bath with hot as well as cold water under pressure, only to be refused admittance by the tenant. The tenant knows that the rent may be increased and suddenly decides that a new bathroom is a luxury he or she can get along without. In such case, the courts have granted eviction orders and have sanctioned the reasonable increase in rent.

Rent control makes possible affordable housing for many families, but inadequate rents (income) discourage maintenance and promote decay and eventual building abandonment. See Figure 2.3. A fair balance must be reached.

Fiscal Aspects The financing of improvements is sometimes an insurmountable obstacle to the lay person. As an aid to the people affected by a housing enforcement program, a "financing clinic" can be formed to advise homeowners in difficult cases. The clinic may be a committee consisting of a banker, an architect, a general contractor, a plumbing contractor, and a representative of the building division, redevelopment board, federal agencies, and community. The department representative would help the owner present the problem. If the homeowner is instructed to submit estimates of cost from two or three reliable contractors, a sounder basis for assistance is established.

An enforcement program must recognize that many investors use the criterion that a dwelling is not worth purchasing unless it yields a gross annual income equal to one-quarter to one-fifth of the selling price. Another rule of thumb for rehabilitation of a dwelling is that the cost of alteration plus selling or purchase price shall not be more than five times the gross annual income, or an individual's income shall be at least 25 to 28 percent of the cost of the dwelling unit (taxes, mortgage, maintenance).

Enforcement Procedures

The fair and reasonable enforcement of the *intent* of a minimum standards housing ordinance requires the exercise of trained judgment by the administrators, supervisors, and field inspectors. Continuing in-service training of the housing staff is essential to carry out the purpose of the housing ordinance in an effective manner.[18] A trained educator can offer valuable assistance and guidance in planning the training sessions and in interpreting the program to the public and legislators. Health department sanitarians are admirably suited to carry out the housing program because of their broad knowledge in the basic sciences and their ability to deal effectively with the public.

The enforcement measures and procedures can be summarized as follows:

1. Prepare a housing operating manual giving a background of the housing program, guides for conduct, inspection report form based on the housing ordinance, interpretation of sections of the ordinance needing clarification for field application, suggested form paragraphs for routine letters, including typical violations and recommendations for their correction, follow-up form letters, building construction details, and related information. A few form paragraphs and architectural details are included in the text to suggest the type of material that can be included in a housing manual to obtain a certain amount of uniformity and organization in a housing enforcement program.
2. Complete an inspection of all types of premises and dwelling units occupied as living units. A comprehensive checklist or survey form based on the housing ordinance similar to Figure 2.4 could be used.
3. Prepare a complete rough-draft letter by the sanitarian based on field inspection, listing what was found wrong, together with recommendations for correction.
4. Review the inspection report and suggested letter by a supervising sanitarian for completeness and accuracy. The letter is signed by the supervisor and a tickler date confirmed for a follow-up inspection. See Figure 2.5.

COUNTY DEPARTMENT OF HEALTH
Division of Environmental Sanitation

Re:
C. , New York

Dear

The City of recently adopted a minimum standards housing ordinance to assist in the conservation and rehabilitation of existing housing. In this connection Mr. of this Department made a survey of dwellings in your neighborhood on Listed below are the conditions found at your building which were in need of improvement or correction.

We shall be glad to discuss any questions or difficulties you may have in complying with the minimum housing standards. Would you please advise this office in writing within 10 days of the action you propose to take?*

Your cooperation will help prevent the deterioration of property values in your neighborhood and help make a more healthful place in which to live.

Very truly yours,
J. A. Salvato, Jr., P.E.,
Chief, Bureau of General Sanitation

By...

* This letter is not to be construed as reason for removal of tenants, unless specifically stated therein.

Alterations or additions must be made in accordance with all applicable laws. Consult with the Division of Buildings, Room 325, City Hall for a permit to perform building, plumbing or electrical work required here. A building unlawfully occupied or with an increased number of living units must be brought into compliance, or if this is not permitted by law, it must revert to its original use.

JAS/er (1) 9/54:1000

FIGURE 2.5 Form letter to confirm findings at time of first inspection.

5. Maintain a visible card-index file or computer entry on each multiple dwelling, boarding house, rooming house, and hotel, in addition to a file on each dwelling, including one- and two-family structures.
6. Send a reinspection letter based on the findings reported in the first letter and remaining uncorrected. This may take the form of an abridged original letter listing what remains to be done, a letter calling for an informal hearing, a letter giving 30 days in which to show substantial progress, or a special letter. See Figure 2.6.
7. In some instances, substantial improvements are requested that justify a reasonable rent adjustment. This should be brought out at the time of

COUNTY OF
HEALTH DEPARTMENT

Re:
C. , New York

Dear

This department notified you by letter on of the housing deficiencies existing on your premises and the need for making corrections. However, a reinspection showed that no substantial progress had been made, and to date we have received no reply from you.

Inasmuch as the conditions enumerated in our letters to you are violations of the Minimum Housing Standards Ordinance, it is imperative that the needed improvements be made. Your failure to reply must be interpreted as an indication of lack of good faith or misunderstanding of the intent of our letters.

Under the circumstances, you are requested to appear in Room , City Hall, at to show cause why legal action should not be started. It is hoped that you will come prepared with an itemized report, indicating when the needed improvements will be completed, so as to make unnecessary further action by this department.

We wish to emphasize that it is our intention and obligation to follow up on violations of the Minimum Housing Standards Ordinance until such time as all work is done. It is only in this way that existing housing in the City of can be conserved and rehabilitated.

Very truly yours,

J. A. Salvato, Jr., P. E.,
Chief, Bureau of General Sanitation

By..

JAS/er(3)
9/54:500

FIGURE 2.6 Administrative hearing letter.

informal hearings when financial hardship is pleaded. Informal administrative hearings are very useful.

8. Conduct office consultation with owners to investigate long-range improvement programs within the limits of the law and the federal, state, and private assistance available.
9. Maintain a list of competent contractors who perform alteration work.
10. Review cost estimates with the owner for completeness.
11. Arrange for expert consultation to finance improvements, including a hearing before a “financing and construction clinic,” which should have

representation from the lending institutions as well as from the contractors, architects, and engineers.

12. In recalcitrant cases, secure a letter from the chief city judge or justice providing for a pretrial hearing to show cause why a summons should not be issued, followed by the hearing. A similar procedure could be followed by the corporation counsel or county attorney. The courts could also establish a special session to hear housing cases.
13. Issue a summons by the corporation counsel at the request of the enforcement agency when other measures have failed, if authorized by local law. A record of appearances and results should be kept.
14. Issue a summons by an authorized member of the enforcement agency in emergencies, if authorized by local law.
15. Cooperate with the press with a view toward obtaining occasional special reports, feature articles, and community support.
16. Cooperate and liaison with all private and public agencies having an interest in housing.
17. Notify the welfare department when public assistance is being given for rental because payment for housing should be made only when the facilities and conditions of maintenance and occupancy meet minimum standards.
18. Educate the legal department to obtain an aggressive, trained, and competent attorney who can become experienced in housing problems and be able to guide the legal enforcement phase of housing work.
19. Stimulate resurgence of neighborhood pride in the rehabilitation and conservation of all buildings on a block or area basis. Information releases and bulletins explaining what community groups and individuals can do to improve their housing is an excellent approach.
20. Discourage profit at the expense of human misery by making it possible through state law to file a lien in the county clerk's office against a property that is in violation of health ordinances, for the information of all interested and affected persons.
21. Notify the mortgage holders and insurance carriers of existing conditions.
22. Propose legislation requiring those who purchase city-owned property at public auctions to first list all the property they have owned in the past five years, properties they own with delinquent city taxes, the name and address of all major stockholders if a corporation, whether the purchaser owns vacant or abandoned buildings, and whether the city had ever taken title to the purchaser's property for back taxes.
23. In the case of corporate ownership, propose legislation requiring that name, address, and the number or percentage of shares owned in the corporation be filed in the county clerk's office.

24. Require registration and periodic reregistration of current ownership to facilitate the service of notices and enforcement. Require an in-state agent for receipt of legal notices.
25. Require a certificate of occupancy each time an apartment is rented to a new tenant.
26. Propose legislation authorizing payment of rent into an escrow account to correct code violations, after which the account is turned over to the owner.
27. Fund a municipal emergency repair program through attachment of rents or a property lien.
28. Arrange low-interest loans and grants to make repairs.
29. Push for legislation permitting tax foreclosure proceedings within two years or less to permit acquisition of property while it still has value, before it has deteriorated beyond hope of economic rehabilitation, with safeguards for the sincere resident owner who is temporarily in financial difficulty. This requires a systematic inspection system, early identification of deficiencies, prompt and vigorous enforcement, or foreclosure, where indicated.

The enforcement procedure generally includes news releases and information bulletins, inspection, notification, reinspection, second notification, third notification, informal hearings, administrative hearings, pretrial hearings, and summonses. In brief, therefore, the enforcement procedure consists of education and persuasion, with legal action being a last resort.

Not to be forgotten is stimulation of the possible role of nongovernment agencies having a direct or indirect interest and concern in the maintenance of good housing and in housing rehabilitation. The role could consist of seminars and individual assistance for home improvement given by banks, material supply companies, builder and contractor organizations, community colleges, urban development and redevelopment agencies, and fire insurance companies. The assistance could include financing methods for improvements; available federal (and state) grants and loans; filing of applications for assistance; owner-contractor relations; value of architectural services; and information on materials, supplies, and equipment for home repairs and improvements, their advantages, disadvantages, and costs.

HOUSING FORM PARAGRAPHS FOR LETTERS

It is necessary to have some reasonable uniformity and accuracy when writing letters or reports to housing code violators. This becomes particularly important when a housing code enforcement unit has a large staff and when court action is taken. By using a dwelling inspection form such as Figure 2.4, and the form paragraphs listed here, it should be possible for the inspector to readily prepare a draft of a suitable letter for review by that inspector's supervisor. The form paragraphs can and should be modified as needed to reflect more precisely the unsatisfactory conditions actually observed and practical suggestions for their correction. Reference to the pages that follow will be helpful in describing violations for use in the form letter (Figure 2.5). All construction must comply with the local or state building and fire prevention code.

Structural Safety

To be considered structurally safe, a building must be able to support two and a half to four times the loads and stresses to which it is or may be subjected.

Certain conditions that may be deemed dangerous or unsafe need explanation. For example, a 12-inch beam that has sagged or slanted more than one-quarter out of the horizontal plane of the depth of floor structural members in any 10-foot distance would be more than 3 inches out of level in 10 feet and, hence, unsafe. An interior wall consisting of 2×4-inch studs or 4-inch terracotta tile blocks more than one-half out of the vertical plane of the thickness of those members between any two floors would be more than 2 inches out of plumb and, hence, unsafe. See Figure 2.7.

A stair, stairway, or approach is safe to use when it is free of holes, grooves, and cracks that are large enough to constitute a possible accident hazard. Rails and balustrades are expected to be firmly fastened and maintained in good condition. Stairs or approaches should not have rotting or deteriorating supports, and stairs that have settled more than 1 inch or pulled away from the supporting or adjacent structure may be dangerous. Stair treads must be of uniform height and sound and securely fastened in position. Every approach should have a sound floor and every tread should be strong enough to bear a concentrated load of at least 400 lb without danger of breaking through. See Figure 2.8.

Incomplete Bathroom

The (first floor rear apartment) did not have a tub or shower. A complete bathroom—including a water closet, tub or shower, and washbasin connected with hot and cold running water—is required to serve each family. See Figures 2.9 and 2.10. The bathroom shall have a window or skylight not less than 10 percent of the floor area, with at least 45 percent openable, providing adequate light and ventilation. A water-repellent floor with a sanitary cove base or its equivalent is necessary. A ventilation system may be approved in lieu of a window or skylight.

No Hot Water

There was no piped hot water in the (kitchen of the first floor-front apartment). This apartment shall be provided with hot water or water-heating facilities of adequate capacity, properly installed and vented. The heater shall be capable of heating water to permit water to be drawn at every required kitchen sink, lavatory basin, bathtub, or shower at a temperature of approximately 110°F (43°C).

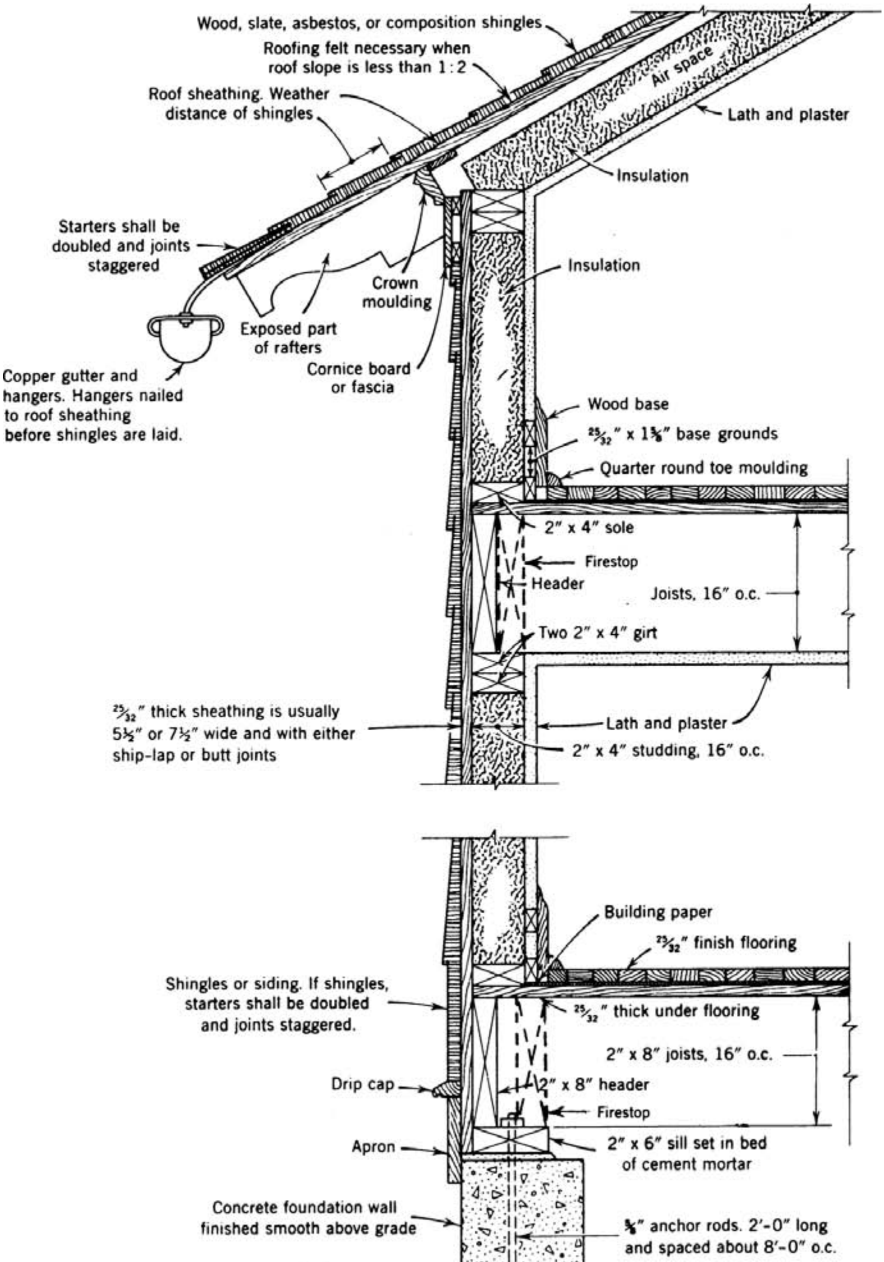


FIGURE 2.7 Wall construction.

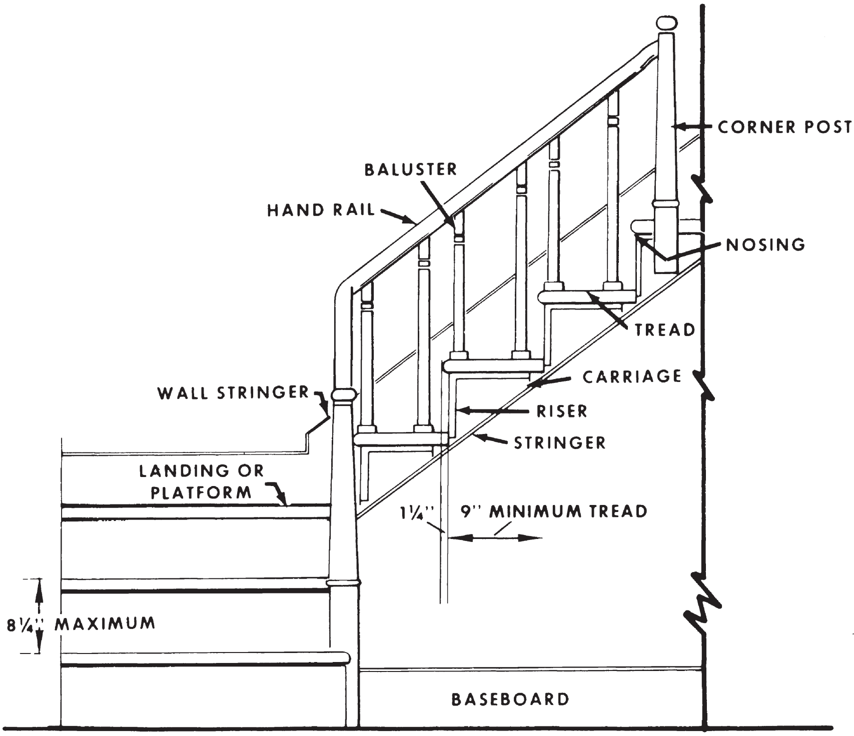


FIGURE 2.8 Stairway details. (*Source: Basic Housing Inspection*, DHEW Pub. (CDC) 80–8315, U.S. Government Printing Office, Washington, DC, p. 38.)

Leaking Water Closet

The water-closet bowl in the (describe location) apartment was (loose) (leaking) at the floor. (When the toilet is flushed, the water drains onto the floor and seeps through the ceiling to the lower apartment.) The water closet should be securely fastened to the floor, floor flange, and soil pipe so that it will be firm and not leak when flushed. (It will also be necessary to repair the loose ceiling plaster in the lower floor and repaint or repaper as needed.)

Floors Not Water Repellent

The bathroom (water-closet compartment) (floor covering) was (worn through) (broken) (bare wood with open joints). The floor should be (repaired) (made reasonably watertight), and the floor covering should extend about 6 inches up the wall to provide a sanitary cove base. Satisfactory material for the floor covering is inlaid vinyl, rubber or composition tile, smooth cement concrete, tile, terrazzo, and dense wood with tightly fitted joints covered with varnish or other similar coating providing a surface that is reasonably impervious to water and easily cleaned.

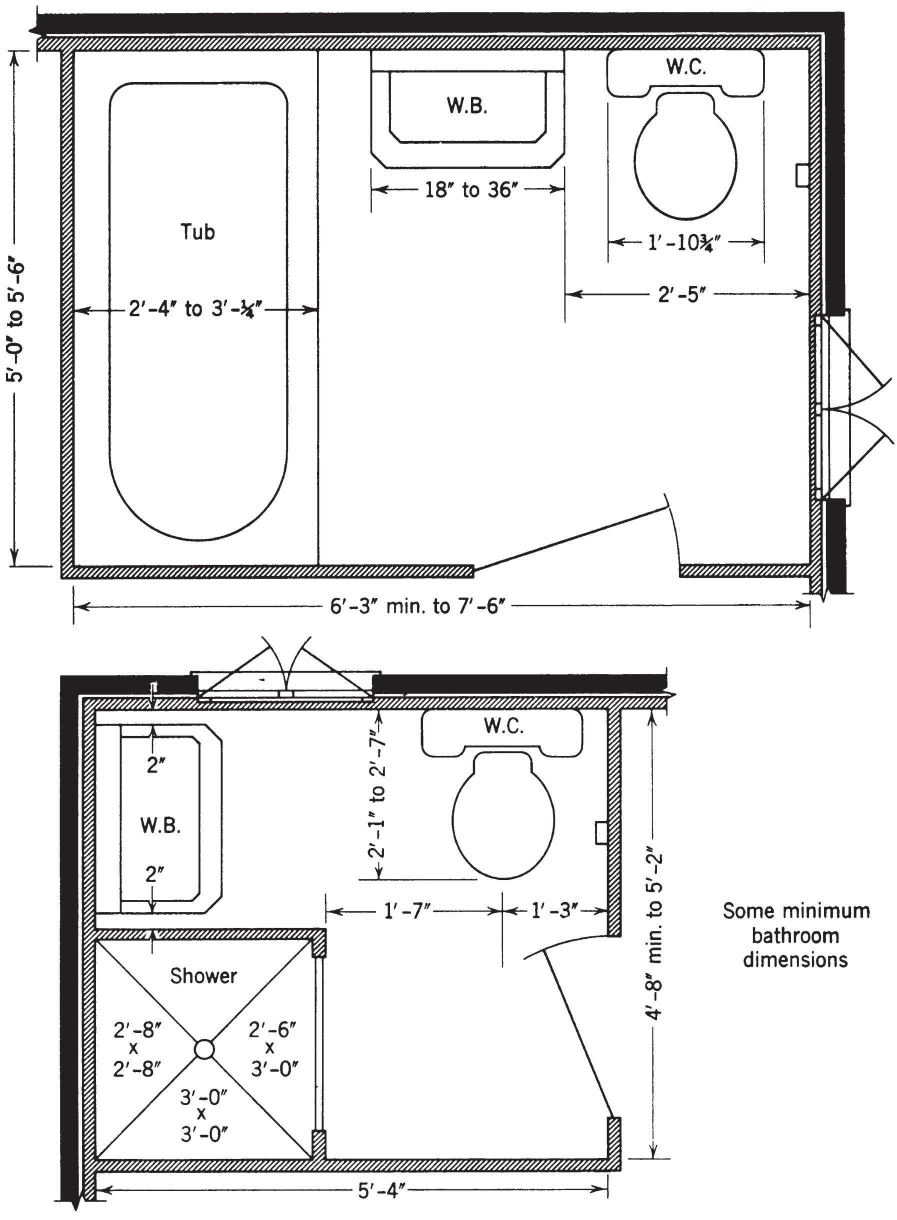


FIGURE 2.9 Three-piece bathroom showing minimum dimensions.

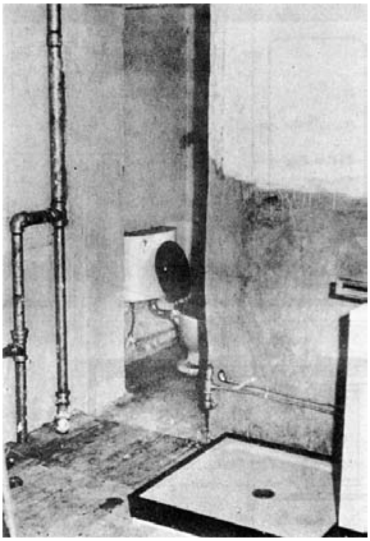


FIGURE 2.10 Alteration for shower and washbasin addition.

Exterior Paint Needed

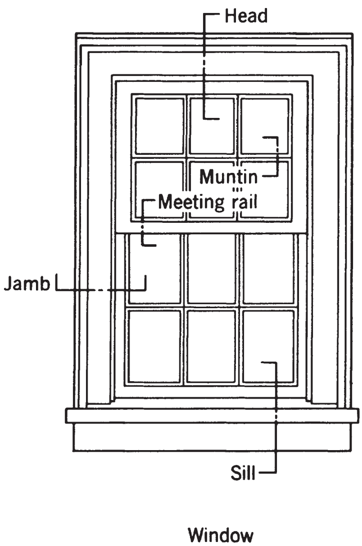
The exterior paint has (peeled, worn off), exposing the bare wood, rusting the nails, causing splitting and warping of the siding. This will lead to the entrance of rainwater, rotting of the siding, sheathing, and studs, as well as inside dampness and falling of the plaster. You are urged to immediately investigate this condition and make the necessary repairs, including painting or other weather- and decay-resistant treatment of the house, to prevent major repairs and expenses in the future.

Rotted and Missing Siding

The (shingles, siding, apron, cornice, exposed rafters) (on the north side of the house at the second-floor windows and foundation) is (are) (rotted and missing). Decayed material should, of course, all be removed, the sheathing repaired wherever necessary, and the shingles, siding, and so on, replaced. Following the carpentry work, all unpainted or unprotected material exposed to the elements should be treated to prolong its life.

Sagging Wall

The (door frames and window frames) in the (location) are out of level, making complete closure of the doors and windows impossible. Outside light could be easily seen through the openings around the (window rails and door jambs). The supporting beams, girders, posts, and studs should be carefully inspected, as there was evidence that some of these members were rotted, causing the outside wall



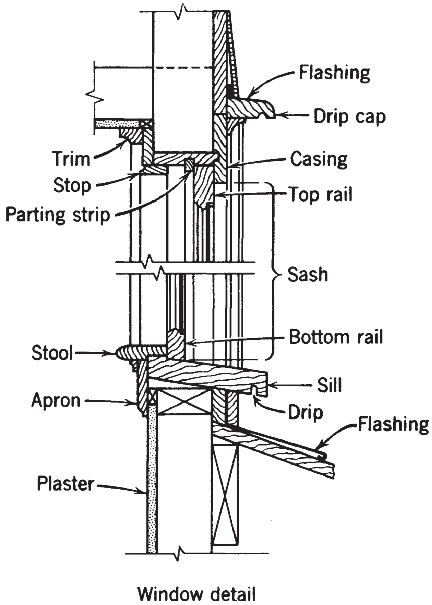


FIGURE 2.11 Window details.

to sag. The building should be shored and made level wherever necessary. The unsound material should be replaced, and the improperly fitting doors, windows, and framing repaired to fit and open properly. See Figures 2.7 and 2.11.

Loose Plaster

The plaster is (loose) (and buckled) (and has fallen) from the living room ceiling and walls in the (name apartment or other location) over an area of approximately 10ft^2. All loose plaster should be removed and the wall replastered; following curing, it should be painted or papered to produce a cleanable, smooth, and tight surface.

Leaking Roof

There is evidence of the roof leaking over or near the (kitchen, living room, etc., in the tenant apartment). The (paint, paper) was stained and peeling. It is essential that the leak be found and repaired, not only to prevent the entrance of water and moisture in the apartment but also to prevent loosening of the plaster, rotting of the timbers, and extension of the damage to your property.

No Gutters or Rain Leaders

There are no gutters or rain leaders on this building. Gutters and rain leaders should be placed where needed and connected to the sewer if permitted to ensure proper drainage of rainwater. This will also make rotting and seepage of water through siding and window frames and entrance of water into the basement less likely.

No Handrails

There are no handrails in the stairway between the (first and second floors at the rear). This is a common cause of preventable serious accidents. Handrails should be provided and securely fastened at a height of 30 to 32 in., measured above the stair tread.

Lead Paint

Children living in apartment (10B) have been screened for lead and were found to have high levels of lead in their blood. Lead is a cumulative poison that causes mental retardation, behavioral changes, anemia, and other impairments. Lead-based paint found on window and door frames in the apartment had flaked and peeled. Lead-based paint must be removed, but it requires special precautions to protect children and adults from the paint dust. Use a contractor who has been licensed to do this type of work.

Refuse in Attic

There are (rags, refuse, paper, and trash) in the attic. These materials are a fire hazard and provide harborage for mice and other vermin. All rags, paper, and trash must be removed from the attic, and the attic maintained in a clean and sanitary condition at all times.

Water-Closet Flush Tank Not Operating Correctly

The (water runs continuously) in the water-closet flush tank in the (John Jones's apartment); OR the water closet in the (John Jones's apartment) cannot be flushed. The broken, worn, or missing ball-cock valve, ball-cock float, flush-valve ball, flush lever, or flush handle should be repaired or replaced to permit proper flushing of the water closet. See Figure 2.12.

Garbage Stored in Paper Box or Bag

Garbage is being stored in (open, uncovered baskets) (paper bags) (paper boxes) (in the rear yard). This encourages rodent, fly, and vermin breeding. All garbage should be drained, wrapped, and properly stored in tightly covered containers. It will be necessary for you to procure needed receptacles for the proper storage of all garbage until collected.

Dilapidated Garbage Shed

The garbage shed in the (specify location) is in a dilapidated, rotted, and unsanitary condition. Garbage sheds tend to accumulate garbage and encourage rodent,

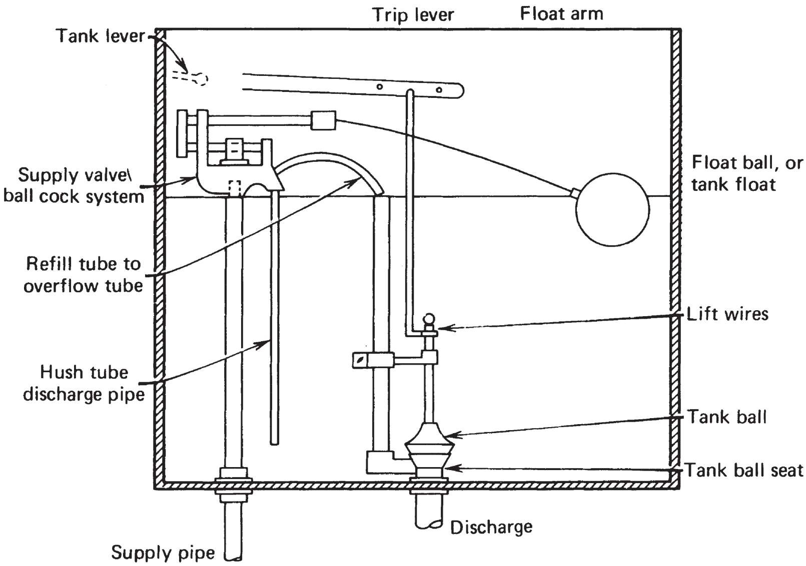


FIGURE 2.12 Water-closet tank. (Flapper valve can replace tank ball. Unvented supply valve requires backflow preventer.)

fly, and vermin breeding. This dilapidated garbage shed should be removed and the premises cleaned. Store the garbage cans on an elevated rack or concrete platform. (Enclose pamphlet showing some suggested storage racks.)

Debris in Yard or Vacant Lot

The vacant lot located at (specify location) was found littered with (old lumber, tin cans, and rubbish). This is unsightly and may serve as rat harborage and as an invitation to dump on the property. It is requested that you make a personal investigation of the conditions reported and arrange to have the lot cleared and cleaned. It is also recommended that you post a "No Dumping" sign to discourage future littering of the property.

Dirty Apartment

The apartment on the (second floor) is in a very unsanitary condition. (Describe.) All occupants are expected to keep their apartment and the premises they control in a clean and sanitary condition at all times. (Give a copy of the letter to the tenant.)

Overcrowded Sleeping Room

The bedroom(s) in the (specify location) are overcrowded. There are *(three) persons in a room having an area of (80) ft*^{2} and (four) persons in a room (85) ft^2.

Every room occupied for sleeping purposes shall contain at least 70 ft^2 of floor space for one person and 50 ft^2 for each additional person. (Suggest correction.) This apartment should not be rerented for occupancy by more persons than can be accommodated in accordance with this standard.

No Window in Habitable Room

No window to the outside air is provided in the (living room, kitchen, bedroom). Every room used or intended to be used as a living room, kitchen, or bedroom is required to have a total unobstructed window area of at least 10 percent of the floor area. Consideration should be given to the possibility of cutting in a new window or providing a skylight if the room is to be continued in use as a bedroom, living room, or kitchen.

Unlawful Third-Floor Occupancy

The third floor of this building had been converted and was occupied for living purposes. The conversion or alteration of a third floor or attic in a frame building for living or sleeping purposes is prohibited by Chapter X of the city ordinances. This is a major hazard in case of fire. Discontinue the use of the third floor immediately. (Refer a copy of the letter to division of buildings.)

Unlawful Cellar Occupancy

The cellar is being used for (sleeping, living, purposes). A cellar may not be used for living purposes; hence, this space must be permanently vacated. (The housing ordinance defines a cellar as “a room or groups of rooms totally below ground level and usually under a building.”)

Clogged Sewer

The (soil stack, building drain, or sewer) is apparently clogged, for sewage from the upper apartment(s) backs into the (kitchen sink, water closet) in the (first-floor front apartment). The clogged sewer must be cleared and, if necessary, repaired to eliminate cause for future complaint.

Unvented Heater

The gas water heater(s) (burning carbonaceous fuel) in the (name room or space and locate) is (are) not vented. Unvented heaters in bathrooms and sleeping rooms have been the cause of asphyxiation, carbon monoxide poisoning, and death. These heaters must be properly vented to the chimney or outside air, supplied with sufficient air to continuously support combustion of the fuel, and be protected to prevent fires and minimize accidental burns. See “Venting of Heating Units,” this chapter.

Furnace Flue Defective

The furnace flue has rusted through in several places (and the connection to the chimney is loose), causing waste gases to escape into the basement. Since such gases rise and seep into the upper apartment(s) and have been known to cause asphyxiation, it is imperative that the flue be repaired and the collar sealed to prevent leakage of any waste gases. This should also improve the efficiency of the furnace.

Rubber-Hose Gas Connection

The gas heater(s) in the (tenant apartment) has (have) (plastic pipe, rubber hose) connection(s). Such materials eventually leak and may cause death in the household. It will be necessary to replace all plastic and rubber-hose connections with rigid, metal pipe.

Rat Infestation

There is evidence of a very bad rat condition existing in this building, as indicated by (explain condition). All holes in the foundation (floors) should be sealed with cement mortar and openings around wood framing closed with metal flashing or with cement mortar where possible. Traps and repeated use of a rodenticide such as Warfarin are suggested to kill rats inside the building. All sources of food and harborages must be eliminated. Such control measures should be continuous for at least two or three weeks to be effective. (Enclose pamphlet giving additional details dealing with accepted control measures.)

Roach Infestation

The apartment is apparently infested with roaches, as indicated by the roachy odor and roaches observed hiding under the sink, baseboard, moldings (stains in the kitchen cabinet, pellets of excrement in the dish cabinet). Roaches are sometimes brought in with boxes of food, baskets, or bags; dirt and filth encourage their reproduction in large numbers. Thorough cleaning, filling of cracks around frames with plaster or plastic wood, followed by the proper application of an insecticide in selected places and in accordance with the manufacturer's directions should bring the problem under control. (Enclose pamphlet that gives additional detailed information.)

Overflowing Sewage Disposal System

The sewage disposal system serving the dwelling is (seeping out onto the surface) (discharging into the ditch in front of your home). This is a health hazard not only to those living there but also to neighbors and pets. Immediate steps should be taken to determine the cause and make corrections.

Improperly Protected Well-Water Supply

A sanitary survey of the well-water supply shows it to be subject to contamination. *The well (is uncapped) (has a hole around the casing where surface water can drain down and into the well) (does not have a tight seal at the point where the pump line(s) pass into the casing as noted by drippage observable from looking into the well).* The necessary repairs should be made to prevent contamination of the water supply and then the well should be disinfected as explained in (enclosed) instructions.

Major Repairs

In view of the major repairs and improvements needed, only some of which have been reported above, plans prepared by a registered architect should be submitted showing the existing conditions and all proposed alterations for approval by this Department and the Division of Buildings, before any work is done. This procedure makes possible the receipt of comparable bids from several contractors and usually results in more orderly prosecution of the work at a minimum cost.

Minor Repairs

In view of the repairs and improvements needed, a sketch drawn to scale should be prepared showing existing and proposed work to ensure that the work can be done as intended. The sketch should be submitted to and approved by the Division of Buildings and this Department before any work is done. This procedure makes possible the receipt of comparable bids from several contractors and usually results in more orderly prosecution of the work at a minimum cost.

Obtain at Least Three Estimates

We urge you to obtain at least three estimates from reputable contractors before having any work done. Written bids should be requested and assurance obtained from the contractor that the estimate is all inclusive.

PLUMBING

Plumbing Code

Sanitary plumbing principles that are based on the latest scientific studies should be fundamentally similar but will be varied in application, depending on the local conditions. Some plumbing designs and standards currently in existence are based on an unsound old rule of thumb or prejudice. They could be reviewed with profit in the light of present-day knowledge.

The *National Plumbing Code*,[16] the *Uniform Plumbing Code*,[17] and the *Standard Plumbing Code* (also called the *Southern Code*)[18] are the three major plumbing codes currently being used in the United States. Public Health Service Pub. 1038[19] is also a comprehensive standard code of minimum requirements for use. Some of the major codes have combined to form the *International Plumbing Code*.[20] The interested person would do well to have copies in a reference file. The sizing of water supply, drainage, vent, and storm-drain piping is concisely covered.

In addition to the major codes, different parts of the country frequently have their local plumbing codes (state, county, or city level). These local code requirements must be checked before doing any plumbing work.

One term used frequently is *plumbing fixture*. This term includes installed receptacles, devices, or appliances either supplied with water or receiving on discharge liquids or liquidborne wastes or both. The bathtub, sink, water closet, dishwasher, and drinking fountain are examples of plumbing fixtures. In practice, the probable flow is estimated based on the fixture unit. *A fixture unit* is the load-producing flow effect for comparing different plumbing fixtures. One water supply fixture unit (wsfu) is usually taken as 7.5 gpm. The drainage fixture unit (dfu) for different fixtures can also be found in most plumbing codes.

Approval of plans for plumbing systems must usually be obtained before construction is started. Health departments can accomplish more in the interest of public health by seeing that proper standards of plumbing exist and are enforced than by actually doing the plumbing inspection. For example, the health department can see to it that plumbing and building codes prohibit dangerous cross-connections and interconnections and require a private three-piece bathroom and kitchen sink served by hot and cold water in every new dwelling unit. This is fundamental to the prevention of disease, the promotion of personal hygiene, and sanitation. Plumbing codes should prohibit the use of lead piping for water distribution and the use of tin–lead (50:50 and 60:40) solder for joining copper piping.

Plumbing codes should specify an adequate number of fixtures for private public, and industrial use, all properly supplied, trapped, vented, and sewered, as noted in Tables 2.6 through 2.9. Water connections with unsafe or questionable water supplies would be prevented, and connections or conditions whereby used or unsafe water could flow back into the potable water system would be prohibited. Of course, a safe water supply and proper sewage disposal should be ensured.

Housing codes should make reference to a modern plumbing code. Housing codes would be of little value unless they were applicable to all new, altered, and existing one-, two-, or multifamily dwellings, hotels, boarding houses, and rooming houses.

The health department should serve as a consultant to the building, plumbing, water, and sewer divisions. Any new or revised codes or regulations should first be reviewed and approved by the health department before being considered for adoption to ensure that the fundamental principles of public health and sanitary engineering are not violated.

TABLE 2.6 Minimum Number of Plumbing Facilities

Fixtures
Number of fixtures per number of occupants

Building Occupancy		Water Closets Males	Water Closets Females	Lavatories	Bathtubs/ Showers	Drinking Fountains	Service Sink
A	Theaters	1 per 125	1 per 65	1 per 200	—	1 per 1,000	1
	Night Clubs	1 per 40	1 per 40	1 per 75	—	1 per 500	1
	Restaurants	1 per 75	1 per 75	1 per 200	—	1 per 500	1
	Halls, museums, etc.	1 per 125	1 per 65	1 per 200	—	1 per 1,000	1
	Coliseums, arenas	1 per 75	1 per 40	1 per 150	—	1 per 1,000	1
	Churches (b)	1 per 150	1 per 75	1 per 200	—	1 per 1,000	1
	Stadiums, pools, etc.	1 per 100	1 per 50	1 per 150	—	1 per 1,000	1
B	Business	1 per 25		1 per 40	—	1 per 100	1
M	Retail sales	1 per 500		1 per 750	—	1 per 1,000	1
F	Factory and industrial	1 per 100		1 per 100	emergency showers and eyewash	1 per 400	1
S	Storage	1 per 100		1 per 100	emergency showers and eyewash	1 per 1,000	1
E	Educational	1 per 50		1 per 50	–	1 per 100	1
H	Hazardous	1 per 100		1 per 100	emergency showers and eyewash	1 per 1,000	1
I	Hospitals (c)	1 per room (f)		1 per room (f)	1 per 15	1 per 100	1 per floor
	I-1 Nurseries, day care centers, sanitariums, and nursing homes with nonambulatory patients (c)	1 per 15		1 per 15	1 per 15 (g)	1 per 100	1
	I-2 Nursing homes for ambulatory patients (c)	1 per room (f)		1 per room (f)	1 per 15	1 per 100	1 per floor
	I-3 Mental hospitals, mental sanitariums, etc.	1 per 15		1 per 15	1 per 15	1 per 100	1

(*continues*)

TABLE 2.6 (*continued*)

Fixtures
Number of fixtures per number of occupants

	Building Occupancy	Water Closets Males	Water Closets Females	Lavatories	Bathtubs/ Showers	Drinking Fountains	Service Sink
	I-3 Jails/ reformatories cells	1 per cell		1 per cell	1 per 8	–	–
	I-3 Dormitory or other institutional rooms with 24 hour access to sanitary facilities	1 per 12	1 per 8	1 per 12	1 per 8	–	–
	I-3 Exercise rooms	1 per room		1 per room	–	–	–
	I-3 Employees (c)	1 per 25		1 per 25	–	1 per 100	–
	I-3 Visitors	1 per 75		1 per 100	–	1 per 500	–
R	Lodges, dormitories, and bed and breakfast facilities	1 per 10		1 per 8	1 per 10	1 per 100	1
	Hotels and motels	1 per guest room		1 per guest room	1 per guest room	–	1
	Multiple family housing (d)	1 per dwelling unit		1 per dwelling unit	1 per dwelling unit	–	1 kitchen sink per dwelling unit

Note (a) The fixtures shown are based on one (1) fixture being the minimum required for the number of persons indicated or any fraction of the number of persons indicated.
Note (b) Fixtures located in adjacent buildings under the ownership or control of the church may be made available during periods the church is occupied.
Note (c) Toilet facilities for employees shall be separate from the facilities for inmates or patients.
Note (d) One (1) automatic clothes washer connection shall be required per twenty (20) dwelling units.
Note (e) One (1) automatic clothes washer connection shall be required per dwelling unit.
Note (f) A single-occupant toilet room and one (1) water closet and one (1) lavatory servicing not more than two (2) adjacent patients rooms shall be permitted where such room is provided with direct access from each patient room and with provisions for privacy.
Note (g) For nurseries, a maximum of one (1) bathtub shall be required.

Source: Indiana General Assembly. TITLE 675 FIRE PREVENTION AND BUILDING SAFETY COMMISSION. http://www.in.gov/legislative/iac/20080423-IR-675070476FRA.xml.html.

TABLE 2.7 Minimum Sizes of Fixture Supply and Drain

Type of Fixture/Device	Pipe Size (in.) Supply	Drain
Bathtubs	$\frac{1}{2}$	$1\frac{1}{2}$
Combination sink and tray	$\frac{1}{2}$	$1\frac{1}{2}$
Drinking fountain	$\frac{3}{8}$	1
Dishwasher, domestic	$\frac{1}{2}$	$1\frac{1}{2}$
Kitchen sink	$\frac{1}{2}$	$1\frac{1}{2}$
Residential		
Commercial	$\frac{3}{4}$	$1\frac{1}{2}$
Lavatory	$\frac{3}{8}$	$1\frac{1}{4}$
Laundry tray, 1 or 2 compartments	$\frac{1}{2}$	$1\frac{1}{2}$
Shower, single head	$\frac{1}{2}$	$1\frac{1}{2}$
Sink, service, P trap	$\frac{1}{2}$	2
Sink, service, floor trap	$\frac{3}{4}$	3
Urinal, flush tank, wall	$\frac{1}{2}$	$1\frac{1}{2}$
Urinal, direct, flush valve	$\frac{3}{4}$	2
Urinal, pedestal, flush valve	1	3
Water closet, tank-type	$\frac{3}{8}$	3
Water closet, flush valve type	1	3
Hose bibs	$\frac{1}{2}$	—
Wall hydrant	$\frac{1}{2}$	—

Note: The minimum water pressure at the outlet, at times of maximum demand, shall not be less than 8 psi, except for direct flush valves, where 15 psi is required, and where special equipment requires other pressure.

Source: PHS Pub. No. 1038, Department of Health, Education, and Welfare, Washington, DC. See also Chapter 4 for trap sizes and fixture unit ratings.

TABLE 2.8 Distance of Fixture Trap from Vent

Size of Fixture Drain (in.)	Maximum Distance (ft)
$1\frac{1}{4}$	$2\frac{1}{2}$
$1\frac{1}{2}$	$3\frac{1}{2}$
2	5
3	6
4	10

Tables 2.6 through 2.9, respectively, give the minimum number of plumbing fixtures for different building occupancies, the minimum sizes of fixture supply and drain, maximum distance of fixture trap from vent, and hot-water demands for different types of buildings. Some plumbing details, with particular emphasis on backflow prevention, recommended minimum number of plumbing

TABLE 2.9 Hot Water Demands and Use for Various Types of Buildings

Type of Building	Maximum Hour	Maximum Day	Average Day
Men's dormitories	3.8 gal/student	22.0 gal/student	13.1 gal/student
Women's dormitories	5.0 gal/student	26.5 gal/student	12.3 gal/student
Motels: number of units			
20 or less	6.0 gal/unit	35.0 gal/unit	20.0 gal/unit
60	5.0 gal/unit	25.0 gal/unit	14.0 gal/unit
100 or more	4.0 gal/unit	15.0 gal/unit	10.0 gal/unit
Nursing homes	4.5 gal/bed	30.0 gal/bed	18.4 gal/bed
Office buildings	0.4 gal/person	2.0 gal/person	1.0 gal/person
Food service establishments			
Type A, full-meal restaurants and cafeterias	1.5 gal/max. meals/hr	11.0 gal/max. meals/hr	2.4 gal/avg. meals/day[a]
Type B, drive-ins, grilles, luncheonettes, sandwich and snack shops	0.7 gal/max. meals/hr	6.0 gal/max. meals/hr	0.7 gal/avg. meals/day[a]
Apartment houses			
20 or less	12.0 gal/apt.	80.0 gal/apt.	42.0 gal/apt.
50 apartments	10.0 gal/apt.	73.0 gal/apt.	40.0 gal/apt.
75 apartments	8.5 gal/apt.	66.0 gal/apt.	38.0 gal/apt.
100 apartments	7.0 gal/apt.	60.0 gal/apt.	37.0 gal/apt.
130 apartments or more	5.0 gal/apt.	50.0 gal/apt.	35.0 gal/apt.
Elementary schools	0.6 gal/student	1.5 gal/student	0.6 gal/student[a]
Junior and senior high schools	1.0 gal/student	3.6 gal/student	1.8 gal/student[a]

[a]Per day of operation

Note: The table remains unchanged in the latest ASHRAE publication—*2007 ASHRAE Handbook: HVAC Applications*. Heaters should be preset to deliver water at 130°F (54°C). The Consumer Product Safety Commission (CPSC) recommends a maximum of 120°F (49°C).

Source: ASHRAE Guide and Data Book, Atlanta, GA, 1970. Copyright by the American Society of Heating, Refrigerating and Air Conditioning Engineers. Inc. Reprinted with permission.

fixtures, the application of indirect waste piping, and other details are discussed below.

Backflow Prevention

The backflow of polluted or contaminated water or other fluid or substance into a water distribution piping system through back pressure or back siphonage is a very real possibility. The best way to eliminate the danger is to prohibit any connections between the water system and any other system, fixture vat, or tank containing polluted or questionable water. This can be accomplished by terminating the water supply inlet or faucet a safe distance above the flood-level rim of the fixture. The distance, referred to as the air gap is 1 inch for a 0.5-inch-or-smaller-diameter faucet or inlet pipe, 1.5 inches for a 0.75-inch-diameter faucet, 2 inches for a 1-inch-diameter faucet, and twice the effective opening (cross-sectional area at point of water supply discharge) when its diameter is greater than 1 inch. When the inside edge of the faucet or pipe is close to a wall—that is, within three or four times the diameter of the effective opening—the air gap should be increased by 50 percent.

Sometimes, as with water closets and urinals equipped with flushometer valves, it is not possible or practical to provide an air gap. Under such circumstances, where the water connection is not subject to back pressure, an approved nonpressure-type backflow preventer, such as that shown in Figure 2.13, may be used to prevent back siphonage. The backflow preventer

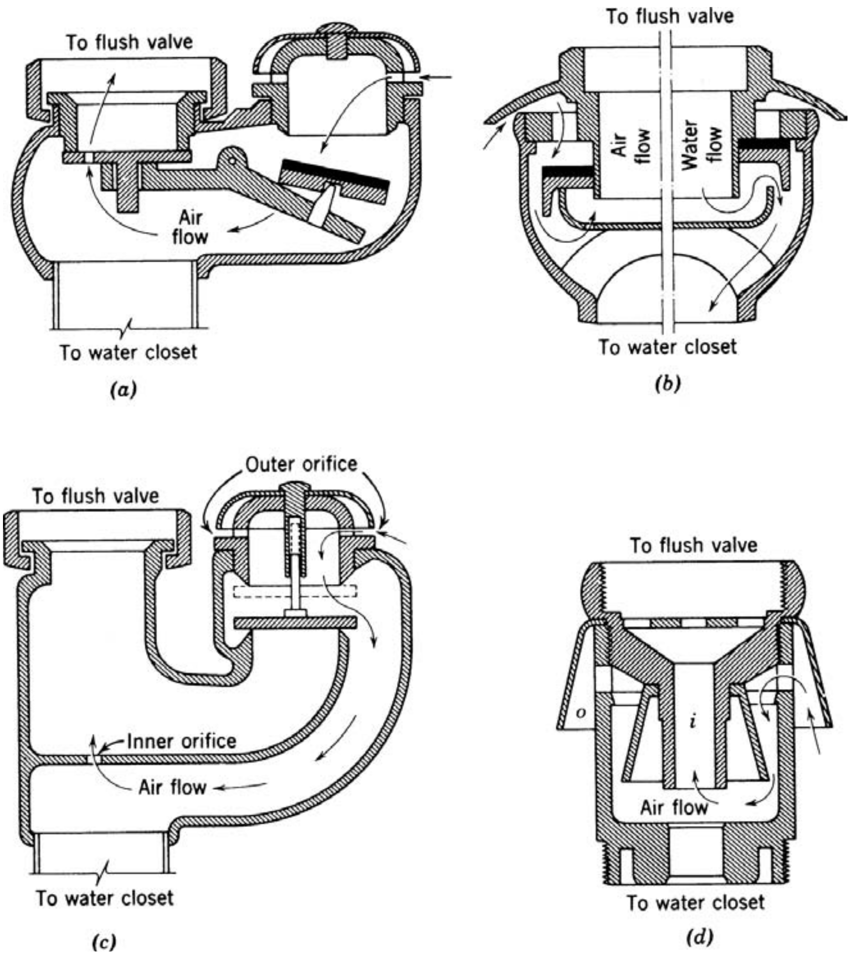


FIGURE 2.13 Vacuum, nonpressure-type siphon-breakers: (*a*), (*b*), (*c*) Moving parts; (*d*) Nonmoving part. Installed *after* fixture valve. (*Source:* R. B. Hunter, G. E. Golden, and H. N. Eaton, "Cross-Connections in Plumbing Systems," Research Paper RP 1086, *J. Res. Natl. Bur. Stand*., 20 (April 1938).)

must be installed on the outlet side of the control valve, at a distance not less than four times the nominal diameter of the inlet, measured from the control valve to the flood-level rim of the fixture, and in no cases less than 4 inches.

A pressure-type vacuum breaker (see Figure 2.14) is installed on a pressurized system and will function only when a vacuum occurs. It should not be installed where backpressure may occur. Figure 2.14 also shows a hose bib vacuum breaker and an atmospheric vacuum breaker.

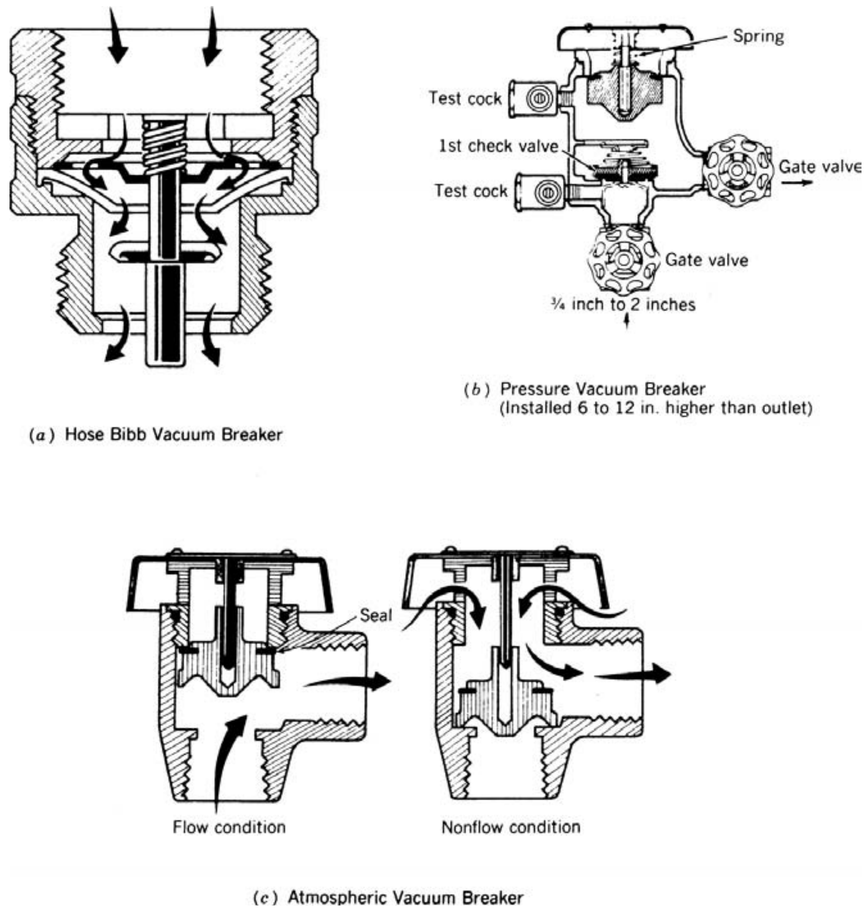


FIGURE 2.14 Vacuum breakers: (*a*) Generally attached to sill cocks and, in turn, are connected to hose supplied outlets such as garden hoses, slop sink hoses, and spray outlets, (*b*) A spring on top of the disc and float assembly, two added gate valves, test cocks, and an additional first check make possible its utilization under constant pressure, (*c*) Must be installed vertically, must not have shutoffs downstream, and must be installed at least 6 in. higher than the final outlet. (*Source: Cross-Connection Control Manual*, EPA 570/9-89-007, U.S. Environmental Protection Agency, Office of Water, Washington, DC, June 1989, pp. 17–18.)

In some instances, an air gap cannot be installed and it is necessary to connect a potable water supply to a line, fixture, tank, vat pump, or other equipment to permit backflow of nonpotable water due to backpressure or back siphonage. Under such circumstances, an approved reduced-pressure-principle backflow preventer *may* be permitted by the regulatory authority. It is essentially a modified double check valve with an atmospheric vent capability placed between the two checks.

Indirect Waste Piping

Waste pipes from fixtures or units in which food or drink is stored, prepared, served, or processed must not connect directly to a sewer or drain. Stoppage in the receiving sewer or drain would permit polluted water to back up into the fixture or unit. Waste piping from refrigerators, iceboxes, food-rinse sinks, cooling or refrigerating coils, laundry washers, extractors, steam tables, egg boilers, steam kettles, coffee urns, dishwashing machines, sterilizers, stills, and similar units should discharge to an open-water-supplied sink or receptacle so that the end of the waste pipe terminates at least 2 inches above the rim of the sink or receptacle, which is directly connected to the drainage system.

A commercial dishwashing machine waste pipe may be connected to the sewer side of a floor drain trap when the floor drain is located next to the dishwashing machine, if permitted by the regulatory agency.

An alternate to the installation of a water-supplied sink waste receptor is the provision of an air gap in the fixture waste line, at least twice the effective diameter of the drain served, located between the fixture and the trap.

The water-supplied sink or air-gap waste receptor should be in an accessible and ventilated space and not in a toilet room.

Plumbing Details

A few typical details and principles are illustrated for convenient reference and as guides to good practice. There are many variations, depending on local conditions and regulations. See Figure 2.15.

INDOOR AIR QUALITY

Causes and Sources of Indoor Air Pollution

Improved building construction and insulation, including weather stripping, caulking, and storm and thermopane windows, reduce infiltration and air exchange, which results in less air dilution and an increase in the concentration of indoor air pollution. Inadequate ventilation and the recirculation of contaminated used air to save on energy costs for heating and cooling further aggravate the problem. Good practice would dictate that at least one-third of the recirculated air should be clean fresh air, even though this would increase energy costs, unless an air-to-air heat exchanger is used.

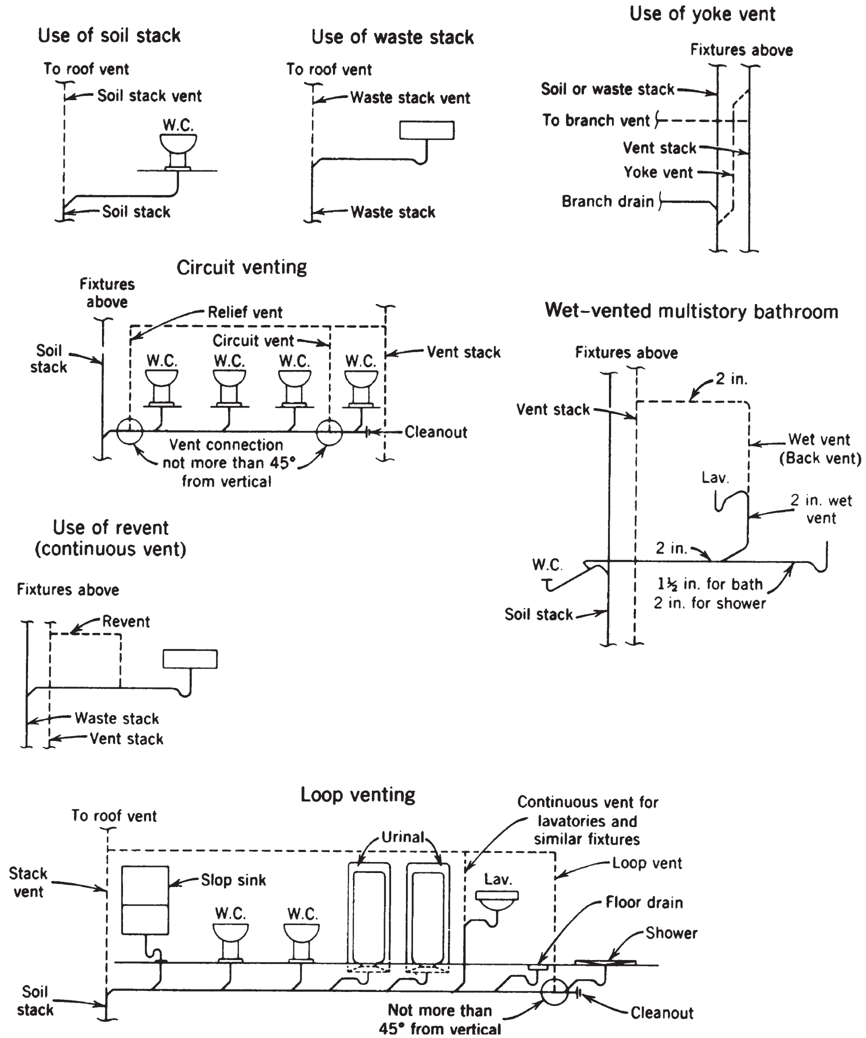


FIGURE 2.15 Some fixture plumbing details. (*Source: New York State Uniform Fire Prevention and Building Code*, Division of Housing and Community Renewal, New York, January 1, 1984.)

Household appliances, aerosol applications, cleaning products, pesticides, photocopying machines (ozone), interior furnishings and building materials (formaldehyde and volatile organic compounds), tobacco smoke, dry-cleaned clothing, and radon may also contribute to the indoor air pollution problem. Noise might also be included. Table 2.10 lists major pollutant/sources, specific contaminants, and acceptable levels. The contaminants may be found in the new or rehabilitated home, office, or other workplace; in the automobile, airplane, or

TABLE 2.10 Sources and Exposure Guidelines of Indoor Air Contaminants

Pollutant/Sources[a]	Guidelines
Asbestos and other fibrous aerosols: friable asbestos—fireproofing, thermal and acoustic insulation, decoration; hard asbestos—vinyl floor and cement products, automatic brake linings (O)	0.2 fibers/ml for fibers longer than 5 μm (based on ASHRAE[b] guidelines of 1/10 of U.S. 8-hr occupational standard)
Biological aerosols: human and animal metabolic activity products, infectious agents, allergens, fungi, bacteria in humidifiers, bacteria in cooling devices	None available
Carbon monoxide: kerosene heaters, gas stoves, gas space heaters, wood stoves, fireplaces, smoking, and automobiles (O)	9 ppm for 8 hr (NAAQS[c]); 35 ppm for 1 hr (NAAQS)
Formaldehyde: particleboard, paneling, plywood, ceiling tile, urea-formaldehyde foam insulation, other construction materials	0.1 ppm (based on Dutch and West German guidelines as reported in ASHRAE Guidelines, 1981, and National Research Council report, 1981)
Inhalable particulates: smoking, vacuuming, combustion sources (O), industrial sources, fugitive dust (O), and other organic particulate constituents	55–110 μg/m^3 annual[d]
Metals and other inorganic paniculate contaminants:	150–350 μg/m^3 for 24 hr[d]
Lead—old paint, automobile exhaust (O)	1.5 μg/m^3 for 3 months (NAAQS)
Mercury—old paint, fossil fuel combustion (O)	2 μg/m^3 for 24 hr (ASHRAE)
Cadmium—smoking, use of fungicides (O)	2 μg/m^3 for 24 hr (ASHRAE)
Arsenic—smoking, pesticides, rodent poisons	None available
Nitrates—outdoor air	None available
Sulfates—outdoor air	4 μg/m^3 annual, 12 μg/m^3 for 24 hr (ASHRAE)
Nitrogen dioxide: Gas stoves, gas space heaters, kerosene space heaters, combustion sources (O), automobile exhaust (O)	0.05 ppm annual (NAAQS)
Ozone: photocopying machines, electrostatic air cleaners, outdoor air	Not exceeding 0.12 ppm once a year (NAAQS)
Pesticides and other semivolatile organics: Sprays and strips, drift from area applications (0)	5 μg/m^3 for chlordane (NRC)[e]
Polyaromatic hydrocarbons and other paniculate constituents: woodburning, smoking, cooking, coal combustion, and coke ovens (O)	None available

(*continues*)

TABLE 2.10 (*continued*)

Pollutant/Sources[a]	Guidelines
Radon and radon progeny: diffusion through floors and basement walls from soil in contact with a residence, construction materials containing radium, untreated groundwater containing dissolved radon, combustion of natural gas used in cooking and unvented heating, radon from local soil emanation (O)	0.01 working level (ASHRAE guidelines)
Sulfur dioxide: kerosene space heaters, coal and oil fuel combustion sources (0)	80 $\mu g/m^3$ annual; 315 $\mu g/m^3$ for 24 hr (NAAQS)
Volatile organics: Cooking, smoking, room deodorizers, cleaning sprays, paints, varnishes, solvents and other organic products used in homes and offices, furnishings such as carpets and draperies, clothing, furniture, emissions from waste dumps (O)	None available

[a](O) refers to outdoor sources.
[b]American Society of Heating, Refrigerating and Air Conditioning Engineers.
[c]U.S. National Ambient Air Quality Standards.
[d]These numbers indicate the probable range for the new NAAQS for particulates of 10 μm or less in size. Based on "Recommendations for the National Ambient Air Quality Standards for Particulates—Revised Draft Paper," Strategies and Air Standard Division, Office of Air Programs, U.S. Environmental Protection Agency, Washington, DC, October 1981.
[e]National Research Council, 1982, "An Assessment of Health Risk of Seven Pesticides Used for Termite Control," National Academy Press, Washington, D.C.

Source: N. L. Nagada, H. E. Rector, and L. A. Wallace, *Project Summary Guidelines for Monitoring Indoor Air Quality*, EPA-600/S4-83-046, U.S. Environmental Protection Agency, Office of Monitoring Systems and Quality Assurance, Washington, DC, January 1984.

bus; or in the school, auditorium, indoor ice skating rink, restaurant, enclosed shopping center, commercial and public building, hospital, and nursing home.

Most urban dwellers spend as much as 80 to 90 percent of their time indoors including transportation vehicles. The primary types of indoor air quality problems are inadequate ventilation (52 percent), contamination from inside the building (17 percent), contamination from outside the building (11 percent), microbiological contamination (5 percent), contamination from building fabrics (3 percent), and unknown (12 percent).[21]

Biological Contaminants and Health Effects

Bacteria, viruses, fungi, pollens, house dust, and mite droppings are found in indoor air. Fungi, including spores and molds, multiply in the presence of increased humidity level (greater than 70 percent, some say 45 to 60 percent).[22]

Pollens, fungi, and other allergens are also brought indoors by ventilation systems, clothing, tracking, and open doors and windows. Substantial reduction in ventilation rates will tend to increase concentrations of contaminants and the probability of infection and allergy to the extent contaminants remain viable and airborne.

Sources of biological contaminants include air-conditioning systems; humidifiers; air ducts; cooling towers; grass, tree, and weed pollens; occupants; and household pets. Keep air-conditioning systems clean and empty, clean humidifiers and sanitize frequently, and minimize household dust.[23] Some unit air cleaners are effective in removing particulates but may also incubate fungi and microorganisms. Air cleaners, such as electrostatic precipitators, ionizers, or filters, are not designed to remove radon or other gases. Humidifiers and filters require scheduled cleaning or filter replacement. Prevent the accumulation of water in equipment; ensure proper drainage. Recirculating or independent steam humidification is said to be preferable to the filter-type humidifier for room humidification. Ensure that the water used is not contaminated with toxic volatile compounds.

The spread of respiratory diseases is facilitated by infectious agents and particulates in contaminated air. Overcrowding and the recirculation of contaminated air, if not adequately diluted, cleaned, or disinfected, permit continual seeding and accumulation of pathogenic microorganisms at a rate exceeding the natural die-off rate. A study at U.S. Army training centers showed a 45 percent increase in respiratory infection in energy-efficient buildings providing 1.8 ft^3 per minute per person outside air. This was compared to older barracks providing 14.4 ft^3 per minute per person outside air where the infection rate was lower.[24]

Legionnaires' disease, meningococcal meningitis, the common cold, influenza, and other respiratory diseases may be transmitted by airborne aerosols. Comprehensive studies on the health effects of long- and short-term exposure to indoor (and outdoor) contaminants are limited. Young children, the elderly, and people suffering from respiratory diseases will be the first to show signs of discomfort from indoor air contamination. Some common complaints are headache; fatigue; eye, nose, and throat irritation; fever; and dizziness. See also "Respiratory Illness Control."

Other Contaminants

Some air contaminants are are associated with noninfectious and communicable disease and are environmentally related. They may also aggravate respiratory and heart diseases and cause nausea, headache, eye, nose, and throat irritation, discomfort, and allergies. Death from chronic or acute exposure may also result. More information on the health effects of specific indoor contaminants is needed, but this does not preclude taking preventive action, particularly where information is available, such as for carbon monoxide, formaldehyde, asbestos, radon, and biological aerosols. Review of a few air contaminants and sources are given next. More detailed information can be found from public health literature.

Radon Radon is an odorless, colorless, and tasteless chemically inert radioactive gas released in the decay of radium from uranium in most soils and rocks. It is found naturally in soil gas, underground water, and outdoor air. It is 60 times more soluble [at 50°F (10°C)] than oxygen in water. Radon has a half-life of 3.8 days. Thorium, one of the uranium decay products, also releases radon. Radon and primarily its alpha-emitting decay products (especially polonium) contribute a major portion of the biologically significant dose associated with natural background radiation. The beta and gamma emissions are not significant. The alpha particles, however, adhere to dust particles that, when inhaled, can become attached to the lungs and remain to irradiate the surrounding tissue, contributing to the cause of cancer.

It has been estimated that exposure to "one working-level month" over a lifetime (assumed to be 70 years) would result in about 350 additional lung cancer deaths per million people exposed. Exposure to a radon level of 4 pCi/1* for 12 hours per day would result in an annual exposure of 0.5 working-level months.[25]† *Working level* is explained later. It has also been estimated that radon causes 13,000 cancer deaths per year.‡ Smokers are at much greater risk. In view of this, a screening program to identify problem areas and recommend mitigation alternatives to homeowners is indicated. Also indicated is radon measurement before the purchase of a new or existing home.

The hazard associated with radon is related to the concentration and time of exposure. Radon should not exceed 2 to 5 pCi/l indoors. The U.S. Environmental Protection Agency (EPA) has set a guideline limit of 4 pCi/l per 24 hours for homes (this is believed to be conservative) and a standard of 20 pCi/l in underground uranium mines. Special problems exist at uranium tailings and phosphate slag sites. The EPA estimates 20 million homes exceed the 4-pCi/l limit.§ The action level for existing dwellings in the United Kingdom is 10 pCi/l and 20 in Canada, with 2.5 in new dwellings in the United Kingdom.[27]

Major potential entry sources of indoor radon from the soil are cracks in dwelling concrete floor slabs and basement walls; pores and cracks in concrete blocks, mortar joints, and floor-wall joints; spaces behind brick veneer walls that rest on uncapped hollow-block foundations; floor drains; footing drains; and exposed soil in the bottom of drainage sumps. Radon-contaminated water, when agitated, aerated, or splashed as in dishwashing, clothes washing, showering, toilet flushing, and opened faucets or when water is heated, permits the release of radon. In addition to rock and soil underlying dwellings, construction materials (some stone masonry, concrete blocks, bricks, concrete), and some well and seepage waters and gas supplies may be the source of radium and radon. In the average dwelling, 10,000 pCi/l of radon in the water can be assumed to release

*Picocuries per liter: 4 pCi/1 = 150 Bq/m^3 (bequerels per cubic meter).

†*Source: Health Risks of Radon and Other Internally Deposited Alpha-Emitters: Bier IV*, National Academy Press, Washington, DC.

‡National Research Council estimate, 1988 (see ref. 26). Lung cancer may be causing 5000 to 10,000 lung cancer deaths per year in the United States based on an average annual dose of 2.4 rem.

§See W. W. Nazaroff and K. Teichman, "Indoor Radon," *Environ. Sci. Technol*. (June 1990): 777.

1 pCi/l to the air, but the actual indoor concentration will be dependent primarily on the amount of radon entering from the soil and on the extent to which the indoor air is diluted by outside air.[28]

The EPA is proposing a level of 200 to 500 pCi/l for drinking water, which might be increased to perhaps 1,000. A level of 20,000 pCi/l in water is considered a significant concentration. If the water is high in radon, it can be removed by filtering through a granular activated-carbon (GAC) filter, by storage until the radon has decayed, or by aeration before it enters the dwelling water system. But the carbon becomes radioactive and in decay releases gamma radiation, which can be a health hazard. Aeration appears to be the most cost-effective procedure for public water systems and a GAC filter for a private dwelling having its own well-water supply, if needed. Activated carbon concentrates the radon and decay products and, hence, poses a disposal problem. Consult with the equipment dealer, the state or local health department, and radiation protection office for the proper way to dispose of the used carbon.

Radon contamination in an existing dwelling, if it is a problem, can be reduced by preventing its entry or by removing the radon. It can be reduced by closing and caulking all cracks, joints, and openings of the structure in the basement or in contact with the ground, or in the flooring above the crawl space, and by tightly covering open drains and sumps as previously noted. Good insulation of water pipes and underflooring beneath living areas would be required in the crawl space in areas subjected to subfreezing temperatures[29] and to reduce heating or cooling costs. If this is not sufficient to reduce the indoor radon level, natural or mechanical forced-air ventilation into basement and crawl spaces can be provided, with openings to allow radon-laden air to exit. Exhaust ventilation would be needed for tightly covered sumps and footing drains. In Florida, a vent area of 1 ft^2 for each 150 ft^2 of floor area for wooden flooring or at least 1.5 ft^2 of opening for each 15 feet of linear perimeter wall for nonwooden flooring is required by the housing code. To reduce radon levels in basements and enclosed crawl spaces, bring in outside air to dilute and displace the inside air. Forced-air ventilation may be necessary; exhaust fans in living areas and combustion air for warm-air furnaces and fireplaces would depressurize the dwelling and draw in radon from the basement and should not be used. Provide outside air vent for furnace and hot-water gas heater and outside air duct for wood stove and fireplace.

In a new building, the gravel under the basement floor or floor slab could have perforated pipe embedded in it to intercept and vent radon gas above the roof using a mechanical exhaust fan. Wind turbines and natural convection are not effective. A polyethylene sheet would be placed under the basement concrete floor slab above the gravel before it is poured. The ventilation method used must not reduce the air pressure within the dwelling. Sealing major potential sources of radon entry, as already stated, and ventilation should greatly reduce radon concentrations to “safe” levels in most cases. The need for radon protection, such as built-in ventilation under the basement floor or floor slab, is best provided in new construction and required in building codes where needed. Local geological information and in-home radon measurements will give an indication of need.

Measurement for radon exposure is in working-level units, which include radon's first four daughter products that will result in MeV of potential alpha energy per liter of air. A working level of 1.0 is assumed to be equivalent to a one-month total of 200 pCi/l of radon in most indoor environments (at 50 percent equilibrium).[30] A working-level month (WLM) is equivalent to an average of 173 hour spent in a mine by a uranium worker. Exposure must not exceed 4 WLMs in any calendar year. The occupational limit for workers is 4.8 WLMs according to the 1985 recommendation of the International Commission on Radiological Protection.[31] The National Council on Radiation, Protection, and Measurement says radon level should not exceed 2 WLMs per year, or 8 pCi/l.[32] The U.S. Mine Safety and Health Administration has set a maximum exposure level of 8 pCi/l for miners.

State and local health departments or state radiation protection offices can usually provide a list of companies supplying radon testing services. Federal and state publications are available to assist the homeowner to understand the problem and take corrective action if indicated.[33] Seek professional advice if a significant problem exists.

Formaldehyde Formaldehyde, a colorless gas, may cause extreme discomfort and contact dermatitis indoors. The odor can be detected at less than 1 ppm. Exposure to 1.0 to 5.0 ppm or less can cause burning of the eyes, tearing, and general irritation of the upper respiratory passages. Levels of 0.3 to 2.7 ppm have been found to disturb sleep and to be irritating to some persons. Exposure to 10 to 20 ppm may produce coughing, tightening in the chest, a sense of pressure in the head, and palpitations. Exposures of 50 to 100 ppm and above can cause serious injury, including pulmonary edema and pneumonitis, and possibly death when above 100 ppm. Exposure to formaldehyde solutions, or urea–formaldehyde-containing resins, is a well-recognized problem.[34] However, a four-year study at the National Cancer Institute concluded that there is "little evidence that mortality from cancer is associated with formaldehyde exposure at levels experienced by workers in this study."[35]

Sources of formaldehyde are resins and glues to bond particle board and plywood, urea–formaldehyde foam insulation, permanent press fabric, embalming fluid, drugs, disinfectants, and cosmetics as well as chemicals used in pathology and anatomy laboratories and in the manufacture of automobiles, furniture, paper, and electrical equipment.[36] Formaldehyde problems are also related to materials in mobile homes and prefabricated housing. Users of formaldehyde should wear protective clothing, use protective equipment, and apply engineering controls such as hoods and separate exhaust systems. The workplace should provide a minimum ventilation of five air changes per hour. Some ameliorative measures suggested, where urea–formaldehyde is a problem, are to remove the product; seal with a specially formulated coating, vinyl covering, latex paint, or varnish after two years; and increase ventilation. Sealing will prevent the penetration of moisture, contact with urea–formaldehyde, and release of formaldehyde gas. The gas release from materials tends to decline in time. Improper formulation of urea–formaldehyde foam insulation is believed to exacerbate the problem. It is no longer used in the United States. Phenol–formaldehyde resins are generally used in outdoor materials and do not release significant quantities of formaldehyde; however, they cost more than urea–formaldehyde products.

The Occupational Safety and Health Administration (OSHA) 8-hr time-weighted average occupational exposure has been reduced from 3.0 to 1.0 ppm with a maximum short-term exposure level of 2.0 ppm for any 15-min period.[37*] The National Research Council has established a limit of 0.1 ppm for space flights. The Department of Housing and Urban Development (HUD) has set a limit of 0.4 ppm for indoor air.

Polychlorinated Biphenyls (PCBs) PCBs are considered "probable" human carcinogens based on animal studies. Although manufacture was banned in 1979, many products containing PCBs remain in use. Possible major exposure routes to PCBs are inhalation when electrical transformers and other equipment containing PCBs are ruptured or burned, breathing PCB-contaminated air or skin contact in the work environment, the ingestion of food (fish) or drinking water containing PCBs, and spills or illegal dumping of fluids containing PCBs. Fluorescent light ballasts and vinyl-coated paper are also a common source of PCBs. It is best to use caution and seek advice immediately from your health or environmental protection department should there be an actual or potential exposure to PCBs.

The Occupational Safety and Health Administration has established an airborne exposure limit of from 0.5 mg/m^3 (54 percent chlorine content) to 1 mg/m^3 (42 percent chlorine content) as an 8-hr time-weighted average (skin).[†] The National Institute of Occupational Safety and Health (NIOSH) recommends that the airborne exposure to PCBs in the workplace be 1 μg/m^3 or less.[‡] The EPA has proposed a limit of 100 μg/m^2 in areas where frequent and regular skin contact with surfaces is possible.

Tobacco Smoke Environmental tobacco smoke consists of a suspension of 0.01 to 1 μm particles leaving the burning tobacco condensate. Also produced are numerous hazardous gases including carbon monoxide. The involuntary chronic exposure to cigarette smoke, also referred to as passive smoking, is associated with an increased risk of lung cancer, according to a 1986 report of the National Academy of Science (NAS).[38] In addition, children of smoking parents have increased respiratory illnesses compared with children whose parents do not smoke; however, data on other diseases such as other cancers and cardiovascular diseases are insufficient. According to the NAS report, passive smoking causes irritation of the eyes, nose, and throat of many nonsmokers. Ventilation rates

[*] Average level is proposed to be reduced to 0.75 ppm.

[†] Potential contribution to overall exposure by the cutaneous route, including mucous membranes and eyes.

[‡] See "NIOSH, CDC, Recommendations for Occupational Safety and Health Standards, 1988," DHHS, PHS, NIOSH, CDC, *MMWR*. Supplement, August 26, 1988, pp. 23 and 24.

of up to five times higher in smoking areas are suggested to achieve acceptable indoor air quality. Office spaces should provide at least 20 ft^3/min per occupant of clean outside air where smoking is permitted and at least 5 ft^3/min per occupant in nonsmoking areas.[39] Effort should be directed to the prohibition of smoking in enclosed spaces and the discouragement of smoking.

Volatile Organic Compounds (VOCs) VOCs are a broad range of chemical compounds, with boiling points in the range of approximately 120 to 480°F (50° to 260°C) and vapor pressures greater than about 4×10^{-5} to 4×10^{-6} in. Hg.[40] Several hundred VOCs have been identified in the indoor environment.[41] The Large Buildings Study by the EPA developed a VOC sample target list that includes aliphatic hydrocarbons, halogenated hydrocarbons, and oxygenated hydrocarbons such as aldehydes, alcohols, ketones, esters, ethers, and acids.[42] Sources of VOCs in nonindustrial environments include building materials, furniture, furnishings, ventilation systems, household and consumer products, office equipment, and outdoor-related activities (e.g., traffic, neighborhood industry).

Little is known about the symptoms of overexposure to VOCs, but some are suspected of causing adverse health effects such as sensory irritation, odor, and the more complex set of symptoms of sick-building syndrome. Also researchers have found that neurotoxic effects may follow from low-level exposures to gaseous air pollutants.[43] Reactions include runny eyes and nose, high frequency of airway infections, asthmalike symptoms among nonasthmatics, along with odor or taste complaints. There is also a possible link between the increase in allergies throughout the industrialized areas of the world and exposure to elevated concentrations of VOCs.

Emission source control, gas-phase air filtration using activated-carbon filters or photocatalytic reactors, and ventilation are common ways of controlling indoor VOCs.[44] Sophisticated models have been developed to simulate the VOC emission, sorption, and transport in the built environment.[45] These models can help explain the physics of VOC transport process, and can be used to guide the building design.[46]

Other Emissions Unvented kerosene, fuel oil, and wood stove space heaters, gas cooking and heating appliances, power equipment including automobiles, and gas clothes dryers lead to the emission of particulates, in addition to hazardous gases. Portable heaters also present risks of burns, injuries, fires, and explosions. Their use should be prohibited. Unvented kerosene space heaters can emit organic compounds, in addition to nitrogen dioxide, carbon dioxide, carbon monoxide, and sulfur dioxide. The concentrations can exceed the EPA ambient air standards, particularly in small spaces and where ventilation is inadequate. Poor-quality kerosene exacerbates the problem. Gas cooking appliances are also sources of carbon dioxide, nitrogen dioxide, formaldehyde, and other organic compounds, in addition to carbon monoxide. Carbon monoxide, nitrogen oxides, and particulates from automobile exhaust in garages can produce increased and hazardous concentrations in office buildings above the garage and in public areas. Gasoline-powered ice resurfacing machinery can cause the same effect in indoor ice-skating rinks and forklifts in enclosed spaces.

The smoke from cooking and heating with open fires in houses in some underdeveloped countries is the cause of serious respiratory illness in infants. Pregnant women exposed to the smoke produce lower-birthweight children.[47]

Thermal and Moisture Requirements

Good ventilation requires that the air contain a suitable amount of moisture and that it be in gentle motion, cool, and free from offensive body and other odors, poisonous and offensive fumes, and large amounts of dust. Comfort zones for certain conditions of temperature, humidity, and air movement are given by the American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE).[48] Air movement, radiant heat, the individual, and the tasks being performed must also be taken into consideration.

There is no one temperature and humidity at which everyone is comfortable. People's sensations, health, sex, activity, and age all enter into the comfort standard. McNall[49] recommends a temperature range between 73 and 77°F (23 and 25°C) and humidity between 20 and 60 percent for lightly clothed adults engaging in sedentary activities in residences. Lubart[50] suggests a comfort level within the range of 68°F (20°C) at inside relative humidity of 50 percent to 76°F (24°C) with 10 percent relative humidity. The EPA recommends a relative humidity of 30 to 50 percent for homes.[51] Indoor relative humidity of 60 percent or higher would cause excessive condensation and greater mildew, corrosion, and decay. Excessive moisture can cause condensation and increasing deterioration of building materials. Humidities above 70 percent promote germination and growth of fungal spores. Ordinarily, however, only temperature and ventilation control is used in the home, with no attempt made to measure or control the relative humidity. Humidity control becomes more important with reduced ventilation because the products of respiratory and metabolic processes and certain indoor operations and activities contribute moisture vapor. In a confined space, this can lead to the accumulation of contaminants and moisture and discomfort or illness.

Ventilation

Indoor air should be free of objectionable odors, unhealthy levels of microorganisms, allergens, and chemical contaminants. The design of a ventilation system should avoid uncomfortable drafts and large temperature variations. National, state,[52] and local building and energy conservation codes specify ventilation requirements for various space uses and should be consulted. It has been proposed that the generally accepted minimum supply of fresh air per occupant be 15 or 20 ft^3/min.[53] Much higher fresh air supply is needed in rooms where smoking is permitted or where other polluting activities are permitted. The OSHA requirements must be met in the workplace. In true air conditioning, air is treated to simultaneously control its temperature, humidity, cleanliness, and distribution to meet requirements of the conditioned space. Room air inlets and returns should be arranged to ensure proper air mixing and ventilation of the space and to avoid drafts.

The tendency to reduce air infiltration and fresh air makeup in ventilation has increased the buildup of air contamination, with resultant occupant complaints. To alleviate the problem, minimum ventilation standards, including fresh air intakes, have been established or proposed in building codes and other publications.[53] In addition, the use of certain indoor products such as urea–formaldehyde insulation and unvented kerosene space heaters has been banned in some jurisdictions. However, owner- or occupant-provided equipment, materials, and furnishings not under regulatory control and ambient air quality may nevertheless contribute to indoor air pollution. Ventilation may be provided by natural or mechanical means. Investigation of an indoor air pollution problem could well start with carbon dioxide tests and interrogation of management, employees, and custodial and union people. If carbon dioxide concentrations are below 600 ppm, with comfortable temperature and humidity levels, complaints about air quality should be minimal.

Natural Ventilation A minimum of one or two air changes per hour can often be secured by normal traffic and leakage through walls, floors, and ceilings and through or around doors and windows, but previously mentioned energy conservation measures may reduce air infiltration and air change by 50 percent or more. Under ordinary circumstances, adequate ventilation can be obtained in residences by natural means with properly designed windows. Openable windows, louvers, or doors are needed to ventilate and keep attics, basement rooms, pipe spaces, and cellars relatively dry. The tops of windows should extend as close to the ceiling as possible, with consideration to roof overhang, to permit a greater portion of the room to be exposed to controlled sunlight. The minimum total window or skylight area, measured between stops, for a habitable room should be at least 8 percent of the floor area and the openable area at least 45 percent of the window or skylight area.[54] The ventilation of modern buildings is usually dependent on mechanical air conditioning and air recirculation, including controlled fresh air intake. Some examples and design criteria are discussed next.

Schools Separate venting of each classroom to the outside is preferred. Good standards specify that the mechanical ventilating system provide a minimum air change of 15 to 20 ft^3/min per student to remove carbon monoxide and odors, without drafts. The air movement should not exceed 25 ft/min, and the vertical temperature gradient should not vary more than 5°F (3°C) in the space within 5 feet of the floor and 2 feet or more from exterior walls. Temperature should be automatically controlled.

Public Areas In recreation halls, theaters, churches, meeting rooms, and other places of temporary assembly, a system of mechanical or induced ventilation is usually needed to meet the requirement of at least 15 ft^3 of clean air per minute per person. Any system of ventilation used should prevent short circuiting, uncomfortable drafts, and the buildup of unhealthy levels of air contaminants. Approximately one-third of the recirculated air should be clean outside air.

Correctional Institutions Where dependence is on natural ventilation, windows or other openings should provide an area of at least 12.5 percent of the floor space of the sleeping, living, educational, and work areas and be located to provide cross-ventilation. Gyms and swimming pools require special temperature, humidity, and ventilation controls. If dependence is on mechanical ventilation, 15 to 20 ft^3/min per person is recommended. Where air is recirculated, approximately one-third should be fresh, clean outside air.[55]

Toilets and Bathrooms Bathroom and toilet room ventilation is usually accomplished by means of windows or ventilating ducts. The common specification for natural ventilation is that the window or skylight area be at least 8 or 10 percent of the floor area and not less than 3 ft^3, of which 45 percent is openable. For gravity exhaust ventilation, vents or ducts at least 72 $in.^2$ in area per water closet or urinal and a minimum of 2 ft^3/min of fresh air per square foot of floor area should be provided. A system of mechanical exhaust ventilation providing at least five air changes per hour of the air volume of the bathroom or toilet room during hours of probable use is usually specified for ventilation where windows, ducts, or vents are not relied on or are not available for ventilation. ASHRAE[53] recommends 50 ft^3/min per water closet and per urinal for a public restroom. Exhaust fans activated by the opening and closing of doors or by a light switch do not provide satisfactory ventilation. The recirculation of air supplied to toilets, lavatories, toilet rooms, bathrooms, and restrooms (also kitchens, laboratories, and garages) is generally not permitted.[56]

Air Change Measurement Air in an enclosed space normally diffuses out and outdoor air filters in at a rate dependent on the tightness of the space or building and wind direction and velocity. The air change can be determined by dividing the volume of air entering an enclosed space or room by the volume of the space or room. For example, if 100 ft^3/min enters a room having a volume of 1,000 ft^3 occupied by five people, there would be six air changes per hour ($100 \times 60 \div 1{,}000$) and 20 ft^3/min per occupant.

The air change may be measured by use of tracers. Desirable qualities of a tracer gas are detectability, nonreactivity, nontoxicity, neutral buoyancy, relatively low concentration in ambient air, and low cost.[57] The commonly used tracers include nitrous oxide (N_2O), carbon dioxide (CO_2), helium (He), and sulfur hexafluoride (SF_6). Several tracer gas measurement procedures exist, including an American Society for Testing and Materials (ASTM) standard.[58] In the measurement, the tracer is released into the building in a specific manner, and the concentration of the tracer within the building is monitored and related to the building's air change rate. Standardization of devices is necessary.

Monitoring The monitoring and measurement of the quality of indoor air can be accomplished by modification, as needed, of equipment used to sample ambient air and occupational exposure and by adapting laboratory equipment and procedures. Passive measuring devices for carbon monoxide, radon, formaldehyde, and asbestos, although not accurate, are acceptable. The Anderson impactor sampler may be used to collect indoor airborne fungi supplemented by plate incubation for colony count and identification. Psychrometers for measuring temperature and humidity and smoke tubes for determining air movement are also generally used. Samplers for volatile organic compounds and continuous samplers are also available. Standardized methods for the determination of air pollutants in indoor air are listed in Table 2.11.

Respiratory Illness Control

The NIOSH suggests seven steps to minimize respiratory illness:

1. Promptly and permanently repair all external and internal leaks in the heating, ventilation, and air-conditioning system (HVAC).
2. Maintain relative humidity below 70 percent in occupied spaces and in low-air-velocity plenums. (At a higher level of humidity, the germination and proliferation of fungal spores are enhanced.)
3. Prevent the accumulation of stagnant water in cooling-deck coils of air-handling units through proper inclination and continuous drainage of drain pans.
4. Use steam rather than recirculated water as a water source for humidifiers in HVAC systems; however, such steam sources should not be contaminated with volatile amines.
5. Replace filters in air-handling units at regular intervals. (These should have at least a moderate efficiency rating—50 percent or more—as measured by the atmospheric-dust spot test and should be of the extended-surface type; prefilters (e.g., roll type) should be used before passage over the higher efficiency filters.)
6. Discard, rather than disinfect carpets, upholstery, ceiling tiles, and other porous furnishings that are grossly contaminated.
7. Provide outdoor air into ventilation systems at minimum rates per occupant of at least 20 ft^3/min in areas where occupants are smoking and at least 5 ft^3/min in nonsmoking areas. (ASHRAE Recommended Standard 62 specifies a minimum of 15 or 20 ft^3/min per person.[53])

These activities should be considered in ongoing preventive maintenance programs.[59]

The usual method of air purification by washing and filtration is relatively inefficient in removing bacteria or viruses from used air, although it can be effective in removing dust and other airborne particles. Electrostatic air precipitator units and special air filters effectively reduce indoor particulates. See also *Biological Contaminants and Health Effects*, this chapter. Central vacuum cleaning

TABLE 2.11 Method for Determination of Air Pollutants in Indoor Air

Method Number	Description	Types of Compounds Determined
IP-1A	Stainless steel canister	Volatile organic compounds (VOCs) (e.g., aromatic hydrocarbons, chlorinated hydrocarbons) having boiling points in the range of 176–392°F (80–200°C)
IP-1B	Solid adsorbent tubes	—
IP-2A	XAD-4 (styrene-divinylbenzene) sorbent tube	Nicotine (gaseous and particulate)
IP-2B	Treated filter cassette	—
IP-3A	Nondispersive infrared (NDIR)	Carbon monoxide and/or carbon dioxide
IP-3B	Gas filter correlation (GFC)	—
IP-3C	Electrochemical oxidation	—
IP-4A	Perfluorocarbon tracer (PTF)	Air exchange rate
IP-4B	Tracer gas	—
IP-5A	Continuous luminox monitor	Nitrogen oxides
IP-5B	Palmes diffusion tube	—
IP-5C	Passive sampling device	—
IP-6A	Solid adsorbent cartridge	Formaldehyde (CH_2O) and other aldehydes/ketones
IP-6B	Continuous colorimetric analyzer	—
IP-6C	Passive sampling device	—
IP-7	Medium-volume polyurethane foam (PUF)/XAD-2 sampler	Polynuclear aromatic hydrocarbons
IP-8	Low-volume PUF sampler followed by gas chromatography/electron capture detection	Pesticides (e.g., organochlorine, organophosphorus, urea, pyrethrin, carbamate, and triazine)
IP-9	Annular denuder system	Acid gases/aerosols/particles (e.g., nitrates, sulfates, and ammonia)
IP-10A	Size-specific impaction	Particulate matter
IP-10B	Continuous particulate monitor	—

Source: W. T. Winberry et al., "EPA Project Summary Compendium of Methods for the Determination of Air Pollutants in Indoor Air," EPA/600/S4–90/010, U.S. Environmental Protection Agency, Atmospheric Research and Exposure Assessment Laboratory, Research Triangle Park, NC, May 1990.

systems are very effective for the removal of dust and other particulates without resuspending the finer particles indoors.

Venting of Heating Units

Proper venting is the removal of all the products of combustion through a designated channel or flue to the outside air with maximum efficiency and safety.

Gravity-type venting relies largely on having the vent gases inside the vent hotter (thus lighter) than the surrounding air. The hotter the vent gases, the lighter they are and the greater their movement up through the vent. Thus, in order to keep the vent gases hot so that they may work at maximum efficiency, proper installation and insulation are necessary.

Factors that prevent proper venting are abrupt turns; downhill runs; common vents to small, uninsulated vent pipes; conditions that cause backdrafts; obstructions in the flue or chimney to which a furnace, heater, or stove is connected such as birds nests, soot and debris, broken mortar and chimney lining, and old rags; and unlined masonry chimneys. Stained and loose paper or falling plaster around a chimney is due to poor construction. A masonry chimney will absorb a great deal of the heat given off by the vent gases, thus causing the temperature in the chimney to fall below the dew point. The high moisture in vent gases condenses inside the chimney, forming sulfuric acid. This acid attacks the lime in the mortar, leaching it out and creating leaks and eventual destruction of the chimney. Therefore, it is necessary to line a masonry chimney with an insulating pipe, preferably terracotta flue lining.

Figure 2.16 shows chimney conditions apt to result in backdrafts. The flue or vent should extend high enough above the building or other neighboring obstructions so that the wind from any direction will not strike the flue or vent from an angle above the horizontal. Unless the obstruction is within 30 feet or is unusually large, a flue or vent extended at least 3 feet above flat roofs or 2 feet above the highest part of wall parapets and peaked roof ridges will be reasonably free from downdrafts.

To ensure proper venting as well as proper combustion, sufficient amounts of fresh air are required, as shown in Figure 2.16. An opening of 100 to 200 in.^{2} will usually provide sufficient fresh air under ordinary household conditions; this opening is needed to float the flue gases upward and ensure proper combustion in the fire box. Proper venting and an adequate supply of fresh air are also necessary for the prevention of carbon monoxide poisoning or asphyxiation.

The connection (breeching) between the furnace or stove and chimney should be tight fitting and slope up to the chimney at least 1/4 in./ft. Chimneys are usually constructed of masonry with a clay tile flue liner or of prefabricated metal with concentric walls with air space or insulation in between and should be Underwriter's Laboratories approved. All furnaces and stoves should be equipped with a draft hood, either in the breeching or built into the furnace or stove, as required, for proper draft. See Figure 2.16.

Before making any vent installations or installing any gas- or oil-fired appliances, consult the building code and the local gas or utility company. Standards for chimneys, fireplaces, and venting systems, including heating appliances and incinerators, are given by the National Fire Protection Association,[60] building codes, and other publications.

Portable kerosene heaters are a fire hazard and, since they are not vented, emit dangerous gases into a room. Their sale and use should be prohibited. The

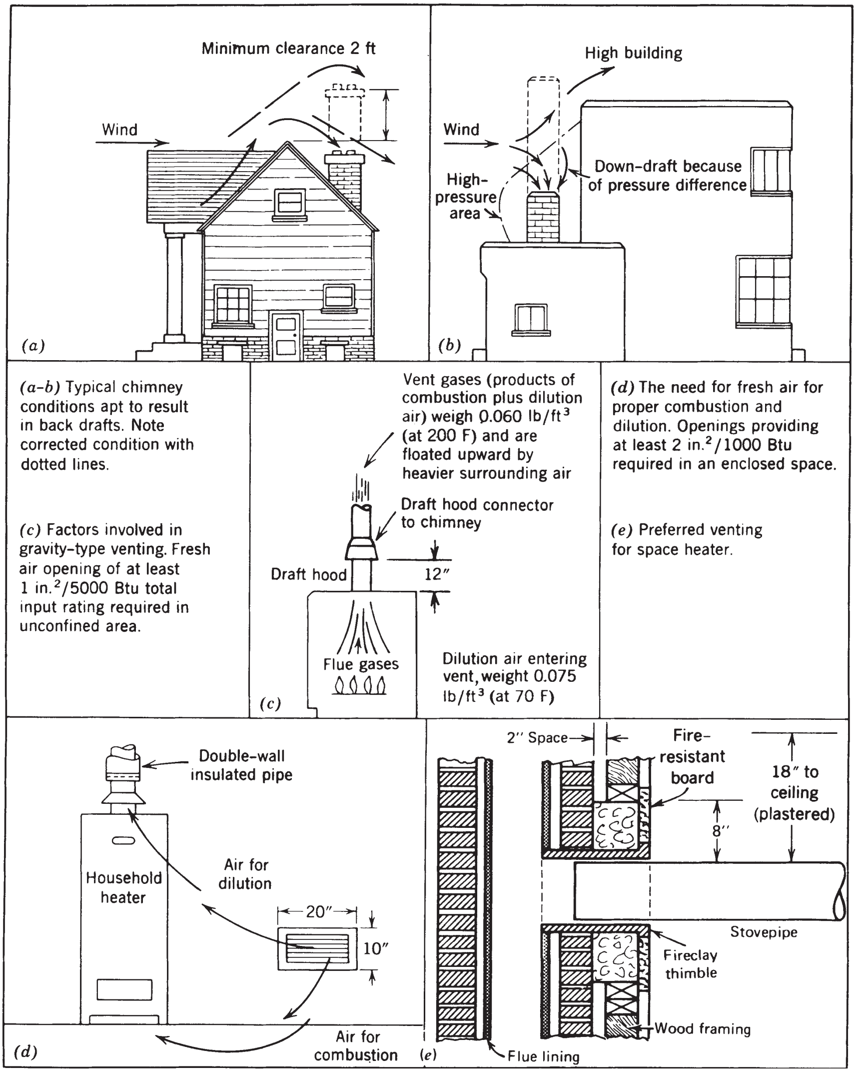


FIGURE 2.16 Some venting details. (Drawings are typical and not necessarily in full accordance with any code.) *See state and local building and fire prevention codes*.

concentrations of carbon dioxide, nitrogen dioxide, and sulfur dioxide emitted into a room usually greatly exceed ambient air standards.

Wood stoves require special fire protection and venting. See Cooperative Extension Service recommendations and local building code requirements.

Chimneys, vents, and ducts can become blocked by bird nests, squirrel nests, soot, grease, leaves, and other debris. Such conditions can develop during the nonheating season, which will prevent proper venting of the heating unit. Dangerous levels of carbon monoxide can accumulate if chimneys, vents, and ducts are not kept clear.

MOBILE HOME PARKS

Mobile homes are defined as "transportable, single-family dwelling units suitable for year-round occupancy and containing the same water supply, waste disposal, and electrical conveniences as immobile housing." 61 A mobile home is also defined as a "manufactured relocatable living unit."[62] Mobile homes produced since 1954 are 10, 12, and 14 feet wide and up to 60 or 70 feet long. Wider units are assembled at the home site by combining sections to form double- and triple-wide units.

The Bureau of the Census identified 5.267 million mobile home units in the United States in 1987 as year-round housing occupied by over 13 million residents. There were 3.9 million homes in 1980 and 2.1 million in 1970. In 1987, 99 percent had complete plumbing, 46 percent were connected to a public sewer, 68 percent used public water, 81 percent had central heating, and 34 percent had central air conditioning. Annual sales dropped to 212,000 units in 1975 and increased to 300,000 units in 1977. Between 1980 and 1984, 1,129,000 units were added. Sales peaked in 1973 with 625,000 units. The typical mobile home is 14 feet wide and 65 feet long. Many are double units; some are triple. In 1974, about one-third of the buyers were married couples under 35 years of age and one-third were retired and over 65. In 1987, about 86 percent of the mobile homes were owner occupied. Modern mobile home parks may have all utilities, swimming pool and other recreational facilities, laundry, community buildings, paved streets with curbs or gutters, trees and landscaping, and patio slab, and may look like an established housing development. Lots are typically 5000 ft^2. Lots larger than 5000 ft^2 permit more flexibility in exposure and siting the mobile home. *It must be kept in mind that, unless the plot is owned by the mobile home owner, continued occupancy is dependent on the desire and future plans of the park owner*; hence, a mobile home park cannot be considered a permanent realty subdivision. Because of the risk of property sale and resultant hardships, consideration has been given to protective laws, cooperative ownership, and contractual arrangements.

The parks established have all of the potential environmental sanitation and safety problems of a small community. Because of this, standards have been prepared to guide mobile home manufacturers, operators, owners, and regulatory agencies to help promote safe and sound manufacture, site preparation, and sanitary practices. Compliance with these standards is facilitated by reference to the pertinent chapters in this text; to the guides cited in the footnotes, which include recommended ordinances; and to the guides published by HUD.63 − 65*

*The American National Standards Institute, National Fire Protection Association, and Building Officials & Code Administrators International also have suggested standards for adoption by local governments.

Other precautions include stable stands, tiedowns to minimize overturning during windstorms, smoke detectors and fire extinguishers in homes, with two exits from each unit, a minimum spacing of 10 feet, minimum site size, protection of water connections against freezing, sufficient electric power for all electrical equipment including approved-type inside wiring, and interior materials that do not cause the release of hazardous pollutants.

INSTITUTION SANITATION

An institution is a complete property with building, facilities, and services having a social, education, or religious purpose. This includes schools, colleges and universities, hospitals, nursing homes, homes for the aged, day-care centers, jails and prisons, reformatories, and the various types of federal, state, city, and county welfare, mental, and detention homes or facilities.

Institutions as Small Communities

Most institutions are communities unto themselves. They have certain basic characteristics in common that require careful planning, design, construction, operation, and maintenance. These include site selection, planning, and development for the proposed use, including subsoil investigation, accessibility, and proximity to sources of noise and air pollution; a safe, adequate, and suitable water supply for fire protection as well as for institutional use; sewers and a wastewater disposal system; roads and a stormwater drainage system; facilities for the storage, collection, and disposal of all solid wastes generated by the institution; boilers and incinerators with equipment and devices to control air pollution; food preparation and service facilities; fire-resistant housing and facilities for the resident population; laundry facilities; and insect, rodent, and noxious weed control. In addition, depending on the particular institution, they might have recreational facilities, such as a swimming pool or bathing beach. A hospital or educational institution often has its own laundry. A state training school or institution might have a dairy farm or produce farm, pasteurization plant, industrial operation, and food-processing plant. The environmental, health, engineering, and sanitation concerns at all these places are, in many instances, quite extensive and complex.

The possibilities for the transmission of illnesses associated with air, water, food, and contact are increased at institutions. Scrupulous cleanliness, hygiene (handwashing), and sanitation are essential at all times. Certain institution advisory committees can be helpful. These might include radiation safety, infection and biohazard control, emergency preparedness, occupational and environmental health and safety, laboratory safety, animal care and research, diving safety, and accident prevention. Institutions provide an ideal environment for the spread of communicable diseases. They require careful surveillance and preventive measures adapted to the particular use and population. The reader is referred to the appropriate subject matter throughout this text for details.

The material that follows will highlight environmental, health, engineering, and sanitation factors at various types of institutions. The institutions have many environmental factors in common.

Hospitals and Nursing Homes

Hospital-acquired, or nosocomial, infections result in additional morbidity, mortality, and costs pointing to the need for greater infection surveillance and control.[66] The majority of nosocomial infections are endemic. They may affect not only the patient who develops the infection but also other patients, the hospital staff, and the community as well. Data accumulated over past years indicate that under certain conditions as much as half of all nosocomial infections may be preventable.[67] Most infections are probably medically or nursing related.

The hospital is expected to provide an environment that will expedite the recovery and speedy release of the patient. Carelessness can introduce contaminants and infections that delay recovery and may overburden the weakened patient, thereby endangering the patient's survival. It has been estimated that 1.5 million patients, out of some 300 million, or about 5 percent, incur infections in hospitals annually.[68]

The hospital-acquired infection rate in 1983 was highest in large teaching hospitals and lowest in nonteaching hospitals, 41.2 and 24.4 per 1000 cases discharged, respectively. Another study found a nosocomial infection rate between 5 and 6 percent. The infection rate was highest on the surgical service, followed generally by medicine, gynecology, and obstetrics. The urinary tract was the most frequent site of infection, followed by surgical wounds and lower respiratory tract, accounting for 70 percent of all infections. *Escherichia coli, Staphylococcus aureus* (coagulase negative), enterococci, and *Pseudomonas aeruginosa* were the most frequently reported pathogens—also *Klebsiella* spp., *Enterobacter* spp., *Proteus* spp., and *Candida* spp.[69] The experience was very similar in 1984.[70]

It is unlikely that the air (or surfaces) in an operating room will be sterile in the strict sense of the word, but it must be maintained at an extremely low bacterial level. Ultraviolet radiation has great potential for reducing the microbial flora of the air, where the patient may be especially vulnerable, but to be effective, particles carrying organisms must make direct contact with the radiation. Chemicals used include aerosols of triethylene glycol, lactic acid, resorcinol, and hypochlorous acid.

Numerous reasons have been offered for hospital-acquired infections: an increase in the number of older patients with chronic diseases; an increase in high-risk patients and surgical procedures such as open-heart surgery and organ transplants; innovations in diagnostic and therapeutic procedures, including widespread use of antibiotics, indwelling catheters, and artificial kidneys; inadequate disinfection or sterilization of respiratory therapy and other equipment; prevalence of *S. aureus* and group A streptococci; and the increasing identification of gram-negative organisms such as *P. aeruginosa*, proteus, *E. Klebsiella*, and *A. aerogenes*; as well as the gram-positive, toxin-producing *Clostridium dificile*.[71–73]

Basic to the prevention of nosocomial infections are hygienic medical, nursing, and staff practices, including frequent handwashing; equipment sterilization; food, water, plumbing, air, laundering, linen handling, and housekeeping sanitation, including floor cleaning to suppress dust; the prevention of overcrowding, minimization of movement of patients and hospital personnel from point to point; and avoidance of antibiotics use when possible. A major control mechanism is the establishment of a representative infection control committee, which should include appointment of a full-time environmental control officer with comprehensive responsibility and authority to coordinate and ensure that medical, nursing, housekeeping, maintenance, and ancillary staffs are following good practices and procedures, including nosocomial infection surveillance and control, proper waste handling, food sanitation, safety including radiation, and occupational health protection. This officer would also have the responsibility of being the liaison between the institution and federal, state, and local regulatory agencies, including fire, health, building, and environmental protection.

The duties of the environmental control officer would include assurance of "satisfactory" responses to all of the items listed in Figure 2.17. Since the survey form is merely suggestive of the broad scope of each subject and far from complete, it is apparent that the environmental control officer must be broadly trained through education and experience to recognize and appreciate the full impact of conditions observed and their possible risk to patients, staff, visitors, and community and the promptness with which unsatisfactory conditions must be corrected. Suggested preparation would include a graduate degree from a recognized institution in environmental health science or a related degree with an internship or training in institutional health management, administrative techniques, and environmental control.

A major concern in hospitals, nursing homes, and other institutions is fire safety. Basic elements include construction, detection and alarm, containment, extinguishment, evacuation, and staff training. The Department of Health and Human Services has a survey report form[74] that is used in Medicare–Medicaid and state programs. The survey report is comprehensive and applicable to a hospital, skilled nursing facility, intermediate-care facility, and facilities with 15 beds or less.

Construction is required to comply with state and local building codes, which usually include extensive fire protection regulations. Requirements relate to such factors as construction materials, exits and exit access, corridors, protection and enclosure of vertical openings, protection of hazardous areas, smoke detection, automatic sprinkler systems, and much more.

Special precautions must be taken with kidney dialysis machines. Water for kidney dialysis machines must be very soft, low in minerals and dissolved solids, and of good physical and microbiological quality. Distillation, deionization or reverse-osmosis treatment, and granular activated-carbon treatment are usually required, as ordinary potable water may be toxic for the dialysis patient. Chloramines in water are harmful to the patient. Chloramines pass through semipermeable membranes.[75] Synthetic resins in softening ion exchange

Name ____________ Address ____________ T.V.C. ________
Operator ____________ Persons interviewed ____________
Inst. No. ______ No. Cert. Beds ______ Inspected by ____________ Date ______

Item	S	U
Structure and grounds		
1. Location		
2. Buildings and grounds		
3. Accessible by emergency vehicles		
4. Service entrances		
5. Elevators		
Water supply		
6. Supply and pressure, hospital and fire		
7. Treatment, physical, biological, chemicals		
8. Quality—hospital, protect, and surveillance; incl. water carafes		
9. Quality—special, medical, and lab.		
10. Hot water		
Liquid and solid wastes		
11. Sewage piping and disposal		
12. Biological wastes collection, storage, disposal		
13. Solid wastes collection, storage, disposal; hazardous per RCRA		
Plumbing		
14. Toilets, lavatories, tubs, showers, sinks		
15. Cross-connection and backflow control		
16. Drinking fountains		
Emergency power and light		
17. Power to vital services		
18. Lighting to vital areas		
Ventilation, heat, and air conditioning		
19. Air flows, rates, pressure, differential		
20. Air filtration		
21. Air temperature		
22. Air humidity		
23. Intake and exhaust locations		
Laundry		
24. Soiled linen handling and transportation		
25. Laundering		
26. Clean linen handling and transportation		
Food protection and quality		
27. Food sources		
28. Refrigerated food storage		
29. Dry food storage		
30. Food preparation		
31. Food serving, hot and cold		
32. HACCP plan		
33. Food equipment and utensils		
34. Ice making and handling		
35. Vending machines		
Insect and rodent control		
36. Physical controls		
37. Chemical controls		
Infant formula and nursery		
38. Equipment, supplies, technicians, records, practices, isolation		
39. Approved source and handling		
Space provisions		
40. Patient rooms		
41. Isolation rooms		
42. Bath and toilet rooms		
43. Nursing service areas		
44. Other services—rooms, spaces		
45. Central and general storage		
Fire safety		
46. Fire-resistive construction		
47. Interior finishes		
48. Smoke and fire doors, open		
49. Fire-resistant enclosures—chutes, shafts, stairs, kitchen, boiler, and incinerator rooms		
50. Exit doors, access, stair, hall, signs		
51. Flame-retardant fabrics, drapes		
52. Flammable liquids		
53. Flammable anesthetics		
54. Oxygen and nitrous oxides		
55. Fire hydrants, hoses, standpipes		
56. Fire extinguishers, portable		
57. Automatic sprinklers in chutes, soiled linen, trash, and storage rooms		
58. Kitchen hoods and grease removal		
59. Fire-detection systems in boiler, kitchen, labs, laundry, pantry, garage		
60. Fire-alarm system, internal		
61. Alarms connected to fire department or station		
62. Electrical hazards controlled		
63. Anesthesia areas—electrical safeguards		
64. No smoking—signs, supervision		
65. Fire plans—posting, drills, training		
Accident safety		
66. Handrails and grab bars—corridors, stairs, ramps, toilets, bath		
67. No obstacles—corridors, ramps, stairs		
68. Floors—nonslip and nontrip		

FIGURE 2.17 Hospital environmental health survey form. Use federal or state form where available.

Item	S	U	Item	S	U
69. Burn protection—heaters, hot water			*Supporting services*		
70. Patient furnishings and equipment			81. Housekeeping		
71. Electrical safety hazards			82. Plant maintenance		
72. Accident reporting, records			*Refrigeration (nondietary)*		
73. Lighting levels			83. Pharmaceutical and blood storage		
Infection Control			84. Morgue		
74. Infection control committee			*Pools (therapy or swimming)*		
75. Sterilization facilities			85. Recirculation and filtration		
76. Sterilization—procedure, surveillance, records			86. Disinfection		
			Radiations and hazardous wastes		
77. Sterilization of medical apparatus			87. Diagnostic X-ray units		
78. Disinfection of patient-used articles			88. Therapeutic X-ray units		
79. Cleanliness of operating, delivery, isolation rooms, and nursery			89. Teletherapy units		
			90. Radioact. materials—storage, use		
80. Disinfection of inhalation therapy apparatus			91. Microwave ovens		

NOTE:
S means satisfactory equipment, construction, operation, maintenance.
U means unsatisfactory.
Contract Services ________ Housekeeping ________ Laundry ________ Dietary ________ Other ________ Give name.

FIGURE 2.17 (*continued*)

units are damaged by dioxide, chlorites, chlorates, and chlorine and, hence, are unsuitable for this purpose. Granular activated-carbon and reverse-osmosis treatment remove chlorite and free chlorine, but the removal of chlorine dioxide and chlorate is unknown.[76] Peracetic acid at 700 ppm for the cleaning and disinfection of reverse-osmosis equipment and system is reported as a promising, nontoxic substitute for certain water treatment systems.[77] The physician involved should determine the water quality standards for water used in kidney dialysis. European Pharmacopeia specifies that the water must be free of pyrogens and made exclusively by distillation for hospital use.

Wash-water temperatures in the hospital laundry have been studied by numerous investigators. A minimum temperature of 160° to 167°F (71°–75°C) for 25 minutes is generally specified. It appears that the temperature can be reduced to 140°F (60°C) for lightly soiled hospital linens from nonisolation areas, but more investigation is needed to ensure that this temperature is adequate for the laundering of *all* linens, including isolation linens. It appears that dilution, the use of bleach, and the drying cycle are more important than water temperature in the laundering of hospital linens. Cycles at 170°F (77°C) and 72°F (22°C) were compared.[78] In any case, proper handling of laundered linen to prevent cross-contamination and contamination in handling is essential.[79]

Extensive infection surveillance and control program guidelines have been published by the Joint Commission on Accreditation of Hospitals and others.[80–82] Guidelines for protecting health care workers have also been prepared.[83]

Health care is provided in hospitals and nursing homes. A hospital usually provides acute care, including diagnosis and treatment. A nursing home provides long-term care, with limited rehabilitation. An adult home or old-age home provides room and board but not health care. The nursing home levels of care vary from “heavy care” to “light care” and may bridge the gap between the hospital and adult home.

A great deal of special emphasis has been placed on hospital and nursing home construction, equipment, and inspection or survey of operations and services. Federal and state standards must be met with respect to fitness and adequacy of the premises, equipment, personnel, rules and bylaws, standards of medical care, and hospital services. Plans for new structures and for additions or modifications of existing facilities are also reviewed for compliance with federal and state requirements to help ensure the best possible facilities for medical care.

The survey or inspection of hospitals and nursing homes takes into consideration the administration, fire prevention, medical, nursing, environmental sanitation, nutrition, accident prevention and safety, operational, and related matters. A proper initial survey of these diverse matters calls for a professionally trained team consisting of a physician, sanitarian, engineer, nurse, nutritionist, and hospital administrator. Figures 2.17 and 2.18 show suggested hospital and nursing home environmental survey items. Of course, they can be greatly amplified.[74] The proper interpretation of the environmental health survey form items requires a well-rounded educational background and specialized training, as previously noted, including thorough knowledge of applicable federal and state laws, with support from consultants when indicated. It is good procedure to coordinate the inspection program with the work of other agencies and to develop continuing liaison with the health department, county medical society, accreditation groups, local nursing home association, local hospitals, fire departments, building departments, social welfare services, and others involved. This can strengthen compliance and avoid embarrassment resulting from conflicting recommendations.

Special attention should be given to non-fire-resistive hospitals and nursing homes, if permitted. Until such places can be replaced with fire-resistive structures, they should be protected against possible fire. This would include automatic sprinklers and alarms; horizontal and vertical fire stopping of partitions; enclosure and protection of the boiler room; outside fire escapes; fire doors in passageways, vertical openings, and stairways; fire detectors, smoke detectors, and fire extinguishers; a fire evacuation plan and drills; 24-hour surveillance; and the housing of nonambulatory patients on the ground floor. These comments are also generally applicable to other health care facilities. Building and fire protection codes must be followed.

Surveillance by official agencies, voluntary organizations, and individuals should ensure that fire protection, safety, and medical care are not compromised in spite of increased costs or lack of funds.

Hospital and Related Wastes

Hospital wastes may include pathological, infectious, hazardous chemical, and radioactive wastes as well as cultures and stocks, blood and blood products, animal carcasses, pharmaceutical wastes, pressurized containers, batteries, plastics,

Name ______ **Address** ______ **T.V.C.** ______
Operator ______ **Person interviewed** ______
Capacity ____ **Bed patients** ____ **Amb. patients** ____ **Personnel: RN** ____ **Pract. nurses** ____ **Other** ____

Housing and fire safety	Yes	No	CM
1. Building, floors, stairs structurally sound			
2. Rooms, kitchen, cellar, attic, yard clean			
3. Rooms, including kitchen, well lighted			
4. Rooms, including kitchen, well ventilated			
5. Rooms, basement, closets free of debris			
6. Beds 4-ft apart and 1 ft from walls			
7. Windows, doors, openings screened			
8. Free of rat and vermin infestation			
9. Bedding clean, storage satisfactory			
10. Heating suitable and adequate			
11. Fire-resistive construction			
12. Smoke and fire doors provided			
13. Boiler rm. and incin. fire-resistant			
14. Exit door signs posted			
15. Flame-retard. drapes, fabrics			
16. Fire alarm system connec. to fire dept.			
17. Fire plans posted; drills			
18. Flammables secured			
19. Elec. hazards controlled			
Water supply			
20. Water supply approved; fire hydrant within 500 ft			
21. Adequate supply hot and cold			
22. Sanitary drinking fountain or paper cups			
23. Cross-connection and interconnection prohibited			
24. Backflow preventers on WC, flushers—bedpan			
Sewage and toilet facilities			
25. Sewage disposal satisfactory			
26. Waterclosets—1 for 8 beds			
27. Washbasins—1 for 8 beds			
28. Shower or tub—1 for 12 beds			

	Yes	No	CM
29. Slop sink—each floor, and 1 for 24 beds			
30. Bedpan sterilizer—1 for 24 bed patients			
31. Toilet room on each floor			
32. Separate toilet and shower for help convenient, washbasin with sanitary towels			
Food protection and quality			
33. Equipment and facilities sanitary and adequate for food storage, preparation, and serving			
34. Dishes, trays, utensils clean and disinfected			
35. Foodhandlers clean, have lockers			
36. Refrigeration adequate			
37. Food service, hot and cold. HACCP plan			
38. Pasteurized milk served in indiv. carton			
39. Refuse storage and disposal satisfactory			
40. No poisons stored in kitchen			
41. Menu planned week in advance			
42. Meals nutritionally balanced			
43. Food service attractive			
44. Leftovers used promptly			
Medical and nursing service			
45. Mental and TB cases prohibited			
46. Patient accidents and CD reported			
47. RN always in attendance			
48. Adequate competent help available			
49. Employees free of CD			
50. Helpless patients get special attention			
51. Records kept giving: (*a*) Name of MD for patient (*b*) Name and address of patient, sex, color, age, marital status, occupation, place of birth, admission, diagnosis, discharge, relative			

FIGURE 2.18 Nursing home inspection form. Use federal or state form where available.

	Yes	No	CM		Yes	No	CM
(*c*) Clinical history and treatment, medications, signed MD's orders				53. Drugs properly labeled in cabinet			
(*d*) Qualification of nurses and attendants				54. Adequate dressings and supplies			
(*e*) Narcotics on hand, dispensed				55. Recreation facilities for patients			
52. Narcotics stored in locked cabinet				56. Occupational therapy 57. Infectious wastes segregated			

Explain "No" items, use back NOTE: CM indicates correction made.

REMARKS ______________________________

____

Date inspected ______________ **By** ______________

FIGURE 2.18 (*continued*)

low-level radioactive wastes, disposable needles, syringes, scalpels, and other sharp items. These are in addition to food service, laboratory, bandage, cleaning, and miscellaneous wastes. Proper handling, segregation, packaging, marking, storage, transport, treatment, and disposal of all hospital wastes are necessary to minimize the potential risks to the health of the patient, health care worker, visitor, refuse handler, and community.[84,85] Only about 15 percent of all hospital wastes are infectious. Although of public health and aesthetic concerns, they do not pose a health risk for the general public.

Infectious and pathological wastes, including packaging, disposable needles, syringes, and scalpels, are best disposed of by incineration providing proper temperature, oxygen, and residence time and by autoclaving followed by compaction or shredding. Chemotherapy and pathological wastes are incinerated. Autoclaved wastes are disposed of in a landfill or incinerator. Older hospital incinerator emissions can be expected to be high in participates, chlorinated toxins, hydrochloric acid, and chlorine (in view of the burning of large quantities of plastic wastes), if the waste is not well mixed and if proper design and operation, including air pollution control devices, are not provided. Most, if not all, old hospital incinerators require upgrading.

Recommendations to equal or exceed air quality standards include temperature of 2,000°F (1,093°C) with 2 seconds residence time and secondary chamber exit temperature of 1,800°F (982°C); 97 percent acid gas removal or 30 ppm; particulates 0.010 gram/ft^3; CO emissions 100 ppm hourly average; and opacity less than 10 percent.[86] A controlled starved air incinerator with flue gas scrubbers has been found satisfactory to control emissions.[87]

General hospital and kitchen wastes can usually be disposed of through the community waste collection system. Centralized regional incinerators and autoclaving with compaction or shredding for hospital wastes are usually recommended over individual plants. Other alternatives include chemical disinfection of macerated wastes with discharge to the sewer system (if permitted by the regulatory agency) and microwave disinfection of shredded wastes. Liquid infectious wastes may be carefully poured to a drain connected to a sanitary sewer.[88]

The usual method for the disposal of *low-level* radioactive solid waste is by storage until decayed, followed by disposal with the general waste. Low-level liquid waste, including body wastes, can be diluted and disposed of to the sanitary sewer. Gaseous radioactive wastes are dispersed directly to the outside air, away from any indoor air intakes or occupied areas. The entire process requires responsible regulatory and institutional surveillance.

The EPA regulates the handling of hazardous wastes and OSHA has jurisdiction over chemical carcinogens and other hazardous chemicals in work areas. Hospital wastes are also controlled by the Nuclear Regulatory Commission, the Toxic Substances Control Act, and the Resource Conservation and Recovery Act. State and local regulations must also be followed. It is incumbent upon hospitals and other generators, including clinics, medical laboratories, nursing homes, doctors, dentists, and veterinarians, to identify infectious and hazardous materials. They must protect workers, patients, and visitors from any hazard within the institution, clinic, or office and the community from any discharges or releases to the air, water, and land.[89]

Schools, Colleges, and Universities

Schools, colleges, and universities may incorporate a full spectrum of facilities and services not unlike a community. Involved—in addition to basic facilities such as water supply, sewage, and other wastewater disposal, plumbing, solid waste management, and air quality—are control of food preparation and service, on-site and off-site housing, hospital or dispensary, swimming pool, radiation installations and radioisotopes, insect and rodent infestations, and safety and occupational health in structures, laboratories, and work areas, including fire safety, electrical hazards, noise, and hazardous materials. In view of their complexity and their effect on life and health, all institutions should have a professionally trained environmental health and safety officer and staff responsible for the enforcement of standards, such as in a sanitary code, encompassing the areas of concern already noted. Such personnel can work closely with federal, state, and local health and safety regulatory officials and thus provide maximum protection for the student population and teaching, research, and custodial staffs.[90] Figures 2.19 and 2.20 suggest the broad areas to be considered when making an inspection. Guidance as to what is considered satisfactory compliance can be found in this text under the appropriate headings and also in federal, state, and local publications.

Correctional Institutions

Correctional institutions include short-term jails, long-term prisons, and various types of detention facilities. The health care services may include primary health care services, secondary care services, health care services for women offenders, mental health care, dental care, environmental concerns, nutrition and food

Name ____________ **Location** ____________ **T.V.C.** ________

Principal ____________ **Supt. of Schools** ____________ **Date** ________

Grades ____ **No. classrooms** ____ **No. boys** ____ **No. girls** ____ **Public** ________

Private ____ **Parochial** ____ **Boarding** ____

Item	Yes	No	CM
1. Water system approved by health department			
2. One sanitary drinking fountain for every 75 children, or			
3. One sanitary paper-cup dispenser for every 75 children, where needed			
4. One washbasin with warm and cold water for every 30 students			
5. Soap, paper towels, and mirrors provided			
6. One toilet including tissue and partition for every 35–45 girls, and one toilet including tissue and one urinal for every 30–40 boys; separate.			
7. Toilet and lavatory rooms convenient, clean, free of odors, ventilated; floors impervious and drained			
8. Shower and locker room clean, drained; adeq. warm water			
9. Sewage and excreta disposal satisfactory			
10. Buildings of fire-resistive construction			
11. Corridors, stairs, exits, doors marked and provide safe and ready escape from building in case of fire			
12. Flammables stored in metal cans			
13. Fire extinguishers, sprinkler heads, fire hydrants, fire hose, fire alarm, fire escapes, panic bolts operable and tested every 6 months.			
14. Fire drills conducted, each floor emptied in 2 min.			
15. Poisons, etc., labeled and secured			
16. Seats in classrooms face away from window or light sources; no glare			
17. Natural and artificial light provided			
(*a*) 50-ft-c in classrooms, libraries, offices, shops, laboratories, gymnasium, pool			
(*b*) 75-ft-c in sewing, drafting, and arts and crafts rooms			
(*c*) 50-ft-c in sightsavings classrooms			
(*d*) 10-ft-c in auditorium, assembly rooms, cafeterias			
(*e*) 10-ft-c in locker rooms, corridors, stairs, toilet rooms			
(*f*) 70-ft-c in kitchen			
18. Thermometer at seat level, provided, which reads in winter at			
(*a*) 68–72°F in classrooms, auditoriums, offices, cafeterias			
(*b*) 66–70°F in corridors, stairways, shops, laboratories, kitchen			
(*c*) 60–70°F in gymnasium			
(*d*) 76–80°F in locker and shower room			
(*e*) 80–86°F in swimming pool			
19. In nonheating season, when outdoor temperature reads 80°, 90°, 95°F, inside temperature reads 75°, 78°, 80°F, respectively.			
20. Ventilation and heating satisfactory (10–30 ft^3 per min per person); drafts and excessive heat prevented			
21. Place provided to store clothes, lunch boxes, rubbers			
22. A separate adjustable and movable seat and desk available for each child			
23. Class room provides 25–30 ft^2; per pupil			

FIGURE 2.19 School sanitation inspection form.

	Yes	No	CM		Yes	No	CM
24. Buildings, windows, rooms, chalkboards, lights, fixtures, corridors, walls, ceilings, etc., clean; grounds free of litter, insects, rodents, weeds, pools of water				28. Solid wastes properly stored and disposal satisfactory			
25. Swimming pool operated and maintained in conformance with sanitary code requirements*				29. Air pollution prevented			
26. Dining room or cafeteria operated and maintained in conformance with sanitary code requirements*				30. A competent person assigned responsibility to see that all environmental hygiene precautions are observed by teachers and students. (Incorporate in curricula.)			
27. Safety precautions taken in shops, laboratories, play area				31. Floors, walls, ceilings in good repair			
				32. No hazardous asbestos			
				NOTE: CM indicates correction made.			

*Use separate inspection form. Explain "No" items.

REMARKS ______________________________

____

Date inspected ______________ **By** ______________

FIGURE 2.19 (*continued*)

services, pharmacy services, health records, evaluation services, and staffing. Environmental health concerns are discussed next.

Incarceration may result in or intensify the need for health care services. The provision of a safe and healthy environment, services, and facilities would minimize the need. Food poisoning, poor and insufficient food, vermin infestations, inadequate work and recreational programs, and overcrowding are known causes of prison unrest and illness. Overcrowding and poor food quality and food service are major problems at many jails and prisons. Walker[91] summarizes the problem very clearly in pointing out that overcrowded conditions often overtax the ventilation system and sanitary facilities, minimize privacy and personal space. Without privacy and personal space, the basic psychological and physiological needs of the residents are not met; tension and hostility grow; security requirements increase; and a negative cycle is put into play.

The elimination of overcrowding and improvement in the wholesomeness, quantity, and sanitation of food service can eliminate major causes of discontent.

The environmental aspects of correctional institutions are, in many respects, similar to those of other institutions and are concerned with many of the same basic environmental engineering and sanitation facets of a community.

Designs for new construction and major alterations should be reviewed and approved by the regulatory agencies having jurisdiction and, in any case, comply with nationally recognized standards. Regulatory agencies should make annual

Name ________ Address ________ T.V.C. ________
Operator ________ Persons interviewed ________
Capacity ____ Men ____ Women ____ Inspected by ________ Date ________

Item	S	U
Water supply		
1. Quality meets drinking water standards		
2. Quantity—yield storage, pressure adequate—hot and cold		
3. Operation, maintenance, and reports satisfactory, no backflow		
4. Qualified operator		
5. On routine sampling schedule		
Sewage and toilet facilities		
6. Flush toilets adequate		
7. Wash basins adequate		
8. Showers adequate		
9. Service sinks adequate		
10. Treatment meets stream standards		
11. Operation, maintenance, and reports satisfactory		
12. Qualified operator		
Air pollution control		
13. Incinerator emissions meet standards		
14. Boiler emissions meet standards		
15. Process emissions meet standards		
16. Fuel composition and use acceptable		
Solid wastes		
17. Garbage storage and collection satisfactory		
18. Refuse storage and collection satisfactory		
19. Disposal satisfactory		
Swimming pool and bathing beach		
20. Life-saving equipment and lifeguards adequate		
21. Adequate clarity		
22. Adequate treatment and reports		

Item	S	U
Dietary		
23. Food sources approved		
24. Refrigerator storage temperature, space, clean		
25. Dry storage clean, dry, space		
26. Food preparation, handling, cooling proper		
27. Food service temperature and protection satisfactory		
28. Utensils and equipment type, condition, satisfactory		
29. Dishwashing—dishes, utensils		
30. Handwashing facil. adequate, convenient		
Structure and grounds		
31. Location suitable		
32. Buildings and grounds well drained		
33. Accessible by emergency vehicles		
34. Service entrances convenient		
35. Elevators serve all floors		
Radiation		
36. Diagnostic X-ray units satisfactory		
37. Therapeutic X-ray units satisfactory		
38. Teletherapy units satisfactory		
39. Radioactive materials properly stored, used		
40. Microwave units satisfactory		
Housing and safety		
41. Rooms clean, lighted, ventilated		
42. Fire escape from rooms		
43. Adequate space for occupancy		
44. Insect and rodent control effective		
45. Clean bedding		
46. Heating safe and adequate for intended use		
47. Fire protection adequate		
48. Fire-resistive construction		
49. OSHA standards met		

S means substantially satisfactory equipment, construction, operation, maintenance.
U means unsatisfactory. Use available codes, rules, and regulations for compliance. Mark items NA if not applicable.
Supplied services ____ Water Supply ____ Sewerage ____ Refuse Collection ____ Dietary ____ Other ____ Give name of contractor or supplier.

FIGURE 2.20 Abbreviated institution environmental health inspection form. (For comprehensive interpretations, see pertinent sections of this text.)

inspections and reports of the facilities and services in the same manner as is done for other state, municipal, and public facilities and establishments.

Environment Inspection and Report Outline

A comprehensive inspection and report would involve investigation of the following items:

A. Grounds and Structures
   1. Location, accessibility, service entrances, cleanliness, noise
   2. Protection from flooding; drainage
   3. Construction materials and maintenance; dampness, drafts, leaks; sound and in good repair
   4. Fire protection, municipal and on-site; adequacy; water supply; alarms
   5. Safety, accident prevention, road signs, lighting

B. Utilities
   1. Water supply: source, treatment, storage and distribution, quality, quantity, pressure; quality surveillance and compliance with federal and state standards; operation control
   2. Wastewater collection and disposal: sewage and all other liquid waste collection, treatment, and disposal; compliance with federal and state standards; operation control
   3. Solid wastes: storage, collection and disposal; storage areas or rooms, cans, bins; on-site processing and disposal; hazardous waste handling, storage, and disposal; compliance with federal and state standards
   4. Heating, electricity and air conditioning; adequacy; safety
   5. Air quality: power plant, incinerator, institution operations; compliance with federal and state standards
   6. Emergency power and disaster planning; power to vital services and lighting to vital areas

C. Shelter
   1. Temperature control: heat, ventilation, humidity control, cooling
   2. Lighting: walkways, assembly areas, cells, kitchens, work areas, special uses, and facilities
   3. Space requirements: cells, assembly areas, recreational areas, dining rooms, visiting areas
   4. Fire safety: fire-resistive construction; compartmentation; interior finishes; enclosures, doors, stairs; extinguishers and extinguisher systems, sprinklers, detection and alarm systems; fire water supply; fire plans and drills

5. Accident prevention: physical design, working conditions, fire and electrical hazards; occupational exposures and recreational facilities; also, occupational health standards (OSHA) as applied to jails and prisons (Drugs, pesticides, flammables, and other hazardous materials stored in a secure place.)
6. Housekeeping: general cleanliness and maintenance; facility interior surfaces (walls, floors, ceilings, facilities, equipment); equipment and facilities maintenance; grounds and spaces; roster and cleaning schedule
7. Noise: interior, exterior; mechanical equipment, work areas comply with OSHA standards

D. Services and Facilities
1. Food and protection: wholesomeness, refrigeration, storage, preparation, transportation, service; processing; equipment; foodhandler inspection; ice; vending machines
2. Radiation protection: diagnostic, therapeutic, teletherapy, X-ray units; radioactive materials storage and use; microwave ovens; industrial uses
3. Vermin control: rodents, insects, and other arthropods; physical and chemical controls; pesticide storage secure and used as directed on label
4. Laundry facilities: soiled linen and clean linen separate storage, handling, and transportation; laundering process
5. Plumbing: water, soil, and waste lines, drains, toilets, washbasins; adequacy of hot and cold water for all purposes; service sinks; ross-connection and backflow control
6. Recreational facilities: bathing beach, swimming pool; other; life-saving equipment and life guards; water clarity and quality; accident control; maintenance, operation and sanitation facilities; safety
7. Institutional operations: canning, slaughtering, dairy, pasteurization; other farm operations; manufacturing; vocational training; hospital; laundry; bakery
8. Facilities available for public and staff: toilets; dressing rooms; visiting areas
9. Medical care facility area: storage of drugs; disinfection and sterilization; refrigeration of blood and drugs; morgue

E. Personal Hygiene
1. Personal hygiene: infestation and disinfestation; showers, towels, clothes, toiletries, etc.
2. Bedding: mattresses, pillows, sheets, blankets, beds
3. Toilet and bathing facilities: number and type of water closets, squatting plates, washbasins, showers; removable pail privies
4. Barber and beauty shops: room designated, equipped, staffed

F. Personnel and Supervision
1. In-service training: staff and inmates having environmental sanitation responsibilities

2. Self-inspection: qualified person designated, responsible to administrator
3. Regulatory agencies: inspection and approval of facilities and services annually

Because of the diverse facilities and services involved, it is essential that the regulatory person assigned to make inspections be broadly trained and have the experience and maturity to know when to call upon a specialist to investigate in greater detail and resolve complex problems. Many resources, including specially trained consultants, laboratory facilities, regulations, and inspection services, are available from various departments and agencies of the government (including federal) as well as national organizations. These should be utilized to identify and help resolve potential and actual deficiencies.

The basic principle involved, the public health rationale, and the basis for satisfactory compliance for each item just listed are given in *Standards for Health Services in Correctional Institutions*.[55]

Day-Care Centers

Day-care centers provide an environment for children of an age conducive to the spread of respiratory, contact, and water- and foodborne diseases discussed in Chapter 1 and in this section. They can also lead to other disease complications. Diapering and food preparation and service are critical activities requiring scrupulous cleanliness and frequent handwashing. Enteric and respiratory disease transmission via the fecal–oral route and by intimate contact is more common among children in a day-care center. Multiple pathogen infection is not uncommon. *Cryptosporidium* spp., *Giardia lamblia, Salmonella, Shigella sonnei, E. coli* (toxic strain), and enteroviruses are some of the more commonly found enteric pathogens in reported outbreaks. The increased interest and private, federal, and state support of day-care centers and their consequent expansion make their regulation an important public health function. Here is an opportunity to apply known preventive measures, including frequent handwashing, hygiene, food sanitation, separation of ill children, and education of staff and management, in disease transmission and prevention.[92]

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CHAPTER 3

SOLID WASTE MANAGEMENT

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Aesthetic, land-use, health, water pollution, air pollution, and economic considerations make proper solid waste management an ongoing concern for municipal, corporate, and individual functions that must be taken seriously by all. Indiscriminate dumping of solid waste and failure of the collection system in a populated community for two or three weeks would soon cause many problems. Odors, flies, rats, roaches, crickets, wandering dogs and cats, and fires would dispel any remaining doubts of the importance of proper solid waste management.

Solid waste management is a complex process because it involves many technologies and disciplines. These include technologies associated with the generation (including source reduction), on-site handling and storage, collection, transfer and transportation, processing, and disposal of solid wastes. All of these processes have to be carried out within existing legal, social, and environmental guidelines that protect the public health and the environment and are aesthetically and economically acceptable. To be responsive to public attitudes, the disciplines that must be considered in integrated solid waste management include administrative, financial, legal, architectural, planning, environmental, and engineering functions. For a successful integrated solid waste management plan, it is necessary that all these disciplines communicate and interact with each other in a positive interdisciplinary relationship.

In the material that follows, the major issues involved with the management of solid waste are presented and discussed. These issues include the elements of integrated solid waste management; the sources, characteristics, and quantities of solid waste; on-site storage and handling, solid waste collection; transfer and transport; waste reduction, recycling, and processing; composting; sanitary landfill planning design and operation; and incineration and hazardous waste. However, before discussing these topics, it will be useful to define the terminology used in the field of solid waste management. Additional details on solid waste management may be found in the U.S. Environmental Protection Agency.[1]

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DEFINITION OF TERMS

To understand the elements and technologies involved in integrated solid waste management it is useful to define some of the more commonly used terms.

Ash residue All the solid residue and any entrained liquids resulting from the combustion of solid waste or solid waste in combination with fossil fuel at a solid waste incinerator, including bottom ash, boiler ash, fly ash, and the solid residue of any air pollution control device used at a solid waste incinerator.

Biodegradable material Waste material capable of being converted, usually by bacteria and other microorganisms, into basic elements. Most organic wastes, such as food remains and paper, are biodegradable in a suitable environment.

Commercial waste Solid waste generated by stores, offices, institutions, restaurants, warehouses, and nonmanufacturing activities at industrial facilities.

Composting The controlled biological decomposition of organic solid waste under aerobic (in the presence of oxygen) conditions. Organic waste materials are transformed into soil amendments such as humus or mulch.

Fly ash The ash residue from the combustion of solid waste or solid waste in combination with fossil fuel that is entrained in the gas stream of the solid waste incinerator and removed by air pollution control equipment.

Food waste Putrescible solid material including animal and vegetable waste resulting from the handling, storage, sale, preparation, cooking, or serving of foods. Food waste originates primarily in home kitchens, stores, markets, restaurants, and other places where food is stored, prepared, or served.

Garbage An older term that is often used interchangeably with the newer term *food waste*.

Geomembrane An essentially impermeable membrane used in landfills to limit the movement of liquids and or gases resulting from the decomposition of waste materials.

Groundwater Water below the land surface in the saturated zone of the soil or rock. Groundwater includes perched water separated from the main body of groundwater by an unsaturated (zadose) zone.

Hazardous waste Defined later in this chapter.

Incinerator A facility designed to reduce the volume and weight of solid waste by a combustion process with or without a waste heat recovery system.

Industrial waste Solid waste generated by manufacturing or industrial processes, excluding wastes resulting from oil or gas drilling, production, and treatment operations (such as brines, oil, and frac fluids); overburden, spoil, or tailings resulting from mining; or solution mining brine and insoluble component wastes.

Integrated solid waste management The comprehensive management of solid waste involving several complementary activities and or process including source reduction, recycling, waste transformation, and landfilling.

Leachate A liquid resulting from precipitation percolating through landfills, which includes liquids resulting from the decomposed waste. With proper management, the amount of leachate can be minimized. Leachate that is collected is treated to prevent contamination of environment.

Municipal solid waste Includes nonhazardous waste generated in households, commercial establishments, institutions, and nonprocess-related industrial wastes (e.g., waste paper and paperboard); it excludes wastes from municipal services such as water and wastewater treatment sludges, industrial process wastes, agricultural wastes, and mining wastes.

Recycling A resource recovery method involving the collection and treatment of a waste product for use as raw material in the manufacture of the same or another produce (e.g., ground glass used in the manufacture of new glass).

Refuse A general term often used interchangeably with the term *solid waste*. To avoid confusion, the term *refuse* is not used in this chapter.

Residuals Water and wastewater sludges, septage, air pollution control facility waste, or any other such waste having similar characteristics or effects and solid waste remaining after the processing of solid waste by composting methods that was not made into compost suitable for use.

Resource recovery A term describing the extraction and utilization of materials that can be used as raw material in the manufacture of new products or as values that can be converted into some form of fuel or energy source. Resource recovery is a key element of an integrated solid waste management program.

Rubbish A general term for solid wastes, excluding food wastes and ashes, for materials collected from residences and commercial and institutional establishments.

Sanitary landfill A method of disposing of solid waste on land without creating nuisances or hazards to public health or safety. Modern sanitary landfills have leachate collection and treatment systems, landfill gas controls, and environmental monitoring systems.

Solid waste Any of a variety of solid materials, as well as some liquids in containers, which are discarded or rejected as being spent, useless, worthless or in excess. Usually the term does not include solid waste from certain community activities (e.g., catch basin cleanings, water and wastewater treatment sludges). Also excluded are solid, liquid, semisolid, or contained gaseous material resulting from industrial, mining, and agricultural operations.

Solid waste management The systematic administration of activities that provide for the collection, source separation, storage, transportation, transfer, processing (including recycling), treatment, and disposal of solid waste.

Source reduction Refers to reducing the amount of waste generated that must eventually be discarded, including minimizing toxic substances in products, minimizing volume of products, and extending the useful life of products. Requires manufacturers and consumers to take an active role in reducing the amount of waste produced.

Source separation The segregation of various materials from the waste stream at the point of generation for recycling. For example, householders separating paper, metal, and glass from the rest of their wastes.

Transfer station A facility with structures, machinery, or devices that receives deliveries of solid waste by local collection vehicles and provides for the transfer of the waste to larger vehicles that are used to deliver the waste to a recycling, treatment, or disposal site.

Waste-to-energy incineration (combustion) Disposal method in which municipal solid waste is brought to a plant where it is combusted either as received or after being processed to a more uniform fuel to generate steam or electricity. Waste-to-energy plants can decrease volume by 60 to 90 percent, while recovering energy from discarded products.

INTEGRATED WASTE MANAGEMENT

Integrated waste management (IWM) can be defined as the selection and application of suitable techniques, technologies, and management programs to achieve specific waste management objectives and goals. Because numerous state and federal laws have been adopted, IWM is also evolving in response to the regulations developed to implement the various laws. The EPA has identified four basic management options (strategies) for IWM: (1) source reduction, (2) recycling and composting, (3) combustion (waste-to-energy facilities), and (4) landfills. As proposed by the EPA, these strategies are meant to be interactive, as illustrated in Figure 3.1a. It should be noted that some states have chosen to consider the management options in a hierarchical order, as depicted in Figure 3.1b. For example, recycling can only be considered after all that can be done to reduce the quantity of waste at the source has been done. Similarly, waste transformation is only considered after the maximum amount of recycling has been achieved. Further, the combustion (waste-to-energy) option has been replaced with waste transformation in California and other states. Interpretation of the IWM hierarchy will, most likely, continue to vary by state. The management options that comprise the IWM are considered in the following discussion. The implementation of IWM options is considered in the remaining sections of this chapter.[2]

Source Reduction

The focus of source reduction is on reducing the volume and/or toxicity of generated waste. Source reduction includes the switch to reusable products and packaging, the most familiar example being returnable bottles. However, legislated

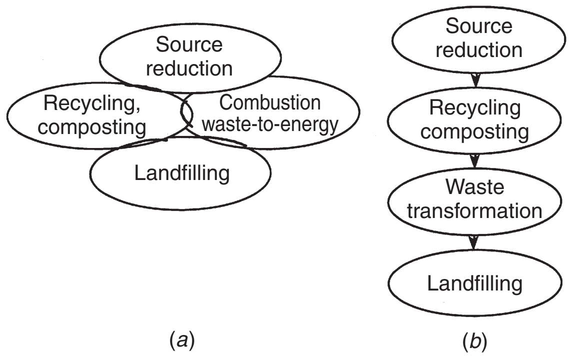


FIGURE 3.1 Definition sketch for integrated solid waste management: (*a*) interactive; (*b*) hierarchical.

bottle bills only result in source reduction if bottles are reused once they are returned. Other good examples of source reduction are grass clippings that are left on the lawn and never picked up and modified yard plantings that do not result in leaf and yard waste. The time to consider source reduction is at the product/process design phase.

Source reduction can be practiced by everybody. Consumers can participate by buying less or using products more efficiently. The public sector (government entities at all levels: local, state, and federal) and the private sector can also be more efficient consumers. They can reevaluate procedures that needlessly distribute paper (multiple copies of documents can be cut back), require the purchase of products with longer life spans, and cut down on the purchase of disposable products. The private sector can redesign its manufacturing processes to reduce the amount of waste generated in the manufacturing process. Reducing the amount of waste may require closed-loop manufacturing processes and the use of different raw materials and/or different production processes. Finally, the private sector can redesign products by increasing their durability, substituting less toxic materials, or increasing product effectiveness. However, while everybody can participate in source reduction, it affects how people go about their business, something that is difficult to mandate through regulation without getting mired in the tremendous complexity of commerce.

Source reduction is best encouraged by making sure that the cost of waste management is fully internalized. *Cost internalization* means pricing the service so that all of the costs are reflected. For waste management, the costs that need to be internalized include pickup and transport, site and construction, administrative and salary, and environmental controls and monitoring. It is important to note that these costs must be considered, whether the product is ultimately managed in a landfill, combustion, recycling facility, or composting facility. Regulation can aid cost internalization by requiring product manufacturers to provide public disclosure of the costs associated with these aspects of product use and development.[2]

Recycling and Composting

Recycling is perhaps the most positively perceived and doable of all the waste management practices. Recycling will return raw materials to market by separating reusable products from the rest of the municipal waste stream. The benefits of recycling are many. Recycling saves precious finite resources, lessens the need for mining of virgin materials—which lowers the environmental impact for mining and processing—and reduces the amount of energy consumed and the process carbon footprint. Moreover, recycling can help stretch landfill capacity. Recycling can also improve the efficiency and ash quality of incinerators and composting facilities by removing noncombustible materials, such as metals and glass.

Recycling can also cause problems if it is not done in an environmentally responsible manner. Many Superfund sites are what is left of poorly managed recycling operations. Examples include deinking operations for newsprint, waste oil recycling, solvent recycling, and metal recycling. In all of these processes, toxic contaminants that need to be properly managed are removed. Composting is another area of recycling that can cause problems without adequate location controls. For example, groundwater can be contaminated if grass clippings, leaves, or other yard wastes that contain pesticide or fertilizer residues are composted on sandy or other permeable soils. Air contamination by volatile substances can also result.

Recycling will flourish where economic conditions support it, not just because it is mandated. For this to happen, the cost of landfilling or resource recovery must reflect its true cost and must be at least \$40 to \$50 per ton or higher (2008 dollars). Successful recycling programs also require stable markets for recycled materials. Examples of problems in this area are not hard to come by; a glut of paper occurred in Germany in the 1984 to 1986 time frame due to a mismatch between the grades of paper collected and the grades required by the German papermills. Government had not worked with enough private industries to find out whether the mills had the capacity and equipment needed to deal with low-grade household newspaper. In the United States, a similar loss of markets has occurred for paper, especially during the period from 1994 through 1997. Prices have dropped to the point where it actually costs money to dispose of collected newspapers in some parts of the country.

Stable markets also require that stable supplies are generated. This supply-side problem has been problematic in certain areas of recycling, including metals and plastics. Government and industry must work together to address the market situation. It is critical to make sure that mandated recycling programs do not get too far ahead of the markets.

Even with a good market situation, recycling, and composting will flourish only if they are made convenient. Examples include curbside pickup for residences on a frequent schedule and easy drop-off centers with convenient hours for rural communities and for more specialized products. Product mail-back programs have also worked for certain appliances and electronic components.

Even with stable markets and convenient programs, public education is a critical component for increasing the amount of recycling. At this point, the United States must develop a conservation, rather than a throwaway, ethic, especially in light of the current energy crisis (2008). Recycling presents the next opportunity for cultural change. It will require us to move beyond a mere willingness to collect our discards for recycling. That cultural change will require consumers to purchase recyclable products and products made with recycled content. It will require businesses to utilize secondary materials in product manufacturing and to design new products for easy disassembly and separation of component materials.[2]

Combustion (Waste-to-Energy)

The third of the IWM options (see Figure 3.1) is combustion (waste-to-energy). Combustion facilities are attractive because they do one thing very well; they reduce the volume of waste noticeably, up to ninefold. Combustion facilities can also be used to recover useful energy, either in the form of steam or in the form of electricity. Volume reduction alone can make the high capital cost of incinerators attractive when landfill space is at a premium or when the landfill is distant from the point of generation. For many major metropolitan areas, new landfills must be located increasingly far away from the center of the population. Moreover, incinerator bottom ash has a promise for reuse as a building material. Those who make products from cement or concrete may be able to utilize incinerator ash.

The major constraints of incinerators are their cost, the relatively high degree of sophistication needed to operate them safely and economically, and the fact that the public is very skeptical concerning their safety. The public is concerned about both stack emissions from incinerators and the toxicity of ash produced by incinerators. The EPA has addressed both of these concerns through the development of new regulations for solid waste combustion (waste-to-energy) plants and improved landfill requirements for ash. These regulations will ensure that well-designed, well-built, and well-operated facilities will be fully protective from the health and environmental standpoints.[2]

Landfills

Landfills are the one form of waste management that nobody wants but everybody needs. There are simply no combinations of waste management techniques that do not require landfilling to make them work. Of the four basic management options, landfills are the only management technique that is both necessary and sufficient. Some wastes are simply not recyclable, because they eventually reach a point where their intrinsic value is dissipated completely so they no longer can be recovered, and recycling itself produces residuals, and is no longer cost-effective and or energy efficient.

The technology and operation of a modem landfill can assure protection of human health and the environment. The challenge is to ensure that all operating landfills are designed properly and are monitored once they are closed. It is critical to recognize that today's modern landfills do not look like the old landfills that are on the current Superfund list. Today's operating landfills do not continue to take hazardous waste. In addition, they do not receive bulk liquids. They have gas control systems, liners, leachate collection systems, and extensive groundwater monitoring systems. Perhaps most importantly, they are better sited and located in the first place to take advantage of natural geological conditions.

Landfills can also turn into a resource. Methane gas recovery is occurring at many landfills today, and CO_2 recovery is being considered. After closure, landfills can be used for recreation areas such as parks, golf courses, or ski areas. Some agencies and entrepreneurs are looking at landfills as repositories of resources for the future; in other words, today's landfills might be able to be mined at some time in the future when economic conditions warrant. This situation could be particularly true of monofills, which focus on one kind of waste material like combustion ash or shredded tires.[2]

Implementing Integrated Solid Waste Management

The implementation of IWM for residential solid waste, as illustrated in Figure 3.2, typically involves the use of a several technologies and all of the

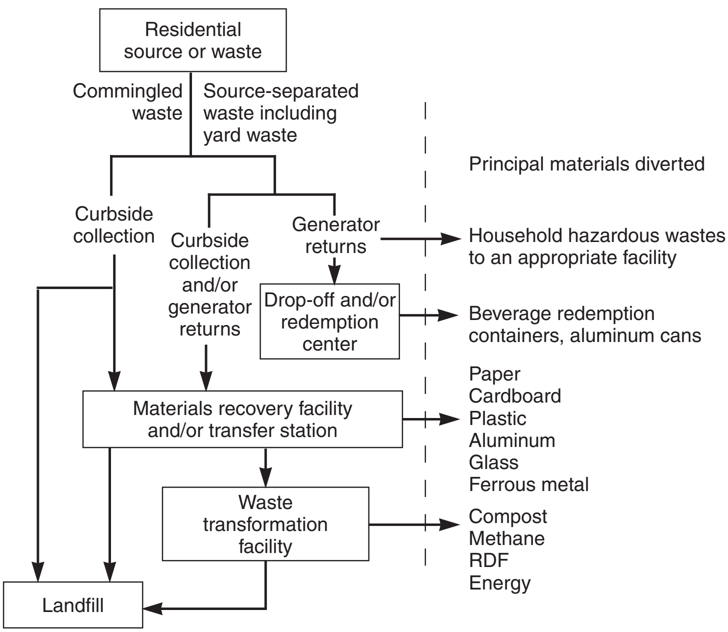


FIGURE 3.2 Implementation of IWM for management of residential solid wastes. Similar diagrams apply to commercial and institutional sources of solid waste. (*Source:* G. Tchobanoglous, and F. Kreith, *Solid Waste Handbook*, 2nd ed., McGraw-Hill, New York, 2002.)

management options already discussed. At present, most communities use two or more of the municipal solid waste (MSW) management options to dispose of their waste, but there are only a few instances where a truly integrated and optimized waste management plan has been developed. To achieve an integrated strategy for handling municipal waste, an optimization analysis combining all of the available options should be conducted. However, at present, there is no proven methodology for performing such an optimization analysis.[2]

SOURCES, CHARACTERISTICS, AND QUANTITIES OF SOLID WASTE

In developing solid waste management programs, it is important to identify the sources, characteristics, and quantities of solid waste. Information on these subjects, as discussed in this section, is of fundamental importance in determining the types of collection service, the types of collection vehicles to be used, the type of processing facilities, and the disposal method to be used. Construction and demolition debris and special wastes that must be collected and processed separately are also considered.

Sources of Solid Waste

Sources of solid wastes in a community are, in general, related to land use and zoning. Although any number of source classifications can be developed, the following categories have been found useful: (1) residential, (2) commercial, (3) institutional, (4) construction and demolition, (5) municipal services, (6) treatment plant sites, (7) industrial, and (8) agricultural. Typical waste generation facilities, activities, or locations associated with each of these sources are reported in Table 3.1. As noted in Table 3.1, *municipal solid waste* is normally assumed to include all community wastes with the exception of wastes generated from municipal services, water and wastewater treatment plants, industrial processes, and agricultural operations. It is important to be aware that the definitions of solid waste terms and the classifications of solid waste vary greatly in the literature and in the profession. Consequently, the use of published data requires considerable care, judgment, and common sense.[2]

Characteristics of Solid Waste

Important characteristics of solid waste include the composition, quantities, and specific weight.

Composition Typical data on the percentage distribution for the wastes from the sources identified in Table 3.1 are reported in Table 3.2. As shown in Table 3.2, residential and commercial waste make up about 60 percent of the total municipal waste generated per person in the United States, excluding industrial and agricultural wastes. It is important to recognize that most surveys of solid

TABLE 3.1 Sources Where Solid Wastes Are Generated within a Community

Source	Typical Facilities, Activities, or Locations Where Wastes Are Generated	Types of Solid Wastes
Residential	Single-family and multifamily dwellings; low-, medium-, and high-rise apartments	Food wastes, paper, cardboard, plastics, textiles, leather, yard wastes, wood glass, tin cans, aluminum other metal, ashes, street leaves, special wastes (including bulky items, consumer electronics, white goods, yard wastes collected separately, batteries, oil, and tires), household hazardous wastes
Commercial	Stores, restaurants, markets, office buildings, hotels, motels, print shops, service stations, and auto repair shops	Paper, cardboard, plastics, wood, food wastes, glass, metal wastes, ashes, special wastes (see above), hazardous wastes
Institutional	Schools, hospitals, prisons, governmental centers	As above for commercial
Industrial (nonprocess wastes)	Construction, fabrication, light and heavy manufacturing, refineries chemical plants, power plants, demolition	Paper, cardboard, plastics, wood, food wastes, glass, metal wastes, ashes, special wastes (see above), hazardous wastes
Municipal solid waste	All of the above[a]	All of the above[a]
Construction and demolition	New construction sites, road repair renovation sites, razing of buildings, broken pavement	Wood, steel, concrete, dirt
Municipal services (excluding treatment facilities)	Street cleaning, landscaping, catch-basin cleaning, parks and beaches, other recreational areas	Special wastes, rubbish, street sweepings, landscape and tree trimmings, catch-basin debris; general wastes from parks, beaches and recreational areas
Treatment plant sites	Water, wastewater, and industrial treatment processes	Treatment plant wastes, principally composed of residual sludges and other residual materials
Industrial	Construction, fabrication, light and heavy manufacturing, refineries chemical plants, power plants, demolition	Industrial process wastes, scrap materials; nonindustrial waste, including food wastes, rubbish, ashes, demolition and construction wastes, special wastes, hazardous waste
Agricultural	Field and row crops, orchards, vineyards, dairies, feedlots, farms	Spoiled food wastes, agricultural wastes, rubbish, hazardous wastes

[a]The term *municipal solid waste* (*MSW*) normally is assumed to include all of the wastes generated in the community with the exception of waste generated from municipal services, treatment plants, industrial processes, and agriculture.

Source: G. Tchobanoglous, H. Theisen, and S. Vigil, *Integrated Solid Waste Management: Engineering Principles and Management Issues*, McGraw-Hill, New York, 1993.

TABLE 3.2 Estimated Percentage Distribution by Weight of All MSW Generated in a Typical Community in 2008, Excluding Industrial and Agricultural Wastes[a]

Waste Category	Percent of Total	
	Range	Typical
Residential and commercial, excluding special and hazardous wastes	50–70	60
Special (bulky items, consumer electronics, white goods, yard wastes collected separately, batteries, oil, and tires)	2–12	5
Hazardous[b]	0.01–1.0	0.1
Institutional	3–5	3.4
Construction and demolition	8–20	14
Municipal services		
Street and alley cleanings		
	2–5	3.8
Tree and landscaping	2–5	3
Parks and recreational areas	1.5–3	2
Catch basin	0.5–1.2	0.7
Treatment plant sludges	3–8	6
—		
Total		100.0

[a]Adapted in part from G. Tchobanoglous, H. Theisen, and S. Vigil, *Integrated Solid Waste Management: Engineering Principles and Management Issues*, McGraw-Hill, New York, 1993; G. Tchobanoglous, and F. Kreith, *Solid Waste Handbook*, 2nd ed., McGraw-Hill, New York, 2002; U.S. EPA, *Municipal Solid Waste Generation, Recycling, and Disposal in the United States: Facts and Figures for 2006, Executive Summary*, Office of Solid Waste, EPA, Washington, DC, 2006a, http://www.epa.gov/garbage/pubs/msw06.pdf.

[b]Range of reported values varies widely depending on method used to identify and classify hazardous wastes found in MSW.

waste generation do not consider the wastes from municipal services, industrial and agricultural sources. The estimate composition of residential and commercial solid waste along with the estimated quantities that are now recycled are reported in Table 3.3. The percentage data given in Table 3.3 are subject to adjustment depending on many factors: time of the year; habits, education, and economic status of the people; number and type of commercial and industrial operations; whether urban or rural area; and location. Each community should be studied and actual weighings made to obtain representative information for design purposes.

Quantities Various estimates have been made of the quantity of solid waste generated and collected per person per day. The amount of municipal and commercial solid waste generated per capita in the Unites States in 2006 (latest

TABLE 3.3 Estimated Physical Composition of Residential MSW Generated and Recycled in 2008, Excluding Food Wastes Discharged with Wastewater[a]

	Percent by Weight			
	Generated		Recycled[b]	
Component	Range	Typical	Range	Typical
Organic Waste				
Food wastes	6–18	10	1–4	2.5
Paper and paperboard	25–40	34	45–55	52
Plastics	8–14	12	6–8	7
Textiles	2–6	4.5	12–18	15
Rubber	0.5–2	1	8–15	11
Leather	0.5–2	1	1.5–4	2.5
Yard wastes	5–20	13.0	50–65	60
Wood	4–8	5.5	8–12	10
Misc. organics	0.05–0.2	0.1	0.4–1.2	1
Inorganic Waste				
Glass	4–10	6.0	20–28	22
Tin cans	2–8	6.0	30–40	36
Aluminum	1–2	1.4	65–80	75
Other metal	1–4	3.0	5–10	67
Dirt, ash, etc	0–5	2.5		0.5
Total		100.0		

[a] Adapted in part from G. Tchobanoglous, H. Theisen, and S. Vigil, *Integrated Solid Waste Management: Engineering Principles and Management Issues*, McGraw-Hill, New York, 1993; G. Tchobanoglous, and F. Kreith, *Solid Waste Handbook*, 2nd ed., McGraw-Hill, New York, 2002; U.S. EPA, *Municipal Solid Waste Generation, Recycling, and Disposal in the United States: Facts and Figures for 2006, Executive Summary*, Office of Solid Waste, EPA, Washington, DC, 2006a, http://www.epa.gov/garbage/pubs/msw06.pdf. Reported percentage distributions are exclusive of special and hazardous wastes (see Table 3.2).
[b] Twenty five percent of the households in the United States assumed to have food waste grinders and that the percentage of food waste ground up and discharged with wastewater is equal to 25 percent.
[c] Current (2008) recycling rate for the United States assumed to be equal to about 50 to 54 percent.

available national data) is estimated to be 4.6 1b/capita•d (pounds of waste generated per capita per day).[3] Additional details on the quantities and characteristics of the solid waste generated in the United States may be found in Franklin Associates and U.S. EPA.[4] Based on the data given in Table 3.2, if hazardous, institutional, construction and demolition, and municipal wastes are considered, the total amount of waste generated per capita is about 7.7 1b/capita•d. Consideration of industrial and agricultural wastes would increase the total per capita generation rate significantly, more than double the amount (15 to 20 1b/capita•d) by some estimates. With the emphasis now placed on source reduction (such as less packaging) and waste recovery and recycling (such as of paper, metals, cans, and glass), the amount of solid waste requiring disposal has been reduced markedly over the past 10 years. For example, the Board of Supervisors of the City of San Francisco has mandated a goal of 75 percent waste diversion by the year 2010. It is estimated that in 2008, about 50 to 54 percent by weight of the waste generated will be recovered for recycling and reprocessing. Recovery and recycling of hazardous wastes and toxicity reduction by substitution of less hazardous or nonhazardous materials is continuing to increase.

Typical data on the quantities of waste generated from specific sources are presented in Table 3.4. Typical data on the quantities of waste generated from miscellaneous nonresidential sources are presented in Table 3.5. Typical data on the quantities of waste generated from industrial sources are presented in Table 3.6, respectively. The data presented in Tables 5.4 through 5.6 are meant to be used as a general guide to expected quantities for the purpose of preliminary planning and feasibility assessment. In all cases the quantity information in these table must be verified locally before final design.

Specific Weight The volume occupied by solid waste under a given set of conditions is of importance, as are the number and size or type of solid waste containers, collection vehicles, and transfer stations. Transportation systems and land requirements for disposal are also affected. For example, the specific weight of loose solid waste will vary from about 100 to 175 lb/yd^3. Specific weights of various solid waste materials are given in Table 3.7. The variabilities in the reported data are due to variations in moisture content.

Commercial and Household Hazardous Waste

The "contamination" of ordinary municipal waste by commercial and household hazardous wastes has exacerbated the potential problems associated with the disposal of municipal waste by landfill, incineration, and composting. Based on a number of past studies, the quantity of hazardous waste typically represents less than about 0.5 percent of the total waste generated by households. Typically, batteries and electrical items and certain cosmetics accounted for the largest amount. The EPA discusses the impact of toxic wastes on solid waste management.[5]

From a practical standpoint, it would appear that more can be accomplished by identifying and prohibiting disposal of commercial hazardous waste with municipal solid waste. The minimal household hazardous wastes could, with education and municipal cooperation, be disposed of by voluntary actions. These could include periodic community collections and provision of central guarded depositories. Many communities have established ongoing programs for the collection of household hazardous waste. The amount of waste can be expected to decrease as old stockpiles are discarded. Restricting sales and promoting development and substitution of nonhazardous household products would also be indicated. It should also be remembered that a large fraction of the household hazardous waste ends up in the sewer.

TABLE 3.4 Approximate Solid Waste Generation Rates from Various Sources in the United States

Source of Waste	Unit	lb/unit · day
Municipal	Capita	4.0
Household	Capita	3.5
Apartment building	Capita per sleeping room	4.0
Seasonal home	Capita	2.5
Resort	Capita	3.5
Camp	Capita	1.5
School		
With cafeteria	Capita	1.0
Without cafeteria	Capita	0.5
University	Student	0.86 to 1.0
Institution, general	Bed	2.5
Hospital	Bed	12–15
	Occupied bed and 3.7 if staff added	9.5
Nurses' or interns' home	Bed	3.0
Home for aged	Bed	3.0
Rest home	Bed	3.0
Nursing home, retirement	Bed	5.0
Infectious waste		
Hospital	Bed	4.0
Residential health care facility	Bed	0.5
Diagnostic and treatment center	Patient per week	0–6.5
Hotel		
First class	Room	3.0
Medium class	Room	1.5
Motels	Room	2.0
Day use facility, resort	Capita	0.5
Trailer camp	trailer	6–10
Commercial building, office	100 ft^2	1.0
Office building	Worker	1.5
Department store	100 ft^2	40
Shopping center	Survey required	Survey required
Supermarket	100 ft^2	9.0
Supermarket	Person	2.4
Restaurant	Meal	2.0
Cafeteria	Capita	1
Fast food	Capita	0.5
Drugstore	100 ft^2	5.0
Airport	Passenger	0.5
Prison	Inmate	4.5
Retail and service facility	1000 ft^2	13.0
Wholesale and retail facility	1000 ft^2	1.2
Industrial building, factory	400–3000 employees	7
	100–400 employees	3
Warehouse	Per 100 ft^2	2.0

(continues)

TABLE 3.4 (*continued*)

Source of Waste	Unit	lb/unit · day
National Forest recreational area		
Campground	Camper	1.2–1.4
Family picnic area	Picnicker	8.0–1.2
Organized camps	Occupant	1.4–2.2
Rented cabin, with kitchen	Occupant	1.2–1.8
Lodge, without kitchen	Occupant	0.2–0.8
Restaurant	Meal served	0.5–1.2
Overnight lodge, winter sports area	Visitor	1.5–2.1
Day lodge, winter sports area	Visitor	2.4–3.4
Swimming beach	Swimmer	0.02–0.05
Concession stand	Per patron	0.10–0.16
Job Corps, Civilian Conservation		
Corps camp, kitchen waste	Per corpsman	1.8–3.0
Administrative and dormitory	Per corpsman	0.5–1.2

Source: Adapted from J. A. Salvato, *Environmental Engineering and Sanitation*, 4th ed., Wiley, New York, 1992.

TABLE 3.5 Miscellaneous Solid Waste Generation

	Solid Waste Generation Rate	
Type	Unit	Range of Values
Tires	Tires discarded per capita per year	0.6–1.0
Waste oil	5 gal per vehicle per year	2.0–3.0
Wastewater sludge, raw	Tons per day per 1,000 people, dewatered to 25% solids, with no garbage grinders	0.3–0.5
	Tons per day per 1,000 people, dewatered to 25% solids, with 100% garbage grinders	0.7–0.9
Wastewater sludge, digested	Tons per day per 1,000 people, dewatered to 25% solids, or 3 lb per capita per day dry solids	0.20–0.30
Water supply sludge	Pounds per million gallons of raw water, on a dry-weight basis, with conventional rapid-sand filtration using alum; raw water with 10 Jackson turbidity units (JTU)	200–220
Scavenger wastes	Gallons per capita per day	0.25–0.35
Pathological wastes	Pounds per bed per day–hospital	0.6–0.8
	Pounds per bed per day–nursing home	0.4–0.6
Junked vehicles	Number per 1000 population—2002	40–80

Source: Adapted in part from Malcolm Pirnie Engineers, *Comprehensive Solid Waste Planning Study—1969*, Herkimer-Oneida Counties, State of New York Department of Health, Albany, 1969.

TABLE 3.6 Typical Solid Waste Generation Rates for Industrial Sources by SIC Code[a]

SIC Code	Industry	Waste Production Rate (tons/employee·yr)
201	Meat processing	6.2
2033	Cannery	55.6
2037	Frozen foods	18.3
Other 203	Preserved foods	12.9
Other 20	Food processing	5.8
22	Textile mill products	0.26
23	Apparel	0.31
2421	Sawmills and planing mills	162.0
Other 24	Wood products	10.3
25	Furniture	0.52
26	Paper and allied products	2.00
27	Printing and publishing	0.49
281	Basic chemicals	10.0
Other 28	Chemical and allied products	0.63
29	Petroleum	14.8
30	Rubber and plastic	2.6
31	Leather	0.17
32	Stone, clay	2.4
33	Primary metals	24
34	Fabricated metals	1.7
35	Nonelectrical machinery	2.6
36	Electrical machinery	1.7
37	Transportation equipment	1.3
38	Professional and scientific institutions	0.12
39	Miscellaneous manufacturing	0.14

[a]Standard Industrial Classification (SIC) Code.

Source: R. F. Weston, *A Statewide Comprehensive Solid Waste Management Study*, New York State Department of Health, Albany, 1970.

Construction and Demolition Debris

Construction and demolition debris consists of uncontaminated solid waste resulting from the construction, remodeling, repair, and demolition of structures and roads and uncontaminated solid waste consisting of vegetation from land clearing and grubbing, utility line maintenance, and seasonal and storm-related cleanup. Such waste includes, but is not limited to, bricks, concrete and other masonry materials, soil, wood, wall coverings, plaster, drywall, plumbing fixtures, nonasbestos insulation, roofing shingles, asphaltic pavement, glass, plastics that are not sealed in a manner that conceals other wastes, electrical wiring and components containing no hazardous liquids, and metals that are incidental to any of the above.[6]

Solid waste that is not construction and demolition debris (even if resulting from the construction, remodeling, repair, and demolition of structures, roads, and

TABLE 3.7 Weight of Solid Waste for Given Conditions

Condition of Solid Waste	Weight (lb/yd^3)
Loose solid waste at curb	125–240
As received from compactor truck at sanitary landfill	300–700
Normal compacted solid waste in a sanitary landfill[a]	750–850
Well-compacted solid waste in a sanitary landfill[a]	1000–1250
In compactor truck	300–600
Shredded solid waste, uncompacted	500–600
Shredded solid waste, compacted	1400–1600
Compacted and baled	1600–3200
Apartment house compactor	600–750
In incinerator pit	300–550
Brush and dry leaves, loose and dry	80–120
Leaves, loose and dry	200–260
Leaves, shredded and dry	250–450
Green grass, compacted	500–1100
Green grass, loose and moist	350–500
Yard waste, as collected	350–930
Yard waste, shredded	450–600

[a] Initial value.

Source: J. A. Salvato, *Environmental Engineering and Sanitation*, 4th ed., Wiley, New York, 1992. and G. Tchobanoglous, H. Theisen, and S. Vigil, *Integrated Solid Waste Management: Engineering Principles and Management Issues*, McGraw-Hill, New York, 1993. Reproduced with permission from Cornell Waste Management Institute, Center for the Environment.

land clearing) includes, but is not limited to, asbestos waste, garbage, corrugated container board, electrical fixtures containing hazardous liquids such as fluorescent light ballasts or transformers, carpeting, furniture, appliances, tires, drums and containers, and fuel tanks. Specifically excluded from the definition of construction and demolition debris is solid waste (including what otherwise would be construction and demolition debris) resulting from any processing technique, other than that employed at a construction and demolition processing facility, that renders individual waste components unrecognizable, such as pulverizing or shredding.

Some of this material, such as bricks, rocks, wood, and plumbing fixtures, can be recycled. However, care must be taken to ensure (by monitoring each load) that hazardous materials such as those mentioned above are excluded and that fire, odor, and groundwater pollution is prevented. Engineering plans and reports, hydrogeologic report, operation and maintenance reports, and permits from the regulatory agency are usually required.

Special Wastes Collected Separately

In every community a number of waste materials are collected separately from residential and commercial solid waste. Special wastes include (1) medical wastes, (2) animal wastes, (3) waste oil, and (4) old tires. These wastes are considered in the following discussion.

Medical Wastes — Infectious and Pathological The Solid Waste Disposal Act, commonly referred to as the Resource Conservation and Recovery Act (RCRA), defines medical waste as "any solid waste which is generated in the diagnosis, treatment, or immunization of human beings or animals, in research pertaining thereto, or in the production or testing of biologicals. The term does not include any hazardous waste identified or listed under Subtitle C (mixtures with medical wastes are not excluded) or any household waste as defined in regulations under Code of Federal Regulations, Title 40, Subtitle C (materials found in waste generated by consumers)."[7]

Infectious waste usually comes from a medical care or related facility. It includes all waste materials resulting from the treatment of a patient on isolation (other than patients on reverse or protective isolation), renal dialysis, discarded serums and vaccines, pathogen-contaminated laboratory waste and animal carcasses used in research (including bedding and other waste), and other articles that are potentially infectious, such as hypodermic and intravenous needles.

Regulated medical waste under the act includes the following waste categories: cultures and stock of infectious agents and associated biologicals; human blood and blood products; pathological waste; used sharps (needles, syringes, surgical blades, pointed and broken glass); and contaminated animal carcasses. The EPA is authorized to exclude, if there is no substantial threat to human health or the environment, surgery or autopsy waste, miscellaneous microbiology laboratory waste, dialysis waste, discarded medical equipment, and isolation wastes. Other waste categories may be added if they pose a substantial threat. Potential hazards associated with the handling of infectious waste necessitate certain precautions. Infectious waste needs to be segregated at the source and clearly color (red) coded and marked. The packaging is expected to maintain its integrity during handling, storage, and transportation with consideration of the types of materials packaged. The storage time should be minimal (treated within 24 hours); the packaging should be moisture proof, puncture resistant, and rodent and insect proof; and the storage places and containers clearly marked with the universal biological hazard symbol and secured. Packaged waste is placed in rigid or semirigid containers and transported in closed, leak-proof trucks or dumpsters. It must at all times be kept separate from regular trash and other solid waste. Health care workers and solid waste handlers must be cautious.

Most infectious waste can be treated for disposal by incineration or autoclaving. The residue can be disposed of in an approved landfill. Liquids may be chemically disinfected; pathological wastes may also be buried, if permitted, or cremated; and blood wastes may, under controlled conditions, be discharged to a municipal sanitary sewer, provided secondary treatment is employed. Infectious waste may also be rendered innocuous by shredding–disinfection (sodium hypochlorite), thermal inactivation, and gas–vapor treatment. Infectious waste is only one component of medical waste.

In all cases, local, state, and federal regulations should be followed closely. Public concerns and fears associated with the possible spread of the viruses causing acquired immunodeficiency syndrome (AIDS) and hepatitis B, as well as other infections, have accelerated legislative and regulatory action, tighter management practices, and provision of specialized treatment and disposal services. Complete records (medical waste tracking form) must be kept by the generator and hauler of infectious waste to the point of final disposal as part of a four-part manifest system.

Animal Wastes Animal wastes may contain disease organisms causing salmonellosis, leptospirosis, tularemia, foot-and-mouth disease, hog cholera, and other illnesses. Manure contaminated with the foot-and-mouth disease virus must be buried in a controlled manner or otherwise properly treated. The excreta from sick animals should be stored 7 to 100 days, or as long as is necessary to ensure destruction of the pathogen, depending on temperature and moisture. Dead animals are best disposed of at an incinerator or rendering plant or in a separate area of a sanitary landfill. Large numbers might be buried in a special trench with due consideration to protection of groundwaters and surface waters if approved by the regulatory authority.

Waste Oil Large quantities of waste motor and industrial oil find their way into the environment as a result of accidental spills, oiled roads, oil dumped in sewers and on the land, and oil deposited by motor vehicles. Used oils contain many toxic metals and additives that add to the pollution received by sources of drinking water, aquatic life, and terrestrial organisms. The lead content of oil is of particular concern. It has been estimated that industrial facilities, service stations, and motorists produce 1.2 billion gallons of used oil, of which about 60 percent is used motor oil. Approximately 60 percent of the waste oil is reprocessed and used for fuel. About 25 to 30 percent is rerefined and reused as a lubricant. The remainder is used for road oil, dirt road dust control and stabilization, and other unacceptable uses. Rerefined oil is so classified when it has had physical and chemical impurities removed and, when by itself or blended with new oil or additives, is substantially equivalent or superior to new oil intended for the same purposes, as specified by the American Petroleum Institute.

Used Tires Tire dumps can cause major fires and release many hazardous chemicals, including oil, contributing to air and groundwater pollution. Tires collect rain water in which mosquitoes breed and provide harborage for rats and other vermin. Tires are not suitable for disposal by landfill but may be acceptable if shredded or split, although recycling is preferred and may be required.

ON-SITE HANDLING AND STORAGE

Where solid waste is temporarily stored on the premises, between collections, an adequate number of suitable containers should be provided.

Low-Rise Residential Areas

To a large extent, the type of container used for the collection of residential solid waste will depend on the type of collection service provided, and whether source

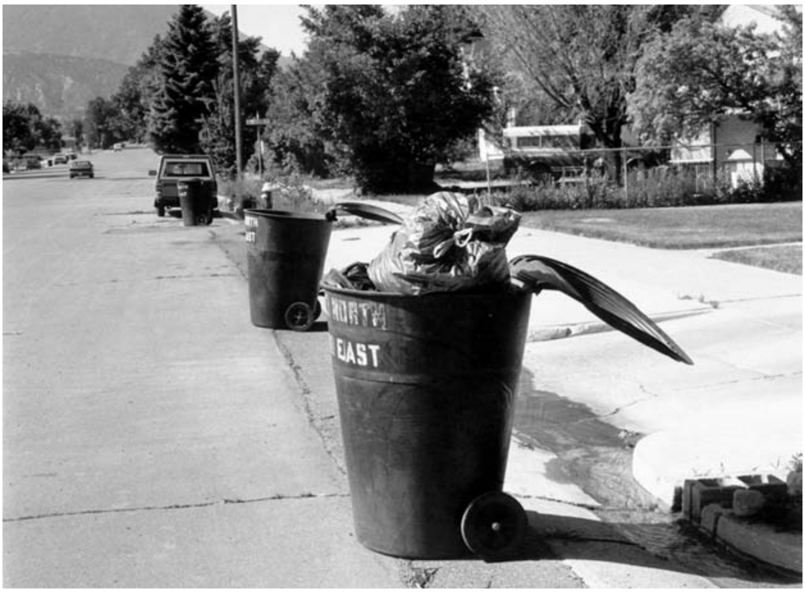
TABLE 3.8 Typical Collection Services for Commingled and Source Separated Solid Waste[a]

Preparation Method for Waste Collected	Type of Service
Commingled wastes	Single collection service of large container for commingled household and yard waste
	Separate collection service for (1) commingled household waste and (2) containerized yard waste
	Separate collection service for (1) commingled household waste and (2) noncontainerized yard waste
Source-separated and commingled waste	Single collection service for a single container with source-separated waste placed in plastic bag along with commingled household and yard wastes
	Separate collection service for (1) source-separated waste placed in a plastic bag and commingled household waste in same container and (2) noncontainerized yard wastes
	Single collection service for source-separated and commingled household and yard wastes using a two-compartment container
	Separate collection service for (1) source-separated and commingled household wastes using a two-compartment container and (2) containerized or noncontainerized yard waste
	Separate collection service for (1) source-separated waste and (2) containerized commingled household and yard wastes
	Separate collection service for (1) source-separated waste, (2) commingled household waste, and (3) containerized yard wastes
	Separate collection service for (1) source-separated waste, (2) commingled household waste, and (3) noncontainerized yard wastes
	Separate collection service for (1) source-separated recyclable materials, (2) source-separated compostable materials (i.e., food and yard waste), and (3) nonrecyclable solid waste

[a] The method of waste preparation for collection is often selected for convenience and efficiency of collection services and subsequent materials processing activities.

Source: H. Theisen, "Solid Waste Collection," in G. Tchobanoglous and F. Kreith (Eds.), Solid Waste Handbook, 2nd ed., McGraw-Hill, New York, 2002, Chapter 7.

(*a*)



(*b*)

FIGURE 3.3 Typical containers used for collection of residential solid waste: (*a*) source-separated recyclable materials are placed in three separate containers (one for paper, one for glass, and one for cans and plastics), residual nonrecyclable wastes are placed in separate containers, and yard wastes are place in the street for collection with specialized collection equipment; (*b*) commingled mixed wastes in a single large (90-gal) container.

separation of wastes is employed (see Table 3.8). The various types of containers used for residential service are illustrated in Figure 3.3.

Low- and Medium-Rise Apartments

Large containers located in enclosed areas are used most commonly for low and medium-rise apartments. In most applications, separate containers are provided for recyclable and commingled nonrecyclable materials. A typical example is shown in Figure 3.4.

Curbside collection service is common for most low- and medium-rise apartments. Typically, the maintenance staff is responsible for transporting the containers to the street for curbside collection by manual or mechanical means. In many communities, the collector is responsible for transporting containers from a storage location to the collection vehicle. Where large containers are used, the contents of the containers are emptied mechanically using collection vehicles equipped with unloading mechanisms.

High-Rise Apartments

In high-rise apartment buildings (higher than seven stories), the most common methods of handling commingled wastes involve one or more of the following: (1) wastes are picked up by building maintenance personnel from the various floors and taken to the basement or service area; (2) wastes are taken to the basement or service area by tenants; or (3) wastes, usually bagged, are placed by the tenants in a waste chute system used for the collection of commingled waste

FIGURE 3.4 Typical example of containers used for low- and medium-rise apartments. Large containers are used for solid waste to be disposed of in a landfill. The smaller containers in front of the enclosure are used for: (1) glass, tin can, aluminum cans, and plastic containers (type 1 and 2) and (2) recyclable paper and paperboard products.

at a centralized service location. Typically, large storage containers are located in the basements of high-rise apartments. In some locations, enclosed ground-level storage facilities will be provided. In some of the more recent apartment building developments, especially in Europe, underground pneumatic tran sport systems have been used in conjunction with the individual apartments chutes.

Commercial and Institution

Bulk containers or solid waste bins are recommended where large volumes of solid waste are generated, such as at hotels, restaurants, motels, apartment houses, shopping centers, and commercial places. They can be combined to advantage with compactors in many instances (see Figure 3.5). Containers should be placed on a level, hard, cleanable surface in a lighted, open area. The container and surrounding area must be kept clean, for the reasons previously stated. A concrete platform provided with a drain to an approved sewer with a hot-water faucet at the site to facilitate cleaning is generally satisfactory.

SOLID WASTE COLLECTION

Collection cost has been estimated to represent about 60 to 75 percent of the total cost of solid waste management, depending on the disposal method. Because the cost of collection represents such a large percentage of the total cost, the design of collection systems must be considered carefully. The type of service provided, the frequency of service, and the equipment used for collection are considered in the following discussion.

Type of Service

The type of collection service provided will depend on the community solid waste management program. Typical examples of the types of collection service provided for the collection of (1) commingled and (2) source-separated and commingled wastes, as reported in Table 3.8. It should be noted that numerous other variations in the service provided have been developed to meet local conditions. In addition to routine collection services, presented in Table 3.8, annual or semi-annual special collections for appliances, tires, batteries, paints, oils, pesticides, yard wastes, glass and plastic bottles, and “spring cleaning” have proven to be an appreciated community service while at the same time providing environmental protection.

Collection Frequency

The frequency of collection will depend on the quantity of solid waste, time of year, socioeconomic status of the area served, and municipal or contractor responsibility. In residential areas, twice-a-week solid waste collection during warm months of the year and once a week at other times should be the maximum

(*a*)

(*b*)

FIGURE 3.5 Typical containers used for collection of large amounts of waste from commercial establishments: (*a*) open top with lids; (*b*) closed container coupled to stationary compactor.

FIGURE 3.6 Commercial waste placed on sidewalk in New York City for manual collection at night or in very early morning hours.

permissible interval. In business districts, solid waste, including garbage from hotels and restaurants, should be collected daily except Sundays (see Figure 3.6). Depending on the type of collection system, the containers used for the on-site storage of solid waste should be either emptied directly into the collection vehicle or hauled away emptied and returned or replaced with a clean container. Solid waste transferred from on-site storage containers will invariably cause spilling, with resultant pollution of the ground and attraction of flies. If other than curb pickup is provided, such as backyard service, the cost of collection will be high. Nevertheless, some property owners are willing to pay for this extra service. Bulky wastes should be collected every three months. Most cities have also instituted ongoing programs for the collection of household hazardous wastes, typically every three months.

Types of Collection Systems

Solid waste collection systems may be classified from several points of view, such as the mode of operation, the equipment used, and the types of wastes collected. Collection systems can be classified, according to their mode of operation, into two categories: (1) hauled container systems and (2) stationary container systems. The individual systems included in each category lend themselves to the same method of engineering and economic analysis.[8] The principal operational features of these two systems are delineated as follows.

Hauled Container Systems (HCSs) These are collection systems in which the containers used for the storage of wastes are hauled to a materials recovery facility (MRF), transfer station, or disposal site, emptied, and returned to either their original location or some other location. There are two main types of vehicles used in hauled container systems: (1) hoist truck for containers in the size range from 2 to 12 yd^3 and (2) tilt-frame vehicles for containers in the size range from 10 to 50 yd^3 (see Figure 3.7). Typical data on the containers and container capacities used with these vehicles are reported in Table 3.9. In addition trash-trailers are used in some locations for construction and demolition wastes.

Hauled container systems are ideally suited for the removal of wastes from sources where the rate of generation is high because relatively large containers are used (see Table 3.9). The use of large containers eliminates handling time as well as the unsightly accumulations and unsanitary conditions associated with the use of numerous smaller containers. Another advantage of hauled container systems is their flexibility: Containers of many different sizes and shapes are available for the collection of all types of wastes.

Stationary Container Systems (SCSs) In the stationary container system, the containers used for the storage of wastes remain at the point of generation, except when they are moved to the curb or other location to be emptied. Stationary container systems may be used for the collection of all types of wastes. The systems vary according to the type and quantity of wastes to be handled, as well as

(*a*)

(*b*)

FIGURE 3.7 Typical examples of collection vehicles and containers used in hauled container system: (*a*) hoist truck; (*b*) tilt frame unloading a drop box; and (*c*) drop boxes used at commercial discount store.

(*c*)

FIGURE 3.7 (*continued*)

the number of generation points. There are two main types: (1) systems in which manually loaded collection vehicles are used (see Figure 3.8) and (2) systems in which mechanically loaded collection vehicles are used (see Figure 3.9).

The major application of manual loading collection vehicles is in the collection of residential source-separated and commingled wastes and litter. Manual loading is used in residential areas where the quantity picked up at each location is small and the loading time is short. In addition, manual methods are used for residential collection because many individual pick-up points are inaccessible to mechanized mechanically loaded collection vehicles. Special attention must be given to the design of the collection vehicle intended for use with a single collector. At present, it appears that a side-loaded compactor, such as the one shown in Figure 3.8*a*, equipped with standup right-hand drive, is best suited for curb and alley collection.

Personnel Requirements

In most hauled container systems, a single collector-driver is used. The collector-driver is responsible for driving the vehicle, loading full containers onto the collection vehicle, emptying the contents of the containers at the disposal site (or transfer point), and redepositing (unloading) the empty containers. In some cases, for safety reasons, both a driver and helper are used. The helper usually is responsible for attaching and detaching any chains or cables used in loading and unloading containers on and off the collection vehicle; the driver is responsible for the operation of the vehicle. A driver and helper should always be used where hazardous wastes are to be handled. Labor

TABLE 3.9 Typical Data on Container Types and Capacities Available for Use with Various Collection Systems

Collection System	Container Type	Typical Range of Container Capacities
Hauled container system		
Hoist truck	Used with stationary compactor	6–12 yd^3
Tilt-frame	Open top, also called debris boxes or roll-off	12–50 yd^3
	Used with stationary compactor	15–40 yd^3
	Equipped with self-contained compaction mechanism	20–40 yd^3
Truck-tractor	Open-top trash-trailers	15–40 yd^3
	Enclosed trailer-mounted containers equipped with self-contained compaction mechanism	30–40 yd^3
Stationary container systems (compacting type) Compactor, mechanically loaded	Open top and closed top with side loading	1–10 yd^3
	Special containers used for collection of residential wastes from individual residences	90–120 gal
Compactor, mechanically loaded with divided hopper	Special split cart containers used for collection of recyclables and other nonrecyclable commingled waste	92–120 gal
Compactor trailer with mechanical lift assembly on semitractor	Special split cart containers used for collection of recyclables and other nonrecyclable commingled waste	90–120 gal
Compactor, manually loaded	Small plastic or galvanized metal containers, disposable paper and plastic bags	20–55 gal
Stationary container systems (noncompacting type)		
Collection vehicle with manually loaded side dump containers	All types of containers used for temporary storage of recyclable materials	32 gal
Collection vehicle with semiautomatic manually loaded side troughs	All types of containers used for temporary storage of recyclable materials	32 gal
Collection vehicle with semiautomatic manually loaded side troughs capable of unloading wheeled containers	All types of containers used for temporary storage of recyclable materials plus wheeled containers	60–120 gal
Collection vehicle with mechanical lift assembly	Special containers used for collection of source separated wastes from individual residences	60–120 gal

Note: $yd^3 \times 0.7646 = m^3$; gal $\times$ $0.003785 = m^3$.

Source: H. Theisen, "Solid Waste Collection," in G. Tchobanoglous and F. Kreith (Eds.), Solid Waste Handbook, 2nd ed., McGraw-Hill, New York, 2002, Chapter 7,and G. Tchobanoglous, H. Theisen, and S. Vigil, *Integrated Solid Waste Management: Engineering Principles and Management Issues*, McGraw-Hill, New York, 1993.

(*a*)

(*b*)

FIGURE 3.8 Typical examples of manually loaded collection vehicles used in stationary container system: (*a*) side-loaded right-hand standup drive collection vehicle for commingled solid waste; (*b*) rear-loaded collection vehicle for commingled solid waste; (*c*) side-loading vehicle used for collection of source-separated materials.

(*c*)

FIGURE 3.8 (*continued*)

requirements for curbside collection with manually and mechanically loaded vehicles with a one-person crew are reported in Table 3.10.

Labor requirements for mechanically loaded stationary container systems are essentially the same as for hauled container systems. Where a helper is used, the driver often assists the helper in bringing loaded containers mounted on rollers to the collection vehicle and returning the empty containers. Occasionally, a driver and two helpers are used where the containers to be emptied must be rolled (transferred) to the collection vehicle from inaccessible locations, such as in congested downtown commercial areas. In stationary container systems, where the collection vehicle is loaded manually, the number of collectors varies from one to four, in most cases, depending on the type of service and the collection equipment. While the aforementioned crew sizes are representative of current practices, there are many exceptions. In many cities, multiperson crews are used for curb service as well as for backyard carry service.

Health Issues

The frequency and severity of injuries in the solid waste management industry are very high. The National Safety Council reported that solid waste collection workers have an injury frequency approximately 10 times the national average for all industries, higher than police work and underground mining. Workmen's compensation rates account for about 9 to 10 percent of payroll for all solid waste collectors.

(*a*)

(*b*)

FIGURE 3.9 Typical examples of mechanically loaded collection vehicles used in stationary container system: (*a*) side-loading vehicle with dual compartment; (*b*) front-loaded collection vehicle. (*Source:* Courtesy of Heil Environmental Industries; reproduced with permission.)

TABLE 3.10 Typical Labor Requirements for Curbside Collection with Manually and Mechanically Loaded Collection Vehicle Using One-Person Crew[a]

Average Number of Containers and/or Boxes per Pickup Location	Time (min/location)	
	Manual Pickup	Mechanical Pickup
1 (60–90 gal)	—	0.5–0.6
1 or 2	0.5–0.6	
3 or 4	0.6–0.9	
Unlimited service[b]	1.0–1.2	

[a] Values given are for typical residential area with lot sizes varying from 1/4 to 1/3 acre.
[b] Not all residents take advantage of unlimited service each collection day.

Source: H. Theisen, "Solid Waste Collection," in G. Tchobanoglous and F. Kreith (Eds.), Solid Waste Handbook, 2nd ed., McGraw-Hill, New York, 2002, Chapter 7.

TRANSFER AND TRANSPORT

The urban areas around cities have been spreading, leaving fewer nearby acceptable solid waste disposal sites. The lack of acceptable sites has led to the construction of incinerators, resource recovery facilities, or processing facilities in cities or their outskirts or the transportation of wastes longer distances to new landfill disposal sites. However, as the distance from the centers of solid waste generation increases, the cost of direct haul to a site increases. A "distance" is reached (in terms of cost and time) when it becomes less expensive to construct a transfer station or incinerator at or near the center of solid waste generation where wastes from collection vehicles can be transferred to large tractor-trailers for haul to more distant disposal sites. Ideally, the transfer station should be located at the centroid of the collection service area.

Economic Analysis of Transfer Operations

A comparison of direct haul versus the use of a transfer station and haul for various distances is useful in making an economic analysis of potential landfill sites. The transfer station site development, transportation system, and social factors involved in site selection should also be considered in making the comparison.

If the cost of disposal by sanitary landfill is added to the cost comparison, the total relative cost of solid waste transfer, transportation, and disposal by sanitary landfill can be compared to the corresponding cost for incineration, if incineration is an option. The relative cost of incineration with the cost of landfill for various haul distances and a given population is illustrated in Figure 3.10. Based on past experience, a direct-haul distance (one-way) of 25 to 30 miles is about the maximum economical distances although longer distances are common, where other options are unacceptable or cannot be implemented for a variety of reasons, including cost. A similar comparison in which distance is shown in terms of times of travel to the disposal site is presented in Figure 3.11.

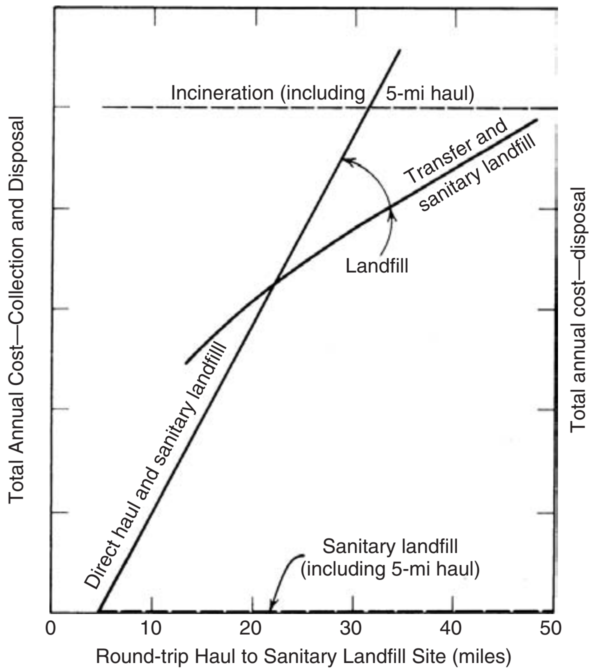


FIGURE 3.10 Effect of haul distances to site on cost of disposal by sanitary landfill compared to cost of disposal by incineration.

Types of Transfer Stations

Transfer stations are used to accomplish transfer of solid wastes from collection and other small vehicles to larger transport equipment. Depending on the method used to load the transport vehicles, transfer stations, as reported in Table 3.11 may be classified into two general types: (1) direct load and (2) storage load (see Figure 3.12). Combined direct-load and discharge-load transfer stations have also been developed transfer stations may also be classified with respect to throughput capacity (the amount of material that can be transferred and hauled) as follows: small, less than 100 tons/day; medium, between 100 and 500 tons/day; and large, more than 500 tons/day.

Direct-Load Transfer Stations At direct-load transfer stations, the wastes in the collection vehicles are emptied directly into the vehicle to be used to transport them to a place of final disposition or into facilities used to compact the wastes into transport vehicles (see Figure 3.13) or into waste bales that are transported to the disposal site. In some cases, the wastes may be emptied onto an unloading platform and then pushed into the transfer vehicles, after recyclable materials have been removed. The volume of waste that can be stored temporarily on the unloading platform is often defined as the *surge capacity* or the *emergency storage*

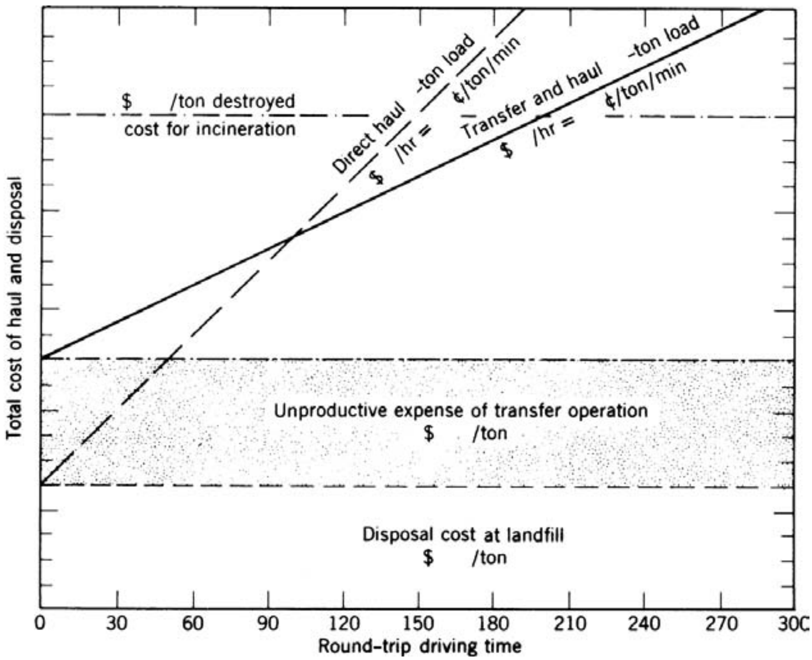


FIGURE 3.11 Cost comparison–incineration versus transfer and haul to landfill.

capacity of the station. Small direct-load transfer stations used to serve industrial parks, rural areas, and entrances to landfills are illustrated in Figure 3.14.

Storage-Load Transfer Station In the storage-load transfer station, wastes are emptied directly into a storage pit from which they are loaded into transport vehicles by various types of auxiliary equipment (see Figure 3.1*b*). The difference between a direct-load and a storage-load transfer station is that the latter is designed with a capacity to store waste (typically one to three days).

Vehicles for Uncompacted Wastes

Motor vehicles, railroads, and ocean-going vessels are the principal means now used to transport solid wastes. Pneumatic and hydraulic systems have also been used. However, in recent years, because of their simplicity and dependability, open-top semitrailers have found wide acceptance for the hauling of uncompacted wastes from direct-load transfer stations (see Figure 3.15*a*). Another combination that has proven to be very effective for uncompacted wastes is the truck-trailer combination (see Figure 3.15*b*). Transport trailers used for hauling solid waste over great distances are all of monoque construction, where the bed of the trailer also serves as the frame of the trailer. Using monoque construction allows greater waste volumes and weights to be hauled.

TABLE 3.11 Types of Transfer Stations Used for Municipal Solid Waste

Type	Description
Direct-Load Transfer Stations	
Large- and medium-capacity direct-load transfer station without compaction	Wastes to be transported to landfill are loaded directly into large open-top transfer trailers for transport to landfill.
Large- and medium-capacity direct-load transfer stations with compactors	Wastes to be transported to landfill are loaded directly into large compactors and compacted into specially designed transport trailers or into bales, which are then transported to landfill.
Small-capacity direct-load transfer stations	Small-capacity transfer stations are used in remote and rural areas. Small-capacity transfer station are also used at landfills as a convenience for residents who wish to haul wastes directly to landfill.
Storage-Load Transfer Station	
Large-capacity storage-load transfer station without compaction	Wastes to be transported to a landfill are discharged into a storage pit where they are pulverized before being loaded into open trailers. Waste is pulverized to reduce the size of the individual waste constituents to achieve more effective utilization of the transfer trailers.
Medium-capacity storage-load transfer station with processing and compaction facilities	Wastes to be transported to a landfill are discharged into a pit where they are further pulverized before being baled for transport to a landfill.
Other Types of Transfer Stations	
Combined discharge-load and direct-load transfer station	Waste to be transported to a landfill can either be discharged on a platform or discharged directly into a transfer trailer. Wastes discharged onto a platform are typically sorted to recover recyclable materials.
Transfer and transport operations at MRFs	Depending on the type of collection service provided, materials recovery and transfer operations are often combined in one facility. Depending on the operation of the MRF, wastes to be landfilled can be discharged directly into open trailers or into a storage pit to be loaded later into open-top trailers or baled for transport to a landfill.

Source: Adapted from G. Tchobanoglous, H. Theisen, and S. Vigil, *Integrated Solid Waste Management: Engineering Principles and Management Issues*, McGraw-Hill, New York, 1993.

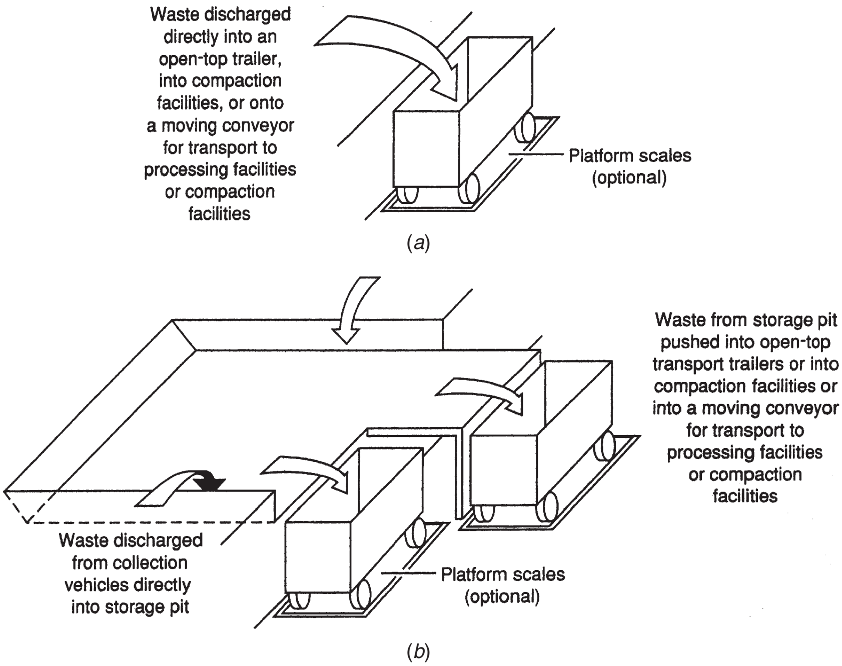


FIGURE 3.12 Definition sketch for two most common types of transfer stations: (*a*) direct discharge; (*b*) storage-discharge. (*Source:* LaGrega, M. D., P. L. Buckingham, and J. C. Evans, *Hazardous Waste Management*, 2nd ed., McGraw-Hill, New York, 2001.)

Transfer Station Siting Issues

A transfer station, resource recovery facility, or processing facility should be located and designed with the same care as described for an incinerator. Drainage of paved areas and adequate water hydrants for maintenance of cleanliness and fire control are equally important. Other concerns are landscaping, weigh scales, and traffic, odor, dust, litter, and noise control. Rail haul and barging to sea also involve the use of transfer stations. They may include one or a combination of grinding, baling, or compaction to increase densities, thereby improving transportation efficiency.

WASTE REDUCTION AND MATERIALS RECOVERY

Proper solid waste management should first prevent and reduce the generation of solid wastes, reduce their hazardous characteristics, and recover and recycle waste to the extent practicable and then dispose of the remaining wastes in a manner that does not endanger public health or the environment. The focus of this section is on waste reduction and the recovery and recycling of materials.

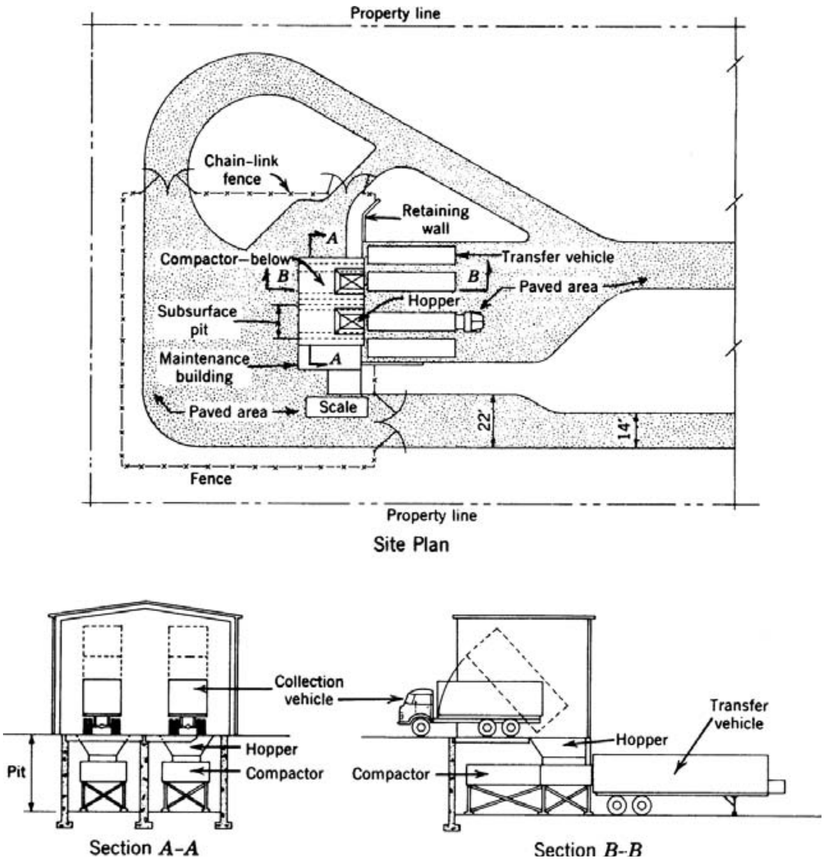
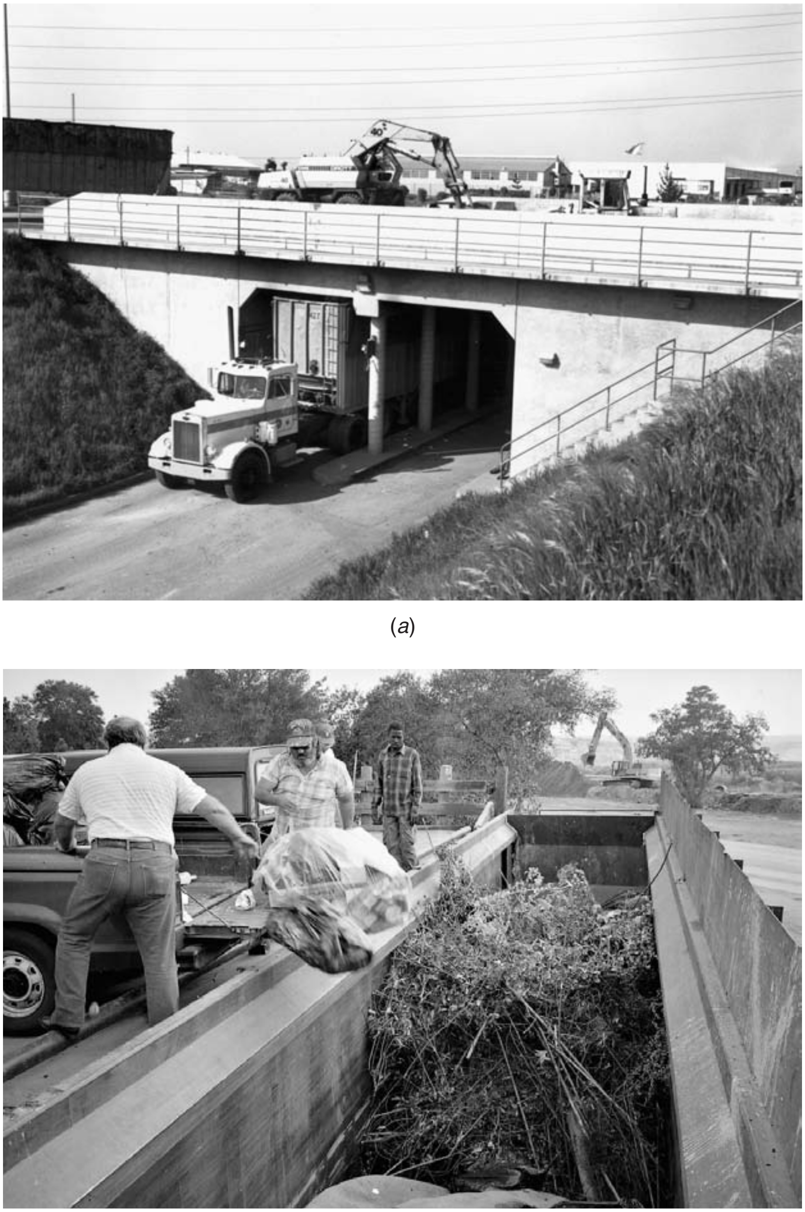


FIGURE 3.13 Direct-discharge transfer station equipped with stationary compactors. (Courtesy of Malcolm Pirnie, Inc. Reproduced with permission.)

Waste Reduction

The extent to which solid wastes can be reduced, recovered, and recycled should be an integral part of every solid waste management system study, whether involving composting, a sanitary landfill, or an incinerator. Composting is also considered a form of recycling. The first step, however, should be waste reduction at the point of generation or product formulation. Industrial material, process, and packaging changes can minimize the waste or substitute a less toxic or objectionable material. The amount of waste can then be reduced, and what waste is produced can be recovered, reused, or recycled to the extent feasible, thereby reducing the amount for final disposal. Additional details on source reduction may be found elsewhere.[9]

There has been considerable interest in a returnable bottle deposit law in some states to reduce highway litter, conserve resources, and reduce the volume



(a)

(b)

FIGURE 3.14 Small direct-discharge transfer stations: (*a*) convenience type located in rural areas at entrance of landfill disposal sites. (*b*) individuals unloading waste materials into a convenience type transfer station located at the entrance to a landfill.

(*a*)

(*b*)

FIGURE 3.15 Typical examples of transfer trailers used to transport waste over large distances to (*a*) single large trailer with drop bottom and (*b*) tractor trailer combination in process of being unloaded at landfill.

of solid wastes for disposal. The bottle law is usually applicable to all types of beverage containers, including glass, metal, and plastic, but not to other types of containers such as food jars, plastic and paper cups, wine and liquor bottles, and the like. The effectiveness of the bottle deposit law has been debated by some considering its limited application, the handling involved, and total cost, tangible and intangible. A substantial number of deposit containers are not returned by the consumer. This results in an unintended income to the supermarket or other retailer and what amounts to an additional cost to the consumer. Other alternatives should be considered. The reduction of *all* types of litter and insults to the landscape, including spillage from uncovered vehicles, elimination of junked cars, debris, and illegal dumps, and education of the public to promote a clean environment such as through Keep America Beautiful, requires greater support. Some returnable bottle laws are being amended to include liquor, wine, and wine cooler bottles and possibly other containers.

Materials Recovery and Recycling

Recovery of materials and energy from solid wastes is not new. Scavengers have salvaged newsprint and cardboard, rags, copper, lead, and iron for years. These materials, together with aluminum, glass, plastics, and wood, are being reclaimed at central collection and processing stations to a greater or lesser extent, depending on the available market, tax policies, and public interest. Energy recovery, where feasible, has been an important consideration in which unsorted solid waste and shredded solid waste, referred to as refuse (solid-waste) derived fuel (RDF), is burned to produce steam or electricity.

Recycling can effect savings in landfill space and in energy. One ton of newspapers can save 3.0 to 3.3 yd^3 of landfill space. It is estimated that 95 percent less energy is required to produce aluminum from recycled aluminum than from bauxite. Crushed recycled glass melts at a lower temperature than virgin raw material, thereby conserving energy. Unfortunately, the recycling of glass has essentially ceased because of a glut of material available, the high cost of handling and processing recycled glass, and the cost associated with pollution control.

Resource recovery is not a municipal operation to be entered into just because it seems like the logical or proper thing to do. It is a complex economic and technical system with social and political implications, all of which require competent analysis and evaluation before a commitment is made. Included are the capital and operating costs, market value of reclaimed materials and material quality, potential minimum reliable energy sales, assured quantity of solid wastes, continued need for a sanitary landfill for the disposal of excess and remaining unwanted materials and incinerator residue, and a site location close to the centroid of the generators of solid wastes. Not all concepts are viable. Incentives and monetary support may be required to obtain an acceptable site.

Resource recovery is a partial waste disposal and reclamation process. Materials not recovered may amount to 40 to 55 percent of the original waste by weight, although a resource recovery system can theoretically be used to separate up to 90 percent of the municipal waste stream into possibly marketable components. It has been estimated that under the best conditions only about 50 to 60 percent of the solid waste will be recovered. In 1979, 7 percent was being recycled for materials or energy. In 1990, the national average was estimated to be 11 percent. In the year 2000, the average was about 26 percent. In 2008, the average is close to 50 percent. As noted previously, the Board of Supervisors of the City of San Francisco has mandated a goal of 75 percent waste diversion by the year 2010. In general, it has been found that the recovery of materials from municipal solid waste is not a paying proposition. Most materials recovery operations are subsidized, in part, by the collection fees or by added monthly charges. In most communities, materials recovery facilities are used to help meet mandated diversion (from landfill disposal) requirements.

Processing Technologies for the Recovery of Materials

In the not-so-distant past, solid-waste processing and disposal methods have included the open dumping, hog feeding, incineration, grinding and discharge to a sewer, milling, compaction, sanitary landfill, dumping and burial at sea (prohibited in the United States), incineration, reduction, composting, pyrolization, wet oxidation, and anaerobic digestion. Currently, the most commonly accepted processing technologies involve the recovery of materials at materials recovery facilities and composting. Materials recovery facilities are considered next; composting is considered in the following section.

Implementation of Materials Recovery Facilities

Because the EPA has mandated diversion goals, most communities have developed a variety of materials recovery facilities. The purpose of this section is to define the type of materials recovery facilities now in use, to review the principal unit operations and processes used for the recovery of materials, and to highlight the planning issues associated with the implementation of a materials recovery facility. Additional details on materials recovery facilities may be found in Ref. 10.

Types of Materials Recovery Facilities (MRFs) The separation of household and commercial waste can be done at the source, at the point of collection by collection crews or at centralized *materials recovery facilities* or large integrated *materials recovery/transfer facilities* (MR/TFs). The type of MRF will depend on the type of collection service provided and the degree of source separation the waste has undergone before reaching the MRF. The two general types of MRFs are (1) for source-separated material and (2) for commingled solid waste. The functions of each of theses types of MRFs are reviewed in Table 3.12. As reported in Table 3.12, may different types of MRFs have been developed, depending on the specific objective. Further, as reported in Table 3.13, materials recovery facilities can also be classified in terms of size and the degree of mechanization. Small MRFs associated with the further processing of source-separated materials tend to be less highly mechanized.

TABLE 3.12 Typical Examples of Materials and Functions/Operations of MRFs Used for Processing of Source-Separated Recyclable Materials and Commingled Solid Waste

Materials	Function/Operation
MRFs for Source-Separated Recyclable Materials	
Mixed paper and cardboard	Manual separation of high-value paper and cardboard or contaminants from commingled paper types; baling of separated materials for shipping; storage of baled materials
	Manual separation of cardboard and mixed paper; baling of separated materials for shipping; storage of baled materials
	Manual separation of old newspaper, old corrugated cardboard, and mixed paper from commingled mixture; baling of separated materials for shipping; storage of baled materials
PETE and HDPE plastics	Manual separation of PETE and HDPE from commingled plastics; baling of separated materials for shipping; storage of baled materials
Mixed plastics	Manual separation of PETE, HDPE, and other plastics from commingled mixed plastics; baling of separated materials for shipping; storage of baled materials
Mixed plastics and glass	Manual separation of PETE, HDPE, and glass by color from commingled mixture; baling of separated materials for shipping; storage of baled materials
Mixed glass With sorting	Manual separation of clear, green, and amber glass; storage of separated materials
Without sorting	Storage of separated mixed glass
Aluminum and tin cans	Magnetic separation of tin cans from commingled mixture of aluminum and tin cans; baling of separated materials for shipping; storage of baled materials
Plastic, aluminum cans, tin cans, and glass	Manual or pneumatic separation of polyethylene terepholate (PETE), high-density polyethylene (HDPE), and other plastics; manual separation of glass by color, if separated; magnetic separation of tin cans from commingled mixture of aluminum and tin cans; magnetic separation may occur before or after the separation of plastic; baling of plastic (typically two types), aluminum cans and tin cans, and crushing of glass and shipping; storage of baled and crushed materials
Yard wastes	Manual separation of plastic bags and other contaminants from commingled yard wastes, grinding of clean yard waste, size separation of waste that has been ground up, storage of oversized waste for shipment to biomass facility, and composting of undersized material
	Manual separation of plastic bags and other contaminants from commingled yard wastes followed by grinding and size separation to produce landscape mulch; storage of mulch and composting of undersized materials
	Grinding of yard wasted to produce biomass fuel; storage of ground material

(*continues*)

TABLE 3.12 (*continued*)

Materials	Function/Operation
MRFs for Commingled Solid Waste	
Recovery of recyclable materials to meet mandated first-stage diversion goals	Bulky items, cardboard, paper, plastics (PETE, HDPE, and other mixed plastic), glass (clear and mixed), aluminum cans, tin cans, other ferrous materials
Recovery of recyclable materials and further processing of source-separated materials to meet second-stage diversion goals	Bulky items, cardboard, paper, plastics (PETE, HDPE, and other mixed plastic), glass (clear and mixed), aluminum cans, tin cans, other ferrous materials; additional separation of source-separated materials, including paper, cardboard, plastic (PETE, HDPE, other), glass (clear and mixed), aluminum cans, tin cans
Preparation of MSW for use as fuel for combustion	Bulky items, cardboard (depending on market value), glass (clear and mixed), aluminum cans, tin cans, other ferrous materials
Preparation of MSW for use as feedstock for composting	Bulky items, cardboard (depending on market value), plastics (PETE, HDPE, and other mixed plastic), glass (clear and mixed), aluminum cans, tin cans, other ferrous materials
Selective recovery of recyclable materials	Bulky items, office paper, old telephone books, aluminum cans, PETE and HDPE, and ferrous materials; other materials, depending on local markets

Source: Adapted from H. Leverenz, G. Tchobanoglous, and D. B. Spencer, "Recycling," in G. Tchobanoglous and F. Kreith (Eds.), *Solid Waste Handbook*, 2nd ed., McGraw-Hill, New York, 2002, Chapter 8.

Methods and Equipment for the Separation and Recovery of Materials

Methods and processes used singly and in various combinations to recover and prepare wastes for reuse and/or disposal are summarized in Table 3.14. Of the methods reported in Table 3.14, manual sorting is by far the most commonly used method for processing waste materials (see Figure 3.16). It is interesting to note that no machine has been developed to date that can match the eye–hand coordination of humans. The particulate grouping of unit processes and operations will depend on the characteristics of the material to be separated.

MRF Process Flow Diagrams Once a decision has been made on how and what recyclable materials are to be recovered, MRF process flow diagrams must

TABLE 3.13 Typical Types of Materials Recovery Facilities, Capacity Ranges, and Major Functions and System Components Based on Degree of Mechanization

System Type	Capacity (tons/day)	Major System Components
Materials recovery Low	5–20	Processing of source-separated materials only; enclosed building, concrete floors, elevated hand-sorting conveyor, baler (optional), storage for separated and prepared materials for one month, support facilities for workers
Intermediate	20–100	Processing of source-separated commingled materials and mixed paper; enclosed building, concrete floors, elevated hand-sorting conveyor, conveyors, baler, storage for separated and baled materials for two weeks, support facilities for workers, buy-back center
High	>100	Processing of commingled materials or MSW; same facilities as intermediate system plus mechanical bag breakers, magnets, shredders, screens, and storage for baled materials for up to two months
Composting Low end system	5–20	Source-separated yard waste feedstock only; grinding equipment, cleared level ground with equipment to form and turn windrows, screening equipment (optional)
High-end system	>20	Feedstock derived from source-separated yard waste or processing of commingled wastes; facilities include enclosed building with concrete floors, in vessel composting reactors; enclosed building for curing of compost product; equipment for processing (e.g. screening and bagging); and marketing compost product

Source: H. Leverenz, G. Tchobanoglous, and D. B. Spencer, "Recycling," in G. Tchobanoglous and F. Kreith (Eds.), *Solid Waste Handbook*, 2nd ed., McGraw-Hill, New York, 2002, Chapter 8.

be developed. In developing MRF process flow diagrams, the following factors must be considered: (1) identification of the characteristics of the waste materials to be processed, (2) consideration of the specifications for recovered materials now and in the future, and (3) the available types of equipment and facilities. For example, specific waste materials cannot be separated effectively from commingled MSW unless bulky items such as lumber and white goods and large pieces of cardboard are first removed and the plastic bags in which waste materials are placed are broken open and the contents exposed. The specifications for the recovered material will affect the degree of separation to which the waste

TABLE 3.14 Typical Methods and Equipment Used for Processing and Recovery of Individual Waste Components from MSW

Processing Options	Description
Manual sorting	Unit operation in which personnel physically remove items from the waste stream. Typical examples include (1) removal of bulky items that would interfere with other processes and (2) sorting material off an elevated conveyor into large bins located below the conveyor.
Size reduction	Unit operation used for the reduction of both commingled MSW and recovered materials. Typical applications include (1) hammermills for shredding commingled MSW, (2) shear shredders for use with commingled MSW and recycled materials such as aluminum, tires, and plastics, and (3) tub grinders used to process yard wastes.
Size separation	Unit operation in which materials are separated by size and shape characteristics, most commonly by the use of screens. Several types of screens are in common use, including (1) reciprocating screens for sizing shredded yard wastes, (2) trommel screens used for preparing commingled MSW prior to shredding, and (3) disc screens used for removing glass from shredded MSW.
Magnetic field separation	Unit operations in which ferrous (magnetic) materials are separated from nonmagnetic materials. A typical application is the separation of ferrous from nonferrous materials (e.g., tin from aluminum cans).
Densification (compaction)	Densification and compaction are unit operations used to increase the density of recovered materials to reduce transportation costs and simplify storage. Typical applications include (1) the use of baling for cardboard, paper, plastics, and aluminum cans and (2) the use of cubing and pelletizing for the production of densified RDF.
Materials handling	Unit operations used for the transport and storage of MSW and recovered materials. Typical applications include (1) conveyors for the transport of MSW and recovered materials, (2) storage bins for recovered materials, and (3) rolling stock such as fork lifts, front-end loaders, and various types of trucks for the movement of MSW and recovered materials.
Automated sorting	Unit operation in which materials are separated by material characteristics. Typical examples include (1) optical sorting of glass by color, (2) X-ray detection of polyvinyl chloride (PVC), and (3) infrared sorting of mixed resins.

Source: G. Tchobanoglous, H. Theisen, and S. Vigil, *Integrated Solid Waste Management: Engineering Principles and Management Issues*, McGraw-Hill, New York, 1993.

(a)

(b)

FIGURE 3.16 Typical manual separation of waste components at a materials recovery facility: (a) separating cardboard, paper, plastic, film plastic, glass, tin cans, and aluminum cans from mixed municipal solid waste at a facility with a current capacity of 400 tons/day with room to expand to 1200 ton/day by adding two more sorting lines and (b) separating contaminants from source separated compostable wastes before preprocessing (size reduction) and placement in piles in long rows (windrows) for composting. (See Figure 3.20(b).) (Courtesy H. Leverenz.)

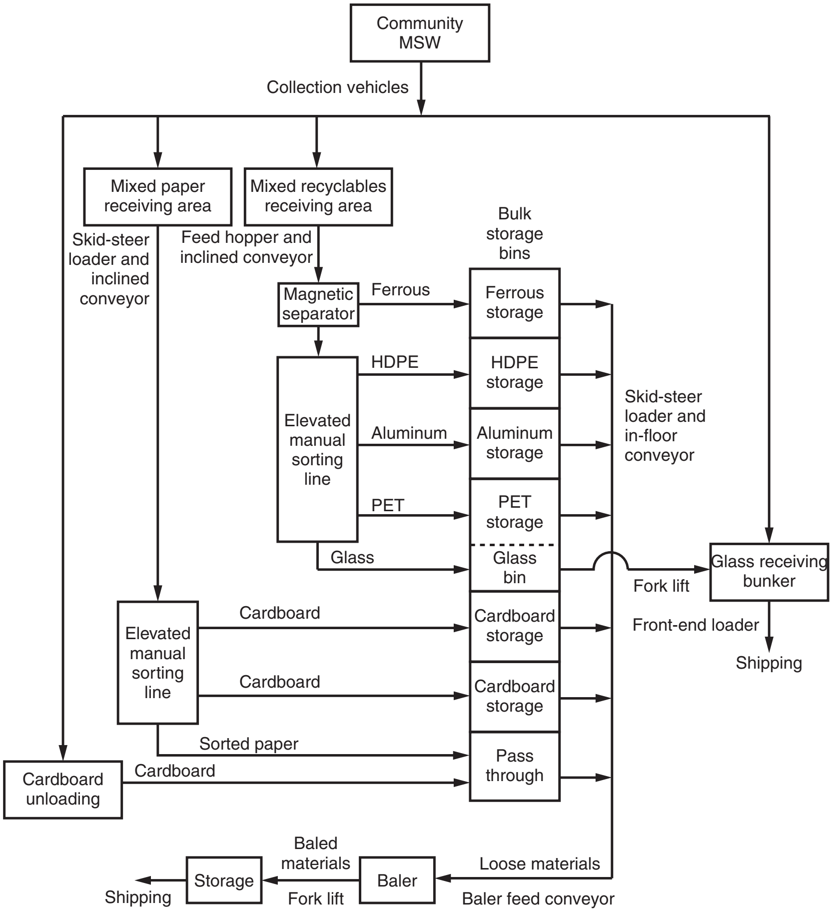


FIGURE 3.17 Process flow diagram for MRF used to further process source-separated waste. (*Source:* H. Leverenz, G. Tchobanoglous, and D. B. Spencer, "Recycling," in G. Tchobanoglous and F. Kreith (Eds.), *Solid Waste Handbook*, 2nd ed., McGraw-Hill, New York, 2002, Chapter 8.)

material is subjected. Three typical MRF process flow diagrams are presented in Figures 3.17, 3.18, and 3.19 for source-separated recyclable material, for mixed paper and cardboard, and commingled solid waste, respectively.[11]

Technical Considerations in the Planning and Design of MRFs

Technical consideration in the planning and design of MRFs involves three basic steps: (1) feasibility analysis, (2) preliminary design, and (3) final design. These planning and design steps are common to all major public works projects such as landfills or wastewater treatment plants. In some cases, the feasibility analysis has

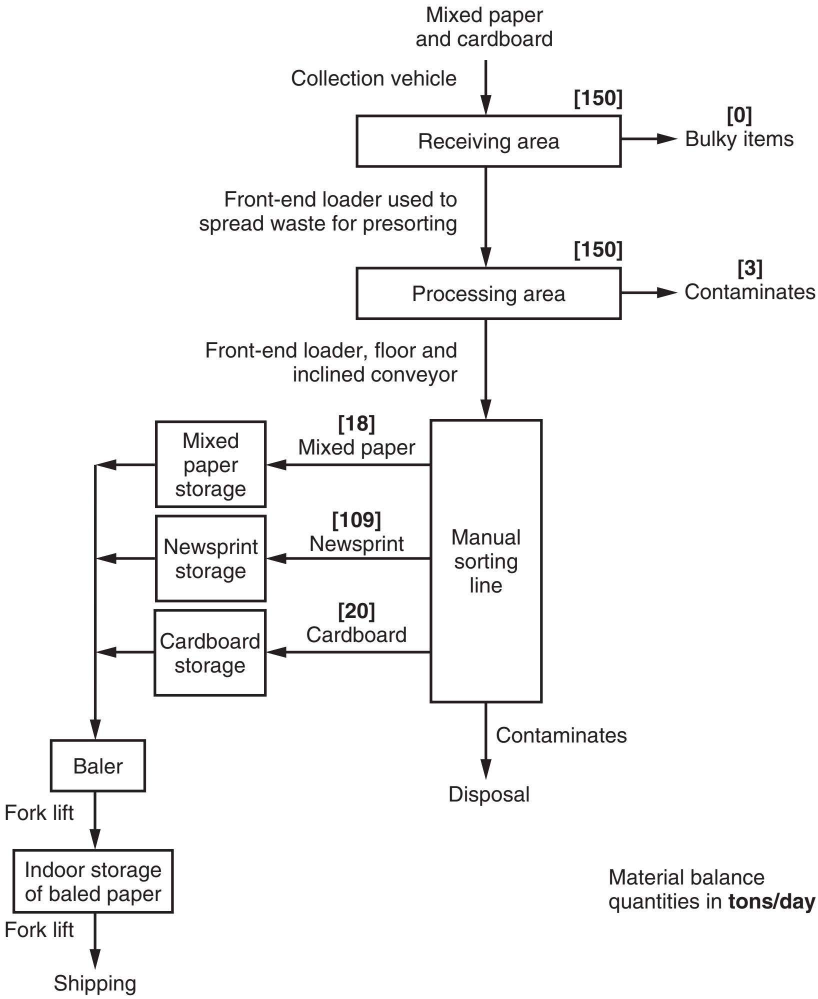


FIGURE 3.18 Process flow diagram for MRF used to separate mixed paper and cardboard. (*Source:* H. Leverenz, G. Tchobanoglous, and D. B. Spencer, "Recycling," in G. Tchobanoglous and F. Kreith (Eds.), *Solid Waste Handbook*, 2nd ed., McGraw-Hill, New York, 2002, Chapter 8.)

already been accomplished as part of the integrated waste management planning process. These topics are considered further in Table 3.15.[11]

COMPOSTING

Composting is the controlled decay of organic matter in a warm, moist environment by the action of bacteria, fungi, and other organisms. The organic matter

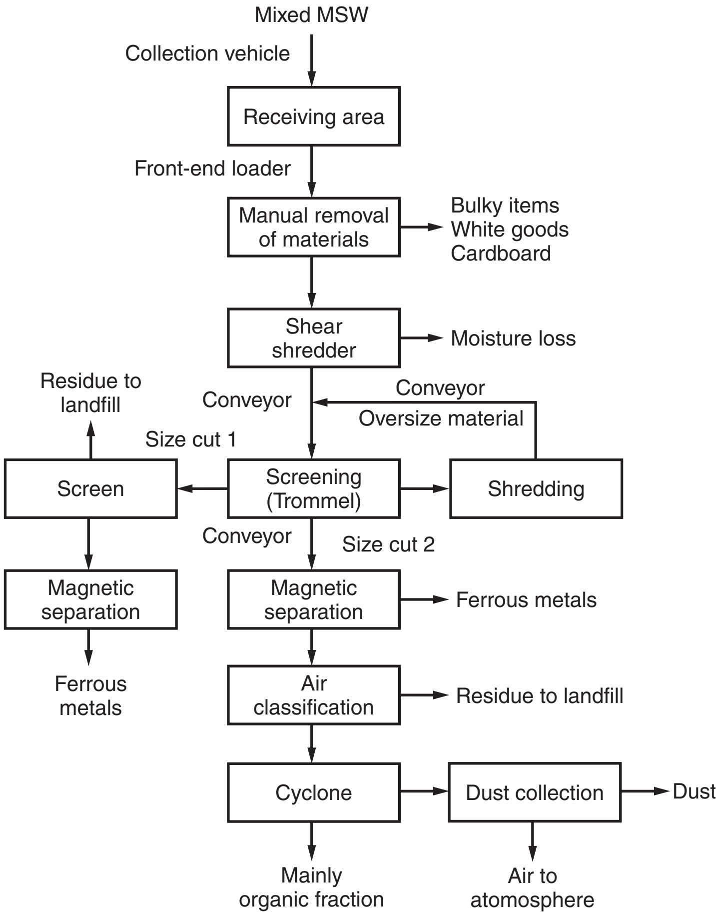


FIGURE 3.19 Process flow diagram for MRF used to process commingled waste for recovery of recyclable materials. (*Source:* H. Leverenz, G. Tchobanoglous, and D. B. Spencer, "Recycling," in G. Tchobanoglous and F. Kreith (Eds.), *Solid Waste Handbook*, 2nd ed., McGraw-Hill, New York, 2002, Chapter 8.)

may be in municipal solid waste, wastewater sludge, septage, agricultural waste, manure, leaves and other yard waste, or combinations of these materials and other organic wastes. Composting is becoming an increasingly popular waste management option as communities look for ways to divert portions of the local waste stream from landfills. The principal applications of composting are for (1) yard wastes, (2) the organic fraction of MSW, (3) partially processed commingled MSW, and (4) co-composting the organic fraction of MSW with wastewater sludge. Because of the importance of composting in meeting mandated waste diversion goals, the number of composting facilities has increased significantly over the past 10 years. The uses of compost and constraints to its uses; a

TABLE 3.15 Important Technical Considerations in the Planning and Design of MRFs

Step 1: Feasibility Analysis	
Function of MRF	The coordination of the MRF with the integrated waste management plan for the community. A clear explanation of the role and function of the MRF in achieving landfill waste diversion, and recycling goals is a key element.
Conceptual design, including types of wastes to be sorted	What type of MRF should be built, which materials will be processed now and in the future, and what should be the design capacity of the MRF? Plan views and renderings of what the final MRF might look like are often prepared.
Siting	While it has been possible to build and operate MRFs in close proximity to both residential and industrial developments, extreme care must be taken in their operation if they are to be environmentally and aesthetically acceptable. Ideally, to minimize the impact of the operation of MRFs, they should be sited in more remote locations where adequate buffer zones surrounding the facility can be maintained. In many communities, MRFs are located at the landfill site.
Economic analysis	Preliminary capital and operating costs are delineated. Estimates of revenues available to finance the MRF (sales of recyclables, avoided tipping fees, subsidies) are evaluated. A sensitivity analysis must be performed to assess the effects of fluctuating prices for recyclables and the impacts of changes in the composition of the waste.
Ownership and operation	Typical ownership and operation options include public ownership, private ownership, or public ownership with contract operation.
Procurement	What approach is to be used in the design and construction of the MRF? Several options exist, including (1) the traditional architect-engineer and contractor process, (2) the turn-key contracting process in which design and construction are performed by a single firm, and (3) a full-service contract in which a single contractor designs, builds, and operates the MRF

(*continues*)

TABLE 3.15 (*continued*)

Step 2: Preliminary Design	
Process flow diagrams	One or more process flow diagrams are developed to define how recyclable materials are to be recovered from MSW (e.g., source separation or separation from commingled MSW). Important factors that must be considered in the development of process flow diagrams include (1) characteristics of the waste materials to be processed, (2) specifications for recovered materials now and in the future, and (3) the available types of equipment and facilities.
Materials recovery rates	Prediction of the materials flow to the MRF is necessary to estimate the effectiveness or performance of the recycling program. The performance of a recycling program, the overall component recovery rate, is generally reported as a materials recovery rate or recycling rate, which is the product of three factors: (1) participation factor, (2) composition factor, and (3) source recovery factor. Component capture rates for the recyclable materials most commonly collected in source separation recycling programs must be estimated. Composition factors are measured in waste composition studies.[a]
Materials balances and loading rates	One of the most critical elements in the design and selection of equipment for MRFs is the preparation of a materials balance analysis to determine the quantities of materials that can be recovered and the appropriate loading rates for the unit operations and processes used in the MRF.
Selection of processing equipment	Factors that should be considered in evaluating processing equipment include: capabilities, reliability, service requirements, efficiency, safety of operation, health hazard, environment impact, and economics.
Facility layout and design	The overall MRF layout includes (1) sizing of the unloading areas for commingled MSW and source-separated materials; (2) sizing of presorting areas where oversize or undesirable materials are removed; (3) placement of conveyor lines, screens, magnets, shredders, and other unit operations; (4) sizing of storage and out-loading areas for recovered materials; and (5) sizing and design of parking areas and traffic flow patterns in and out of the MRF. Many of these layout steps are also common to the layout and design of transfer stations.

(*continues*)

TABLE 3.15 (*continued*)

Staffing	Depends on type of MRF (i.e., degree of mechanization).
Economic analysis	Refine preliminary cost estimate prepared in feasibility study.
Environmental issues	Important environmental issues include groundwater contamination, dust emissions, noise, vector impacts, odor emissions, vehicular emissions, and other environmental emissions.
Health and safety issues	Important health and safety issues are related to worker and public access issues.
Step 3: Final Design	
Preparation of final plans and specifications	Plans and specifications will be used for bid estimates and construction.
Preparation of environmental documents	The necessary environmental documents (e.g., Environmental Impact Report) are prepared.
Preparation of detailed cost estimate	A detailed engineer's cost estimate is made based on materials take-offs and vendor quotes. The cost estimate will be used for the evaluation of contractor bids if the traditional procurement process is used.
Preparation of procurement documents	A bidding process is used to obtain supplies, equipment, and services related to the construction, operation, and maintenance of the facility.

[a]Typical component recovery rates may be found in Leverenz et al. (2002).

Source: H. Leverenz, G. Tchobanoglous, and D. B. Spencer, "Recycling," in G. Tchobanoglous and F. Kreith (Eds.), *Solid Waste Handbook*, 2nd ed., McGraw-Hill, New York, 2002, Chapter 8.

description of the compost process; descriptions of some of the more common composting processes, important design and operational considerations, and the implementation of the compost process are considered in the following discussion. Additional details on the compost process can be found in Refs. 12–15.

Uses of Compost and Constraints to Its Use

Compost improves soil moisture retention; it is a good soil conditioner but a poor fertilizer. Compost, depending on the waste source and its composition, may be used as a soil amendment for agricultural soil and landscaping in municipal parks, golf courses, gardens, and green belts; sod growing; home gardens; and nursery and greenhouse use. Compost may also be used as landfill cover, land reclamation, animal litter, and possibly animal feed. It may also be used as an additive to fertilizer, as a fuel, or in building materials.

The presence of toxic levels of pesticides, heavy metals, and pathogens should be determined and evaluated to ensure the levels are compatible with the intended

TABLE 3.16 Maximum Allowable Metal Concentrations for Class I and II Compost and Allowable Usage

Parameter	Concentration (ppm dry weight)	
	Class I[a]	Class II[b]
Mercury	10	10
Cadmium	10	25
Nickel	200	200
Lead	250	1000
Chromium, total	1000	1000
Copper	1000	1000
Zinc	1000	2500
Polychlorinated biphenyls (PCBs) total	1	10

[a]Must not be used on crops grown for direct human consumption (i.e., crops consumed without processing to minimize pathogens). Can be used on food chain crops and other agricultural and horticultural uses. Must not exceed 10 mm (0.39 in.) particle size.
[b]Must be restricted to use on nonfood chain crops. Must not exceed 25 mm (0.98 in.) particle size.

Source: New York State, *Municipal Energy Recovery Facilities Handbook*, New York State Environmental Facilities Corporation, Albany, 1988.

use of the compost. A typical listing of permissible metal concentrations in compost is presented in Table 3.16. For pathogen reduction purposes, the temperature of the mixture must be maintained at or above 131 °F (55 °C) for at least three consecutive days.

The total composting time, including curing, is determined by the material, process used, and exposure to the elements. Two weeks to as much as 18 months may be required for complete stabilization and curing of the compost. Thus, a plant location distant from habitation is recommended, as odors may become a problem. Also, because the demand for compost may be seasonal, provision must be made for compost storage.

Composting Process

Composting involves the biological decomposition of organic materials (substrates) under controlled conditions that allow for the development of an end product that is biologically stable and free of viable pathogens and plant seeds and can be applied to land beneficially. The key concepts and objectives contained in the definition of compost are as follows:

- Composting is a biological process (e.g., aerobic anaerobic).
- Composting results in the production of a biologically stable end product.
- The end products free of viable pathogens.
- The end product is free of viable plant seeds.
- The end product can be applied to land beneficially.

(*a*)

(*b*)

FIGURE 3.20 Overview of windrow composting operation: (a) preparation (size reduction) of yard waste for composting and (b) processed waste placed in windrows to undergo the composting process (see also Figure 3.21).

To meet the above objectives, the composting process, as illustrated in Figure 3.20, usually involves the following three basic steps:

1. Preprocessing (e.g., size reduction, seeding, nutrient addition, and addition of bulking agent)
2. Decomposition and stabilization of organic material (two-stage process comprised of a first-stage high-rate phase followed by second-stage curing phase)

3. Postprocessing (e.g., grinding, screening, bagging, and marketing of compost product)

Composting of mixed solid waste should be preceded by a separation and recycling program, including glass, plastic, and metal separation; then usually shredding or grinding; and a program for the periodic collection of household hazardous waste. Industrial and other hazardous waste must be excluded.

The two-stage decomposition and stabilization of organic solid waste to a compost process can be described by the following reaction:

$$\left.\begin{array}{r}\text{Proteins}\\ \text{Amino acids}\\ \text{Lipids}\\ \text{Carbohydrates}\\ \text{Cellulose}\\ \text{Lignin}\\ \text{Ash}\end{array}\right\} \begin{array}{l} + O_2 + \text{Nutrients} + \text{Bacteria} \rightarrow \text{Compost} \\ + \text{Newcells} + CO_2 + H_2O + NO_3^- + SO_4^{-2} + \text{Heat}\end{array}$$

(Principal components comprising the organic fraction of MSW) (Principally cellulose, lignin, and ash)

As shown by this reaction, essentially all of the organic matter with the exception of cellulose and lignin are converted during the compost process. It should be noted that, in time, both the cellulose and lignin will undergo further biological decomposition, primarily through the action of fungi and actinomycetes.

Postprocessing will typically include screening and nutrient and other amendment additions, depending on the application. Many municipalities make the compost available to the residents for a nominal price.

Composting Technologies

The three composting methods used most commonly in the United States are (1) windrow, (2) aerated static pile, and (3) in-vessel methods. It should be noted that over the past 100 years more than 50 individual compost processes have been developed. The more important of these processes based on function and/or the type of reactor used for the process are summarized in Table 3.17. Some of the processes are described next.

Although many process variations are in use, odor control is a major concern in all processes. Aeration and controlled enclosed processing facilities can be used to minimize the problem. Provision must also be made for vector control, leachate collection, and the prevention of groundwater and surfacewater pollution. The stabilized and cured compost may be ground but is usually screened before sale. Storage space is required.

TABLE 3.17 Municipal Composting Systems Grouped by Function or Reactor Configuration

Function or Configuration	Commercial Process
Heaps and windrows, natural aeration, batch operation	Indore/Bangalore
	Artsiely
	Baden-Baden (hazemag) Buhler
	Disposals Associates
	Dorr-Oliver
	Spohn
	Tollemache
	Vuilafvoer Maatschappij (VAM)
Cells with natural or forced aeration, batch operation	Beccari
	Biotank (Degremont)
	Boggiano-Pico
	Kirkconnel (Dumfriesshire)
	Metro-Waste
	Prat (Sofranie)
	Spohn
	Verdier
	Westinghouse/Naturizer
Horizontal rotating and inclined drums, continuous operation	Dano Biostabilizer
	Dun Fix
	Fermascreen (batch)
	Head Wrightson
	Vickers Seerdrum
Vertical flow reactors, continuous operation, agitated bed, natural or forced aeration	Earp-Thomas
	Fairfield-Hardy
	Frazer-Eweson
	Jersey (John Thompson)
	Multibacto
	Nusoil
	Snell
	Triga
Agitated bed	Fairfield-Hardy

Source: G. Tchobanoglous, and F. Kreith, *Solid Waste Handbook*, 2nd ed., McGraw-Hill, New York, 2002.

Windrow Composting In the windrow process, after processing the material to be composted is placed in long windrows (see Figure 3.20). The windrows are 3 to 6 feet high (1–2 m) and 6 to 15 feet wide (2–5 m) at the base. The windrow process is conducted normally in uncovered pads and relies on natural ventilation with frequent mechanical mixing of the piles to maintain aerobic conditions. The windrow process can be accelerated if the compost is turned over every four or five days, until the temperature drops from about 150 ° or 140 °F (66 ° or 60 °C) to about 100 °F (38 °C) or less. Under typical operating conditions, the windrows are turned every other day. The turning is accomplished with specialized equipment (see Figure 3.21) and serves to aerate the pile and allow moisture to escape. To meet the EPA pathogen reduction requirements, the windrows have to be turned five times in 15 days, maintaining a temperature of 55 °C. The complete compost process may require two to six months.

Because anaerobic conditions can develop within the windrow between turnings, putrescible compounds can be formed that can cause offensive odors, especially when the windrows are turned. In many locations, negative aeration is provided to limit the formation of odorous compounds. Where air is provided mechanically, the process is known as aerated windrow composting.[12] Odors will result if the compost is not kept aerobic. It may be necessary to enclose the operation and provide fans and collectors of the odorous air, forcing it through a scrubber or other treatment device for discharge up a stack to the atmosphere.

Aerated Static Pile Composting In the aerated static pile process, the material to be composted is placed in a pile and oxygen is provided by mechanical aeration systems. Most states require paved surfaces for the pile construction areas to permit capture and control runoff and allow operation during wet weather. The most common aeration system involves the use of a grid of subsurface piping (see Figure 3.22). Aeration piping often consists of flexible plastic drainage tubing assembled on the composting pad. Because the drainage-type aeration piping

FIGURE 3.21 View of machine used to aerate compost placed in windrows (Courtesy H. Leverenz.)

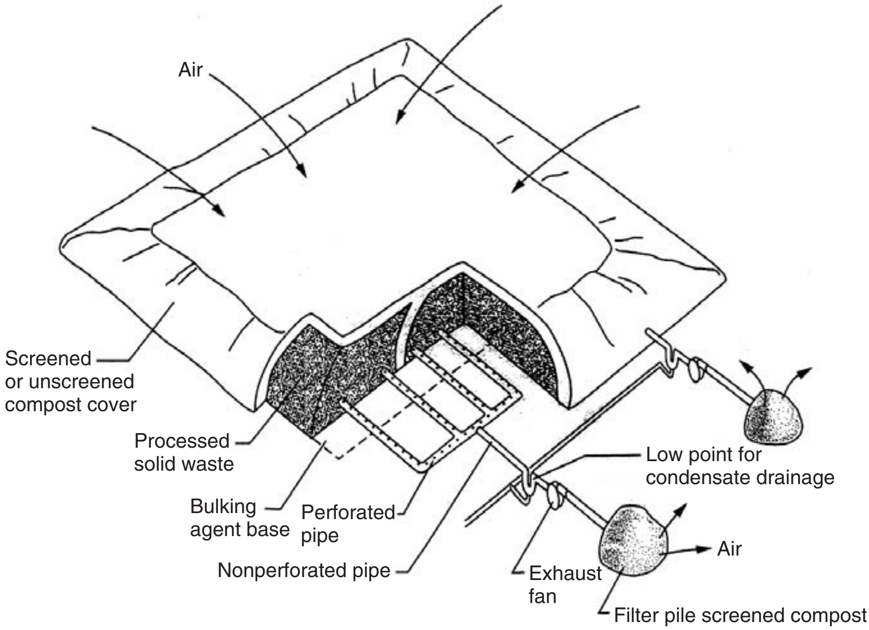


FIGURE 3.22 Schematic of static aerated compost pile.

is inexpensive, it is often used only once. Before constructing the static pile, a layer of wood chips is placed over the aeration pipes or grid to provide uniform air distribution. The static pile is then built up to 8 to 12 feet (2.6–3.9 m) using a front-end loader. A cover layer of screened or unscreened compost is placed over the sludge to be composted. Typically, oxygen is provided by pulling air through the pile with an exhaust fan. Air that has passed through the compost pile is vented to the atmosphere though a compost filter for odor control.

In-Vessel Composting Systems In-vessel composting is accomplished inside an enclosed container or vessel. Every imaginable type of vessel has been used as a reactor in these systems, including vertical towers, horizontal rectangular and circular tanks, and circular rotating tanks. In-vessel composting systems can be divided into two major categories: plug flow and dynamic (agitated bed). In plug flow systems, the relationship between particles in the composting mass stays the same throughout the process, and the system operates on the basis of a first-in, first-out principle. In a dynamic system, the composting material is mixed mechanically during the processing.

Mechanical systems are designed to minimize odors and process time by controlling environmental conditions such as air flow, temperature, and oxygen concentration. The popularity of in-vessel composting systems has increased in recent years. Reasons cited for this increased use are process and odor control, faster throughput, lower labor costs, and smaller area requirements. The detention time for in-vessel systems varies from 1 to 2 weeks, but virtually all systems employ a 4- to 12-week curing period after the active composting period.

Other Composting Technologies *Naturizer* composting uses sorting, grinding and mixing, primary and secondary composting including three grinding operations, aeration, and screening. Digested wastewater sludge, raw-wastewater sludge, water, or segregated wet garbage is added at the first grinding for dust and moisture control. The total operation takes place in one building in about six days.

The *Dano* composting (stabilizer) plant consists of sorting, crushing, biostabilization three to five days in a revolving drum to which air and moisture are added, grinding, air separation of nonorganics, and final composting in open windrows. Temperatures of 140 °F (60 °C) are reached in the drum. Composting can be completed in 14 days by turning the windrows after the fourth, eighth, and twelfth days. Longer periods are required if the windrows are not kept small, turned, and mixed frequently and if grinding is not thorough. In a more recent version, the drum treatment is for 8 hours followed by screening, final composting in covered aerated piles for about three weeks, and then three weeks of aging in static piles.

The *Fairfield–Hardy* process handles garbage and trash and wastewater sludge. The steps in the process are (1) sorting—manual and mechanical to separate salvageable materials; (2) coarse shredding; (3) pulping; (4) wastewater sludge addition, if desired; (5) dewatering to about 50 percent moisture; (6) three-to five-day digestion with mixing and forced air aeration, temperature ranges from 140° to 170 °F (60°–76 °C); (7) air curing in covered windrows; and (8) pelletizing, drying, and bagging. Compost from the digester is reported to have heat values of 4,000 Btu/lb and, when pelletized and dried, 6,450 Btu/lb.

The *Bangalore* process is used primarily in India. Layers of unshredded solid waste and night soil are placed in a shallow trench; the top is covered with soil. The duration of the treatment is 120 to 150 days.

Compost Process Design and Operational Considerations

The principal design considerations associated with the aerobic biological decomposition of prepared solid wastes are presented in Table 3.18. It can be concluded from this table that the preparation of a composting process is not a simple task, especially if optimum results are to be achieved. For this reason, most of the commercial composting operations that have been developed are highly mechanized and are carried out in specially designed facilities. Because of their importance, pathogen and odor control are considered further below. Additional details on the design and operation of compost processes may be found in Refs. 13 and 16.

Pathogen Control Pathogenic organisms and weed seeds exposed to the higher temperatures for the times indicated in Table 3.19 will be destroyed. However, because of the nature of solid waste, the processes used, and the

TABLE 3.18 Important Design Considerations for Aerobic Composting Process

Item	Comment
Particle size	For optimum results, the size of solid wastes should be between 25 and 75 mm (1 and 3 in).
Carbon to nitrogen (C/N) ratio	Initial C/N ratios (by mass) between 25 and 50 are optimum for aerobic composting. At lower ratios ammonia is given off. Biological activity is also impeded at lower ratios. At higher ratios, nitrogen may be a limiting nutrient.
Blending and seeding	Composting time can be reduced by seeding with partially decomposed solid wastes to the extent of about 1–5% by weight. Wastewater sludge can also be added to prepared solid wastes. Where sludge is added, the final moisture content is the controlling variable.
Moisture content	Moisture content should be in the range between 50 and 60% during the composting process. The optimum value appears to be about 55%.
Mixing/turning	To prevent drying, caking, and air channeling, material in the process of being composted should be mixed or turned on a regular schedule or as required. Frequency of mixing or turning will depend on the type of composting operation.
Temperature	For best results, temperature should be maintained between 122° and 131°F (50° and 55°C) for the first few days and between 131° and 140°F (55° and 60°C) for the remainder of the active composting period. If temperature goes beyond 151°F (66°C), biological activity is reduced significantly.
Control of pathogen	If properly conducted, it is possible to kill all the pathogens, weeds, and seeds during the composting process. To do this, the temperature must be maintained between 140° and 158°F (60° and 70°C) for 24 hours.
Air requirements	The theoretical quantity of oxygen required can be estimated using the stiochiometrc equation for the conversion of organic matter. Air with at least 50% of the initial oxygen concentration remaining should reach all parts of the composting material for optimum results, especially in mechanical systems.
pH control	To achieve an optimum aerobic decomposition, pH should remain at 7–7.5 range. To minimize the loss of nitrogen in the form of ammonia gas, pH should not rise above about 8.5.
Degree of decomposition	The degree of decomposition can be estimated by measuring the reduction in the organic matter present using the chemical oxygen demand (COD) test. Another measurement that has been used to determine the degree of decomposition is the use of respiratory quotient (RQ)
Land requirement	The land requirements for a plant with a capacity of 50 tons/day will be 1.5–2.0 acres. The land area required for larger plant will be less.

Note: $1.8 \times {}^{\circ}C + 32 = {}^{\circ}F$.

Source: G. Tchobanoglous, and F. Kreith, *Solid Waste Handbook*, 2nd ed., McGraw-Hill, New York, 2002; and U.S. EPA, *Composting of Municipal Solid Wastes in the United States*, EPA, Washington, DC, 1971.

TABLE 3.19 Temperature and Time of Exposure Required for Destruction of Some Common Pathogens and Parasites

Organism	Observations
Salmonella typhosa	No growth beyond 46 °C; death within 30 min. at 55–60 °C and within 20 min. at 60 °C; destroyed in a short time in compost environment.
Salmonella sp.	Death within 1 hr at 55 °C and within 15–20 min. at 60 °C.
Shigella sp.	Death within 1 hr at 55 °C.
Escherichia coli	Most die within 1 hr at 55 °C and within 15–20 min. at 60 °C.
Entamoeba histolytica cysts	Death within a few min. at 45 °C and within a few sec at 55 °C.
Taenia saginata	Death within a few min. at 55 °C.
Trichinella spiralis larvae	Quickly killed at 55 °C; instantly killed at 60 °C.
Brucella abortus or Br. suis	Death within 3 min. at 62–63 °C and within 1 hr at 55 °C.
Micrococcus pyogenes var. aureus	Death within 10 min. at 50 °C.
Streptococcus pyogenes	Death within 10 min. at 54 °C.
Mycobacterium tuberculosis var. hominis	Death within 15–20 minutes at 66 °C or after momentary heating at 67 °C.
Corynebacterium diphteria	Death within 45 min. at 55 °C.
Necator americanus	Death within 50 min. at 45 °C.
Ascaris lumbricoides eggs	Death in less than 1 hr at temperatures over 50 °C.

Note: $1.8 \times (^\circ C) + 32 = {}^\circ F$.

Source: G. Tchobanoglous, H. Theisen, and S. Vigil, *Integrated Solid Waste Management: Engineering Principles and Management Issues*, McGraw-Hill, New York, 1993.

range in temperature within compost clumps or zones and between the outside and inside of a mass of compost, the required lethal temperatures cannot be ensured. The EPA requires 131 °F (55 °C) for three days to obtain pathogen destruction before compost land spreading, but this temperature does not kill all pathogens. The World Health Organization (WHO) recommends that the compost attain a temperature of at least 140 °F (60 °C). It has been found that salmonella repopulation is possible in a soil amendment from composted sludge. Microbial activity is greatest when mean municipal compost temperature is 114° to 140 °F (40°–60 °C), using aeration to control the temperature to achieve the highest composting rates. Temperatures above 140 °F (60 °C) tend to slow down the process as many organisms die off at and above this temperature.

Control of Odor The majority of the odor problems in aerobic composting processes are associated with the development of anaerobic conditions within the compost pile. In many large-scale aerobic composting systems, it is common to find pieces of magazines or books, plastics (especially plastic films), or similar materials in the organic material being composted. These materials normally cannot be decomposed in a relatively short time in a compost pile. Furthermore, because sufficient oxygen is often not available in the center of such materials, anaerobic conditions can develop. Under anaerobic conditions, organic acids will be produced, many of which are extremely odorous. To minimize the potential odor problems, it is important to reduce the particle size, remove plastics and other nonbiodegradable materials from the organic material to be composted, or use source-separated and uncontaminated feedstocks.

Issues in the Implementation of Composting Facilities

The principal issues associated with the use of the compost process are related to (1) the production of odors, (2) the presence of pathogens, (3) the presence of heavy metals, and (4) definition of what constitutes an acceptable compost. The blowing of papers and plastic materials is also a problem in windrow composting. Unless the questions related to these issues are resolved, composting may not be a viable technology in the future.

Production of Odors Without proper control of the composting process, the production of odors can become a problem, especially in windrow composting. It is fair to say that every existing composting facility has had an odor event and in some cases numerous events. As a consequence, facility siting, process design, and biological odor management are of critical importance.

Facility Siting Important issues in siting as related to the production and movement of odors include proper attention to local microclimates as they affect the dissipation of odors, distance to odor receptors, the use of adequate buffer zones, and the use of split facilities (use of different locations for composting and maturation operations).

Proper Process Design and Operation Proper process design and operation are critical in minimizing the potential for the production of odors. If composting operations are to be successful, special attention must be devoted to the following items: preprocessing, aeration requirements, temperature control, and turning (mixing) requirements. The facilities used to prepare the waste materials for the composting process must be capable of mixing any required additives, such as nutrients, seed (if used), and moisture with the waste material to be composted completely and effectively. The aeration equipment must be sized to meet peak oxygen demand requirements with an adequate margin of safety. In the static pile method of composting, the aeration equipment must also be sized properly to provide the volume of air required for cooling of the composting material. The composting facilities must be instrumented adequately to provide for positive and effective temperature control. The equipment used to turn and mix the compost to provide oxygen and to control the temperature must be effective in mixing all portions of the composting mass. Unmixed compost will undergo anaerobic decomposition, leading to the production of odors. Because all of these operations are critical to the operation of an odor-free composting facility, standby equipment should be available.

Biological Odor Management Because occasional odor events are impossible to eliminate, special attention must be devoted to the factors that may affect biological production of odors. Causes of odors in composting operations include low carbon-to-nitrogen (C/N) ratios, poor temperature control, excessive moisture, and poor mixing For example, in composting operations where the compost is not turned and the temperature is not controlled, the compost in the center of the composting pile can become pyrolyzed. When subsequently moved, the odors released from the pyrolyzed compost have been *extremely severe*. In enclosed facilities, odor control facilities such as packed towers, spray towers, activated-carbon contactors, biological filters, and compost filters have been used for odor management. In some cases, odor-masking agents and enzymes have been used for the temporary control of odors.

Public Health Issues If the composting operation is not conducted properly, the potential exists for pathogenic organisms to survive the composting process. The absence of pathogenic organisms is critical if the product is to be marketed for use in applications where the public may be exposed to the compost. Although pathogen control can be achieved easily with proper operation of the composting process, not all composting operations are instrumented sufficiently to produce pathogen-free compost reliably. In general, most pathogenic organisms found in MSW and other organic material to be composted will be destroyed at the temperatures and exposure times used in controlled composting operations (typically 55 °C for 15–20 days). Temperatures required for the control of various pathogens were given previously in Table 3.19.

Health Hazards

Exposure of workers to dust at a wastewater sludge and other composting site might cause nasal, ear, and skin infections, burning eyes, skin irritation, and other symptoms, pointing to the need for worker protection safeguards.

Other concerns are possible leachate contamination of groundwater and surface water, toxic chemicals remaining in the finished compost, insect and rodent breeding, noise, and survival of pathogens, including molds and other parasite spores and eggs. Pathogens may be spread by leachate, air, insects, rodents, and poor housekeeping and personal hygiene. Tests for pathogens, and the toxic level of chemicals and metals listed in Table 3.16 should be made periodically. Precautions are indicated in view of the potential hazards. Workers should be advised of the infectious and hazardous materials likely to be present in the solid waste handled and the personal hygiene precautions to be taken and be provided with proper equipment, protective gear, and housing. Their health should be monitored. All solid waste should be inspected before acceptance to ensure that it does not contain hazardous wastes. A dressing room, including lockers, toilet, lavatory, and shower facilities, is needed. Equipment cabs should have air conditioning, including dust filters.

Heavy-Metal Toxicity A concern that may affect all composting operations, but especially those where mechanical shredders are used, involves the possibility of heavy-metal toxicity.[5] When metals in solid wastes are shredded, metal dust particles are generated. In turn, these metal particles may become attached to the materials in the light fraction. Ultimately, after composting, these metals would be applied to the soil. While many of them would have no adverse effects, metals such as cadmium (because of its toxicity) are of concern. In general, the heavy-metal content of compost produced from the organic fraction of MSW is significantly lower than the concentrations found in wastewater treatment plant sludges. The metal content of source separated-wastes is especially low. The co-composting of wastewater treatment plant sludges and the organic fraction of MSW is one way to reduce the metal concentrations in the sludge.

Product Quality Product quality for compost material can be defined in terms of the nutrient content, organic content, pH, texture, particle size distribution, moisture content, moisture-holding capacity, presence of foreign matter, concentration of salts, residual odor, degree of stabilization or maturity, presence of pathogenic organisms, and concentration of heavy metals. Unfortunately, at this time, there is no agreement on the appropriate values for these parameters. The lack of agreement on appropriate values for these parameters has been and continues to be a major impediment to the development of a uniform compost product from location to location. For compost materials to have wide acceptance, public health issues must be resolved in a satisfactory manner.

Cost The cost of composting should reflect the total cost of the operation less the savings effected. The cost of the operation would include the cost of the site, site preparation, compost concrete or asphalt platform, worker housing and facilities, utilities, equipment (grinder, bucket loader, and composting drum and aeration facilities if part of the process), power, separation and recycling preparation, and disposal of noncompostable materials as well as leachate collection, treatment and disposal, odor control, final screening, bagging, and maintenance. Savings would include reduced landfill disposal cost, income from sale of salvaged material, and sale of stabilized compost. Under favorable conditions, the total net cost of composting might be less compared to other methods. The size of the operation, labor costs, process used, sustained market for recovered materials, need for an enclosure, and other factors will determine the net cost.

A comprehensive market analysis should be made in the planning stage. The cost of an indoor system is much higher than an outdoor system. The operation of an outdoor system is significantly affected by the ambient temperature and precipitation. The indoor system makes possible better temperature, leachate, odor, and operation control as well as better public relations. Composting is not a profit-making operation.

SANITARY LANDFILL PLANNING, DESIGN, AND OPERATION

A sanitary landfill is a controlled method of solid waste disposal. The site must be geologically, hydrologically, and environmentally suitable. *It is not an open dump*. The nuisance conditions associated with an open dump, such as smoke, odor, unsightliness, and insect and rodent and seagull and other bird problems, are not present in a properly designed, operated, and maintained sanitary landfill. The principal types of landfills used for the disposal of residual material after materials recovery are identified in Table 3.20. Although several types of landfills are identified in Table 3.20, the primary focus of this section is planning, design and operation, and landfill closure of municipal landfills. Details on the other types of landfills may be found in Refs. 2,15, and 17.

Sanitary Landfill Planning

Key elements in the planning and implementation of a landfill include (1) legal requirements, (2) intermunicipal cooperation, (3) social and political factors, and (4) long-term planning issues. Landfill design considerations are considered in the section following the description of the types of landfills.

Legal Requirements State environmental protection agency regulations and local sanitary codes or laws usually build on federal regulatory requirements. A new solid waste disposal location may not be established until the site, design, and method of proposed operation, including waste reduction, resource recovery, and recycling, have been approved by the agency having jurisdiction. The agency should be authorized to approve a new solid waste disposal area and require such plans, reports, specifications, and other necessary data to determine whether the site is suitable and the proposed method of operation feasible. Intermunicipal planning and operation on a multimunicipal, multicounty, or multiregional basis should be given very serious consideration before a new solid waste disposal site is acquired. Larger landfills usually are more efficient and result in lower unit costs.

The principal federal requirements for municipal solid waste landfills are contained in Subtitle D of the Resource Conservation and Recovery Act (RCRA) and in EPA Regulations on Criteria for Classification of Solid Waste Disposal Facilities and Practices (*Code of Federal Regulations*, Title 40, Parts 257 and 258). The final version of Part 258—Criteria for Municipal Solid Waste Landfills (MSWLFs)—was signed on September 11, 1991. The subparts of Part 258 deal with the following areas:

Subpart A General
Subpart B Location restrictions
Subpart C Operating criteria

TABLE 3.20 Types of Landfills Used in the United States[a]

Classification of Landfill	Description
Conventional, municipal	A sanitary landfill is a controlled method of solid waste disposal, following the recovery of materials for recycling, which complies with the legal federal requirements for municipal solid waste landfills contained in Subtitle D of the Resource Conservation and Recovery Act (RCRA) and in EPA Regulations on Criteria for Classification of Solid Waste Disposal Facilities and Practices (*Code of Federal Regulations*, Title 40, Parts 257 and 258) Conventional municipal landfills are discussed in detail in this section.
Municipal bioreactor	Three types are identified: aerobic, anaerobic, and hybrid. Bioreactor landfills are designed to accelerate the biological stabilization of the organic fraction of municipal solid waste.
Aerobic	Air is injected into the waste mass, using vertical or horizontal wells, to promote aerobic activity and accelerate waste stabilization. Leachate, removed from the bottom layer, is stored, and recirculated into the landfill in a controlled manner to obtain optimal moisture levels and, thus, both stimulate and accelerate the biological activity within the landfill.
Anaerobic	Leachate, removed from the bottom layer, is stored, and recirculated into the landfill in a controlled manner to obtain optimal moisture levels and, thus, both stimulate and accelerate the biological activity within the landfill. Biodegradation occurs anaerobically (in the absence of oxygen) and produces landfill gases (carbon dioxide and methane). Landfill gas, primarily methane, is captured to minimize greenhouse gas emissions and for the production of energy.
Hybrid (Aerobic/anaerobic)	The biodegradation of the waste degradation is accelerated by employing a sequential aerobic-anaerobic strategy to degrade organics in the upper sections of the landfill and to collect gas from lower sections.
Construction and demolition (C &D)	There are special landfills for the disposal of construction and demolition waste that is not recovered.
Ash monofill	There are special landfills for the disposal of ash from the combustion of municipal solid waste.
Industrial commercial	There are special landfills for the disposal of industrial wastes such as coal ash, paper mill sludges and similar materials.

[a] Adapted in part from G. Tchobanoglous, and F. Kreith, *Solid Waste Handbook*, 2nd ed., McGraw-Hill, New York, 2002; U.S. EPA, *Process Design Manual, Municipal Sludge Landfills*, EPA-625/1-78-010, EPA, Washington, DC. 1978; and U.S. EPA, *Bioreactors*, Office of Solid Waste, EPA, Washington, DC. 2008, http://www.epa.gov/garbage/landfill/bioreactors.htm.

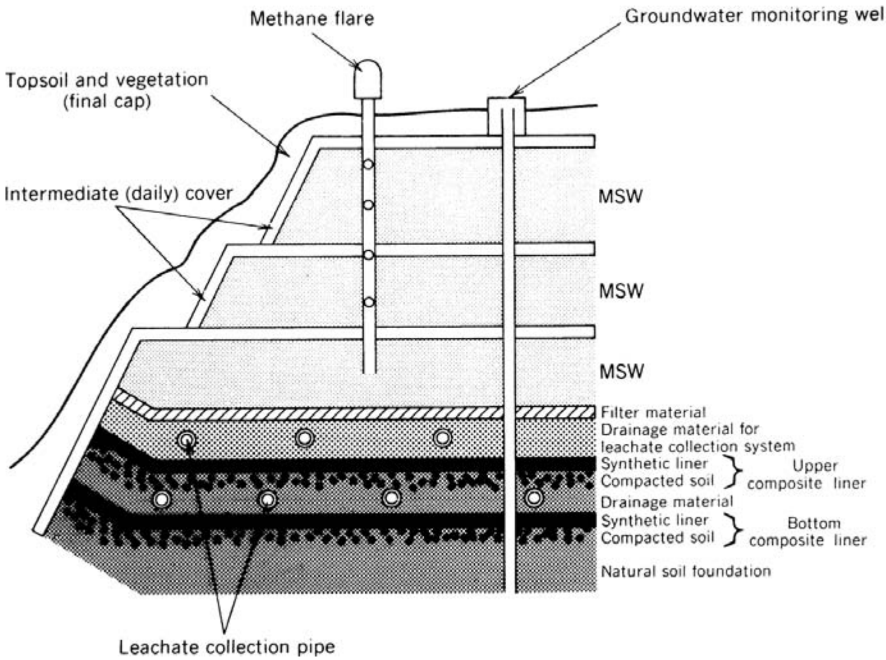


FIGURE 3.23 Schematic diagram of configuration of selected engineering features at MSW landfills.

Subpart D Design criteria
Subpart E Groundwater monitoring and corrective action
Subpart F Closure and postclosure care
Subpart G Financial assurance

In addition, many state environmental protection agencies have parallel regulatory programs that deal specifically with their unique geologic and soil conditions and environmental and public policy issues.

Intermunicipal Cooperation — Advantages County or regional areawide planning and administration for solid waste collection, treatment, and disposal can help overcome some of the seemingly insurmountable obstacles to satisfactory solution of the problem. Some of the advantages of county or regional areawide solid waste management are the following:

1. It makes possible comprehensive study of the total area generating the solid wastes and consideration of an areawide solution of common problems on short-term and long-term bases. A comprehensive study can also help overcome the mutual distrust that often hampers joint operations among adjoining municipalities.

2. There is usually no more objection to one large site operation than to a single town, village, or city operation. Coordinated effort can therefore be directed at overcoming the objections to one site and operation, rather than to each of several town, village, and city sites.
3. The unit cost for the disposal of a large volume of solid waste is less. Duplication of engineering, overhead, equipment, labor, and supervision is eliminated.
4. Better operation is possible in an areawide service, as adequate funds for proper supervision, equipment, and maintenance can be more easily provided.
5. More sites can be considered. Some municipalities would have to resort to a more costly method because suitable landfill sites may not be available within the municipality.
6. County or regional financing for solid waste disposal often costs less, as a lower interest rate can usually be obtained on bonds because of the broader tax base.
7. A county agency or a joint municipal survey committee, followed by a county or regional planning agency, and then an operating department, district, or private contractor, is a good overall approach because it makes possible careful study of the problem and helps overcome interjurisdictional resistance.

Social and Political Factors An important aspect of solid waste disposal site selection, in addition to the factors mentioned below, is the evaluation of public reaction and education of the public so that understanding and acceptance are developed. A long-term program of public information is needed. Equally important are the climate for political cooperation, cost comparison of alternative solutions, available revenue, aesthetic expectations of the people, organized community support, and similar factors. Films and slides that explain proper sanitary landfill operations are available from state and federal agencies and equipment manufacturers. Sites having good operations can be visited to obtain first-hand information and show the beneficial uses to which a completed site can be put.

Long-Term Planning and Design Issues Local officials can make their task easier by planning ahead together on a county or regional basis for 20 to 40 years in the future and by acquiring adequate sites at least 5 years prior to anticipated needs and use. The availability of federal and state funds for planning, collection, recycling, treatment, and disposal of solid waste on an areawide basis such as a county or region should be explored. The planning will require compliance with public health, environmental, planning, and zoning requirements, both state and local; and an engineering analysis of alternative sites. Also required are population projections, volume and characteristics of all types of solid wastes to be handled, cost of land and site preparation, expected life of the site, haul distances from the sources of solid waste to the site, cost of equipment, cost of operation, cost of closure and maintenance, and possible use and value of the finished site.

Consideration must also be given to the climate of the region, including precipitation and prevailing winds; geology, soils, hydrology, flood levels, and topography; and the need for liners, leachate collection and treatment [National Pollutant Discharge Elimination System (NPDES) permit], and methane gas control. Location and drainage to prevent surfacewater and groundwater pollution, groundwater monitoring (at least one well up gradient and three wells down gradient), access roads to major highways, location of airports and wetlands, and availability of suitable cover material are other considerations. *Public information and involvement should be an integral and continuing part of the planning process leading to a decision*. The reader is referred to Chapter 6 for a discussion of the broad aspects of community and facility planning and environmental impact analysis.

Once a decision is made, it should be made common knowledge and plans developed to show how it is proposed to reclaim, improve, and reuse the site upon completion. Public education should include a series of talks, slides, news releases, question-and-answer presentations, and inspection of good operations. To aid in the planning process, Table 3.21 presents some general guidelines for landfill design, construction, and operation. Artist's renderings and architectural models are very helpful in explaining construction methods and final land use. Landscape architects can make a contribution in converting the sanitary landfill to a community asset, such as parks, playgrounds with picnic areas, nature trails, bicycle and jogging paths, and hills with scenic observation sites. Unfilled land sites or islands could be set aside for permanent buildings.

Sanitary Landfill Methods

There are many methods of operating a sanitary landfill. The most common are the trench, area, ramp, and valley fill methods, as illustrated in Figure 3.24. These landfill methods are described as follows. With the regulatory requirements for constructed liner and leachate collection and removal systems now imposed by the EPA as set forth in RCRA, a defined operational area and well-designed operational plan are essential and must be closely followed to ensure an efficient and environmentally sound operation.

Trench Method The trench method (see Figure 3.24*a*) is used primarily on level ground, although it is also suitable for moderately sloping ground. In this method, trenches are constructed by making a shallow excavation and using the excavated material to form a ramp above the original ground. Solid waste is then methodically placed within the excavated area, compacted, and covered at the end of each day with previously excavated material. Because of the need to install landfill control measures (e.g., liners), a number of trenches are typically excavated at one time. Trenches are made 20 to 25 feet wide and at least twice as wide as any compacting equipment used. The depth of fill is determined by the established finished grade and depth to groundwater or rock. If trenches can be made deeper, more efficient use is made of the available land area.

TABLE 3.21 Some General Sanitary Landfill Design, Construction, and Operation Guidelines

Benchmark—Survey benchmark measured from U.S. Geological Survey benchmark established on-site and landfill cells referenced to it; a benchmark for each 25 acres of landfill.
Bottom liners—As specified by the regulatory agency and as indicated by the hydrogeological survey. See Figure 3.27.
Distance from any surface water—Based on soil attenuation, drainage, natural and manmade barriers, but not less than 100 feet, preferably 200 feet or more.
Equipment—Adequate numbers, type, and sizes; properly maintained and available.
Equipment shelter—Available for routine maintenance and repair.
Flood plains—No solid waste management facility permitted unless provisions made to prevent hazard.
Gas control—Prevent hazard to health, safety, and property; provide vents, barriers, collection, monitoring. Gas monitoring is required, also for volatile organic chemical and toxic emissions. See Figures 3.34 to 3.35.
Leachate—Not to drain or discharge into surface waters, except pursuant to State Pollutant Discharge Elimination System, and shall not contravene groundwater quality standards. Leachate collection system maintained.
Limits of fill—No closer than 100 feet from boundary lines of property. Restrictions primarily on proximity to water supply aquifers, wellhead areas, wetlands, floodplains, and surface waters.
Monitoring wells—Four or more at new or modified facility; at least three located down gradient for a small site. Regulatory agency may require wells at existing facility. Off-site wells may be used. Wells must reflect groundwater flow and quality under the landfill site.

- Water monitoring may be required. Safe Drinking Water Act MCLs are used to determine pollution and evaluate pollution travel.
- Baseline water quality and annual seasonal data are required at a new site and some existing sites.

Plans and construction—Engineering plans and specifications as required and approved by regulatory agency. Construction under supervision of project engineer who certifies construction is in accordance with approved plans and specifications.
Site—A hydrogeological survey of the site and surrounding land, soil borings, permeability, and groundwater levels. Check with Federal Aviation Administration.
Termination—Prevent contravention of surface water, groundwater, and air-quality standards and gas migration, odors, vectors, and adverse environmental or health effects. At least 2 feet final cover, including an impervious barrier and gas-venting layer, along with an upper grass cover crop; 4% slope to minimize infiltration, prevent ponding and a surface water drainage system.
Vertical separation—five-foot separation between bottom liner and high groundwater. If natural soil is equivalent to 10 ft of soil with coefficients of permeability less than 5×10^{-6} cm/sec, separation may be reduced if a doubleliner system is provided; 10-ft vertical separation required to bedrock.
Access—Permitted when attendant on duty; controlled by fencing, signs, or other means.
Compaction and cover—Solid waste spread in 2 feet or less layers and promptly compacted. Working face minimal.

- Ten feet of maximum lift height.
- At least 6 in. daily cover at end of each day, or more often.
- At least 12 in. intermediate cover if solid waste not deposited within 30 days.
- Surface water drainage control during operation.
- Final cover when additional lift is not applied within 1 year; when final elevation is reached and within 90 days; when a landfill is terminated. Capped as required by regulatory agency. See Figure 3.37.

(*continues*)

TABLE 3.21 (*continued*)

Hazardous wastes—No industrial or commercial solid waste or septage, or other materials producing hazardous waste, without specific permit authorization. No bulk liquids or 55-gal drums filled with liquids.
Litter and papers—Confined by fencing or suitable means. Vehicles confining papers and litter to be admitted.
Maintenance—Cover material and drainage control designed and maintained to prevent ponding and erosion, and to minimize infiltration, based on a 25-year storm and from a 24-hour, 25-year storm. Prepare a landscape plan.

- Grass or ground cover established within 4 months and maintained.
- Soil cover integrity, slopes, cover vegetation, drainage, groundwater and gas monitoring, and structures maintained for a period of 30 years or longer.
- Leachate collection and removal system, inspection manholes, and lift stations maintained operational as long as necessary.
- Liner leakage monitored and reported to regulatory agency.
- Establish a trust fund, surety bond, insurance, etc., to ensure long-term maintenance.

Noise—Shall not cause excessive sound levels beyond property lines in residential areas. Level 7 a.m.–10 p.m.: rural 60 dBA, suburban 65 dBA, urban 70 dBA. Level 10 p.m.–7 a.m., rural 50 dBA, suburban 55 dBA, urban 60 dBA.
On-site roads—Maintained passable and safe.
Open burning—Prohibited except under permit.
Personnel shelter—Adequately heated and lighted; includes safe drinking water, sanitary toilet and shower facilities, telephone or radio communications.
Reports—As required in permit.
Safety—Safety hazards minimized.
Salvaging—Controlled, if permitted.
Small loads—Separate facility (convenience station) at the site for use of local residents and small trucks.
Solid waste disposal—Confined to an area effectively maintained, operated, and controlled. No industrial, commercial solid waste, no sludge or septage unless specifically approved. Inspection for hazardous waste required.
Supervision—Operation supervised by a certified operator, including dumping sequence, compaction, cover, surface drainage.
Vectors, dust, and odors—Controlled to prevent nuisance or hazard to health, safety, or property.
Weigh station—For weight measurement, fees, and waste inspection.

Note: See also applicable federal and state regulations.

Source: J. A. Salvato, *Environmental Engineering and Sanitation*, 4th ed., Wiley, New York, 1992.

Area or Ramp Method On fairly flat and rolling terrain, area method (see Figure 3.24*b*) can be utilized by using the existing natural slope of the land. The width and length of the fill slope are dependent on the nature of the terrain, the volume of solid waste delivered daily to the site, and the approximate number of trucks that will be unloading at the site at one time. Side slopes are 20 to 30 percent; width of fill strips and surface grades are controlled during operation by means of line poles and grade stakes. The working face should be kept as small as practical to take advantage of truck compaction, restrict dumpingto a

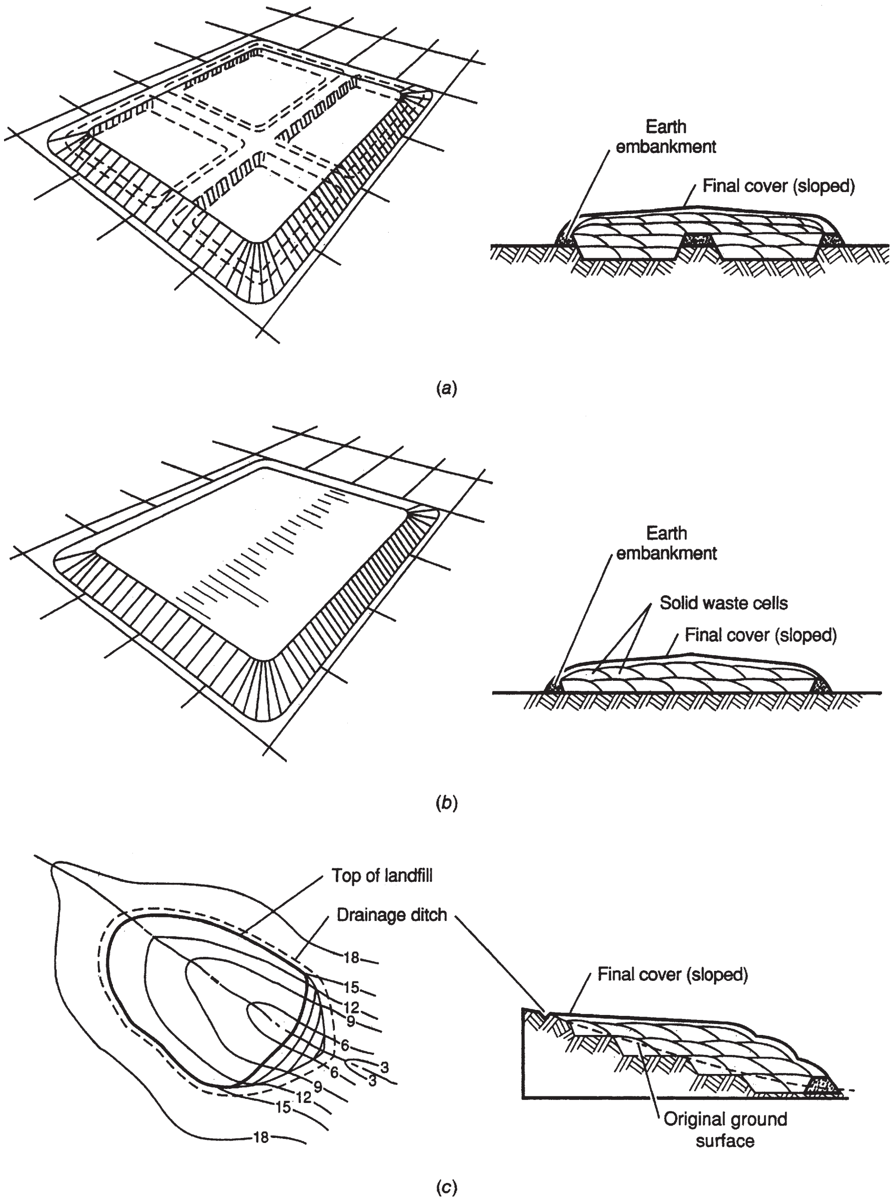


FIGURE 3.24 Schematic view of different types of landfills: (*a*) trench, (*b*) area; (*c*) canyon or ravine. (*Source:* G. Tchobanoglous, H. Theisen, and S. Vigil, *Integrated Solid Waste Management: Engineering Principles and Management Issues*, McGraw-Hill, New York, 1993.)

limited area, and avoid scattering of debris. In the area method, cover material is hauled in from a nearby stockpile or other source. The base of the landfill is established by the previously determined elevation of bedrock, groundwater, and bottom liners and leachate collection and removal systems.

Valley or Ravine Area Method In valleys and ravines, the ravine method (see Figure 3.24*c*) is usually the best method of operation. The development of a large ravine landfill site is illustrated in Figure 3.25. In those areas where the ravine is deep, the solid waste should be placed in "lifts" from the bottom up with a depth of 8 to 10 feet. Cover material is obtained from the sides of the ravine. It is not always desirable to extend the first lift the entire length of the ravine. It may be desirable to construct the first layer for a relatively short distance from the head of the ravine across its width. The length of this initial lift should be determined so that a one-year settlement can take place before the next lift is placed, although this is not essential if operation can be controlled carefully. Succeeding lifts are constructed by trucking solid waste over the first lift to the head of the ravine. When the final grade has been reached (with allowance for settlement), the lower lift can be extended and the process repeated. The bottom landfill liner and leachate collection and removal system must be designed carefully to ensure that slope stability of the liner system and the waste placed is adequately maintained.

FIGURE 3.25 Development of large ravine landfill site. Equipment is compacting sub-base of landfill in preparation for placement of geomembrane liner.

General Landfill Design Issues

The general planning process described above is followed by specific site selection and preparation. Site preparation requires that an engineering survey be made and a map drawn at a scale of not less than 200 feet to the inch with contours at 2-foot intervals, showing the boundaries of the property; location of lakes, streams, springs, marine waters, and structures within 1,000 feet; adjoining ownership; and topography. Also required are soil borings, including *in situ* hydraulic conductivity determinations, designs for liners and leachate collection systems, groundwater levels, up-gradient and down-gradient monitoring wells, water quality samples, prevailing winds, and drainage plans.

Location The site location directly affects the total solid waste collection and disposal cost. If the site is remotely situated, the cost of hauling to the site may become high and the total cost excessive. It has been established that the normal, economical hauling distance to a solid waste disposal site is 10 to 15 miles, although this will vary depending on the volume of solid waste, site availability, and other factors. Actually, a suitable site and the hauling time and route are more important than the hauling distance. The disposal site may be as far as 40 to 80 miles away if a transfer station is used. Rail haul and barging introduce other possibilities. The cost of transferring the solid waste per ton is used to compare solid waste collection and disposal costs and make an economic analysis. Open excavations left by surface mining operations may be considered for solid waste disposal as a means of reclaiming land and restoring it to productive use.

Accessibility Another important consideration in site selection is accessibility. A disposal area should be located near major highways to facilitate use of existing arterial roads and lessen the hauling time to the site. Highway wheel load and bridge capacity and underpass and bridge clearances must also be investigated. It is not good practice to locate a landfill in an area where collection vehicles must constantly travel through residential streets to reach the site. The disposal area itself should normally be located at least 500 feet from habitation, although lesser distances have been successfully used to fill in low areas and improve land adjacent to residential areas for parks, playgrounds, or other desirable uses. Where possible, a temporary attractive screen should be erected to conceal the operation. To allow vehicular traffic to utilize the site throughout the year, it is necessary to provide good access roads to the site so that trucks can move freely in and out of the site during all weather conditions and seasons of the year. Poorly constructed and maintained roads to a site can create conditions that cause traffic tie-ups and time loss for the collection vehicles.

Land Area (Volume) Required The volume needed for solid waste disposal is a function of population served, per-capita solid waste contribution, resource recovery and recycling, density and depth of the solid waste in place, number of lifts, total amount of earth cover used, and time in use, adjusted for nonhazardous commercial and industrial wastes. Because of the high startup costs associated with a modern landfill, the capacity of a proposed landfill should be sufficient for a 20- to 40-year period (see Figure 3.25). Further, because the population in an area will not usually remain constant, it is essential that population projections and development be taken into account. These factors plus the probable nonhazardous solid waste contributions by commercial establishments, industry, and agriculture must be considered in planning for needed land. A density of compacted fill of 800 to 1,000 lb/yd^3 is readily achieved with proper operation; 600 lb/yd^3 or less is poor; 1,200 lb/yd^3 or more is very good.

Leachate Generation, Control, and Treatment

The best solution to the potential leachate problem is to prevent its development. Landfill leachate generation cannot in practice be entirely avoided, particularly during operation, except possibly in some arid climates. A tight soil cap and/or liner on completion can greatly minimize the possibility; however, a leachate-free landfill may not be *entirely* desirable. Leachate control measures for groundwater and surface-water quality protection must be incorporated in the site design and monitoring started before operation (see Figure 3.26). A water balance for the landfill disposal facility should be established to serve as a basis for the design of leachate control and surface runoff systems, taking into consideration heavy rainfall, landfill, cap construction, in addition to runoff, infiltration, and evapotranspiration.

Leachate from existing community sanitary landfills and from industrial waste storage and disposal sites can be expected to contain organic and inorganic chemicals characteristic of the contributing community and industrial wastes. Household hazardous wastes may include small amounts of cleaning solvents, paints and paint thinners, oils, pesticides, and drugs if not restricted or their sale prohibited. The EPA and others have reported that hazardous wastes probably represent less than 0.5 percent of the total waste generated by households. A knowledge of the industry and its production will provide a starting point in the selection of parameters to be analyzed in characterizing the leachate from an existing site.

Leachate Generation The precipitation less runoff, transpiration, and evaporation will determine the amount of infiltration. Infiltration and percolation will, in the long term, after field capacity has been reached, determine the amount of leachate, if any, produced, assuming groundwater and lateral flow are excluded. A major factor is a cover material that is carefully graded, which ideally permits only limited infiltration and percolation to support vegetative cover and solid waste decomposition, with optimal runoff but without erosion to prevent significant leachate production. The soil cover should have a low permeability with low swell and shrink tendency upon wetting and drying. Runoff depends on rainfall intensity and duration, permeability of the cover soil, surface slope (4 percent, not greater than 30 percent for side slopes), condition of the soil and its moisture content, and the amount and type of vegetative cover. Evapotranspiration during the growing season for grasses and grains may be 20 to 50 inches.

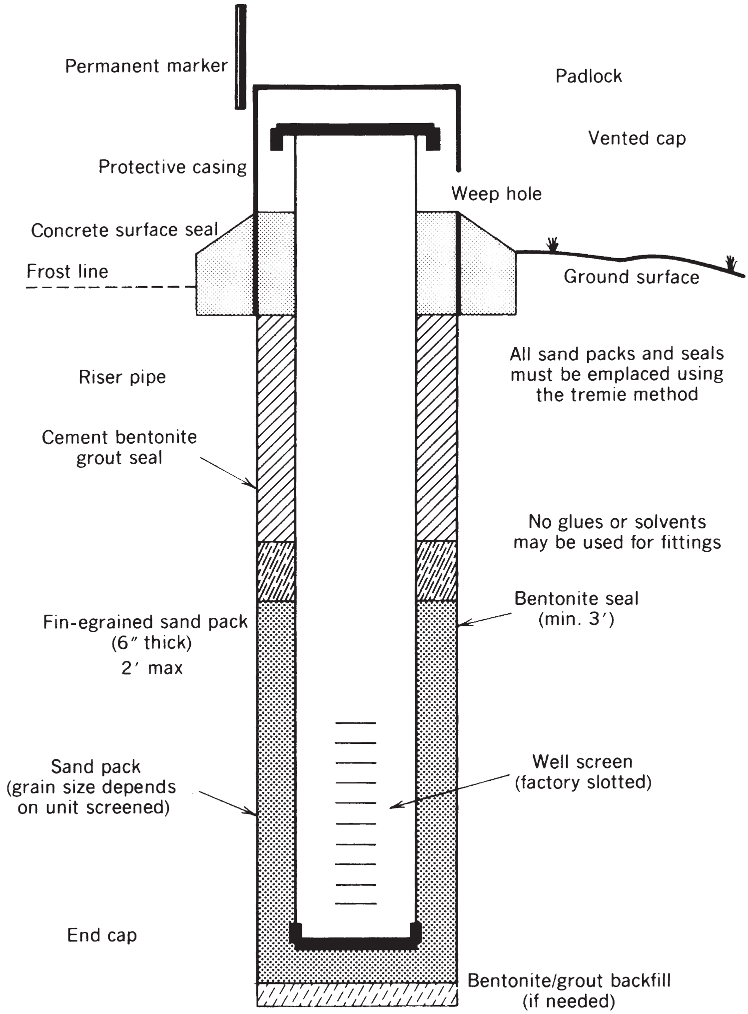


FIGURE 3.26 Typical monitoring well diagram. (*Source:* New York State, *6 NYCRR Part 360, Solid Waste Management Facilities*, New York State Department of Environmental Conservation, Division of Solid Waste, Albany, 1990a.)

Leachate Control It should be noted that if all infiltration is excluded and the solid waste kept dry, biodegradation by bacteria, fungi, and other organisms will cease and the solid waste will be preserved in its original state. Bacterial activity will generally cease when the moisture content drops below 14 to 16 percent. The maintenance of an optimal amount of moisture in the fill, as in controlled composting (an aerobic process), is necessary for biodegradation (an anaerobic process in a landfill), methane production, final stabilization, and possible future recycling of the solid waste or reuse of the site.

The objective in the design of landfill liners is to minimize or eliminate the infiltration of leachate into the subsurface soils below the landfill so as to eliminate the potential for the groundwater contamination. A number of liner designs have been developed to minimize the movement of leachate into the subsurface below the landfill. One of the many types of liner designs that have been proposed is illustrated in Figure 3.27. In the multilayer landfill liner design illustrated in Figure 3.27, each of the various layers has a specific function. For example, in Figure 3.27, two composite liners are used as a barrier to the movement of leachate and landfill gas. The drainage layer is to collect any leachate that may be generated within the landfill. The final soil layer is used to protect the drainage and barrier layers. The placement of a geomembrane liner in an area-type landfill is illustrated in Figure 3.28. A modification of the liner design shown in Figure 3.27 is shown in Figure 3.29. The liner system shown in Figure 3.29 is for a monofill (e.g., a landfill for a single waste component such as glass). Composite liner designs employing a geomembrane and clay layer provide more protection and are hydraulically more effective than either type of liner alone.

If leachate migration is or may become a problem at an old or existing landfill, and depending on the local situation and an engineering evaluation, several options may be considered. These include a cap on the surface consisting of clay or a liner regraded with topsoil seeded to grass to effectively shed precipitation;

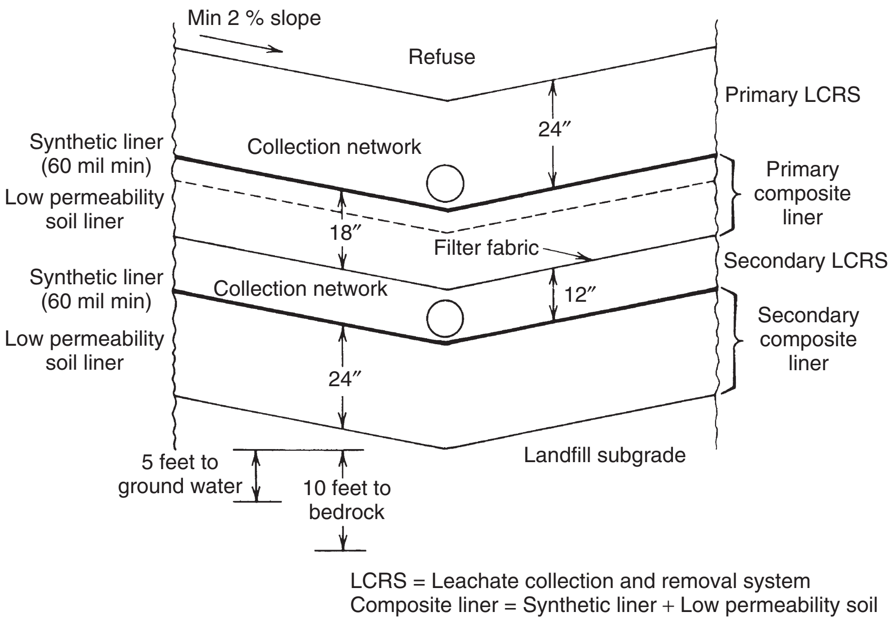


FIGURE 3.27 Double-bottom composite liner system. (New York State, *6 NYCRR Part 360, Solid Waste Management Facilities*, New York State Department of Environmental Conservation, Division of Solid Waste, Albany, 1990a.)

FIGURE 3.28 Placement of geomembrane liner in area-type landfill.

cutoff walls or dams keyed into an impermeable stratum to isolate the fill; pressure treatment and sealing of the bottom and sides of the fill; surface-water drains up-gradient and around the landfill area; curtain drains or wells to intercept and drain away the contributing groundwater flow, collection and recirculation of leachate with treatment of any excess, or, in special cases and if warranted, the material in the landfill can be excavated, treated, recycled, and/or disposed of at a controlled site. The excavation of an existing landfill may, however, introduce other problems if hazardous wastes are involved and hence must be carefully evaluated in advance.

Leachate Recirculation Waste biodegradation and stabilization of the biodegradable organic matter in a landfill can be accelerated by leachate

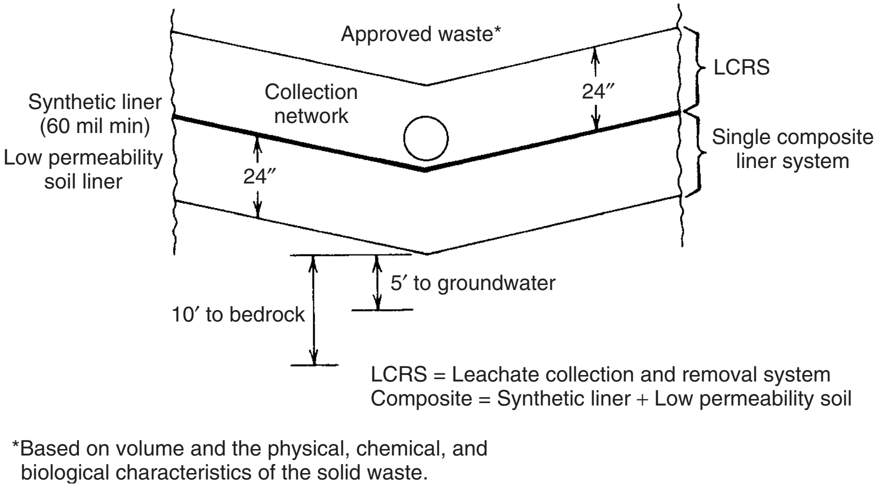
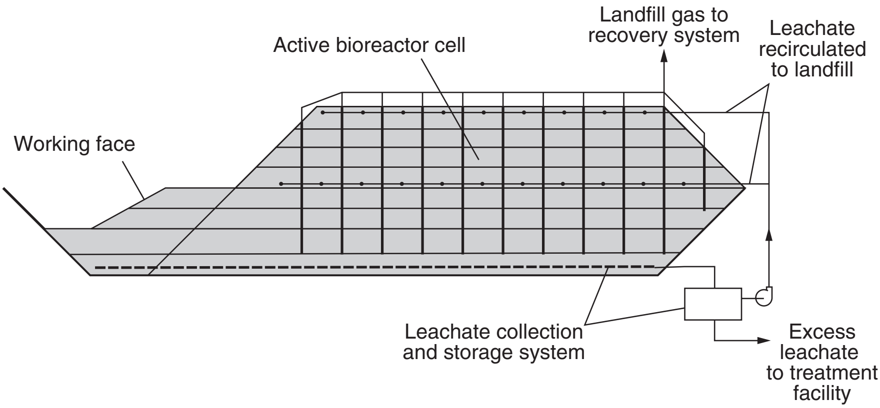


FIGURE 3.29 Industrial/commercial and ash monofill waste landfill liner configuration. (New York State, *6 NYCRR Part 360, Solid Waste Management Facilities*, New York State Department of Environmental Conservation, Division of Solid Waste, Albany, 1990a.)

recirculation. Controlled leachate recirculation, including nutrient addition to maintain optimum moisture and pH, can enhance anaerobic microbial activity, breakdown organics as shown by reduced total organic carbon (TOC) and chemical oxygen demand (COD, convert solid waste organics to methane and carbon dioxide, and precipitate heavy metals. Complete biological stabilization can be achieved in four to five years. Heating of recirculated leachate to 86 °F (30 °C) has been found to accelerate the stabilization process.

A landfill designed for leachate recirculation should, as a minimum, incorporate a conservatively designed liner system and an effectively maintained leachate collection, removal, and recirculation distribution system, in addition to a gas collection and venting system (see Figure 3.30). A double-liner system with leak detection monitoring wells would enable the landfill owner and regulatory agency to monitor the liner system performance. The leachate collection and removal system should be designed to be accessible for routine maintenance and cleaning in view of the potential for biological film clogging. Recirculation would increase the strength of the recirculated leachate and accelerate fill stabilization. Establishment of early gradual recirculation and an active anaerobic biomass is important as each cell is closed. A final site closure utilizing a relatively impermeable crowned cap and surface-water drainage system should be implemented for final site closure.

Leachate Treatment Leachates containing a significant fraction of biologically refractory high-molecular-weight organic compounds (i.e., those in excess of 50,000) are best treated by physicochemical methods, such as lime addition followed by settling. Leachates containing primarily low-molecular-weight organic compounds are best treated by biological methods, such as activated sludge.



(*a*)

(*b*)

FIGURE 3.30 Bioreactor type landfill with leachate recirculation: (a) schematic diagram and (b) photograph of a highly instrumented anaerobic landfill bioreactor located at Davis, California. Photo of bioreactor was taken shortly after landfill was completed, before significant decomposition had occurred. (*Source:* O'Leary, P. R., and G. Tchobanoglous, "Landfilling," in G. Tchobanoglous and F. Kreith (Eds.), *Solid Waste Handbook*, 2nd ed., McGraw-Hill, New York, 2002, Chapter 14.)

Combinations of these methods may be required to achieve permit requirements and stream discharge standards. In the final analysis, the treatment required will depend on the composition of the fill material, leachate volume and characteristics, and the water pollution control standards to be met.

TABLE 3.22 Typical Constituents in Landfill Gas

Component	Percent (dry volume basis)
Methane	45–60
Carbon dioxide	40–60
Nitrogen	2–5
Oxygen	0.1–1.0
Sulfides, disulfides, mercaptans, etc.	0–1.0
Ammonia	0.1–1.0
Hydrogen	0–0.2
Carbon monoxide	0–0.2
Trace constituents	0.01–0.6
Characteristic	**Value**
Temperature, °F	100–120
Specific gravity	1.02–1.06
Moisture content	Saturated
High heating value, Btu/sft^{3a}	475–550

[a] sft^3 = standard cubic foot.

Source: G. Tchobanoglous, H. Theisen, and S. Vigil, *Integrated Solid Waste Management: Engineering Principles and Management Issues*, McGraw-Hill, New York, 1993.

Landfill Gas Generation, Control, and Recovery and Utilization

Gases found in landfills include ammonia (NH_3), carbon dioxide (CO_2), carbon monoxide (CO), hydrogen (H_2), hydrogen sulfide (H_2S), methane (CH_4), nitrogen (N_2), and oxygen (O_2). The typical percentage distribution of the gases found in the landfill is reported in Table 3.22. As shown in Table 3.22, methane and carbon dioxide are the principal gases produced from the anaerobic decomposition of the biodegradable organic waste components in MSW. In addition, a number of trace gases will also be found in landfill gas. The type and concentration of the trace gases will depend to a large extent on the past history of the landfill. Issues related to the generation, control of migration, and utilization of landfill gas are considered in the following discussion.

Generation of the Principal Landfill Gases The generation of principal landfill gases is thought to occur in five more or less sequential phases, as illustrated in Figure 3.31. Each of these phases is described briefly here. Additional details may be found in Ref. 15.

Phase I: Initial adjustment. Phase I is the *initial adjustment phase*, in which the organic biodegradable components in municipal solid waste begin to undergo bacterial decomposition soon after they are placed in a landfill. In phase I, biological decomposition occurs under aerobic conditions because a certain amount of air is trapped within the landfill.

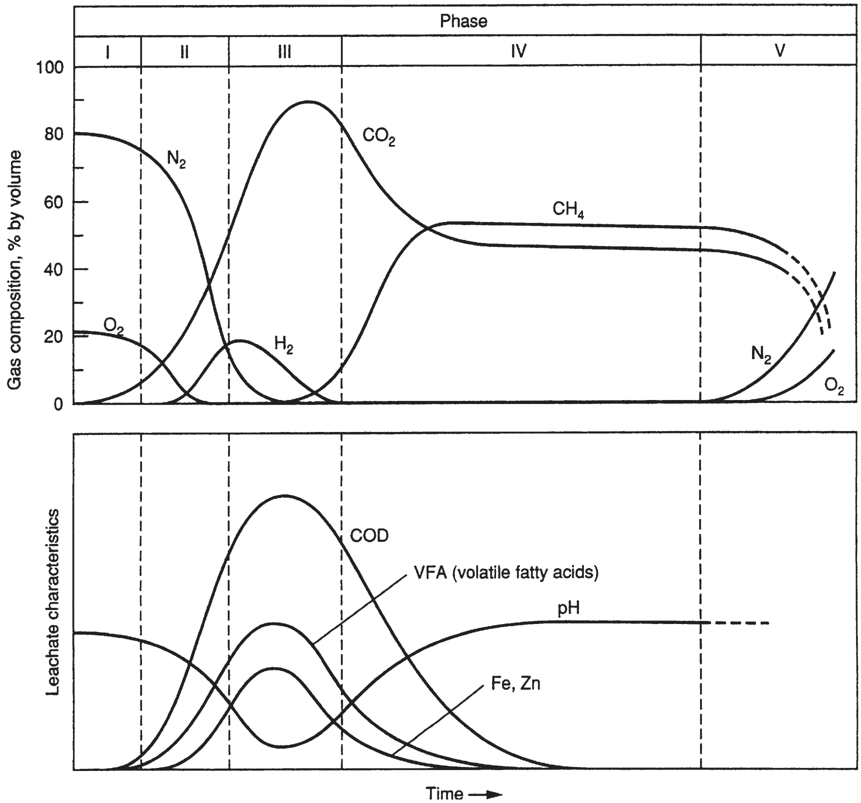


FIGURE 3.31 Generalized phases in generation of landfill gases (I—initial adjustment, II—transition phase; III—acid phase; IV—methane fermentation; V—maturation phase) (*Source:* G. Tchobanoglous, H. Theisen, and S. Vigil, *Integrated Solid Waste Management: Engineering Principles and Management Issues*, McGraw-Hill, New York, 1993.)

Phase II: Transition phase. In phase II, identified as the *transition phase*, oxygen is depleted and anaerobic conditions begin to develop.

Phase III: Acid phase. In phase III, the bacterial activity initiated in phase II is accelerated with the production of significant amounts of organic acids and lesser amounts of hydrogen gas. The first step in the three-step process involves the enzyme-mediated transformation (hydrolysis) of higher molecular mass compounds (e.g., lipids, organic polymers, and proteins) into compounds suitable for use by microorganisms as a source of energy and cell carbon. The second step in the process (acidogenesis) involves the bacterial conversion of the compounds resulting from the first step into lower molecular weight intermediate compounds, as typified by acetic acid (CH_3COOH) and small concentrations of fulvic and other more complex organic acids. Carbon dioxide (CO_2) is the principal gas generated during phase III.

Phase IV: Methane fermentation phase. In phase IV, a second group of microorganisms that convert the acetic acid and hydrogen gas formed by the acid formers in the acid phase to methane (CH_4) and CO_2 becomes more predominant. Because the acids and the hydrogen gas produced by the acid formers have been converted to CH_4 and CO_2 in phase IV, the pH within the landfill will rise to more neutral values in the range of 6.8 to 8.

Phase V: Maturation phase. Phase V occurs after the readily available biodegradable organic material has been converted to CH_4 and CO_2 in phase IV. As moisture continues to migrate through the waste, portions of the biodegradable material that were previously unavailable will be converted.

Control of Landfill Gas Migration When methane is present in the air in concentrations between 5 and 15 percent, it is explosive. Because only limited amounts of oxygen are present in a landfill when methane concentrations reach this critical level, there is little danger that the landfill will explode. However, methane mixtures in the explosive range can be formed if landfill gas migrates off site and is mixed with air. The lateral migration of methane and other gases can be controlled by impermeable cutoff walls or barriers (see Figure 3.32) or by the provision of a ventilation system such as gravel-filled trenches around the perimeter of the landfill (see Figure 3.33). Gravel-packed perforated pipe wells or collectors may also be used to collect and diffuse the gas to the atmosphere, if not recovered. To be effective, the system must be carefully designed, constructed, and maintained.

Cutoff walls or barriers should extend from the ground surface down to a gas-impermeable layer such as clay, rock, or groundwater. Clay soils must be water saturated to be effective. Perforated pipes have been shown to be of limited effectiveness and are not recommended for the reduction of gas pressure when used alone. Gravel-filled trenches may permit migration of gases across the trench, especially when covered by snow or ice; vertical perforated pipes reduce somewhat the effect of snow or ice. Gravel-filled trenches require removal of leachate or water from the trench bottom and are susceptible to plugging by biomass buildup. Gravel-filled trenches in combination with an impermeable barrier provide good protection against gas migration when keyed to a gas-impermeable strata below the landfill. Induced exhaust wells or trenches with perforated pipes and pump or blower are reported to be very effective. Where enclosed structures are constructed over or in close proximity to a landfill, it is necessary to have these places continuously monitored. A combustible gas detection system to provide early warning (light and alarm) can alert personnel. The monitors comprising the detection system can also activate ventilation fans at present low methane levels. Soil and cement bentonite trenches or cutoff walls have also been used to prevent lateral gas migration.

Methane Recovery and Utilization Methane is produced in a landfill when anaerobic methane-producing bacteria are active. The condition shown

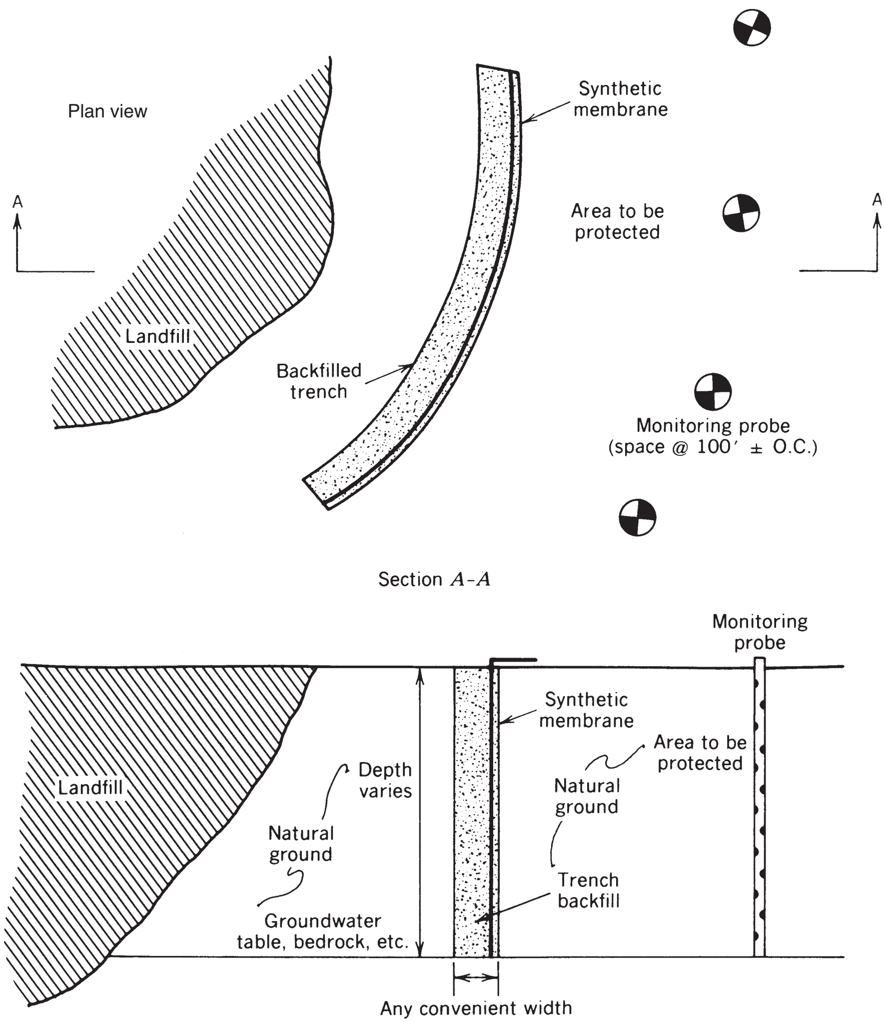


FIGURE 3.32 Typical passive gas control synthetic membrane.

in Figure 3.31 may be reached in six months to five years depending on the landfill. Acidic conditions inhibit growth of methane-producing bacteria; alkaline conditions have the opposite effect. Methane production is quite variable depending on the amount and type of decomposable material in the landfill, moisture content, temperature, and resulting rate of microbial decomposition under anaerobic conditions.

Methane is odorless, has a heat value of about 500 Btu/ft^3 compared to 1000 Btu for commercial gas, has a specific gravity less than air, and is nearly insoluble in water. The gases from landfills, after anaerobic conditions have been established, are quite variable, ranging from 50 to 60 percent methane and 40

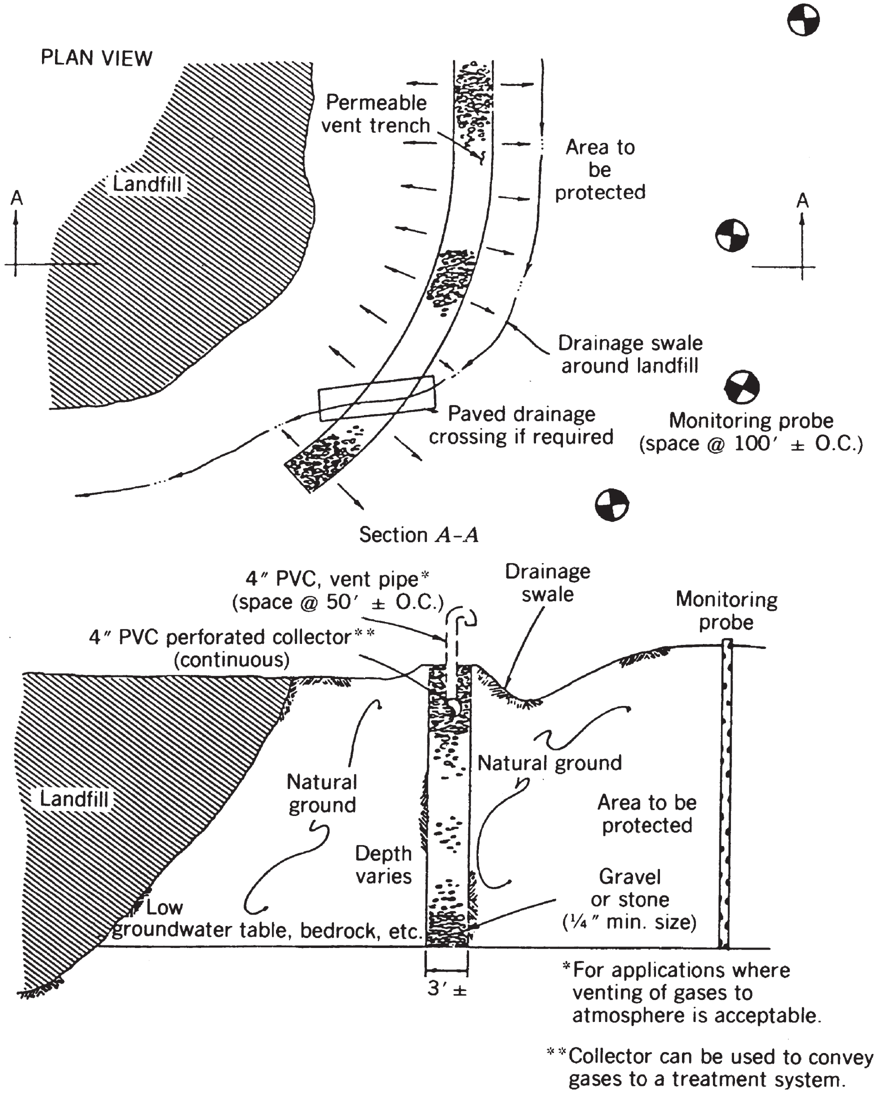


FIGURE 3.33 Passive gas control using permeable trench. (*Source:* SCS Engineers, Inc., *Procedural Guidance Manual for Sanitary Landfills: Volume I Landfill Leachate Monitoring and Control Systems and Volume II Landfill Gas Monitoring and Control Systems*, California Waste Management Board, Sacramento, CA, April, 1989.)

to 50 percent carbon dioxide. Included are small amounts of nitrogen, oxygen, water, mercaptans (very odorous), and hydrocarbons. Hydrogen sulfide may also be released if large amounts of sulfates are in the landfill. Vinyl chloride, benzene, and other toxics in trace amounts may also be produced by the action of bacteria on chlorinated solvents deposited in the fill. The presence of oxygen and nitrogen with methane gas would indicate the entrance of air into the landfill due to methane being withdrawn too rapidly. If methane extraction is not controlled to reduce or eliminate the entrance of oxygen and nitrogen, the production of methane will slow down or stop.

In the early stages the landfill gases are primarily carbon dioxide, with some methane. The carbon dioxide is heavier than air and can dissolve in water to form carbonic acid, which is corrosive to minerals with which it comes into contact. Mercaptans, carbon dioxide, and water are usually extracted to upgrade the methane to pipeline quality. Removal of carbon dioxide may improve Btu content to 900 or 1,000 Btu/ft^3. Methane as it comes from a landfill is often very corrosive. Deep landfills, 30 feet or deeper, and 30 acres or more in area with a good cover are better methane producers. Actually, gas will be generated as long as biodegradable material remains and is primarily dependent on precipitation, infiltration, and moisture content. Gas can be extracted using plastic tube wells in each cell with perforations or well screens toward the bottom connected to a controlled vacuum pump (see Figure 3.34) or a series of covered horizontal gravel trenches connected to a pipe collection system (see Figure 3.35). The extracted gas may be used for heating and generating electricity.

Management of Surface Waters

The runoff from the drainage area tributary to the solid waste disposal site must be determined by hydraulic analysis to ensure that the surface-water drainage system, such as ditches, dikes, berms, or culverts, is properly designed and that flows are diverted to prevent flooding, erosion, infiltration, and surface-water and groundwater pollution, both during operation and on completion. The design basis should be the maximum 25-year, 24-hour precipitation. The topography and soil cover should be examined carefully to ensure that there will be no obstruction of natural drainage channels. Obstructions could create flooding conditions and excessive infiltration during heavy rains and snow melt. Uncontrolled flooding conditions can also erode the cover material.

A *completed* landfill for residential solid waste that is properly capped should, ideally, not present any serious hazard of groundwater pollution, *provided surface water* (*and groundwater*) *and most of the precipitation are drained, transpired, and evaporated off the landfill and the landfill site*. Two different types of landfill covers are presented in Figures 5.36 and 5.37. The major source of water for leachate production would then be precipitation–infiltration during operation, before the final cap is put in place. Precipitation–infiltration can be minimized by the temporary use of impervious geo-membrane sheets over the completed landfill. A small amount of infiltration is desirable to support biological decomposition of the solid waste, as already noted. It becomes essential, therefore, that the solid waste working face be kept at a minimum, that the final cover be placed and graded promptly, and that a surface-water drainage system be installed as soon as possible.

Cover Material The site should preferably provide adequate and suitable cover material. The most suitable soil for cover material is one that is easily worked and

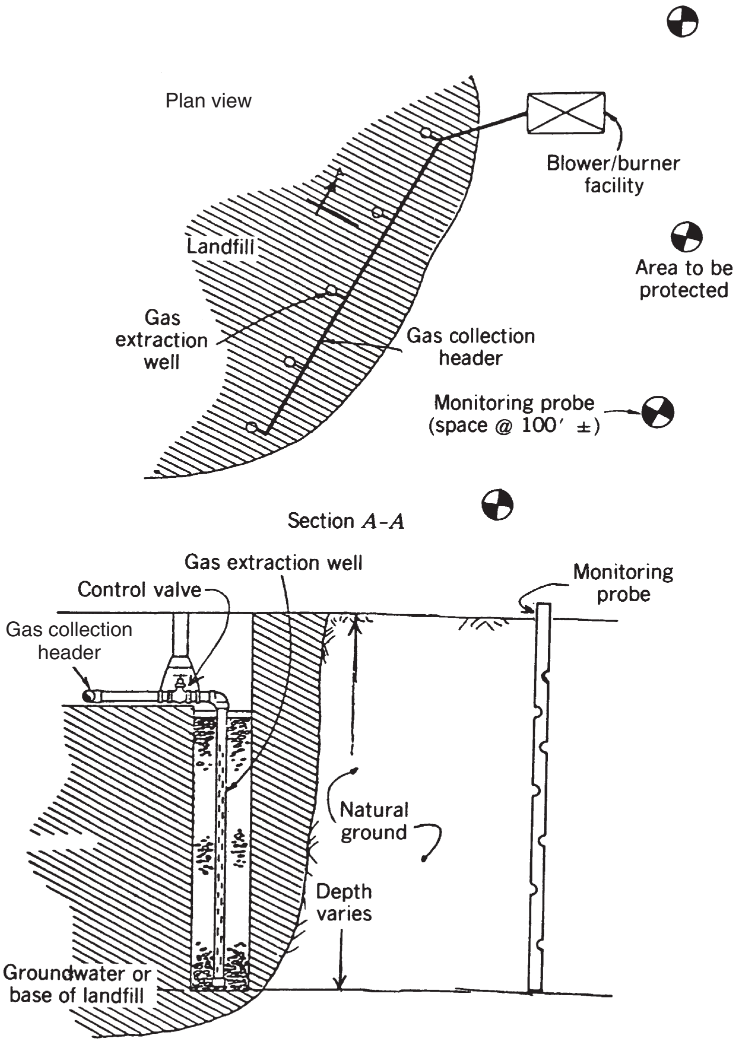


FIGURE 3.34 Typical gas extraction system. (*Source:* U.S. EPA, *Handbook Remedial Action at Waste Disposal Sites*, EPA/625/6-85/006, Hazardous Waste Engineering Research Laboratory, Office of Research and Development, EPA, Cincinnati, OH, 1985.)

yet minimizes infiltration; however, this is not always available. It is good practice to stockpile topsoil for final cover and other soil for cold-weather operation and access road maintenance. Shredded (milled) solid waste in a landfill does not cause odors, rodent or insect breeding, or unsightliness, and it may not require daily earth cover. However, precipitation will be readily absorbed and leachate produced unless the waste is covered with a low-permeability soil that is well graded to shed water.

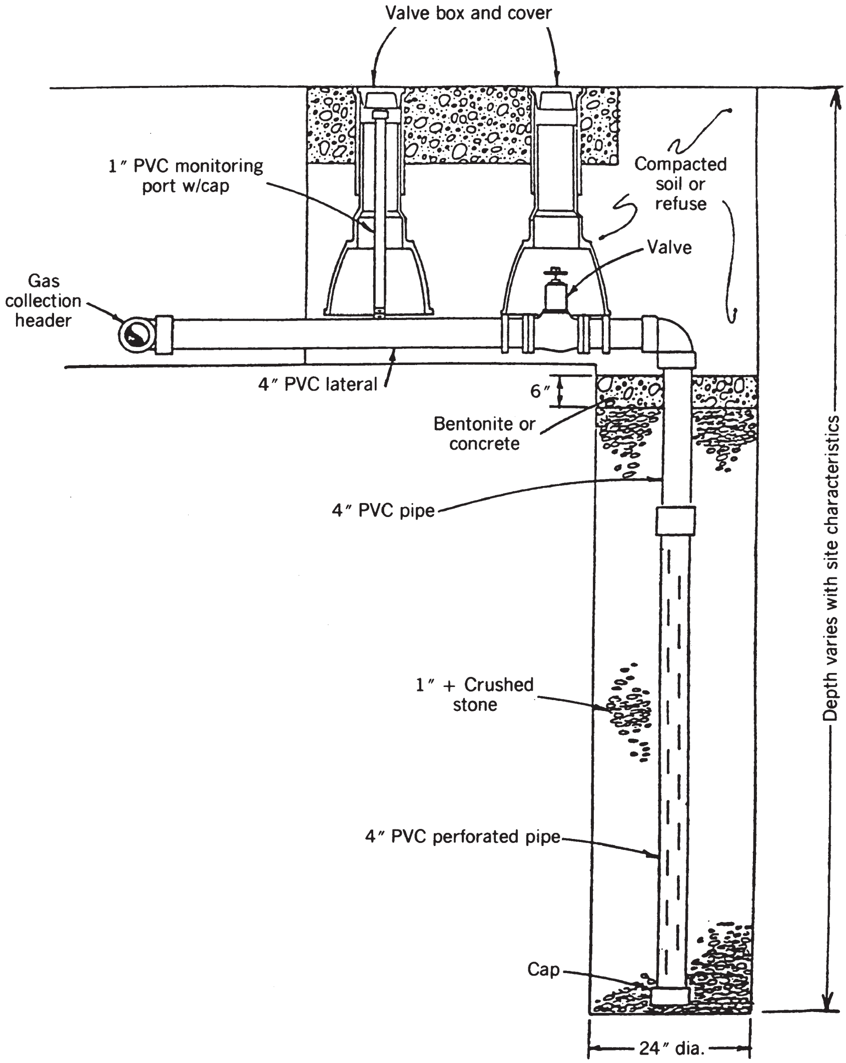


FIGURE 3.35 Typical gas extraction well. (*Source:* U.S. EPA, *Handbook Remedial Action at Waste Disposal Sites*, EPA/625/6-85/006, Hazardous Waste Engineering Research Laboratory, Office of Research and Development, EPA, Cincinnati, OH, 1985.)

The control of leachate and methane and the role played by the final earth cover, including the importance of proper grading of the landfill final cover (4 percent slope) to minimize infiltration, promote runoff, and prevent erosion, have been previously discussed. A final cover to minimize infiltration of precipitation, support vegetation, and encourage evapotranspiration is recommended. The vegetation, such as seeded grass (hydroseeded for rapid cover), will prevent

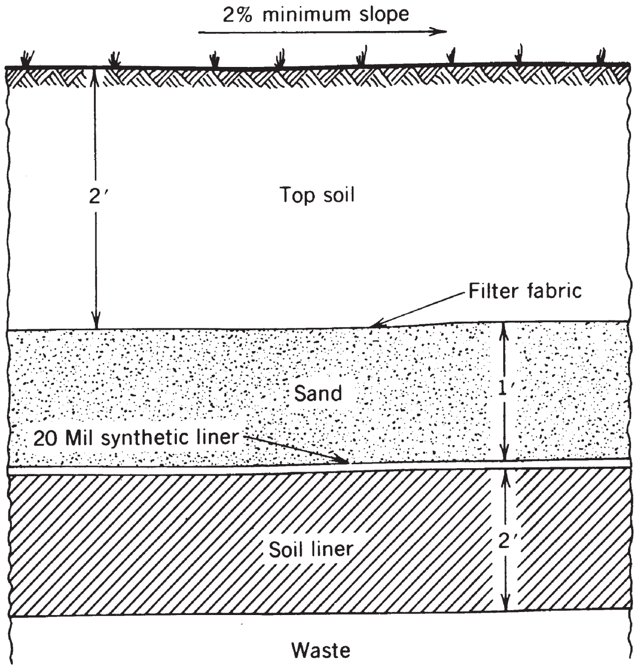


FIGURE 3.36 Typicalmultiplayer landfill cap. Minimum of 4 percent surface slope is usually preferred (*Source:* U.S. EPA, *Handbook Remedial Action at Waste Disposal Sites*, EPA/625/6-85/006, Hazardous Waste Engineering Research Laboratory, Office of Research and Development, EPA, Cincinnati, OH, 1985.)

wind and water erosion and contribute to transpiration and evaporation. The final slope should be maintained at 1:30. A tight cover or membrane cap requires provision for effective gas collection and release.

Landfill Vegetation Four feet or more earth cover is recommended if the area is to be landscaped, but the amount of cover depends on the plants to be grown. Native grasses may require 2 feet of topsoil, and large trees with deep tap roots may require 8 to 12 feet. The carbon dioxide and methane gases generated in a landfill may interfere with vegetation root growth, if not prevented or adequately diffused. The gases can be collected and disposed of through specially designed sand or gravel trenches or a porous pipe gas-venting system. Oxygen penetration to the roots is necessary. Carbon dioxide as low or lower than 10 percent in the root zone can be toxic to roots; methane-utilizing bacteria deplete the oxygen. Precautions to help maintain a healthy vegetation cover include selecting a tolerant species and seeking professional advice, avoiding areas of high gas concentrations, excluding gas from root zone (use built-up mounds for planting or line with membrane or clay soil barrier and vent trench and plant in suitable backfill soil), avoiding heavily compacted soil (loosen first if necessary and

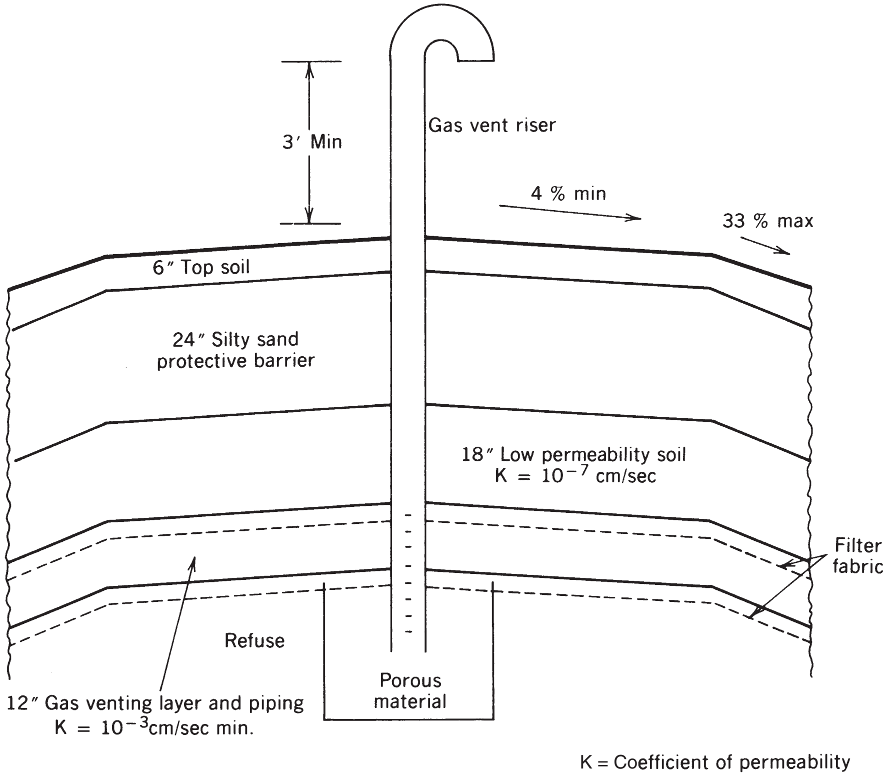


FIGURE 3.37 Final cover with passive gas vent. (*Source:* New York State, *Municipal Energy Recovery Facilities Handbook*, New York State Environmental Facilities Corporation, Albany, 1988.)

supplement soil fertility and improve its physical condition following good nursery practice), using smaller plant stock, and providing adequate irrigation (see Figure 3.38).

Landfill Mining

The excavation and recycling of a landfill waste appears to be feasible where there has been adequate moisture to permit decomposition and stabilization of the waste. On the one hand, in locations where rainfall averages 60 inches/year or more, a portion of the decomposed waste is generally suitable for recycling or for use as cover material for a new landfill at the same location excavated. On the other hand, in arid regions where the rainfall averages 10 to 20 inches/year or less, the waste placed in landfills is often well preserved after more than 20 years. Other factors such as landfill design, type of cover material, waste composition, and age of the landfill must be evaluated and regulatory approval obtained.

FIGURE 3.38 Completed landfill with irrigation system.

A thorough hydrogeological investigation of an old landfill site is necessary before considering its excavation (mining), recycling, and possible reuse. The up-gradient and down-gradient groundwater levels and quality, the depth and type of soil beneath the fill, the thickness of the fill and its composition, including the possible presence of hazardous wastes, are among the conditions to be investigated. Numerous tests are necessary as landfill waste is not homogeneous. If reuse of the excavated site as a municipal landfill site is proposed, preliminary discussions with the regulatory agency are essential.

Landfill Facilities and Equipment for Disposal by Sanitary Landfill

In addition to the control of leachate and landfill gases, a number of other facilities and operating equipment are required for the effective implementation of a sanitary landfill. Personnel requirements are discussed in the following section.

Fire Protection The availability of fire protection facilities at a site should also be considered as fire may break out at the site without warning. Protective measures may be a fire hydrant near the site with portable pipe or fire hose, a watercourse from which water can be readily pumped, a tank truck, or an earth stockpile. The best way to control deep fires is to separate the burning solid waste and dig a firebreak around the burning solid waste using a bulldozer. The solid waste is then spread out so it can be thoroughly wetted down or smothered with earth. Limiting the solid waste cells to about 200 tons, with a depth of 8 feet and 2 feet of compacted earth between cells (cells 20×85 feet assuming 1 yd^3 of compacted solid waste weighs 800 lb), will minimize the spread of underground fires. The daily 6-inch cover will also minimize the start and spread of underground fires. Fires are a rare occurrence at a properly compacted and operated sanitary landfill.

Weigh Station It is desirable to construct a weigh station at the entrance to the site. Vehicles can be weighed upon entering and, if necessary, billed for use of the site. Scales are required to determine tonnage received, unit operation costs, relation of weight of solid waste to volume of in-place solid waste, area work loads, personnel, collection rates, organization of collection crews, and need for redirection of collection practices. However, the cost involved in construction of a weigh station cannot be always justified for a small sanitary landfill handling less than 20 to 50 tons/day. Nevertheless, estimates of volume and/or weights received should be made and records kept on a daily or weekly basis to help evaluate collection schedules, site capacity, usage, and so on. At the very least, an annual evaluation is essential.

Equipment Requirements To attain proper site development and ensure proper utilization of the land area, it is necessary to have sufficient proper equipment available at all times at the site (see Figure 3.39). One piece of solid waste compaction and earth-moving equipment is needed for approximately each 80 loads per day received at the solid waste site. The type of equipment should be suitable for the method of operation and the prevailing soil conditions. Additional standby equipment should be available for emergencies, breakdowns, and equipment maintenance. Typical equipment requirements are summarized in Table 3.23.

Excavating, Spreading, and Compaction Equipment The type of equipment used at landfills for the spreading and compaction of the material to be landfilled include the crawler, rubber-tired, and steel-wheeled types equipped with bulldozer blade, bullclam, or front-end loader. The crawler tractor with a front-end bucket attachment is an all-purpose piece of equipment (see Figure 3.40). It may be used to excavate trenches, place and compact solid waste, transport cover material, and level and compact the completed portion of the landfill. Some types can also be used to load cover material into trucks for transportation and deposition near the open face. The steel-wheeled compactor is a common piece of equipment at landfills.

A bulldozer blade on a crawler tractor is good for landfills where hauling of cover material is not necessary. It is well suited for the area method landfill in which cover material is taken from nearby hillsides. It can also be used for trench method operation where the trench has been dug with some other type of equipment. A bulldozer is normally used in conjunction with some other type of earth-moving equipment, such as a scraper, where earth is hauled in from a nearby source.

The life of a tractor is figured at about 10,000 hours. Contractors usually depreciate their equipment over a five-year period. On a landfill, if it is assumed that the equipment would be used 1,000 hours a year, the life of the

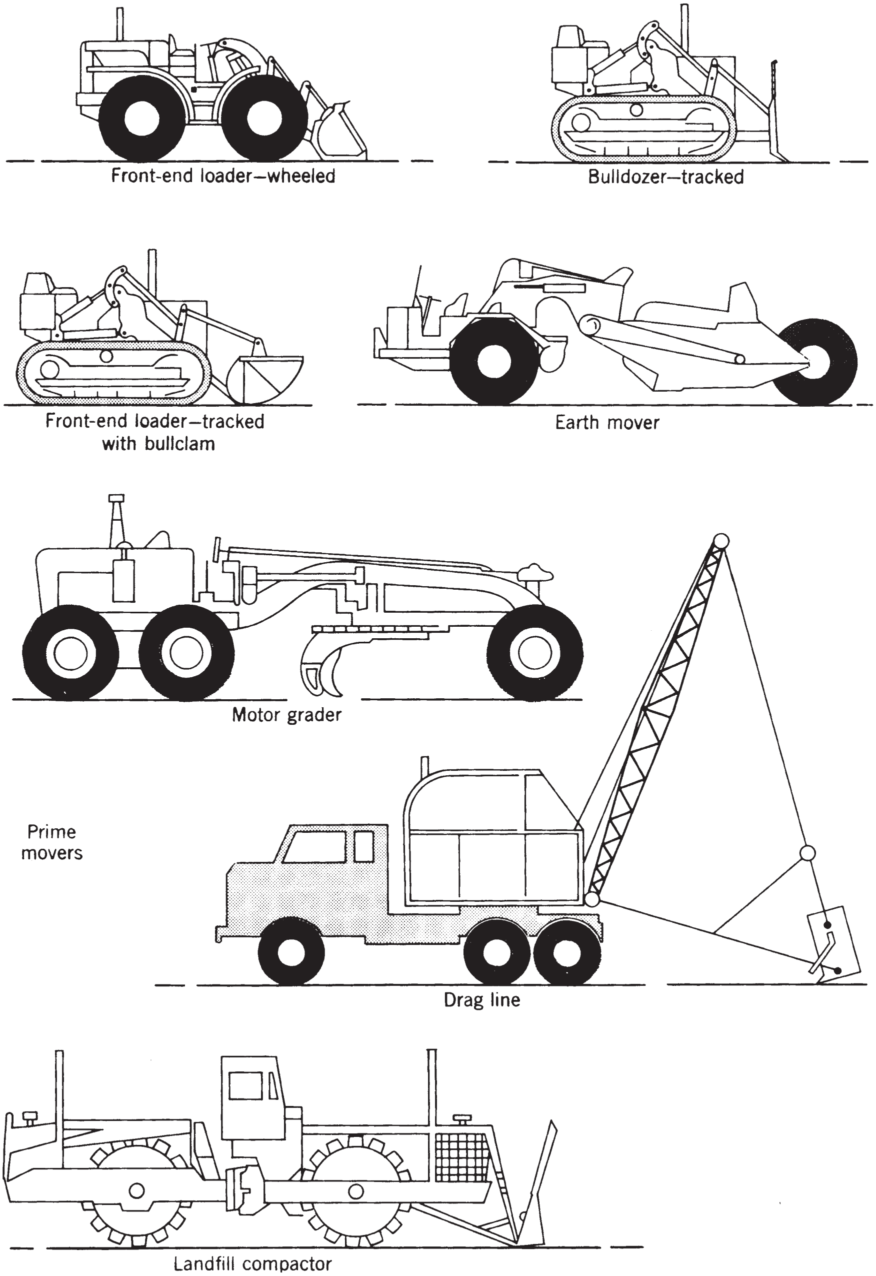


FIGURE 3.39 Typical equipment used for operation of sanitary landfill.

TABLE 3.23 Typical Minimum Landfill Equipment Requirements

Service Population	Daily Tonnage	Equipment			Accessory
		Number	Type	Size (lb)	
0–15,000	0–50	1	Tractor, crawler, or rubber-tired	10,000–30,000	Dozer blade, landfill blade, front-end loader (1–2 yd^3)
15,000–50,000	50–150	1	Tractor, crawler, or rubber-tired	30,000–60,000	Dozer blade, landfill blade, front-end loader (2–4 yd) multipurpose bucket
		1 each	Scraper or dragline, water truck		
50,000–100,000	150–300	1–2	Tractor, crawler, or rubber-tired	30,000 or more	Dozer blade, landfill blade, front-end loader (2–5 yd), multipurpose bucket
		1 each	Scraper or dragline, water truck		
100,000 or more	300 or more	2 or more	Tractor, crawler, or rubber-tired	45,000 or more	Dozer blade, landfill blade, front-end loader, multipurpose bucket
		1 each	Scraper, dragline, steel-wheeled compactor, road grader, water truck		

Source: Adapted from D. R. Brunner, and D. J. Keller, *Sanitary Landfill Design and Operation*, EPA (SW-65ts), Washington, DC, 1972.

(*a*)

(*b*)

FIGURE 3.40 Common types of compaction equipment used at sanitary landfills: (*a*) track compactor with with trash blade and (*b*) wheeled compactor with trash blade.

equipment could be 10 years. After 10 years, operation and maintenance costs can be expected to approach or exceed the annual cost of new equipment. Lesser life is also reported. Equipment maintenance and operator competence will largely determine equipment life.

The size and type of machine needed at the sanitary landfill are dependent on the amount of solid waste to be handled, availability of cover material, compaction to be achieved, and other factors.[18] A rule that has been used is that a community with a population of less than 10,000 requires a 1 1/8-yd^3 bucket on a suitable tractor. Communities with a population between 10,000 and 30,000 should have a 2 1/4-yd^3 bucket, and populations of 30,000 to 50,000 should have at least a 3-yd^3 bucket. Larger populations will require a combination of earth-moving and compaction equipment depending on the site and method of operation. A heavy tractor (D-8) can handle up to 200 tons of solid waste per day, although 100 to 200 tons per day per piece of equipment is a better average operating capacity. Tire fill foam and special tire chains minimize tire puncture and other damage on rubber-tired equipment.

Many small rural towns have earth-moving equipment that they use for highway maintenance and construction. For example, a rubber-tired loader with special tires can be used on a landfill that is open two days a week. On the other three days the landfill can be closed (with fencing and locked gate), and the earth-moving equipment can be used on regular road construction work and maintenance. The people and contract users of the site should be informed of the part-time nature of the operation to receive their full cooperation. The public officials responsible for the operation should establish a definite schedule for the assignment of the equipment to the landfill site to ensure the operation is always under control and maintained as a sanitary landfill.

Other Equipment The dragline is suitable for digging trenches, stockpiling cover material, and placing cover material over compacted solid waste. An additional piece of equipment is necessary to spread and compact the solid waste and cover material. Although not commonly used, the backhoe is suitable for digging trenches on fairly level ground, and the power shovel is suitable for loading trucks with cover material.

In large operations, earth movers can be used for the short haul of cover material to the site when adequate cover is not readily available nearby. Dump trucks may also be needed where cover material must be hauled in from some distance. Other useful equipment is a grader, a sheepsfoot roller, and a water tank truck equipped with a sprinkler to keep down dust or a power sprayer to wet down the solid waste to obtain better compaction.

Equipment Shelter An equipment shelter at the site will protect equipment from the weather and possible vandalism. The shelter can also be used to store fire protection equipment and other needed materials and for routine equipment maintenance and repair. Operators of sanitary landfills have found a shelter to be of great value during the winter months since there is much less difficulty in starting motorized equipment. However, the shelter location must be on solid ground, not subject to gas migration from the landfill.

Landfill Operation and Supervision

Operational issues for modern landfills include operational control, personnel and operation, salvaging policy, area policing, insect and rodent control, maintenance, and operational policies (see also Table 3.21).

Operation Control The direction of operation of a sanitary landfill should be with the prevailing wind to prevent the wind from blowing solid waste back toward the collection vehicle and over the completed portion of the landfill. To prevent excessive wind scattering of solid waste throughout the area, snow fencing or some other means of containing papers should be provided. The fencing can be utilized in the active area and then moved as the operation progresses. In some instances, the entire area is fenced. Other sites have natural barriers around the landfill, such as is the case in heavily wooded areas. It is desirable to design the operation so that the work area is screened from the public line of sight. Noise levels between 7 a.m. and 10 p.m. are generally required to be kept below 60 dBA in rural areas, 65 in suburban areas, and 70 in urban areas beyond property lines.

Large items such as refrigerators, ranges, and other "white goods" and tires should be recycled. Brush and yard wastes are preferably composted. Other bulky items not recyclable should be placed in a separate area of the landfill for periodic burial. Prior compression or shredding of bulky objects will improve compaction of the fill, reduce land volume requirements, and allow more uniform settlement. Consideration should always be given to resource recovery and recycling where possible. Tires are usually not acceptable in landfills but may be if chipped or properly cut.

Drivers of small trucks and private vehicles carrying rubbish and other solid wastes interfere with the operation of a landfill. To accommodate these individuals on weekends and avoid traffic and unloading problems during the week, it is good practice to provide a special unloading area (convenience station) adjacent to the landfill entrance. A satellite transfer station is also an alternative, in conjunction with a regional landfill.

Personnel and Operation Proper full-time supervision is necessary to control dumping, compaction, and covering. Adequate personnel are needed for proper operation. Depending on the size of the community, there should be a minimum of one man at a site and six men per 1,000 yd^3 dumped per day that the site is open. The supervisor should erect signs for direction of traffic to the proper area for disposal. It is essential that the supervisor be present at all hours of operation to ensure that the landfill is progressing according to plan. Days and hours of operation should be posted at the entrance to the landfill. A locked gate should be provided at the entrance to keep people out when closed. It is also advisable to inform the public of the days and hours of operation.

Solid waste treatment and disposal facilities represent very large investments. They have the potential for grave air, water, and land pollution and contain complex equipment and controls. Proper operation meets regulatory agency permit conditions and requires continuous, competent operational control. The training and certification of operators of resource recovery facilities, landfills, incinerators, and hazardous waste sites are provided by various state and private organizations.

In supervising an operation, the length of the open face should be controlled, since too large an open face will require considerably more cover material at the end of a day's operation. Too small an open face will not permit sufficient area for the unloading of the expected number of collection vehicles that will be present at one time. After vehicles have deposited the solid waste at the top or, preferably, at the base of the ramp as directed, the solid waste should be spread and compacted from the bottom up into a 12- to 18-inch layer (24 in. maximum) with a tractor. Three to five passes should give a compaction of 1,000 to 1,250 lb/yd^3. *Passing over the waste should be done continually throughout the day* to ensure good compaction and vermin and fire control. If solid waste is allowed to pile up without spreading and compaction for most of the day, proper compaction will not be achieved, resulting in uneven settlement and extra maintenance of the site after the fill is completed. At the end of each day, the solid waste should be covered with at least 6 inches of earth or a suitable foam. For final cover of solid waste, at least 2 feet of earth is required.

No Burning or Salvaging Air pollution standards and sanitary codes generally prohibit any open burning. Limited controlled burning might be permitted in some emergency cases (for uncontaminated wood and stumps), but special permission would be required from the air pollution control agency, health department, and local fire chief. Arrangements for fire control, complete burning in one day, control over material to be burned (no rubber tires or the like), and restrictions for air pollution control would also be required. Salvaging at sanitary landfills is not recommended since, as usually practiced, it interferes with the operation. It will slow down the entire operation and thus result in time loss. Salvaging can also result in fires and unsightly stockpiles of the salvage material in the area.

Area Policing Since wind will blow papers and other solid waste around the area as the trucks are unloading, it will be necessary to clean up the area and access road at the end of each day. One of the advantages of portable snow fencing is that it will usually confine the papers near the open face, thereby make the policing job easier and less time consuming. At many sanitary landfills, dust will be a problem during dry periods of the year. A truck-mounted water sprinkler can keep down the dust and can also be used to wet down dry solid waste to improve compaction. The bulldozer operator should be protected by a dust mask, special cab, or similar device.

Insect and Rodent Control An insect and rodent control program is not usually required at a properly designed and operated landfill. However, from time to time, certain unforeseen conditions may develop that will make control necessary. For this reason, prior arrangement should be made to take care of such emergencies until the proper operating corrections can be made. Prompt covering of solid waste is necessary.

Maintenance Once a sanitary landfill, or a lift of a landfill, is completed or partially completed, it will be necessary to maintain the surface to take care of differential settlement. Settlement will vary, ranging up to approximately 20 to 30 percent, depending on the compaction, depth, and character of solid waste. Ninety percent of the settlement can be expected in the first five years. Settlement maintenance is required for perhaps 20 or 30 years. Maintenance of the cover is necessary to prevent excessive precipitation and surface-water infiltration, erosion, ponding, and excessive cracking, allowing insects and rodents to enter the fill and multiply.

It is necessary to maintain proper surface-water drainage to reduce precipitation–infiltration and minimize percolation of contaminated leachate through the fill to the groundwater table or the surface. A final 4 percent grade, with culverts and lined ditches as needed, is essential. The formation of water pockets is objectionable since this will promote surface-water infiltration. Vehicular traffic over these puddles will wash away the final earth cover over the solid waste and cause trucks to bog down. The maintenance of access roads to the site is also necessary to prevent dust and the formation of potholes, which will slow down vehicles using the site. Finally, provision must be made for groundwater, surface-water and gas monitoring, and control. The landfill surface should be properly capped, graded, and planted with suitable tolerant vegetation as previously noted.

Summary of Recommended Operating Practices

1. The sanitary landfill should be planned as an engineering project, to be constructed, operated, and maintained by qualified personnel under technical direction, without causing air, land, or water pollution, safety or health hazards, or nuisance conditions. Surveying benchmarks should be established and maintained to guide fill progression and site closure. Careful supervision must be given to landfill bottom separation and soil compaction, construction of primary and secondary composite liners, synthetic liner placement and seals, and leachate drainage and collection system. Construction of the landfill cap requires similar supervision.
2. The face of the working fill should be kept as narrow as is consistent with the proper operation of trucks and equipment in order to keep the area of exposed waste material to a minimum.
3. All solid waste should be spread as dumped and compacted into 12- to 18-inch-thick layers as it is hauled in. Operate tractor up- and downslope (3:1) of fill to get good compaction—three to five passes.

4. All exposed solid waste should be covered with 6 inches of earth at the end of each day's operation.
5. The final earth covering for the surface and side slopes should minimize infiltration, be compacted, and be maintained at a depth of at least 24 inches. See state regulations.
6. The final level of the fill should provide a 4 percent slope to allow for adequate drainage. Side slopes should be as gentle as possible to prevent erosion. The top of the fill and slopes should be promptly seeded. Drainage ditches and culverts are usually necessary to carry away surface water without causing erosion.
7. The depth of solid waste should usually not exceed an average depth of 8 to 10 feet after compaction. In a landfill where successive lifts are placed on top of the preceding one, special attention should be given to obtain good compaction and proper surface water drainage. A settlement period of preferably one year should be allowed before the next lift is placed.
8. Control of dust, wind-blown paper, and access roads should be maintained. Portable fencing and prompt policing of the area each day after solid waste is dumped are necessary. If possible, design the operation so that it is not visible from nearby highways or residential areas.
9. Salvaging, if permitted by the operator of the solid waste disposal area, should be conducted in such a manner as not to create a nuisance or interfere with operation. Salvaging is not recommended at the site.
10. A separate area or trench may be desirable for the disposal of such objects as tree stumps, large limbs, if not shredded and recycled, and nonrecyclable miscellaneous materials.
11. Where necessary, provision should be made for the disposal, under controlled conditions, of small dead animals and septic tank wastes. These should be covered immediately. The disposal of wastewater sludge, industrial or agricultural wastes, and toxic, explosive, or flammable materials should not be permitted unless study and investigation show that the inclusion of these wastes will not cause a hazard, nuisance, or groundwater or air pollution. See appropriate regulatory agency for details.
12. An annual or more frequent inspection maintenance program should be established for completed portions of the landfill to ensure prompt repair of cracks, erosion, and depressions.
13. Sufficient equipment and personnel should be provided for the spreading, compacting, and covering of solid waste. Daily records should be kept, including type and amount of solid wastes received. *At least annually*, an evaluation should be made of the weight of solid waste received and volume of solid waste in place as a check on compaction and rate at which the site is being used.
14. Sufficient standby equipment should be readily available in case there is a breakdown of the equipment in use.

15. The breeding of rats, flies, and other vermin; release of smoke and odors; pollution of surface waters and groundwaters; and causes of fire hazards are prevented by proper operation, thorough compaction of solid waste in 12- to 18-inch layers, daily covering with earth, proper surface-water and groundwater drainage, and good supervision.
16. Leachate and gas-monitoring wells should be sampled periodically to detect significant changes. This should include methane concentrations in on-site or other nearby buildings.

Site Closure or Conversion

If a disposal site is to be closed, the users, including contractors, should be notified and an alternate site designated. A rat-poisoning (baiting) program should be started at least two weeks before the proposed closing of a site that has not been operated as a sanitary landfill and continued until the site has been completely closed. The site should be closed off and made inaccessible; it should be covered with at least 2 feet of compacted earth on the top and all exposed sides or as required by the regulatory agency, graded to shed water, seeded to grass, and then posted to prohibit further dumping. Side slopes should be no greater than 3:1 to reduce erosion and maintenance. Steps must be taken to prevent contravention of surface-water and groundwater standards, gas migration, or adverse health or environmental hazards. If the site is adjacent to a stream, the solid waste must be moved an appropriate distance back from the high-water level to allow for the construction of an adequate and substantially protected earth dike. Legal closure requirements may be quite onerous if groundwater pollution is suspected or if enclosed structures are in a vicinity that might be affected by methane migration.

Where adequate land is available and the site is suitable as determined by an engineering and hydrogeological analysis, it may be possible to convert the landfill into a properly designed, constructed, operated, and maintained sanitary landfill. Conversion of a *suitable* existing site can overcome the problems associated with the selection of a new site.

Landfill Closure Requirements The state regulatory agency closure requirements must be followed.

Use of Completed Landfill A sanitary landfill plan should provide for landscaping and a specific use for the area after completion. Final grades for a sanitary landfill should be established in advance to meet the needs of the proposed future use. For example, the use of the site as a golf course can tolerate rolling terrain while a park, playground, or storage lot would be best with a flat graded surface. Other uses of completed landfills include toboggan and ski runs for children, nature areas, bicycle and hiking paths, open areas, and airport runway extensions. In planning for the use of such an area, permanent buildings or habitable dwellings should not be constructed close to or over the fill since gas production beneath the ground may migrate into sewers, utility conduits, and basements or through floor slabs and sump drains of such dwellings or buildings, reaching explosive levels. Some open structures that would not require excavation, such as grandstands and open equipment shelters, can be built on a sanitary landfill with little resulting hazard. Buildings constructed on sanitary landfills can be expected to settle unevenly unless special foundation structures such as pilings are provided; however, special provisions must be made to monitor and dissipate gas production. When the final land use is known beforehand, selected undisturbed ground islands or earth-fill building sites are usually provided to avoid these problems, but gas monitoring is still necessary.

INCINERATION

The incineration (also referred to as combustion) of solid waste involves the conversion of solid wastes into gaseous, liquid, and solid conversion products with the concurrent or subsequent release of heat energy. Incineration is typically implemented to reduce the volume of solid waste and, to the extent possible, recover energy. A properly designed and controlled incinerator is satisfactory for burning combustible municipal solid waste and chemical, infectious, and pathological wastes. In general, incineration is not generally recommended for small towns, villages, apartment buildings, schools, institutions, camps, and hotels unless good design and supervision can be ensured and cost is not a factor. Further, a landfill is a necessary adjunct for the disposal of incinerator residue and unrecycled solid waste. The purpose of this section is to review (1) the basic operations involved in the incineration of solid waste, (2) briefly the principal combustion products and residues formed during combustion, (3) the types of incinerators that are used for solid waste, (4) factors that must be controlled in the incineration process, (5) residuals management, (6) site selection, plant layout, and building design, and (7) issues in the implementation of incineration facilities.

Description of Operation of MSW Incinerator

The basic operations involved in the combustion of commingled MSW are identified in Figure 3.41. The operation begins with the unloading of solid wastes from collection trucks (1) into a storage pit (2). The length of the unloading platform and storage bin is a function of the size of the facility and the number of trucks that must unload simultaneously. The depth and width of the storage bin are determined by both the rate at which waste loads are received and the rate of burning. The capacity of the storage pit is usually equal to the volume of waste for two to four days. The overhead crane (3) is used to batch load wastes into the feed (charging) chute (4), which directs the wastes to the furnace (5). The crane operator can select the mix of wastes to achieve a fairly even moisture content in the charge. Large or noncombustible items are also removed from the wastes. Solid wastes from the feed (charging) chute fall onto the grates (6), where

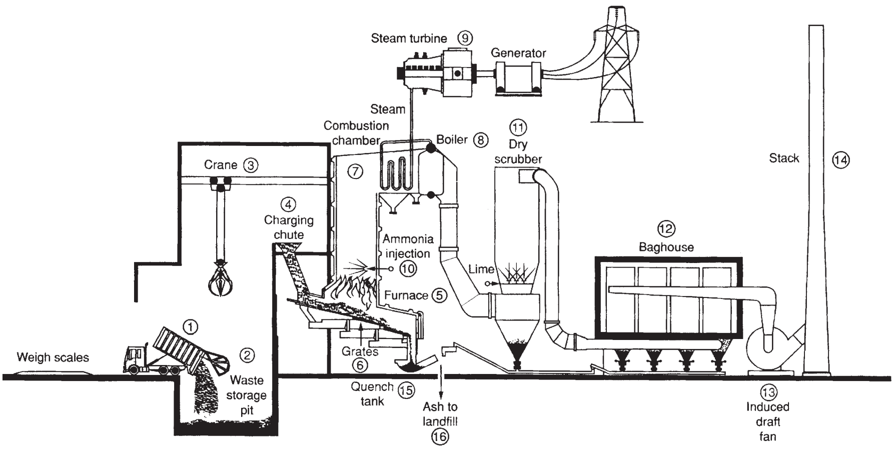


FIGURE 3.41 Definition sketch for operation of modern mass-burn incinerator.

they are mass fired. Several different types of mechanical grates are commonly used. Typical physical and chemical characteristics of incinerator solid waste are reported in Table 3.24.

Air may be introduced from the bottom of the grates (under-fire air) by means of a forced-draft fan or above the grates (over-fire air) to control burning rates and furnace temperature. Because most organic wastes are thermally unstable, various gases are driven off in the combustion process taking place in the furnace. These gases and small organic particles rise into the combustion chamber (7) and burn at temperatures in excess of 1600 °F. Heat is recovered from the hot gases using water-filled tubes in the walls of the combustion chamber and with a boiler (8) that produces steam that is converted to electricity by a turbine generator (9). When 30 percent or less of the solid waste is rubbish or when the solid waste contains more than 50 percent moisture, additional supplemental fuel will be needed.

Air pollution control equipment is required on all new incinerators. Air pollution control equipment may include ammonia injection for NO_x (nitrogen oxides) control (10), a dry scrubber for SO and acid gas control (11), and a bag house (fabric filter) for particulate removal (12). To secure adequate air flows to provide for head losses through air pollution control equipment, as well as to supply air to the combustor itself, an induced-draft fan (13) may be needed. The end products of combustion are hot combustion gases and ash. The cleaned gases are discharged to the stack (14) for atmospheric dispersion. Ashes and unburned materials from the grates fall into a residue hopper (15) located below the grates where they are quenched with water. Fly ash from the dry scrubber and the bag house is mixed with the furnace ash and conveyed to ash-treatment facilities (16). Details on incinerator design, air pollution control equipment, and ash treatment and disposal may be found in Refs. 2 and 15.

TABLE 3.24 Physical and Chemical Characteristics of Incinerator Solid Waste[a]

Constituents	Percent by Weight (as received)
Proximate analysis	
Moisture	15–35
Volatile matter	50–65
Fixed carbon	3–9
Noncombustibles	15–25
Ultimate analysis	
Moisture	15–35
Carbon	15–30
Oxygen	12–24
Hydrogen	2–5
Nitrogen	0.2–1.0
Sulfur	0.02–0.1
Noncombustibles	15–25
Higher heating value (Btu/lb as received)	
Without recycling	3000–6000
With recycling	3000–5000

[a]Principally residential–commercial waste.

Source: J. DeMarco, D. J. Keller, J. Leckman, and J. L. Newton, *Incinerator Guidelines—1969*, PHS Pub. 2012, Department of Health and Education, Washington, DC, 1969;. and G. Tchobanoglous, H. Theisen, and S. Vigil, *Integrated Solid Waste Management: Engineering Principles and Management Issues*, McGraw-Hill, New York, 1993.

In addition to these operational aspects, complex instrumentation, including transmission to a central control panel, is necessary to properly operate a modern incinerator. Included are temperature indicators, air and water flows, pressure indicators, alarms, waste feed cutoffs when combustion and emission regulations are violated, and other indicators and controls that may be required by the regulatory authority.

Combustion Products and Residues

Municipal solid waste burned in incinerators will result in the production of combustion gases, particulates, and bottom and fly ash. The characteristics of these products will depend on the types of wastes burned and the incinerator design, operating temperature, residence time, and controls.

Combustion Essentials The three essentials for combustion, as outlined previously, are (1) time, (2) temperature, and (3) turbulence, including sufficient oxygen. There must be sufficient time to drive out the moisture, the temperature must be raised to the ignition point, and there must be sufficient turbulence to ensure mixing of the gases formed with enough air to burn completely the volatile combustible matter and suspended particulates. The combustion process involves first, drying, volatilization, and ignition of the solid waste and, second, combustion of unburned furnace gases, elimination of odors, and combustion of carbon suspended in the gases. The second step requires a high temperature, at least 1500 to 1800 °F (816–982 °C) sufficient air, and mixing of the gas stream to maintain turbulence until burning is completed. The temperature in the furnace may range from 2100 to 2500 °F (1149–1371 °C) if not controlled. A combustion temperature of 2500 °F (1371 °C) is normal for steam generation and energy recovery.

When the gases leave the combustion chamber, the temperature should be between 1500 and 1800 °F (816 and 982 °C), and the gas entering the stack should be 1000 °F (538 °C) or less. The minimum temperature for burning carbonaceous wastes to avoid release of smoke is 1500 °F (816 °C). A temperature of less than 1500 °F will also permit the release of dioxins and furans. The exit temperature will have to be lowered to 200 °F (93 °C) for wool or cotton filters, 450 ° to 500 °F (232 °–260 °C) for glass fiber filters before the gas is filtered, or 600 °F (316 °C) or less if electrical precipitators are used. At a temperature of 1200 to 2000 °F (649–1093 °C) or higher, depending on temperature and residence time, oxides of nitrogen are formed that contribute to air pollution. Hospital wastes require incineration at a temperature of 1800 to 2000 °F (982–1093 °C) to ensure degradation of organic compounds. Inorganic agents are not destroyed.

Gaseous Combustion Products The principal elements of solid wastes are carbon, hydrogen, oxygen, nitrogen, and sulfur. Under ideal conditions, the gaseous products derived from the combustion of municipal solid wastes would include carbon dioxide (CO_2), water (H_2O, flue gas), oxygen (O_2), nitrogen (N_2), and small amounts of sulfur dioxide (SO_2). Because many different reaction sequences are possible, depending on the exact nature of the wastes and the operating characteristics of the combustion reactor, the gaseous emissions from combustion may include sulfur and nitrogen oxides and smaller amounts of hydrogen chloride, mercury, lead, arsenic, cadmium, dioxins and furans, and organic compounds. The amounts and concentrations going up the stack are determined also by the combustion effectiveness and the efficiency of air pollution control equipment.

The basic reactions for the oxidation (combustion) of the carbon, hydrogen, and sulfur contained in the organic fraction of MSW are as follows:

$$\underset{(12)}{C} + \underset{(32)}{O_2} \longrightarrow CO_2 \quad \text{(for carbonA)} \tag{3.1}$$

$$\underset{(4)}{2H_2} + \underset{(32)}{O_2} \longrightarrow 2H_2O \quad \text{(for hydrogen)} \tag{3.2}$$

$$\underset{(32.1)}{S} + \underset{(32)}{O_2} \longrightarrow SO_2 \quad \text{(for sulfur)} \tag{3.3}$$

If it is assumed that dry air contains 23.15 percent oxygen by weight, then the amount of air required for the oxidation of 1 lb of carbon would be equal to 11.52 lb [(32/12)(1/0.2315)]. The corresponding amounts for hydrogen and sulfur are 34.56 and 4.31 lb, respectively. Thermal processing systems are often categorized on the basis of their air requirements. Combustion with exactly the amount of oxygen (or air) needed for complete combustion is known as *stoichiometric combustion*. Combustion with oxygen in excess of the stoichiometric requirements is termed *excess air combustion*.

Combustion Residues The principal solid residues are (1) bottom ash, (2) fly ash, and (3) noncombusted organic and inorganic materials. The residue after burning (bottom and fly ash) is about 25 percent of the original weight (10 to 15 percent by volume), 5 percent where intensive recycling is practiced. Other residuals associated with the incineration of solid waste may include scrubber sludge and wastewater treatment plant sludge, both of which will tend to concentrate contaminants. It is essential, therefore, that the fly ash, bottom ash, and scrubber and wastewater sludge be analyzed for contaminants likely to be present and evaluated for their significance. The disposal method and facility should be tailored to ensure protection of the public health and the environment.

Types of Incinerators (Combusters)

A variety of incinerator types have been used for the combustion of solid waste, including (1) mass-fired combustors, (2) refuse-derived fuel- (RDF) fired combustors, (3) modular combustion units, and (4) on-site commercial and industrial incinerators.

Mass-Fired Combustors In a mass-fired combustor, minimal processing is given to solid waste before it is placed in the hopper used to feed the combustor. The crane operator in charge of loading the charging hopper can manually reject obviously unsuitable items. However, it must be assumed that anything in the MSW stream may ultimately enter the combustor, including bulky oversize noncombustible objects (e.g., broken tricycles) and even potentially hazardous wastes deliberately or inadvertently delivered to the system. For these reasons, the combustor must be designed to handle these objectionable wastes without damage to equipment or injury to operational personnel. The energy content of mass-fired waste can be extremely variable, dependent on the climate, season, and source of waste. In spite of these potential disadvantages, mass-fired combustors have become the technology of choice for most existing and planned incineration facilities.[25]

A typical mass-burn incinerator schematic showing steam and electricity production is illustrated in Figure 3.42. Types of furnaces used are the rectangular refractory lined, the rotary kiln, and the rectangular furnace with waterwalls. In the rectangular furnace, two or more grates are arranged in tiers. The rotary kiln furnace incorporates a drying grate ahead of a rotary drum or kiln where burning is completed. Waterwall furnaces substitute water-cooled tubes for the exposed furnace walls and arches. Other types of furnaces are also available.

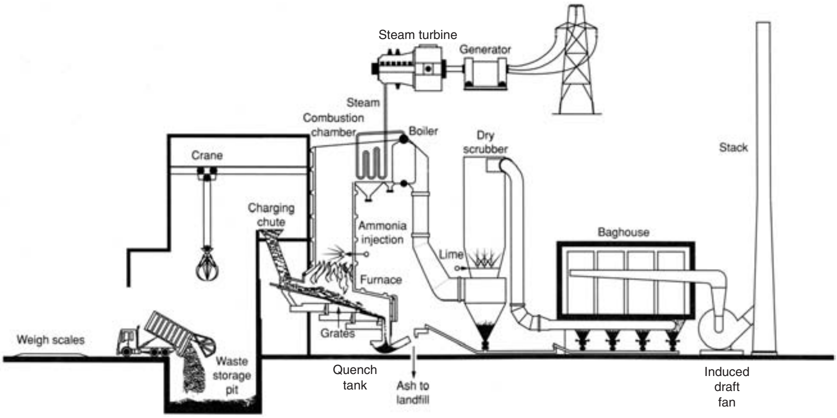


FIGURE 3.42 Schematic of typical mass-burn municipal waste combustion facility with energy production facilities. (*Source:* County Sanitation Districts of Los Angeles County.)

All furnaces should be designed for continuous feed. Reciprocating or moving and traveling grates are the most common. Mass-burn incinerators usually burn raw solid wastes in a refractory-lined rotary kiln after drying and combustion, with underfire and overfire air and a tube boiler to generate steam, hot water, or electricity. In a cogeneration incinerator, steam and electricity are produced.

Modern furnace walls are usually lined with tile or have waterwalls. With tile refractories, repairs can be readily made without the need for expensive and time-consuming rebuilding of entire solid brick walls found in old plants. Special plastic or precast refractories can be used for major or minor repairs. Waterwalls in a furnace actually consist of water-cooled tubes that also serve as heat exchangers, thereby reducing the outlet gas temperature and simplifying dust collection. The tubes also cover and protect exposed furnace walls and arches. Less air is required: 100 to 200 percent excess air for refractory walls compared to less than 80 percent for waterwalls. External pitting of the water-cooled tubes may occur if the water temperature drops below 300 °F (149 °C) due to condensation of the corrosive gases. Internal tube corrosion must also be prevented by recirculation of conditioned water.

RDF-Fired Combustors Compared to the uncontrolled nature of unprocessed commingled MSW, RDF can be produced from the organic fraction of MSW with fair consistency to meet specifications for energy content, moisture, and ash content. The RDF can be produced in shredded or fluff form or as densified pellets or cubes. Densified RDF (d-RDF) is more costly to produce but easier to transport and store. Either form can be burned by itself or mixed with coal and combusted in a waterwall furnace (see Figure 3.13) equipped with a traveling gate for ash management.

Because of the higher energy content of RDF compared to unprocessed MSW, RDF combustion systems can be physically smaller than comparatively rated mass-fired systems. However, more space will be required if the front-end processing system needed to prepare the RDF is to be located adjacent to the combustor. A RDF-fired system can also be controlled more effectively than a mass-fired system because of the more homogeneous nature of RDF, allowing for better combustion control and better performance of air pollution control devices. Additionally, a properly designed system for the preprocessing of MSW can effect the removal of significant portions of metals, plastics, and other materials that may contribute to harmful air emissions.[15]

Modular Combustion Units Modular combustion units are available for capacities of less than 700 lb/hr to 250 tons/day and include a secondary combustion chamber. These units may be used for the batch incineration of municipal, hospital, commercial, and industrial wastes. Volume reduction of 80 to 90 percent and energy recovery of about 55 percent are claimed. Emission control (scrubber and/ or baghouse) is needed and skilled operation is required.

On-site Commercial and Industrial Incinerators When possible, a large municipal incinerator should be used in preference to a small on-site incinerator. Better operation at lower cost with less air pollution can usually be expected. Based on past experience, conventional mass-fired incinerators generally are not economically feasible for communities with a population of less than 50,000 to 100,000, but modular controlled air units incorporating heat recovery are suitable for smaller volumes of waste. However, on-site incinerators are used in hospitals, schools, and commercial and industrial establishments. Their continued use is being severely limited by air pollution control requirements. Many of the units now in use need to be replaced or redesigned to meet modern air-pollution control standards. The controlled-air incinerator with a waste-heat boiler for energy recovery can overcome many, if not all, of the deficiencies.

Incinerator Capacity and Stack Heights Incinerators are rated in terms of tons of burnable or incinerable waste per day. For example, an incinerator having a furnace capacity of 600 tons/day can theoretically handle 600 tons in 24 hours with three-shift operation, 400 tons in 16 hours with two-shift operation, and 200 tons in 8 hours with one-shift operation. Hence, if 400 tons of incinerable wastes collected per day are to be incinerated in 8 hours, an incinerator with a rated capacity of 1,200 tons per day will be required plus a 15 percent downtime allowance for repairs. In determining design capacity, consideration must also be given to daily and seasonal variations, which will range from 85 to 115 percent of the median.

High stacks (chimneys) 150 to 200 feet above ground level are usually constructed to provide natural draft and air supply for combustion. Stack heights of 300 to 600 feet are not uncommon. Discharge of gases at these heights also facilitates dilution and dispersal of the gases. In some designs, short stacks are used for aesthetic reasons, and the equivalent effective stack height is obtained by induced draft. Meteorological conditions, topography, adjacent land use, air pollution standards, and effective stack height should govern.

Control of the Incineration Process

The poor image that incineration has in the eyes of many people is due largely to the failure to control the operation, with resultant destruction of the equipment and air pollution. A properly designed and operated incinerator requires control instrumentation for (1) temperature, (2) draft pressures, (3) smoke emission, (4) weights of solid wastes coming in and leaving the plant, and (5) air pollution control equipment. Competent well-trained operators are also essential.

Temperature Temperature monitoring is necessary for control purposes to monitor the incoming air and gases leaving the combustion chamber at the settling chamber outlet, the cooling chamber outlet, the dust collector inlet and outlet, and the stack temperature. Furnace temperature can be controlled by adjusting the amount of overfire or underfire air. The temperature of the gases leaving the furnace is reduced by spraying with water (causes a white stack plume unless the flue gas is reheated before discharge), dilution with cool air (high equipment cost to handle large volumes of diluted gases), or passing through heat exchangers (ready market for heat, steam, electricity, or high-temperature water needed). Gas scrubbers using water sprays can be used to cool effluent gas so that an induced-draft fan can be used to reduce the chimney height; large particulates can also be removed.

Draft Pressure Draft pressure measurements are needed to control the induced-draft fan and the stack draft. Measurements should be made at the underfire air duct, overfire air duct, stoker compartment, sidewall air duct, sidewall low-furnace outlet, dust collector inlet and outlet, and induced fan inlet. Control of underfire air can provide more complete combustion with less fly-ash carryover up the stack.

Smoke Density The smoke emission can be controlled by continuous measurement of the particulate density in the exhaust gas. A photoelectric pickup of light across the gas duct is used, preferably located between the particulate collector and the induced fan duct.

Weigh Station Platform scales to weigh and record the incoming solid waste and outgoing incinerator residue, fly ash, siftings, and other materials are generally required.

Instrumentation Devices should include those to keep record of overfire and underfire air flow rates; temperature and pressure in the furnace, along gas passages, in the particulate collectors, and in the stack; electrical power and water use; and grate speed.

Odor Odor control requires complete combustion of hydrocarbons—that is, excess air and a retention time of 1 sec at 1500 °F (816 °C) [above 1400 °F (760 °C) at the exit of the furnace]. Adequate dilution of gases leaving the stack by an effective stack height (actual stack height plus plume rise) is another possible method for odor control, but its effectiveness is related to meteorological conditions and persistence of the odors. Wet scrubbers can also be used to absorb odors while removing particulates.

Gaseous Emissions The principal gaseous emissions from the combustion of mixed wastes are: carbon dioxide, water vapor, sulfur oxides, nitrogen oxides, carbon monoxide, and hydrogen chloride. Hydrogen chloride and other acids can cause corrosion of air pollution control equipment. A lime spray dry scrubber followed by a baghouse (fabric) filter is effective in greatly reducing sulfur dioxide and hydrogen chloride gases, metals, dioxins, furans, and organic emissions, as well as fly ash. There is some evidence that the lower the temperature of flue gases [below about 300 °F (149 °C)] entering the pollution control devices, the greater the amount of phenols, benzenes, dioxins, and other organics condensed and collected on the particulates. Typical gaseous emission guidelines are presented in Table 3.25.

Particulate Emissions These can be controlled by settling chambers, wetted baffle spray system, cyclones, wet scrubbers, electrostatic precipitators, and fabric filters. Apparently, only wet scrubbers, electrostatic precipitators, and bag filters can meet air pollution code requirements. Cyclones in combination with other devices might approach the standard. Typical particulate emission design and operating guidelines are presented in Table 3.25.

Residue Management

Incinerator ash and fly ash leaving the furnace (collected by scrubber, baghouse, electrostatic precipitator) may contain various concentrations of hazardous pollutants. These may require treatment and disposal so as not to endanger the public health or the environment. Concentrations of pollutants in incinerator bottom ash and fly ash will be determined by the characteristics of the waste burned, plant design, operation, efficiency of air cleaning devices, and other factors. It should also be noted that the EPA does not consider ash from an incinerator burning residential solid waste a hazardous waste, even though it may contain some metals.

To minimize the potential for the release of leachate from incinerator ash, there is a trend toward stabilization of the ash by cementing, vitrification, or asphalting. Recycling of ash into a useful material is the preferred solution. Prevention of hazardous leachate is the goal. Up to 30 percent ash, by weight, can be used as an additive to cement for building materials and solidification in ceramics or glass. Incinerator bottom ash can be mixed with fly ash and lime from a dry scrubber. When properly moistened, the resultant ash–lime mixture will form a pozzolanic-like cement in which the metals are immobilized and cannot leach out under normal conditions. It can be used as a road base or for similar purposes.

It is recommended that bottom and fly ash, if not reused, be disposed of in a properly designed and constructed sanitary landfill with a double liner or a

TABLE 3.25 Some Municipal Solid Waste Incineration Emission Design and Operation Guidelines

Control	Guidelines
Particulate emissions	Not greater than 0.010 grains[a] per dry standard cubic foot of exhaust (stack) gas, corrected to 7% oxygen; not greater than 0.015 grains at startup; existing, small to midsize units, up to 0.030 grains.
Carbon monoxide	Outlet concentration not greater than 50 ppm on an 8-hr average; 4-hr average and 100 ppm maximum proposed.
Hydrogen chloride emissions	A running 8-hr average emission of not greater than 10% by weight of uncontrolled emissions reduced by not less than 90%, or less than 50 ppm stack concentration (25 ppm proposed); flue gas at control device outlet not greater than 300 °F (149 °C); RCRA requires, for hazardous waste, 99% HCl removal, unless less than 4 lb/hr.
Sulfur dioxide	Not greater than 30 ppm or not less than 70% reduction, 24-hr daily average.
Nitrogen oxides	Best available technology to limit emissions, additional requirements in nonattainment areas.
Furnace design—operating temperature and residence time	Residence time for flue gas of at least 1 sec at no less than 1800 °F (982 °C) in combustion zone or a furnace design to provide a residence time for flue gas and a temperature which, in combination, are shown to be equivalent; auxiliary burner required; combustion index[b] of 99.9% for 8-hr average or 99.5% based on 7-day average; minimum furnace temperature of 1500 °F (816 °C) after last overfire air injection and 10% plume opacity, 15 min average; auxiliary burners to maintain furnace temperature.
Stack testing (at startup and at 18-month interval)	Within specified periods for carbon monoxide, carbon dioxide, sulfur dioxide, nitrogen dioxide, oxygen, hydrogen chloride, and trace contaminants including arsenic, beryllium, cadmium, chromium, copper, zinc, lead, mercury[c], nickel; polychlorinated dibenzo-*p*-dioxins, polychlorinated dibenzofurans, benzo-*a*-pyrene, total aromatic hydrocarbons, formaldehyde, and polychlorinated biphenyls; also particulates.
Continuous emission monitoring	Instrumentation for continuously monitoring emissions and operation parameters, including oxygen, plume opacity, sulfur dioxide, hydrogen chloride, nitrogen oxides, carbon monoxide, carbon dioxide, temperatures, and combustion index[b]; file is kept of measurements and operation parameters, including steam pressure and flow, auxiliary fuel used, operation controls of electrostatic precipitators, fabric filters, gaseous contaminant emission control devices.

(*continues*)

TABLE 3.25 (*continued*)

Control	Guidelines
Dioxin or furan emissions[d]	Minimize to approach 0.2 ng/dry m^3 corrected to 7% oxygen, but not in excess of 2.0 ng/dry m^{3e}.
Startup shutdown	Plan of practices and procedures to avoid unacceptable or excess emissions.
Operator certification	Operator training program; operation is directed at all times by certified operator.
Noise	Not greater than 60 dBA between 7 a.m. and 10 p.m. in rural area, 65 dBA suburban, and 70 dBA urban; between 10 p.m. and 7 a.m., 50 dBA rural, 55 dBA suburban, and 70 dBA urban.
Opacity	No emissions having average opacity of 10% or greater for any consecutive 6-min period, but may exceed 20% in 60-min period.
Operating records	As specified, retained at least 3 years; plan prepared for proper operation and maintenance prior to operation.

[a] 1 grain $= 0.064\,g \leq 180$ mg/dry m^3 (RCRA).
[b] $Cl = CO_2 \times 100/CO_2 + CO$; CO_2 and CO in the exhaust gas, ppm by volume (dry) = combustion Index at 7% oxygen ($\leq$99.80% 8-hr average). Continuous monitoring is required.
[c] Mercury and mercury compounds in flue gas exist as a gas. They are not captured by fabric filters or electrostatic precipitators and hence may escape out of the stack. Mercury release should not exceed 0.002 lb Hg/ton of solid waste. Wet scrubbers remove mercury by condensing, but sludge requires treatment.
[d] RCRA requires 99.9999% destruction and removal efficiency.
[e] Approximately equivalent to 70 nanograms per normal cubic meter (ng/Nm^3) (EPA). One nanogram = one billionth of a gram. A limit of 30 ng/m^3 has been proposed.
Note: Plants and animals around incinerators can cumulate pollutants (contaminants) and serve as biological monitors for airborne metal and organic pollutants. Additional guidelines (and regulations) are being developed. See the Clean Air Act of 1990 and state regulations.
Source: J. A. Salvato, *Environmental Engineering and Sanitation*, 4th ed., Wiley, New York, 1992.

dedicated monofill. Bottom ash alone or bottom ash combined with fly ash may be disposed of in a sanitary landfill with a single liner. Control of dioxin, cadmium, and lead in ash is the major concern. The preferred landfill design would have two liners with groundwater monitoring and leachate collection above and between the liners, or the equivalent, to prevent the migration of hazardous leachate into groundwater.

Site Selection, Plant Layout, and Building Design

It is extremely important that a careful investigation be made of the social, physical, and economic factors involved when incineration is proposed. Some of the major factors are the following:

1. Public acceptance in relation to the surrounding land use and precautions to be taken in location and design to offset public objections should be

considerations. A location near the wastewater treatment plant, for example, may meet with less objection. Heat utilization for sludge drying or burning and use of treated wastewater for cooling are possibilities.

2. Site suitability in reference to foundation requirements, prevailing winds, topography, surface water and groundwater, floods, adjacent land uses, and availability of utilities should be considered. A location central to the source of wastes for minimum haul distance and smooth movement of traffic in and out of the site and readily accessible to major highways without interrupting traffic are important considerations.
3. Plant layout should be arranged to facilitate tasks to be performed and provide for adequate space, one-way traffic, parking, paving, drainage, and equipment maintenance and storage.
4. Building design should be attractive and provide adequate toilets, showers, locker room, and lunchroom. A control room, administrative offices, weighmaster office, maintenance and repair shops, and laboratory should be included. Adequate lighting contributes to attractiveness, cleanliness, and operating efficiency. Good landscaping will promote public acceptance.
5. Also to be evaluated are the availability and cost of providing electric power, water supply, sanitary sewers, and pretreatment required before plant wastewater can be discharged to the sewer and availability of storm sewers, telephone, and fuels.
6. The proposed method and cost of handling bulky and nonincinerable wastes should be taken into consideration when incineration is proposed. Also to be determined are the location and size of the sanitary landfill and its ability to receive incinerator residue as well as the bulky and nonincinerable solid wastes that are not recycled.
7. The incinerator design should provide for resource and energy recovery to the extent feasible.

The reader is referred to Chapter 2 for the broad aspects of community and facility planning and environmental impact analysis.

Issues in the Implementation of Incineration Facilities

The principal issues associated with the use of the incineration facilities for the transformation of MSW are related to (1) siting, (2) management of emissions, (3) public health, and (4) economics. Unless the questions related to these issues are resolved, implementation of solid waste incineration facilities will continue to be an uphill battle. These subjects are introduced briefly as follows.

Siting As with the siting of MRFs, discussed previously, it has been possible to build and operate combustion facilities in close proximity to both residential and industrial developments; however, extreme care must be taken in their operation if they are to be environmentally and aesthetically acceptable. Ideally, to minimize the impact of the operation of combustion facilities, they should be sited in more remote locations where adequate buffer zones surrounding the facility can be maintained. In many communities, combustion facilities are in remote locations or at the landfill site.

Management of Emissions The operation of incineration facilities, as noted previously, results in the production of a variety of emissions, including (1) gaseous and particulate emissions, many of which are thought to have serious health impacts; (2) solid residuals, including bottom ash, fly ash, and scrubber product; and (3) liquid emissions, which can result from one or more of the following sources: wastewater from the ash removal facilities; effluent from wet scrubbers; wastewater from pump seals, cleaning, flushing, and general housekeeping activities; wastewater from treatment systems used to produce high-quality boiler water; and cooling tower blowdown. The demonstrated ability to control these emissions from an incineration facility effectively is of fundamental importance in the siting of incineration facilities. The proper design of control systems for these emissions is a critical part of the design of incineration facilities. In some cases, the cost and complexity of the environmental control system(s) are equivalent to or even greater than those of the combustion facilities.

Public Health Issues Emissions from a modern, properly designed and operated incineration facility are considered to be of little, if any, health significance but are perceived by some to be a serious hazard. The evidence is not conclusive as emissions are widely dispersed and their effects are difficult to evaluate. Nevertheless, pollution controls to prevent accidental emissions must be ensured. Sensitive individuals who have been exposed to high concentrations of dioxin have developed chloracne, a persistent skin dermatitis, and suffered liver and other disorders. Birth defects and cancer have not been demonstrated. Additional studies are needed to better identify and measure the effects of air pollutants inhaled and the effects of fallout. The significance of the types and amounts of pollutants and their persistence in the environment remain to be clarified.

Economics The economics of incineration must be evaluated carefully to choose between competing systems. The least expensive operation for a particular community would be determined by comparing the total annual cost, including operating costs and fixed charges on the capital outlay, for each method. It will generally be found that, for large cities, three-shift operation will be the least expensive. The two- or one-shift operation will be somewhat cheaper for the smaller community. The relative cost of maintenance, however, will be higher and the efficiency poor because of startup and shutdown of the furnace, with accompanying refractory brick spalling due to differential expansion and air pollution from fly ash. The best way to compare alternatives is by the use of life-cycle costing, which accounts for operating and maintenance costs over the lifetime of the system. The solid waste industry has developed a standardized approach to life-cycle costing through the use of the pro forma income statement.

HAZARDOUS WASTES

The identification and management of hazardous waste have become a major environmental undertaking and are the subject of a number of textbooks and numerous reference books. The purpose here is to introduce the subject of hazardous waste management. Topics to be considered include (1) definition of hazardous waste, (2) a review of pertinent legislation, (3) the generation of hazardous wastes, and (4) an introduction to hazardous waste management. Additional details may be found in Ref. 19.

Definition of Hazardous Waste

Under the RCRA of 1976, the term *hazardous waste* means a solid waste, or combination of solid wastes, that, because of its quantity, concentration, or physical, chemical, or infectious characteristics, may do one of two things:

1. Cause or significantly contribute to an increase in mortality or an increase in serious irreversible or incapacitating reversible illness.
2. Pose a substantial present or potential hazard to human health or the environment when improperly treated, stored, transported, or disposed of or otherwise managed.

Hazardous wastes include chemical, biological, flammable, explosive, and radioactive substances. They may be in a solid, liquid, sludge, or gaseous (contained) state and are further defined in various federal acts designed to protect the public health and welfare, including land, air, and water resources.

A waste is regarded as hazardous if it is lethal, nondegradable, and persistent in the environment, can be magnified biologically (as in food chains), or otherwise causes or tends to cause detrimental cumulative effects. The EPA lists four characteristics of hazardous wastes:

1. *Ignitability*—wastes that pose a fire hazard during routine management. Fires not only present immediate dangers of heat and smoke but also can spread harmful particles (and gases) over wide areas.
2. *Corrosivity*—wastes requiring special containers because of their ability to corrode standard materials or requiring segregation from other wastes because of their ability to dissolve toxic contaminants.
3. *Reactivity* (or explosiveness)—wastes that, during routine management, tend to react spontaneously, react vigorously with air or water, are unstable to shock or heat, generate toxic gases, or explode.
4. *Toxicity*—wastes that, when improperly managed, may release toxicants in sufficient quantities to pose a substantial hazard to human health or the environment. Toxic wastes are harmful or fatal when ingested or absorbed. When toxic wastes are disposed of on land, contaminated liquid may

drain (leach) from the waste and pollute groundwater. Toxicity is identified through a laboratory procedure called the toxicity characteristics leaching procedure, which replaces the extraction procedure leach test. Organic chemicals, metals, and pesticides regulated under the toxicity rule are reported in Table 3.26.

Not included in RCRA hazardous waste regulations are domestic wastewater, irrigation waters or industrial discharges permitted under the federal Water Pollution Control Act, certain nuclear materials as defined by the Atomic Energy Act, household wastes (including toxic and hazardous waste), certain mining wastes, agricultural wastes (excluding some pesticides), and small-quantity wastes from businesses generating fewer than 220 lb of hazardous waste per month.

The Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA), as amended in 1986, defines hazardous substances as used in the Clean Air Act and the Clean Water Act (federal Water Pollution Control Act). The Department of Transportation, the Food and Drug Administration, the Occupational Safety and Health Administration, and the Consumer Product Safety Commission also define toxic or hazardous substance exposure.

Legislation

The RCRA of 1976, as amended, expands the purposes of the Solid Waste Disposal Act of 1965. It promotes resource recovery and conservation and mandates government (federal and state) control of hazardous waste from its point of generation to its point of ultimate disposal, including a manifest identification and permitting system. Legislation was prompted by the serious dangers associated with the improper handling and disposal of hazardous waste. The most common problems associated with the disposal of hazardous waste, in addition to public opposition, are groundwater pollution from lagoons, landfills, dumps, sludge disposal, other land disposal systems, spills, and unauthorized dumping.

RCRA Amendments In 1984, the RCRA was amended to require double liners or the equivalent and leachate collection systems at hazardous waste surface impoundments and landfills. Variances from groundwater monitoring to characterize the water quality before, during, and after operation are not allowed. The act as amended in 1984 applies to generators producing as little as 220 lb (100 kg) of hazardous waste in a calendar month, which must be sent to a state or federal approved facility.

The RCRA as amended also prohibits land disposal of certain classes of untreated hazardous wastes beyond specified dates unless it can be demonstrated to the EPA that there will be no migration of hazardous constituents from the land disposal unit for as long as the wastes remain hazardous. Land disposal includes landfill, surface impoundment (treatment and surface storage), waste pile, injection well, land treatment facility, salt dome or salt bed formation, and underground mine or cave.

TABLE 3.26 Organic Chemicals, Metals, and Pesticides Regulated under RCRA Toxicity Characteristic Rule[a]

New Constituents	Regulatory Levels[b] (mg/l)	Old EP Constituents	Regulatory Levels[c] (mg/l)
Benzene	0.50	Arsenic	5.0
Carbon tetrachloride	0.50	Barium	100.0
Chlordane	0.03	Cadmium	1.0
Chlorobenzene	100.0	Chromium	5.0
Chloroform	6.0	Lead	5.0
m-Cresol	200.0[d]	Mercury	0.2
o-Cresol	200.0	Selenium	1.0
p-Cresol	200.0	Silver	5.0
1,4-Dichlorobenzene	7.5	Endrin	0.02
1,2-Dichloroethane	0.50	Lindane	0.4
1,1-Dichloroethylene	0.70	Methoxychlor	10.0
2,4-Dinitrotoluene	0.13[e]	Toxaphene	0.5
Heptachlor (and its hydroxide)	0.008	2,4-Dichlorophenoxycetic acid	10.0
Hexachloro-1,3-butadiene	0.5	2,4,5-Trichlorophenoxy propionic acid	1.0
Hexachlorobenzene	0.13[e]		
Hexachloroethane	3.0		
Methyl ethyl ketone	200.0		
Nitrobenzene	2.0		
Pentachlorophenol	100.0[f]		
Pyridine	5.0[e]		
Tetrachloroethylene	0.7		
Trichloroethylene	0.5		
2,4,5-Trichlorophenol	400.0		
2,4,6-Trichlorophenol	2.0		
Vinyl chloride	0.20		

[a] Based on the Toxicity Characteristics Leaching Procedure (TCLP)
[b] Added in 1990.
[c] Based on old Extraction Procedure (EP) leach test
[d] If o-, m-, and p-Cresol concentrations cannot be differentiated, the total cresol concentration is used. The regulatory level for total cresol is 200.0 mg/L.
[e] Quantification limit is greater than the calculated regulatory level. The quantification limit, therefore, becomes the regulatory level.
[f] The agency will propose a new regulatory level for this constituent, based on the latest toxicity information.

Source: U.S. EPA (1990).

It should be noted that domestic wastewater, any mixture of domestic wastewater and any other waste that passes through a sewer system to a publicly operated treatment works (POTW) for treatment, and industrial wastewater discharges that are point-source discharges subject to NPDES permits are not considered to be solid or hazardous wastes. The POTW is then responsible to ensure that discharges to its sewers or plant do not contravene its NPDES permit or interfere with plant operation or sludge management.

Comprehensive Environmental Response, Compensation, and Liability Act of 1980 CERCLA (Superfund) regulates leachate and other releases of hazardous substances from inactive and abandoned hazardous waste sites or from sites operating prior to November 1980. Businesses that produce between 220 and 2,000 lb of hazardous wastes in a calendar month are also regulated.

Most of the existing hazardous waste sites were created by the petroleum and chemical industries. Some municipal landfills received mixed solid waste, including toxic and hazardous commercial and industrial waste, in addition to small quantities of household cleaners, solvents, and pesticides. The result was pollution of the soil, groundwater, and surface water due to the infiltration and percolation of rain and snow melt, dissolution, and migration in the waste. In addition, toxic gases could be released from evaporating liquids, sublimating solids, and chemical reactions. CERCLA comes into play when hazardous waste sites are identified and classified.

The federal government can require the "person" who generated or transported the waste or owned or operated the disposal site to clean up the site. If a responsible person cannot be found, the federal government can perform the cleanup using a special fund (Superfund) established mainly by a tax on chemical production. Under such circumstances, states are required to contribute 10 percent of the cost of the cleanup. The federal and state governments may recover the cost, if the responsible person can be found.

Toxic Substances Control Act of 1976 The Toxic Substances Control Act (TSCA) of 1976 regulates the production, use, and disposal of chemical substances that may present an unreasonable risk of injury to health or environment. Manufacturers must give notice of plans to produce a new chemical or market a significant new use for an old chemical; they may be required to provide and keep records and reports.

Other Laws Other laws controlling hazardous substances include the following:

Clean Air Act (EPA)—regulates the emission of hazardous air pollutants.

Clean Water Act (EPA)—regulates the discharge of hazardous pollutants into the nation's waters.

Marine Protection, Research, and Sanctuaries Act (EPA)—regulates waste disposal at sea.

Occupational Safety and Health Act (OSHA)—regulates hazards in the workplace, including worker exposure to hazardous substances.

Hazardous Materials Transportation Act (Department of Transportation)—regulates the transportation of hazardous materials.

Atomic Energy Act (Nuclear Regulatory Commission)—regulates nuclear energy production and nuclear waste disposal.

Surface Mining Control and Reclamation Act (Department of the Interior)—regulates the environmental aspects of mining (particularly coal) and reclamation.

Priority Toxic Pollutants and Hazardous Wastes Twenty-four toxic substances have been identified by the EPA, the Consumer Products Safety Commission (CPSC), the Food and Drug Administration (FDA), and the Occupational Safety and Health Administration (OSHA) for *joint* attack. The National Institute for Occupational Safety and Health (NIOSH) is also concerned with the control of toxic substances. The substances include acrylonitrile, arsenic, asbestos, benzene, beryllium, cadmium, chlorinated solvents (trichloroethylene, perchloroethylene, methylchloroform, and chloroform), chlorofluorocarbons, chromates, coke oven emissions, diethylstilbestrol (DES), dibromochloropropane (DBCP), ethylene dibromide, ethylene oxide, lead, mercury and mercury compounds, nitrosamines, ozone, polybrominated biphenyls (PBBs), polychlorinated biphenyls (PCBs), radiation, sulfur dioxide, vinyl chloride and polyvinyl chloride, and toxic waste disposals that may enter the food chain. Initially, the EPA listed 129 specific toxic pollutants, as reported in Table 3.27, for priority action.

Although legislation is very important, control also requires consideration of the social, political, and economic impacts of hazardous materials, in addition to health and environmental factors. Continual surveillance of spills and existing and abandoned waste sites for the present and for as long as the waste remains hazardous will be necessary.

Generation of Hazardous Waste

The major generators of hazardous waste among 15 industries studied by the EPA are as follows, more or less in order of the quantities produced:

- Primary metals
- Organic chemicals
- Electroplating
- Inorganic chemicals
- Textiles
- Petroleum refining
- Rubber and plastics

Examples of hazardous waste types generated by businesses and industries are given in Table 3.28. Hazardous wastes that are characterized as ignitable,

TABLE 3.27 Original 129 Priority Toxic Pollutants Identified by Council on Environmental Quality

Pollutant	Characteristics	Sources	Remarks
Pesticides: Generally chlorinated hydrocarbons	Readily assimilated by aquatic animals, fat soluble, concentrated through food chain (biomagnified), persistent in soil and sediments	Direct application to farmland and forestland, runoff from lawns and gardens, urban runoff, discharge in industrial wastewater	Several chlorinated hydrocarbon pesticides already restricted by EPA; aldrin, dieldrin, DDT, DDD, endrin, heptachlor, lindane, chlordane
Polychlorinated biphenyls (PCBs): used in electrical capacitors and transformers, paints, plastics, insecticides, other industrial products	Readily assimilated by aquatic animals, fat soluble, subject to biomagnification, persistent, chemically similar to chlorinated hydrocarbons	Municipal and industrial waste discharges disposed of in dumps and landfills	TSCA ban on production after June 1, 1979, but will persist in sediments; restrictions on many freshwater fisheries as result of PCB pollution (e.g., lower Hudson, upper Housatonic, parts of Lake Michigan)
Metals: antimony, arsenic, beryllium, cadmium, copper, lead, mercury, nickel, selenium, silver, thallium, zinc	Nonbiodegradable, persistent in sediments, toxic in solution, subject to biomagnification	Industrial discharges, mining activity, urban runoff, erosion of metal-rich soil, certain agricultural uses (e.g., mercury as fungicide)	
Asbestos	May cause cancer when inhaled, aquatic toxicity not well understood	Manufacture and use as retardant, roofing material, brake lining, etc.; runoff from mining	
Cyanide	Variably persistent, inhibits oxygen metabolism	Wide variety of industrial uses	

(*continues*)

TABLE 3.27 (*continued*)

Pollutant	Characteristics	Sources	Remarks
Halogenated aliphatics: used in fire extinguishers, refrigerants, propellants, pesticides, solvents for oils and greases and dry cleaning	Largest single class of "priority toxics," can cause damage to central nervous system and liver, not very persistent	Produced by chlorination of water, vaporization during use	Large-volume industrial chemicals, widely dispersed, but less threat to environment than persistent chemicals
Ethers: Used mainly as solvents for polymer plastics	Potent carcinogen, aquatic toxicity and fate not well understood	Escape during production and use	Though some are volatile, ethers have been identified in some natural waters
Phthalate esters: Used chiefly in production of polyvinyl chloride and thermoplastics as plasticizers	Common aquatic pollutant, moderately toxic but teratogenic and mutagenic properties in low concentrations; aquatic invertebrates are particularly sensitive to toxic effects; persistent and can be biomagnified	Waste disposal vaporization during use (in nonplastics)	
Monocyclic aromatics (excluding phenols, cresols, and phthalates): used in manufacture of other chemicals, explosives, dyes, and pigments and in solvents, fungicides, and herbicides	Central nervous system depressant; can damage liver and kidneys	Enters environment during production and byproduct production states by direct volatilization; wastewater	

Phenols: large-volume industrial compounds used chiefly as chemical intermediates in production of synthetic polymers, dyestuffs, pigments, pesticides, and herbicides	Toxicity increases with degree of chlorination of phenolic molecule; very low concentrations can taint fish flesh and impart objectionable odor and taste to drinking water; difficult to remove from water by conventional treatment; carcinogenic in mice	Occur naturally in fossil fuels, wastewater from coking ovens, oil refineries, tar distillation plants, herbicide manufacturing, and plastic manufacturing; can all contain phenolic compounds
Polycyclic aromatic hydrocarbons: used as dyestuffs, chemical intermediates, pesticides, herbicides, motor fuels, and oils	Carcinogenic in animals and indirectly linked to cancer in humans; most work done on air pollution; more is needed on aquatic toxicity of these compounds; not persistent and are biodegradable though bioaccumulation can occur	Fossil fuels (use, spills, and production), incomplete combustion of hydrocarbons
Nitrosamines: used in production of organic chemicals and rubber; patents exist on processes using these compounds	Tests on laboratory animals have shown nitrosamines to be some of most potent carcinogens	Production and use can occur spontaneously in food cooking operations

Source: Council on Environmental Quality, *Environmental Quality*, the Ninth Annual Report of the Council on Environmental Quality, U.S. Government Printing Office, Washington, DC, 1978.

TABLE 3.28 Examples of Hazardous Waste Generated by Business and Industries

Waste Generators	Waste Type
Chemical manufacturers	Strong acids and bases, spent solvents, reactive wastes
Vehicle maintenance shops	Heavy-metal paint wastes, ignitable wastes, used lead acid batteries, spent solvents
Printing industry	Heavy-metal solutions, waste inks, spent solvents, spent electroplating wastes, ink sludges containing heavy metals
Leather products manufacturing	Waste toluene and benzene
Paper industry	Paint wastes containing heavy metals, ignitable solvents, strong acids and bases
Construction industry	Ignitable paint wastes, spent solvents, strong acids and bases
Cleaning agents and cosmetics manufacturing	Heavy-metal dusts, ignitable wastes, flammable solvents, strong acids and bases
Furniture and wood manufacturing and refinishing	Ignitable wastes, spent solvents
Metal manufacturing	Paint wastes containing heavy metals, strong acids and bases, cyanide wastes, sludges containing heavy metals

Source: U.S. EPA *Solving the Hazardous Waste Problem*, EPA/530-SW-86-037, EPA, Office of Solid Waste, Washington, DC, 1986.

corrosive, explosive, or toxic should be removed from industrial wastes prior to discharge to a municipal sewer. Many toxic wastes upset biological wastewater treatment processes and are transferred to the effluent and sludge, adding to the disposal problem.

Hazardous Waste Management

Hazardous waste management is a major health and environmental challenge. The ultimate *goal* should be *zero discharge*. However, until that goal is approached, the elements of hazardous waste management that must be dealt with include (1) source reduction at the point of generation; (2) recycling both on- and off-site; (3) transportation to processing and/or disposal facilities; (4) treatment and processing to reduce or eliminate toxicity, to reduce the volume, and to immobilize contaminants; and (5) secure long-term storage and disposal. Each of these subjects is considered briefly in the following discussion. Details on hazardous waste management may be found on the EPA web site and in Ref. 19.

Hazardous Waste Reduction In plant waste, reduction measures can be most effective in reducing the air, liquid, and solid waste contaminants generated, and hence the treatment needed to meet disposal standards, with resultant cost savings. In addition, treatment can result in the recovery of valuable materials that can offset, in whole or in part, the cost of treatment. However, treatment to recover valuable materials may result in the production of other hazardous wastes, which, in turn, would require treatment and disposal.

Hazardous Waste Recycling Often, it may not be possible to reduce the volume or toxicity of some hazardous wastes. However, it may be possible to reuse the waste material in other processes within the same facility or other related facilities. Hazardous wastes that may be recycled either directly or after processing include water, solvents, spent oils, and selected solids. To enhance the recycling of waste materials at other facilities, waste exchange clearinghouses have been developed to facilitate such exchanges. Information that is required for waste exchange programs includes company ID code, category (acid, solvent, cutting fluid, etc.), primary usable constituents, contaminants, physical state, quantity, packaging, and geographic location.[19]

Hazardous Waste Transportation The transportation of hazardous wastes always introduces the possibility of accidental spills. Should this happen, the transporter is required to immediately notify the appropriate authorities (state police, environmental protection agency) and take whatever action is necessary to protect the public health and the environment. Information and advice on what to do and on the characteristics of the chemicals involved (see manifest) in an emergency is available 24 hours a day, 365 days a year, from the Chemical Emergency Center (CHEMTREC) operated by the Chemical Manufacturers Association. CHEMTREC's telephone number is 800-424-9300.

In case of fire or other emergency at a facility having hazardous materials, information concerning the site, materials, and precautions to be taken can be immediately obtained by response personnel from the National Oceanic and Atmospheric Administration (NOAA). A Computer-Aided Management Emergency Operations (CAMEO) system has been developed to facilitate immediate communication. More information is available from NOAA at 206-526-6317. Information availability is required by the Superfund Amendments and Reauthorization Act (SARA).

Hazardous Waste Processing Technologies The principal objectives of hazardous waste treatment are (1) toxicity reduction, (2) conversion to forms that can subsequently be processed by other technologies, (3) total elimination (e.g., complete destruction), (4) volume reduction, and (5) immobilization. Treatment technologies used to process hazardous wastes may be classified as (1) biological methods, (2) physicochemical processes, (3) stabilization and solidification, and (4) thermal destruction. The principal processes comprised by these technologies are reported in Table 3.29.[19–23]

Long-Term Storage of Hazardous Wastes So-called secure land burial and deep-well disposal under carefully controlled conditions, *where permitted*,

TABLE 3.29 Typical Treatment Methods for Hazardous Wastes

Method	Typical Processes	Description
Biological methods	(1) Suspended growth processes (aerobic, anoxic, and anaerobic); (2) attached growth processes (aerobic, anoxic, and anaerobic); (3) combined suspended and attached growth processes (aerobic, anoxic, and anaerobic)	Biological processes are used to treat (1) liquids (contaminated groundwater, industrial process wastewaters, and landfill leachate); (2) slurries (sludges and contaminated soils with clean or contaminated water); (3) solids (contaminated soils); and (4) vapors (from other treatment processes).
Physicochemical processes	(1) Carbon adsorption; (2) chemical oxidation; (3) gas stripping; (4) steam stripping; (5) membrane separation; (6) supercritical fluids extraction and supercritical water oxidation	Granular activated carbon adsorption is used for the sorption of organic compounds from liquids. Powdered activated carbon is typically used in conjunction with the activated sludge treatment process. Chemical oxidation is used to detoxify a wide array of organic compounds. Stripping processes are used to remove volatile and semivolatile organics from industrial process waters. Membrane separation is used to remove contaminants from a variety of process waters and liquids. Supercritical fluids extraction and supercritical water oxidation are used to remove organics from water, sediments, and soil.

Stabilization and solidification	(1) Cement-based solidification; (2) pozzolan-based aggregate; (3) thermoplastic; (4) organic polymers	Stabilization and solidification processes are used for the (1) treatment of industrial wastes; (2) treatment of a variety of wastes, including incinerator bottom and fly ash, before placement in a secure landfill; and (3) treatment of large quantities of contaminated soil. These processes are all used to immobilize hazardous waste contaminants.
Thermal methods	(1) Vapor, liquid, and solid combustion; (2) catalytic volatile organic chemical (VOC) combustion; (3) fluidized-bed incinerators; (4) pyrolysis reactors	Thermal processes are used to destroy organic fraction of hazardous waste contaminants found in all types of waste streams, including gases and vapors, liquids, slurries, and solids.
Land disposal	(1) Municipal landfills; (2) monofill landfills; (3) land farming; (4) impoundment and storage facilities; (5) deep-well injection	The objective of land disposal is to ensure that wastes placed in such facilities do not migrate off-site. In land framing the objective is to bring about natural and biological decay of hazardous waste materials. The problem with deep-well injection is that the final location of the injected wastes is unknown.

Source: Adapted in part from LaGrega, M. D., P. L. Buckingham, and J. C. Evans, *Hazardous Waste Management*, 2nd ed., McGraw-Hill, New York, 2001.

are a last resort. In general, these types of disposal are strongly discouraged as they simply transfer the problem to another environmental media and must be monitored for the life of the hazardous waste. Some hazardous wastes, both solid and liquid, may be temporarily stored in clay, asphalt, concrete, soil cement, or (sodium) bentonite–soil lined basins, or in polymeric membrane lined basins, pending a decision on the best methods for treatment and disposal. Membrane linings are made of special rubber, polyethylene, polyolefin, polychloroprene, and polyvinyl chloride. All are usually suitable for wastewater and biodegradable industrial wastes. However, solvents, strong acids and caustics, and brines could damage clay or soil-based linings. Benzene and toluene, for example, are not contained by a clay liner, but when mixed with a small proportion of water and placed in a landfill, clay remains a good barrier. These chemicals, including pesticides, are best destroyed by controlled incineration. Petroleum-based organic wastes could damage some polymeric membranes and asphaltic materials. Carbon tetrachloride and xylene cause soil dehydration and possible cracking of clay soil. Clay liners must be carefully constructed with concern for lift thickness, soil moisture, type and weight of roller and number of passes, soil texture, and dry density to achieve the required permeability.

In view of the many limitations, *wastes and lining materials should be tested for effectiveness and compatibility before use*. In any case, all liners should be carefully placed on well-compacted subbases and, in addition, all basins storing hazardous wastes should incorporate a groundwater monitoring and surveillance system, including a leachate collection system and peripheral well monitoring. Two layers of linings with intermediate collection systems to collect possible leachate percolation and a groundwater monitoring system are required by the EPA. It can be assumed that all liners, cutoff walls, or other containments will eventually leak to some degree. Storage should be considered a temporary expedient. In all cases, strict compliance with approved design and construction specifications, and continuous professional inspection during construction must be ensured.

Monitoring of the air, surface water, and groundwater for as long as the waste remains a threat to the public health and the environment is an essential component of any site. Surface-water runoff and groundwater would be monitored for organic and inorganic chemicals. The air would be monitored for odors, volatile organics, and indicated toxic chemicals.

Basic Control Principles for Hazardous Waste Management As with most air, water, solid waste, and other pollution control activities, certain general and basic control principles can also be applied, as appropriate, to hazardous wastes. These include the following nine:

1. Elimination and reduction of waste at the source—This is done by prevention of leakage, segregation of hazardous waste, product reformulation, process or materials change, good housekeeping practices, and inventory control.

2. Recovery, reuse, and recycling of wastes—This includes return to the manufacturer, energy recovery, and waste exchange among compatible industries.
3. Concentration of waste by treatment—centrifugation, coagulation, sedimentation, filtration, flotation, surface impoundment, distillation, reverse osmosis, precipitation, solidification, encapsulation, evaporation, electrodialysis, absorption, or blending.
4. Thermal decomposition—controlled high-temperature incineration and proper disposal of residue, also ocean incineration. Incinerators used include refractory lined, fixed hearth (controlled air), rotary kiln, cement kiln furnace, and fluidized bed.
5. Chemical treatment—chemical oxidation, precipitation, reduction, neutralization, chlorination, pyrolysis, detoxification, ion exchange, absorption, or chemical dechlorination processes.
6. Burial in a secure landfill—storage or containment with proper monitoring and surveillance (may be banned by the EPA or state).
7. Biological degradation accomplished through activated sludge, lagoon, or other biological treatment.
8. Stabilization, solidification, or encapsulation, including in-place vitrification.
9. Deep-well, mine, and ocean disposal under controlled conditions and if permitted; possibly composting and microwave decomposition. Ocean disposal of sludge has been banned effective December 31, 1991, but this prohibition is being reevaluated.

The methods available are not always completely effective and must be tailored to specific contaminants.

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CHAPTER 4

AIR POLLUTION AND NOISE CONTROL

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AIR POLLUTION

Air pollution is the presence of solids, liquids, or gases in the outdoor air in amounts that are injurious or detrimental to humans, animal, plants, or property or that unreasonably interfere with the comfortable enjoyment of life and property. Air pollution inside dwellings or places of assembly is discussed under Indoor Air Quality in Chapter 5, "Environmental Emergencies and Emergency Preparedness" by Pedro M. Armenante, James P. Mack in *Environmental Engineering, Sixth Edition: Prevention and Response To Water-, Food-, Soil-, and Air-Borne Disease And Illness*. The composition of clean air is shown in Table 4.1. The effects of air pollution are influenced by the type and quantity of pollutants and their possible interactions* as well as wind speed and direction, typography, sunlight, precipitation, vertical change in air temperature, photochemical reactions, height at which pollutant is released, and susceptibility of the individual and materials to specific contaminants—singularly and in combination. Air pollution is not a new or recent phenomenon. It has been recognized as a source of discomfort for centuries as smoke, dust, and obnoxious odors. The solution of any air pollution problem must avoid transferring the pollutant removed to another medium, without adequate treatment.

*Synergism, antagonism, additive.

Environmental Engineering: Environmental Health and Safety for Municipal Infrastructure, Land Use and Planning, and Industry Sixth Edition Edited by Nelson L. Nemerow, Franklin J. Agardy, Patrick Sullivan, Joseph A. Salvato

TABLE 4.1 Composition of Clean, Dry Air near Sea Level

Component	Percent by Volume	Content (ppm)
Nitrogen	78.09	780,900
Oxygen	20.94	209,400
Argon	0.93	9,300
Carbon dioxide	0.0318	318[a]
Neon	0.0018	18
Helium	0.00052	5.2
Krypton	0.0001	1
Xenon	0.000008	0.08
Nitrous oxide	0.000025	0.25[b]
Hydrogen	0.00005	0.5
Methane	0.00015	1.5[c]
Nitrogen dioxide	0.0000001	0.001
Ozone	0.000002	0.02
Sulfur dioxide	0.00000002	0.0002
Carbon monoxide	0.00001	0.1
Ammonia	0.000001	0.01

[a] 352 ppm in 1989; 369 ppm in 2000, Mauna Loa, Hawaii.
[b] 0.304 ppm in 1985; 0.314 ppm in 1999 based on Advanced Global Atmospheric Gases Experiment (AGAGE), Cape Grim, Tasmania, Australia monitoring sites.
[c] 1.7 ppm in 1990; 1.73–1.84 ppm in 1999 based on AGAGE values from Cape Grim, Tasmania, Australia and Mace Head, Ireland monitoring sites.
Note: The concentrations of some of these gases may differ with time and place, and the data for some are open to question. Single values for concentrations, instead of ranges of concentrations, are given to indicate order of magnitude, not specific and universally accepted concentrations.

Sources: Cleaning Our Environment—The Chemical Basis for Action, American Chemical Society, 1969, p. 4 (copyright 1969 by the American Chemical Society; reprinted with permission); with C. E. Junge, *Air Chemistry and Radioactivity*, Academic, New York, 1963, p. 3; A. C. Stern (ed.), *Air Pollution*, Vol. 1, 2nd ed., Academic, New York, 1968, p. 27; E. Robinson and R. C. Robbins, *Sources, Abundance, and Fate of Gaseous Atmospheric Pollutants*, prepared for American Petroleum Institute by Stanford Research Institute, Menlo Park, CA, 1968.

Health Effects

Humans are dependent on air. We breathe about 35 lb of air per day as compared with the consumption of 3 to 5 lb of water and 1∼HF lb (dry) of food. Pollution in the air may place an undue burden on the respiratory system and contribute to increased morbidity and mortality, especially among susceptible individuals in the general population. Particulates greater than 3 μm in diameter are likely to collect in the lung lobar bronchi; smaller particulates (less than 3 μm) end up in the alveoli, the thoracic or lower regions of the respiratory tract, where more harm can be done. Health effects are discussed under under illnesses associated with air pollution—lung disease in Chapter 3 “Control of Diseases of The Air and Land” by Nabarun Dasgupta in *Environmental Engineering, Sixth Edition: Prevention and Response To Water-, Food-, Soil-, and Air-Borne Disease And Illness*.

Some well-known air pollution episodes are given in Table 4.2. The illnesses were characterized by cough and sore throat; irritation of the eyes, nose, throat, and respiratory tract; and stress on the heart. The weather conditions were typically fog, temperature inversion, and nondispersing wind. The precise levels at which specific pollutants become a health hazard are difficult to establish by existing surveillance systems, but they probably are well in excess of levels currently found in the ambient air. Meteorological factors, sample site, frequency and measurement methods, including their accuracy and precision, all enter into data interpretation. Nevertheless, standards to protect the public health are necessary and have been established. (See Tables 4.5 through 4.7 later in the chapter.)

It should be noted that whereas smoking is a major contributor to respiratory disease in the smoker, air pollution, climate, age, sex, and socioeconomic conditions affect the incidence of respiratory disease in the general population. Occupational exposure may also be a significant contributor in some instances. However, the effects may be minimized by engineering and individual controls. Where engineering controls are not adequate, respirators can provide good protection if adapted to the type and concentration of airborne contaminants, provided they are properly fitted, maintained, and actually used. However, respirators should never be considered an equivalent alternate to engineering controls. They should only be used after a thorough review of engineering controls has determined that process modifications and engineering controls are absolutely infeasible or where the risk to human health associated with the failure of an engineering control is excessive.

Economic Effects

Pollutants in the air cause damage to property, equipment, and facilities, in addition to increased medical costs, lost wages, and crop damage. Sulfur and formaldehyde pollution attack copper roofs and zinc coatings. Steel corrodes two to four times faster in urban and industrial areas due to moisture, chloride, sulfate, and ammonium pollution. The usual electrical equipment contacts become unreliable unless serviced frequently; clothing fabric, rubber, plastics, and leather are weakened; lead-based paints, banned in home construction but still in use in certain industrial applications, are degraded by hydrogen sulfide and oil-based paints by sulfur dioxide; and building surfaces and materials (especially carbonate rock by sulfur dioxide) and works of art are corroded and deteriorate. In addition, particulates (including smoke) in polluted air cause erosion, accelerate corrosion, and soil clothes, buildings, cars, and other property, making more frequent cleaning and use of indoor air-filtering equipment necessary. Ozone reduces the useful life of rubber and other elastomers, attacks some paints, discolors dyes, and damages textiles. See also “Measurement of Materials’ Degradation,” later in this chapter.

The U.S. Environmental Protection Agency (EPA) is required to periodically assess the cost and benefit of the Clean Air Act (CAA). These reviews have

TABLE 4.2 Some Major Air Pollution Episodes

Location	Excess Deaths	Illnesses	Causative Agents
Meuse Valley, Belgium			
December 1930	63	6000	Probably SO_2 and oxidation products with particulates from industry—steel and zinc.
Donorra, Pennsylvania			
October 1948	20	7000	Not proven; particulates and oxides of sulfur high; probably from industry—steel and zinc; temperature inversion
Poza Rica, Mexico 1950	22	320	H_2S escape from a pipeline
London, England			
December 1952	4,000	Increased	Not proven; particulates and oxides of sulfur high; probably from household coal-burning; fog
January 1956	1,000	—	—
December 1957	750	—	—
January 1959	200–250	—	—
December 1962	700	—	—
December 1967	800–1,000	—	—
New York, New York			
November 1953	165	—	Increased pollution
October 1957	130	—	Increased pollution
January–February 1963	200–400	—	SO_2 unusually high (1.5 ppm maximum)
November 1966	152,168	—	Increased pollution and inversion
New Orleans, Louisiana			
October 1955	2	350	Unknown
1958	—	150	Believed related to smoldering city dump

Location	Excess Deaths	Illnesses	Causative Agents
Seveso and Meda, Italy[a] July 1976	Unknown, long-term	200+	Dioxin, an accidental contaminant formed in the manufacture of 2,4,5-T and hexachlorophene—a bactericide
Bhopal, India December 1985	2,000–5,000	8,000 disabled, 200,000 injured	Leak of methyl isocyanate from pesticide factory
Chernobyl, Soviet Union[b] April 1986	31 on site, more than 300 total	130,000 evacuated; 6,000 workers	Nuclear power plant accidental release, explosion and fire

[a] A reactor overheated, the safety valve opened, and 4~HF lb of dioxin discharged for 30 min to the atmosphere. About 50 persons were hospitalized, 450 children had a skin disease, 200 families (735 persons) were evacuated, and 40,000 contaminated animals were killed. (*Conserv. News*, December 1, 1976, pp. 8–9; Associated Press, Seveso, Italy, July 10, 1977.) Contaminated soil and vegetation over 272 acres was stripped and incinerated. By July 1977, many homes were cleaned and 500 persons were ready to be admitted. No major illnesses or effects reported other than chloracine (dermatitis) and increased stress-related cardiovascular mortality. [P. Bertazzi et al., *Am. J. Epidemiol.*, **129**, 1187 (1989).]

[b] Excess fallout-related cancer cases over the lifetime of the populations of Europe and the Soviet Union are estimated at 800,000–950,000. (R. H. Nussbaum, Comments on "Health Effects from Radiation," *Environ. Sci. Technol*. (July 1988).) The actual risk is not likely to be known. Excess lifetime cancer deaths are estimated at 17,000. (T. G. Davis, "Chernobyl: The Aftermath," *J. Environ. Health*, (March/April 1989): 185–186.) Perhaps 150,000 people suffered some sort of thyroid illness, of which 60,000 were children, 13,000 very seriously. An estimated 6000 workers became ill. (F. X. Clines, "A New Arena for Soviet Nationalism: Chernobyl," *New York Times*, December 30, 1990, p. 1.) The United Nations International Atomic Energy Agency concluded in May 1991 that the major harm was that due to anxiety and stress rather than physical illness. ("Ten Years after Chernobyl," *Ann. Med.*, (April 1996).) Thyroid cancers increased dramatically in Belarus, Ukraine, and Bryansk regions of Russia. [Radioactive Contamination of Wood and Its Products," *J. Environ. Radioactivity*, **55** (2), (2001): 179–86.] Contamination of timber and subsequent distribution of irradiated products such as furniture and lumber will likely lead to increase in radiation exposure.

been both retrospective and prospective. In a retrospective review of the cost and benefit of the CAA between 1970 and 1990, a mean monetized benefit of \$22.2 trillion (in 1990 dollars) was estimated. The cost of compliance in the same period was estimated at \$0.5 trillion. Specific benefits included in these estimates were as follows:

- Agriculture; net surplus due to ozone reduction, \$23 billion
- IQ (intelligence quotient, lost IQ points + children with IQ $<$ 70 points), \$399 billions
- Chronic bronchitis, \$3.3 trillion
- Reduced mortality due to particulate matter reduction, \$16.6 billion

All of these values are mean values and have varying ranges based on the uncertainty associated with estimating each parameter. For example, the 5th percentile "low" benefit associated with the period of 1970 to 1990 was \$5.6 trillion, while the 95th percentile "high" benefit was \$49.4 trillion. The costs associated with complying with the CAA are more easily monetized and have much less variability because they are primarily associated with pollution control equipment design, purchase, and maintenance. Other control costs include policy development, regulatory enforcement, and regulatory pollution monitoring, all of which are eventually borne by shareholders, customers, and taxpayers.[1] The daily personal cost of air pollution can be tallied by over-the-counter medicines to treat the medical symptoms of air pollution as well as lost work days and decreased productivity and quality of life.[2]

Effects on Plants

It has been suggested that plants be used as indicators of harmful contaminants because of their greater sensitivity to certain specific contaminants. Hydrogen fluoride, sulfur dioxide, smog, ozone, and ethylene are among the compounds that can harm plants. Urban smog is likely to contain carbon monoxide, soot, dust, and ozone from the reaction of sunlight on nitrogen oxides, hydrocarbons, and other volatile organic compounds. Assessment of damage shows that the loss can be significant, although other factors such as soil fertility, temperature, light, and humidity also affect production. Ozone has been indicated in forest decline and in damage to a variety of other agriculture products.[3] Among the plants that have been affected are truck garden crops (New Jersey), orange trees (Florida), orchids (California), and various ornamental flowers, shade trees, evergreen forests, alfalfa, grains, tobacco, citrus, lettuce (Los Angeles), and many others. In Czechoslovakia more than 300 mi^2 of evergreen forests was reported severely damaged by sulfur dioxide fumes.[4] Smog such as the type found in Los Angeles is the product of a photochemical reaction involving nitrogen oxides, hydrocarbons and oxygen. Where local topography and meteorology inhibit dispersion, smog can accumulate to unhealthy concentrations. Photochemical smog has also been reported in New York, Japan, Mexico City, Madrid, the United

Kingdom, and other congested areas with high motor vehicle traffic. The brown clouds associated with smog are due to excess NO_x, which preferentially absorbs light from the blue-green spectrum. The remaining colors result in the brownish color associated with smog that can reduce visibility and is aesthetically displeasing.[5]

Injury to plants due to ozone shows up as flecks, stipple and bleaching, tip burns on conifers, and growth suppression. Peroxyacyl nitrate* (PAN) injury is apparent by glazing, silvering, or bronzing on the underside of the leaf. Sulfur dioxide injury shows up as bleached and necrotic areas between the veins, growth suppression, and reduction in yield. Hydrogen fluoride injury is evidenced by plant leaf tip and margin burn, chlorosis, dwarfing, abrupt growth cessation, and lowered yield.[6] See also "Acid Rain (Acidic Precipitation)," later in this chapter.

Effects on Animals

Fluorides have caused crippling skeletal damage to cattle in areas where fluorides absorbed by the vegetation are ingested. Animal laboratory studies show deleterious effects from exposure to low levels of ozone, photochemical oxidants, and PAN. Lead and arsenic have also been implicated in the poisoning of sheep, horses, and cattle. All of the canaries and about 50 percent of the animals exposed to hydrogen sulfide in the Poza Rica, Mexico, incident (see Table 4.2) were reported to have died. Morbidity and mortality studies are ongoing to determine actual impacts of air pollutants on animals.

Aesthetic, Climatic, and Related Effects

Insofar as the general public is concerned, smoke, dust, and haze, which are easily seen, cause the greatest concern. Reduced visibility not only obscures the view but is also an accident hazard to air, land, and water transportation. Soiling of statuary, clothing, buildings, and other property increases municipal and individual costs and aggravates the public to the point of demanding action on the part of public officials and industry. Correction of the air pollution usually results in increased product cost to the consumer, but failure to correct pollution is usually more costly.

Air pollution, both natural and manmade, affects the climate. Dust and other particulate matter in the air provide nuclei around which condensation takes place, forming droplets and thereby playing a role in snowfall and rainfall patterns. Haze, dust, smoke, and soot reduce the amount of solar radiation reaching the surface of the earth. Aerosol emissions from jet planes also intercept some of the sun's rays.

Certain malodorous gases interfere with the enjoyment of life and property. In some instances, individuals are seriously affected. The gases involved include hydrogen sulfide, sulfur dioxide, aldehydes, phenols, polysulfides, and some

*Also cause of eye irritation.

olefins. Air pollution control equipment such as thermal oxidizers and carbon absorbers are available to eliminate or control these objectionable compounds.

Effect of Carbon Dioxide and Other Gases on Global Warming Solar energy, as light in the form of short-wavelength radiation, that reaches the earth is absorbed and reradiated back to the atmosphere as long-wavelength infrared radiation or heat energy. (Ultraviolet radiation has little effect on earth warming.) However, carbon dioxide, methane, chlorofluorocarbons (CFCs), clouds and atmospheric water vapor, and nitrous oxides tend to trap the reradiated heat, causing a reflection of that heat back to the earth and a warming of the lower atmosphere, oceans, and the earth's surface—known as the greenhouse effect. According to the EPA, carbon dioxide constitutes 49 percent of the greenhouse effect, as compared to methane 18 percent, CFCs 14 percent, nitrous oxides 6 percent, and other gases 13 percent.[7] Still other estimates place the relative contributions as carbon dioxide 57 percent, CFCs 25 percent, methane 12 percent, and nitrous oxide 6 percent.[8] The relative contributions will always be flux depending on the concentration in the atmosphere and because all greenhouse gases are not equal in their warming potential. Certain manmade compounds are far more effective greenhouse gases than other naturally occurring compounds. Nitrous oxide, both man made and naturally occurring, is 310 times more effective than carbon dioxide. Hydrofluorocarbon (HFC) 23, a manmade refrigerant, is 11,700 times more effective than carbon dioxide.[9]

Industrial, power plant, and automobile emissions and the burning of fossil fuels and forests contribute carbon dioxide and other gases to the atmosphere. This is in addition to the carbon dioxide naturally released during respiration and decomposition. Methane is produced by the decay of organic matter in wetlands, rice paddies, ruminant animals and termites, forest fires and wood burning, landfills, and gas drilling and releases. Chlorofluorocarbon sources include refrigerants, solvents, and plastic foam manufacture. Sources of nitrogen oxides include burning coal and other fossil fuel, fertilizer breakdown, and soil bacteria reactions. Other gases involved to a lesser extent are carbon monoxide and sulfur dioxide.

The warming effect of the gases in the lower atmosphere is offset to some extent by the cooling effect of the haze, dust, smoke, soot, and dust from volcanic eruptions that intercept and reduce the solar radiation reaching the earth. However, evaporation from the warmed oceans and other bodies of water and land surfaces due to greenhouse warming would be increased, as would vegetation transpiration, causing further cooling. The increased evaporation would also cause an increase in precipitation in some areas. In addition, the oceans, rain, and growing forests and other vegetation during photosynthesis altogether remove or absorb significant quantities of carbon dioxide. These processes that remove carbon dioxide from the environment are often referred to as carbon dioxide "sinks." Tropical rain forests are a major carbon dioxide sink, and their destruction both adds carbon dioxide to the atmosphere and removes a carbon repository.

There seems to be agreement that the destruction of tropical rain forests should be brought under control and that a massive global reforestation program is desirable. However, the planting of even a billion trees a year for 10 years is estimated to absorb only about 1 to 3 percent of the carbon dioxide produced by human activity in the United States. Federal analysts have reached similar conclusions. They estimated that planting 20 billion trees per year could capture up to 67 percent of the nation's annual emissions of carbon dioxide under the best of conditions. Although trees take in carbon dioxide and return oxygen to the air, storing the carbon in the wood, fully mature trees neither store nor emit carbon. Eventually, annual tree growth roughly equals the loss and decay of branches and leaves.[10] But there are many other ecological and aesthetic reasons to save the tropical forests.

Ultimately, large reductions in oil and coal burning are needed to substantially reduce carbon dioxide emissions. Energy conservation and greater use of renewable resources such as hydroelectric power, solar energy, wind power, geothermal energy, wave energy, and biomass energy, where possible, can all reduce the net increase of global warming gases. However, they are not without their own technical and feasibility issues. Nuclear power generation is essentially carbon dioxide emission free, but political as well as safety concerns have prevented wider adoption of the technology in the United States. The result has been the expansion of fossil-fueled power plants. The release of carbon dioxide will expand for many years to come if alternate sources of energy are not developed.

New-generation nuclear reactors such as pebble bed systems offer the possibility of intrinsic safety and even decentralized power systems. Recent research has shown that if the full production process is considered when comparing nuclear to coal-fueled power systems, the actual damage to human health has been far greater historically with coal power production than with nuclear production. These analyses consider the total product cycle from raw-material extraction to power delivery. When the dangers of fuel extraction and processing are factored into the risk associated with coal power production, the nuclear options appear safer.[11]

In addition to temperature rise, the probable net projected effects of increased greenhouse gases include changes in rain, snow, and wind patterns that affect agriculture, overall precipitation, humidity, soil moisture, and storm frequency. The growing season would be lengthened. Melting polar ice would raise ocean levels.

In spite of many uncertainties, according to *Climate Change 2001: The Science Basis*, and *Climate Change 2007: The Physical Science Basis*,[12] it appears that the carbon dioxide level and global warming are increasing. However, many scientists believe that the facts (and assumptions) do not adequately support the predictions.[13] A recently published journal article points out that the earth has been in a warming cycle since the year 1800 and the increased use of fossil fuels beginning in about 1950 has had no effect on glacier shortening. Moreover, Artic air temperature appears to correlate well with solar activity, while hydrocarbon use does not correlate.[14] An astrophysicist with the Harvard Smithsonian Centre for Astrophysics commented that the "best current science offers little justification for rapid cuts in carbon dioxide" and believes "human-made global warming is relatively minor and will be slow to develop."[15] In any case, there is agreement on the need to maintain and improve environmental quality and conserve natural resources.

Effect of Ozone and Chlorofluorocarbons Another global factor is the ozone layer in the upper atmosphere (stratosphere), about 8 to 30 miles above the earth's surface. It helps shield the earth by filtering out or absorbing harmful UV solar radiation. Ozone is formed naturally by the action of sunlight on the oxygen molecule. When released in the lower atmosphere (troposphere), CFCs and halons (a compound consisting of bromine, chlorine, and carbon) migrate upward to the stratosphere through the mixing force of wind, where they remain chemically stable as long as 400 years. When exposed to UV solar radiation, CFCs release chlorine atoms and certain other gases that react with ozone in the stratosphere, reducing the total amount of ozone available to intercept destructive UV radiation. The chlorine in one CFC molecule is believed to destroy tens of thousands of ozone molecules. Bromine is more than 40 times as destructive as chlorine. Nitrous oxide also contributes to ozone depletion.[16] Chemical fertilizers, soil bacteria, burning forests, and fossil fuels are sources of nitrous oxide.

The destruction of ozone by CFCs, halons, and other compounds permits more of the solar radiation to reach the earth, which could cause an increase in skin cancer, eye cataracts, and changes in climate and animal and plant life. This additional solar radiation could also overexpose and kill phytoplankton, a major source of food for fish, seals, penguins, and whales. Subsequent phytoplankton reduction, including algae, would result in less uptake of carbon dioxide. This would cause an increase in the atmospheric carbon dioxide level and contribute to the earth's warming and a reduction in aquatic life and our food supply, as previously noted.

Chlorofluorocarbons remain in the stratosphere for 75 to 110 years.[17] Because of the potential health and environmental effects, steps have been taken to phase out products containing CFCs and halons throughout the world. The product sources include refrigerants (dichlorodifluoromethane, or freon), industrial solvents, volatile paints, plants manufacturing plastic foams, and aerosol spray cans containing CFC propellant. The CFCs are no longer used as blowing agents in the manufacture of food service disposables.[18] Bromine from halons used primarily in fire extinguishers and from chemicals used to make fire retardants, soil fumigants, and agricultural products also destroy ozone by reacting with chlorine synergistically in the absence of oxygen and sunlight.[19] Methyl chloroform and carbon tetrachloride contribute to the problem. Existing refrigerating systems using CFCs that are scrapped remain future sources of CFC release if not contained, recycled, or otherwise controlled. Suggested alternatives to CFCs include hydrochlorofluorocarbons (HCFCs),[20] which, although not as harmful as CFCs, should nevertheless be recycled. A global attack was started in 1987—the Montreal Protocol on Substances that Deplete the Ozone Layer—was signed by 32 countries, with a goal to reduce the 1986 level of use of CFCs and halons by 50 percent.[21] In May 1989, representatives of the European Economic Community (EEC) and 81 other countries, including the United States and Canada, agreed to phase out all CFC use by the year 2000, if possible, as well as the use of halons, carbon tetrachloride, and methyl chloroform.[22] In June 1990, environment ministers from 93 nations met in London and agreed to phase out the production and use of CFCs and related chemicals, including halons and carbon tetrachloride, by the end of the century and methyl chloroform by 2005. The HCFCs are to be phased out between 2000 and 2040.

Ozone is also formed in the lower atmosphere (troposphere), which extends upward for about 8 miles. There, nitrogen oxides, gasoline vapors, and other hydrocarbon emissions from refineries, motor vehicles, solvents, and the like react with sunlight and heat. However, the EPA believes that ozone in the lower atmosphere near the ground level does not replace ozone lost from the upper levels.[23] Ozone at ground level causes lung dysfunction and irritation of the mucous membranes of the eyes, nose, and throat as well as tree and crop damage. Under stable conditions, ozone interactions cause smog and deterioration of exterior paints, rubber, synthetic fibers, and plastics.

Acid Rain (Acidic Precipitation) Releases of nitrogen and sulfur oxides and carbon dioxide, as well as other pollutants, are carried into the atmosphere, where they interact with sunlight and vapor and may be deposited as *acid rain* many miles from the source. The term includes rain, snow, sleet, fog, mist, and clouds containing sulfuric acid, nitric acid, and carbonic acid, as well as direct dry deposition. Large regional emissions and then deposition over a limited area exacerbate the acid rain problem, such as in the northeast United States and eastern Canada. The Southeast, Midwest, West, Rocky Mountain states, western Europe, Scandinavia, and eastern Europe are also affected. In New York and the Northeast, 60 to 70 percent of the reported acidity is due to sulfuric acid, 30 to 40 percent to nitric acid. The relative proportion of each is indicative of the probable preponderant pollutant sources.[24] Major sources of sulfur dioxide, nitrogen oxides, and carbon dioxide are coal- and oil-burning power plants, refineries, and copper and other metal smelters. Principal sources of nitrogen oxide emissions[25] are electric utility and industrial boilers and motor vehicles. Nitrogen oxides from motor vehicle and high-temperature combustion not only contribute to photochemical smog but to changes in the atmosphere, and they return to earth in acid form mixed with precipitation.

High stacks permit the discharge of pollutants into the upper air stream that are then carried great distances by prevailing winds, usually from west to east in the United States. Natural sources of sulfur dioxide, such as active volcanoes, the oceans, and anaerobic emissions from decaying plants, fertilizers, and domestic animals, contribute to the problem. However, the risk to the public health and welfare is complex and very difficult to quantify.[26] There does not appear to be any significant threat to the public health,[27] although this is debatable. About half of all atmospheric sulfur worldwide is reported to come from natural sources.[28] The main contributor to *natural* acidity is carbon dioxide. The natural acidity of precipitation may vary from pH 5.4 to 5.7* (with the lower pH in the northeast

*Lemon juice has a pH of 2, vinegar 3, pure rain 5.6, distilled water 7, and baking soda 8.2.

United States according to the National Acid Deposition Program of 1978 to 1984) and may be as low as 4.0 to 4.6 or lower. While a forest canopy may reduce acidity and ammonia, particulates in the air may, in part, neutralize the acid.

As previously noted, acidic precipitation contributes to deterioration of buildings, monuments and statues, roofing materials, and automobiles. It is also believed to adversely affect trees (mainly conifers at high altitudes), possibly crops and other vegetation. Ozone at ground level is also reported to be a major cause of forest decline.[29] Acidic precipitation may be temporarily beneficial to some vegetation.[30] However, a second stage of acid rain can kill nitrogen-fixing microorganisms and cause decreased production, and then death, as acidity penetrates the soil profile and root system. Calcium and magnesium, necessary for tree growth, are leached from the soil. Aluminum in the soil also becomes available for vegetative uptake. The calcium and magnesium/aluminum ratio is decreased, impairing tree and root growth as the toxic aluminum accumulates in the roots. Susceptibility to insects and stresses due to cold, drought, and heat increase.[31] Forest management, climate, soil nutrients, and geology may also play a role.

Acid rain also adversely affects lakes and streams, where the pH may be reduced to less than 5.0, with resultant reduced fish production. The decomposition of organic deposits contributes to lake acidity. Acidification and demineralization of soils cause higher input of toxic aluminum and other metals to lakes and streams. The condition is more apparent in a lake or groundwater when its buffering capacity and that of the surrounding soil (alkalinity and calcium) are reduced or exhausted. This leads to the release of toxic metals to water supply sources, particularly to shallow well-water supplies. There could also be accumulation in fish, as, for example, increased levels of mercury, aluminum, cadmium, and zinc of 10 to 100 times the normal range.

Control measures should start with coal desulfurization at mining sites and source reduction, such as at high-sulfur oil- and coal-burning plants, and with nitrogen oxides from motor vehicles. Further reduction can be achieved by flue gas desulfurization and the use of scrubbers and other emission control devices. The use of alternative, low-sulfur fuels, as well as hydroelectric, nuclear, and solar power, should also be considered. The application of lime or limestone to lakes and their watersheds is only a temporary measure, a long-term solution must be found.

Acid rain is only one aspect of air pollution. Other toxic stack emissions requiring control include hazardous air pollutants (HAPs) such as lead, mercury, cadmium, zinc, vanadium, arsenic, copper, selenium, and organic pollutants. These must be eliminated or reduced to innocuous levels.

SOURCES AND TYPES OF AIR POLLUTION

The sources of air pollution may be manmade, such as the internal combustion engine, or natural, such as plants (pollens). The pollutants may be in the form of particulates, aerosols, and gases or microorganisms. Included are pesticides, odors, and radioactive particles carried in the air.

Particulates range from less than 0.01 to 1000 μm* in size; generally they are smaller than 50 μm. Smoke is generally less than 0.1 μm size soot or carbon particles. Those below 10 μm can penetrate the lower respiratory tract; particles less than 3 μm reach the tissues in the deep parts of the lung. Particles over 10 μm are removed by the hairs at front of nose. Included are dust and inorganic, organic, fibrous, and nonfibrous particles. Aerosols are usually particles 50 μm to less than 0.01 μm in size; although generally they are less than 1 μm in diameter. Gases include organic gases such as hydrocarbons, aldehydes, and ketones and inorganic gases (oxides of nitrogen and sulfur, carbon monoxide, hydrogen sulfide, ammonia, and chlorine).

Manmade Sources

Air pollution in the United States is the result of industrialization and mechanization. The major sources and pollutants are shown in Table 4.3. It can be seen that carbon monoxide is the principal pollutant by weight and that the motor vehicle is the major contributor, followed by industrial processes and stationary fuel combustion. However, in terms of hazard, it is not the tons of pollutant that is important but the toxicity or harm that can be done by the particular pollutant released. Lead has shown the most dramatic reduction, due to the use of nonleaded gasoline.

Agricultural spraying of pesticides, orchard-heating devices, exhaust from various commercial processes, rubber from tires, mists from spray-type cooling towers, and the use of cleaning solvents and household chemicals add to the pollution load. Toxic pollutant emissions and their fate in the environment need further study.

Particulates, gases, and vapors that find their way into the air without being vented through a stack are referred to as *fugitive emissions*. They include uncontrolled releases from industrial processes, street dust, and dust from construction and farm cultivation. These need to be controlled at the source on an individual basis.

Wood stoves contribute significantly to air pollution. This type of pollution is a potential health threat to children with asthma and elderly people with chronic lung problems. Wood stove use may have to be limited. Stoves are being redesigned to keep the air pollution at acceptable levels.

Natural Sources

Discussions of air pollution frequently overlook the natural sources. These include dust, plant and tree pollens, arboreal emissions, bacteria and spores, gases and dusts from forest and grass fires, ocean sprays and fog, esters and terpenes from

*A micron (μm) is 1/1000 of a millimeter, or 1/25,000 of an inch. Particles of 10 μm and larger in size can be seen with the naked eye.

TABLE 4.3 Air Pollution According to Source and Type of Pollutant: United States, Selected Years 1970–1998

Year	All Sources	On-Road Transportation	Nonroad Engines and Vehicles	Stationary Fuel Combustion	Industrial Process	Waste Disposal and Recycling	Other
Carbon Monoxide (Millions of Short Tons)							
1970	129.4	88.0	12.0	4.6	9.8	7.1	7.9
1975	116.8	83.1	13.1	4.5	7.5	3.2	5.3
1980	117.4	78.0	14.5	7.3	7.0	2.3	8.3
1985	117.0	77.4	16.0	8.5	5.2	1.9	8.0
1987	108.4	71.2	14.5	7.0	4.9	1.9	8.9
1988	118.7	71.1	17.3	7.4	5.2	1.8	16.0
1989	106.4	66.1	17.8	7.4	5.2	1.7	8.2
1990	98.5	57.8	18.2	5.5	4.7	1.1	11.2
1991	100.9	62.1	18.6	5.9	4.6	1.1	8.7
1992	97.6	59.9	19.0	6.2	4.5	1.1	7.0
1993	98.2	60.2	19.4	5.6	4.6	1.2	7.1
1994	102.6	61.8	19.8	5.5	4.6	1.2	9.7
1995	93.4	54.1	20.2	5.9	4.6	1.2	7.3
1996	95.5	53.3	20.2	6.1	3.5	1.1	11.2
1997	94.4	51.7	20.3	5.4	3.6	1.1	12.2
1998	89.5	50.4	19.9	5.4	3.6	1.2	9.0
Nitrogen Oxides (Millions of Short Tons)							
1970	20.9	7.4	1.9	10.1	0.8	0.4	0.3
1975	22.6	8.6	2.6	10.5	0.5	0.2	0.2
1980	24.4	8.6	3.5	11.3	0.6	0.1	0.2
1985	23.2	8.1	3.9	10.0	0.8	0.1	0.3
1988	24.1	7.7	4.4	10.5	0.8	0.1	0.7
1989	23.9	7.7	4.5	10.5	0.8	0.1	0.3
1990	24.0	7.1	4.8	10.9	0.8	0.1	0.4
1991	24.2	7.5	4.9	10.8	0.7	0.1	0.3
1992	24.6	7.6	4.9	10.9	0.8	0.1	0.3
1993	25.0	7.8	4.9	11.1	0.7	0.1	0.2
1994	25.4	8.1	5.0	11.0	0.8	0.1	0.4
1995	24.9	7.8	5.1	10.8	0.8	0.1	0.3
1996	24.7	7.8	5.2	10.4	0.7	0.1	0.5
1997	24.8	7.9	5.3	10.4	0.8	0.1	0.4
1998	24.5	7.8	5.3	10.2	0.8	0.1	0.3
Volatile Organic Compounds (VOCs) (Millions of Short Tons)							
1970	31.0	13.0	1.9	0.7	3.2	2.0	10.2
1975	26.1	10.5	2.1	0.7	3.3	1.0	8.5
1980	26.3	9.0	2.3	1.0	3.5	0.8	9.7
1985	24.4	9.4	2.4	1.6	2.0	1.0	8.0
1988	24.3	8.3	2.6	1.4	2.1	1.0	9.0
1989	22.5	7.2	2.6	1.4	2.1	0.9	8.4
1990	20.9	6.3	2.5	1.0	1.8	1.0	8.3

TABLE 4.3 (*continued*)

Year	All Sources	On-Road Transportation	Nonroad Engines and Vehicles	Stationary Fuel Combustion	Industrial Process	Waste Disposal and Recycling	Other
1991	21.1	6.5	2.6	1.1	1.9	1.0	8.1
1992	20.7	6.1	2.6	1.1	1.9	1.0	8.0
1993	20.9	6.1	2.6	1.0	1.9	1.0	8.2
1994	21.5	6.4	2.7	1.0	1.9	1.0	8.5
1995	20.8	5.7	2.7	1.1	1.9	1.1	8.4
1996	18.7	5.5	2.7	1.0	1.4	0.4	7.7
1997	18.9	5.3	2.6	0.9	1.4	0.4	8.2
1998	17.9	5.3	2.5	0.9	1.4	0.4	7.4
Sulfur Dioxide (Millions of Short Tons)							
1970	31.2	0.4	0.1	23.5	7.1	*a*	0.1
1975	28.0	0.5	0.1	22.7	4.7	*a*	*a*
1980	25.9	0.5	0.2	21.4	3.8	*a*	*a*
1985	23.7	0.5	0.6	20.0	2.4	*a*	*a*
1988	23.1	0.6	0.7	19.8	2.0	*a*	*a*
1989	23.3	0.6	0.8	19.9	2.0	*a*	*a*
1990	23.7	0.5	0.9	20.3	1.9	*a*	*a*
1991	23.0	0.6	0.9	19.8	1.7	*a*	*a*
1992	22.8	0.6	1.0	19.5	1.7	*a*	*a*
1993	22.5	0.5	1.0	19.2	1.6	0.1	*a*
1994	21.9	0.3	1.0	18.9	1.6	0.1	*a*
1995	19.2	0.3	1.0	16.2	1.6	*a*	*a*
1996	19.1	0.3	1.0	16.3	1.4	*a*	*a*
1997	19.6	0.3	1.0	16.7	1.5	*a*	*a*
1998	19.6	0.3	1.1	16.7	1.5	*a*	*a*
PM_{10} (Millions of Short Tons)							
1988	61.1	0.4	0.5	1.4	0.9	0.3	57.7
1989	53.1	0.4	0.5	1.4	0.9	0.3	49.7
1990	30.0	0.3	0.5	1.2	0.9	0.3	26.7
1991	29.6	0.3	0.5	1.1	0.9	0.3	26.4
1992	29.5	0.3	0.5	1.2	0.9	0.3	26.3
1993	28.0	0.3	0.5	1.1	0.8	0.3	25.0
1994	30.9	0.3	0.5	1.1	0.8	0.3	27.9
1995	27.1	0.3	0.5	1.2	0.8	0.3	24.0
1990	30.0	0.3	0.5	1.2	0.9	0.3	26.7
1991	29.6	0.3	0.5	1.1	0.9	0.3	26.4
1992	29.5	0.3	0.5	1.2	0.9	0.3	26.3
1993	28.0	0.3	0.5	1.1	0.8	0.3	25.0
1994	30.9	0.3	0.5	1.1	0.8	0.3	27.9
1995	27.1	0.3	0.5	1.2	0.8	0.3	24.0
1996	33.0	0.3	0.5	1.2	0.6	0.3	30.2
1997	34.2	0.3	0.5	1.1	0.6	0.3	31.5
1998	34.7	0.3	0.5	1.1	0.6	0.3	32.0

(*continues*)

TABLE 4.3 (*continued*)

Year	All Sources	On-Road Transportation	Nonroad Engines and Vehicles	Stationary Fuel Combustion	Industrial Process	Waste Disposal and Recycling	Other
$PM_{2.5}$ (Millions of Short Tons)							
1990	8.0	0.3	0.4	0.9	0.5	0.2	5.6
1991	7.7	0.3	0.4	0.9	0.5	0.2	5.4
1992	7.6	0.3	0.4	0.9	0.5	0.2	5.2
1993	7.3	0.3	0.4	0.9	0.4	0.3	5.1
1994	8.0	0.3	0.4	0.8	0.5	0.3	5.7
1995	7.2	0.2	0.4	0.9	0.5	0.2	4.9
1996	8.2	0.2	0.4	0.9	0.3	0.2	6.1
1997	8.5	0.2	0.4	0.8	0.4	0.2	6.5
1998	8.4	0.2	0.4	0.8	0.4	0.2	6.4
Lead (Thousands of Short Tons)							
1970	220.9	172.0	9.7	10.6	26.4	2.2	*b*
1975	159.7	130.2	6.1	10.3	11.4	1.6	*b*
1980	74.2	60.5	4.2	4.3	3.9	1.2	*b*
1985	22.9	18.1	0.9	0.5	2.5	0.9	*b*
1988	7.1	2.6	0.9	0.5	2.3	0.8	*b*
1989	5.5	1.0	0.8	0.5	2.4	0.8	*b*
1990	5.0	0.4	0.8	0.5	2.5	0.8	*b*
1991	4.2	*a*	0.6	0.5	2.3	0.8	*b*
1992	3.8	*a*	0.6	0.5	1.9	0.8	*b*
1993	3.9	*a*	0.5	0.5	2.0	0.8	*b*
1994	4.0	*a*	0.5	0.5	2.2	0.8	*b*
1995	3.9	*a*	0.5	0.5	2.3	0.6	*b*
1996	3.9	*a*	0.5	0.5	2.3	0.6	*b*
1997	4.0	*a*	0.5	0.5	2.3	0.6	*b*
1998	4.0	*a*	0.5	0.5	2.3	0.6	*b*

[a]Emissions less than 0.05 million short tons per year (less than 0.05 thousand short tons per year in the case of lead emissions).
[b]No emissions calculated.
Note: Data are calculated emissions estimates, PM_{10}, $PM_{2.5}$ = particulate matter, particles less than 10 and 2.5 μm in diameter.
Sources: Office of Air Quality Planning and Standards, *National Air Pollutant Emission Estimates, 1900–1998*, EPA 454/R-00-002, U.S. Environmental Protection Agency, Research Triangle Park, NC, March 2000.

vegetation, ozone and nitrogen dioxide from lightning, ash and gases (SO_2, HCl, HF, H_2S) from volcanoes, natural radioactivity, and microorganisms such as bacteria, spores, molds, or fungi from plant decay. Most of these are beyond control or of limited significance.

Ozone is found in the stratosphere at an altitude beginning at 7 to 10 miles. The principal natural sources of ozone in the lower atmosphere are lightning discharges and, in small amount, reactions involving volatile organic compounds released by forests and other vegetation. Ozone is also formed naturally in the upper atmosphere by a photochemical reaction with UV solar radiation.

Types of Air Pollutants

The types of air pollutants are related to the original material used for combustion or processing, the impurities it contains, the actual emissions, and reactions in the atmosphere. See Table 4.3. A *primary pollutant* is one that is found in the atmosphere in the same form as it exists when emitted from the stack; sulfur dioxide, nitrogen dioxide, and hydrocarbons are examples. A *secondary pollutant* is one that is formed in the atmosphere as a result of reactions such as hydrolysis, oxidation, and photochemistry; photochemical smog is an example.

Most combustible materials are composed of hydrocarbons. If the combustion of gasoline, oil, or coal, for example, is inefficient, unburned hydrocarbons, smoke, carbon monoxide, and, to a lesser degree, aldehydes and organic acids are released.

The use of automobile catalytic converters to control carbon monoxide and hydrocarbon emissions causes some increase in sulfates and sulfuric acid emissions, but this is considered to be of minor significance. The elimination of lead from gasoline has, in some cases, led to the substitution of manganese for antiknock purposes, with the consequent release of manganese compounds, which are also potentially toxic.

Impurities in combustible hydrocarbons (coal and oil), such as sulfur, combine with oxygen to produce SO_2 when burned. The SO_2 subsequently may form sulfuric acid and other sulfates in the atmosphere. Oxides of nitrogen, from high-temperature combustion in electric utility and industrial boilers and motor vehicles [above 1,200°F (649°C)], are released mostly as NO_2 and NO. The source of nitrogen is principally the air used in combustion. Some fuels contain substantial amounts of nitrogen, and these also react to form NO_2 and NO. Fluorides and other fuel impurities may be carried out with the hot stack gases. (The role of sulfur and nitrogen oxides in acid rain is discussed earlier in this chapter.)

Photochemical oxidants* are produced in the lower atmosphere (troposphere) as a result of the reaction of oxides of nitrogen and volatile organics in the presence of solar radiation, as previously noted. Ozone may contribute to smog, respiratory problems, and damage to crops and forests (as previously stated).

Of the sources just noted, industrial processes are the principal source of volatile organics (hydrocarbons), with transportation the next largest contributor. Stationary fuel combustion plants and motor vehicles are the major sources of nitrogen oxides. Ozone, the principal component of modern smog, is the photochemical oxidant actually measured, which is about 90 percent of the total (see p. 9 of Ref. 23). Ozone and other photochemical products formed are usually found at some distance from the source of the precursor compounds.

*Including ozone, PANs, formaldehydes, and peroxides. Nitrogen dioxide colors air reddish-brown.

SAMPLING AND MEASUREMENT

State and local government agencies participate in the EPA national air quality monitoring system. The EPA focuses on the National Ambient Air Quality Standards—airborne particulate matter, sulfur dioxide, ozone, and lead—in over 4,000 locations across the United States.[32]

Air-sampling devices are used to detect and measure smoke, particulates, acid deposition, and gaseous contaminants. The equipment selected and used and its siting are determined by the problem being studied and the purpose to be served. Representative samples free from external contamination must be collected and readings or analyses standardized to obtain valid data. Supporting meteorological and other environmental information are needed to properly interpret the data collected. Continuous sampling equipment should be selected with great care. The accuracy and precision of equipment needs to be demonstrated to ensure that it will perform the assigned task with a minimum of calibration and maintenance. Reliable instruments are available for the monitoring of ambient air parameters, such as those listed in Table 4.4. Other instruments such as for *opacity*, hydrocarbons, and sulfur are also available.

TABLE 4.4 Measurement Methods for Ambient Air Quality Parameters

Pollutant	Measurement Methods
SO_2	Ultraviolet pulsed fluorescence, flame photometry, coulometric; dilution or permeation tube calibrators
CO	Nondispersive infrared tank gas and dilution calibration, gas filter correlation
O_3	Gas-phase chemiluminescence ultraviolet (UV) spectrometry; ozone UV generators and UV spectrometer or gas-phase titration (GPT) calibrators
NO_2	Chemiluminescence permeation or GPT calibration
Lead	High-volume sampler and atomic absorption analysis
PM_{10}[a]	Tapered-element oscillating microbalance, automated beta gauge
$PM_{2.5}$	Twenty-four-hour filter sampling
TSPs[b]	High-volume sampler and weight determination
Sulfates, nitrates	High-volume sampler and chemical analysis—deposit dissolved and analyzed colorimetrically
Hydrocarbons	Flame ionization and gas chromatography[c]; calibration with methane tank gas
Asbestos and other fibrous aerosols	Induced oscillation/optical scattering, microscope, and electron microscope
Biologic aerosols	Impaction (Petri dish), incubated 24 hr and microbial colonies counted

[a] 10 μm or small particle.
[b] Total suspended particulates. type, size, and composition are important.
[c] Not generally required to measure these if O_3 is measured.

A continuous air-quality monitoring system for the measurement of selected gaseous air pollutants, particulates, and meteorological conditions over a large geographical area can make possible immediate intelligence and reaction when ambient air quality levels or emissions increase beyond established standards. In the system, each monitoring station sends data to a data reception center, say every hour, via telephone lines or other communication network. The collected data are processed by computer and visually displayed for indicated action. Field operators who can perform weekly maintenance and calibration checks and a trained central technical staff to coordinate and scrutinize the overall daily monitoring system operation and data validation are essential for the production of usable and valid "real-time" data.[33]

The air monitoring data can be used to measure ambient air quality and its compliance with state and national standards; detect major local source air quality violations; provide immediate information for a statewide air pollution episode alert warning system; provide long-term air quality data to meet public and private sector data needs, such as for environmental planning and environmental impact analysis; determine long-term air pollution concentrations and trends in a state; and provide air quality information to the public.

A continuous air quality monitoring system requires use of continuously operating analyzers of a design that measures ambient concentrations of specified air pollutants in accordance with EPA "reference methods" or "equivalent methods."[34] The EPA designates air pollution analyzers after reviewing extensive test data submitted by the manufacturers for their instrumentation. Only analyzers designated as reference or equivalent methods may be used in ambient air monitoring networks to define air quality. This is necessary to ensure correct measurements and operation, thereby promoting uniformity and comparability of data used to define national ambient air quality.

The EPA has specified[35] a detailed ambient monitoring program for use by states, local government, and industry. Included in the program are formal data quality assurance programs, monitoring network design, probe (air intake) siting, methodology, and data reporting requirements. The EPA has specified a daily uniform air pollution index known as the pollutant standard index (or PSI) for public use in comparing air quality. The PSI values are discussed and summarized later in Table 4.7.

Types of analyzers used to measure national ambient air quality parameters are summarized in Table 4.4. Continuous analyzers utilizing "gas-phase" measurements with electronic designs, rather than "wet chemistry" measurements, are preferred as they are more accurate and reliable. However, inasmuch as not all regulatory agencies, particularly those at a local level, have the resources or need for sophisticated equipment, other devices are also mentioned here.

Particulate Sampling — Ambient Air

Measurements needing much more development are in the area of particulates, where inhalable particles sizing (less than 10^{-3} μm), identification, metals, sulfates, and nitrates are important. Particulates can also be collected and tested for their mutagenic properties. Of all the particulate ambient air sampling devices, the high-volume sampler is the one most commonly used in the United States, although alternate continuous monitoring devices are increasingly being used. Other devices also have application for the collection of different-sized particulates.

High-volume (*Hi-vol*) *samplers* pass a measured high rate of (40–60 cfm) through a special filter paper (or fiberglass), usually for a 24-hour period. The filter is weighed before and after exposure, and the change in weight is a measure of the suspended particulate matter in (PM) in micrometers per square meter of air filtered. The particulates can be analyzed for weight, particle size (usually between 50 and 0.1 μm), composition (such as benzene solubles, nitrates, lead, and sulfates), and radioactivity. Particle size selective inlets can be put on high-volume samplers, and samples can be separated into two parts using impactor principles, those in the particle size ranging above and below 2 to 3 μm. There is more interest in measuring 10 μm or smaller particles (PM_{10}) since they penetrate deeper into the respiratory tract and are more likely to cause adverse health effects.

High-volume sampling is the EPA reference method. Air flow measurement is very important. An orifice with a manometer is recommended for flow measurement.

Sedimentation and settling devices include fallout or dustfall jars, settling chambers or boxes, Petri dishes, coated metal sheets or trays, and gum-paper stands for the collection of particulates that settle out. Vertically mounted adhesive papers or cylinders coated with petroleum jelly can indicate the directional origin of contaminants. Dustfall is usually reported as milligrams per centimeter squared per month. Particulates can also be measured for radioactivity.

The *automatic* (*tape*) *smoke sampler* collects suspended material on a filter tape that is automatically exposed for predetermined intervals over an extended period of time. The opacity of the deposits or spots on the tape to the transmission or reflectance of light from a standard source is a measure of the air pollution. This instrument provides a continuous electrical output that can be telemetered to give immediate data on particulates. Thus, the data are available without the delay of waiting for laboratory analysis of the high-volume filter. The equipment is used primarily to indicate the dirtiness of the atmosphere and does not directly measure the particulate total suspended particulate (TSP) ambient air quality standard.

Inertial or centrifugal collection equipment operates on the cyclone collection principle. Large particles above 1 μm in diameter are collected, although the equipment is most efficient for the collection of particles larger than 10 μm.

Impingers separate particles by causing the gas stream to make sudden changes in direction in passing through the equipment. The wet impinger is used for the collection of small particles, the dry impinger for the larger particles. In the dry impinger, a special surface is provided on which the particles collide and adhere.

In the *cascade impactor*, the velocities of the gas stream vary, making possible the sorting and collection of different-sized particles on special microscopic slides. Particulates in the range of 0.7 to 50 μm are collected.

Electrostatic precipitator-type sampling devices operate on the ionization principle using a platinum electrode. Particles less than 1 μm in size collect on an electrode of opposite charge and are then removed for examination. Combustible gases, if present, can affect results.

Nuclei counters measure the number of condensation nuclei in the atmosphere. They are a useful reference for weather commentators. A sample of air is drawn through the instrument, raised to 100 percent relative humidity, and expanded adiabatically, with resultant condensation on the nuclei present. The droplets formed scatter light in proportion to the number of water droplets, which are counted by a photomultiplier tube. Concentrations of condensation nuclei may range from 10 to 10,000,000 particles/cm^3.[36] Condensation nuclei are believed to result from a combination of natural and man-made causes, including air pollution. A particle count above 50,000 is said to be characteristic of an urban area.

Pollen samplers generally use petroleum-jelly-coated slides placed on a covered stand in a suitable area. The slides are usually exposed for 24 hours, and the pollen grains are counted with the aid of a microscope. The counts are reported as grains per centimeter squared. See Chapter 2 for ragweed control and sampling.

Gas Sampling

Gas sampling requires separation of the gas or gases being sampled from other gases present. The temperature and pressure conditions under which a sample is collected must be accurately noted. The pressure of a gas mixture is the sum of the individual gas pressures, as each gas has its own pressure. The volumes of individual gases at the same pressure in a mixture are also additive. *Concentrations of gases when reported in terms of ppm and ppb are by volume rather than by weight*.* Proper sampling and interpretation of results require competency and experience, knowledge concerning the conditions under which the samples are collected, and an understanding of the limitations of the testing procedures. Automated and manual instruments and equipment for gas sampling and analysis include the following.

Pulsed Fluorescent Analyzer This instrument measures sulfur dioxide by means of absorption of UV light. [37] Pulsating UV light is focused through a narrow-bandpass filter that reduces the outgoing light to a narrow wavelength band of 230 to 190 nm and directs it into the fluorescent chamber. Ambient air containing SO_2 flows continuously through this chamber where the UV light excites the SO_2 molecules, which, in turn, emit their characteristic decay radiation. This radiation, specific for SO_2, passes through a second filter and

*In either metric (SI) or customary (U.S.) units.

onto a sensitive photomultiplier tube. This incoming light energy is transformed electronically into an output voltage that is directly proportional to the concentration of SO_2 in the sample air. The World Health Organization (WHO) Global Environmental Monitoring System determinations use the following methods: acidimetric titration or hydrogen peroxide, the colormetric pararosaniline or West-Gaeke, the amperometric or coulometric, and the conductimetric.

Atomic Spectrometry In atomic spectrometry a sample solution is atomized into a flame that produces a characteristic and measurable spectrum of light wavelengths. *Gas chromatography* separates compounds that can be volatilized, while *liquid chromatography* separates compounds that are not volatile. *Mass spectrometry* identifies a separated pure component by its characteristic mass spectrum. Sampling analytical methods for the examination of toxic and hazardous organic materials include gas chromatography with flame ionization detector, gas chromatography–mass spectrometry, gas chromatography–photoionization detector, and electron capture. Calibration is accomplished through laboratory standards and certified permeation tubes.

Some continuous monitoring instruments for atmospheric measurement of pollution are quite elaborate and costly. The simplest readily available instrument should be selected that meets the required sensitivity and specificity. Power requirements, service, maintenance, calibration frequency, and time required to collect and transmit information are important considerations.

Nitrogen Oxide Chemiluminescence Analyzer Nitric oxide (NO) is measured by the gas-phase chemiluminescent reaction between nitric oxide and ozone.[37] This technique is also used to determine nitrogen dioxide (NO_2) by catalytically reducing NO_2 in the sample air to a quantitative amount of NO. Sample air is drawn through a capillary into a chamber held at 25 in. Hg vacuum. Ozone produced by electrical discharge in oxygen is also introduced into the chamber.

The luminescence resulting from the reaction between NO and ozone is detected by a temperature-stabilized photomultiplier tube and wavelength filter. An automatic valving system periodically diverts the sample air through a heated activated-carbon catalyst bed to convert NO_2 to NO before it enters the reaction chamber. The sample measured from the converter is called NO_x. Since it contains the original NO plus NO produced from the NO_2 conversion, the differences between the sequential NO_x and NO readings are reported as NO_x. Primary dynamic calibrations are performed with gas-phase titration using ozone and nitric oxide standards and with NO_2 permeation tubes.

Ozone Chemiluminescence Analyzer Ozone is measured by the gas-phase chemiluminescence technique, which utilizes the reaction between ethylene and ozone (O_3).[37] Sample air is drawn into a mixing chamber at a flow rate of 1 1/min, where it is mixed with ethylene gas and introduced at a flow rate of 25 cc/min. The luminescence resulting from the reaction of the ethylene with ambient ozone in the air supply is detected by a temperature-stabilized photomultiplier tube. This signal is then amplified and monitored by telemetry and on-site recorders. These ozone instruments contain provision for weekly zero and span checks. Primary dynamic calibrations are periodically performed that require standardization against a known, artificially generated ozone atmosphere. Ozone is also measured by UV light instrumentation.

Carbon Monoxide Infrared (IR) Analyzer This method utilizes dual-beam photometers with detection accomplished by means of parallel absorption chambers or cells that are separated by a movable diaphragm.[37] The IR energy passes into each chamber—one containing the sample with CO, the other containing the reference gas. The reference gas heats up more than the ambient air sample with CO because CO absorbs more of the IR energy. This results in higher temperature and, hence, the volume–pressure in the reference chamber that is transmitted to the separating diaphragm designed to provide an electrical output to measure the CO concentration. However, it is necessary to remove water vapor interference as the humidity in ambient air absorbed by IR energy can introduce a significant error in CO readings. In one instrument (the EPA reference method), the interference due to water vapor is eliminated by first passing one portion of the ambient air sample through a catalytic converter, where CO is converted to CO_2 prior to entry into the reference chamber. The other half of the air sample containing CO passes directly into the sample chamber. This procedure cancels out the effect of moisture since both gas streams are identical except for the presence of CO.[42] Carbon monoxide is also measured by gas-phase correlation.

Smoke and Soiling Measurement

Historically, smoke and/or opacity was measured by The *Ringelmann smoke chart*.[38] This consists of five* rectangular grids produced by black lines of definite width and spacing on a white background. When held at a distance, about 50 feet from the observer, the grids appear to give shades of gray between white and black. The grid shadings are compared with the pollution source (stack), and the grid number closest to the shade of the pollution source is recorded. About 30 observations are made in 15 minutes, and a weighted average is computed of the recorded Ringelmann numbers. The chart is used to determine whether smoke emissions are within the standards established by law; the applicable law is referenced to the chart. The system cannot be applied to dusts, mists, and fumes. Inspectors need training in making smoke readings. A reading of zero would correspond to all white; a reading of five would correspond to all black.

The Ringelmann chart has been replaced by a determination of the *percent opacity* of a particular emission as seen by a trained observer.† For example,

*Reduced to four grids or charts in the United States. The width or thickness of lines and their spacing in each grid or chart vary. A handy reduction of the Ringelmann smoke chart is the Power's Micro-Ringelmann available from Power, 33 West 42nd Street, New York, NY 10036.

†See U.S. EPA Method 9, Appendix A, 40 CFR 60, 2001.

a Ringelmann reading of 1 would correspond to an opacity of about 20 percent.

Tape Sampler — Soiling Soiling can be indicated as RUDS (reflectance units of dirt shade). One RUDS is defined as an optical reflectance of 0.01 caused by 10,000 feet of air passing through 0.786 in.^{2} (1-in.-diameter circle) of filter paper. A vacuum pump draws the air to be sampled through the filter tape. The particles collected soil a spot on the tape. The tape is advanced automatically after a 2-hour period; the air flow rate used is 0.455 cfm. A filter is used with the light source that admits light with a wavelength of approximately 400 nm to measure the light reference; this information can be sent to a monitor. The sampling time period and air flow rate were chosen to conform with ASTM (American Society for Testing and Materials) standards.

Tape Sampler — Coefficient of Haze (COH) The tape sampler can be designed to measure light transmittance rather than reflectance. This will produce soiling measurements expressed as COH, an index of contaminant concentration, which is the EPA preferred method. The method is similar to that previously outlined except the photocell is under the tape. White light is used. It is necessary to automatically rezero the instrument near each spot to compensate for tape thickness variation. The compensation is performed by solid-state electronics.

The automated filter tape air sampler can also be used to monitor some gases. Special filter tapes are used to measure hydrogen sulfide, fluorides, and other gases. The spots produced by the gaseous pollutant are chemically treated and evaluated using the reflectance or transmission method.

Many of these measures of smoke and or opacity have been moved back to the source (smoke stack) where more enforceable standards can be applied. Industrial operation permits can require the installation of electronic opacity monitors. These monitors measure either the transmission of light from a source to a sensor across the stack (extinction) or the variability of light transmission across the stack (scintillation). Inspectors may request operation records and maintenance logs during facility inspection.

Stack Sampling

The collection of stack samples, such as fly ash and dust emissions, requires special filters of known weight and a measure of the volume of gases sampled. The sample must be collected at the same velocity at which the gases normally pass through the stack. The gain in weight divided by the volume of gases sampled corrected to 0°C (or 21°C) temperature and 760 mm Hg gives a measure of the dust and fly ash going out of the stack, usually as grains per cubic foot. When a series of samples is to be collected or measurements made, a *sampling train* is put together. It may consist of a sampling nozzle, several impingers, a freeze-out train, a weighed paper filter, dry gas meter, thermometers, and pump.

A common piece of equipment for boiler and incinerator stack sampling is the Orsat apparatus. By passing a sample of the stack gas through each of three different solutions, the percent carbon dioxide, carbon monoxide, and oxygen constituents in the flue gas are measured. The remainder of the gas in the mixture is usually assumed to be nitrogen. Special methods are used to test for other gases and metals.

Tracer materials may be placed in a stack to indicate the effect of a pollution source on the surrounding area. The tracer may be a fluorescent material, a dye, a compound that can be made radioactive, a special substance or chemical, or a characteristic odor-producing material. The tracer technique can be used in reverse—that is, to detect the source of a particular pollutant, provided there are no interfering sources.

Measurement of Materials' Degradation

The direct effects of air pollution can be observed by exposing various materials to the air at selected monitoring stations. The degradation of materials is measured for a selected period on a scale of 1 to 10, with 1.0 representing the least degradation and 10.0 the worst, as related to the sample showing the least degradation. Materials exposed and conditions measured include steel corrosion, dyed fabric (nonspecific) for color fading, dyed fabric (NO_x sensitive), dyed fabric (ozone sensitive), dyed fabric (fabric soiling), dyed fabric (SO_2 sensitive), silver tarnishing, nylon deterioration, rubber cracking (crack depth), leather deterioration, copper pitting, and others. The samples are exposed for a selected period, such as rubber, 7 days at a time; silver, 30 days at a time; nylon, 30 or 90 days at a time; cotton, 90 days at a time; steel, 90 days and 1 year at a time; and zinc, 1 year at a time. Shrubs, trees, and other plants sensitive to certain contaminants or pollutants can also be used to monitor the effects of air pollution.

ENVIRONMENTAL FACTORS

The behavior of pollutants released to the atmosphere is subject to diverse and complex environmental factors associated with meteorology and topography. Meteorology involves the physics, chemistry, and dynamics of the atmosphere and includes many direct effects of the atmosphere on the earth's surface, ocean, and life. Topography refers to both the natural and manmade features of the earth's surface. The pollutants can be either accumulated or diluted, depending on the nature and degree of the physical processes of transport, dispersion, and removal and the chemical changes taking place. Because of the complexities of pollutant behavior in the atmosphere, it is important to distinguish between the activity of short-range primary pollutants (total suspended solids, sulfur dioxide), to which micrometeorology applies, and long-range secondary pollutants (ozone, acid rain), to which regional meteorology applies.

Within the scope of this text, the intention is not to provide a complete technical understanding of all the meteorological and topographical factors involved but to provide an insight into the relationships to air pollution of the more important processes.

Meteorology

The meteorological elements that have the most direct and significant effects on the distribution of air pollutants are wind speed and direction, solar radiation, stability, and precipitation. Therefore, it is important to have a continuing baseline of meteorological data, including these elements, to interpret and anticipate probable effects of air pollution emissions. Data on temperature, humidity, wind speed and direction, and precipitation are generally available through official government weather agencies. The National Weather Service (formerly U.S. Weather Bureau), Asheville, North Carolina, is a major source of information. Other potential sources of information are local airports, stations of the state fire weather service, military installations, public utilities and industrial complexes, and colleges and universities.

Wind Wind is the motion of the air relative to the earth's surface. Although it is three-dimensional in its movement, generally only the horizontal components are denoted when used because the vertical component is very much smaller than the horizontal. This motion derives from the unequal heating of the earth's surface and the adjacent air, which in turn gives rise to a horizontal variation in temperature and pressure. The variation in pressure (pressure gradient) constitutes an imbalance in forces so that air motion from high toward low pressure is generated.

The uneven heating of the surface occurs over various magnitudes of space, resulting in different magnitudes of organized air motions (circulations) in the atmosphere. Briefly, in descending order of importance, these are:

1. The primary or general (global) circulation associated with the large-scale hemispheric motions between the tropical and polar regions
2. The secondary circulation associated with the relatively large-scale motions of migrating pressure systems (highs and lows) developed by the unequal distribution of large land and water masses
3. The tertiary circulation (local) associated with small-scale variations in heating, such as valley winds and land and sea breezes

For a particular area, the total effect of these various circulations establishes the hourly, daily, and seasonal variations in wind speed and direction. With respect to a known source or distribution of sources of pollutants, the frequency distribution of wind direction will indicate toward which areas the pollutants will most frequently be transported. It is customary to present long-term wind data at a given location graphically in the form of a *wind rose*, an example of which is shown in Figure 4.1.

The concentration resulting from a continuous emission of a pollutant is inversely proportional to wind speed. The higher the wind speed, the greater the separation of the particles or molecules of the pollutant as they are emitted, and vice versa. This is shown graphically in Figure 4.2*a*. Wind speed, therefore, is an indicator of the degree of dispersion of the pollutant and contributes to the

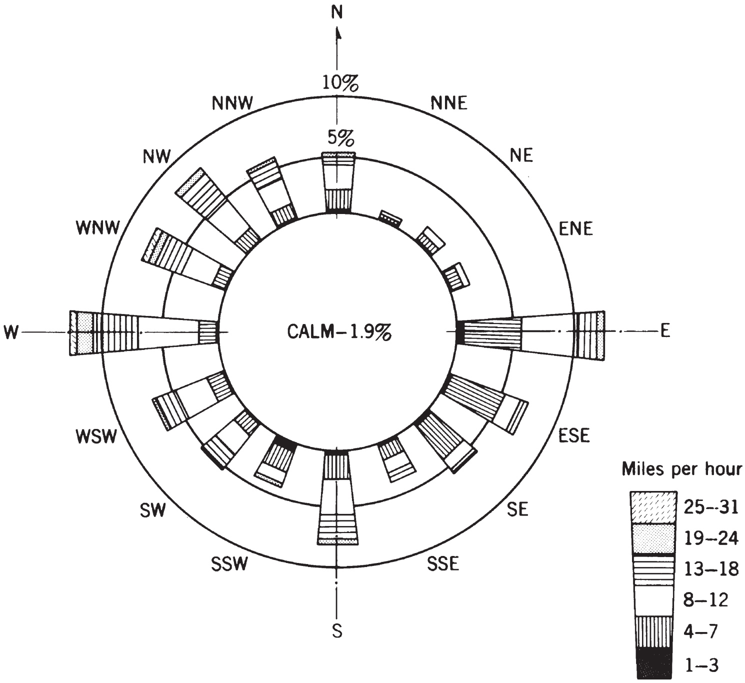

FIGURE 4.1 Example of wind rose for a designated period of time, by month, season, or year. The positions of the spokes show the direction from which the wind was blowing. The total length of the spoke is the percentage of time, for the reporting period, that the wind was blowing from that direction. The length of the segments into which each spoke is divided is the percentage of time the wind was blowing from that direction at the indicated speed in miles per hour. Horizontal wind speed and direction can vary with height.

determination of the area most adversely affected by an emission. Although an area may be located in the most frequently occurring downwind direction from a source, the wind speeds associated with this direction may be quite high so that resulting pollutant concentrations will be low as compared to another direction occurring less frequently but with lower wind speeds.

Smaller in scale than the tertiary circulation mentioned, there is a scale of air motion that is extremely significant in the dispersion of pollutants. This is referred to as the micrometeorological scale and consists of the very short term, on the order of seconds and minutes, fluctuations in speed and direction. As opposed to the "organized" circulations discussed previously, these air motions are rapid and random and constitute the wind characteristic called *turbulence*. The turbulent nature of the wind is readily evident upon watching the rapid movements of a wind vane. These air motions provide the most effective mechanism for the dispersion or dilution of a cloud or plume of pollutants. The turbulent fluctuations occur in both the horizontal and vertical directions. The dispersive effect of fluctuations in horizontal wind direction is shown graphically in Figure 4.2*b*.

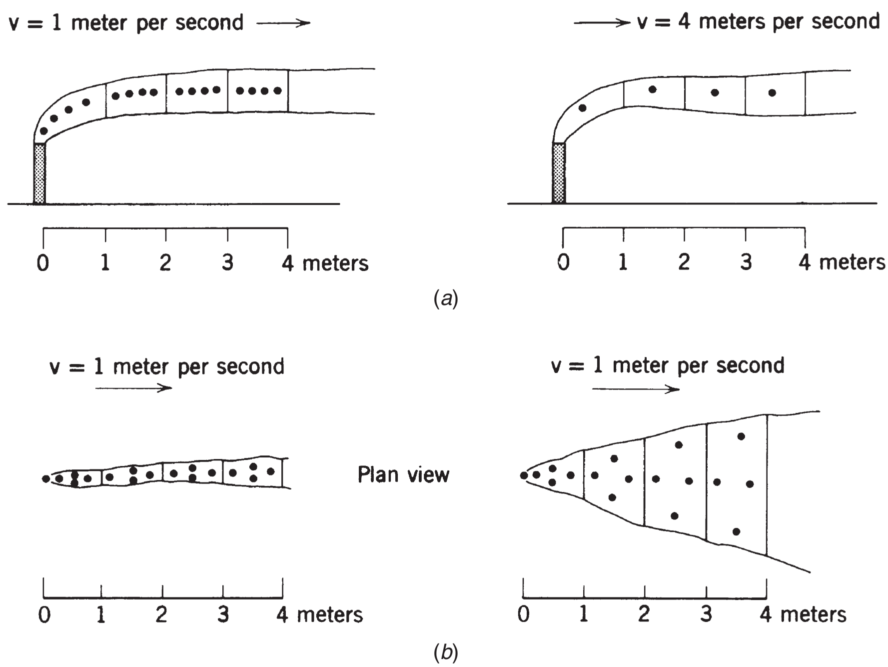

FIGURE 4.2 (*a*) Effect of wind speed on pollutant concentration from constant source; (*b*) Effect of variability of wind direction on pollutant concentration from constant source (continuous emission of 4 units/sec).

Turbulent motions are induced in the air flow in two ways: by thermal convective currents resulting from heating from below (thermal turbulence) and by disturbances or eddies resulting from the passage of air over irregular, rough ground surfaces (mechanical turbulence).

It may be generally expected that turbulent motion and, in turn, the dispersive ability of the atmosphere would be greatly enhanced during a period of good solar heating and over relatively rough terrain.

Another characteristic of the wind that should be noted is that wind speed generally increases with height in the lower levels. This is due to the decrease with height of the "frictional drag" effect of the underlying ground surface features.

Stability and Instability The stability of the atmosphere is its ability to enhance or suppress vertical air motions. Under unstable conditions the air motion is enhanced, and under stable conditions the air motion is suppressed. The conditions are determined by the vertical distribution of temperature.

In vertical motion, parcels of air are displaced. Due to the decrease of pressure with height, a parcel displaced upward will encounter decreased pressure and expand. If this expansion process is relatively rapid or over a large area so that there is little or no exchange of heat with the surrounding air or by a change of state of water vapor, the process is dry adiabatic and the parcel of air will be cooled. Likewise, if the displacement is downward so that an increase in pressure and compression is experienced, the parcel of air will be heated.

The rate of cooling of a mass of warm dry air in a dry environment with height is the *dry adiabatic process lapse rate* and is approximately -5.4°F/1,000 feet (-1°C/100 m). The normal lapse rate (cooling) on the average is -3.5°F/1,000 feet (-0.65°C/100 m). This relationship holds true in the troposphere up to about 10 km (6 miles). Temperature increases above this level in the stratosphere.

The *prevailing* or *environmental lapse rate* is the decrease of temperature with height that may exist at any particular time and place. It can be shown that if the decrease of temperature with height is greater than -5.4°F/1,000 feet, parcels displaced upward will attain temperatures higher than their surroundings. Air parcels displaced downward will attain lower temperatures than their surroundings. The displaced parcels will tend to continue in the direction of displacement. Under these conditions, the vertical motions are enhanced and the layer of air is defined as *unstable*.

Furthermore, if the decrease of temperature with height is less than -5.4°F/1,000 feet, it can be shown that air parcels displaced upward attain temperatures lower than their surroundings and will tend to return to their original positions. Air parcels displaced downward attain higher temperatures than their surroundings and also tend to return to their original position. Under these conditions, vertical motions are suppressed and the layer of air is defined as "stable."

Finally, if the decrease of temperature with height is equal to -5.4°F/1,000 feet, displaced air parcels attain temperatures equal to their surroundings and tend to remain at their position of displacement. This is called *neutral stability*.

Inversions Up to this point, the prevailing temperature distribution in the vertical has been referred to as a *lapse rate*, which indicates a decrease of temperature with height. However, under certain meteorological conditions, the distribution can be such that the temperature increases with height within a layer of air. This is called an *inversion* and constitutes an extremely stable condition.

There are three types of inversions that develop in the atmosphere: radiational (surface), subsidence (aloft), and frontal (aloft).

Radiational inversion is a phenomenon that develops at night under conditions of relatively clear skies and very light winds. The earth's surface cools by reradiating the heat absorbed during the day. In turn, the adjacent air is also cooled from below so that within the surface layer of air there is an increase of temperature with height.

Subsidence inversion develops in high-pressure systems (generally associated with fair weather) within a layer of air aloft when the air layer sinks to replace air that has spread out at the surface. Upon descent, the air heats adiabatically, attaining temperatures greater than the air below.

A condition of particular significance is the subsidence inversion that develops with a stagnating high-pressure system. Under these conditions, the pressure gradient becomes progressively weaker so that the winds become very light, resulting in a great reduction in the horizontal transport and dispersion of pollutants. At the same time, the subsidence inversion aloft continuously descends, acting as a barrier (lid) to the vertical dispersion of the pollutants. These conditions can persist for several days so that the resulting accumulation of pollutants can cause a serious health hazard.

Frontal inversion forms when air masses of different temperature characteristics meet and interact so that warm air overruns cold air.

There are many and varied effects of stability conditions and inversions on the transport and dispersion of pollutants in the atmosphere. In general, enhanced vertical motions under unstable conditions increase the turbulent motions, thereby enhancing the dispersion of the pollutants. Obviously, the stable conditions have the opposite effect.

For stack emissions in inversions—depending on the elevation of emission with respect to the distribution of stability in the lower layers of air—behavior of the plumes can be affected in many different ways. On the one hand, pollutants emitted within the layer of a surface-based (radiational) inversion by low stacks can develop very high and hazardous concentrations at the surface level. On the other hand, when pollutants are emitted from stacks at a level aloft within the surface inversion, the stability of the air tends to maintain the pollutant at this level, preventing it from reaching the surface. However, after sunrise and continued radiation from the sun resulting in heating of the earth's surface and adjacent air, the inversion is "burned off." Once this condition is reached, the lower layer of air becomes unstable and all of the pollutant that has accumulated at the level aloft is rapidly dispersed downward to the surface. This behavior is called "fumigation" and can result in very high concentrations during the period. See Figure 4.3.

Precipitation Precipitation constitutes an effective cleansing process of pollutants in the atmosphere in three ways: the washing out or scavenging of large particles by falling raindrops or snowflakes (washout), accumulation of small particles in the formation of raindrops or snowflakes in clouds (rainout), and removal of gaseous pollutants by dissolution and absorption.

The most effective and prevalent process is the washout of large particles, particularly in the lower layer of the atmosphere, where most of the pollutants are released. The efficiencies of the various processes depend on complex relationships between properties of the pollutants and the characteristics of the precipitation.

Topography

The topographic features of a region include both the natural (e.g., valleys, oceans, rivers, lakes, foliages) and manmade (e.g., cities, bridges, roads, canals) elements distributed within the region. These elements, per se, have little direct effect on pollutants in the atmosphere. The prime significance of topography is its effects on the meteorological elements. As stated previously, the variation in the distribution of land and water masses gives rise to various types of circulations.

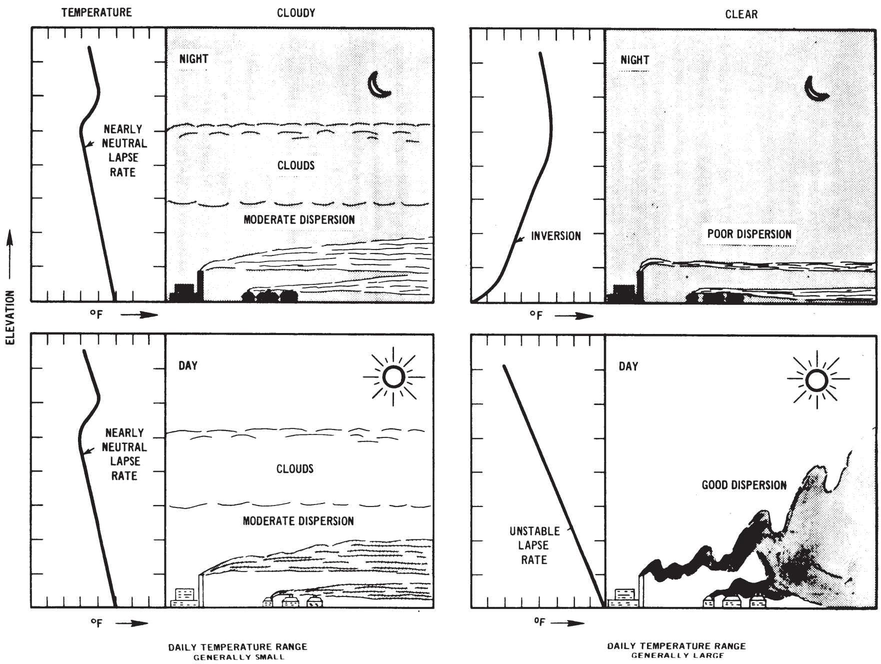

FIGURE 4.3 Diurnal and nocturnal variation of vertical mixing. (*Source*: M. I. Weisburd, *Field Operation and Enforcement Manual for Air Pollution*, Vol. 1: *Organization and Basic Procedures*, U.S. Environmental Protection Agency, Office of Air Programs, Research Triangle Park, NC, 1972, p. 1.24.)

Of particular significance are the local or small-scale circulations that develop. These circulations can contribute either favorably or unfavorably to the transport and dispersion of the pollutants.

Along a coastline during periods of weak pressure gradient, intense heating of the land surface, as opposed to the lesser heating of the contiguous water surface, develops a temperature and pressure differential that generates an onshore air circulation. This circulation can extend to a considerable distance inland. At times during stagnating high-pressure systems, when the transport and dispersion of pollutants have been greatly reduced, this short-period afternoon increase in airflow may well prevent the critical accumulation of pollutants.

In valley regions, particularly in the winter, intense *surface inversions* are developed by the drainage down the slopes of air cooled by the radiationally cooled valley wall surfaces. Bottom valley areas that are significantly populated and industrialized can be subject to critical accumulation of pollutants during these periods.

The increased roughness of the surface created by the widespread distribution of buildings throughout a city can significantly enhance the turbulence of the airflow over the city, thereby improving the dispersion of the pollutants emitted.

But at the same time the concrete, stone, and brick buildings and asphalt streets of the city act as a heat reservoir for the radiation received from the sun during the day. This, plus the added heat from nighttime space heating during the cool months of the year, creates a temperature and pressure differential between the city and the surrounding rural area so that a local circulation inward to the city is developed. The circulation tends to concentrate the pollutants in the city. This phenomenon called the *urban heat island effect*.

Areas on the windward side of mountain ranges can expect added precipitation due to the forced rising, expansion, and cooling of the moving air mass with resultant release of available moisture. This increased precipitation serves to increase the removal of the pollutants.

It is apparent, then, that topographical features can have many and diverse effects in the meteorological elements and the behavior of pollutants in the atmosphere.

AIR POLLUTION SURVEYS

An air pollution survey of a region having common topographical and meteorological characteristics is a necessary first step before a meaningful air resources management plan and program can be established. The survey includes an inventory of source emissions and a contaminant and meteorological sampling network, supplemented by study of basic demographic, economic, land-use, and social factors.

Inventory

The inventory includes the location, height, exit velocity, and temperature of emission sources and identification of the processes involved; the air pollution control devices installed and their effectiveness; and the pounds or tons of specific air pollutants emitted per day, week, month, and year, together with daily and seasonal variations in production. Inventories of area sources (e.g., home heating, small dry cleaners) can be done simply through fuel use and solvent sales data. The emissions are calculated from emission tables or by material balance. An estimate can then be made of the total pollution burden on the atmospheric resources of any given air basin.[39] Tables have been developed to assist in the calculation of the amounts and types of contaminants released; they can also be used to check on information received through personal visits, questionnaires, telephone calls, government reports, and technical and scientific literature.[40] Additional sources of information are the complaint files of the health department, municipal and private agencies, published information, university studies, state and local chamber of commerce reports and files, and results of traffic surveys as well the Census of Housing local fuel and gasoline sales. Much of this material is now available electronically via the Internet. Data about concentration of primary pollutants, for example, are available via the Aerometric Information Retrieval System (AIRS) at www.epa.gov/airs.

Air Sampling

Air and meteorological sampling equipment located in the survey area will vary, depending on a number of factors such as land area, topography, population densities, industrial complexes, and manpower and budget availability. A minimum number of stations is necessary to obtain meaningful data.

Specific sampling sites for a comprehensive survey or for monitoring are selected on the basis of objective, scope, and budgetary limitations; accessibility for year-round operation, availability of reliable electrical power, amount and type of equipment available, program duration, and personnel available to operate stations; meteorology of the area, topography, adjacent obstructions, and vertical and horizontal distribution of equipment; and sampler operator problems, space requirements, protection of equipment and site, possible hazards, and public attitude toward the program.[41] The EPA can provide monitoring and siting guidance.[42] Careful attention must also be given to the elimination of sampling bias and variables as related to size of sample, rate of sampling, collection and equipment limitations, and analytical limitations.

Basic Studies and Analyses

Basic studies include population densities and projections; land-use analysis; mapping; and economic studies and proposals, including industrialization, transportation systems, community institutions, environmental health and engineering considerations, relationship to federal, state, and local planning, and related factors. Liaison with other planning agencies can be helpful in obtaining needed information that may already be available.

When all the data from the emission inventory, air sampling, and basic studies are collected, analyzed, and evaluated, a report is usually prepared. The analysis step should include calculations to show how the pollutants released to the atmosphere are dispersed and their possible effects under existing conditions and with future development.

Mathematical models could be developed, or commercially available modeling packages could be utilized, based on certain assumptions and the data collected, to estimate the pollution levels that might result under various emission, topographical, and meteorological conditions. A data bank and a system for the collection and retrieval of information would generally be indicated. The approximate cost to achieve selected levels of air quality (for health, aesthetic, plant, and animal considerations) and the possible effect on industrial expansion, transportation modes and systems, availability and cost of fuel, and community goals and objectives should be determined. See also "Planning and Zoning" and "Air Quality Modeling," later in this chapter.

The report would recommend air quality objectives based on EPA standards for areas in the region studied based on existing and proposed land uses. This will require consultation and coordination with state and local planning agencies.[43]

Short- and long-term objectives and priorities should be established to achieve the desired air quality. Recommendations to reduce air pollution might include control of pollutant emissions and limits in designated areas and under hazardous weather conditions and predictions; time schedules for starting control actions; control of fuel composition; requirement of plans for new or altered emission sources and approval of construction for compliance with emission standards; denial of certain plan approvals and prohibition of activities, or requirement of certain types of control devices; and performance standards to be met by existing and new structures and facilities.

The report is then formally submitted to the regulatory agency, board, or commission for further action. It would generally include recommendations for needed laws, rules, and regulations and administrative organization and staffing for the control of existing and new sources of air pollution.

AMBIENT AIR QUALITY STANDARDS*

Topographic, meteorological, and land-use characteristics of areas within an air region will vary. The social and economic development of an area will result in different degrees of air pollution and demands for air quality. Because of this, it is practical and reasonable to establish different levels of air purity for certain areas within a region. However, any standards adopted must ensure, at a very minimum, no adverse effects on human health.†

Federal Standards

The federal Air Quality Act of 1967 (Public Law 90-148) was amended in 1970, 1974, 1977, 1990, and 1997 and is now known as the Clean Air Act (CAA). The original act was passed in 1955. Emissions from stationary sources and motor vehicles are regulated under the act. Stationary sources must obtain permits that specify the amount and type of allowable emissions from the air quality regulatory agency. Modifications to an existing facility are subject to the provisions of the Act. The Act requires that the administrator of the EPA develop and issue

*"Ambient air" means that portion of the atmosphere, external to buildings, to which the general public has access.

†In the United States national primary and secondary ambient air quality standards were promulgated effective April 30, 1971. *Primary* ambient air quality standards are those that, in the judgment of the EPA administrator, based on the air quality criteria and allowing an adequate margin of safety, are required to protect the public health. *Secondary* ambient air quality standards are those that, in the judgment of the administrator, based on the air quality criteria, are required to protect the public welfare from any known or anticipated adverse effects associated with the presence of air pollutants in the ambient air (on soil, water, vegetation, materials, animals, weather, visibility, personal comfort, and well-being). In England (Ministry of Housing and Local Government 1966B), the standard states, in part: "No emission discharged in such amount or manner as to constitute a demonstrable health hazard in either the short or long term can be tolerated. Emissions, in terms of both concentration and mass rate of emission, must be reduced to the lowest practicable amount." In the Soviet Union, the goal is protection from any agent in the atmosphere that can be demonstrated to produce physiological effect, even if the effect cannot be shown to be harmful.

to the states criteria of air quality for the protection of public health and welfare and further specifies that such criteria shall reflect the latest scientific knowledge useful in indicating the kind and extent of all identifiable effects on health and welfare that may be expected from the presence of an air contaminant, or combination of contaminants, in varying quantities.

The act requires the administrator to designate interstate or intrastate air quality control regions throughout the country as considered necessary to ensure adequate implementation of air quality standards. These regions are to be designated on the basis of meteorological, social, and political factors, which suggests that a group of communities should be treated as a unit.

The federal Clean Air Act, as amended, requires that the administrator of the EPA promulgate national ambient air quality standards (NAAQSs) for sulfur oxides, particulate matter, carbon monoxide, photochemical oxidants, hydrocarbons, and nitrogen oxides. These standards are included in Table 4.5.

The act requires each state to adopt a plan that provides for the implementation, maintenance, and enforcement of such national ambient air quality standards within each air quality control region (or portion thereof) within the State (Title I, Sec. 110 (a)(1)).

States are expected to attain the national primary ambient air quality standards after approval by the administrator of the state plan. Both primary and secondary federal standards apply nationwide; however, state standards may be more stringent, except for motor vehicle emission standards, which are prescribed by law (California is exempt).

The 1977 amendments to the Clean Air Act allow each state to classify clean air areas as class I, where air quality has to remain virtually unchanged; class II, where moderate industrial growth would be allowed; or class III, where more intensive industrial activity would be permitted.

Class I areas *shall* include international parks, national wilderness areas exceeding 5,000 acres, national memorial parks exceeding 5,000 acres, and national parks exceeding 6,000 acres. This classification and designation was made by Congress.

The EPA has expanded its concerns beyond the conventional air pollutants, because of government agency and public concern and accidental toxic chemical releases, to include the regulation of some 188 chemicals and chemical categories that may be classified as hazardous air pollutants.* Chemicals may fall into an acutely hazardous category depending on their dermal, oral, and inhalation effects, which are based on the dose or concentration that will kill one-half of a group of test animals (LD_{50} or LC_{50}). A dermal dose less than 50 ppm, an oral dose less than 25 ppm, and an inhalation dose less than 0.5 mg/l for up to 8 hrs would qualify the chemical as an acutely hazardous air pollutant.[44] Some hazardous pollutants that deserve attention are listed in Table 4.6.

Air quality issues also arise from federal legislation, especially the Resource Conservation and Recovery Act (RCRA), Comprehensive Environmental

*See the Clean Air Act of 1990.

TABLE 4.5 National Ambient Air Quality Standards (NAAQS) in Effect in 1988

	Primary (Health Related)		Secondary (Welfare Related)	
	Standard Level			
Pollutant	Average Time	Concentration[a]	Averaging Time	Concentration
PM_{10}	Annual arithmetic mean[b]	50 $\mu g/m^3$	Same as primary	
	24 hr[b]	150 $\mu g/m^3$	Same as primary	
$PM_{2.5}$	Annual arithmetic mean	15 $\mu g/m^3$	Same as primary	
	24 hr	65 $\mu g/m^3$	Same as primary	
SO_2	Annual arithmetic mean	0.03 ppm (80 $\mu g/m^3$)	3 hr[c]	1300 $\mu g/m^3$ (0.50 ppm)
	24 hr[c]	0.14 ppm (365 $\mu g/m^3$)		
CO	8 hr[c]	9 ppm (10 mg/m^3)	No secondary standard	
	1 hr[c]	35 ppm (40 mg/m^3)	No secondary standard	
NO_2	Annual arithmetic mean	0.053 ppm (100 $\mu g/m^3$)	Same as primary	
O_3	1 hr	0.12 ppm (235 $\mu g/m^3$)	Same as primary	
	Maximum daily 8-hr average[d]	0.08 ppm (157 $\mu g/m^3$)	Same as primary	
Pb	Maximum quarterly average	1.5 $\mu g/m^3$	Same as primary	

[a] Parenthetical value is an approximately equivalent concentration.
[b] TSP was the indicator pollutant for the original particulate matter (PM) standards. This standard has been replaced with the new PM_{10} standard and it is no longer in effect. New PM standards were promulgated in 1987 using PM_{10} (particles less than 10 μm in diameter) as the new indicator pollutant. The annual standard is attained when the expected annual arithmetic mean concentration is less than or equal to 50 $\mu g/m^3$; the 24-hr standard is attained when the expected number of days per calendar year above 150 $\mu g/m^3$ is equal to or less than 1; as determined in accordance with Appendix K of the PM *NAAQS*.
[c] Not to be exceeded more than once per year.
[d] The standard is attained when the expected number of days per calendar year with maximum hourly average concentrations above 0.12 ppm is equal to or less than 1, as determined in accordance with Appendix H of the Ozone NAAQS.

Source: National Ambient Air Quality Standards (*NAAQS*) *2002*, U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards Technical Support Division, Research Triangle Park, NC, March 2002. Available: www.epa.gov/airs/criteria.html.

TABLE 4.6 Some Hazardous Air Pollutants

Acrylontrile	Ethylene oxide
Arsenic	Formaldehyde
Benzene	Methylene chloride
1,3-Butadiene	Nickel
Cadmium	Perchloroethylene
Carbon tetrachloride	Polycyclic organic matter
Chloroform	Radionuclides
Chromium	Trichloroethylene
Ethylene dichloride	Glycol ethers

Response, Compensation, and Liability Act (CERCLA or Superfund), and the Emergency Planning and Community Right-to-Know Act, also called Superfund Amendments and Reauthorization Act Title III (SARA Title III). Of these, SARA Title III has the most dramatic and far-reaching impact on industry regarding the control of toxic chemicals in air. In addition, the EPA has proposed standards limiting emissions of volatile organic pollutants from process vents and equipment leaks at new and existing hazardous waste transfer, storage, treatment, and disposal facilities. These regulations will impose additional air monitoring and emission control responsibilities on RCRA-permitted facilities. Current air quality aspects of RCRA apply to hazardous waste incinerators and land treatment and disposal facilities as well as to remedial action to clean designated sites.

Clean Air Act of 1990

The Clean Air Act amendments of 1990 have added significantly to potential ambient air quality improvement. Some of the major features follow.

Title I deals with the attainment of ambient air quality standards. The EPA may establish geographical boundaries and grade nonattainment areas that exceed standards for carbon monoxide, ozone, and particulate matter. States must reduce overall emissions, and the EPA can impose sanctions (loss of funds for highways and construction) against states and cities for noncompliance.

Title II deals with mobile sources of air pollution. Stricter tailpipe emission limits are established for oxides of nitrogen, hydrocarbons, and carbon monoxide. Cleaner fuel and vehicles will be required in certain cities having ozone, smog, or carbon monoxide problems.

Title III deals with the reduction and regulation of 188 toxic air emissions from commercial and industrial sources and municipal incinerators. The “maximum achievable control technology” will be required at existing, new, or modified sources.

Title IV deals with the control of acid deposition, commonly referred to as acid rain, primarily from plants burning fossil fuels. Reductions in sulfur dioxide emissions will be required on an EPA-phased-time basis, taking into consideration location of sources and existing emissions. Emissions of nitrogen oxides are to be reduced, and standards are to be issued by the EPA. Continuous monitoring of sulfur dioxide, nitrogen oxides, and opacity will be required. Utilities may save, buy, or sell pollution emission allowances.

Title V deals with the development and requirement of a permit system by the EPA similar to the National Pollutant Discharge Elimination System used under the Clean Water Act. All sources of toxic air pollutants will be required to obtain an operating permit valid for up to five years. The permit will list the compliance requirements; the program will be administered by the states.

Title VI deals with the phasing out of ozone-depleting chemicals, including CFCs. halons, HCFCs, carbon tetrachloride, and methyl chloroform. Under the law, CFCs, halons, and carbon tetrachloride are to be phased out by the year 2000. Methyl chloroform is to be phased out in 2002 and HCFCs by 2030. Recycling of refrigerants from motor vehicle air-conditioning units is required. The Act requires that assistance be provided to developing countries.

Title VII deals with enforcement. Corporations and corporate officials are subject to civil and criminal liabilities. The EPA may issue administrative penalties of up to $200,000 and field citations up to $5,000. Also, private citizens or groups may take action against violators.

Title VIII deals with the study of visibility impairment, regulation of air pollution from outer continental shelf activities, monitoring of carbon dioxide emissions by utilities, and grants for air pollution planning and control programs.

Title IX requires that the EPA conduct a research program that includes sampling, measurement, monitoring, analysis, and modeling of air pollution.

Title X requires that the EPA ensure, to the extent possible, that 10 percent of research funding be made available to disadvantaged business concerns.

Title XI authorizes a training and benefits program for workers who become unemployed because of the Act.

Clean Air Act Amendments of 1997

In 1997, the EPA proposed more restrictive NAAQSs for ozone and particulate matter. A new standard for particulate matter was drafted that regulated particulates less than 2.5 μm in diameter. These fine particulates are implicated in respiratory distress because of their ability to penetrate deep into the lungs. The proposed ozone standard reduced the permissible concentration to an 8-hour average of 0.080 ppm. This is in contrast to the previous 12-hour 0.120-ppm standard. The EPA estimated these standards would affect 125 million people, including 35 million children in the United States. The proposed rules were challenged in court in 1997 and remained in litigation until the Supreme Court of the United States and subsequently the District of Columbia Circuit Court sided with the EPA in 2002. The standards will should have a significant effect on the number of communities that will have to address ground-level ozone issues. Mobile sources of $PM_{2.5}$, such as heavy-duty diesel trucks, may also be significantly affected by these amendments.

Pollutant Standards Index (PSI)

The pollutant standards index is a uniform method recommended* to classify and report urban air quality. Five criteria pollutants are judged for the amount and adverse effects on human health, as shown in Table 4.7. On that basis, the air quality evaluated is designated as presenting "hazardous conditions" if the PSI is greater than 300; "very unhealthful conditions" if the PSI is between 200 and 300; "unhealthful conditions" if the PSI is between 100 and 200; "moderate" if the PSI is 50 to 100; and "good" if the PSI is between 0 and 50. The PSI for one day rises above 100, that is, to the "Alert" level or higher, when any one of the five criteria pollutants reaches a level that may be judged to have adverse effects on human health.

CONTROLS

Air pollution involves a source such as a power-generating plant burning heavy fuel oil; a production byproduct or waste such as particulates, vapors, or gases; release of pollutants into the atmosphere, such as smoke or sulfur dioxide; transmission by airflows; and receptors who are affected, such as people, animals, plants, structures, and clothing. Controls can be applied at one or more points between the source and the receptor, starting preferably at the source. The application of control procedures and devices is more effective when supported by public information, raw-material or production and process revision, and installation of proper air-cleaning equipment. Regulatory persuasion and, if necessary, legal action would follow.

Source Control

Processes that are sources of air pollution include chemical reaction, evaporation, crushing and grinding, drying and baking, and combinations of these operations.

For stationary combustion installations, such as fossil-fuel-fired electric generating stations and plants generating steam for space heating or processes, the amounts and types of pollutants can be kept to a minimum using a fuel with less air pollution potential. Some examples of the types and amounts of contaminants from different types of fuels are given in Table 4.8. As can be seen, sulfur dioxide is a major pollutant in all fuels. Its removal for health and environmental (acid rain) reasons has a high priority.

Processes can also be designed and modified to reduce waste and the pollutants produced at the source. This has been a fundamental step in the reduction of industrial wastewater pollution and can certainly be applied to air pollution control.

*Recommendation of task force consisting of the Council on Environmental Quality, the EPA, Department of Commerce, National Oceanic and Atmospheric Administration, and the National Bureau of Standards.

TABLE 4.7 Comparison of PSI Values with Pollutant Concentrations and Health Effects

Index Value	Air Quality Level	Pollutant Levels: $PM_{2.5}$, 24 hr ($\mu g/m^3$)	SO_2, 24 hr (ppm)	CO, 8 hr (ppm)	O_3, 8 hr (ppm)	NO_2, 1 hr (ppm)	Health Effect Descriptor	General Health Effects	Cautionary Statements
500	Significant harm	500	1.004	50.4	—	2.04	Hazardous	Premature death of ill and elderly. Healthy people will experience adverse symptoms that affect their normal activity.	All persons should remain indoors, keeping windows and doors closed. All persons should minimize physical exertion and avoid traffic.
400	Emergency	350	0.804	40.4	—	1.64	Hazardous	Premature onset of certain diseases in addition to significant aggravation of symptoms and decreased exercise tolerance in healthy persons.	Elderly and persons with existing diseases should stay indoors and avoid physical exertion. General populations should avoid outdoor activity.

300	Warning	250	0.604	30.4	0.374[a]	1.24	Very unhealthful	Significant aggravation of symptoms and decreased exercise tolerance in persons with heart or lung disease, with widespread symptoms in the healthy population.	Elderly and persons with existing heart or lung disease should stay indoors and reduce physical activity.
200	Alert	150.4	0.304	15.4	0.124	0.65	Unhealthful	Mild aggravation of symptoms in susceptible persons, with irritation symptoms in the healthy population.	Persons with existing heart or respiratory ailments should reduce physical exertion and outdoor activity.
100	Moderate	40.4	0.144	9.4	0.084	[b]	Moderate		
50	Good	15.4	0.034[c]	4.4	0.064	[b]			

[a] When 8-hr O_2 concentrations exceed 0.374 ppm, air quality index (AQI) values of 301 or higher must be calculated with 1-hr O_3 concentrations.
[b] NO_2 has no short-term NAAQS and can generate an AQI only above AQI value of 200.
[c] Annual primary National Ambient Air Quality Standards (NAAQS); see Table 4.5.

Source: Guideline for Public Reporting of Daily Air Quality—Pollutant Standards Index (*PSI*), EPA 454/R-99-010, U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards (OAQPS), Research Triangle Park, NC, 1999, Table 7, p. 13.

TABLE 4.8 Uncontrolled Contaminant Emissions (lb/10^6 Btu of Fuel)[a]

Contaminant	Bituminous Coal[b]	Anthracite Coal	Residual Fuel Oil	Distillate Fuel Oil	Natural Gas
Solids	0.39 (A)[c]	0.39 (A)	0.112	0.085	0.018
SO_2	1.52 (S)[d]	1.52 (S)	1.046 (S)	1.120 (S)	0.006
NO_2	0.82	0.70	0.439	0.365	0.200
Organics, volatile organic carbon	0.003	0.003	0.020	0.021	0.020
Organic acids	1.150	0.595	0.714	0.765	0.003
Aldehydes	<0.001	<0.001	0.007	0.014	0.005
NH_3	0.078	0.040	0.047	0.050	0.020
CO	0.023	0.023	0.001	0.014	0.004

[a]Typical fuel values:

Bituminous coal=25.629 m $\times$ 10^6 Btu/ton
Anthracite coal=25.721 m $\times$ 10^6 Btu/ton
Residual fuel oil=149.7 m $\times$ 10^6 Btu/10^6 gal
Distillate fuel oil=138.7 m $\times$ 10^6 Btu/10^6 gal
Natural gas=1029 Btu/ft^3

[b]Utility.
[c]Contaminant emission in pounds=0.0630 $\times$ (A), where (A) is ash content in percent.
[d]Contaminant emission in pounds=1.407 $\times$ (S), where (S) is sulfur content in percent.

Source: From E. W. Davis, Division of Air Resources, New York State Department of Environmental Conservation, Albany, personal communication, 1990. An extensive collection of emission factors is available from the EPA AP-42 at http://www.epa.gov/ttn/chief/ap42/index.html.

The internal combustion engine is a major producer of air pollutants. A change from gasoline to another fuel or a major improvement in the efficiency of the gasoline engine would attack that problem at the source. Inspection of cars and light trucks for compliance with exhaust emissions standards can significantly reduce hydrocarbon and carbon monoxide levels in the ambient air. Heavy-duty gasoline trucks also add a large percentage of carbon monoxide and hydrocarbons; however, their reduction will require phasing out old trucks and catalytic converter installation on new trucks. Reducing the lead content of gasoline and capturing gasoline evaporation during handling from filling stations, petroleum storage tanks, auto tanks, and carburetors are other means of source control. Improved mass transit, use of bus lanes, reduced travel by personal car, better traffic control for faster vehicle travel, and less stop-and-go are other means to reduce emissions.

Significant air pollution control can be achieved by process and material changes, recovery and recycling of waste materials, or product recovery, as by collection of combustion product particles of value.

Proper design of basic equipment, provision of adequate solid waste collection service, elimination of open burning, and the upgrading or elimination of inefficient apartment house, municipal, institutional, and commercial incinerators also attack the problem at the source.

Proper operation and maintenance of production facilities and equipment will often not only reduce air pollution but also save money. For example, air–fuel ratios can determine the amount of unburned fuel going up the stack, combustion temperature can affect the strain placed on equipment when operated beyond rated capacity, and the competency of supervision can determine the quantity and type of pollutants released and the quality of the product.

Emission Control Equipment

Municipal waste incinerators can emit hazardous levels of dioxins and other organic chemicals, metals, and acid gases if not regulated. In view of this, the EPA is requiring strict controls on air emissions from such facilities.[45] In addition to dioxins, the organics include furans, chlorobenzenes, chlorophenols, formaldehyde, polycyclic aromatic hydrocarbons, and polychlorinated biphenyls. The metals are arsenic, beryllium, cadmium, chromium, lead, and mercury. The EPA believes that proper incinerator combustion, acid gas scrubber, and particulate removal can achieve 99 percent or greater reduction of dioxins and furans, 95 percent or greater reduction of organics, 90 percent or greater reduction of hydrogen chloride, and 97 to 99 percent reduction of metals.

Emission control equipment is designed to remove or reduce particulates, aerosols (solids and liquid forms), and gaseous byproducts from various sources and, in some instances, emissions resulting from inefficient design and operation.

Here are four operating principles of aerosol collection equipment:

1. Inertial entrapment by altering the direction and velocity of the effluent
2. Increasing the size of the particles through conglomeration or liquid mist entrainment to subject the particles to inertial and gravitational forces within the operational range of the control device
3. Impingement of particles on impact surfaces, baffles, or filters
4. Precipitation of contaminants in electrical fields or by thermal convection.[46]

The collection of gases and vapors is based on the particular physical and chemical properties of the gases to be controlled.

Particulate Collectors and Separators

Some of the more common collectors and separators are identified in this section. These have application in mechanical operations for dust control such as in pulverizing, grinding, blending, woodworking, and handling flour as well as at power stations, incinerators, cement plants, heavy metallurgical operations, and other dusty operations. In general, collector efficiencies increase with particle size and from a low efficiency with baffled settling chambers, increasing with cyclones, electrostatic precipitators, spray towers, scrubbers, and baghouses, depending also on design, operation, and combinations of collectors used.

Settling chambers cause velocity reduction, usually to slower than 10 fps, and the settling of particles larger than 40 μm in diameter in trays that can be removed for cleaning. Special designs can intercept particles as small as 10 μm.

Cyclones impose a downward spiraling movement on the tangentially directed incoming dust-laden gas, causing separation of particles by centrifugal force and collection at the bottom of the cone. Particle sizes collected range from 5 to 200 μm at gas flows of 30 to 25,000 ft^3/min. Removal efficiency below 10 μm particle size is low. Cyclones can be placed in series or combined with other devices to increase removal efficiency. See Figures 4.4 and 4.5.

Sonic collectors can be used to facilitate separation of liquid or solid particles in settling chambers or cyclones. High-frequency sound pressure waves cause particles to vigorously vibrate, collide, and coalesce. Collectors can be designed to remove particles smaller than 10 μm.

Filters are of two general types: the baghouse and cloth screen. The filter medium governs the temperature of the gas to be filtered, particle size removed, capacity and loading, and durability of the filter. Filter operating temperatures

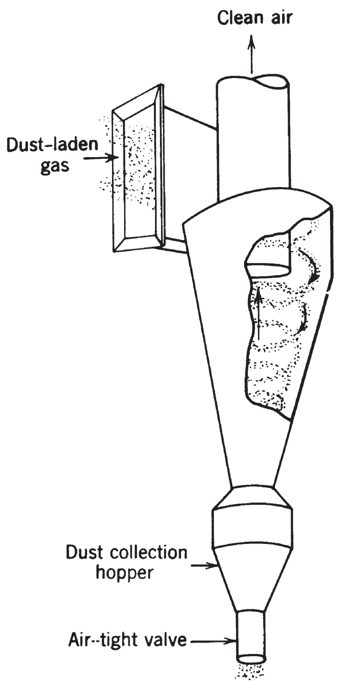

FIGURE 4.4 Flow of dust through cyclone. (*Source:* Adapted from *Air Pollution Control Field Operations Manual*, PHS Pub. No. 937, Department of Health, Education, and Welfare, Washington, DC, 1962.)

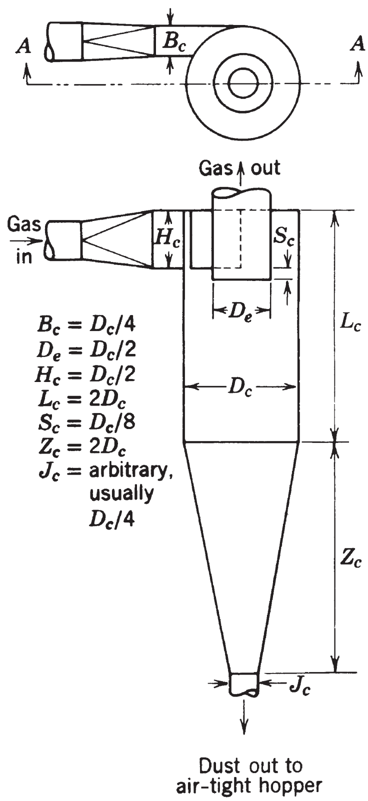

FIGURE 4.5 Diagram of cyclone separator. (*Source: Air Pollution Control Field Operations Manual*, PHS Pub. No. 937, Department of Health, Education, and Welfare, Washington, DC, 1962.)

vary from about 200°F (93°C) for wool or cotton to 450° to 500°F (232°–260°C) for glass fiber.

A *baghouse filter* is shown in Figure 4.6. The tubular bags are 5 to 18 inches in diameter and from 2 to 30 feet in length. The dust-laden gas stream to be filtered passes through the bags where the particles build up on the inside and, in so doing, increase the filtering efficiency. Periodic shaking of the bags (tubes) causes the collected dust to fall off and restore the filtering capacity. The baghouse filter has particular application in cement plants, heavy metallurgical operations, and other dusty operations. Efficiencies exceeding 99 percent and particle removal below 10 μm in size are reported, depending on the major form and buildup. Baghouses are usually supplemented by scrubber systems.

Cloth-screen filters are used in the smaller grinding, tumbling, and abrasive cleaning operations. Dust-laden air passes through one or more cloth screens in series. The screens are replaced as needed. Other types of filters use packed fibers, filter beds, granules, and oil baths.

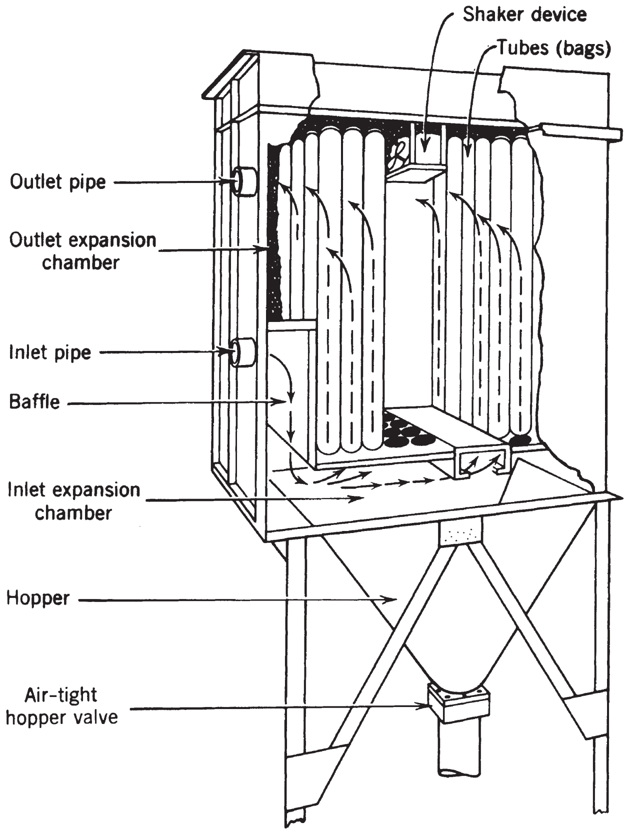

FIGURE 4.6 Simplified diagram of a baghouse. (*Source: Air Pollution Control Field Operations Manual*, PHS Pub. 937, Department of Health, Education, and Welfare, Washington, DC, 1962.)

Electrostatic precipitators have application in power plants, cement plants, and incinerators as well as in metallurgical, refining, and heavy chemical industries for the collection of fumes, dusts, and acid mists. Particles, in passing through a high-voltage electrical field, are charged and then attracted to a plate of the opposite charge where they collect. The accumulated material falls into a hopper when vibrated. See Figure 4.7.

The gases treated may be cold or at a temperature as high as 1,100°F (593°C), but 600°F (316°C) or less is more common, typically 280° to 300°F (138°–149°C). Precipitators are efficient for the collection of particles less than 0.5 μm in size; hence, cyclones and settling chambers, which are better for the removal of larger particles, are sometimes used ahead of precipitators. Single-stage units operate at voltages of 25,000 V or higher; two-stage units (used in air conditioning) operate at 12,000 V in the first or ionizing unit and at 6,000 V in the second collection unit.

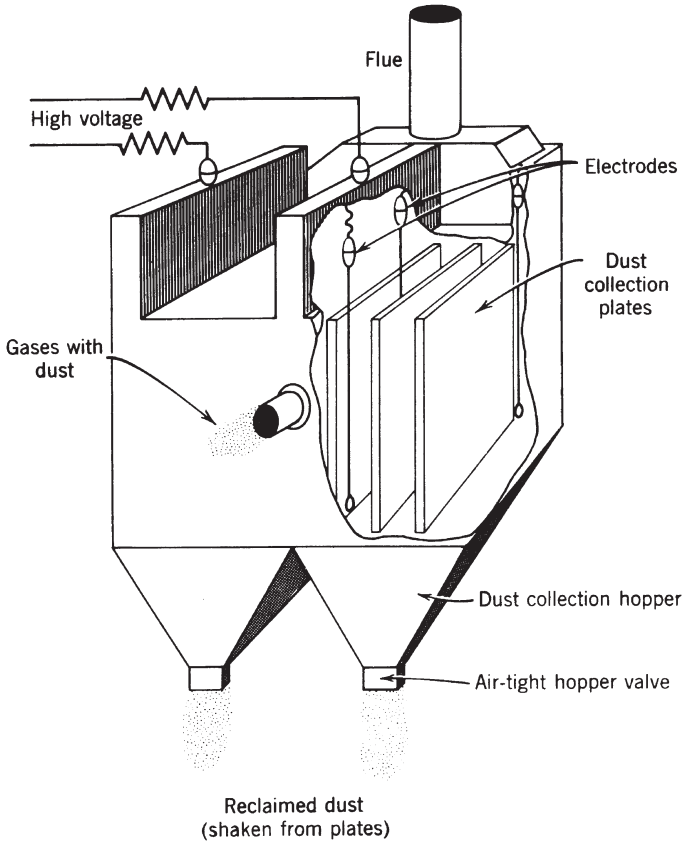

FIGURE 4.7 Diagram of plate-type electrostatic precipitator used to collect catalyst dust. (*Source:* Adapted from *Air Pollution Control Field Operations Manual*, PHS Pub. 937, Department of Health, Education and Welfare, Washington, DC, 1962.)

Electrostatic precipitators are commonly used at large power stations and incinerators to remove particulates from flue gases. Particulate removal of at least 98 to 99 percent can be achieved. They are considered one of the most effective devices for this purpose. Flue gases may be cooled by water spray, air cooling, or passage through a boiler.

Scrubbers are of different types, selected for specific applications. They include spray towers, ejector venturis, venturi scrubbers, and packed-bed, plate, moving-bed, centrifugal, impingement, and entrainment types. See Figures 4.8 and 4.9.

Wet collectors are generally used to remove gases such as hydrogen chloride, nitrous oxides, and sulfur dioxide and particles that form as a dust, fog, or mist. A high-pressure liquid spray is applied to the gas passing through the washer, filter, venturi, or other device. In so doing, the gas is cooled and cleaned. Although

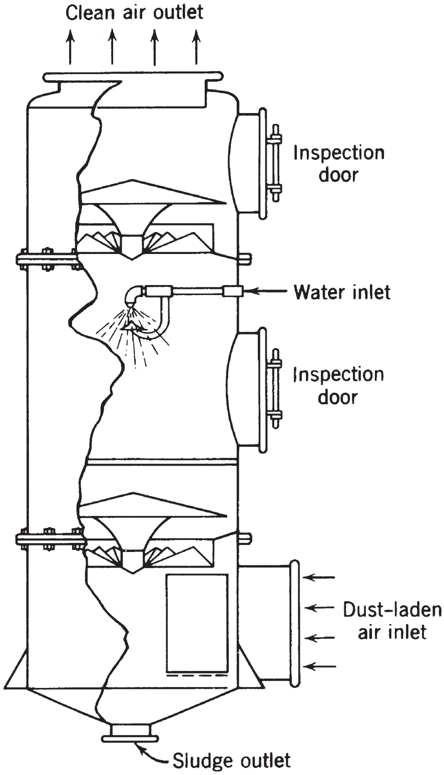

FIGURE 4.8 Centrifugal wash collector. (*Source: Air Pollution Control Field Operations Manual*, Department of Health, Education, and Welfare, Washington, DC, 1962.)

water is usually used as the spray, a caustic may be added if the gas stream is acidic. Where the spray water is recirculated, corrosion of the scrubber, fan, and pump impeller can be a serious problem. Particle size collected may range from 40 μm to as low as 1 μm with efficiency as high as 98 to 99 percent, depending on the collector design. Required removal efficiencies for hydrogen chloride, sulfur dioxide, and hydrogen fluoride can usually be met.

Controls for sulfur dioxide emissions include wet and dry flue gas desulfurization and fuel switching and physically cleaning coal. Nitrogen oxide emissions can be controlled by special burners or by catalytic or selective noncatalytic reduction. A *duct injection* technology (dry scrubber) is being emphasized by the Department of Energy (DOE) to reduce sulfur dioxide emissions from existing coal-fired power plants: "Lime is sprayed into existing ductwork located just after the combustion chamber. Fly ash in the exhaust stream reacts with the small pieces of lime, then with sulfur oxides and is finally captured by a filter fabric."[47]

For every ton of sulfur removed, 3 to 6 tons of sludge from wet scrubbers will require safe disposal.

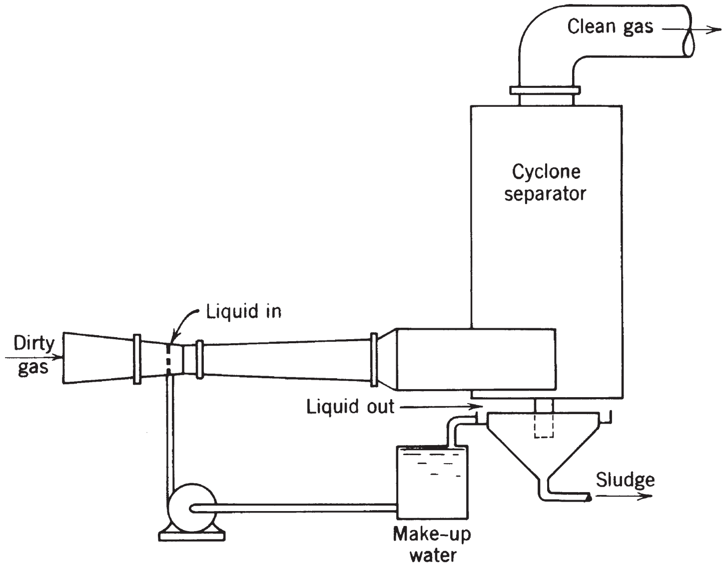

FIGURE 4.9 Venturi scrubber. (*Source: Air Pollution Control Field Operations Manual*, PHS Pub. 937, Department of Health, Education, and Welfare, Washington, DC, 1962.)

Gaseous Collectors and Treatment Devices

The release of gases and vapors to the atmosphere can be controlled by combustion, condensation, absorption, and adsorption. Combustion devices include thermal afterburners, catalytic afterburners, furnaces, and flares.

Thermal afterburners are used to complete the combustion of unburned fuel, such as smoke and particulate matter, and to burn gaseous hydrocarbons and odorous combustible gases. Apartment house and commercial incinerators and meat-packing plant smokehouses are examples of smoke and particulate emitters. Rendering, packing house, refinery, and paint and varnish operations; fish processing; and coffee roasting are examples of odor-producing operations. Afterburners usually operate at around 1200°F (649°C) but may range from 900° to 1600°F (482°–871°C), depending on the ignition temperature of the contaminant to be burned.

Catalytic afterburners may be used for the burning of lean mixtures of combustible gaseous air contaminants. They are also used to reduce nitrous oxides, with ammonia injection.

Condensers are best used to remove vapors by condensation, generally prior to passage to other air pollution control equipment, thus reducing the load on this equipment. Condensers are of the surface and contact types. In the surface condenser, the vapor comes into contact with a horizontal cool surface and condenses to form liquid droplets with a pure saturated vapor or, more commonly, a film. In the contact condenser, the coolant, vapors, and condensate are all in intimate direct contact.

Adsorbers are of the fixed-bed stationary or rotating type, in horizontal or vertical cylinders, usually with activated-carbon beds or supported screens, through which the gas stream passes. In adsorption, the molecules of a fluid such as a gas, liquid, or dissolved substance to be treated are brought into contact with the adsorbent, such as activated carbon, aluminas, silicates, char, or gels that collect the contaminant in the pores or capillaries. The material adsorbed is called the adsorbate. In some cases, the adsorbent, such as activated carbon, is regenerated by superheated steam at about 650°F (343°C); the contaminant is condensed and collected for proper disposal. In other cases, the adsorbent and adsorbate are separated from the fluid and discarded. Solid adsorbents have very large surface-to-volume ratios and different adsorptive abilities, depending on the particular adsorbate. The life of an activated-carbon adsorption bed is reduced if particulate matter is not first removed.

In *absorption*, the gaseous emission to be treated is passed through a packed tower, spray or plate tower, and venturi absorbers, where it comes in contact with a liquid absorbing medium or spray that selectively dissolves or reacts with the air contaminants to be removed. For example, oxides of nitrogen can be absorbed by water; hydrogen fluoride, by water or an alkaline water solution. Absorption is generally also used to control emissions of sulfur dioxide, hydrogen sulfide, hydrogen chloride, chlorine, and some hydrocarbons. Lime injection controls acid gas emissions from incinerators.

Vapor conservation equipment is used to prevent vapors escaping from the storage of volatile organic compounds such as gasoline. A storage tank with a sealed floating roof cover or a vapor recovery system connected to a storage tank is used. Vapors that can be condensed are returned to the storage tank.

Dilution by Stack Height

Since wind speed increases with height in the lower layer of the atmosphere, the release of pollutants through a tall stack enhances the transport and diffusion of the material. The elevated plume is rapidly transported and diffused downwind. This generally occurs at a rate faster than that of the diffusion toward the ground. The resulting downwind distribution of pollutant concentrations at the ground level is such that concentrations are virtually zero at the base of the stack, increase to a maximum at some downwind distance, and then decrease to negligible concentrations thereafter. This distribution and the difference due to stack height are shown schematically in Figure 4.10. This applies to uncomplicated weather and level terrain. Obviously, if the plume is transported to hill areas, the surfaces will be closer to the center of the plume and hence will experience higher concentrations.

Meteorological conditions will determine the type of diffusion the pollutant plume will follow. See Figure 4.3. With heavy atmospheric turbulence associated with an unstable lapse rate, the plume will "loop" as it travels downwind. With

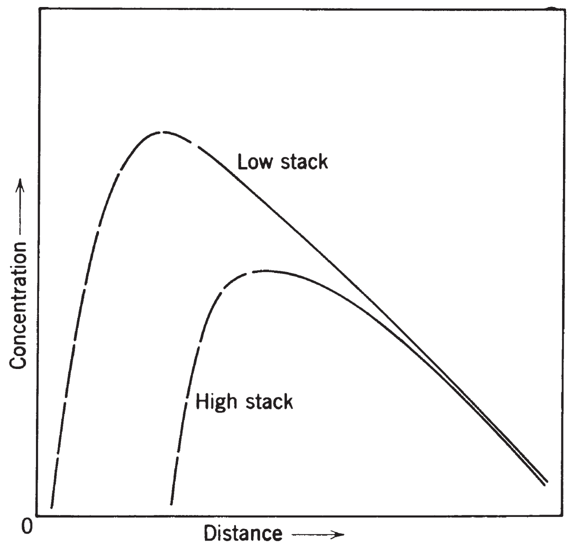

FIGURE 4.10 Variation of ground-level pollutant concentration with downwind distance. (The distance may be hundreds of miles.)

lesser turbulence associated with a neutral lapse rate, the plume will form a series of extended, overlapping cones called *coning*. With stable air conditions and little turbulence associated with an inversion, the plume will "fan" out gradually. With the discharge of a plume below an inversion, the plume will be dispersed rapidly downward to the ground surface, causing *fumigation*. With the discharge of a plume within the inversion layer, the plume will spread out horizontally as it moves downwind with little dispersion toward the ground. Erratic weather conditions can cause high concentrations of pollutants at ground level if the plume is transported to the ground.

It has been general practice to use high stacks for the emission of large quantities of pollutants, such as in fossil-fueled power production, to reduce the relatively close-in ground-level effects of the pollutants. Stacks of 250 to 350 feet in height are not unusual, and some are as high as 800 to 1,250 feet. It should be recognized, however, that there is a practical limit to height beyond which cost becomes excessive and the additional dilution obtained is not significant. There may also be legal permitting restrictions on the maximum stack height.

Although local conditions are improved where a tall stack is used, adverse environmental effects continue to be associated with the distant (long-range) transport of pollutants. For example, the pollutants contribute to acid rain, heavy-metal particle deposition, and toxic metal dissolution from surrounding or downwind soils and rocks into surface and groundwaters, which adversely affect the flora and fauna hundreds or more miles away (as previously noted). Therefore, emphasis should be placed on reduction of emission concentrations, rather than on dispersion from a tall stack, to improve ambient air quality. The EPA is also considering requiring pollution control devices on tall stacks and limiting tall stacks for emission dispersion by requiring removal instead.

Planning and Zoning

The implementation of planning and zoning controls requires professional analysis and the cooperation of the state and regional planning agencies and the local county, city, village, and town units of government.

The local economic, social, and political factors may limit what can realistically be achieved in many instances. For example, a combination of factors, including planning and zoning means, should be considered in locating a new plant. These means could include plant siting downwind from residential, work, and recreational areas, with consideration given to climate and meteorological factors, frequency of inversions, topography, air movement, stack height, and adjacent land uses. Additional factors are distance separation, open-space buffers, designation of industrial areas, traffic and transportation control, and possible regulation of plant raw materials and processes. All these controls must recognize the present and future land use and especially the air quality needed for health and comfort, regardless of the land ownership.

The maintenance of air quality that meets established criteria requires regulation of the location, density, and/or type of plants and plant emissions that could cause contravention of air quality standards. This calls for local and regional land-use control and cooperation to ensure that the permitted construction of plants would incorporate practices and control equipment that would not emit pollution that could adversely influence the air quality of the community in the airshed. See Tables 4.6 and 4.7 and "Ambient Air Quality Standards," later in this chapter.

Monitoring of the air at carefully selected locations would continually inform and alert the regulatory agency of the need for additional source control and enforcement of emission standards. Conceivably, under certain unusually adverse weather conditions, a plant may have to take previously planned emergency actions to reduce or practically eliminate emissions for a period of time.

Air zoning establishes different air quality standards for different areas based on the most desirable and feasible use of land. As discussed earlier in this chapter, the 1977 amendments to the Clean Air Act allow each state to classify air areas as either class I, II, or III. Class I areas would remain virtually unchanged and class III could permit intensive industrial activity. Specific standards are established for each classification level. In all levels, however, protection of the public health is paramount. Insofar as air zoning is concerned, an industry should be able to choose its location and types of emission controls provided the air quality standards are not violated.

Although air zoning provides a system or basis for land use and development, sound planning can assist in greatly minimizing the effects of air pollution. A WHO Expert Committee suggests seven steps:[48]

1. The siting of new towns should be undertaken only after a thorough study of local topography and meteorology.
2. New industries using materials or processes likely to produce air contaminants should be so located as to minimize the effects of air pollution.
3. Satellite (dormitory) towns should restrict the use of pollution-producing fuels.
4. Provision should be made for greenbelts and open spaces to facilitate the dilution and dispersion of unavoidable pollution.
5. Greater use should be made of hydroelectric and atomic power and of natural gas for industrial processes and domestic purposes, thereby reducing the pollution resulting from the use of conventional fossil fuels.
6. Greater use should be made of central plants for the provision of both heat and hot water for entire (commercial or industrial) districts.
7. As motor transport is a major source of pollution, traffic planning can materially affect the level of pollution in residential areas.

It is apparent that more needs to be learned and applied concerning open spaces, bodies of water, and trees and other vegetation to assist in air pollution control. For example, parks and greenbelts appear to be desirable locations for expressways because vegetation, in the presence of light, will utilize the carbon dioxide given off by automobiles and release oxygen. In addition, highway designers must give consideration to such factors as road grades, speeds and elevations, natural and artificial barriers, interchange locations, and adjacent land uses as means of reducing the amounts and effects of automobile noise and emissions.

Air Quality Modeling

It is possible to calculate and predict, *within limits*, the approximate effects of existing and proposed air pollution sources on the ambient air quality.[49] A wide variety of models are used to estimate the air quality impacts of sources on receptors, to prepare or review new industrial and other source applications, and to develop air quality management plans for an area or region.

Air quality models can be categorized into four classes:

1. *Gaussian:* Most often used for estimating the ground-level impact of nonreactive pollutants from stationary sources in a smooth terrain.
2. *Numerical:* Most often used for estimating the impact of reactive and nonreactive pollutants in complex terrain.
3. *Statistical:* Employed in situations where physical or chemical processes are not well understood.
4. *Physical:* Involves experimental investigation of source impact in a wind tunnel facility.

Because of the almost limitless variety of situations for which modeling may be employed, no single model can be considered "best." Instead, the user is encouraged to examine the strengths and weaknesses of the various models available and select the one best suited to the particular job at hand.

The EPA has made a number of models available to the general public through its User's Network for Applied Modeling of Air Pollution (UNAMAP). These models can be obtained from the National Technical Information Service (NTIS).

The information needed to use an air quality model includes source emission data, meteorological data, and pollutant concentration data.

Source Emission Data Sources of pollutants can generally be classified as point, line, or area sources. Point sources are individual stacks and are identified by location, type and rate of emission, and stack parameters (stack height, diameter, exit gas velocity, and temperature). Line sources are generally confined to roadways and can be located by the ends of roadway segments. Area sources include all the minor point and line sources that are too small to require individual consideration. These sources are usually treated as a grid network of square areas, with pollutant emissions totaled and distributed uniformly within each grid square.

Meteorological Data The data needed to represent the meteorological characteristics of a given area consist of (as a minimum) wind direction, wind speed, atmospheric stability, and mixing height. The representativeness of the data for a given location will depend on the proximity of the meteorological monitoring site to the area being studied, the period of time during which data are collected, and the complexity of terrain in the area. Local universities, industries, airports, and government agencies can all be used as sources of such data.

Pollutant Concentration Data In order to assess the accuracy of a model for a particular application, predicted concentrations must be compared against observed values. This can be done by obtaining historical pollutant concentration data from air quality monitors located in the study area. Air quality data from monitors located in remote areas should also be obtained to determine if a background concentration should be included in the model. Data should be verified using appropriate statistical procedures.

The accuracy of the model used depends on the following factors:

1. How closely do the assumptions upon which the model is based correspond to the actual conditions for which the model is being used? For example, a model that assumes that the area being modeled is a flat plain of infinite extent may work well in Kansas but not in Wyoming.
2. How accurate is the information being used as input for the model? Of particular importance here is verifying the accuracy of source emission data. Some points to consider are as follows:

a. Should the source emission data be given in terms of potential, actual, or allowable emissions? "Actual" emissions should always be used for model verification.
b. Does emission rate vary by time of day or time of year?
c. What level of production, percent availability, and so on should be assumed for each emission source? The emission rates for industrial sources will often decline significantly during periods of economic recession. Similarly, stationary fuel combustion sources (for space heating) will vary according to the severity of the winter.
d. Are stack parameters correct? Are there nearby structures or terrain features that could influence the dispersion patterns of individual sources?
e. Is the source location correctly identified?
f. How reliable is the pollution control equipment installed on each emission source?

The user will often find that the job of verifying the input data are the most difficult and time-consuming part of the modeling process.

As the cost of computer services continues to decline, it is expected that air quality modeling will become an available technology for smaller agencies such as local health and planning departments. The person who performs this modeling will have to be knowledgeable not only in traditional air pollution control engineering but also in the fields of air pollution meteorology and computer programming.

PROGRAM AND ENFORCEMENT

General

A program for air resources management should be based on a comprehensive areawide air pollution survey including air sampling, basic studies and analyses, and recommendations for ambient air quality standards. The study should be followed by an immediate and long-term plan to achieve the community air quality goals and objectives, coupled with a surveillance and monitoring system and regulation of emissions.

MacKenzie proposes six conclusions and decisions for the implementation of a study:[43]

1. Select air quality standard, possibly with variations in various parts of the area.
2. Cooperate with other community planners in allocating land uses.
3. Design remedial measures calculated to bring about the air quality desired. Such measures might include several or all of the following: limitations on pollutant emissions, variable emission limits for certain weather conditions and predictions, special emission limits for certain areas, time schedules for

commencing certain control actions, control of fuel composition, control of future sources by requiring plan approvals, prohibition of certain plan approvals, prohibition of certain activities or requirements for certain types of control equipment, and performance standards for new land uses.

4. Outline needs for future studies pertaining to air quality and pollutant emissions and design systems for collection, storage, and retrieval of the resultant data.
5. Establish priorities among program elements and set dates for implementation.
6. Prepare specific recommendations as to administrative organization needed to implement the program, desirable legislative changes, relationships with other agencies and programs in the area and adjoining areas and at higher governmental levels, and funds, facilities, and staff required.

As in most studies, a continual program of education and public information supplemented by periodic updating is necessary. People must learn that air pollution can be a serious hazard and must be motivated to support the need for its control. In addition, surveys and studies must be kept current; otherwise, the air resources management activities may be based on false or outdated premises.

International treaties, interstate compacts or agreements, and regional organizations are sometimes also needed to resolve air pollution problems that cross jurisdictional boundaries. This becomes more important as industrialization increases and as people become more concerned about the quality of their environment.

It becomes apparent that the various levels of government each have important complementary and cooperative roles to play in air pollution control.

The federal government role includes research into the causes and effects of air pollution, as well as the control of international and interstate air pollution on behalf of the affected parties. It should also have responsibility for a national air-sampling network, training, preparation of manuals and dissemination of information, and assisting state and local governments. In the United States, this is done primarily through the EPA. Other federal agencies making major contributions are the U.S. Weather Service; the Nuclear Regulatory Commission, in relation to the effects of radioactivity; the Department of Agriculture, in relation to the effects of air pollution on livestock and crops; the Department of Interior; the Department of Commerce, including the National Bureau of Standards; and the Civil Aeronautics Administration.

The state role is similar to the federal role. It would include, in addition, the setting of statewide standards and establishment of a sampling network, the authority to declare emergencies and possession of appropriate powers during emergencies, the delegation of powers to local agencies for control programs, and the conducting of surveys, demonstration projects, public hearings, and special investigations.

The role of local government is that delegated to it by the state and could include complete program implementation and enforcement.

Organization and Staffing

Organization and staffing will vary with the level of government, the legislated responsibility, funds provided, government commitment, extent of air pollution, and other factors. Generally, air pollution programs are organized and staffed on the state, county, large-city, and federal levels. In some instances, limited programs of smoke and nuisance abatement are carried out in small cities, towns, and villages as part of a health, building, or fire department program. Because of the complexities involved, competent direction, staff, and laboratory support are needed to carry out an effective and comprehensive program. A small community usually cannot afford—and, in fact, might not have need for—a full staff, but it could play a needed supporting role to the county and state programs. In this way, uniform policy guidance and technical support could be provided and local on-the-spot assistance utilized. The local government should be assigned all the responsibilities it is capable of handling effectively.

An organization chart for an air resources management agency is shown in Figure 4.11. There are many variations.

Regulation and Administration

A combination of methods and techniques is generally used to prevent and control air pollution after a program is developed, air-quality objectives established, and problem areas defined:

- Public information and education
- Source registration
- Plan review and construction operation approval
- Emission standards
- Monitoring and surveillance
- Technical assistance and training
- Inspection and compliance follow-up
- Conference, persuasion, and administrative hearing
- Rescinding or suspension of operation permit
- Legal action—fine, imprisonment, misdemeanor, injunction

Effective administration requires the development and retention of competent staff and the assignment of responsibilities. In a small community, the responsibilities would probably be limited to source location and surveillance, data collection, smoke and other visible particulate detection, complaint investigation, and abatement as an arm of a county, regional, or state enforcement unit.

Regulatory agencies usually develop their own procedures, forms, and techniques to carry out the functions just listed. Staffing, in addition to the director of air pollution control, may include one or more of the following: engineers, scientists, sanitarians, chemists, toxicologists, epidemiologists, public information

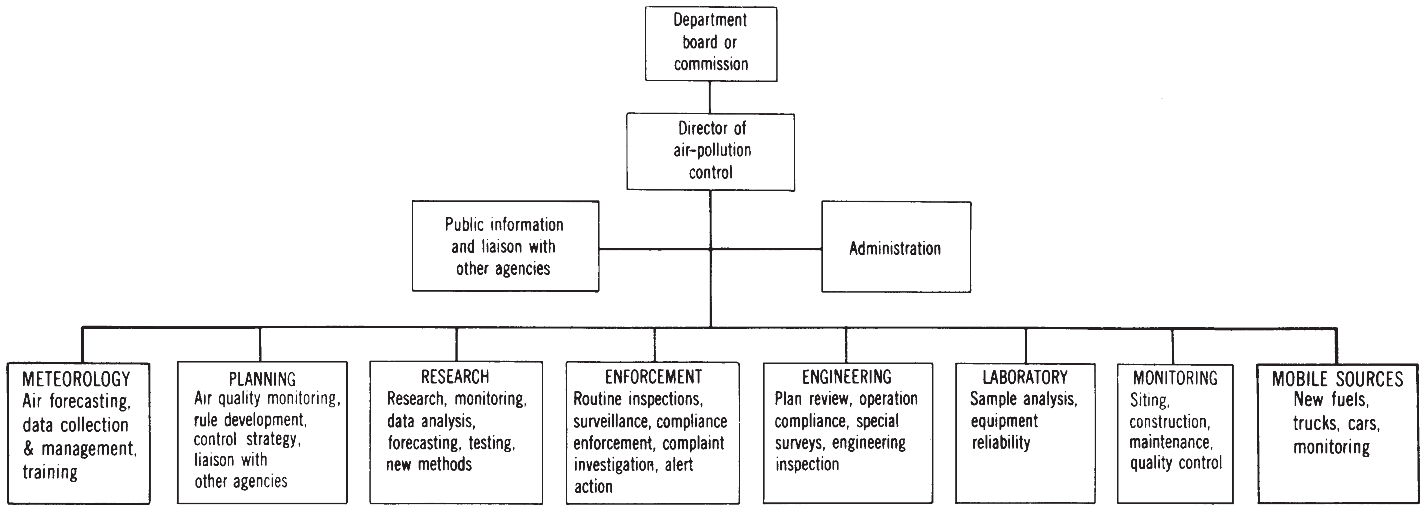

FIGURE 4.11 Air resources management functional organization chart.

specialists, technicians, inspectors, attorneys, administrative assistants, statisticians, meteorologists, electronic data processing specialists, and personnel in supporting services.

Important in regulation is the development of working relationships and memoranda of agreements with various public and private agencies. For instance, government construction, equipment, and vehicles could set examples of air pollution prevention. The building department would ensure that new incinerators and heating plants have the proper air pollution control equipment. The police would enforce vehicular air pollution control requirements. The fire department would carry out fire prevention and perhaps boiler inspections. The planning and zoning boards would rely on the director of air pollution control and the director's staff for technical support, guidance, and testimony at hearings. Equipment manufacturers would agree to sell only machinery, equipment, and devices that complied with the emission standards. The education department would incorporate air pollution prevention and control in its environmental health curriculum. Industry, realty, and chain-store management would agree to abide by the rules and police itself. Cooperative training and education programs would be provided for personnel responsible for operating boilers, equipment, and other facilities that may contribute to air pollution. These are but a few examples. With ingenuity, many more voluntary arrangements can be devised to make regulation more acceptable and effective.

NOISE CONTROL

One of the most important tasks of architects, builders, acoustic engineers, urban planners, industrial hygiene engineers, equipment manufacturers, and public health personnel is to ensure that noise and vibration are kept to an acceptable level in the general environment, in the workplace, and inside dwellings. Noise is of special concern in occupational health where hearing loss has been documented.

The discussion that follows will touch on some of the fundamentals of noise and its effects, measurement, reduction, and control. Special problems should involve experts such as acoustical consultants.

Definitions and Explanation of Selected Terms and Properties of Sound

Sound Sound and, therefore, all noise, is physically a rapid alteration of air pressure above and below atmospheric pressure. Basically, all sounds travel as sound pressure waves from a vibrating body such as a human larynx, radio, TV, record player speaker, or vibrating machine.

A sound that contains only one frequency is a *pure tone*, which is expressed in Figure 4.12 as a sine curve. Most sounds contain many frequencies. In general, the waves travel outward from the source in three dimensions. The *pitch* of a sound is determined primarily by frequency: vibrations per second. The amplitude or magnitude of sound is the *sound pressure*.

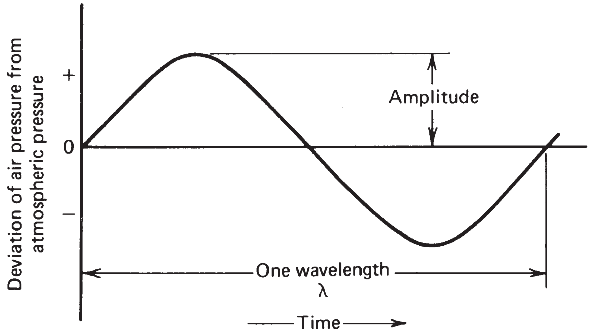

FIGURE 4.12 Pure tone, sine wave.

The distance that a sound wave travels in one cycle or period is the wavelength of the sound. This is illustrated in Figure 4.12. Wavelength is given by the equation

$$\lambda = \frac{c}{f}$$

where

λ = wavelength, ft
f = frequency, Hz (cycles/sec)
c = speed of sound, ft/sec

Sound travels through gases, liquids, and solids but not through a vacuum. The speed with which sound travels through a particular medium is dependent on the compressibility and density of the medium. Our own voice reaches us primarily through the bony structures in our head. Most sound reaches us through the air and less frequently through solids and liquids. The speed of sound through various media is given in Table 4.9.

As sound travels through a medium, it loses energy or amplitude in two ways: molecular heating and geometric spreading. For example, drapes absorb sound, releasing the energy as heat to the surrounding air. Air itself also absorbs sound to a smaller degree because it is not perfectly elastic. Plane waves emitted from a large distant source travel in a plane or front perpendicular to their direction of travel. There is no geometric spreading or energy loss in plane waves, neglecting molecular heating. Spherical waves, resulting from a small vibrating sphere in close proximity, spread in three dimensions. They lose energy according to the inverse square law, given by

$$I_{\text{ave}} = \frac{W}{4\pi r^2}$$

where

I = sound intensity, watts/cm^2
r = distance to the source, cm
W = total source power, watts

TABLE 4.9 Speed of Sound in Various Media

Media	Speed	
	m/s	fps
Air, 69.8°F (21°C)	344	1,129
1,213°C)	331	1,086
Alcohol	1,213	3,980
Lead	1,220	4,003
Hydrogen, 32°F (0°C)	1,269	4,164
Water, fresh	1,480	4,856
Water, salt, 69.8°F (21°C), at 3.5% salinity	1,520	4,987
Human body	1,558	5,112
Plexiglas	1,800	5,906
Wood, soft	3,350	10,991
Concrete	3,400	11,155
Fir timber	3,800	12,468
Mild steel	5,050	16,570
Aluminum	5,150	16,897
Glass	5,200	17,061
Gypsum board	6,800	22,310
Copper	3,901	12,800
Brick	4,176	13,700

Source: A. J. Schneider, *Noise and Vibration Rocket Handbook*, Bruel & Kjaer, Cleveland. OH. p. 18; *IAC Noise Control Handbook*, Industrial Acoustics Co., New York, 1982, p. A-6.

For every doubling of distance, the intensity is reduced by a factor of four, or 6 dB. The sound from an infinite line source spreads geometrically in two dimensions so that energy is halved, or loses 3 dB, when the source distance doubles. When reflecting objects are near, a more complex sound field results.

Noise Noise is unwanted sound. It may be unwanted for a variety of reasons: causing hearing loss, interfering with communication, causing loss of sleep, adversely effecting human physiology, or causing just plain annoyance.

Noise Pollution Noise pollution is the condition in which noise has characteristics and duration injurious to public health and welfare or unreasonably interferes with the comfortable enjoyment of life and property in such areas as are affected by the noise.

Ambient Noise Ambient noise is the total noise in a given situation or environment.

Noise Level Noise level is the weighted sound pressure level in dBA* obtained by the use of an approved type [American National Standards Institute (ANSI)]

*The A-weighted scale approximates the frequency response of the human ear.

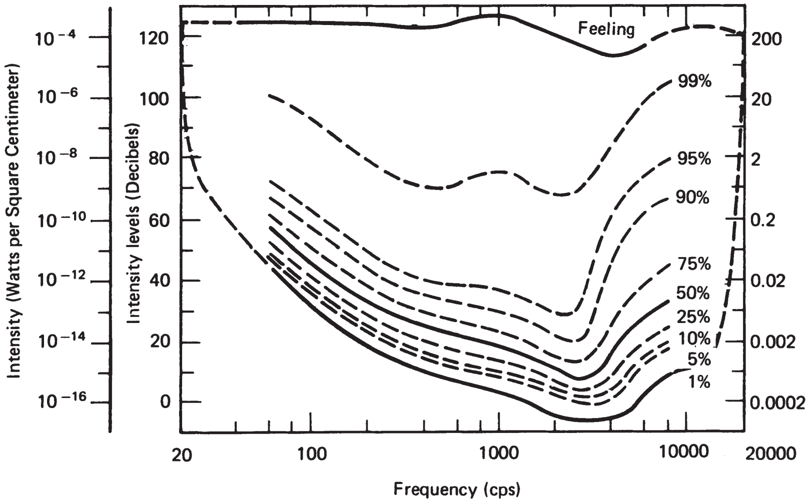

FIGURE 4.13 Absolute auditory threshold for a typical group of Americans. Curves are labeled by percent of group that could hear tones below the indicated level. (*Source: Toward a Quieter City*, A report of the Mayor's Task Force on Noise Control, New York, 1970.)

sound-level meter. See "Decibel" and "Sound Pressure," as well as "Sound-Level Meter," later in this chapter.

Frequency Frequency of sound is the number of times a complete cycle of pressure variation occurs in 1 second, both an elevation and a depression below atmospheric pressure. The frequency of a sound determines its *pitch*. Frequency is expressed in hertz (Hz), which is the metric unit for cycles per second (cps). For example, sounds with a frequency of 30 Hz are considered very low pitch; sounds with a frequency of 15,000 Hz are very high pitch. A young, healthy ear can detect frequencies over a range of about 20 to 20,000 Hz, but the most common sensitive hearing range is between 1,000 and 6,000 Hz. Normal speech is in the range of 250 to 3,000 Hz. However, the audibility of sound is dependent on both frequency and sound pressure level. This is illustrated in Figure 4.13 for a typical group of Americans. Since most sounds are made up of several frequencies, a narrow-band analyzer is used to determine the various frequencies in a sound. Most sounds are in the sonic frequency range of 20 to 20,000 Hz. Ultrasonic range is 20,000 Hz and above; infrasonic range is 20 Hz and below. See "Sound Analyzer" and "Octave-Band Analyzer" later in this chapter.

Decibel Decibel (dB) is a dimensionless unit to express physical intensity or sound pressure levels. The starting or reference point for noise-level measurement is 0 dBA, the threshold of hearing for a young person with very good hearing. The threshold of pain is 120 dBA. The decibel is one-tenth of the bel, a unit using common logarithms named for Alexander Graham Bell.

Sound Pressure The sound pressure level of a noise source is expressed by this relationship:

$$\text{Sound pressure level (SPL) in dB} = 20 \log_{10} \frac{P}{P_0}$$

where

P = pressure of measured sound, micropascals (μPa)
P_0 = sound pressure reference level of 20 μPa*; for measurements in air, this is the threshold of human hearing at 1,000 Hz

A change in sound pressure level with distance from a source can be determined by

$$P_2 = P_1 - 20 \log \frac{d_2}{d_1}$$

where

P_1 = sound pressure level at location 1, dB
P_2 = sound pressure level at location 2, dB
d_1 = distance from noise source to location 1
d_2 = distance from noise source to location 2

The sound pressure level is measured by a standard sound-level meter. The meter has built-in electrical characteristics or weighting that simulates the way the ear actually hear sound.

Pascal (Pa) is a unit of pressure corresponding to a force of 1 N acting uniformly upon an area of 1 m^2; 1 Pa = 1 N/m^2.

Newton (N) is the force required to accelerate 1 kg mass at 1 m/s^2. It is approximately equal to the gravitational force on a 100 g mass. The *A*-weighting, which simulates the frequency bias of the human ear, is most commonly used in measurements regarding impact on humans and the sound levels are read in dBA. The B, C, and D scales are normally used only for special occasions. For example, the D scale is used to measure and compare the effect of airplane noise on the human ear. The C scale is used for very loud sounds and the B scale for moderately loud sounds. See "Sound-Level Meter" for further discussion.

Table 4.10 shows the calculated sound pressure levels in decibels for selected sound pressure values.

To add sound-level values, it is first necessary to convert each decibel reading to sound intensity using these formulas:

$$\text{Sound intensity level in dB} = 10 \log_{10} \frac{I}{I_0}$$

$$= 10 \log_{10} \frac{I_1 + I_2}{I_0}$$

*Equals 10^{-12} W for sound power and 10^{-12} W/m^2 for intensity, also 0.0002 dyn/cm^2, or 0.0002 μbar, or 0.00002 N/m^2 or 20 $\mu N/m^2$.

TABLE 4.10 Sound Pressures for Selected Decibel Values

Sound Pressure[a]		Sound Pressure Level (dB)[b]
μbar	μPa	
0.0002	20	0[c]
0.00063	63	10
0.002	200	20
0.0063	630	30
0.02	2,000	40
0.063	6,300	50
0.2	20,000	60
0.63	63,000	70
1.0	100,000	74
2.0	200,000	80
6.3	630,000	90
20	2,000,000	100
63	6,300,000	110
200	20,000,000	120
2,000	200,000,000	140

[a] 0.0002 microbars (μbar) for sound pressure in air = 20 μPa = 0.00002 N/m^2 (20 μN/m^2) = 2.9×10^{-9} psi = 0.0002 dyn/cm^2.
[b] Relative to 20 μPa or 0.0002 μbar = standard reference value.
[c] 0 dB = 2.9×10^{-9} psi = 10^{16} W/cm^2 = 10^{-12} W/m^2 for sound intensity = threshold of human hearing.

where

I = unknown sound intensity, watts/m^2
I_0 = sound intensity reference base = 10^{-12} W/m^2
I_1 = sound intensity from source 1
I_2 = sound intensity from source 2

All sound intensities are added and then the sum is converted to a resultant decibel reading. A similar procedure is followed to subtract the numbers of decibels. For example, to add two sound levels dB_1 and dB_2, find the I_1, corresponding to dB_1; find I_2 corresponding to dB_2 and add to I_1 yielding I; then reconvert to decibels using the formulas just given. This rather complex process is much simplified by use of Table 4.11. For example, consider the summation of a 50-dB sound with a 56-dB sound. For a difference of 6 dB, we find from Table 4.11 that 1 dB is added to the higher of the two sounds. The combined sound level is 57 dB. In adding several sound levels, start with the lowest.

Consider another example involving three noise sources. An industrial safety engineer wants to compute the total sound pressure level in a work area from the machinery nearby. An air compressor, a drill press, and ventilation fans contribute 85, 81, and 75 dB sound pressure levels, respectively. Starting with the lowest, according to Table 4.11, an 81-dB level and a 75-dB level sum to 82 dB. The 82-dB level and the 85-dB level sum to 86.8 dB. Note that if the 75-dB level were missing, the total would have been 86.5 dB, almost the same.

TABLE 4.11 Approximate Increase When Combining Two Sound Levels

Difference between Levels (dB)	Decibels to Be Added to Higher Level
0	3.0
1	2.6
2	2.1
3	1.8
4	1.5
5	1.2
6	1.0
7	0.8
8	0.6
10	0.4
12	0.3
14	0.2
16	0.1

Source: A. C. Hosey (Ed.), *Industrial Noise, A Guide to Its Evaluation and Control*, PHS Pub. No. 1572, Department of Health, Education, and Welfare, Washington, DC, 1967.

A noise contribution less than 10 dB lower than the other noise contributions can usually be neglected.

It should be noted that in using the previous formula the following generalization can be made: Any two *identical* sound levels will have the effect of increasing the overall level by 3 dB and any three will increase the overall level by 4.8 dB.

Intensity Intensity of a sound wave is the energy transferred per unit time (in seconds) through a unit area normal to the direction of propagation. It is commonly measured in W/ml^2 or W/cm^2. For a pure tone (single frequency), there is a one-to-one correspondence between loudness and intensity. However, almost all sound contains multiple frequencies. The relationship is not simple because of the interference effects of the sound waves.[50] For example, increasing the sound pressure level by 3 dB is equivalent to increasing the intensity by a factor of 2. Increasing the sound pressure level by 10 dB is equivalent to increasing the intensity by a factor of 10, and increasing the sound pressure level by 20 dB is equivalent to increasing the intensity by a factor of 100. Expressed in another way, whereas 10 dB is 10 times more intense than 1 dB, 20 dB is 100 times (10×10) more intense, and 30 dB 1,000 times ($10 \times 10 \times 10$) more intense.

Loudness Loudness, or amplitude, of sound is the sound level or sound pressure level as perceived by an observer. The apparent loudness varies with the sound pressure and frequency (pitch) of the sound. This is illustrated in Figure 4.14. It is specified in sones or phons. For a pure tone, each time the sound pressure level increases by 10 dB, the loudness doubles (sones increase

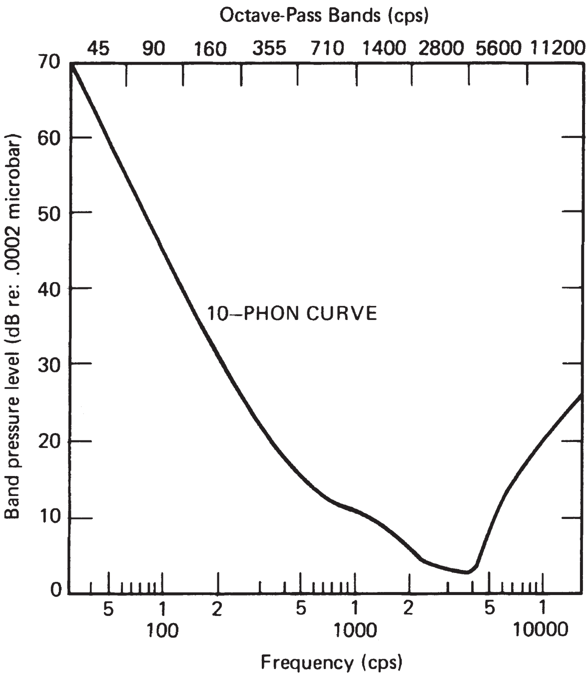

FIGURE 4.14 Equal loudness contour. (*Source: Toward a Quieter City*, A report of the Mayor's Task Force on Noise Control, New York, 1970.)

by a factor of 2). Sound levels of the same intensity may not sound the same since the ear does not respond the same to all types of sound.

A 1,000-Hz pure tone 40 dB above the listener's hearing threshold (0 dB) produces a loudness of 1 *sone*, which is a unit of loudness. [51] This loudness of 1 sone is equal to 40 phons. Loudness levels are usually expressed in phons. For practical purposes, each doubling of the sones increases the phons by 10—that is, 1 sone = 40 phons; 2 sones = 50 phons; 4 sones = 60 phons. Also for pure tones, a 10-dB increase in sound level would be perceived as a 10-phon increase in loudness by a person with good hearing in the frequency range of 600 to 2,000 Hz.

For example, take a human listener with normal hearing who hears a 100-Hz pure tone with a SPL of 90 dB. What loudness does the listener perceive?

From Figure 4.14, a SPL of 40 dB at approximately 100 Hz equals a loudness of 10 phons. Since a 50-dB increase in SPL is equivalent to a 50-phons increase in loudness, the tone's loudness is 60 phons, or 4 sones.

Noys Noys is a measure of the perceived noise level (PNL) (in decibel) in relation to the noisiness or acceptability of a sound level. Although similar to loudness, the ratings by observers when tested were different.

Procedures for the calculation of loudness and noisiness are given in standard texts.[52]

Day–Night Average Sound Level (DNL) System The day–night average sound level is the 24-hour average sound level, expressed in decibels, obtained after the addition of a 10-dB penalty for sound levels that occur at night between 10 p.m. and 7 a.m. It is recorded as L_{dn}. The DNL system has been adopted by the EPA, the Department of Defense, the Department of Housing and Urban Development (HUD), and the Federal Aviation Administration (FAA), specifically for describing environmental impacts for airport actions.[53]

Effects of Noise — A Health Hazard

Noise pollution is an environmental and workplace problem. Excessive noise can cause permanent or temporary loss of hearing. Loud sounds affect the circulatory and nervous systems, although the effects are difficult to assess. It interferes with speech, radio, and TV listening; disturbs sleep and relaxation; affects performance as reduced work precision and increased reaction time; and causes annoyance, irritation, and public nuisance. There is a hearing loss with age, particularly at the higher frequencies, and in younger people who have been exposed to loud noises. Occupation-related hearing loss has been documented since the sixteenth century and is still a serious problem. An estimated $835 million compensation was paid workers from 1978 to 1987.[54] Sonic booms can cause physical damage to structures. David G. Hawkins, assistant EPA administrator reported the following:[55]

> A poll conducted by the U.S. Bureau of the Census showed that noise is considered to be the most undesirable neighborhood condition—more irritating than crime and deteriorating housing.

Criteria for hearing protection and conservation have been established primarily for the worker. The major factors related to hearing loss are intensity (sound pressure levels in decibels), frequency content, time duration of exposure, and repeated impact (a single pressure peak incident). In measuring the potential harm of high-level noise, frequency distribution as well as intensity must be considered. Continuous exposure to high-level noise is more harmful than intermittent or occasional exposure. High- and middle-frequency sounds at high levels generally are more harmful than low-frequency sounds at the same levels. Greater harm is done with increased time of exposure.

Individuals react differently to noise depending on age, sex, and socioeconomic background. The relation of noise to productivity or performance is contradictory and not well established.

For workers, a sound level over 85 dBA calls for study of the cause. A level above 90 dBA should be considered unsafe for daily exposure over a period of months and calls for noise reduction or personal ear protection if this is practical.

An EPA report identified a 24-hour exposure level of 70 dBA as the level of environmental noise that will prevent any measurable hearing loss over a lifetime. Levels of 55 dBA outdoors and 45 dBA indoors are identified as preventing annoyance and not interfering with spoken conversation and other activities such as sleeping, working, and recreation.[56] Some common sound levels and human responses are noted in Table 4.12.

Other effects of noise are reduced property values; increased compensation benefits and possible accidents, inefficiency, and absenteeism; and increased building construction costs.

Sources of Noise

Transportation, industrial, urban, and commercial activities are the major sources of noise, plus the contributions made by household appliances and equipment.

TABLE 4.12 Sound Levels and Human Response

Sources	Noise Level (dBA)	Response
Carrier deck, jet operation	140	Painfully loud
Live rock music	130	Limits amplified speech
Jet takeoff (200 ft)	120	Maximum vocal effort
Discotheque	115	
Rock band (10 ft)	115	
Auto horn (3 ft) loud	110	
Riveting machine	110	
Jet takeoff (2000 ft)	110	
Garbage truck, snowmobile	100	
Power lawn mower (operator)	95	
New York subway station	90	Very annoying
Heavy truck (50 ft)	90	Hearing damage (8 hr)
Food blender	90	
Pneumatic drill (50 ft)	85	
Diesel truck, 40 mph (50 ft)	85	
Dishwasher	80	
Alarm clock	80	Annoying
Garbage collection	80	
Freeway traffic (50 ft)	70	Telephone use difficult
Vacuum cleaner	70	
Normal speech	60	
Air-conditioning unit (20 ft)	60	Intrusive
Light auto traffic (100 ft)	50	Quiet
Living room	40	Quiet
Bedroom	40	
Public library	35	
Soft whisper (15 ft)	30	Very quiet
Broadcasting studio	20	
Breathing	10	Just audible
	0	Threshold of hearing

Sources: Sound Levels and Human Responses, Office of Planning Management, U.S. Environmental Protection Agency, Washington, DC, July 1973; *MMWR*, March 1986, p. 185.

The major sources of transportation noise are motor vehicles, including buses and trucks, aircraft, motorcycles, and snowmobiles.

Industrial, urban, and commercial noises emanate from factories, equipment serving commercial establishments, and construction activities. Construction equipment sources are power tools, air compressors, earthmovers, dump trucks, garbage collection trucks, diesel cranes, pneumatic drills, and chain saws. Compactor trucks manufactured after October 1, 1980, may not exceed a noise level of 79 decibels and may not exceed 76 decibels after July 1, 1982, measured on the *A*-weighted scale 7 m from the front, side, and rear of the vehicle while empty and operating.

Residential noise is associated with dishwashers, garbage disposal units, air conditioners, power lawn mowers, and home music amplifier units.

Measurement of Noise

Noise measurement equipment selection depends on the task to be performed. For an initial survey, a sound-level meter is adequate for a rapid evaluation and identification of potential problem areas. To study and also determine the characteristics of a noise problem area, a sound-level meter, frequency analyzer, and recorder are needed to determine sound pressure distribution with frequency and time. More sophisticated equipment would be needed for research or solution of special noise problems.

Sound-Level Meter A sound-level meter is used to measure the sound pressure level; it is the basic instrument for noise measurement.

Meters are available to cover the range of 20 to 180 dB. The specifications usually refer to the American National Standards Institute (ANSI) and particularly to the standard *Specification for Sound Level Meters*, ANSI S1.4-1971. Three weighting networks, *A, B*, and *C*, are provided to give a number that best approximates the total loudness level for a particular situation, with consideration of the sound frequency, intensity, and impact levels. There are three types of meters. Type I is highest quality; type III is lowest quality and not suitable for public health professionals. Type II is the most common type used by public health officials. Most noise laws and regulations permit either type I or II but not type III meters.

The B and C networks are no longer normally used. The A-weighted scale is most commonly used. It discriminates against frequencies below 500 Hz and most nearly encompasses the most sensitive hearing range of sound—that is, 1,000 to 6,000 Hz. The symbol dBA is used to designate the A-weighted decibel scale, which combines both frequency and pressure levels; it measures environmental noise and should be supplemented by the time or duration to determine the total quantity of sound affecting people. The sound level meter provides the total quantity of sound affecting people. The sound-level meter provides settings for "F" (fast time response) and "S" (slow time response).

The most important part of the equipment is a calibrator that generates a known decibel standard. Without a calibration before and after a measurement, the measurement is suspect.

Noise Dosimeter The noise dosimeter will measure the amount of potentially injurious noise to which an individual is exposed over a period of time. A dosimeter can be set to the desired level and will then total the exposure time to noise above the set level. The noise dosimeter does not, however, identify noise sources. Therefore, if a study is being conducted to determine noise exposure and culpability, it is imperative that the dosimeter be coupled with a frequency analyzer or better still with a human observer to record noise source identities.

Sound Analyzer A frequency analyzer may be necessary to measure complex sound and sound pressure according to frequency distribution. It will supplement readings obtained with a sound-level meter. Noise analyzers cover different frequency bands. The octave-band analyzer is the most common. The impact noise analyzer is used to measure the peak level and duration of impact noise. Examples of impact noises are drop hammer machines and gun fire.

Cathode-Ray Oscillograph This makes possible observing the wave form of a noise and pattern. The magnetic tape recorder makes possible the collection of noise information in the field and subsequent analysis of the data in the office or laboratory. Environmental noise monitors are now available that can be located in a community and will retain noise levels in a memory.

Octave-Band Analyzer This has filters that usually divide a noise into eight possible frequency categories. Each category is called an octave band, with frequency ranges of 45 to 90, 90 to 180, 180 to 355, 355 to 710, 710 to 1,400, 1,400 to 2,800, 2,800 to 5,600, and 5,600 to 11,200 Hz (or cps). The bands are identified by their center or midfrequencies: 63, 125, 250, 500, 1,000, 2,000, 4,000, and 8,000 Hz. With center-frequency bands at 31.5 and 16,000 Hz, the audible frequency range of 20 to 20,000 Hz is then covered with 10 octave bands.

Background Noise Background noise is noise in the absence of the sound being measured that may contribute to and obscure the sound being measured. A rough correction could be made by applying the correction factors given in Table 4.13. However, such subtractions typically introduce significant error in the final result. The message to be obtained from Table 4.13 is that the background noise should be at least 10 dB lower than the noise being measured. This will introduce negligible error (less than 0.5 dB) due to interfering background.

Methods for Noise Control

Noise can be controlled at the source, in its path of transmission (through a solid, air, or liquid), or where it is received. Sometimes, because no one method

TABLE 4.13 Correction for Background Noise

Total Noise Level Less Background Level (dB)	Decibels to Subtract from Total Noise Level to Get Noise Level Due to Source
10	0.5
9	0.6
8	0.7
7	1.0
6	1.2
5	1.6
4	2.2
3	3.0
2	4.3
1	6.9

Source: H. H. Jones, "Noise Measurement," *Industrial Environment. . . Its Evaluation and Control*, PHS Pub. No. 614, Department of Health, Education, and Welfare, Washington, DC, 1958, p. B-21.

is sufficiently effective, controls are instituted at two or at all three steps in the path of noise travel from the source to the receptor. In general, it is best to reduce the noise at the source. This should include establishment of clear, reasonable, and enforceable noise design objectives for manufacturers and installers.

Noise control generally involves adoption and effective enforcement of reasonable and workable regulations; protection of workers from hazardous occupational noise levels; building quieter machines, use of vibration isolators, new product regulation, and product labeling for consumer information; improved building construction and use of rubber sleeves, gaskets, paddings, linings, seals, and noise barriers; compatible land-use planning and zoning; and informing the public of harmful effects of noise and methods to reduce noise to acceptable levels. Regulations may encompass ambient noise in general and industrial noise, motor vehicle noise, and aircraft noise as well as building and construction codes, housing occupancy codes, sanitary codes, and nuisance codes.

A WHO Expert Committee[57] suggests the following preventive measures to control noise and vibration:

- General measures such as locating noisy industrial plants, airports, landing fields for helicopters, railway stations and junctions, superhighways, and so on, outside city limits
- Improving technical processes and industrial installations with a view to reducing noise and vibration and installing noise suppressors (mufflers) on automobiles, motorcycles, and so on
- Improving the quality of surface highways and urban streets (also tire tread designs)
- Creating green spaces in each neighborhood district
- Perfecting procedures for acoustic insulation

- Adopting administrative regulations with a view to limiting the intensity of background noise within the urban environment

The committee recommends close international collaboration and close cooperation between metropolitan planners and environmental health personnel to reduce noise and vibration to a minimum.

Control of Industrial Noise

Noise control should start in the planning of a new plant or when planning to modernize an existing plant. Consideration should be given at that time to minimizing the effects of noise on the workers, office personnel, and nearby residents. The control of an existing noise problem first requires suitable noise standards and an identification of the location, extent, and type of noise sources. This would be followed by the application of needed noise-control measures to achieve the required or desired levels.

Eight factors are considered in industrial noise control:[58]

1. Select building site that is isolated or an area where there is a high background noise level. Topography and prevailing winds should be considered, as well as the use of landscaping and embankments, to reduce the noise travel where it may cause a nuisance.
2. Building layout should separate and isolate noisy operations from quiet areas.
3. Substitute low-noise-level processes for noisy operations, such as welding instead of riveting, metal pressing instead of rolling or forging, compression riveting instead of pneumatic riveting, and belt drives in place of gears.
4. Select new equipment with the lowest possible noise level (also modification of existing equipment with better mufflers).
5. Reduce noise at its source through maintenance of machinery, covers and safety shields, and replacement of worn parts; reduction of driving forces; reduction of response of vibrating surfaces; intake and discharge sound attenuation and flexible connections or collars; use of total or partial enclosures, with sound-absorbing materials (also coatings or sound-absorbing materials on metals to dampen vibration noise); and isolation of vibration and its transmission. See "Noise Control" and "Noise Reduction," earlier in this chapter.
6. Use acoustic absorption materials to prevent noise reflections.
7. Control noise in ventilation ducts or conveyor systems.
8. Use personnel shelters.

Sometimes the only practical and economical method of noise control is through the use of personal protective devices. These may also be a supplement to the applied engineering, worker, and education controls. Personal ear protector types include properly fitted and sized earplugs, earmuffs, and helmets providing a good seal around the ear. They should meet established criteria for comfort, tension, sound attenuation (at least 15 dBA), simplicity, durability, and so on. To be effective, however, *the worker must cooperate by wearing the protective device* where needed. Dry cotton plugs do not provide significant sound attenuation.

Control of Transport Noise

Noise from various forms of transport and its transmission into the home may be reduced as follows:[59]

- At the source, that is, by controlling the *emission* of noise
- By means of town and country planning and traffic engineering, that is, by controlling the *transmission* of noise
- In the home, that is, by controlling the *reception* of noise by the occupants

Eight specific measures can be used to reduce the effect of highway noise:

1. Enclose highways going through residential areas.
2. Use wider rights-of-way, that is, separation or buffer zone between the source and the receptor.
3. Design walls to deflect or absorb noise (earth berms covered with vegetation are more effective).[60]
4. Change highway alignment and grade to avoid sensitive areas, minimizing stop-and-go traffic, and shifting to low gears.
5. Set lower speed limits for certain sections of a highway.
6. Use adjacent barriers, nonresidential buildings in sound transmission path, earth embankments or berms, and elevation or depression of highways. It is reported, however, that barriers provide little attenuation of low-frequency sounds and that a thick band of deciduous trees 200 to 300 ft in width is relatively ineffective in cutting down traffic noises, reducing them only on the order of 4 or 5 dB.[61] Separation distance is most effective in reducing noise from highways.
7. Establish alternate truck routes.
8. Write building codes to require building insulation to limit interior transmission of noise. Additional measures are masonry walls, elimination of windows, use of double windows or glazing, soundproofing of ceilings, thick carpeting, overstuffed furniture, and heavy drapes.

Noise Reduction

Sound Absorption The amount of sound energy a material can absorb (soak up) is a function of its absorption coefficient (α) at a specified frequency. The sound absorption coefficient is the fractional part of the energy of an incident sound wave that is absorbed by a material. A material with an absorption coefficient of 0.8 will absorb 80 percent of the incident sound energy. A material that absorbs all incident energy, such as an open window, has an absorption coefficient of 1. The sound absorption of a surface is measured in sabins. A surface having an area of 100 ft^2 made of material having an absorption coefficient of 0.06 has an absorption of 6 sabin units (100 $\times$ 0.06). To determine the noise reduction in a room, the floor, walls, and ceiling surface areas multiplied by the absorption coefficient of each surface, at a given frequency, before and after treatment, must be added to obtain the total room surface absorption in sabin units.

The *noise reduction* (NR) in decibels at a given frequency of a surface before and after treatment can be determined by the following equation:

$$\mathrm{NR} = 10 \log_{10} \frac{A_2}{A_1}$$

where

A_2 = total room surfaces absorption after treatment, sabins
A_1 = total room surfaces absorption before treatment, sabins

Incremental noise reduction from a piece of machinery can be obtained by a rigid, sealed enclosure, plus vibration isolation of a machine from the floor using spring mounts or absorbent mounts and pads, plus acoustical absorbing material on the inside of the enclosure, plus mounting the enclosure on vibration isolators and enclosing, without contact, in another enclosure having inside acoustical absorbing material. If machinery air cooling and air circulation are needed, provide baffled air intakes. Insert a flexible connector, if a physical pipe or duct connection is needed between the machinery and other building piping or duct work, to reduce noise transmission.

However, sound energy can go around or through a particular material (around corners) or pass through openings (cracks, windows, ducts) and thereby nullify the sound absorption as well as transmission reduction efforts. For example, 1 in.^{2} of opening transmits as much sound as about 100 ft^2 of a 40-dB wall.[62] This emphasizes the importance of sealing all cracks, pipe and conduit sleeves, electrical receptacles, or openings with nonsetting caulking compound.

Sound-absorptive materials include rugs, carpets with felt pads, heavy drapes, stuffed furniture, and ceiling and wall acoustical materials designed to absorb sound. These materials absorb high-frequency sounds much more effectively than low frequency. Sound absorptive materials are most effective to the occupant when used in and near the areas of high-level noise. These materials can control interior noise, sound reflection, and reverberation*; however, noise easily passes through. Hard, smooth, impervious materials reflect sound. Some absorption coef-

*The sound that persists in an enclosed space after the sound source has stopped, which is reflected by the wall, floor, or ceiling.

ficients at 1000 Hz are plate glass 0.03; brick wall 0.01 to 0.04; linoleum, asphalt, or rubber tile on concrete 0.03; smooth plaster on brick or hollow tile 0.03; $\frac{3}{8}$-in. plywood paneling 0.09; felt-lined carpet on concrete 0.69; velour (14 oz/yd^2) 0.75; painted concrete block 0.07; and unpainted concrete block 0.29.

Sound Transmission Sound transmission loss (TL) is the ratio of the energy passing through a wall, floor, or ceiling to the energy striking it—that is, how effective a material is in stopping the passage of sound. The sound transmission varies with the frequency of the sound, the weight or mass, and the stiffness of the construction. Hence, any reduction of noise transmission from outside to inside a building is accomplished through control of the design, thickness, and weight of wall, floor, door, window, and ceiling materials. Improved design of building equipment and its installation, noise and vibration isolation, and discontinuance or gaps in structural members are interior factors also to be considered. The transmission loss increases as the frequency increases. Hollow doors readily transmit sound; solid wood or solid core doors do not.

Mechanical equipment, household appliances, and other stationary sources of noise should be isolated from the floors or walls or on mountings by means of rubber or similar resilient pads to absorb vibration and prevent or reduce sound transmission to the structure, as noted previously under "Sound Absorption." Small-diameter pipe carrying water at high velocity causes noise to travel long distances. Air chambers on pipelines may also be needed to prevent water hammer.

Sound transmission class (STC) loss ratings for various types of materials are given in decibels in design handbooks, texts, and standards such as the National Bureau of Standards, Building Materials and Structures Report BMS 144 for "Insulation of Wall and Floor Construction." For example, 4-inch cinder block weighing 25 lb/ft^2 has an average approximate STC loss rating of 25 dB; if the block is plastered on one side, its rating is 40 dB. A 4-inch brick wall weighing 40 lb/ft^2 has a rating of approximately 45 dB. A 4-inch concrete slab with a resiliently suspended ceiling has a rating of 55 dB. A quarter-inch plywood sheet nailed to studs has an STC rating of 24 dB; half-inch gypsum board on studs has a rating of 32 dB. The frequency of the sound affects the sound transmission loss. In general, the sound transmission loss rating increases with frequency increase. Theoretically, transmission loss increases at the rate of 6 dB per doubling of the weight of the construction. Some building codes recognize the need to prevent sound transmission between apartments in a multiple dwelling or in row houses. A double *separated* wall with two layers of insulation is effective. A sound-pressure-level reduction of about 50 dB in the normal speaking range (250–3000 Hz) is suggested.

Since a room floor, wall, and ceiling are usually constructed of different materials, an average transmission coefficient must be calculated taking into consideration the coefficient for each material (including doors, windows, and vents) and its area to determine the room noise insulation factor in decibels. The total noise reduction level accomplished by a wall or other divider is a function of the wall transmission loss, the room absorption characteristics, and the absorption in the rooms separated. It is determined by measuring the difference in sound levels in the rooms. The types of windows (single or double-hung) and doors can have a major effect on the overall noise insulation factor. For example, opening a window can double the interior noise.

Numerous sample calculations for sound and vibration control situations are given in various texts, including the *ASHRAE Guide and Data Book, Systems, 1970*.[63]

Mechanical noises such as high-velocity noises require proper design of ventilation systems and plumbing systems to reduce flow velocity. Hammering noise in a plumbing system is usually due to a quick-closing valve in the plumbing system, which requires installation of an air chamber on the line or a pressure or vacuum-breaker air-relief valve to absorb the pressure change created when the momentum of the flowing water suddenly stops.

Separation distance between the sound source and receptor should be emphasized and not overlooked in the planning stages as a practical noise reduction method. In general, if there are no sound-reflecting surfaces in the vicinity, a sound pressure level will be reduced approximately 6 dB for each doubling of the distance. Doubling the air space between panels increases the transmission loss by about 5 dB. When a sound barrier, such as a wall, is erected between a source and a receptor, some sound is reflected back toward the source, some is transmitted through the barrier, and some is diffracted over and around the barrier. With a partition close to the source, part of the sound is absorbed, part is reflected back, and part is transmitted through.

Federal Regulations

Maximum acceptable or permissible noise levels are established for certain categories by federal or state regulations or by local ordinances. Some guides are given in Table 4.14.

In May 1969 the Department of Labor issued the first federal standards for occupational exposure to noise. The Occupational Safety and Health Administration (OSHA) sets and enforces regulations, under the Occupational Safety and Health Act of 1970, for the protection of workers' hearing. These standards have been made more stringent over the years as more human hearing loss research has become available. Table 4.15 shows the year 2000 American Conference of Governmental Hygienists suggested daily durations and sound pressure levels. The federal regulatory approach is to start control at the point of manufacture.

The Federal Highway Act of 1970 led to design noise levels related to land use as a condition to federal aid participation. If the design noise levels shown in Table 4.16 are exceeded, noise abatement measures are required in the highway design. Federal highway funds may also be used to abate noise on previously approved highway projects.

The Noise Control Act of 1972 [Public Law (PL) 92-574] directed the EPA to promote an environment for all Americans free from noise that jeopardizes

TABLE 4.14 Some Guides for Maximum Acceptable Sound Levels

Space	Sound Level (dBA)	
	Maximum	Design
Auditoriums	30–45	25–30
Drafting rooms	55	35–50
Hospital rooms	40	25–35
Hotel rooms	45	30–40
Indoor recreational areas		30–45
Libraries	40–45	30–40
Manufacturing, light machinery		45–70
Movie theaters	35–45	30–35
Private offices	40–45	30–40
Residences, rural or suburban		20–30
Residences, urban		25–35
Restaurants	50	35–45
School rooms	30–40	30–40
Secretarial offices	55–60	35–50
Small conference rooms	35–40	25–35
Sports arenas		30–40
Stores, department and supermarkets		35–50

their health and welfare. It is required to set limits on noise emission, and the Act requires manufacturers to warrant product performance and label products. Regulation of noise from a broad range of sources and products is required. The EPA and the Department of Transportation (DOT) have been given the responsibilities to implement the law. The EPA estimates that 16 million people are exposed to aircraft noise levels with effects ranging from moderate to very severe.

The Aviation Safety and Noise Abatement Act of 1979 requires the FAA to develop a single system for measuring noise at airports and under certain conditions to prepare and publish noise maps. The Noise Abatement Criteria established by the Federal Highway Administration for residential areas, schools, parks, hospitals, and other sensitive areas is 67 dBA equivalent steady state and 72 dBA for commercial land use.*

The FAA, in the Department of Transportation, has primary authority for aircraft noise regulations and standards. The FAA has adopted noise emission standards for new aircraft and has a plan to retrofit older aircraft.

The Quiet Communities Act of 1978 amended the Noise Control Act of 1972 to encourage noise control programs at the state and community levels.

*A. Charabegian, "GIS/CAD Enhance Traffic Noise Study," *Public Works*, November 1990, pp. 61–62.

TABLE 4.15 Sound Pressure Levels as Suggested by American Conference of Governmental Industrial Hygienists for Permissible Noise Levels at Various Durations of Exposure[a]

Duration per Day	Sound Pressure Level (dBA)[b]	Duration per Day	Sound Pressure Level (dBA)[b]
24 hr	80	28.12 sec	115
16 hr	82	14.06 sec	118
4 hr	88	7.03 sec	121
2 hr	91	3.52 sec	124
1 hr	94	1.76 sec	127
30 min	97	0.88 sec	130
15 min	100	0.44 sec	133
7.50 min[c]	103	0.22 sec	136
3.75 min[c]	106	0.11 sec	139
1.88 min[c]	109		
0.94 min[c]	112		

[a]2000 TLVs and BEIs, American Conference of Governmental Industrial Hygienists. No exposure to continuous, intermittent, or impact noise in excess of a peak C-weighted level of 140 dB.
[b]Sound level in decibels is measured on a sound-level meter, conforming as a minimum to the requirements of the American National Standards Institute Specification for Sound Level Meters, S1.4 (1983)[(2)] Type S2A, and set to use the A-weighted network with slow meter response.
[c]Limited by the noise source, not by administrative control. It is also recommended that a dosimeter or integrating sound-level meter be used for sounds above 120 dB.

TABLE 4.16 Design Noise Level–Land Use Relationships

Design Noise Level (dBA)	Description of Land-Use Category
60 (exterior)	Areas such as amphitheaters, certain parks, or open spaces in which local officials agree serenity and quiet are of extraordinary significance
70 (exterior)	Residences, motels, hotels, public meeting rooms, schools, churches, libraries, hospitals, recreational areas
75 (exterior)	Developed land, properties, or activities not included in above two categories
55 (interior)	Residences, motels, hotels, public meeting rooms, schools, churches, libraries, hospitals, auditoriums

Source: U.S. Department of Transportation, Policy Procedure Memorandum 90-2 Appendix B, Transmittal 279, February 8, 1973.

The Housing Act of 1949 (PL 81-171), among other things, sets forth the national goal of “a decent home and suitable living environment for every American family.” This goal was affirmed by the Housing and Urban Development Act of 1968 (PL 89-117).[64]

TABLE 4.17 Noise Levels for Sleeping Quarters in New Structures

Exterior	Interior
Does not exceed 45 dBA for more than 30 min per 24 hr (Acceptable)	Not greater than 55 dBA for more than an accumulation of 60 min in any 24-hr day
Does not exceed 65 dBA for more than 8 hr per 24 hr (normally acceptable)	Not greater than 45 dBA for more than 30 min during nighttime sleeping hr 11 p.m. to 7 a.m. and not greater than 45 dBA for more than an accumulation of 8 hr in any 24-hr day

Note: Not greater than 30 dBA preferred for bedrooms.

Source: Department of Housing and Urban Development, Circular 1390, amended September 1, 1971.

The Department of Housing and Urban Development has criteria for the sound insulation characteristics of walls and floors in row houses, nursing homes, and multifamily housing units. These criteria must be met by housing of this type in order to qualify for HUD mortgage insurance.

The National Bureau of Standards and the National Science Foundation are concerned with research in noise control and abatement in factories, homes, offices, and commercial work areas.

The EPA has issued noise control regulations for interstate trucks, interstate railroad carriers, new medium and heavy-duty trucks, and new air compressors. The EPA and DOT regulations establish a maximum noise level of 90 dBA for interstate trucks and buses over 10,000 lb in speed zones over 35 mph and 86 dBA at 35 mph or less, measured 50 feet from the center line of the lane of travel. New trucks over 10,000 lb must achieve a sound level no higher than 83 dBA.

The EPA program for certain noise-emitting and noise-reducing products requires a noise rating giving the number of decibels (dBA) a product emits and a noise reduction rating. Noise emissions from new products (including portable air compressors) are not to exceed 76 dBA at 23 feet (7 m).

The HUD noise levels for new sleeping quarters are given in Table 4.17.

State and Local Regulations

New York State enacted a state highway antinoise law in 1965 and California followed in 1967. Chicago put into effect a comprehensive noise control program in July 1971. Regulations require reduced noise levels after 1979 for vehicles, construction machinery, home-powered equipment, and like-manufactured equipment. St. Louis County has a noise code that limits noise in residential areas to 55 dBA and in industrial areas to 80 dBA. New Jersey enacted comprehensive noise legislation January 1972. Most states in the snow belt have established a maximum noise level for snowmobiles of 78 dBA at 50 ft. Some 12,000 states and municipalities have noise control legislation, but enforcement has been weak and spotty.

Local regulations consistent with federal and state laws and enforced locally are encouraged as being more practical for enforcement. Model noise control ordinances are available to assist local communities in the development of a local program.[71*]

Maximum acceptable sound levels for different situations are given in Tables 4.14, 4.16, and 4.17. Maximum permissible sound levels for workers in industrial plants and factories regulated by the Occupational Safety and Health Act are given in Table 4.15.

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CHAPTER 5

SURVEYING AND MAPPING FOR ENVIRONMENTAL ENGINEERING

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INTRODUCTION

The practice of environmental engineering often entails the use of maps and map-based land information systems and the conduct of related surveying operations. Accordingly, this chapter is intended to set forth certain basic surveying and mapping concepts, the understanding of which is required for the practice of environmental engineering. Historically, surveying and mapping constituted a highly specialized branch of civil engineering, just as city and regional planning once did. And, historically, university civil engineering curriculums included extensive course work in surveying and mapping, and textbooks in surveying and mapping were often authored by practicing civil engineers. The American Society of Civil Engineers maintains a division of surveying and mapping—a field now known as *geomatics*—and annually awards a prize for notable achievement in the field. Surveying and mapping have, however, increasingly become a discipline separate from civil and environmental engineering, and some branches—such as land surveying, which could once be practiced by licensed engineers—are now practiced by a separately licensed profession. Some universities no longer include any courses in surveying and mapping as a part of the civil and environmental engineering curriculum. Nevertheless, the practice of environmental engineering will inevitably involve the use of maps, and, in some cases, the conduct of related surveying operations. Therefore, an understanding of the basics concepts underlying surveying and mapping is essential to the competent practice of environmental engineering. Accordingly, this chapter sets forth these basic concepts in summary—and in some cases greatly simplified—form.

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IMPORTANCE OF MAPS

The most efficient and effective way of not only presenting, but of integrating, information about a number of factors that must be considered in any environmental engineering effort, is through the preparation of good maps designed specifically for engineering application. Good maps serve at least two important purposes in environmental engineering: (1) to provide a graphic representation of the geographic area concerned; and (2) to relate pertinent data to geographic location. Before considering the specific map requirements for environmental engineering, a review of some of the basic concepts and definitions involved in the preparation and use of maps is in order.

BASIC DEFINITIONS AND CONCEPTS

A map may be defined as a flat, true-scale, graphical representation of a portion of the earth's surface. In this respect, it should be recognized that the spherical surface of the earth cannot be presented on a flat surface without some distortion. Map scale may be defined as the relationship that exists between a distance on a map and the corresponding distance on the surface of the earth. Map scale may be expressed as an equivalence, a ratio, or a graph.

Foundational Elements for Creation of Maps

The creation of a map requires three foundational elements. The first of these is a system for accurately locating features on the surface of the earth. The system used consists of spherical coordinates expressed as latitude in degrees, minutes and seconds north or south of the equatorial plane, and longitude expressed in degrees, minutes and seconds east or west of the prime meridian through Greenwich, England.

The topographic surface of the earth constitutes the physical entity upon which the measurements of latitude and longitude, and indeed all survey measurements, are made. The surface of the earth is an irregular, roughly spherical surface; flattened at the poles and elongated through the equatorial plane. The latitude of a point on this surface is given as the angular distance north or south of the equator, and can be determined by direct astronomic observation as, for example, by observation of the angular elevation of the pole star—using a transit or sextant. The longitude of a point on this surface can be determined by observation of the time difference between the meridian of longitude concerned, east or west of a reference meridian—or prime—meridian—the longitude of Greenwich, England, being the reference meridian in universal use today. See Figures 5.1 and 5.2.

The geoid is defined as a surface everywhere perpendicular to the direction of gravity—conceptually equivalent to the surface that would be assumed by mean

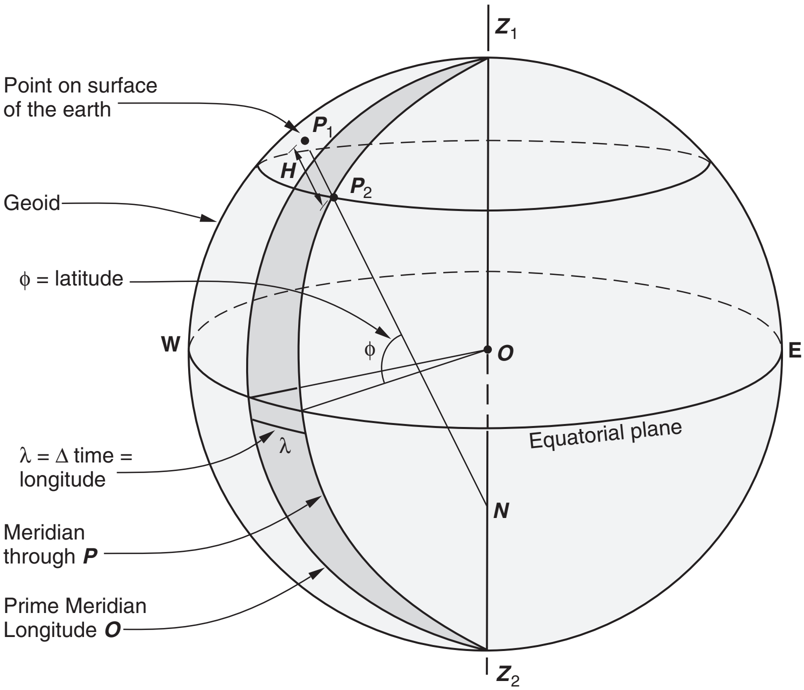


FIGURE 5.1 Ellipsoid latitude (ϕ), longitude (λ), and the orthometric height ($\boldsymbol{H}$) of a point $\boldsymbol{P}_1$.

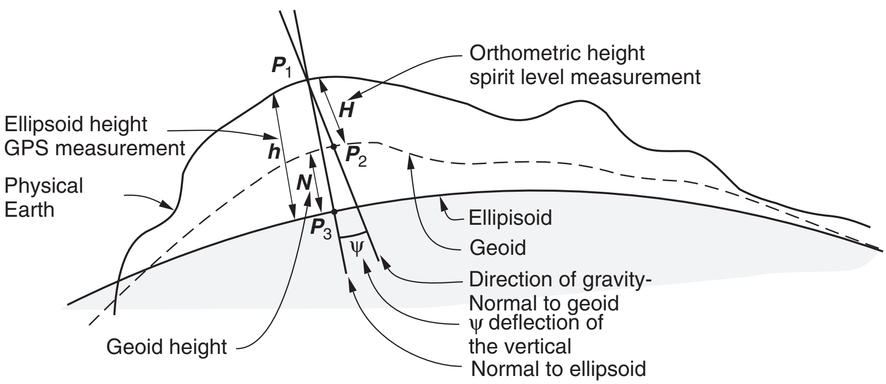


FIGURE 5.2 Relationships between the topographic surface of the earth, the geoid, and a reference ellipsoid.

sea level if the seas extended under the continents. The geoid is the figure to which all survey measurements are referenced and to which surveying instruments are oriented through the use of spirit level vials or plumb lines. The geoid is, however, an irregular, undulating surface.

Since it is impossible to make survey computations on the irregular surface of the geoid, a mathematical surface is substituted that closely approximates the geoid. This surface is created by rotating a two-dimensional ellipse about its semiminor axis to create a three-dimensional, mathematically defined surface, known as the ellipsoid.

Geographic locations and relationships—distances and directions—are expressed as though they were located on the ellipsoid. Historically, a number of ellipsoids have been used as a basis for surveying and mapping operations. Within the continental United States, the historically most widely used ellipsoid is know as the Clark spheroid of 1866. This ellipsoid was adopted for use in geodetic surveying and in hydrographic mapping operations in the continental United States by the U.S. Coast and Geodetic Survey—now known as the National Geodetic Survey—and for use in topographic mapping operations by the U.S. Geological Survey in the later part of the nineteenth century. This ellipsoid is the basis for the North American Datum of 1927 (NAD-27), and for the older State Plane Coordinate Systems still in use within the United States. The grid coordinate values under these older systems are expressed in U.S. survey feet. The newer State Plane Coordinate Systems in use within the United States are based on the Geodetic Reference System of 1980. This spheroid is the basis for the North American Datum of 1983 (NAD-83), and for the revised State Plane Coordinate Systems. The grid coordinate values under these newer systems are expressed in meters.

Map Projections

The second of the foundational elements required for the creation of a map is a map projection. A map projection typically consists of a set of mathematical equations for converting the spherical surface of the earth to a flat surface upon which maps may be constructed. Map projections thus serve to convert the spherical geometry of the mapping ellipsoid to the plane geometry of the flat mapping surface. A number of projection systems are in use for surveying and mapping.

Tangent Plane Projection

The tangent plane projection was the most common form of projection once used by land surveyors and civil engineers. It is the basis for “plane” surveying procedures, the procedures usually taught in introductory courses in surveying. This projection is applicable only to the surveying and mapping of small areas and is being replaced by more sophisticated projections and attendant and mapping surveying procedures. Many land surveyors and civil engineers engaged in the application of plane surveying may not even be aware that they are using this type of projection in the preparation of maps and plats attendant to their work. In application, the surveyor selects a point in, or near, the area to be surveyed and mapped, at which point the survey is oriented to some form of directional control that is recoverable. The directional control may be provided by magnetic observation; celestial observation; or by the direction of a line defined by two monumented U.S. Public Land Survey system one-quarter section corners. The surveyor then measures the angles formed by the lines of the survey and the central direction. This is very different from independently measuring a magnetic or astronomic direction for each line as is the case in projection-less mapping. The angles so measured may then be drawn to scale on the map. Bearings shown on tangent projection maps do not represent the astronomic or geodetic bearings of the survey lines. The curvature of the earth and convergence of the meridians are ignored. The distances are measured as, or reduced to, horizontal distances. The distances are assumed to be measured at the mean elevation of the area surveyed, and are horizontal and not level distances. No adjustments are made for differences between distances as measured on the surface of the earth and these same distances on the flat plane of the projection. The map—often termed a *plat*—derived from the measured angles and distances is, in effect, a projection of the curved surface of the earth onto a flat plane.

The principal advantage of this system is its simplicity. Straight lines are considered to have a constant bearing; parallel straight lines are considered to have the same bearing; level surfaces are considered to be flat planes; and plumb lines are considered to be parallel. The errors introduced by these assumptions become noticeable when the areas concerned exceed about 75 square miles, and then approximate 0.05 foot and 0.1 second of arc. Individually compiled maps cannot be coordinated and become diagrams rather than true maps. Other surveys conducted in the same manner will disagree in the lengths and directions of common lines, and directions between identical points on adjacent parcels will have different values. This means that discrepancies, gaps, and overlaps will not be apparent from mere review of plats of survey of adjacent parcels. Resurveys are entirely dependent on recovery of survey markers or monuments set during the original work.

Tangent plane projection surveys are of limited use to comprehensive planners and to civil and environmental engineers concerned with areawide projects. The lack of a common reference system makes the task of relating individual parcels to each other difficult or impossible. Indeed, existing municipal maps compiled from plats of survey are often no more than representations of the compilations of paper records, so poorly done as to make their use in planning and engineering difficult and costly, and the use of such plan implementation devices as official mapping legally questionable.

The need to identify real property boundaries permanently and precisely, and the need for large-scale, areawide planning and engineering has led to the use of projection systems that eliminate the disadvantages of the tangent plane system.

Lambert Projection

The Lambert conformal conic projection conceptually uses a cone passed through two parallels of the ellipsoid—known as standard parallels—to develop the spherical surface into a plane surface. See Figures 5.3, 5.4, and 5.5. Meridians of longitude are represented on the projection by converging straight lines; and parallels of latitude are represented as arcs of circles with a common center.

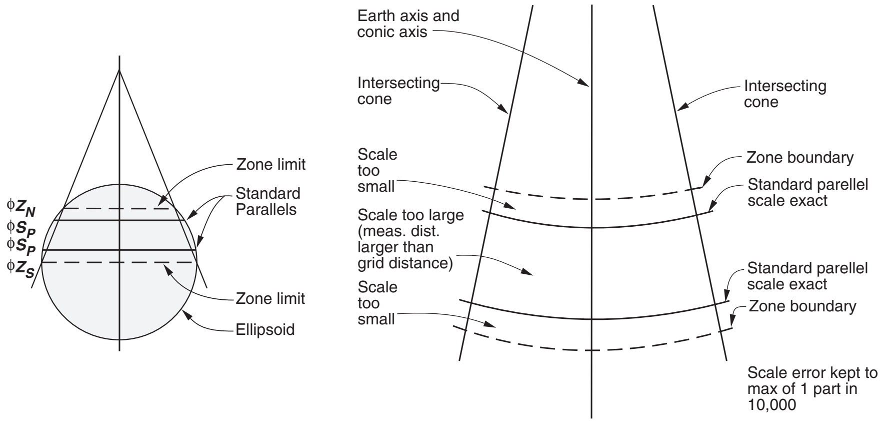


FIGURE 5.3 Concepts underlying creation of a conic projection.

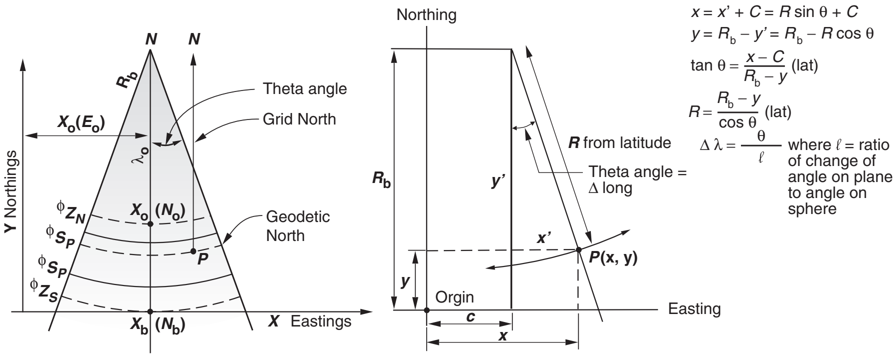


FIGURE 5.4 Concepts underlying creation of a State Plane Coordinate System grid from conic projection.

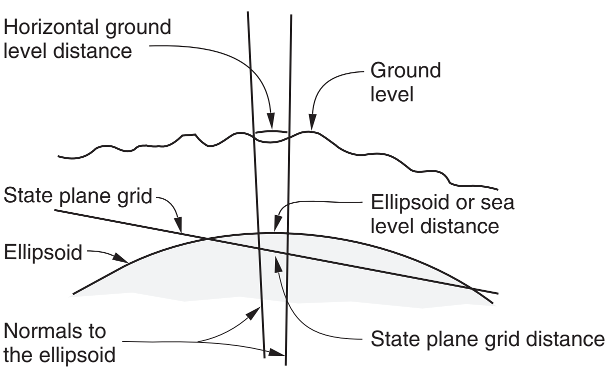


FIGURE 5.5 Relationship of ground level distances to state plane grid distances.

Angles are correctly represented on this projection. The scale is exact only along the standard parallels, and is continuously changing along the meridians. Since more than one cone may be fitted to the ellipsoid to create projection zones, the projection concerned is also known as the Lambert conformal polyconic projection.

With respect to projections, the term *conformal* has a special meaning. Since it is impossible to develop a spherical surface onto a plane, all maps will contain distortions according to the projection used in their compilation. The distortions may relate to scale; area; angles; or to the shape of figures. The unique properties of a conformal projection include the following:

- All figures on the surface of the earth retain their shape on the map.
- Angles measured on the map approximate their true values on the surface of the earth.
- The map scale at any point is uniform in all directions.

These properties are important to all who use grid coordinates in their work, including surveyors, engineers, and planners. The Lambert conformal conic projection is typically used as the basis for the State Plane Coordinate Systems in states having the greatest dimension in the east–west direction.

Mercator Projection

The Mercator projection is a projection that conceptually uses a cylinder tangent to the ellipsoid at the equator to develop the spherical surface of the earth into a plane surface. The equator is represented as a straight line true to scale; meridians of longitude are represented as straight lines perpendicular to the equator; and parallels of latitude are represented by straight lines parallel to the equator. The scale is exact only along the equator and expands along the meridians north and south of the equator. A line of constant bearing—called a *rhumb line*—appears as a straight line on this projection. Therefore, the course between two points can be scaled from the map, a useful characteristic for mariners. This will not, however, be the shortest distance between the two points concerned.

Transverse Mercator Projection

The transverse Mercator projection is equivalent to a Mercator projection rotated 90 degrees. Neither meridians of longitude—except for the central meridian—nor parallels of latitude appear as straight lines. This projection is used as a basis for the State Plane Coordinate Systems in states having the greatest dimension in a north–south direction.

Other Projections

There are a number of other projections in use for various mapping purposes, including the Universal Transverse Mercator (UMT) projection system. This is a system devised for military purposes, but is used for some civil purposes. It divides the entire earth into 62 zones, much larger than the zones used for the State Plane Coordinate System. The later systems are to be preferred for use in most public planning, engineering, surveying, and large-scale mapping efforts. Unlike the Transverse Mercator projection used as a basis for the state plane coordinate systems, which is a tangent projection, the transverse Mercator projection used as a basis for the UMT projection is a secant projection.

The State Plane Coordinate System

The State Plane Coordinate System converts the spherical coordinates—latitude and longitude—of the projection, as measured in degrees, minutes and seconds, to rectangular grid coordinates measured in feet. The x axis values are known as *eastings*, the y axis values are known as *northings*. See Figure 5.4. The State Plane Coordinate Systems permit the conduct of surveys using plane surveying methods, while accounting for the curvature of the earth, and maintaining distortions within specified limits.

In the use of the State Plane Coordinate System, it is important to determine whether the system concerned is the older system based on the North American Datum of 1927, in which the grid coordinate values and related distances are expressed in U.S. survey feet; or is the newer system based on the North American Datum of 1983, in which the grid coordinate values and related distances are expressed in meters. It is also important to understand the relationship of ground level distances to State Plane Coordinate distances; see Figure 5.5. The following definitions may be helpful in examining Figure 5.4, and are essential to the proper understanding and use of the State Plane Coordinate Systems. The term *scale factor* is defined as the state plane coordinate distances divided by the ellipsoidal, or sea level, distances. The term *sea level reduction factor* is defined as the ellipsoidal, or sea level, distances, divided by the horizontal ground level distances. The combination *scale and sea level reduction factor* is defined as the product of the scale factor and the sea level reduction factor so that State Plane Coordinate grid distances are equal the horizontal ground level distances multiplied by the combination factor.

Survey Control Networks

The third fundamental element required for the creation of a map is a system of survey control that makes manifest on the surface of the earth the map projection used, and makes it possible to accurately relate the measurements involved in surveying and mapping to the map projection. A survey control network consists of a framework of monumented points, or stations, the locations of which, on the surface of the earth, are accurately known—either relatively or absolutely. The control survey stations are used to locate, orient, and adjust local surveys, to provide a means of verification and check for such surveys, and in the use of surveys in the preparation of maps. Survey control networks are of two types:

horizontal, in which the locations of the monumented stations are given either in terms of latitude and longitude, or in terms of State Plane Coordinates; and vertical in which the orthometric heights—elevations—of the monumented stations (called *bench marks*) are given in feet above the geoid—mean sea level configuration—of the earth.

There are, in fact, two horizontal survey control networks in place and used within much of the United States: (1) the geodetic control survey network created by the federal government through the National Geodetic Survey, formerly known as the U.S. Coast and Geodetic Survey; and (2) the U.S. Public Land Survey System, also created by the federal government through the Bureau of Land Management and its predecessor agencies. The National Geodetic Survey also provides a vertical control network complimentary to the horizontal control network. The geodetic control survey system provides the basis for all federal topographic mapping efforts, and for the preparation of all nautical and aeronautical charts within the continental United States, including Alaska.

The U.S. Public Land Survey System provides the basis for all real property boundary surveys and mapping in much, but not all, of the continental United States. The states in which the Public Land Survey System has been established include the 30 states that were created out of the public domain—that is, out of the lands originally ceded to, and owned by, the federal government. These states are Alabama, Alaska, Arizona, Arkansas, California, Colorado, Florida, Idaho, Illinois, Indiana, Iowa, Kansas, Louisiana, Michigan, Minnesota, Mississippi, Missouri, Montana, Nebraska, Nevada, New Mexico, North Dakota, Oklahoma, Ohio, Oregon, South Dakota, Utah, Washington, Wisconsin, and Wyoming.

The National Geodetic Survey Control System

As already noted, the national geodetic survey control system actually consists of two networks: a horizontal survey control network and a complimentary vertical survey control network. The system is a scientific system designed to provide, as already noted, the basic control for all federal topographic mapping and hydrographic and aeronautical charting operations.

The horizontal survey control network consists of thousands of monumented points whose positions on the surface of the earth—expressed in terms of latitude and longitude—were established to known high orders of accuracy by the U.S. Coast and Geodetic Survey (USC and GS), now National Geodetic Survey. The positions were established by high-order triangulation and traverse surveys. The stations are relatively widespread, being typically located on topographic high points, and are often relatively inaccessible. The use of the stations requires knowledge and skill in the use of geodetic survey techniques and equipment, knowledge, and skills, not generally historically available to public works engineers and land surveyors.

In order to make the national horizontal survey control network more readily available to and usable by local surveyors, the USC and GS in 1933 devised the State Plane Coordinate System. As already noted, the State Plane Coordinate

System, as originally developed, is based on the Clark Spheroid of 1866 and the attendant North American Datum of 1927 (NAD-27). The State Plane Coordinate grid values are expressed in U.S. survey feet. Also as noted, the system translates the spherical coordinates—latitude and longitude—of the primary federal survey control stations into rectangular coordinates on a plane surface mathematically related to the ellipsoid on which the spherical coordinates have been determined. The State Plane Coordinate System is designed so that the effect of the distortion inherent in the projection of the curved surface of the ellipsoid onto the plane used for the rectangular grid is not more than one part in 10,000. The State Plane Coordinate System, thus, permits local engineers and surveyors to connect surveys by simple, well established plane surveying techniques tied to the extensive network of precisely located triangulation and traverse stations of the national geodetic control survey network.

If the location of a point is defined by stated coordinates on the State Plane Coordinate System grid, then the location of that point is also known by its corresponding latitude and longitude. Thus, the precise location on the surface of the earth of all survey stations and landmarks established in local engineering and land surveys can be accurately described by stating their coordinates referred to the common origin of the State Plane Coordinate System grid. Once plane coordinates are established for any survey station or landmark, these coordinates may become the best available evidence for the original positions concerned, should physical monuments be lost. Computations relating to the lengths and bearings of lines and to related coordinate values using the State Plane Coordinate System are simple, being made with the well-established formulas of plane surveying.

The National Geodetic Survey (NGS) readjusted the horizontal survey control network in 1983, creating the North American Datum of 1983 (NAD-83). This datum has been further refined in some areas of the United States, such refined datums being identified by a suffix attached to the notation NAD-83. For example, in Wisconsin the refined datum is indicated as NAD-83(91). As already noted, NAD-83 is based on the Geodetic Reference System ellipsoid of 1980. The attendant State Plane Coordinate values are given in meters. The shifts in latitude and longitude values between the two datums can be significant. For example, in Southeastern Wisconsin, the maximum shift in latitude between NAD-27 and NAD-83(91) approximates 11 feet; while the maximum shift in longitude approximates 39 feet. Although these shifts are important globally, affecting courses and distances between intercontinental locations, the shifts do not significantly affect the relative bearings and distances between monumented points and control stations within local areas.

The vertical survey control network of the national geodetic control system consists of a network of monumented benchmarks, the elevations—orthometric heights—of which have been determined by the USC and GS through differential spirit level surveys. The original vertical datum is known as National Geodetic Vertical Datum of 1929 (NGVD-29). This datum was also known as Mean Sea Level Datum. The national level net concerned was based on 26 tide stations located along the coasts of the United States and Canada, interconnected by high-order-accuracy differential spirit level surveys.

The NGS readjusted the level network in 1988 to produce a new vertical datum known as the North American Vertical Datum of 1988 (NAVD-88). The differences in elevations on the two datums can be significant. For example, in Southeastern Wisconsin, the difference between NGVD-29 and NAVD-88 elevations ranges from 0.08 to 0.32 foot.

Some local vertical control survey datums are still in use. These can present significant problems when engineering efforts requiring an areawide approach—such as the hydrologic and hydraulic studies that are required to be conducted on a watershed bases—are involved. The use of the national datums and the conversion of local datums to the national datums is to be encouraged.

U.S. PUBLIC LAND SURVEY SYSTEM

After the Revolutionary War and Louisiana Purchase, the newly created federal government found itself to be the owner of a vast wilderness area stretching westward from the original 13 colonies. Subsequent additions of territory through treaty and purchase greatly expanded this already vast area. In order to facilitate the sale of the public lands and their development through private ownership, it was necessary to provide a convenient and certain method of land description and identification. To this end, the U.S. Public Land Survey (USPLSS) system was devised, and the federal lands were surveyed and monumented by the federal government before sale. The USPLSS is a brilliantly devised system providing a simple means of writing short, unique legal descriptions for each and every parcel of land to be conveyed in the vast area concerned. However, the system depends, as a control survey system, on being able to identify, in the field, the location of the original monuments established by the government surveyors. This is a significant weakness in an otherwise virtually ideal system for real property boundary description and field location identification.

The scheme of subdivision can be summarized as follows (see Figure 5.6): The primary unit of subdivision is the survey township, a nominally 36-square-mile area. The secondary unit of subdivision is the section, a nominally one-square-mile, or 640-acre, area. These units are located with respect to a set of coordinate axes consisting of an initial point, a principal meridian through that point, and a base line, surveyed as a parallel of latitude and therefore a curved line on the surface of the earth, through that point. A set of standard lines, consisting of standard parallels, or correction lines, and guide meridians are used to control for the convergence of the meridional lines. The subdivision of areas enclosed by standard lines into survey townships is accomplished by running range lines (meridional lines) and township lines (latitudinal lines). It should be noted that in the identification system it is the ranges and tiers of townships that are numbered and not the lines. The townships are subdivided into 36 sections as shown and numbered in Figure 5.6. The sections can be further subdivided

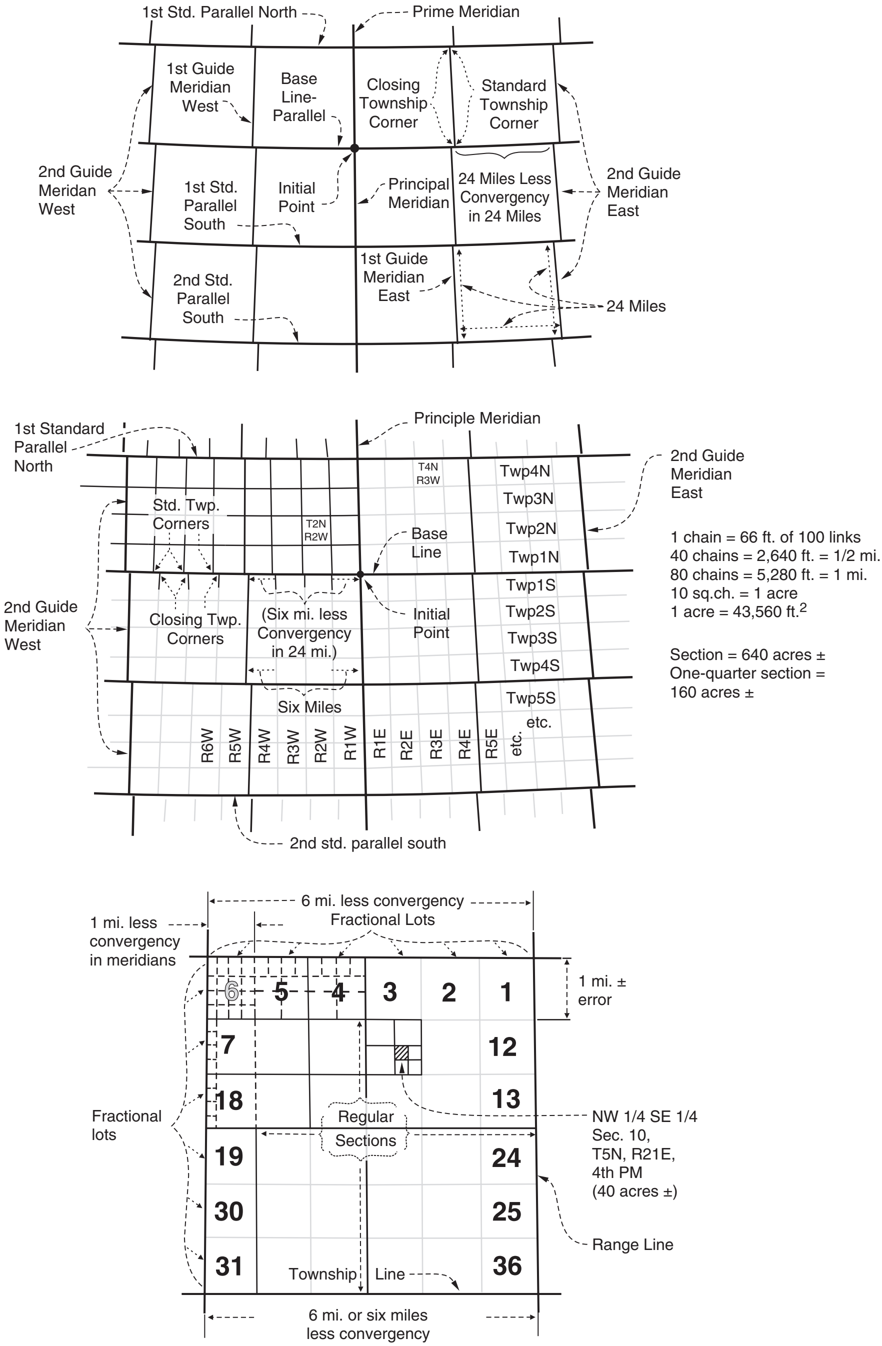


FIGURE 5.6 Standard lines, township and range lines, and township subdivisions.

into one-quarter sections—nominally 160 acre areas, and smaller areas such as 80, 40, 20, 10 and 5 acre areas—by simple descriptions.

A typical legal description might read: NE 1/4 of SE 1/4 of Section 10, Township 5 North, Range 21 East of the Fourth Principle Meridian. Often, the reference to the numbered meridian is dropped and a county and state location substituted. In this example, a nominally 40-acre tract is simply and unambiguously identified. This type of description can readily identify parcels down to a nominal 5 acre size.

The U.S. Public Land Survey System not only provided a simple, unambiguous means for describing and locating real property boundaries for, but also provided the first maps and natural resource inventories of the vast areas covered by the survey system. The instructions to the government surveyors provided that, as the township, range, and section lines were run, notes had to be kept indicating where such lines crossed streams, together with the width of the streams shown and the direction of flow, intersected lake shores, which were then meandered, where wetlands were entered and left, and where woodlands were entered and left. The government surveyors also had to make notations concerning the types of trees in the woodlands, the types and potential fertility of the soils encountered, and the potential presence of gravel, stone, and other mineral deposits. The survey data, when assembled on township plats, provided the first maps of the area surveyed, and the first resource inventory. The survey notes can be used to readily construct an accurate map of the surface water system, wetlands, woodlands, and prairies as they existed at the time of settlement by Europeans.

It should be noted that the two control systems—topographic and real property boundary line—are not on a common datum. This was not critical when topographic maps were compiled by field survey methods, but is critical today when topographic maps are compiled photogrammetrically.

MAP REQUIREMENTS FOR PLANNING AND ENVIRONMENTAL ENGINEERING

The proper planning and design of land development projects and of supporting public works facilities and the proper conduct of environmental studies and assessments require constant attention to two factors: The land itself with its topography and other physical characteristics; and the boundaries of real property ownership. Definitive information about these two factors is essential if land is to be properly developed, if supporting public works are to be soundly conceived and effectively executed, and if environmental studies and assessments are to be properly completed. The need to provide this information, in turn, generates the need for a control survey network, both as a basis for the production of adequate maps and as a basis for the cost-effective execution of land and engineering surveys that can be properly integrated on an areawide basis.

Two basic types of maps are required to adequately meet municipal planning and engineering and environmental study and assessment needs:

1. *Large-scale topographic maps.* Such maps accurately show the configuration and elevation of the ground (hypsometry); stream and watercourse lines, and other natural and cultural (manmade) features of the land and cityscapes (planimetry). The desirable scale of such maps for planning and engineering purposes may range from one inch equals 50 feet to one inch equals 200 feet, with vertical contour intervals ranging from 1 to 2 feet.

   The maps should be prepared on a map projection to National Map Accuracy Standards (i.e., all horizontal control survey stations and all map projection tick markers should be plotted to an accuracy of 0.01 inch on the map sheet). All well-defined planimetric features should be plotted to an accuracy of $1/30^{th}$ of an inch; 90 percent of all contour lines should be accurate to within one-half contour interval; and all spot elevations should be accurate to within one-quarter of a contour interval.
2. *Large-scale cadastral maps.* Such maps accurately show the location, arrangement, and dimensions of all real property boundary lines, including all street and other public rights-of-way. The cadastral maps should be prepared on the same map projection and at the same scale as the topographic maps. The use of a common map projection is essential so that the data presented on the cadastral maps can be readily and precisely correlated with the data presented on the topographic maps by simple "overlay" processes—that is, so that the two types of maps can be readily and accurately integrated by analog or digital means.

These two types of maps, if properly prepared, are not only useful in the conduct of day-to-day planning and engineering functions, but can provide the basis for the economical preparation of a number of other maps such as zoning district maps and official maps, and to create planning base maps. The later show specific types of fundamental information—such as, for example, real property lines, copies of which can then be utilized to display other information. Importantly, these two types of maps, if carefully designed and constructed on a common map projection, can be used to create automated, parcel-based, land information systems.

Topographic maps should be prepared by photogrammetric methods. Cadastral maps will normally be prepared by conventional plotting techniques that require the interpretation of the legal descriptions of real property boundaries. As already noted, the maps should be prepared on a common map projection. All horizontal control survey stations and all map projection grid tick marks should be shown with an accuracy of 0.01 inch on the map sheet; all real property boundary lines should be plotted to an accuracy of 2.5 feet, and all gaps and overlaps of 2.5 feet or more should be shown; all smaller gaps and overlaps should be annotated. A peculiar feature of cadastral maps that is not in accord with the basic definition of a map is that the dimensions and bearings of real property boundary lines are typically shown on the maps. However, the dimensions given are ground-level figures and are not reduced to sea level and grid values. This introduces small differences in the values concerned, usually less than 0.01 foot in 100 feet.

Desirable Control Survey and Mapping System

It is essential that the control survey system meet two basic design criteria if the maps based on it are to be effective planning and engineering tools. First, the control survey system must facilitate the accurate correlation of real property boundary line maps with topographic maps. Second, the control survey network must be monumented on the ground so that lines on the maps can be correctly reproduced in the field when planned land-use development and supporting public works projects reach the construction stage. That is, the control survey system should provide not only the foundation for the preparation of maps that accurately reflect topographic and cadastral conditions, but also maps the lines of which can be readily and accurately reproduced on the ground as well. The topographic and cadastral maps should be prepared at scales large enough not only for use in comprehensive planning, but also for use in site-development planning, preliminary engineering, and environmental studies and assessments. Importantly, the topographic and cadastral maps should be based on a common control survey network so that the two types of maps can be accurately correlated.

In areas covered by the U.S. Public Land Survey System, the control survey network should entail the relocation and monumentation of all U.S. Public Land Survey section and quarter section corners, including the centers of sections, and the use of these corners as stations in high-order surveys tied to the national horizontal control survey and national vertical control survey systems. The horizontal control surveys should establish the grid lengths and grid bearings of all quarter section lines, as well as the geographic positions in the form of state plane coordinates, of the U.S. Public Land Survey corners; while the vertical control surveys should establish orthometric heights—elevations—for the monuments marking the U.S. Public Land Survey corners and of certain accessories thereto.

The adopted control survey system provides the desirable common system of control for real property boundary line, as well as for topographic mapping, and for the conduct of both land and engineering surveys. Since all new land subdivision plats must typically, in states covered by the U.S. Public Land Survey System, by state law be tied to corners established in that system, and since the accuracy of these plats can be controlled by state and local land subdivision regulations, the cadastral maps can be readily and accurately updated and extended into newly developed areas. By locating and monumenting the U.S. Public Land Survey System corners and accurately placing those corners on the State Plane Coordinate System, it becomes at once possible to prevent the future loss of these corners and to make the use of the State Plane Coordinate System practical for land and engineering surveys.

The ability to accurately correlate topographic and real property boundary line data by simple overlay techniques—analog or digital—can provide great savings in research time during the planning and design phases of municipal public projects and in the conduct of environmental engineering studies and environmental assessments. Such correlated information makes possible the consideration and analysis of many alternative configurations for such public works facilities as drainage and flood control works, trunk sewers, water transmission mains and major traffic ways, and thereby of many alternative solutions to drainage, flooding, sewerage, water supply, and transportation problems. The control survey system and attendant maps also facilitate the preparation, calibration, and validation of the hydrologic and hydraulic simulation models essential to drainage and flood control, sanitary sewerage, and water supply system planning and engineering.

The control survey system provides a common bearing basis for all surveys and plats and permits elevations to be referenced to a common datum. The system places a monumented recoverable control survey station accurately located on both the U.S. Public Land Survey System and on the State Plane Coordinate System, and an attendant monumented reference benchmark at approximately one-half-mile intervals throughout the area covered so that a user is never more than about one-quarter mile from a monumented control survey station of known location on the two control survey systems concerned and of known elevation. The system thus facilitates the conduct of surveys required for certain types of environmental engineering efforts such as, among others, the delineation of floodlands, wetlands, woodlands, wildlife habitat, and contaminated areas, and facilitates the preparation of maps displaying the delineated areas.

The system permits lines drawn on maps—whether marking the limits of land to be reserved for various public and private uses, the limits of regulatory districts, or the selection and alignment (horizontal and vertical) of proposed public works to be accurately and precisely reproduced in the field. The system and attendant maps facilitate the administration of zoning, land subdivision control, the official map ordinances and the delineation of flood hazard areas. The system and attendant maps also facilitate the preparation of derived maps, such as land use maps, base maps for planning and engineering studies, and utility system maps, and facilitate the graphic display of planning data. The control survey system and attendant maps facilitate the preparation of accurate facility "as-built" records. Importantly, the system and attendant maps provide the foundations for the creation of automated parcel based land information systems and public works managements systems.

If a county or municipality has a properly staffed engineering department, the basic mapping work should be the responsibility of that department—thereby, freeing the city planning and other departments to conduct long-range and current planning operations. Planners, environmental engineers, and other users must, in any case, be familiar with the use and limitations of maps in the conduct of their work.

APPLICATIONS OF MAPPING SYSTEM

The utility of the described control survey and mapping system in the conduct of environmental engineering studies and assessments may be illustrated by the presentation of the types of control survey data and maps envisioned, and a few examples of the application of particularly the maps to environmental studies and assessments. The control survey data should be presented in a series of summary diagrams covering the area concerned—typically a county or metropolitan region. The diagrams, as shown in Figure 5.7, should show the State Plane Coordinates of the monumented U.S. Public Land Survey System corners; the ground level lengths, sea level–grid lengths, and grid bearings of the exterior boundaries of each one-quarter section, the number of degrees, minutes, and seconds in the interior angle of each one-quarter section; and the elevations of the control survey station monuments. Any national control survey stations within the area concerned, and used to tie the U.S. Public Land Survey system corners to the National Geodetic Control Survey Network, should be shown, together with the coordinates of those stations. The angle between geodetic and grid north (theta angle) should be given, as should the combination scale and sea-level reduction factor used to convert grid to horizontal ground level distances. In addition, the area in acres of the one-quarter sections, as computed using ground level distances and grid bearings, should be given.

A data sheet similar to the one shown in Figure 5.8 should be prepared for each control survey station to facilitate the ready recovery and use of the station. These sheets should identify the U.S. Public Land Survey corner concerned, the State Plane Coordinates of the corner, and the elevation (orthometric height) of the corner monument and of one or more attendant reference benchmarks. The grid bearing to an azimuth mark visible from the station should be given. The sheets should contain a land surveyor's affidavit certifying to the validity of the corner location, and its use in the conduct of land surveys.

The attendant topographic maps (such as that shown in Figure 5.9) should be constructed upon the State Plane Coordinate System grid and the adopted control survey network. The State Plane Coordinate grid tick marks should be shown at five-inch intervals, and the monumented control survey stations—the U.S. Public Land Survey System corners—and the related one-quarter section lines should be shown, together with the State Plane Coordinates of the monumented corners, and the grid and ground level lengths, and grid bearings of the one-quarter section lines. The maps should be prepared to National Map Accuracy standards and should accurately show the hypsometry and planimetry of the mapped area.

Matching cadastral maps, such as that shown in Figure 5.10, should be compiled on the same coordinate grid as the topographic maps, and should show in their correct location and orientation, the U.S. Public Land Survey System corners and the State Plane Coordinates of those corners, together with the one-quarter section lines and the ground-level lengths and grid bearings of those lines as established by the control surveys. State Plane Coordinate System grid ticks should be shown at five-inch intervals. In addition to showing the real property boundary and street and railway rights-of-way lines, the maps should contain an identification number for each ownership parcel. These parcel identification numbers can be used to link the map parcels to a computerized database containing attribute data for each parcel, thus providing the foundation for the creation of a parcel-based land

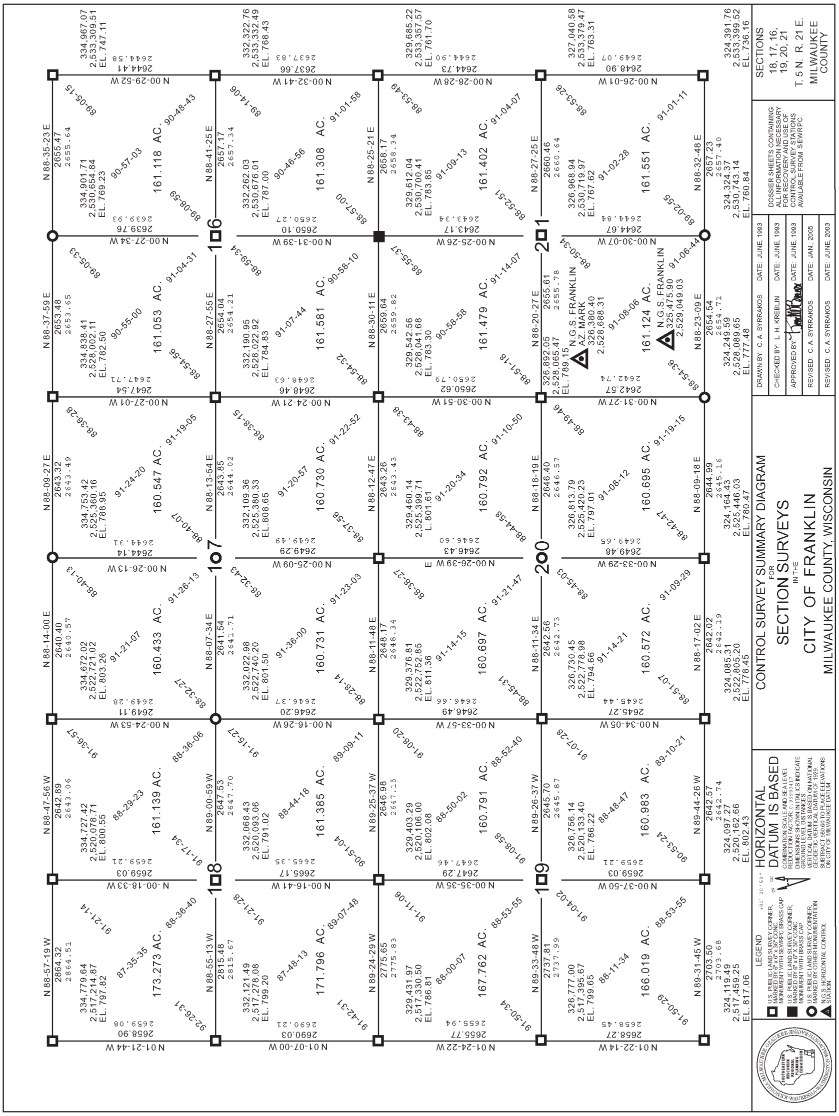
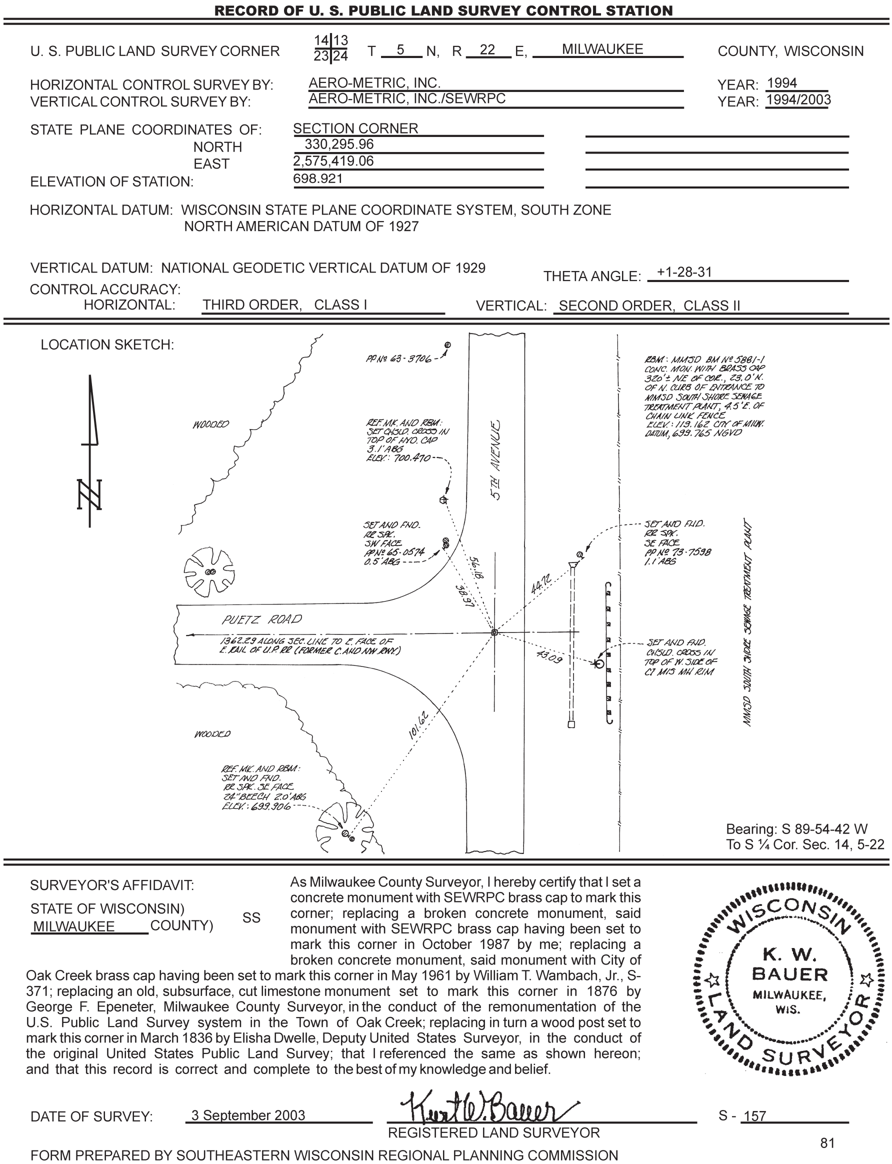


FIGURE 5.7 Example: control summary diagram.



RECORD OF U. S. PUBLIC LAND SURVEY CONTROL STATION

U. S. PUBLIC LAND SURVEY CORNER 14|13 23|24 T 5 N, R 22 E, MILWAUKEE COUNTY, WISCONSIN

HORIZONTAL CONTROL SURVEY BY: AERO-METRIC, INC. YEAR: 1994
VERTICAL CONTROL SURVEY BY: AERO-METRIC, INC./SEWRPC YEAR: 1994/2003

STATE PLANE COORDINATES OF: SECTION CORNER
NORTH 330,295.96
EAST 2,575,419.06
ELEVATION OF STATION: 698.921

HORIZONTAL DATUM: WISCONSIN STATE PLANE COORDINATE SYSTEM, SOUTH ZONE
NORTH AMERICAN DATUM OF 1927

VERTICAL DATUM: NATIONAL GEODETIC VERTICAL DATUM OF 1929 THETA ANGLE: +1-28-31
CONTROL ACCURACY:
HORIZONTAL: THIRD ORDER, CLASS I VERTICAL: SECOND ORDER, CLASS II

LOCATION SKETCH:

Bearing: S 89-54-42 W
To S ¼ Cor. Sec. 14, 5-22

SURVEYOR'S AFFIDAVIT:
STATE OF WISCONSIN)
MILWAUKEE COUNTY) SS

As Milwaukee County Surveyor, I hereby certify that I set a concrete monument with SEWRPC brass cap to mark this corner; replacing a broken concrete monument, said monument with SEWRPC brass cap having been set to mark this corner in October 1987 by me; replacing a broken concrete monument, said monument with City of Oak Creek brass cap having been set to mark this corner in May 1961 by William T. Wambach, Jr., S-371; replacing an old, subsurface, cut limestone monument set to mark this corner in 1876 by George F. Epeneter, Milwaukee County Surveyor, in the conduct of the remonumentation of the U.S. Public Land Survey system in the Town of Oak Creek; replacing in turn a wood post set to mark this corner in March 1836 by Elisha Dwelle, Deputy United States Surveyor, in the conduct of the original United States Public Land Survey; that I referenced the same as shown hereon; and that this record is correct and complete to the best of my knowledge and belief.

DATE OF SURVEY: 3 September 2003 Kurt W. Bauer
REGISTERED LAND SURVEYOR S - 157
81

FORM PREPARED BY SOUTHEASTERN WISCONSIN REGIONAL PLANNING COMMISSION

FIGURE 5.8 Example: control survey station recovery sheet.

information system. Such data may include—among a virtually infinite variety of physical, social and economic data—street address, parcel area, ownership, valuation, existing land use, zoning, and presence of such conditions as flood hazard, and environmental contamination. The topographic maps, cadastral maps, and related attribute data should be prepared and maintained in digital format for ready computer manipulation and automated display.

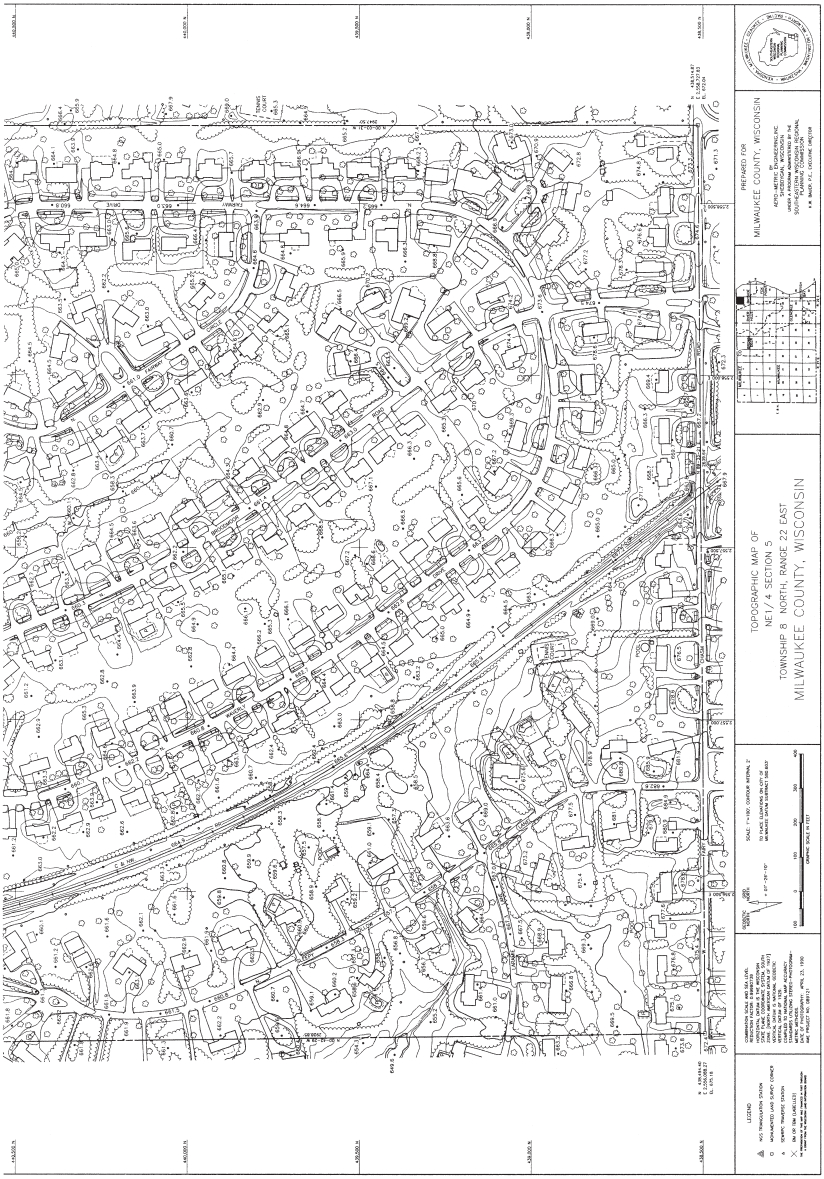


FIGURE 5.9 Typical topographic map.

-8-

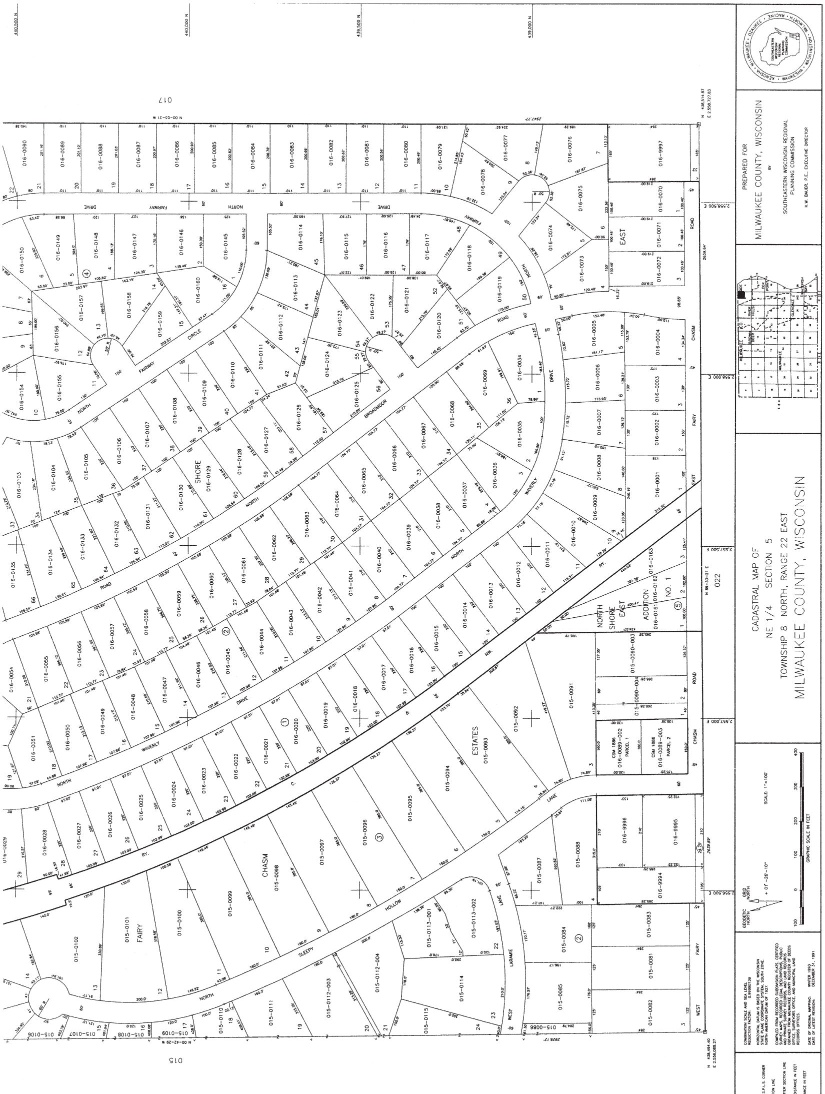


FIGURE 5.10 Typical cadastral map.

Flood Hazard Area Mapping

Figure 5.11 illustrates the use of the control survey and mapping system in the delineation of flood hazard areas. The figure illustrates the accuracy and precision with which flood hazard lines can be delineated. It should be noted, however, that the maps also greatly facilitate the conduct of the engineering studies required to delineate the flood hazard areas, particularly the hydrologic and hydraulic studies that provide the flood stage elevations that are projected on the map hypsometry to produce the flood hazard lines. The control survey and mapping system facilitates the delineation of the channel profiles and cross-sections and the conduct of the field surveys necessary to determine bridge and culvert waterway openings and related hydraulic characteristics. The maps permit the accurate delineation of both natural and artificial watershed and drainage boundaries essential to determining drainage areas for use in the hydrologic analyses. It should also be noted that since the map planimetry accurately displays rooftops, driveways, paved parking areas, and street and alley pavements, it permits the accurate determination of the impervious surface areas within a water shed, data useful in determining the C values used in the rational method, and the runoff factors in the SCS-TR55 method used in calculating runoff. The control survey network also facilitates the conduct of any field surveys that might be necessary to validate the flood hazard delineation and to relate such delineation to historic flood events and attendant flood damages.

Wetland Area Mapping

Figure 5.12 illustrates the use of the control survey and mapping system for the delineation of wetland areas. In wetland delineation, an experienced biologist, soil scientist, or specially trained environmental engineer visits the site concerned and marks (stakes) the boundaries of the wetland and associated plant communities and animal habitats in the field. This visit and survey is facilitated by having a copy of the large-scale topographic map of the area concerned in hand. A registered land surveyor then surveys the boundaries as marked, utilizing plane surveying techniques; and then delineates the surveyed boundaries on a plat of survey tied to the control survey network. This permits integration of the resulting wetland maps into the existing base maps and into a parcel-based land information system for the area concerned.

For some environmental reconnaissance surveys and inventories, somewhat cruder survey techniques may be utilized. These could involve the use of commercially available handheld global positioning system instruments that—with an attendant proper software program—can provide State Plane Coordinate locations with an accuracy of about three to five meters. In this manner, the biologist or soil scientist involved can obtain crude coordinates for the wetland boundaries as they are marked in the field. These boundaries can then be plotted on the topographic maps, cadastral maps, or on a combination of the topographic and cadastral maps for use in the environmental engineering effort.

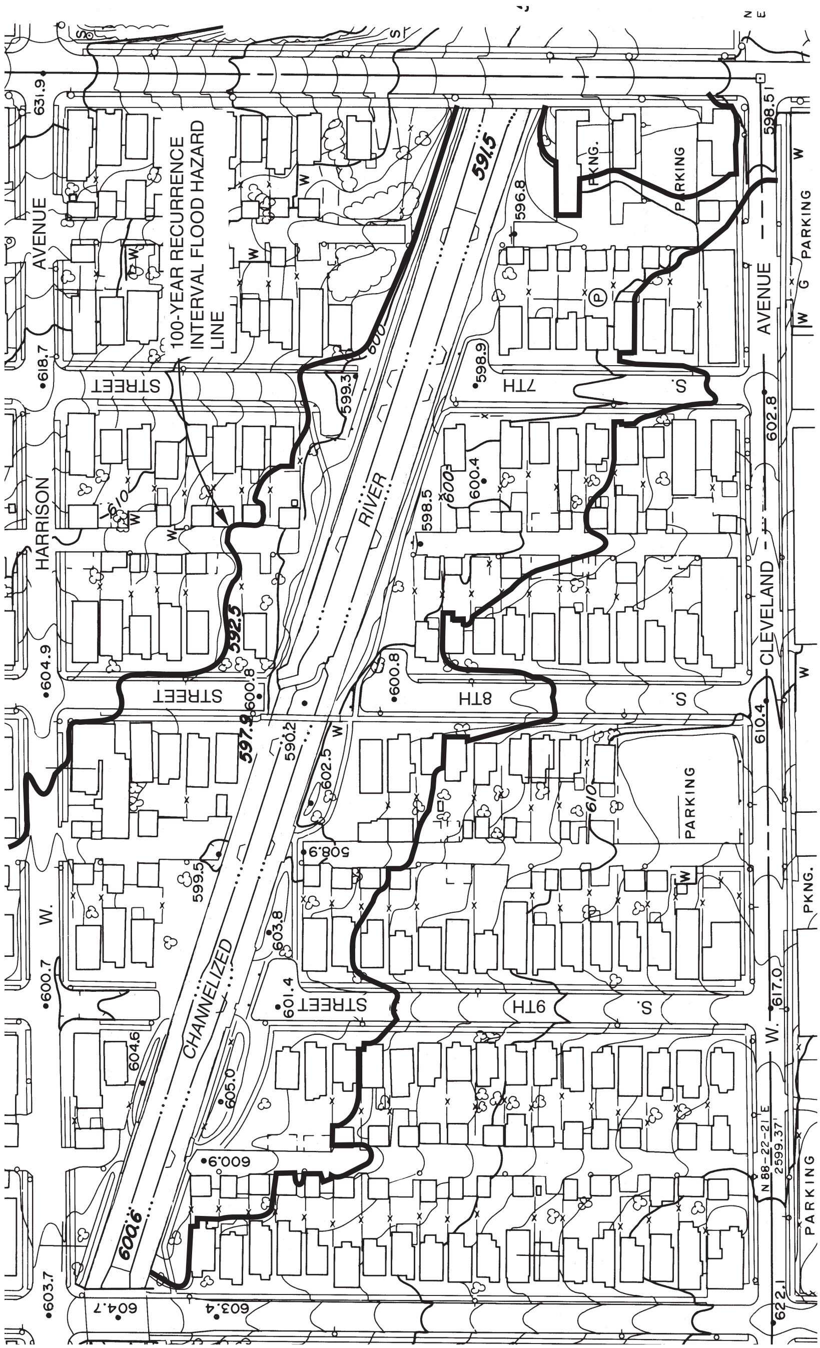


FIGURE 5.11 Example: flood hazard area delineation.

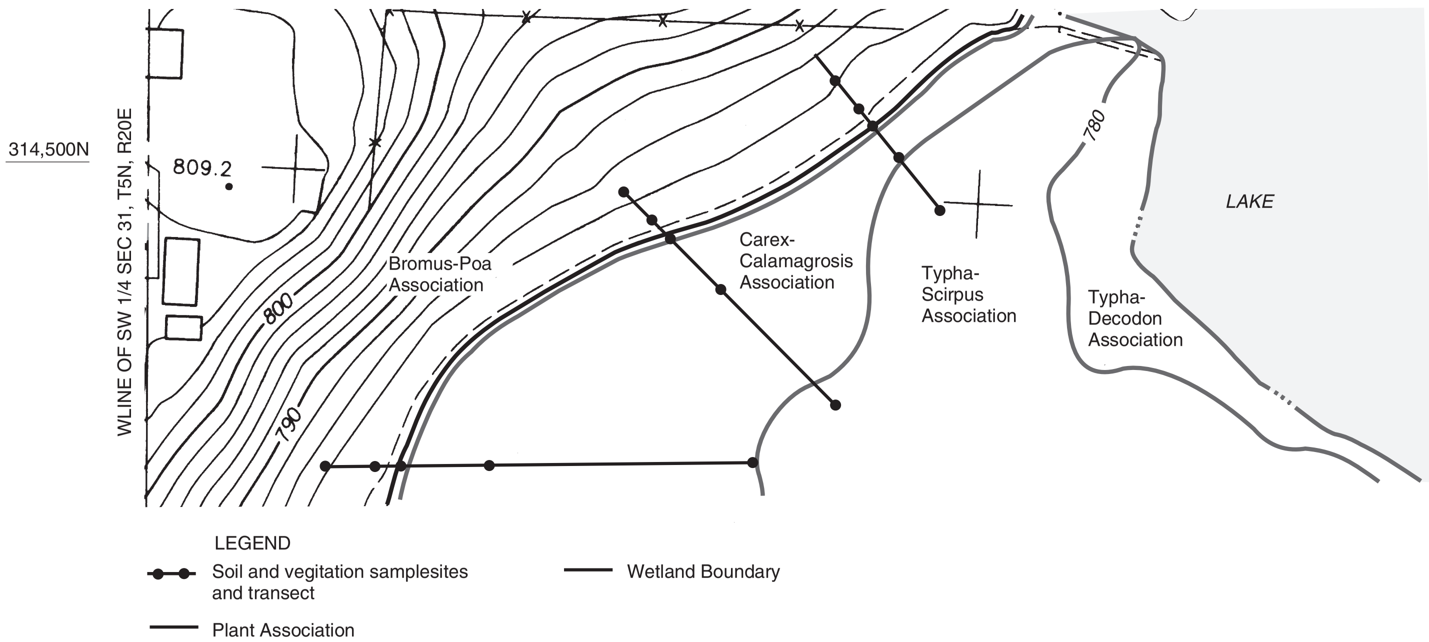


FIGURE 5.12 Example: wetland delineation.

Public Works Management Information System

Public works facilities—water mains, sanitary sewer lines, storm drains, and street improvements—provide the infrastructure essential for urban life. The efficient management of public works requires detailed knowledge about the configuration, condition, and performance of each of the various systems of public works serving the urban area. Such knowledge requires not only the collection of data about the system to be managed, but also the conversion of that data through analyses into pertinent information, and then, by the exercise of professional judgment, into intelligence on the basis of which sound management decisions can be made.

Historically, data about public works were kept on paper records, such as file index cards, construction plans, as-built construction records, special-purpose maps and plats, and written reports. Sometimes, the data resided only in the living memory of staff. The records were often duplicative, poorly maintained, difficult and time-consuming to access and use, and not well coordinated between different functional areas such as tax assessment, planning, and engineering. When meticulously kept and well indexed, such manual systems have worked tolerably well, particularly in smaller communities. As the size and complexity of a community increases, however, the use of manually kept records becomes increasingly difficult and unsatisfactory. The means now exist for the modernization of these records and, therefore, of their conversion into an efficient and effective computer-based public works management information system. The existence of such systems greatly facilitates the conduct of environmental engineering studies and assessments, as well as the preparation of facility system plans.

Two developments make such computer-based public works management information systems possible: the development of powerful, yet relatively low-cost and user-friendly, microcomputer systems; and the development of high-quality, automated base maps. Together, these two developments provide the basis for the creation of parcel-based, automated, land information systems, and in turn, automated public works management information systems. The control survey and mapping system described herein provide a sound foundation for the creation of these land information and public works management information systems.

Figure 5.13 illustrates use of the control survey and mapping system in the development of a public works management information system for a sanitary sewerage system. The addition of sanitary sewerage facilities to an automated base map is valuable in and of itself. Such addition permits sewerage system maps to be readily produced at various scales for analytical and display purposes. If a common control survey and mapping system is used, the sewerage system mapping can be readily correlated with other public and private utility system maps. Importantly, service areas can be delineated for analytical and design purposes, and these service areas can be correlated with real property boundary maps. The sanitary sewerage facilities should be delineated on a base map consisting of a combination of selected features drawn from the available

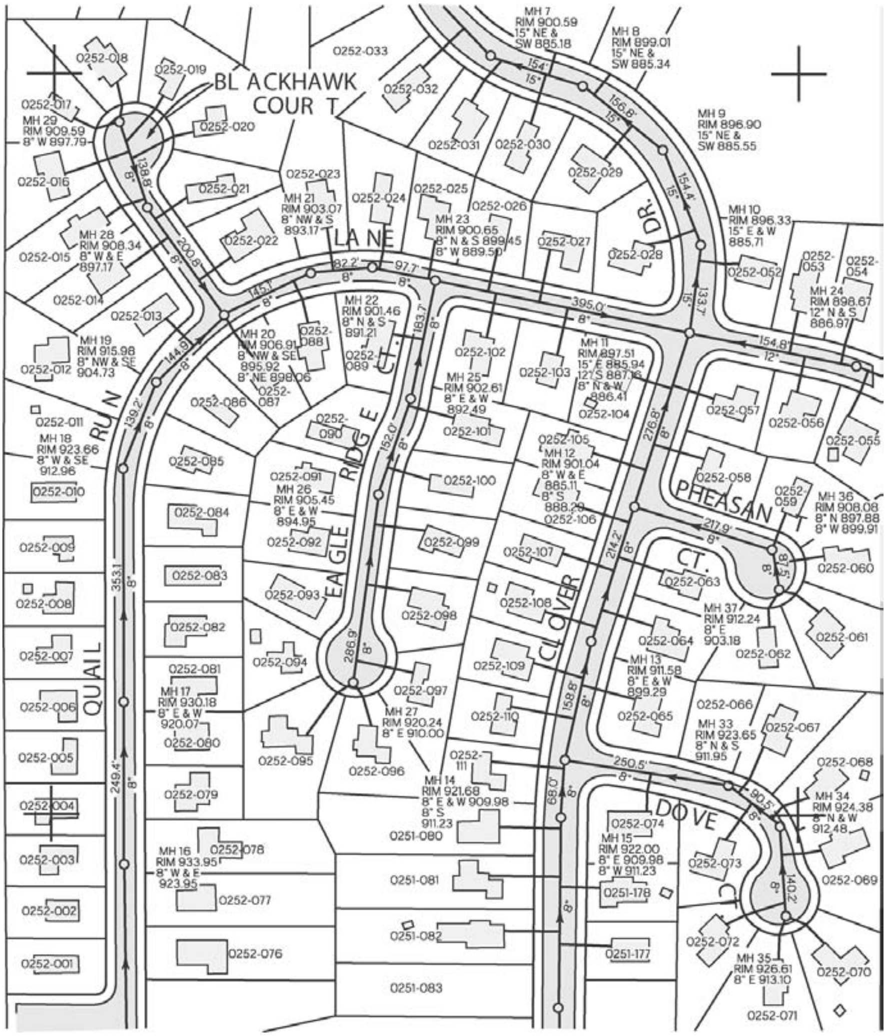


FIGURE 5.13 Portion of a public works information system base map with sanitary sewerage system overlay.

topographic and cadastral maps to provide the necessary foundational element for the facility mapping. The topographic map provides information on building locations and pavement lines; the cadastral map on property boundary and street rights-of-way lines. Since the two maps are constructed on a common projection—the State Plane Coordinate System—the existing sewerage system can be readily inventoried by field surveys using global positioning system techniques for both horizontal and vertical positioning determination. New facilities can then be readily added through the preparation of proper as-built records tied to the State Plane Coordinate System and common vertical datum. Spatial location identification numbers are provided for manholes, and attendant data on manhole rim and sewer invert elevations, and on segment sizes, lengths, and grades added together with service area delineations.

Although the accurate mapping of the facilities is valuable in and of itself, the creation of a public works management information system requires the systematic development of a set of facility attribute data that can be linked by computer to the geographic location data provided by the automated base map. The attribute data files provide information on the structural type, condition, and performance of the facilities concerned. Creation of the attribute data file for each facility system should be accomplished in accordance with detailed memoranda that clearly specify the form and content of the computerized attribute data file. Attribute data for the sanitary sewerage system should be structured to facilitate efficient planning, design, construction, operation, and maintenance of the system. The scope and conduct of the data file should be structured in close cooperation with the director of public works, the city engineer, and system operating and maintenance personnel. A typical list of attribute data is provided in the following.

Sanitary Sewerage System Attribute Data

I. **General**
   - A. System name
   - B. System number
   - C. Primary contact

II. **Gravity flow sanitary sewers—data by segment between manholes**
   - A. Identification number
   - B. Date of construction
   - C. Material
   - D. Pipe size in inches
   - E. Pipe length in feet
   - F. Grade in feet per foot
   - G. Manholes
     1. Type
     2. Cover
     3. Location—State Plane Coordinates, NAD-27
     4. Rim elevation in feet, NGVD-29
     5. Invert elevations in feet, NGVD-29
   - H. Capacity flowing full in cubic feet per second
   - I. Flow in cubic feet per second
     1. Average daily
     2. Instantaneous peak

J. Surcharge elevation in feet, NGVD-29
K. Overflow
    1. Gravity flow
        a. Size in inches
        b. Length in feet
        c. Location in State Plane Coordinates, NAD-27
        d. Invert elevation in feet, NGVD-29
        e. Materials of construction
        f. Capacity in cubic feet per second
        g. Frequency
        h. Duration
        i. Rate in gallons per day
        j. Receiving watercourse
    2. Pumped
        a. Type
        b. Location in State Plan Coordinates, NAD-27
        c. Rated capacity
        d. Idling capacity
        e. Frequency
        f. Duration
        g. Receiving watercourse
L. Condition
M. Service connections
    1. Identification number
    2. Date installed
    3. Location in cumulative feet from downstream manhole
    4. Lateral size in inches
    5. Material
    6. Service street address
N. Service area in acres
O. Construction plans
P. Construction as-built drawings
Q. Plan proposals
R. Instrumentation
    1. Flow meter
        a. Manufacturer
        b. Model and serial number
        c. Date installed
        d. Calibration

e. Supervisory control and data acquisition system
f. identification link to historical database
g. Correction factors

2. Flume
   a. Manufacturer
   b. Model and serial number
   c. Date installed
   d. Calibration
3. High-level/surcharge monitor
   a. Manufacturer
   b. Model and serial number
   c. Date installed
   d. Calibration
   e. Supervisory control and data acquisition system
   f. identification link to historical database

S. Pumping and lift stations data by station
   1. Identification number
   2. Date of construction
   3. Location in State Plane Coordinates, NAD-27
   4. Floor elevation, NGVD-29
   5. Type
   6. Capacity
      a. Pump
         (1) Manufacturer
         (2) Model and serial number
         (3) Date installed
         (4) Life in feet
         (5) Capacity at operating head in cubic feet per second
         (6) Motor
            (a) Manufacturer
            (b) Model and serial number
            (c) Date installed
            (d) Starter type
            (e) Horsepower
            (f) Voltage
      b. Wet well storage–gallons
      c. Power
      d. Auxiliary
         (1) Generator

(a) Manufacturer
(b) Model and serial number
(c) Horsepower
(2) Engine
(a) Manufacturer
(b) Model and serial number
(c) Horsepower
(d) Fuel
(e) Cooling

T. Influent pipes
1. Sizes in inches
2. Invert elevations in feet, NGVD-29
3. Capacities flowing full in cubic feet per second

U. Effluent force main
1. Size in inches
2. Length in feet
3. Receiving facility
4. Materials of construction
5. Capacity in cubic feet per second

V. Emergency bypass
1. Outfall
a. Location—State Plane Coordinates, NAD-27
b. Size in inches
c. Length in feet
d. Invert elevation in feet, NGVD-29
e. Materials of construction
f. Capacity in cubic feet per second
g. Receiving watercourse
2. Bypassing
a. Frequency
b. Duration
c. Rate in gallons per day

W. Construction plans

X. Construction as-build drawings

Y. Service area
1. Size in acres
2. Resident population
3. Commercial area in acres
4. Industrial area in acres

Z. Plan proposals

AA. Instrumentation and controls

1. Controller
    a. Manufacturer
    b. Model and serial number
    c. Date installed
    d. Date serviced by
    e. As-built drawings
2. Instrumentation
    a. Manufacturer/model and serial number
    b. Date installed
    c. Date calibrated
    d. Date last serviced

III. **Treatment plant: data by plant**

A. Plant identification number

B. Type of plant

C. Date of construction by major treatment units

D. Site, location—State Plane Coordinates, NAD-27—of site boundary, site area, in acres

E. Hydraulic capacity by major treatment units

F. Hydraulic loading by major treatment units

G. Biological capacity by major treatment units

H. Biological loading by major treatment units

I. Plant capacity in population equivalent

J. Plant loading in population equivalent

K. Permit effluent quality

L. Operating effluent quality

1. Dry weather flows
2. Wet weather flows

M. Outfall

1. Size in inches
2. Length in feet
3. Invert elevation in feet, NGVD-29
4. Materials of construction
5. Capacity in cubic feet per second
6. Receiving watercourse

N. Bypassing

1. Frequency
2. Duration

3. Rate in gallons per day

O. Construction plans

P. Construction as-built drawing

Q. Replacement cost by major treatment unit and total service area

1. Size in square miles
2. Resident population

R. Plan proposals

Similar tables listing attribute data for public water supply, stormwater management and street systems can be developed to provide a comprehensive public works management information system. The existence of the resulting public works management information system can greatly facilitate the conduct of environmental planning and engineering studies and assessments; the assessment of the condition and performance of existing systems; the existence of environmental problems relating to the existing systems; and the preparation of system, preliminary engineering, and construction plans.

SURVEY METHODS

Many environmental engineering studies and assessments can be facilitated by direct use of the mapping system herein described; that is, by direct use of the topographic maps, cadastral maps, or maps that combine selected elements of these two types of maps. The maps can be used directly in the field during the conduct of reconnaissance studies and of certain types of inventories, the findings of which can be directly sketched on copies of the maps. The maps, together with the attribute data residing in attendant land information and public works management information systems, can be used in the preparation of maps displaying such information as ownership, valuation, historic and existing land use, soils and soil capabilities, flood hazard areas, wetlands, utility facilities, and utility service areas, among others. In the presence of attendant land information and public works management information systems, many of the display and analytical maps required can be provided by computer plots.

The conduct of some environmental engineering studies and assessment will, however, require the conduct of field surveys. Such surveys may be required for the accurate location of site boundaries and of features such as buildings and other structures; existing and abandoned wells, waste outfalls, and old mine shafts; above and underground active and abandoned storage tanks; areas of contaminated soils; plant and animal habitat areas; and active and abandoned waste treatment, storage and disposal areas, among others. The field surveys may require the determination of vertical, as well as horizontal, locations and alignments, and information on, for example, the crown and invert elevations of buried conduits and tanks.

If the control survey network such as herein described is available, the surveys can usually be efficiently and effectively conducted utilizing plane surveying techniques. Modern instrumentation, including total stations equipped with electronic distance measuring capabilities, automated spirit levels, and computerized data collectors, facilitate the connection of the needed surveys to monumented control survey stations of known position on both the State Plane Coordinate and U.S. Public Land Survey Systems, and to the National Vertical Datum. This will permit the survey results to be accurately plotted on the available maps, and correlated with data residing in attendant parcel-based land information and public works management systems. With respect to required elevations (orthometric heights), spirit level surveys initiated at control survey bench marks will directly provide such elevations.

The control survey network herein described, will also facilitate obtaining needed data through traditional photogrammetric means, or through the conduct of newer light detection and ranging (LiDAR) surveys. Properly controlled, such remote sensing technology can be used to quickly obtain information on such features as the location and volume of stock and waste piles that, due to their ephemeral nature, may not be shown on the available topographic maps. Indeed, use of LiDAR technology is being promoted by the Federal Emergency Management Administration for flood plain mapping.

Global positioning system (GPS) equipment can, in many situations, be used in place of the more conventional plane surveying instrumentation. In areas where base stations are available, GPS instrumentation can be used in the real-time kinematic mode to provide horizontal positions to control survey accuracy levels. The surveys can, moreover, be conducted by one person, greatly reducing costs. In the use of GPS instrumentation, care must be exercised to ensure that the instrumentation and attendant software programs are providing coordinate and elevation data referred to the proper datums that are used for the control survey and mapping systems concerned.

The GPS instrumentation can also be used to provide vertical survey control data in the form of ellipsoid heights, as indicated in Figure 5.2. The conversion of such heights to the needed orthometric heights requires knowledge of the geoid heights. Geoid heights are available from the National Geodetic Survey, but the accuracy of the known values (2.5 to 3.0 centimeters) is generally insufficient to provide survey accuracies adequate for many engineering purposes. The availability of the control survey network herein described, however, permits GPS instrumentation to provide orthometric heights to within an accuracy of a few one-hundredths of a foot. This can be done by occupying the monumented control survey stations (e.g., the four corners of a one-quarter section for which orthometric heights are available) and determining the geoid heights at these four locations by comparison of the known orthometric heights to the GPS measured ellipsoid heights. These four values can then be averaged to provide a value for the one-quarter section, and the GPS instrumentation can then be used to obtain both horizontal and vertical positions of utilities and other features located within the one-quarter section. The relationship utilized in the previously described procedure ($H = \mathrm{h} - N$) is an approximation, but can be used with excellent results for municipal engineering purposes. Theoretically, as is apparent from an examination of Figure 5.2, the ellipsoid height, H, and the geoid height, N, are measured along the normal to the ellipsoid, while the orthometric height, h, is measured along the plumb line. Because the ellipsoid and geoid heights are not parallel with the orthometric height, the measurements involved must theoretically be added as vectors, not as scalars. The nonparallelism of the normal to the ellipsoid and the plumb line is known as the deflection of the vertical, and in most cases is small enough to be neglected in surveys conducted for public works and similar engineering purposes.

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CHAPTER 6

PLANNING AND ENVIRONMENTAL ASSESSMENT

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INTRODUCTION

The practice of environmental engineering requires an understanding of urban planning objectives, principles, and practices. Accordingly, this chapter is intended to serve as an introduction to what was, for a time, a highly specialized branch of civil engineering, namely, city and regional planning. Historically, university courses in city and regional planning were often taught in the civil engineering departments, and textbooks in city and regional planning were often authored by practicing civil engineers. The American Society of Civil Engineers, to this day, maintains a division of urban planning and development, and annually awards the Harland Bartholomew Prize for notable achievement in planning. City and regional planning has, however, increasingly become a discipline separate from civil and environmental engineering—a discipline practiced by the now-separate planning profession. A close association and mutual understandings between these two professions is needed.

This chapter considers city and regional planning as a rational process that seeks the orderly and economic development of urban and urbanizing areas—a process that is oriented to the formulation and attainment of sound urban development objectives, and the formulation and application of standards that specify desirable physical arrangements of cities and urban regions. This view of city planning assumes that the orderly physical development of urban areas is in the public interest, and that public planning should be oriented to furthering the public health, safety, and general welfare. Other views of city and regional

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planning exist, such as user-oriented, participatory planning; advocacy planning; and incremental or market-oriented planning. These other views are not, in this chapter, regarded as sound models. Emphasis in this chapter is placed on the central concept of the comprehensive plan, and on plan implementation devices such as zoning, land subdivision control, official mapping, and capital improvement programming. Emphasis is also given to the concept of environmental assessment, which should be an integral part of the planning process, or closely related to that process.

DEFINITION OF TERMINOLOGY

The term *planning* is defined and used in different ways by different professions. Planning is often defined as one of the five functions of management: planning, organizing, directing, coordinating, and controlling. Used in this way, planning is an analytical and creative process that involves the establishment of goals or objectives for organizations, and the establishment of a systematic means for the attainment of these goals or objectives over time. Used in this way, planning, then, is concerned with identifying needs and problems; gathering and analyzing relevant data concerning these needs and problems; developing and testing alternative means for meeting the identified needs and alternative solutions to the identified problems; and adopting and implementing the solution that is judged best. Used in this way, planning is an activity of people who decide matters within an organization, and it encompasses three core tasks, or functions: inventory, goal formulation, and plan design. Techniques aside, planning in this general sense is essentially the same process in whatever milieu it may be applied.

Planning may be classified in a number of ways:

- According to the realm within which the planning decisions lie—as public- or private-sector planning
- According to the disciplines involved in the planning—as economic, social, or physical planning
- According to the jurisdiction concerned as—regional, state, or national planning
- According to the facility or service being planned—as school, hospital, highway, sewerage, water supply, or park planning

Often, several types of resources may be affected by the planning effort, so that planning for the development of any one of these resources may affect one or more others. When this occurs, then one of the resources concerned will be of primary concern, and the others will be of secondary concern in the planning process. Thus, planning for a cultural activity may be defined as social planning, while planning a building for the conduct of this activity may be defined as physical planning. In this case, the physical planning is secondary to the primary social planning. Planning for the development of physical resources is almost always intended to serve primary social and economic development objectives.

Planners operating within municipal government have appropriated the term *planning*, as heretofore considered in its broadest and most general sense, for their own use, giving it a more narrow and restricted meaning. This is the meaning that will be used in the rest of this chapter.

Under this narrower definition, city—and, by extension, regional—planning is a process concerned with guiding the amount, rate, character, and quality of urban change; and is concerned primarily with the arrangement of land uses and with the provision of the necessary supporting transportation, utility, and community facilities and services. Under this definition, planning is directly concerned with the physical development of cities and metropolitan areas. It does not attempt to establish the broader policies to be pursued with respect to the social and economic development of these areas, but is concerned with providing the physical infrastructure required for such development. It thereby greatly influences the quality of life within cities and urban regions. Under this narrower definition, the core function of city planning includes the preparation of plans for land use, and for the supporting transportation, utility, and community facilities; and the preparation and administration of plan implementation devices such as zoning, land subdivision control, official mapping, and capital improvement programming.

City planning takes effect largely through the operation of government, and requires the application of specialized survey, analysis, forecast, and design techniques. City planning may, therefore, be viewed as a social movement, as a local governmental function, or as a technical profession. Each viewpoint has, to a certain extent, its own concepts, history, and principles of practice. Together, they fuse into the effort of modern societies to shape and improve the environment within which increasing proportions of humanity live and work: cities and their urban regions.

CRITERIA FOR GOOD PLANNING

Good urban planning should meet at least three criteria:

1. Good planning should be comprehensive, considering all aspects of the physical development of an area, and relating these to common unifying objectives. A comprehensive approach is essential to the making of intelligent decisions concerning relative needs and the effective allocation of resources to areas of greatest need.
2. Good planning should be relatively long-range, looking well beyond obvious needs of the moment and attendant expedient solutions.
3. Good planning should encompass a geographic area that permits a sound technical approach to the issues and problems concerned. Thus, for example, drainage and flood control planning must consider natural watersheds as rational planning areas; and transportation system planning must consider entire commuter sheds as rational planning areas.

Consideration of these criteria leads to the conclusion that some important aspects of local urban planning can only be properly conducted within the framework of broader regional planning. Moreover, regional planning can best be conducted within a framework provided by formally adopted state development objectives, and should serve to make these objectives operational at the multicounty regional or metropolitan area. Thus, an adopted state policy might be to maintain floodlands in essentially naturally open uses. The hydrologic and hydraulic studies required to establish flood flows and stages, and to map the attendant flood hazard areas, can best be accomplished at the regional level based on areawide land-use inventories and plans. The adopted regional plans are then made operational through preparation of local plans that are consistent with the regional plans. In the example used, the local land use and community facility plans would identify the mapped floodlands and recommend their preservation in park and open space uses. Local zoning, land subdivision control, and official mapping can then be used to implement the local plans in a manner consistent with regional plans and the state development objectives.

INSTITUTIONAL STRUCTURE FOR URBAN PLANNING

In the United States, municipalities are creatures of the states and have only such powers, duties, and functions as the state legislatures grant to them. Accordingly, states must enact city and regional planning enabling legislation to permit municipalities—cities, villages, and civil towns—counties and multicounty regions to engage in planning. Many state enabling acts follow the approach recommended in the federal model city planning enabling act of 1927, which delegates the urban planning function to advisory bodies known as plan commissions. In theory, this delegation entrusts this important municipal function to a continuing body of public officials and citizens qualified for the task, free from the distractions of routine matters of administration, and somewhat detached and insolated from partisan politics. The state enabling legislation provides for the creation of such commissions and specifies their composition, functions, duties, and powers. The enabling legislation will normally provide that the plan commission may retain a staff and, as necessary, consultants, in accordance with an annual budget provided by the governing body of the municipality. The staff that serves the commission will normally be a department of a municipal government. Some planners argue that the planning function should be under the direction of the chief executive officer of the municipality, rather than under the direction of the plan commission.

The state enabling legislation usually provides that the plan commissions are entirely advisory to the executive and legislative branches of municipal government. The commissions may make reports and recommendations relating to the development of the municipality, not only to municipal officials and agencies, but also to public utility companies, other organizations and citizens. Importantly, the commissions are usually responsible for recommending long-term capital improvement programs to the executive and legislative branches, for example, to the mayor and common council. In addition, certain matters usually must be referred to the plan commission before the municipal governing body, or other public officer having final authority, thereon acts. These matters usually include, among others, the location and architectural design of public buildings; and the location, extension, alteration, vacation, or acquisition of land for streets and other public ways, and for parks, playgrounds, and other open spaces; and the location, extension, abandonment, or authorization for any public utility; and all land subdivision plats. The enabling legislature usually also provides for the municipal government to adopt, upon recommendation by the plan commission, certain plan implementation devices such as zoning, land subdivision control, and official map ordinances.

THE COMPREHENSIVE PLAN

The most important function and duty of a municipal or regional plan commission is to make and adopt a comprehensive plan for the physical development of the city or region. The plan should show the commission's recommendations for the physical development of the area concerned. The plan is intended to be made with the general purpose of guiding and accomplishing a coordinated, adjusted, and harmonious development of the municipality that will best promote the public health, safety, and general welfare, as well as efficiency and economy in the process of development. In some states, the enabling legislation may specify the permissible content of the comprehensive plan only very generally—in other states, in specific detail.

A comprehensive plan report may be expected to have the following composition:

Chapter 1 Introduction

This chapter should include background information on the geographic limits of the planning area and on its regional setting; the need for and purpose of the plan; the planning process; the planning organization and staff structure; and the scheme of presentation.

Chapter II Demographics and Economic Base

This chapter should provide for the planning area information on the population size, distribution, characteristics, and on historic growth trends in these factors. It should also provide information on the labor force, economic base and structure, trade area, personal income, and property tax base; and on historic trends in these factors.

Chapter III The Natural Resource Base

This chapter should provide for the planning area information on such factors as climate; air quality; geology and physiography, topography and drainage patterns and areas; soils, ground and surface water resources; wetlands, woodlands, wildlife habitat and environmental corridors.

Chapter IV Land Use

This chapter should provide information on historic urban growth patterns in the planning area; and on the existing land use patterns, including the amount and areal distribution of the residential, commercial, industrial, and institutional land uses.

Chapter V Transportation

This chapter should provide information on the location, configuration, capacity and utilization of the transportation facilities of the planning area, including the arterial streets and highways and public transit facilities and, as applicable, railway and airport facilities.

Chapter VI Public Utilities

This chapter should provide information on the location, configuration, capacities, and use of the utilities in the planning area, including the sanitary sewerage, water supply, stormwater management and flood control, and solid waste management facilities.

Chapter VII Community Facilities

This chapter should provide information on the existing parks, public buildings, such as fire and police stations, administrative offices, libraries, and, in some cases, hospitals and public housing facilities of the planning area.

Chapter VIII Housing

This chapter should provide information on the existing housing stock by number of units; distribution, occupancy, and vacancy statistics; structure types, and costs in terms of valuations and rents. The chapter may also include descriptions of existing governmental and private activities in providing decent, safe and sanitary low-income housing within the planning area together with data on housing costs and affordability.

Chapter IX Adopted Plans and Land Use Regulations

This chapter should provide information on areawide plans affecting the local planning area; on past comprehensive plans; on existing land use regulations, including zoning, subdivision control, and official mapping; and on any special purpose districts such as metropolitan sewerage districts, and the relationship of these districts to the local planning area.

Chapter X Anticipated Growth and Change

This chapter should present projections and forecasts of future population, household, and employment levels; and on the demand for the various types of land uses within the planning area.

Chapter XI Objectives, Principles, and Standards

This chapter should set forth agreed-upon land use, transportation, utility, and community facility development objectives, together with a set of supporting standards that can be used to quantitatively link the objectives to alternative and recommended plan elements.

Chapter XII Plan Elements

A. Land Use

This plan element should consist of a recommended future land use pattern for the planning area, including recommendations on the amount and distribution of land proposed to be used for residential, commercial, industrial, and institutional uses. The plan should identify existing land uses to be retained and areas to be devoted in the future to each of the various types of land uses. The plan should identify environmentally sensitive lands that should be maintained in essentially open use, such as in parks, parkways, and open space reservations. The plan should include recommendations concerning the desirable densities and intensities of the various recommended uses. In some cases, provisions may have to be made for lands to be devoted to mineral extraction, sanitary landfills, cemeteries, and other special use areas. At the regional level, the plan should contain recommendations for the preservation of prime agricultural lands.

B. Transportation

This element should include recommendations for the future configurations and capacities of the arterial streets and highway system and of the transit system, and in some cases may address vehicular parking, railway, airport, and seaport facilities. The plan should identify the location, configuration, and proposed capacities of facilities to be retained; those to be improved or otherwise altered, and of new facilities proposed to be constructed.

C. Utilities

This plan element should include recommendations for the future configuration and capacities of the sanitary sewerage, water supply, stormwater management and flood control, and solid waste management facilities, including the location and capacity of needed conveyance, storage and treatment facilities; and for the control of both point and non-point sources of water pollution. The plan should identify the locations and proposed capacities and levels of treatment to be provided by sewage and water treatment plants and of trunk sewer and water transmission lines.

D. Community Facilities

This element should include recommendations for park and parkway development; and for the location, size, and design of public buildings, such as administrative centers, fire and police stations, libraries, and hospitals. The plan should identify facilities to be retained, remodeled and expanded.

E. Special

Depending on the characteristic of the community concerned, the comprehensive plan may include special plan elements relating to the provision of low- and moderate-income housing, including public housing; for urban revitalization and redevelopment; for historic preservation; and for railway facility realignment and airport facility development.

Chapter XIII Plan Implementation

The comprehensive plan report should also contain recommendations for plan implementation. The chapter should contain recommendations for the adoption of a new, or for the amendment of the existing, zoning ordinance to help carry out the land-use plan by regulating the use of land, the height and bulk of buildings, and the density of population. The chapter should contain recommendations for the adoption of a new, or for the amendment of the existing, land subdivision control ordinance, regulating the development and redevelopment of land. The chapter may contain recommendations for the adoption of an official map to help implement and reserve land for the arterial street, park, and parkway elements of the plan, the official map being final and conclusive as to the location and extent of all exiting and proposed streets, parks, and parkways. The chapter may also contain recommendations for the preparation and maintenance of a five-year capital improvement program identifying improvements needed to implement the various recommended plan elements. Finally, the chapter may address the adoption of new or the amendment of the existing, housing and building codes.

Chapter XIV Summary

Each individual plan element is intended to deal with identified developmental or environmental problems. The individual plan elements are coordinated by being related to the land-use plan. Thus, the land-use plan comprises the most basic element of a comprehensive plan, an element upon which all of the other elements are based.

A comprehensive plan for the physical development of the community is essential if land-use development is to be properly coordinated with the development of supporting transportation, utility, and community facility systems; if the development of each of these individual systems is to be coordinated with the development of the others; if serious and costly environmental and developmental problems are to be minimized; and if a more healthful, attractive and efficient settlement pattern is to be evolved.

The preparation, adoption, and use of the comprehensive plan are considered to be the primary objectives of the planning process. All planning and plan implementation techniques are based on, or otherwise related to, the comprehensive plan.

In the late 1960s and early 1970s, the validity of the concept of the comprehensive plan was questioned and its application was opposed by some academicians and even some practicing planners. The critics, however, suggested no constructive replacement that would prevent public planning from becoming an arbitrary and capricious process—more destructive than constructive. The comprehensive plan has, therefore, remained a viable and valid concept, a concept essential to coping with the environmental and developmental problems generated by urban development and redevelopment in a rational manner.

The comprehensive plan not only provides the necessary framework for coordinating and guiding development, but also provides the best conceptual basis available for the application of system engineering techniques to the growing problems of urban areas. This is because systems engineering focuses on the design of physical systems. It seeks to achieve good design by setting good objectives; assessing the ability of alternative plans to meet those objectives through quantitative analyses; cultivating interdisciplinary team activity; and considering all of the relationships involved, both within the system being defined and between that system and its environment.

THE PLANNING PROCESS

As shown in Figure 6.1, the comprehensive planning process consists of seven major steps: the definition of the planning area; inventory and analysis; formulation of development objectives, principles, and standards; identification of

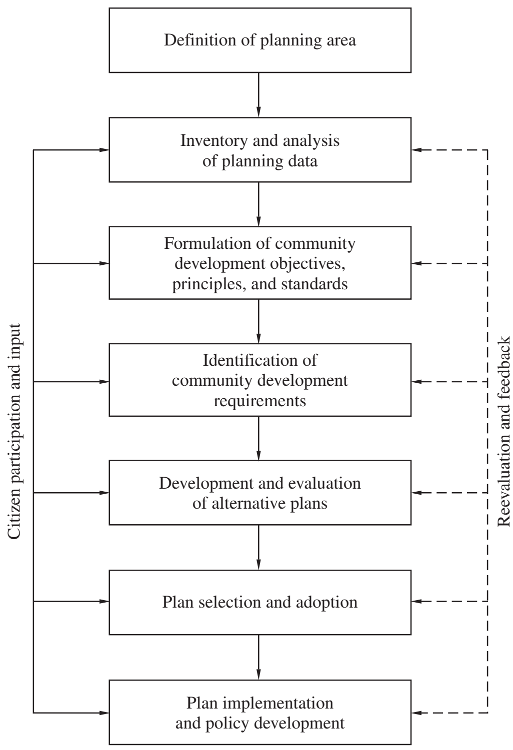


FIGURE 6.1 Comprehensive plan preparation process. (*Source:* SEWRPC.)

development requirements; development and evaluation of alternative plans; plan selection and adoption; and plan implementation policy development.

Definition of Planning Area

The proper definition—or delineation—of the planning area to be considered requires careful study. For comprehensive urban planning, the planning area should include the existing corporate boundaries and current urbanized areas plus such adjacent open areas as general growth prospects and likely directions of expansion may indicate. Considerations should include, among others, natural drainage basins; existing and proposed transportation facilities; salient topographic features such as large wetlands, woodlands, and open space reservations; and prime agricultural lands. Considerations should also include adopted state, regional, county, and preexisting local plans, and importantly, statutory extraterritorial planning, zoning, and plat approval jurisdictions. Planning areas may be defined by state law and federal administrative regulations—such as the federal regulations governing water quality management and transportation system planning. Some types of planning efforts may require the delineation of planning areas such as water sheds and a commuter shed.

Inventory and Analysis

Reliable planning data are absolutely essential to the formulation of workable development plans. Consequently, inventory becomes the first operational step in the planning process. The crucial nature of factual information in the planning process should be evident, since no intelligent forecast can be made, or alternative courses of action formulated and evaluated, without definitive knowledge of the current state of the area or system being planned.

The necessary inventory and analysis step not only provides data definitively describing the existing conditions, but also provides a basis for identifying existing and potential problems, as well as opportunities and potentials for good development. The inventory data are also crucial to the preparation of forecasts and to the formulation and evaluation of alternative plans.

It is important to recognize that, to a considerably extent, urban development and redevelopment can be guided and shaped in the public interest through the task of collecting, analyzing, and disseminating accurate planning and engineering data. Experience has shown that if the inventory function is properly carried out, the resulting information will indeed be used and acted on by federal, state, and local units and agencies of government and by private investors. This will contribute positively to the shaping and guiding of development in the public interest, even in the absence of a comprehensive plan. For example, the development and dissemination of accurate flood hazard maps will influence the location of new flood-prone development and of redevelopment in the planning area. Similarly, the development and dissemination of detailed operational soils data will influence the location, configuration, and design of land subdivision plats that are to be served by on-site sewer disposal systems. The development and dissemination of accurate data on the location and configuration of wetlands will similarly shape development decisions.

The proper preparation of comprehensive plans requires the collection of a wide range of definitive data, including data in the following list:

I. **Maps**
    A. Large-scale topographic maps
    B. Large-scale cadastral maps
    C. Aerial photographs
    D. Base maps that can serve as a basis for the collection, analysis, and display of planning data and plans
II. **The Demographic and Economic Base**
    A. Demographic base
        1. Existing and historic population size and distribution
        2. Components of population change
        3. Population distribution
        4. Population characteristics
            a. Age and sex composition
            b. Race and Hispanic origin
            c. Marital status
            d. Educational attainment
        5. Diurnal changes in population distribution
        6. Number and characteristics of households
    B. Economic base
        1. Labor force
            a. Labor force size and distribution
            b. Labor force characteristics
        2. Employment
            a. Number and distribution of jobs
            b. Occupational characteristics by place of work
    C. Personal income
    D. Property tax base
        1. Equalized property values
        2. Property tax levies and rates
III. **The Natural Resource Base**
    A. Climate
    B. Air quality
        1. Ozone
        2. Particulate matter

- C. Geology and physiography
    1. Surface geology and physiography
    2. Bedrock geology
- D. Topography and drainage patterns
- E. Soils
    1. Detailed operational soils maps
    2. Soil suitability interpretations
    3. Suitability for urban development served by public sanitary sewers
- F. Suitability for onsite sewage disposal systems
    1. Conventional systems
    2. Mound systems
    3. Aerobic treatment systems
- G. Suitability for agriculture
- H. Suitability for extraction of minerals
- I. Groundwater resources
    1. Groundwater systems
    2. Aquifer recharge and discharge
    3. Groundwater quality
    4. Vulnerability to contamination
    5. Radium concentrations
- J. Surface water resources
    1. Lakes
    2. Rivers and streams
    3. Floodlands
- K. Wetlands
- L. Woodlands
- M. Wildlife habitat
- N. Natural resource-base-related elements
    1. Major park and open space sites
    2. Historic sites
    3. Natural area and critical species habitat sites
- O. Environmental corridors
    1. Primary
    2. Secondary
    3. Isolated natural areas

IV. **Land Use**

- A. Historic urban growth patterns
- B. Existing land use
    1. Urban land uses
    2. Nonurban land uses

C. Residential land use
   1. Residential building permit authorizations
   2. Residential platting activity
D. Commercial land use
E. Industrial land use
F. Governmental and institutional land use
G. Agricultural land use
H. Extractive land use
I. Inefficient and conflicting land uses and blighted areas
J. Housing
   1. Housing stock
   2. Housing occupation and vacancy rates
   3. Housing building activity
   4. Housing value and costs

V. **Transportation and Public Utility Facilities**
   A. Transportation facilities—locations and capacities
      1. Freeways
      2. Surface arterial streets and highways
      3. Public transit facilities
      4. Intracity transit facilities
      5. Intercity transit service
      6. Specialized transportation services
      7. Railway facilities
      8. Airports
      9. Bikeways
   B. Public utility systems—locations and capacities
      1. Sanitary sewerage
      2. Water supply
      3. Stormwater drainage
      4. Quasi-public utilities—electric power, gas, communications
   C. Solid waste management facilities
      1. Landfills
      2. Recycling
      3. Yard waste

VI. **Community Facilities**
   A. Parks, parkways, and open space
   B. Schools
   C. Libraries
   D. Administrative buildings
   E. Police and fire stations
   F. Medical care facilities

VII. **Adopted Plans and Land Use Regulations**
   A. Land-use regulations
   B. Local zoning regulations
      1. Background
      2. General zoning
      3. Floodland zoning
      4. Shoreland zoning
      5. Land-use pattern proposed under existing zoning
   C. Land subdivision regulations
   D. Official mapping
   E. Special-purpose districts
      1. Tax incremental financing districts
      2. Town sanitary districts
      3. Public inland lake protection and rehabilitation districts
      4. Business improvement districts
      5. Redevelopment areas

The focus, scope, and depth of the inventory and analysis step will differ at the regional, as opposed to the local, level of planning. This difference has important implications for the use of the inventory data in environmental engineering. At the regional level, the inventory efforts will focus on such matters as the accurate delineation of watershed boundaries and the collection of the hydrologic and hydraulic data needed to assess stream flows and attendant stages and the location and extent of floodways and floodplains; surface and groundwater quality, and related point and nonpoint sources of pollution; location, extent, and quality of woodlands, wetlands, and wildlife habitat areas; the location of sites having historic cultural and recreational value; existing land uses determined on a uniform, areawide basis; preparation of detailed soil maps and attendant interpretations for various rural and urban uses; commuter sheds and attendant travel habits and patterns; and transportation system capacity and use. At the regional level, the inventories may involve costly travel inventories, stream gaging and water-quality monitoring efforts, and the formulation, calibration, and validation of simulation models of travel and traffic; stream flows and stages; water quality, and air pollution. Horizontal and vertical control surveys may be conducted, and the large-scale topographic and cadastral maps may also be prepared at the regional level. Automated, parcel-based land information systems may also be developed at the regional level. These systems have uses in many areas, including planning, engineering, assessing, and general public administration. The local inventories will focus on the more detailed factors affecting the preparation of plans, including the configuration, capacity, and use of the total street system; on the sanitary sewerage, water supply and storm water management facilities;

and such community facilities, as parks and parkways, libraries, police and fire stations, administrative centers, and housing.

The inventory efforts should be carried out in accordance with a predesigned structure for the creation of an automated planning information system and of a companion automated public works management system.

Formulation of Objectives and Standards

Planning is a rational process for formulating and attaining objectives. The objectives are intended to guide the preparation and evaluation of alternative plans, and the selection of recommended plans from among the alternatives considered. The comprehensive plan and its various elements should be clearly related to the defined objectives through a set of quantitative standards. The formulation of objectives should involve the active participation of public officials, business and industrial leaders, and citizens and citizen groups.

Some planners make a distinction between the terms *goals* and *objectives*. Under this distinction, the goals are defined as ideal ends toward which the planning process is directed. Objectives are defined as the realistically obtainable ends toward the attainment of which plans and policies are directed. In any case, it should be understood that goals and objectives may change over time as new information is developed, as objectives are achieved through plan implementation, or as objectives fail to be achieved owing to changing public attitudes and values. The objectives should recognize the economic, social, and physical development and redevelopment aspirations of the community, and should include environmental quality objectives. These latter may include a safe and sustainable water supply adequate to meet domestic, industrial, recreational, and firefighting needs; adequate sewage and other wastewater collection, treatment, and disposal facilities; adequate drainage and flood-control facilities; water and air pollution abatement; proper solid waste collection, reduction, treatment, and disposal; adequate parks and outdoor recreational facilities; noise abatement and control; a safe, convenient, and efficient transportation system; decent, safe and sanitary housing; elimination of sources and causes of diseases such as mosquitoes, ticks, black flies, rats, and other vectors; adequate schools; adequate hospitals and other medical care facilities; and adequate power and communication facilities.

Identification of Development Requirements

Any development plan must, to the extent possible, anticipate future requirements as a basic for the formulation of alternative plans and the selection of a recommended plan. Therefore, in the comprehensive planning effort, forecasts are required of future events and conditions that lie outside the scope of the system to be planned. The future demand for land and facilities will depend, to a considerable extent, on the size of the future population and the number of households, and on the nature of future economic activity. Therefore, future levels of population, households, and economic activity must be forecast. These forecast levels can then be used to determine the probable future demand for the various land uses and for the supporting infrastructure facilities. This is not to say that public policies at the local level cannot influence the course of economic development and, consequently, of population and economic activity growth rates.

Development and Evaluation of Alternative Plans

Having forecast the probable future demand for the various land uses and supporting facilities, alternative plans that meet those demands can be developed. The alternative plans should be evaluated based on their relative ability to obtain the agreed upon development objectives. This is done through the application of quantitative standards that relate the objectives to physical development. The plan that is judged best to meet those objectives should be selected for adoption.

Plan Selection and Adoption

The plan that is judged best to meet the agreed-upon development objective, together with the alternative plans considered, should then be subjected to intensive public review. The public should be involved in the review of the preferred plan and of the alternatives considered through such techniques as the creation and use of advisory committees, public educational programs; and presentation at a series of well-organized public informational meetings supported by the dissemination of information about the plans and the planning process. Special briefings on the plan should be held with cognizant elected and appointed public officials and interested and concerned business and community organizations. In this respect it should be noted that one of the most meaningful ways of providing public participation in the planning process is through the plan commission itself, which directs the work and which should contain citizen members.

The public participation process should culminate in a formal public hearing, or hearings. Based upon the testimony presented at the hearing, or hearings, the preliminarily preferred plan may be revised prior to presentation to the plan commission and governing body concerned for consideration and adoption. This may result in further changes to the plan. Following its adoption the plan should be certified to the appointed public officials responsible for implementation, and as may be necessary to concerned state and federal agencies.

Following plan adoption, the plan commission should guide plan implementation, and monitor changing conditions in the planning area that might affect the structure of the adopted plan. Observed changes in conditions that would require changes in the forecasts upon which the plan is based should initiate a plan review and revision process, as should failure to implement key recommendations in the plan. In any case, the adopted plan should be reevaluated and revisions considered at a minimum of ten-year intervals.

Plan Implementation and Policy Development

Implementation of adopted public plans usually involves the application of several planning tools of a legal and administrative nature. Land subdivision regulations are used to assure that any proposed land subdivision plats conform to the adopted plans with respect to both the proposed land uses to be accommodated, and to such details as street, block, and lot layout, and required infrastructure improvements. The zoning ordinance and attendant zoning district map are used to legally assure that private development and redevelopment occur in conformance with the adopted plans. The zoning regulation should govern the types of the various land uses permitted in the various parts of the planning area; the height and arrangement of buildings on the land; the intensity of use of the land; and the supporting facilities required; all as necessary to carry out the intent of the adopted plans. An official map is used to assure that the land required for proposed streets, parks, and parkways included in the adopted plan is reserved for public use.

A building code sets forth detailed standards and regulations for the construction and alteration of buildings, including materials of construction; structural and fire safety; light and ventilation; and electrical, heating and air conditioning and plumbing facilities. The building code provides authorization for construction plan and specification review, approval of construction and alterations, and the issuance of occupancy permits.

A sanitary code sets forth standards and regulations for the following:

- Disease control
- Qualification of personnel responsible for the operation of food services
- Safe water supply, wastewater disposal, air-pollution prevention
- Solid waste management
- Food, including milk, sanitation
- Radiation
- Noise
- Disease vectors
- Hospitals, nursing homes, and other institutions
- Schools, camps, and resorts
- Bathing beaches and swimming pools
- Occupational health and other preventative measures required to ensure the protection of public health

A housing code sets forth standards and regulations for the provision of decent safe and sanitary dwellings; for necessary utilities and services; occupancy; and maintenance. All of these codes authorize inspection to determine compliance, and are intended to promote the public health, safety, and welfare.

A capital improvement program is used to guide the investment of public funds in improvements that carry out the adopted plan. Project priorities are established. Approximate costs are estimated, and sources of revenue and means for financing are determined. The estimated costs should include operation and maintenance costs, as well as capital costs. The program is usually prepared for a five-year period into the future. When the governing body of the municipality concerned considers the annual budget for the next calendar or fiscal year, the first year of the capital improvement program is considered for incorporation into the adopted budget, either as proposed or as may be modified by the budget deliberations. At that time, the remaining four years of the capital improvement program are reviewed and an additional year added, so that the program always looks at least five years ahead.

The program should consider all public works construction contemplated by the municipality concerned, and should coordinate such construction within the municipality concerned, and with county, state, and private utility construction. Moreover, the proposed public works construction projects should be coordinated with committed and contemplated public and private land use development projects. Programs should incorporate (as may be appropriate) probable state and federal funding assistance, special assessment and impact fee revenues, and the local tax burden. The program should treat the public works infrastructure as an asset, and should provide for the timely maintenance of existing facilities, as well as the construction of needed new facilities.

The preparation of a capital improvement program requires a working knowledge of engineering economics and of the financing of municipal improvements. Such financing may involve the use of revenue, general obligation and special assessment bonds, and taxes and other revenues. If bonding is used, the effects of debt service on the program must be considered. State laws will usually impose specific limitations on the amount of debt that a municipality may incur. Such debt limits are often set at a percentage of the average full value real property assessment of the municipality concerned. Sometimes, indebtedness for an essential revenue-producing service, such as water supply, may be excluded from such state limitations.

General obligation bonds are issued by a governmental agency such as a municipality. Repayment is guaranteed through the municipal power of taxation. Revenue bonds are repaid from a special source of revenue, such as water service, sewer service, or toll bridge and toll road charges. The cost of the service made possible by the bond issue is, thereby, directly related to the monthly, quarterly, or annual billing for a specific service. Revenue bonds are not backed by the full credit of the municipality. Therefore, interest rates may be somewhat higher than for general obligation bonds.

Although these legal and administrative plan implementation actions are primarily the prerogative of county and municipal governments, federal and state regulations may also be involved. The protection of floodways and floodplains; the delineation of areas to be served, by public sanitary sewer and water supply facilities; the location, capacity, and level of treatment to be provided by wastewater and water treatment plans; and the protection of woodlands and wildlife habitat areas, are often specified by federal and state legislation and attendant regulations. Federal grants for the improvement of highway and transit facilities in metropolitan areas require the preparation and adoption of transportation system plans and of capital improvement programs that serve to implement such plans.

PUBLIC WORKS DEVELOPMENT PROCESS

The foregoing description of capital improvement programming clearly implies that plan implementation will involve the development of the public works infrastructure required to support planned land-use development, as well as the application of legal and administrative devices. The public works development process should take place in three successive stages:

1. System planning
2. Preliminary engineering
3. Final engineering and construction

Most public works facilities are composed of integrated systems, and each existing and each new facility must function as an integral part of the system concerned—transportation, sanitary sewerage, stormwater management, flood control, parks, and open space. The systems planning stage will often involve the application of mathematical models that can be used to simulate the performance of the system concerned, and the systems planning process should be accomplished as an integral part of the comprehensive planning process. System plans for sanitary sewerage water supply and stormwater management are often termed *facility plans*. If such plans are developed outside of the comprehensive planning process, the effort may require heroic assumptions to be made concerning future population, household, and employment levels, and future land-use patterns within the service areas concerned; as well as about such matters as surface and groundwater quality objectives and the sustainability of water supply sources. Outlines for typical sewerage, stormwater management, and water-supply facilities planning reports follow.

Outline for a Sewerage Facilities Planning Report

I. **Introduction**
   A. Purpose of planning effort and plan report
   B. Brief description of planning area
   C. Impetus and authority for planning effort
   D. Description of sewerage system planning and development process
      1. Areawide framework plan
      2. Facilities plan
      3. Preliminary engineering plans
      4. Final engineering and construction
      5. Required approvals

II. **Historic Studies and Plans**
   A. Pertinent areawide framework plan recommendations
      1. Service area
      2. Treatment
   B. Pertinent local plans
      1. Land use and zoning
      2. Utility service
      3. Stormwater management

III. **Description of Existing Conditions**
   A. Available mapping
      1. Survey control and datums
      2. Topographic maps
      3. Cadastral maps
      4. Parcel-based land information systems
   B. Demographic
      1. Population—historic and existing
         a. Levels
         b. Distribution and densities
         c. Seasonal
      2. Households—historic and existing
         a. Size and numbers
         b. Distribution
         c. Type, including group quarters
         d. Seasonal
   C. Employment
      1. Type
      2. Distribution
      3. Special industrial and institutional
   D. Land use—historic, existing, planned
   E. Topography and drainage patterns
   F. Geology and depth to bedrock
   G. Soils
      1. Suitability for development with convention septic tanks
      2. Suitability for development with mound systems
      3. Suitability for development with sewer systems
   H. Climate and weather
      1. Rainfall and snowfall
      2. Temperature
      3. Wind
      4. Frost depth

I. Physical, chemical, biological, and hydrological characteristics of receiving water

J. Characteristics of municipal and industrial wastewater volumes, strengths, flow rates

K. Existing sanitary and combined sewer facilities
   1. Location, configuration, service areas, and capacities of conveyance and storage facilities
      a. Trunk sewers
      b. Collection sewers
      c. Manholes
      d. Junction chambers
      e. Pumping stations
      f. Storage facilities
         (1) Near surface
         (2) Deep tunnel
      g. Pumping stations
   2. Location, type, capacities, and performance of treatment facilities
   3. Existing flows and related problems such as surcharging and basement backups
   4. Surface and groundwater quality impacts

L. On-site sewage disposal facilities—septic tank systems and holding tanks
   1. Number and age
   2. Distribution and densities
   3. Soil suitability
   4. Sanitary records
   5. On-site inspections results
   6. Well water testing
   7. Leachate detector surveys
   8. Household questionnaire surveys

M. Water supply facilities and service area

N. Stormwater management facilities and drainage areas

O. Natural resource base
   1. Surface water
      a. Use objectives
      b. Quality conditions
         (1) In stream quality
         (2) Fishery resources
         (3) Benthic organisms
         (4) Aquatic habitat

            c. Sources of pollution
                (1) Point
                (2) Nonpoint
        2. Groundwater
            a. Depth to water table
            b. Quality
        3. Floodlands
        4. Wetlands
        5. Woodlands
        6. Wildlife habitat
        7. Environmental corridors
    P. Archaeologic and historic sites
    Q. Problems and needs with geographic differentiation
        1. Surcharging
        2. Basement backups
        3. Sanitary sewer overflows
    R. Water pollution control requirements; federal, state and interstate receiving water classifications and efficient standards

IV. **Forecast of Future Conditions to Design Year**
    A. Demographic
        1. Population
            a. Levels
            b. Distribution and densities
            c. Seasonal
        2. Households
            a. Size and number
            b. Distribution
            c. Type, including group quarters
            d. Seasonal
    B. Employment
        1. Type
        2. Distribution
        3. Special industrial
    C. Land use
    D. Problems and needs with geographic differentiation

V. **Sanitary Sewerage Objectives, Standards, and Design Criteria**
    A. Objectives and supporting standards
        1. Quantity management
        2. Quality management
        3. Land-use relationship

B. Design criteria
   1. Flows
      a. Per capita sewage contribution by size of contributing area
         (1) Average daily
         (2) Peak daily
         (3) Instantaneous peak
      b. Clear water infiltration by size of contributing area
         (1) Average daily
         (2) Peak daily
         (3) Instantaneous peak
      c. Clear water inflow by size of contributing area
         (1) Average daily
         (2) Peak daily
         (3) Instantaneous peak
      d. Waste water reduction, reclamation and reuse
      e. Total flows by size of contributing area
         (1) Average daily
         (2) Peak daily
         (3) Instantaneous peak
   2. Hydraulics of gravity and pressure flow sewers
      a. Computational methodologies
      b. Flow to depth relationships
      c. Minimum size
      d. Minimum grade and velocity
      e. Minimum depth
C. Pumping and lift stations

VI. **Alternative Plans**
   A. General description of alternatives
      1. On-site sewage disposal
      2. Conventional gravity flow sewerage systems
      3. Pressure flow sewerage systems
   B. On-site treatment and disposal
      1. Description
         a. Replace existing systems
         b. Mound system
         c. Holding tanks
         d. Aerobic systems
      2. Performance and environmental impacts
      3. Costs

C. Centralized treatment and disposal—may have multiple alternatives and may include pressure flow as well as gravity flow systems
   1. Description
      a. Collection
      b. Conveyance
      c. Storage
      d. Treatment
         (1) Pollution loads
         (2) Degree of treatment required
         (3) Land requirements and buffer zones
         (4) Outfall sewer
         (5) Sludge disposal
      e. Flows
   2. Performance evaluation—simulation modeling
   3. Environmental assessment
   4. Costs
      a. Capital
      b. Operating and maintenance

D. Comparative evaluations of alternatives considered
   1. Costs
      a. Capital
      b. Operation and maintenance
      c. Present worth
      d. Cost effectiveness
   2. Attainment of objectives and standards
   3. Environmental impacts

VII. **Recommended Plan**

A. Description

B. Performance and environmental assessment

C. Costs
   1. Capital
   2. Operation and maintenance

D. Implementation
   1. Institutional structure
   2. Procedure
      a. Plan adoption
      b. Capital improvement programming, financing, and cost allocation
      c. Preliminary engineering
      d. Final engineering and construction

e. As-built documentation
f. Operation and maintenance

VIII. **Public Participation**
A. Cognizant authority structure
B. Advisory committee
C. Public information meetings and hearing
D. Reflection in recommended plan

Outline for a Stormwater Management Facilities Planning Report

I. **Introduction**
A. Purpose of planning effort and plan report
B. Brief description of planning area
C. Impetus and authority for planning effort
D. Description of stormwater management planning and development process
1. Areawide framework plans
2. Local system plans
3. Preliminary engineering
4. Final engineering and construction
5. Required approvals
E. Basic concepts involved in storm water management planning
1. Difference between stormwater management and flood control planning
2. Areawide flood control plans
3. Major and minor storm water drainage systems
4. Performance simulation
5. Relation of sanitary sewerage and stormwater management system planning and performance
F. Planning approach
1. Cognizant public body oversight and guidance
2. Public participation
3. Adoption

II. **Historic Studies and Plans**
A. Introduction
B. Pertinent areawide framework plans
1. Land use
2. Flood control
C. Pertinent local plans

1. Land use and zoning
2. Utility service
3. Drainage

III. **Stormwater Management System Components**
- A. Introduction
- B. Drainage components
  1. Overland flow
  2. Collection
     - a. Drainage swales
     - b. Roadside ditches
     - c. Roadway curbs and gutters
     - d. Stormwater inlets
     - e. Stormwater catch basins
  3. Conveyance
     - a. Open channels
     - b. Culverts
     - c. Sewers
     - d. Manholes
     - e. Junction chambers
     - f. Outfalls
     - g. Pumping stations
  4. Storage facilities
- C. Water quality management components
  1. Infiltration devices
  2. Sedimentation—floatation basins
  3. Outfall treatment
  4. Construction erosion control
  5. Street sweeping and litter control
  6. Leaf collection
  7. Wetlands
     - a. Natural
     - b. Constructed

IV. **Description of Existing Conditions**
- A. Introduction
- B. Available mapping
  1. Survey control and datums
  2. Topographic maps
  3. Cadastral maps
  4. Parcel-based land information systems

C. Land use—historic, existing, planned
D. Geology and depth to bedrock
E. Soils
   1. Suitability for development
   2. Hydrologic classification
F. Climate and weather
   1. Rainfall and snowfall
   2. Temperature and seasonal considerations
   3. Snow cover and frost depth
G. Sanitary sewerage
   1. Service areas
   2. Facility configuration
   3. Areas of surcharging and basement flooding
H. Existing flood control and storm water management systems
   1. Topography and drainage patterns
   2. Flood stages and inundation areas along receiving streams
   3. Overland flow paths
   4. Street cross-sections
      a. Rural—ditches and swales
      b. Urban—curbs and gutters
   5. Storm sewers
      a. Sewers, manholes, and junction chambers
      b. Inlets
      c. Catch basins
      d. Pumping stations
      e. Outfalls
   6. Roadside ditches and culverts
   7. Drainage channels
   8. Storage
   9. Off-street culverts
   10. Catchment areas and subbasins
   11. Pollution control facilities
I. Natural resource base
   1. Surface water
      a. Use objectives
      b. Quality conditions
         (1) In-stream quality
         (2) Fishery resources
         (3) Benthic organism
         (4) Aquatic habitat

c. Sources of pollution
    (1) Point
    (2) Nonpoint
        (a) Agricultural runoff
        (b) Urban runoff
        (c) Leaks and spills
        (d) On-site sewage disposal

2. Groundwater
    a. Depth to water table
    b. Quality
3. Floodlands
4. Wetlands
5. Woodlands
6. Wildlife habitat
7. Environmental corridors

J. Archaeologic and historic sites

K. Existing storm water drainage problems
    1. History of significant rainfall events
    2. Areas of ponding and inadequate drainage
        a. Location and extent
        b. Relation to sanitary sewerage system surcharging and backup
        c. Monetary damages

L. Summary and conclusions

V. **Stormwater Management Objectives, Standards, and Design Criteria**

A. Objectives and supporting standards
    1. Quantity management
        a. Minor system, 10-year recurrence interval level of protection
        b. Major system, 100-year recurrence interval level of protection
    2. Quality management
    3. Land-use relationship

B. Analytical procedures and design criteria
    1. Rainfall intensity—duration—frequency data
    2. Time distribution of design rainfall
    3. Hydraulic design criteria
        a. Open channel flow
        b. Inlet capacity
        c. Piped flow
        d. Culvert flow

C. System performance simulation
    1. Flow delivery
    2. Pollutant delivery
    3. Flow control
    4. Pollutant control
D. Assumptions
    1. Site grading
    2. Street cross sections
    3. Open drainage channels
    4. Outlet conditions
E. Summary

VI. **Performance Evaluation of Existing System**

A. Introduction
B. Comparative evaluation of existing hydraulic capacities and anticipated stormwater flows
    1. Minor system
    2. Major system
C. Identification of problem areas
    1. Structure flooding
    2. Yard flooding
    3. Street flooding
    4. Relationships to sanitary sewer system surcharging
D. Evaluation of nonpoint source pollutant abatement characteristics of existing system and required pollutant reductions
E. Summary and conclusions

VII. **Design of Alternative Stormwater Management System Plans**

A. Introduction
B. Alternative measures
    1. Structural measures for drainage and pollution abatement
        a. Storm sewer conveyance
        b. Roadside ditch and swale conveyance
        c. Centralized detention
        d. Decentralized, on-site detention
        e. Centralized retention
        f. Decentralized, on-site retention
        g. Wetland storage
        h. Outfall treatment
    2. Nonstructural measures for pollution abatement

C. Alternative stormwater drainage system plans considered
   1. Maximum conveyance alternative
      a. Configuration
      b. Capacity
      c. Performance
   2. Maximum storage alternative
      a. Configuration
      b. Capacity
      c. Performance
   3. Composite alternative
      a. Configuration
      b. Capacity
      c. Performance
   4. Comparative evaluation of alternatives considered
      a. Costs
         (1) Capital
         (2) Operating and maintenance
         (3) Cost effectiveness
      b. Attainment of objectives and standards
   5. Selection of preliminary recommended system plan
      a. Configuration
      b. Performance

VIII. **Recommended Stormwater Management System Plan**

A. Integration of preliminary recommended storm water drainage, sanitary sewerage, and water quality management plans

B. Description of recommended drainage component
   1. Configuration
      a. Minor drainage system
         (1) Overland flow
         (2) Curb and gutter street cross sections and locations
            (a) Inlets and catch basins
            (b) Sewers
            (c) Storage
            (d) Outfalls
            (e) Open channels
         (3) Rural street cross-sections and locations
            (a) Roadside ditches
            (b) Parallel culverts
            (c) Cross culverts

(d) Storage
(e) Open channels
b. Major drainage system
(1) Flow paths
(2) Storage and areas of inundation
(3) Storage
2. Capacity
3. Performance
4. Cost
a. Capital
b. Operating and maintenance
C. Description of recommended water pollution abatement component
1. Configuration
a. Structural measures
(1) Infiltration
(2) Sedimentation—flotation basins
(3) Outfall treatment
b. Nonstructural measures
(1) Constructions erosion control
(2) Street sweeping and litter control
(3) Leaf collection
(4) Wetlands
2. Capacity
3. Performance
4. Cost
a. Capital
b. Operating and maintenance
D. Performance and environmental impacts
1. Ability to meet objectives and standards
a. Land use
b. Hydrologic and hydraulic performance
c. Water quality management performance
d. Cost effectiveness
e. Environmental impacts
2. Relationship to adopted areawide flood control plans
E. Summary

IX. **Plan Implementation**
A. Introduction
B. Institutional structure

1. General-purpose municipal government
2. Stormwater utility district

C. Procedure
1. Plan adoption
2. Capital improvement programming, financing and cost allocation
3. Preliminary engineering
4. Final engineering and construction
5. As-built documentation
6. Operation and maintenance

D. Capital improvement program
1. Prioritization of required capital improvements and sequencing of projects
2. Financing and cost allocations

E. Regulatory consideration
1. Stormwater management ordinance
2. Administrative code and ordinance requirements

X. **Summary**

Outline for a Water Supply Facilities Planning Report

I. **Introduction and Background**

A. Background

B. Study area

C. The water supply planning program
1. Previous planning efforts
2. Initiation of water supply planning program
3. Plan purpose
4. Relationship to other planning program
5. Staff, cooperating agencies, consultants, and committee structure
6. Plan presentation and organization

II. **Description of the Planning Area**

A. Manmade features
1. Regional setting of watershed and political boundaries
   a. Civil divisions
   b. Special-purpose units of government with water supply management responsibilities
2. Demographic
   a. Demographic base
   b. Population and housing unit size and distribution
3. Economic base

4. Land use
   a. Historical development
   b. Existing land use
5. Public and private utility base
   a. Sanitary sewer service
   b. Water supply service

B. Natural resource base
1. Topographic and physiographic features
   a. Topographic maps
   b. Cadastral maps
   c. Survey control and datums
   d. Geology
2. Soils
3. Vegetation
   a. Wetlands
   b. Woodlands
   c. Grasslands
   d. Natural and critical plant species areas
4. Surface-water resources
   a. Streams
   b. Lakes
   c. Floodlands
5. Groundwater resources
6. Fish and wildlife resources
   a. Fish and aquatic life
   b. Wildlife habitat
7. Park and open space sites
8. Environmental corridors

III. **Existing Water Supply Conditions in the Region**

A. Water Supply Sources
1. Groundwater
   a. Shallow Aquifer
      (1) Water uses
      (2) Aquifer-quantity characteristics
      (3) Water-quality characteristics
   b. Deep aquifer
      (1) Water uses
      (2) Aquifer-quantity characteristics
      (3) Water-quality characteristics

2. Surface water
   a. Availability
   b. Quality

B. Existing Water Supply Facilities
   1. Public utility
   2. Private utility
      a. Industrial
      b. Commercial
      c. Agricultural
      d. Domestic (residential)

IV. **Legal Structures Affecting Water-Supply Planning**

A. Water law
   1. Surface water
   2. Groundwater
   3. State water-supply regulations
   4. Source water assessment requirements
   5. Water-supply facility requirements
   6. Other related state water-quality management regulations

B. Local water-supply management regulations and policies

V. **Water-Supply Management Objectives and Standards**

A. Basic concepts and definitions

B. Water-supply planning objectives

C. Design and planning standards for water supply facilities
   1. Water demand standards
      a. Residential demand
      b. Commercial demand
      c. Industrial demand
      d. Public demand
      e. Firefighting demand
      f. Unaccounted for water
      g. Water used in treatment
   2. Water quality standards
      a. Raw water
      b. Finished water
   3. Water system design standards
      a. Design objective
      b. Water demand standards
         (1) Peak day to average day pumpage ratio
         (2) Peak hour to peak day pumpage ratio

(3) Distribution system pressures
(4) Fire flow considerations
c. Pumping and storage standards
(1) Source capacity
(2) Peak hour storage
(3) Fire flow
(4) Emergency supply
d. Main looping and sizing
4. Cost-effectiveness analysis

D. Other related land and water-resource management planning objectives and standards

VI. **Analysis and Forecasts**

A. Population
B. Households
C. Employment
D. Land-use demand
E. Water supply service areas
F. Forecast water uses and evaluation of existing systems
1. Public utility
2. Private utility
a. Industrial
b. Commercial
c. Agricultural
d. Domestic (residential)

G. Groundwater systems
1. Shallow aquifer
2. Deep aquifer
3. Groundwater contamination potential analysis
4. Important groundwater recharge areas
5. Groundwater quantity and sustainability analysis

H. Surface water systems

VII. **Problem Identification and Issues to Be Addressed**

A. Problem identification
1. Groundwater quantity and quality
a. Shallow aquifer
b. Deep aquifer
2. Surface water quantity and quality
3. Groundwater–surface water interrelationships

B. Issues to be addressed
   1. Groundwater sustainability and relationships to areas of groundwater recharge and use
   2. Groundwater quality
   3. Surface water quantity sustainability
   4. Surface water quality
   5. Relationship of water supply to land use
   6. Groundwater–surface water issues
   7. Relationship of water-supply systems to sanitary sewerage systems

VIII. **Future Scenarios and Alternative Plan Descriptions and Evaluation**

A. Applicable water-supply management measures
   1. Water conservation
   2. Preservation of groundwater recharge areas
   3. Groundwater supply options
   4. Surface water–supply options
   5. Water-supply system optimization
   6. Water-supply system interconnection
   7. Water-supply treatment
   8. Options for areas outside water-supply service areas

B. Alternative plan 1–expansion of existing systems with current groundwater use and probable loss of recharge areas

C. Alternative plan 2–expansion of existing systems with high level of water conservation and recharge area protection

D. Alternate plan 3–expansion of existing systems using existing sources

E. Alternate plan 4–expansion of existing systems using groundwater sources

F. Alternate plan 5–expansion of existing systems using surface water sources

G. Alternate plan 6–combination alternatives

H. Evaluation of alternative water supply plans
   1. Evaluation criteria
   2. Cost analysis
   3. Nonmonetary factors analysis
   4. Ranking of alternatives

I. Description of preferred alternative combination plan

IX. **Recommended Water Supply Plan**

A. Public reaction to the preliminary recommended regional water supply plan

B. Final recommended regional water supply plan

C. Relationship of recommended plan to identified water supply issues

X. **Plan Implementation**
   A. Basic concepts and principles
   B. Plan implementation organizations
      1. Local agencies
      2. Areawide-level agencies
      3. State agencies
      4. Federal agencies
      5. Private concerns
   C. Plan adoption and integration
   D. Financial and technical assistance
   E. Subsequent adjustment of the plan and continuing planning process
   F. Summary
XI. **Summary and Conclusions**
   A. Study organization and purpose
   B. Recommended water supply plan
   C. Plan implementation
   D. Resolution of major issues
   E. Conclusions

PUBLIC PARTICIPATION

For comprehensive plans to be effective, it is necessary that the planning process provides for public participation during important stages in the process. Increasingly, citizens of more economically prosperous and technically advanced nations are demanding, as a fundamental right, not only clean air and pure water and food, but also decent, safe, and sanitary housing; unpolluted land; freedom from excessive noise and glare; adequate outdoor recreational facilities; and communities that provide convenient access to work, shopping, medical services, and educational opportunities. The historic, single purpose type of planning for highway, sanitary sewerage, water supply and drainage and flood control facilities, and for development projects should be set within a comprehensive approach, and thereby broadened to consider a full range of the potential economic, social, and environmental effects produced by the proposed development projects. The planning efforts must ensure that potential problems are avoided in the planning stages; that the solution of one pollution problem is not transferred from one medium to another, such as from water to land; and that projects are designed so as to enhance the overall quality of life.

Public participation is particularly important in the initial formulation of the scope and content of a proposed planning effort; in the formulation and development objectives and standards; in the formulation and evaluation of alternatives, and in the selection of recommended plan elements. Public participation can result in plan improvement, and in implementation programs that achieve agreed upon development objectives. Public participation is not only a critical function in comprehensive planning, but must also be a part of subsequent plan implementation efforts through the preliminary and final engineering phases.

Public participation can be achieved through various means. One of the most meaningful means is through the composition of official planning bodies such as city plan commissions. The composition of such planning bodies should include the chief executive of the municipality concerned, who should serve as chairman of the planning body, a member of the legislative body of the municipality concerned, and a number of qualified citizens. The director of the planning staff should not be a member of the planning body, but together with the municipal engineer, should constitute the necessary technical advisors to the planning body. Other forms of public participation may include informational meetings and public hearings. Behavioral observational and attitudinal surveys can constitute particularly objective and meaningful means for public participation in the planning process.

Informational meetings should be held with concerned interest groups, as well as with the general public. Such meetings should be carefully planned in order to provide the citizens concerned with the essential information necessary for intelligent participation in the planning work. The process should be supported by newsletters and Internet web sites, as well as through plan commissioners and staff presentations to business, civic, and environmental organizations. Special efforts should be made to bring community leaders into the public participation process. Although state law may specify the means by which public hearings must be advertised, efforts should be made to contact community leaders directly in order to encourage attendance at the hearings.

Good minutes should be kept of the public hearings, and the public reaction to alternative and recommended plans summarized in the planning reports. Sincere efforts should be made to address the issues raised and comments made at the hearings.

CONTINUING NATURE OF COMPREHENSIVE PLANNING PROCESS

The comprehensive planning process should be viewed as a continuing, cyclical process, alternating between comprehensive planning and project planning. With respect, for example, to transportation facility development and management, plan proposals are initially advanced at the areawide, systems level of planning. Attempts are then made to implement the plans through local project planning. If, for whatever reasons, a particular facility construction or management proposal advanced at the areawide systems level of planning cannot be implemented at the local project level, that situation must be taken into account in the next round of systems level planning. Similar situations may exist in land use, park and open space, flood control, and water-pollution-abatement planning, among others. In addition to monitoring the success in plan implementation—or lack thereof—the continued validity of the basic data, analyses, and forecasts and of the objectives and standards upon which the plans are based should be continually monitored, and the plans revised as may be found necessary by the findings of the monitoring efforts. In any case, plans should be reviewed and revised at approximately 10-year intervals.

Community development objectives and goals may be expected to change with time. New land-use concepts; means of transportation; housing needs and designs; economic, technological, and sociological developments; and changing public aspirations require periodic reevaluation of the comprehensive plan, and revisions of the plan as may be indicated. Keep in mind that human wants are insatiable; as soon as an objective is approached, or reached, another will be sought. This tendency should be kept within realistic bounds, however, and continuing planning should help to accomplish this.

Not be forgotten, is the continuing need for the extension by the planning agency of information, and of descriptions of plans and plan proposals to federal, state, and county agencies; to school districts; to other municipalities; to other sister departments such as public works and engineering, police and fire protection, and tax assessment; to businesses and industries, realtors, appraisers, developers, utilities, and to the general public. Properly carried out, this extension function can be of major assistance in achieving plan adoption and implementation.

The entire process of comprehensive planning can at best be only of limited value unless provision is made for competent direction, staffing and administration, particularly during plan implementation following plan preparation and adoption. Plan implementing ordinances, improvement programs, codes and rules and regulations have little meaning unless administered by competent personnel who are adequately compensated.

PROJECT PLANNING

Following completion and adoption of the comprehensive plan and the attendant capital improvement program, selected improvement projects can move to more definitive planning and engineering phases. The comprehensive planning function is the responsibility of municipal, county, and regional planning agencies, utilizing staff and, as may be necessary, consultants. Responsibility for the execution of the preliminary and final engineering phases of plan implementation projects will normally shift to a municipal, county, or state engineering agency, utilizing staff and consultants. If federal or state grants are involved in the funding of the projects, state agencies, such as state departments of transportation, and federal agencies, such as the Federal Highway Administration may become involved in oversight roles.

As the projects move from preliminary engineering into final engineering and construction, the agencies involved in administration of the projects will become involved in such matters as engineering design, right-of-way acquisition; and funding, including establishment of service districts, levying of special assessments, approval of bond issues, rate setting and debt retirement. Detailed construction plans and specifications must be completed, advertisements for bids issued, and contracts awarded to construction firms. Construction should be under the supervision of a resident engineer employed by the implementing agency. Importantly, upon completion of construction, the owner of the facility concerned should be provided with adequate *as-built* documents. In some cases, the final engineering may require the provision of operating manuals, and consultants may be responsible for placing a facility into operation and training staff for the continued operation and maintenance of the facilities concerned.

In the systems planning stage, general consideration is given to site and right-of-way requirements, and the location and alignment of proposed facilities will be approximate and subject to refinement and detailing in latter stages of development. Accordingly, the types of environmental impacts normally considered are areawide, including the probable impacts of the proposed systems on existing and planned land-use patterns, on travel habits and patterns, on the provision of sewerage and water supply sources, on air and on surface and groundwater quality, and on the natural resource base, including on woodlands, wetlands, floodlands, and prime agricultural areas. Public hearings should be held to solicit public reaction to each of the alternatives considered and to the recommended plan.

For certain types of major public infrastructure development projects, a corridor planning stage may be inserted between the systems planning and preliminary engineering stages. Corridor planning may be required by federal regulations for major transportation system improvement proposals supported by federal grants. In corridor planning, the transportation improvements recommended in the comprehensive plan for certain major travel corridors are reviewed and detailed. If, for example, the comprehensive plan calls for the development of a fixed guideway transit facility in a given major travel corridor of the planning area, corridor planning will consider alternative applicable fixed guideway modes such as busway, light rail, heavy rail, or commuter rail. The alternatives will include a no-build alternative, and will be evaluated in terms of cost-effectiveness and potential environmental impacts. Such corridor planning may also be conducted for major arterial highway, electric power transmission line, and high-pressure gas transmission line development proposals.

As projects move from system planning through preliminary engineering to final engineering and construction, the proposals become increasingly more definitive and detailed. In the preliminary engineering phase, greater consideration will be given to alternative site and right-of-way requirements, and to the horizontal location and vertical alignment of facilities. In transportation improvement projects, consideration will be given to alternative alignments, facility cross-sections and intersection treatments. In sanitary sewerage, drainage and flood control, and water supply development, consideration will be given to alternative locations for storage, transmission, and treatment facilities, and to alternative types of treatment. Environmental factors considered will become more detailed and include consideration of such factors as specific impacts on existing land uses; wetlands, floodlands, woodlands, and wildlife habitats, as well as of costs attendant to alternative facility alignments, and treatment options. At the preliminary engineering stage, no detailed engineering or architectural construction plans are prepared. However, the probable engineering, legal, economic, social, and environmental impacts of each alternative considered are presented together with cost estimates and methods of financing for each alterative. Public meetings and hearings should be held to solicit public reaction to each of the alternatives considered, and to the recommended plan.

Final engineering involves the completion of engineering design, and the preparation of construction plans, specifications, and bid documents. The assessment of environmental impacts and incorporation of environmental protection measures becomes even more detailed in the final engineering stage of a project. For example, the design of a major highway improvement must take into consideration the need for service and rest areas with picnic spaces, adequate sanitary facilities, safe drinking water, insect and weed control, and adequate wastewater and solid waste storage and disposal. It must also consider the effects of impervious surfaces on the quantity and quality of stormwater runoff; potential spills of toxic and hazardous chemicals; accident hazards; landscaping, and buffer zones; and the effects of entrance and exit routes on adjoining urban and rural communities. The long-term control of noise vibration and air pollution; the need for dust and weed suppression; and the control of chemical pesticides and herbicides and other pollutants must be carefully considered, particularly to avoid adverse effects on water supply wells, reservoirs, watersheds and recreational areas, as well as on wildlife and vegetation. Beyond these direct environmental concerns, the potential impacts of the project on community cohesion; population and employment levels, infrastructure costs; urban design and quality of life must be considered. Environmental effects during, as well as after, construction must also be considered, including erosion control, control of noise, vibration, and dust; potential pollution effects on lakes and streams, and on fish and wildlife; and the safe disposal of demolition materials without causing air, water, or land pollution.

SITE PLANNING

Introduction

Comprehensive public planning is generally focused on large planning areas such as entire cities, counties, and metropolitan areas. Urban development and redevelopment normally proceed through the conversion of existing land uses to proposed land uses on discrete sites. Such development must then be preceded by a process known as site planning. Site planning is usually undertaken in response to a perceived market demand for the type of proposed development concerned and is generally conducted in the private, as opposed to public, sector. It should, however, take place within the framework provided by adopted publically prepared comprehensive city, county or metropolitan plans. Site planning is concerned with site selection and the design of land developments that are economically and environmentally sound.

Site Selection

Site selection for major developments such as large manufacturing plants, major shopping and office centers, recreational and entertainment complexes, research and medical centers, prisons and other detention centers, major electric power generation stations, and military installations usually involves a two-stage process. The first stage will usually be conducted by a multidisciplinary location team retained by the developer—usually a private corporation, but in some instances a public utility or a federal or state agency. In the first stage, relatively large alternative areas may be considered such as—for some types of proposed developments—alternative metropolitan areas; for other types of proposed developments, alternative prime agricultural regions; and for yet others, prime recreational resource areas. Considerations in this initial stage will be primarily economic. The location selection criteria will be primarily cost oriented, involving the following factors:

- Market study findings, labor availability, and costs
- Availability of business and industrial service support, including legal, accounting, and marketing services
- Availability and adequacy of transportation facilities and services, including airport, freeway, and, for some developments, railway and waterway facilities
- In some cases, availability of raw or semimanufactured material sources
- Tax structure and burden

Increasingly, the quality of the infrastructure of the alternative areas being considered will be an important factor, considered together with the available amenities that contribute to a high quality of life. In some cases, the criteria will be primarily functional, such as in the case of electric power-generation facilities and military installations. The kinds of information collected for regional and local comprehensive planning will be most useful to the location teams.

In the second stage of site location for major developments, specific sites within the selected metropolitan area, prime agricultural area, or prime recreational resource area are considered. At this stage, more definitive physical site requirements are defined, including the desirable site size, accessibility to freeway interchanges and airport facilities, and in some cases, accessibility to railway and waterway facilities. The need for sanitary sewerage, water supply, telecommunication electric power and gas service, the need for police and fire protection, and the need for emergency medical service will be specified, together with any special liquid or solid waste disposal requirements, foundation conditions, buffer area needs, and zoning requirements.

Sites for the development of such public facilities as parks and parkways, schools, sewage and water storage facilities and treatment plants, stormwater detention or retention facilities, libraries, police and fire stations, and administrative buildings should be identified on the comprehensive plan. The comprehensive plan should also contain standards for the size of the sites required for the proposed facilities of the type concerned, together with, as may be appropriate, service radii or areas. Thus, the comprehensive plan, if technically sound and valid, greatly facilitates and simplifies that process,

Site Assessment

The site selection process should be followed by a site suitability assessment. This assessment is intended to provide the definitive information required for site design, and to identify any physical, environmental, or regulatory constraints on the design, or any obstacles to site development. The assessment should also provide information on the availability and adequacy of required sanitary sewage and water supply facilities; on the availability and adequacy of electric power, gas and telecommunications facilities; and on the adequacy of the arterial street and highway network serving the site. The assessment should identify the presence of flood hazards, contaminated soils, and contaminated groundwater, and should determine if the site was historically used as a hazardous or other solid waste disposal site. The presence of any old burial areas, areas of archeological and cultural significance, and of any old buried tanks, foundation walls, abandoned wells, active or abandoned agricultural drain tiles, or other structures should be determined. Information required for the assessment will include the location and configuration of the boundaries of the site, the existing land uses on the site, the presence of easements and other encumbrances, the topography as depicted by 1 foot or 2 feet vertical interval contours, the soils and soil characteristics, depths to water table and bedrock, and the presence of wetlands, woodlands, and wildlife habitat areas. Information on the frontages along, and attendant access to, public streets. The relationship of the site to existing and proposed freeway interchanges, public transit stations, and aircraft flight patterns should be determined. The existing zoning and recommendations concerning planned future land uses on the site and environs, as set forth in the comprehensive plan, should be obtained.

Much of the required information should be available from the planning database assembled for, and maintained under, the comprehensive planning process. Obtaining this information in a readily usable format will be greatly facilitated if the county or municipality involved has developed an automated, parcel-based, land information system. The comprehensive planning agency should also be able to provide topographic and cadastral maps, and ratioed and rectified aerial photographs, or ortho photographs, of the site and environs. These maps and photographs can be used, together with real property boundary land survey, to prepare a base map that can be used to display the required information in an integrated and useful manner. Soil survey information, together with interpretations of the characteristics of the mapped soils for various rural and urban uses, should be available from the U.S. Natural Resources Conservation Service, preferably through the local land information system. U.S. Geologic Survey 1-to-24,000 scale quadrangle maps may be useful in providing a general setting for the site. Such maps are, however, at too small a scale and have too large a contour interval to be useful in a site assessment, or in urban planning, for that matter.

The site assessment should include an inspection by a qualified and experienced engineer. A base map, or aerial photograph, displaying the pertinent information, as collated from the existing sources, should be prepared for use in the field inspection. The purpose of the inspection should be to verify the information shown on that map or photograph. The inspection may include personal interviews with former owners or users of the site, and present owners and occupants of surrounding sites,. Based on the field inspection findings, the map or photograph should be annotated to show any conflicts with existing data shown; desirable features such as attractive overviews, and undesirable features such as unattractive land uses or adjacent sites, should be noted; together with locations of the locations of safe ingress and egress along bordering streets and highways.

Generally Desirable Site Features

The desirable features of a site will depend on the specific intended use. Generally desirable site features, however, will include the presence of ten characteristics or features:

1. An adequate groundwater or surface-water source not subject to pollution that can be developed into a satisfactory supply at an accessible and convenient location on the site if an adequate public water supply is not available. The water supply source should meet federal and state standards.
2. Permeable soils that will readily absorb rainwater, and permit the disposal of sanitary sewage and other wastewater by conventional, on-site, anaerobic subsurface means—septic tanks and drain tile fields—where public sewer service is not available. Depths to watertable, impervious subsoil, or bedrock should be at least 5 feet.
3. Land to be used for the location of buildings and other structures should have soils with suitable load-bearing characteristics, and should be well above flood levels. Ground slopes should normally not exceed 10 percent; slopes of more than 10 percent require careful soil analyses for stability and careful site design.
4. Areas of well-drained, dry land, open to sunshine part of the day, on gently sloping, partly wooded hillsides or ridges. The cleared land should have a firm, grass-covered base to prevent erosion and dust. Slopes having a southern or eastern exposure protected from strong north and west winds are generally desirable.

5. The area of the site should be large enough to provide privacy, avoid crowding, accommodate needed buildings and structures in a well-sited manner, and allow for future expansion. The property should be accessible by automobile; and, for some intended uses, by public transit. For some intended uses, the site should have access to railway and waterway services, and be conveniently located for airport service. Careful attention should be given to traffic conditions on arterial streets and highways serving the site area. Inner-city locations should facilitate ready pedestrian and bicycle, as well as public transit access.
6. For sites intended for certain types of major recreational use, area for the provision of bathing, swimming, and other water sport facilities should be available. The facilities may include a clean stream or lake or an artificial swimming pool. A stream should not have a strong current, or remain muddy during its period of use. An artificial swimming pool equipped with filtration, recirculation, and chlorination equipment may be proposed to advantage.
7. Noxious plants, poisonous reptiles, harmful insects, excessive dust, steep cliffs, old dumps, chemical burial grounds, old mine shafts or wells, dangerous rapids, dampness, and fog should be absent.
8. Availability of centralized public sewerage, water supply, solid waste disposal, police and fire protection, and emergency medical services is desirable and may be essential for some intended uses. Electric power, gas, and telecommunication services should be readily available.
9. An adopted land-use plan and implementing zoning ordinance should provide for the development and protection of the intended use. A modern building construction code vigorously enforced by competent people should be ensured.
10. Air pollution, noise, and traffic problems from adjoining areas should not interfere with the proposed use.

Site Inventory

The information required as a basis for good site planning and design will also depend on the specific intended use. A good site inventory, however, will consist of the following general data collation and collection efforts.

Topography and Site Survey A boundary and topographic survey of the property, at a scale of 1 to 1,200 or larger, with the topography depicted by contours with 1 foot or 2 feet vertical intervals and with roadways, watercourses, wetlands, woodlands, existing structures, powerlines, rock outcrops, and other significant physical features indicated, is essential to the proper study and analysis of a site. If such a survey map is not available, a large scale ratioed and rectified aerial photograph, or orthophotograph may be used.

If a natural bathing and swimming area is to be involved in the intended use, the bathing and swimming area should be sounded and the slope of the bottom determined. The need for cleaning and removal of mud, rocks, and aquatic growths should be noted. The drainage area tributary to the stream or lake to be used for bathing should be determined, and the probable minimum flow, or level, should be determined to ascertain if an adequate quantity of water will be available during the dry months of the year. Long-term hydrological data, such as provided by U.S. Geological Survey stream gaging stations, would be very valuable in this report.

In most cases, the watershed area tributary to a beach on a stream or lake will extend beyond the boundary of the land under consideration. Therefore, it will be important to determine the existing and planned land uses in the watershed. The existing level of water quality of the streams or lakes concerned, existing and probable future sources of pollution, and probable future levels of water quality should be determined. This should permit determination of whether or not chemical, bacterial, or physical pollution may be expected to make the stream or lake concerned unsuitable for bathing and swimming use, or for water supply purposes. It may be necessary to collect water samples at different times of the year for chemical, physical, and microbiological analyses. Municipal, county, environmental, and agricultural agencies may be able to provide assistance. In addition to satisfactory quantity and quality, the water should be relatively clear and slow moving. Study of the stream bottom, and float or weir measurements to determine the velocity and quantity of water at different seasons of the year will provide supplemental information.

The presence of any flood hazard should be determined. This should involve delineation of the 10- and 100-year recurrence interval flood flows, stages, and attendant inundation areas. Evidence of high-water levels, as indicated by stranded tree trunks and debris; discoloration of rocks and trees; the width, depth, and slope of the stream channel; pertinent highway and railway culvert and bridge waterway openings; and the limits of terrestrial and aquatic vegetation, should be observed.

The presence of old orchards may indicate the presence of pesticide-contaminated soil and groundwater. Municipal, county, and state government agencies should be questioned regarding past agricultural, industrial, and commercial land uses on the site; permits issued; known accidental spill occurrences of toxic and hazardous materials; old dumps; and illegal dumping.

Geology, Soil, and Drainage Detailed, operational soil maps prepared by the U.S. Natural Resources Conservation Service (formerly the U.S. Soil Conservation Service), together with attendant soil properties and use suitability interpretations should be obtained. It may be necessary to obtain soil samples at representative locations to supplement the information provided by the soil maps. Borings should be made to a depth of about 15 feet in order to record variations in the strata penetrated, and the elevation of the groundwater level, if encountered, with respect to the ground surface. Borings may also indicate the depth to bedrock and the presence and thickness of clay or hardpan layers that might interfere with proper drainage, or construction of foundations for buildings and other structures. Old dump sites will require careful investigation with respect to the presence of toxic and hazardous wastes, groundwater pollution by leakage of septage, leakage of methane with attendant fire hazard, and stability of foundations for buildings, other structures, roadways, driveways, service walks and parking areas. Soil percolation tests may be required to determine the suitability of the site for subsurface sewage disposal, if needed.

If a proposed development is to be located on the side of a long hill or slope, the necessity and feasibility of providing stormwater runoff diversion facilities should be noted. The possibility of erosion and earth slides should be given careful study. Slopes with a greater than 10 percent incline require special engineering study and treatment to control and prevent erosion, slides, and runoff. All wetlands, as defined by federal and state laws and regulations, need to be identified and mapped for consideration in the site design. Where appropriate, wetland mitigation and banking may be considered.

Utilities The need for and existence of centralized sanitary sewerage, water supply, solid waste collection and disposal, electric power and gas, and telecommunications services should be determined. This will indicate the type of on-site services that may be needed.

If an adequate, satisfactory, and safe water supply is not obtainable on- or off-site at a reasonable cost—with or without treatment—further consideration of the site should be abandoned. This is of particular importance in large-scale residential, commercial, industrial and institutional developments that are dependent on the availability of large volumes of safe water.

The probable cost of wastewater collection and treatment should be estimated before any commitment to a site is made. The use classification, minimum flow, and effluent standards for recovering streams and lakes, and water pollution abatement requirements will govern the degree of treatment required, and hence the wastewater treatment facility capital operating and maintenance costs. For large developments, elaborate wastewater treatment plants may be required. For small developments, subsurface sewage treatment and disposal system may suffice if the soil conditions are satisfactory.

The ready availability of centralized electric power for lighting, the operation of water and wastewater pumps, kitchen equipment, refrigerator compressors, and other electrical and mechanical equipment is often taken for granted. If the provision of adequate electric power requires the construction of long transmission lines, the purchase of electric-generating units, or gasoline motor-driven equipment, then the capital, operating, maintenance, and replacement cost should be estimated.

Roads to the buildings and structures forming the intended uses, will be needed for access, for the provision of freight and package deliveries, and for the provision of various maintenance services. The distance from the main arterial roads to the property, the length and condition of secondary roads, and the length and width of access roads within the property should be determined, as well as the need for culverts and bridges. The traffic generation potential of the intended use should be considered, together with the impacts on the existing street and highway system. Options for alternative sites in urban areas served by public transit facilities should be given weight.

If a proposed electric power generation of industrial plant will cause air pollution, prevailing winds, temperatures, and air-pollution requirements will have to be studied, and the cost of treatment devices will have to be determined in evaluating the suitability of a proposed site. If a plant process will result in the production of large quantities of solid wastes, the treatment and disposal of the residue must also be considered. If a brownfield site involving redevelopment of an urban area is involved, the need for and cost of remedial measures required to restore polluted soil and groundwater should be determined.

Meteorology In North America, slopes having an eastern or southern exposure are preferred for building locations in order to obtain the benefit of the morning sun. This possibility can be ascertained by inspection of available topographic maps and by field inspection. The potential for solar space and water heating should be considered; this will require knowledge of the latitude of the site and of existing and proposed buildings and other structures and of tree growth. Information about the direction of prevailing winds under both summer and winter conditions is valuable. Needed information on maximum, minimum, and average monthly temperatures, humidity, snowfall, and rainfall should be available from federal and state agencies and some water and power companies.

Location The relative location of the property can best be appreciated by marking its outline on planning base maps available from the cognizant municipal or county planning agencies. In the absence of such base maps, a recent U.S. Geological Survey quadrangle map may be used. In this way, the distances to freeway interchanges, airports, railway and bus stations, shopping and employment centers, recreational areas, schools, and medical facilities will be apparent. The plan proposals of municipal, county, and state transportation agencies should be obtained and proposed new or widened arterial street and highway should be marked on the site maps to determine the probable effects of the planned facilities.

Natural Resource Base For large tracts, the presence, location, content, and character of significant elements of the natural resource base should be determined. Much useful natural resource base information can be obtained from municipal, county, state, and federal agencies. The location, size, and type of wetlands, woodlands, and prairies and of economically workable sand, gravel and bedrock formations should be determined.

Broad knowledge and extensive investigation are needed to properly evaluate the presence and importance of animal and plant life on the site and environs and the need for protection and conservation measures. The presence of poison ivy, for example, must be accepted as a potential source of serious skin irritations, and ragweed and other noxious plants as sources of allergic reactions. It is important to mark the location of any infested areas on the site map so that attention is directed to their existence in the construction and planning program. This would also apply to the presence of mosquitoes, flies, ticks, chiggers, rodents, poisonous reptiles, and dangerous animals. Attention should also be given to the presence of wildflowers, useful reptiles and wild animals, and native trees. The location and extent of rare and endangered species habit should be determined.

Environmental Corridors Beginning with its first regional land use plans proposed and adopted in the early 1960s, the Southeastern Wisconsin Regional Planning Commission advanced the concept of the environmental corridor. This concept was not originated by the Commission, but had its roots in the earliest parkway system planning for Milwaukee County early in the turn of the twentieth century. In the late 1950s, this concept was articulated and advanced in an academic sense by Professor Phillip H. Lewis Jr. of the Department of Landscape Architecture of the University of Wisconsin, Madison. The Commission then advanced the concept in its land-use planning efforts, and thereby accomplished the first practical application of the concept on a regional scale.

Environmental corridors were defined by the Commission as linear areas in the landscape that encompass the most important elements of the natural resource base. Constituting about 17 percent of the 2,700 square mile southeastern Wisconsin region, the corridors encompass about all of the best remaining elements of the natural resource base, including the best remaining woodlands, wetlands, and wildlife habitat areas; surface waters and associated shorelands and floodlands; areas covered by organic soils; areas containing rough topography and significant geological formations; sites having scenic, historic, and scientific value; and areas of groundwater recharge and discharge. The delineation of the corridors required the conduct of detailed inventories of the various elements of the natural resource base, and the integration of the inventory data into an, at first, graphic database, later an automated, geographic information system.

Through its land-use planning efforts, the Commission collected the detailed, definitive information necessary to delineate these corridors, accurately delineated the corridors, and promoted their protection and preservation in essentially natural open uses. The Commission has found the corridors to be essential to the protection and wise use of the natural resource base, to the preservation of the cultural heritage and natural beauty of the region, and to the enrichment of the physical, intellectual, and spiritual development of the resident population of the region. The preservation of the corridors not only helps to ensure the maintenance of the overall quality of the environment in the region, but also helps to prevent the creation of serious and costly environmental and developmental problems. These problems include surface and groundwater pollution; poor drainage and flooding; failing on-site sewage disposal systems; excessive infiltration of clear water into sanitary sewerage systems; wet basements and excessive operation of sump pumps; and settlement and structural failure of roadways, parking areas, utilities, and buildings. Importantly, the corridors help to give form and structure to urban development within the region.

Through the Commission planning efforts, the environmental corridor concept has been institutionalized not only in southeastern Wisconsin but throughout the state of Wisconsin, finding its way into county, and local land-use plans, county and local zoning and land subdivision control ordinances, and state water pollution abatement and sanitary sewer extension regulations, state land acquisition programs for park and resource conservation purposes, and into federal and state wetland protection regulations. The concept of the environmental corridor has become well established in contemporary planning practice within the region.

Improvements Needed

Inasmuch as the ideal site for an intended use is rarely, if ever, found, the work that needs to be done to make the site suitable should be determined. An undesirable feature may, for example, be a low, swampy area on and adjacent to the site. It may not be possible to fill this area unless mitigative measures have been arranged with federal and state regulatory agencies. With careful site design, that swamp may be retained as needed for open space, stormwater storage area, and wildlife preserve. Each possibility and constraint should be examined and reviewed with the regulatory agencies having jurisdiction, the cost of the work estimated, and the probable value of the improvement appraised. Needed clearing, seeding, and reforestation should be considered.

The need for new roads and drives within the site connecting with the existing municipal, county, or state roads is an important consideration. The need for the widening of existing public arterial streets and highways and, for intersection improvements and traffic signalization engendered by the proposed development should be determined. The needed road improvements may involve major earth work and culvert and bridge construction, all of which may mean high costs. Other needed physical improvements may include surface-water diversion ditches, brush clearing, boat docks, parking areas, and the preparation of areas for recreational purposes. All such improvements will have environmental impacts that must be assessed.

Site Design

After a site has been selected and its properties have been inventoried and analyzed, site design may be undertaken. If not already available as a part of the site inventory, this will require a preparation of a property boundary and topographic map of the proposed site at a scale of 1 to 1,200 or larger, with 1 foot or 2 feet as vertical interval contour lines, displaying the information collated and collected in the site inventory and assessment. Desirable and undesirable features of the site should be noted on the map. Alternative plans for the development of the site should then be prepared. The location of buildings; access roads, parking and truck loading and unloading areas; sanitary sewage, water supply, refuse disposal facility locations; and other needed facility locations determined. Particular attention should be given to drainage requirements and to the design of stormwater runoff conveyance and storage facilities. The alternatives should be evaluated on the basis of costs, effectiveness, and environmental impacts, and a final site plan prepared. For major developments, preparation of a scale model may be desirable. Such a model will help others visualize the proposed buildings and structures to each other and to roadways, streams, lakes, hills, and neighboring land uses. Scheduled public information and participation sessions should be an essential component of the site planning process for major developments.

For major projects a design team consisting of an architect, landscape architect, planner, and engineer should be assembled to prepare the site plan and engineering designs. State, county, and municipal planning and engineering agencies should be consulted on applicable regulations and requirements. Environmental protection and conservation agencies should be consulted about required measures for the protection of the flora, fauna, and ecology of the site and environs, and the need for an environmental impact assessment or environmental impact statement. Such consultation is particularly important when a large housing development, industrial plant, office complex, shopping center, landfill, wastewater treatment plant, hospital, or other major development is contemplated. The agency staff may also be in a position to offer valuable information regarding former uses of the site and possible hazards not readily apparent.

The site plan should show, in addition to the improvements already noted, such other details as may be required by the regulatory agencies having jurisdiction in order to permit their staffs to review and approve the plans. After plan approvals are received and permits issued, contract drawings and specification can be prepared, bids solicited, contracts let, a construction schedule established, and the work carried on in accordance with a preconceived, carefully thought-out plan. There should then be no looking back at useless, inefficient, wasteful structures or spaces; but instead, satisfaction with the realization of a good development.

The importance of obtaining competent professional advice in the site selection and planning process cannot be emphasized too strongly. All too often, developers may seek the cheapest, rather than the best, professional services, while charitable institutions may often solicit "free" engineering and architectural services. This represents poor policy. The consultants so engaged may, for economic reasons, have to conclude the site selection, planning, and design process as quickly as possible; and the recipients of the services may proceed with development on the basis of a possibly inadequately studied site and incompetently conceived plans, detailed drawings, specifications, and contract documents. For major site developments, it may be useful to assemble a committee of outside experts to assist in the selection of the design team, contractors, and construction equipment and techniques; to review plans, specifications, and contracts; and to evaluate bids received. The fee for consultant services, in comparison to the cost of a project, is usually relatively small. Moreover, these fees pale in comparison to the costs associated with such errors as the incorrect sizing of building; the use of improper materials; poor planning and design of equipment and facilities; foundation and structural weaknesses; and bad location or exposure of buildings. When savings in the selection of proper materials and equipment for minimum long-term maintenance and operating costs, and compliance with plans and specifications, are considered, the savings far outweighs the professional fees involved.

LAND SUBDIVISION

The design of land subdivisions may be viewed as a special case of site planning, often involving large tracts of land ranging in area from 80 acres to 1,200 or more acres. The process of land subdivision may be described as the division of land into smaller parcels, usually for the purpose of urban development. Land subdivision, however, is more than a means of describing, marketing, and taxing land; it is, in effect, the first step in the process of building a community. Much of the form and character of a community is determined by the quality of its land subdivisions. Once land has been divided into blocks and lots, streets constructed, schools and park sites dedicated, and utilities installed, the urban development pattern is established and is unlikely to be changed. Residential, commercial, and industrial structures will be built on the sites created by the land subdivision. After many decades of use, some of the structures may be razed to make way for new structures and, thereby, accommodate new uses. Yet the street pattern established by the initial land subdivision will probably remain basically unchanged. For generations the entire community, as well as the individuals who occupy the subdivision, will be influenced by the quality of its design and by the character of its improvements. Many of the environmental problems that affects communities, such as traffic congestion, drainage, flooding, high street and utility operation and maintenance costs, inadequate park and school sites and facilities, high fire and police protection costs, and urban blight may be directly attributable to the manner in which areas of the community were originally subdivided. Just as important, in this respect, in the design of land subdivisions is the issue of whether or not the areas concerned should have been subdivided at all. The scattering land subdivisions—often referred to as *urban sprawl*—located too far from essential community services such as sanitary storage, water supply, fire and police protection, emergency medical services, public transportation and schools, not only create a less desirable place in which live and work, but also tax the resources of the community in attempting to furnish the necessary public facilities and services. The continued availability of agricultural areas may also be destroyed through scattered land subdivision development. Also important in this respect is the issue of whether an excess of building sites is being created at any one time, thereby leaving the community with scattered, partially developed neighborhoods.

The community is required in one way or another to provide the public facilities and services that make urban life possible. Therefore, the community should be able to require that street rights-of-way and roadway pavements be wide enough to accommodate firefighting, emergency service, solid-waste collection and snow removal equipment; that street configuration, grades, and curves are adequate for the safe movement of traffic, good access to building sites, and snow storage; that building sites are adequately drained and not subject to flooding; and, if public sanitary sewer facilities are not be provided, that lots are of sufficient size and have soil characteristics that can accommodate on-site sewage disposal facilities without creating a public health hazard. Land subdivisions will have impacts extending beyond the site boundaries and the subdivision itself, and the community should be able to require that the developer bear a fair and proportionate share of required off-site improvement costs, considering the impacts of the proposed subdivision development on arterial traffic, on sanitary sewerage conveyance, storage, and treatment facilities; on water supply transmission, storage, and treatment facilities; on stormwater management facilities; and on school, library, and park facilities. Subdivision development will also have important fiscal impacts. These impacts may be positive or negative, depending on whether the revenues obtained from the new development exceed the costs of the facilities and services to be provided or are less than those costs. In the latter case, some development may results in higher incremental costs of services than the taxable value of the development may provide in revenues. The potential fiscal impacts of a proposed subdivision development warrant careful analysis, even though the developer may be required to pay the costs of all on-site improvement, costs that the developer will pass on to the lot purchasers.

Because land subdivision affects a broad spectrum of interests, and the welfare of the community in many respects, the public regulation of land subdivision has become widely accepted as a function of municipal, county, and state government. Land subdivision regulation is an exercise of control by the community over the conversion of land into building sites. It is through such regulation that the public interest in land subdivision is expressed and directed. Land subdivision regulation is intended to accomplish the following seven purposes:

1. Ensure that proposed land subdivision will fit harmoniously into the existing land-use pattern, and will serve to implement the community comprehensive plan for the physical development of the community.
2. Ensure that adequate provision is made for the necessary and planned neighborhood and community facilities, including parks, access ways to navigable waters, schools, and shopping areas, so that a healthy, attractive, and efficient urban environment results.
3. Ensure that sound standards for the development of land are met with particular attention to such factors as street layouts, widths, and grades; vehicular and pedestrian circulation; park and open space requirements; block configurations and lot sizes; and street, utility, stormwater management, and transit improvements.
4. Provide a basis for clear and accurate property boundary line, demarcations and records. This was the sole purpose of many original state subdivision control enabling acts dating back to the early nineteenth century.
5. Ensure the fiscal stability of the community, minimizing the capital, operating and maintenance costs of public facilities and services, and protecting against the development over time of blighted areas.

6. Promote the public health safety and general welfare.
7. Balance private property rights against the need to protect and preserve the public health safety and general welfare.

The community zoning ordinance relates to the type of building development that can be placed on the land, whereas the land subdivision control ordinance relates to the way in which land is divided and made ready for building development. The purpose of a land subdivision control ordinance should be to ensure compliance with at least minimum standards for sound development, and to prevent further occurrence of the abuses in land development that have occurred in the past.

Because of its importance to sound community development, subdivision design and development is highly regulated. State statutes provide the enabling authority for the exercise of subdivision control at the county and municipal levels. State statutes and administrative codes will usually also provide for the review and approval of proposed land subdivision plats by such state agencies as the departments of transportation and natural resources. State administrative codes will often specify in great detail the survey data that must be shown on final subdivision plats, as well as the levels of precision and accuracy required for the surveys and survey computations on which the plats are based. County and municipal ordinances will usually specify in great detail design standards and required improvements such as of streets, sanitary sewers, water mains, stormwater management facilities, and street trees, lighting, and signing. Approved plats must be recorded with the county register of deeds in order to permit reference to plats in the conveyance of title to real properties, to levy real property taxes, and to prevent fraud. State statutes normally require that the plats be prepared by registered land surveyors, and the surveyors are usually made responsible for the compliance with subdivision control regulations.

Subdivision Design

Land subdivision design is an art requiring a high degree of technical skill and full realization of the importance of the design of the various interests involved and affected. Good land subdivision design requires imagination and creativity, as well as adherence to sound principles of land planning and engineering practices and to sound design and development standards. For these reasons, public regulation alone is no guarantee of good land subdivision design. For large subdivisions, a design team consisting of a land planner, a landscape architect, a civil engineer, and a land surveyor should be employed. In undertaking a subdivision design, a designer, or design team, may face one of three situations that will determine the manner in which the design must be approached:

1. The land proposed to be subdivided is located within a community that has not prepared and adopted a comprehensive plan.

2. The land proposed to be subdivided is located within a community that has prepared and adopted a comprehensive plan, but that plan does not include, as a component, detailed neighborhood unit development plans or platting layouts.
3. The land proposed to be subdivided is located within the community that has prepared and adopted a comprehensive plan, and that plan includes detailed neighborhood unit development plans or platting layouts.

In the case where a community has not prepared and adopted a comprehensive plan, the designer or design team will have no overall planning framework within which to work. Accordingly, great skill and experience are required, together with intimate knowledge of the principles and practices governing good subdivision design. Substantially greater effort will be required on the part of the designer, or design team, than would be the case if sound local planning had provided a framework for the design process.

In the case where the land proposed to be subdivided is located within the community that has prepared and adopted a comprehensive plan, but has not prepared and adopted detailed neighborhood unit development plans or platting layouts as an element of that plan, the adopted community plan will provide a broad, invaluable guidance to the designer, or design team. The comprehensive plan should contain specific recommendations relative to such matters important to good subdivision design as the location and width of arterial streets, the generalized location of needed school and park sites; and the generalized location and configuration of needed drainage ways and stormwater retention or detention areas. The plan should also provide much of the information essential to good design, including current aerial photography, large-scale topographic and cadastral maps; detailed soil maps with attendant use interpretations; definitive information on the location and configuration of flood hazard areas; and on the location and configuration of such elements of the natural resources base as wetlands, woodlands, and wildlife habitat areas. Importantly, the comprehensive plan should specify the type and densities of land uses to be accommodated within the proposed subdivision; the densities for residential use usually being expressed as the maximum number of dwelling units permitted per gross acre. In this case, the designer, or design team, can focus on the creation of an efficient and attractive street, block, and lot layout, and on the creation of a unified design for the proposed subdivision.

In the case where the land proposed to be subdivided lies within a community that has adopted a comprehensive plan that includes detailed neighborhood development plans or platting layouts, the local unit of government concerned will have provided not only data concerning the types of and entities of land use to be accommodated on the land concerned, but proposed specific locations for neighborhood schools, parks and drainage ways, together with a specific layout for collector and land access, as well as arterial, streets. In this case, the designer or design team will be responsible for reviewing the design provided in the comprehensive plan, for proposing design improvement to that plan, and for ensuring the unity of design with the subdivision itself. In this case, the adopted neighborhood unit plans or platting layouts should be viewed as points of departure for the design of the subdivisions of individual tracts of land included within the neighborhood units. The adopted neighborhood unit plan should not unduly constrain the designer, or design team, in seeking more creative or cost-effective approaches to the subdivision design concerned. Changes in the adopted neighborhood unit development plan may be particularly warranted if that plan no longer adequately reflects current market conditions.

Figure 6.2 depicts a neighborhood unit plan that incorporates sound design principles. It provides, for example, a centrally located neighborhood park in conjunction with a neighborhood school site. The collector street layout is designed to carry traffic into and out of the neighborhood, rather than through it; and neighborhood shopping center having access to the collector and arterial street system is provided. The collector and land access streets are carefully designed to fit the topography of the site in order to minimize grading, and the destruction of existing tree growth, ground cover, and top soil; to facilitate good drainage; and to facilitate the design of gravity drainage sanitary sewers. The street layout facilitates good lot layout; and access to arterial streets is limited. The system of natural drainage ways, together with the street rights-of-way, form a viable major stormwater drainage system. The neighborhood shown is an area slightly larger than one square mile and a development density of about 5,200 persons per square mile, or about eight persons per gross acre. The elementary school would have an enrollment of about 450 children.

It should be noted that the principles underlying the design of the particular neighborhood unit shown predate the recent interest in what has been termed *new urbanism design*. The new urbanism design is, however, in essence little more than a return to older subdivision designs used in developing the central cities and first-ring suburbs of American cities. The neighborhood unit shown would meet the new urbanism design principles in many respects, such as the provision of neighborhood shopping, park and playground, and school facilities. A new urbanism design would probably favor a higher density of development—perhaps up to about 10,000 persons per square mile—and the promotion of mixed land uses, particularly in the provision of commercial and residential subareas.

Site Selection and Assessment

As in any site planning effort, the land subdivision design process should be preceded by site selection and assessment. Site selection should be determined by market analyses and land availability and value studies, but should be constrained by the recommendations contained in adopted comprehensive plans and in the implementing zoning ordinances. The comprehensive plan should identify the areas recommended for new residential, commercial, industrial, and institutional development within the municipal planning area, including the extraterritorial areas envisioned as being part of the municipal sphere of interest. The comprehensive plan should recommend the placement of new land-use development in time as well as space, while the zoning ordinance, in accordance with the

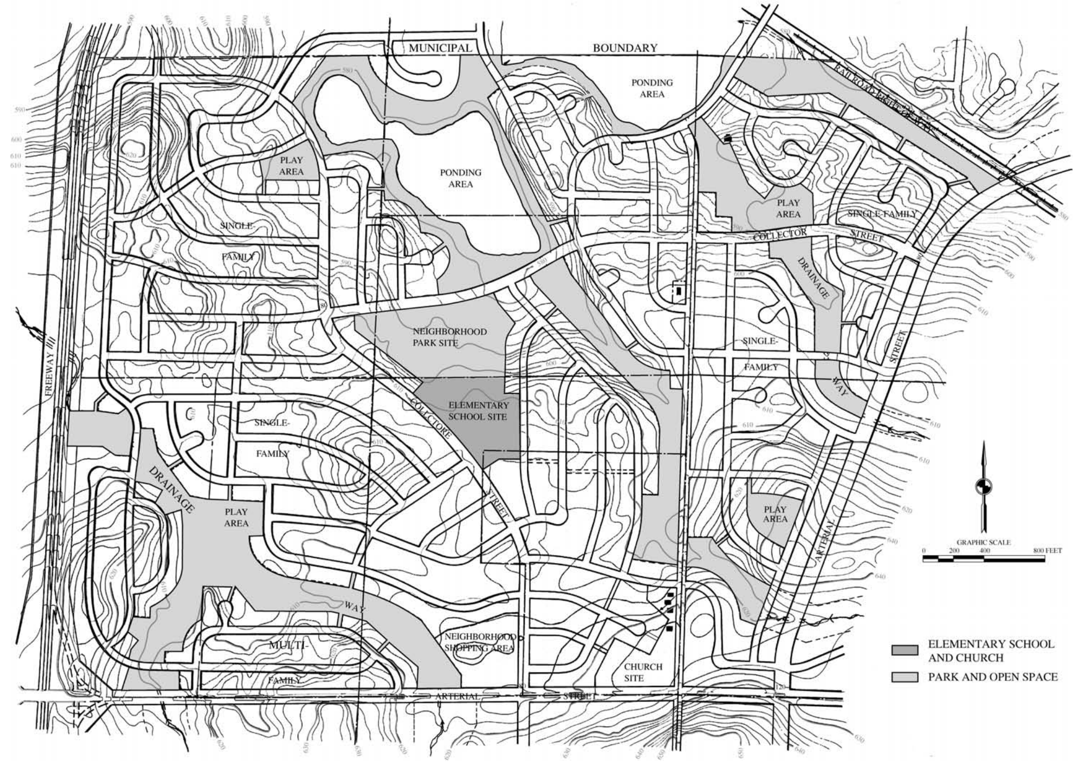


FIGURE 6.2 Depicts a neighborhood unit design that incorporates the five design principles described herein. It provides, for example, a centrally located neighborhood park in conjunction with a neighborhood school site, allowing dual use of the facilities and efficient maintenance. The collector street layout is designed to carry traffic into and out of the neighborhood, rather than through it. A neighborhood shopping center convenient to the collector and arterial street system is provided. The collector and land access streets are carefully adjusted to the topography of the site to minimize grading a destruction of tree growth and ground cover. Access to arterial streets is limited by backing lots against such streets. The street layout facilitates good lot layout. A system of natural drainageways, together with the streets rights-of-way, form a viable major stormwater drainage system.

comprehensive plan, should set aside holding areas for future development. As the market for additional building sites develops, appropriate portions of the holding zones can be redistricted to provide for the needed additional development. The placement of new development in time and space should be such as to facilitate the completion of all partially development neighborhood units before the development of part or all of other such units is contemplated.

Site assessment should be based on field inspection. The assessment should include the following:

- A topographic analysis, identifying areas of steep slopes, the locations of hilltops, ridges, and scenic overviews
- Analysis of drainage patterns
- Delineation of areas of existing vegetation and, particularly, of fine stands of trees
- Identification of water bodies and associated flood hazard areas, and of wetlands
- Identification of the boundaries and characteristics of environmental corridors
- Identification of existing structures having historic or other cultural value

The assessment should also identify the classification of existing streets and highways located adjacent to the development parcel or tract, and the location of desirable and safe points of entrance to and exit from the site. Proposed streets within, or adjacent to, the parcel depicted on the adopted comprehensive plan or official map should be identified. Pertinent existing physical conditions surrounding the parcel, and recommendations in municipal, county, regional, or state plans affecting the parcel, should be identified. The availability of public sanitary sewerage and water-supply services should be determined. Certain areas within a proposed subdivision may be considered for maintenance in permanent open space, including land within any 100-year recurrence interval flood hazard areas, wetlands, and areas of steep slopes. The results of the field assessment should be presented in a site analysis map, similar to the one shown in Figure 6.3.

Alternative Subdivision Design Types

There are three basic subdivision design types in current use at the municipal scale of development: conventional curvilinear, urban cluster, and new urbanism. Selection of the design type that should be used for any given tract of land depends on many factors, including market identification and conditions, surrounding land uses, and site conditions. Site conditions are a particularly important consideration in this respect, as some sites are more suited to a given design type due to the topographic and natural resource features present on the site. The application of these three subdivision design types to the 80-acre tract depicted in the site analysis map given in Figure 6.3 are set forth in Figure 6.4.

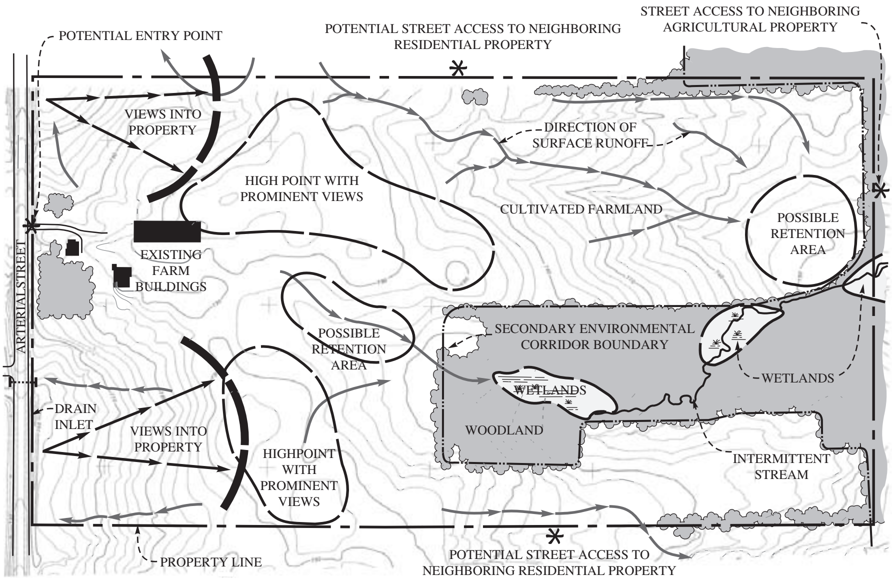
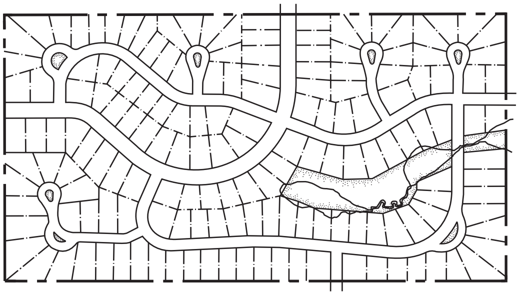


FIGURE 6.3 A site analysis should be conducted before a subdivision design type is selected and any subdivision layout created. In general, the analysis should include a topographic analysis, identifying areas of steep slopes; the locations of hilltops, ridges, and scenic overviews; an analysis drainage patterns; a vegetation analysis; a delineation of soil types and characteristics; an identification of water bodies, wetlands, woodlands, and flood hazard areas; an identification of the boundaries and characteristics of environmental corridors; and identification of structures having historic or other cultural value. The site analysis should also identify the classification of existing streets and highways adjacent to the development parcel, and the location of desirable and undesirable points of entrance to and exit from the site.

It is important to note that the subdivision layouts shown were prepared assuming that a local comprehensive plan was available to specify the type and density of land use to be accommodated, and assuming further that the comprehensive plan concerned did not include a neighborhood unit development plan or platting layout. The comprehensive plan was assumed to set forth a specific overall residential development density for the 80-acre tract concerned; and identified the arterial street pattern and related right-of-way widths. It is particularly important that the comprehensive plan set forth a specific maximum density of development in order to ensure that the public infrastructure and services are adequate and appropriate to serve development within the community.

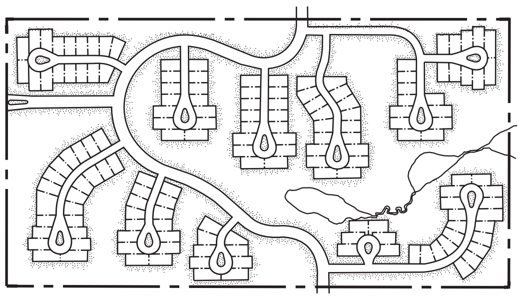
Table 6.1 sets forth a comparative analysis of the three designs shown. To facilitate the comparison, a common development density of approximately two dwelling units per gross acre—or a total of 160 dwelling units for the tract—was assumed. In an actual design setting, the density used might be varied between the three designs, as long as it did not exceed the maximum density specified in the comprehensive plan.



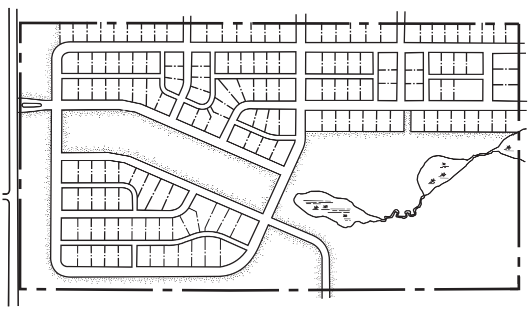
The curvilinear subdivision design type has been the most common type of subdivision developed in the United States in the post–World War II era. The curvilinear subdivision has generally been designed to provide relatively large lots that permit larger homes with more private open space on each lot. The design of a curvilinear subdivision facilitates adjustment to fit the topography and minimize required grading while providing good drainage and efficient sewerage.

(*a*)

The urban cluster subdivision design type maintains a significant portion of a site in common open space bye minimizing individual lot sizes while maintaining the required overall density of development. The cluster subdivision, whether located in an urban or rural area, can effectively protect environmentally sensitive areas by maintaining such areas in open space, while concentrating lot into small groups or "clusters." Each residential lot in this subdivision layout has direct access to the common open space, and the use of cul-de-sac streets enhances residential quiet, privacy, seclusion, and safety.



(*b*)



The new urbanism design type is based on urban development patterns of the past, with consideration given to the open space concerns of the present. New urbanism subdivisions attempt to provide a central public common that is surrounded by residential lots, or, in some larger subdivisions, may provide for a neighborhood business or civic center. Residential lots are often double-fronted, with one face to the street and one to a utility corridor or alley running behind the lots, where garages are located. The new urbanism design is better suited to relatively level sites where the desired density of development is easily achieved without substantial grading. The grid street pattern provides more connections to adjoining tracts, and often results in shorter walking and bicycling distances, but may also result in higher volumes of through traffic using subdivision streets, increasing noise levels and safety concerns.

(*c*)

FIGURE 6.4 (*a*) Conventional curvilinear subdivision layout, (*b*) urban cluster subdivision layout, and (*c*) new urbanism subdivision layout.

The curvilinear subdivision design is intended to maximize the use of developable land for lots, while limiting open space to environmentally sensitive areas that are to be protected based on recommendations contained within the local comprehensive plan, or restrictions contained in the local zoning ordinance. The design process focuses on the street layout, considering desirable block lengths and widths, and desirable lot configuration. The curvilinear street pattern is fitted to the topography of the site to minimize earth work, achieve good drainage, and facilitate the provision of gravity drainage sanitary sewerage. The design provides

TABLE 6.1 Comparative Analysis of Subdivision Designs

	Subdivision Type		
	Conventional Curvilinear	Urban Cluster	New Urbanism
Lot information			
Number of lots	160 lots	160 lots	160 lots
Average lot size	17,002 square feet	6,028 square feet	7,325 square feet
Average lot width	95 feet	60 feet	62 feet
Average lot depth	179 feet	101 feet	118 feet
Total area within lots	62.5 acres	22.1 acres	27.3 acres
Percent of site area within lots	77.0 percent	27.3 percent	33.2 percent
Street information			
Total street length	10,363 lineal feet	10,730 lineal feet	17,154 lineal feet
Total area within street rights-of-way	14.7 acres	12.8 acres	16.6 acres
Percent of site area within street rights-of-way	18.1 percent	15.8 percent	20.7 percent
Open space information			
Total area within open space	4.0 acres	46.4 acres	37.4 acres
Percent of site area in open space	4.9 percent	57.2 percent	46.1 percent
Grading information			
Volume of earth work	51,000 cubic yards	93,000 cubic yards	130,000 cubic yards

relatively large lots that can accommodate larger homes with more private open space on each lot. Grading for a curvilinear subdivision is typically minimum and preserves much of the existing topography and vegetation. Disadvantages of a curvilinear subdivision design may include higher costs of infrastructure per lot due to the relatively large size of the individual lots. Also, such subdivisions usually provide smaller areas of land for public or common open space. The urban cluster design type maximizes the provisions of common open space by minimizing individual lot size while maintaining the required overall density of development.

A cluster subdivision can be used to effectively protect environmentally sensitive areas by maintaining such areas in open space, while concentrating lots into smaller groups or clusters. The urban cluster design provides relatively small lots fronting on a public street, with all lots being adjacent to common open space. This design type usually results in the lowest percentage of combined area devoted to streets and lots, thus providing the greatest amount of common open space. The design is somewhat more conducive to use with more level sites, where terracing of the small lots making up the clusters is not necessary.

The advantages of a cluster subdivision design include protection of natural resource features and the opportunity to maintain a significant portion of the site in common open space. This can provide attractive recreational opportunities for residents of the subdivision; maintain the scenic beauty and biodiversity of the site; and decrease the amount of impervious surface area. If the subdivision is laid out in a way that concentrates lots on a limited portion of the site, the cost of providing infrastructure may be less than that required for a curvilinear type subdivision. Disadvantages of cluster subdivisions may include relatively small lots that require careful design of lot arrangements and building placement in order to provide privacy for the individual residences. The control of architectural design may be needed in urban cluster subdivisions due to the relatively small lots and the proximity of the clustered homes. A homeowners associations is required to own and maintain the common open space and related facilities. Provision must be made, however, for public assumption of the maintenance if the homeowners association fails to meet its responsibilities, with the associated costs assessed back to the lots in the subdivision.

Because the subdivision design shown in Figure 6.4 is assumed to be located in an area provided with a full range of urban services, including public sewer and water supply, the design presented is for an urban cluster. Cluster subdivisions may also be located in rural areas, in which case they are often known as conservation subdivisions. Although such rural locations may, in the absence of a comprehensive plan, raise concerns about urban sprawl, the cluster design can be effectively used to maintain agricultural uses in an area, preserve and protect wildlife habitat, and provide outdoor recreational opportunities. A rural cluster—or conservation—design subdivision is shown in Figure 6.5. Such rural conservation subdivisions may also facilitate the provision of sanitary waste disposal and the provision of water supply in rural areas not served by centralized sewerage and water supply systems. This may be illustrated by a simple example. If a rural area is planned and zoned to permit residential use at a gross density not to exceed one dwelling unit per 5 acres, a 100-acre tract might be subdivided into twenty 5-acre lots, using a curvilinear design each with its own on-site sewage treatment and disposal system—usually a septic tank system—and with its own on-site well for water supply. If the development were to use a cluster design with a net lot size of 1 acre, while maintaining the overall density of the tract at 20 dwelling units, approximately 24 acres of the site would be used for residential development, including supporting streets, and 76 acres would be maintained in common open space. This would permit the provision of a sanitary sewage collection and conveyance system tributary to an integrated anaerobic or aerobic treatment unit and an integrated soil drainage tile disposal facility located on a carefully selected part of the open space area. This approach could even be used with a centralized holding tank, the accumulated wastes in the tank being tracked to a recovery wastewater treatment plant. Similarly, water mains properly sized, valved, and equipped with fire hydrants and served by a common well could be provided. In this way occupants of the subdivision would perceive no difference between the sanitation services provided and such services provided in

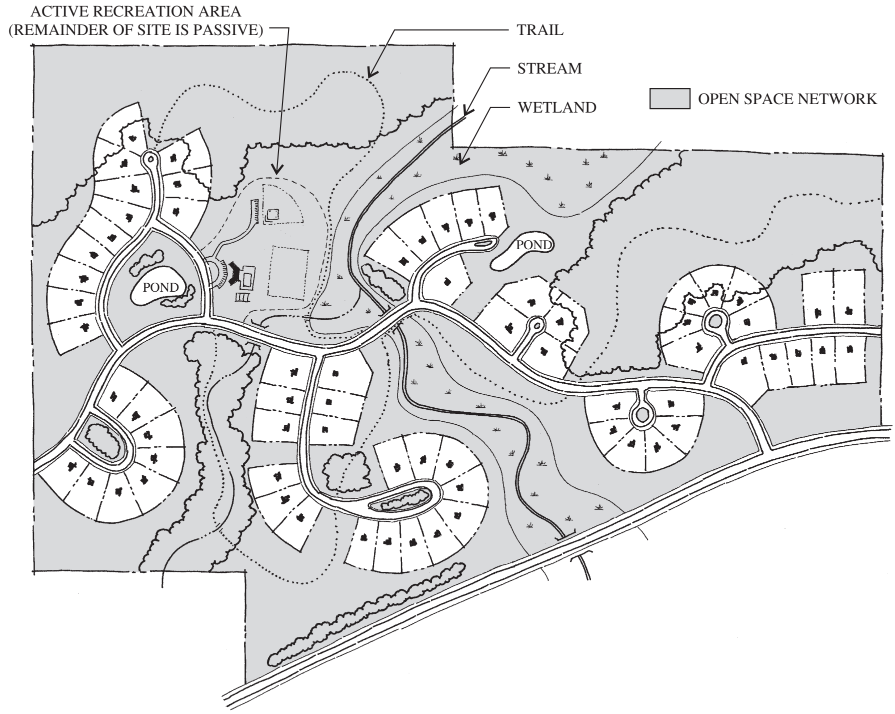


FIGURE 6.5 The open space system should be connected and contiguous; active and passive recreation areas should be designed.

an area served by public centralized sanitary sewer and water supply services. The common sewer and water supply facilities could be owned and operated by a homeowners association. In such an arrangement, however, it is important that public oversight be provided in order to assure proper operation and maintenance of the sanitation facilities. Failure to properly perform these functions should result in the facilities being taken over by a public entity—a civil town or sanitary district—for proper operation and maintenance, with the associated costs being assessed back to the lots in the subdivision. Alternatively, a public sanitary district could be created to oversee the design and construction of the facilities concerned, and to operate and maintain those facilities.

The new urbanism design type subdivision layout is conceptually based on the urban development patterns of the past, with consideration given to the open space concerns of the present. Large-scale new urbanism subdivisions typically attempt to provide a central focal point in the form of a public “common” that is surrounded by mixed-use residential and commercial lots, and which may provide a neighborhood business and community center. Residential lots are often double-fronted, with one frontage on a public street and a second frontage on a utility corridor or alley running behind the lots and on which garages are located. The lots are smaller than typical in a curvilinear or even cluster design type subdivision, and residences are intended to be located close to the street line. The hierarchy—functional classification—of the streets is typically less distinct in a new urbanism design type subdivision than in a curvilinear or cluster design, and street rights-of-way and street pavement widths are often narrower. A grid, or modified grid street pattern, is typically favored. The closely spaced lots and small front yards are intended to contribute to an increased sense of neighborhood for the subdivision residents, but may demand a uniform architectural treatment of the buildings. The disadvantages associated with the new urbanism design type include smaller on-lot areas for private outdoor use due both to the smaller lot sizes and the location of garages adjacent to alleys. The grid street pattern may encourage the use of residential land access streets by through traffic, reducing desirable residential quiet, privacy, seclusion, and safety. Importantly, the grid street pattern cannot be readily adjusted to the topography of even gently rolling sites and may require excessive grading.

Utility Services

The type and quality of subdivision design will affect the location and cost of the utilities required to serve the development. In each of the three design types presented, sanitary sewers, water mains, and storm sewers would typically be located in the street rights-of-way. In a curvilinear design type subdivision, electric power and telecommunications facilities would typically be located within easements along side and rear lot lines. In a new urbanism design type subdivision, the electric power and telecommunications facilities would typically be located within the alley rights-of-way. The location and configuration of utilities to serve the urban cluster design type subdivision requires particularly careful consideration on site specific bases. Where narrow street rights-of-way and roadway pavements are used, utilities can only be located under the street pavements to the extent that required horizontal separation distances between sanitary sewers, storm sewers, gas mains and water mains can be maintained within the limits of the narrower pavements.

The provision of adequate treatment and disposal of sanitary wastes, and the provision of a safe water supply are particularly important to the sound development of land subdivisions. The preferred method of providing these essential services is through the provision of centralized public sanitary sewer and water supply services. If a subdivision is not located within the boundaries of an existing service district, the needed services may become available through annexation to the central municipality, through the formation of a sanitary district, or through a utility corporation. In some situations, developers may propose to construct their own facilities including treatment plants. Rising federal and state environmental standards, together with the need to operate and maintain the systems over time, makes this approach problematic in the absence of public over sight and regulation. An increase in the number of connections required to sustain a financially viable sanitary sewerage or water supply system means that a growing number of small systems may no longer be financially viable. Therefore, questions of the future size, ownership, and quality of management need to be addressed as part of the development proposal.

In some situations, on-site well water and septic tank treatment and disposal systems may offer the only practical means of serving scattered low-density residential developments. To be acceptable, the individual sanitary facilities must be carefully designed, constructed, and maintained in accordance with good practices. Where the soils are unsuitable for the proper treatment and disposal of septic tank wastes by conventional subsurface means, every effort should be made to prevent the subdivision and development of the land concerned until public sewer service becomes available.

Where individual on-site wells are proposed for a subdivision, a hydrogeologic study, including test wells, may be indicated to ensure that the aquifer concerned can supply adequate water for the proposed development. It may also be desirable to require that wells drilled on-site be tested for yield and for microbiological, chemical, and physical quality before a permit to build is given. To constitute an adequate water supply for a single-family home, a well should have a sustained yield of 8 to 10 gallons per minute. In some situations, a lesser yield may be acceptable, but a special engineered design, including storage, may be required.

When either individual well or septic tank systems are required, or when both are required, the preparation of a proper set of plans for the subdivision development will make possible the orderly installation of these facilities on individual lots. Details to be included on the development plans should include the site topography; soil maps; location of required soil borings and test pits, and the attendant soil tests and test results; depth to water table; lot layouts showing the proposed location of houses, wells, and sewage disposal systems; together with the provision for good lot, block, and street drainage; diagrams showing, typical well construction, pump connections, and sanitary seals. Similar diagrams showing details of typical septic tank, distribution box, and soil absorption field details should be given. In some situations, mound-type systems may be required. Each lot requires careful study and adaptation of general principles and typical details so that proper development results. For example, the soil percolation tests and soils information should determine the type and size of the required on-site sewage disposal facility. The final lot grade and house, driveway, walks, and patio locations should determine the locations of the on-site well and sewage disposal system. The type of well, required minimum depth of casing, need for grouting of the annular space around the casing, and sealing of the bottom of the casing in solid rock will vary with each location. These are some of the considerations requiring the adequate engineering services.

Counties, cities, villages, and towns should adopt sanitary, building and plumbing codes, and zoning ordinances regulating the use, installation, operation, and maintenance of on-site sewage treatment and disposal and water-supply facilities. These codes and ordinances should be adopted within the context of a comprehensive plan. Individuals proposing to install an on-site sewage treatment and disposal, or an on-site water-supply facility, should be required to make application to a designated department for a permit to build and to use and install attendant proposed sewage disposal and water supply facilities. The applications should be accompanied by soil maps, percolation tests, and facility-location design details. The cognizant public agency staff should be responsible for inspection during construction of the facilities to ensure compliance with the plans. When the facilities concerned have been properly installed, an occupancy permit may be issued for the residence concerned.

Fiscal Analysis

A proposed land subdivision should be accompanied by a fiscal impact, as well as an environmental assessment. The fiscal impact assessment requires estimates to be made of the total cost of providing the required public infrastructure, including capital investment, operation, maintenance, and replacement costs, together with estimates of the total public revenues to be derived from the proposed development. The types of infrastructure and attendant public services to be considered should include, among others, sanitary waste treatment and disposal; water supply; solid-waste collection and disposal; parks and playgrounds; libraries; street cleaning, snow plowing and pavement maintenance; traffic control; police and fire protection; emergency medical services; street lighting; street trees and other plantings; and schools, The costs of providing these facilities and services should be estimated based on local conditions and experience. Sources of revenue may include real property taxes, impact fees, sales taxes, income taxes, property transfer fees, permit and license fees, user charges, interest earnings and federal and state loans and grants. An analysis of the potential cost of the required facilities and services versus the potential revenues derived from the development will provide important information on the probable fiscal impact of the proposed development on the community. This impact, together with other factors, such as compatibility with the adopted comprehensive plan and findings of an environmental assessment should be considered in granting approval, or conditional approval, for the proposed development, or in rejecting the proposed development. Generally, fiscal impact assessment will show that low- and moderate-value residential development does not yield enough in property taxes to pay for the municipal services required unless supplemented by user charges or other revenues.

PROGRAM PLANNING

A number of laws related to environmental protection have emerged at the federal and state levels. These include, at the federal level:

- National Environmental Policy Act of 1969 (NEPA)
- Chemical Safety Information, Site Security and Fuels Regulatory Relief Act

- The Clean Air Act (CAA)
- The Clean Water Act (CWA)
- Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA, or Superfund)
- The Emergency Planning and Community Right-to-Know Act (EPCRA)
- The Endangered Species Act (ESA)
- Federal Insecticide, Fungicide and Rodenticide Act (FIFRA)
- Federal Food, Drug, and Cosmetic Act (FFDCA)
- Food Quality Protection Act (FQPA)
- The Freedom of Information Act (FOIA)
- The Occupational Safety and Health Act (OSHA)
- The Oil Pollution Act of 1990 (OPA)
- The Pollution Prevention Act (PPA)
- The Resource Conservation and Recovery Act (RCRA)
- The Safe Drinking Water Act (SDWA)
- The Superfund Amendments and Reauthorization Act (SARA)
- The Toxic Substances Control Act (TSCA)

States have adopted similar legislation mirroring the federal legislation in order to maintain some level of state control over the issues concerned. Many of these federal and state laws contain planning requirements. Some of these federal laws have included substantial grant programs intended to encourage the conduct of planning at the state and local levels of government. Other federal laws support the development of infrastructure facilities and include grant programs that promote planning for the physical development of urban areas. Historically, such programs have included the Federal Housing Act of 1954, Section 701, which provided grants to local municipalities, counties, and areawide planning agencies in partial support of the development of comprehensive plans. The Section 701 planning program, which was initially administered by the Federal Housing and Home Finance Agency (HHFA), did indeed result in the preparation of a large number of municipal comprehensive plans. Section 208 of the Federal Demonstration Cities and Metropolitan Development Act of 1966, administered by the U.S. Department of Housing and Urban Development (HUD), the successor agency to the HHFA, required that all applications for federal loans and grants be submitted to cognizant metropolitan planning agencies for review and comment prior to federal consideration. This requirement provided a powerful incentive for areawide planning and plan implementation.

These types of federal laws and grant programs often led to the establishment of federally driven areawide planning programs. Perhaps the most important and far reaching of such federally driven programmatic planning requirements were those initiated by the Federal Aid Highway Act of 1962. This act required the preparation of metropolitan transportation system plans as a prerequisite for the receipt of federal grants in support of highway system improvements. The engineering staffs of the U.S. Bureau of Public Roads, the predecessor agency to the Federal Highway Administration, understood and were firmly committed to the need for areawide transportation system planning in metropolitan areas and, unlike other federal agencies, such as the U.S. Environmental Protection Agency, remained steadfastly committed to the support of such planning over time. The program was instrumental in developing the current state-of-the-art of transportation system planning, requiring the integration of land use and transportation system planning, and the application of mathematical simulation models in the design of transportation system plans. The program was also instrumental in the development of the present state-of-the art of environmental assessment of transportation system plans, particularly with respect to the abatement of air pollution emissions and the pursuit of air quality management. Successive amendments broadened the required planning to include transit as well as highway facilities. The inclusion of strong implementation measures, including the required biennial preparation of metropolitan transportations improvement programs, is evidence of the federal transportation engineers' commitment to effective system planning. The latest version in the chain of acts initiated by the 1962 Act is known as the Safe, Accountable, Flexible, Efficient Transportation Equity Act of 2005. Without the Federal Aid Highway Act of 1962, and its successor acts, it is highly unlikely that strong metropolitan and regional planning programs would have developed in the United States as they indeed have.

Similar federal programs, exemplified by the programs administered by the Federal Aviation Administration (FAA) for airport system planning and by the U.S. Environmental Protection Agency (EPA) for water quality management planning have been less successful. This is particularly true of the planning requirements contained in Section 208 of the Federal Water Quality Act of 1972. Although the federal planning requirement and attendant grant program produced some very good areawide water-quality management plans, the lack of a firm commitment to those plans and the planning process over time by the EPA staff has hampered the ability to achieve the national objective of fishable and swimable surface waters. Other federal and state planning requirements have been established in, among others, the fields of solid-waste management, coastal zone management, and air-quality management. Unfortunately, with the exception of the transportation planning program, most of these federal and state planning initiatives are not well integrated at the federal or state levels, and often ignore the needed foundation in comprehensive metropolitan or regional planning. Ideally, all such federal and state programmatic planning requirements should be coordinated through metropolitan or regional planning agencies so that the plans and plan implementation actions may be effective rather than counterproductive.

OPERATIONAL PLANNING

All of the planning efforts previously considered in this chapter have dealt with planning for the physical development of municipalities, counties, metropolitan areas, and regions; recognizing, however, that all physical development is intended to serve social and economic needs, and that planning for such development must contain a strong environmental assessment and protection orientation. Such physical planning is appropriate in both developed and developing countries.

A parallel need exists, however, to promote strong public heath organizations and services, and, as a basis for such promotion, to develop sound public health agency operational plans, perhaps as operational public health plans. Such plans should be directed at guiding the organization and operation of public agencies responsible for the protection and enhancement of public health. In the United States, this need is recognized at the federal level by the existence of the U.S. Public Health Service. This need was also recognized in the past by the historic development of strong public health departments within the structures of state and large city governments. The city departments were often headed by medical doctors, and employed competent staffs of public health nurses, sanitary engineers, and sanitation officers. A decline in the importance attached to such departments with respect to the containment of contagious diseases and the provision of pure food and water appears to have occurred following the close of World War II and the introduction of antibiotics, new immunization techniques, and advanced medical treatments to control, and in some cases eliminate, infectious diseases such as tuberculosis, poliomyelitis, and some socially transmitted diseases. The development of intercontinental travel based on rapid air transport, together with the emergence of often-fatal diseases, such as human immunodeficiency virus–acquired immunodeficiency syndrome (HIV–AIDS), bovine spongiform encephalopathy (mad cow disease), avian influenza (bird flu), and severe acute respiratory syndrome (SARS), among others, is creating a critical need to strengthen public health agencies and services at all levels of government. Good public administration would dictate that the operation of public health agencies be focused through the preparation of sound operational plans. An outline for a potential public health element of a comprehensive plan follows.

Public Health Element of Comprehensive Plan

I. **Introduction**
   A. Purpose of planning effort and plan report
   B. Brief description of planning area
   C. Impetus and authority for planning effort
   D. Planning approach
      1. Cognizant public body oversight and guidance
      2. Adoption
II. **Historic Studies and Plans**
   A. Pertinent federal and state public health planning efforts, plans and programs
   B. Pertinent local public health planning efforts, plans and programs

III. **Description of Existing Conditions**
   A. Epidemiological and demographic
      1. Population—historic and existing
         a. Levels
         b. Fertility, mortality and morbidity rates
         c. Age and sex distribution
         d. Diseases—types and prevalence, age and sex specific occurrences
            (1) Infectious
            (2) Noninfectious
            (3) Chronic
         e. Disease vectors
            (1) Waterborne
            (2) Rodent and Insect borne
            (3) Foodborne
            (4) Domestic and wild animal related
            (5) Air related
            (6) Pesticide and other chemical poisonings
            (7) Congenital malformations, mental disorders
      2. Households—historic and existing
         a. Levels
         b. Types
         c. Housing conditions
      3. Health Services
         a. Types
         b. Availability
   B. Cultural and Natural Resource Base
      1. Land use—historic, existing, planned
      2. Topography and drainage patterns
      3. Geology and depths to water and bedrock
      4. Soils
      5. Climate and weather
      6. Surface water resources
      7. Groundwater resources
      8. Floodlands, wetlands
   C. Public water supply
      1. Sources, treatment, storage, distribution
         a. Operator qualifications
         b. Quality control

c. Cross-connection control
d. Well construction control
e. Fire protection
f. Costs

2. Areas and populations served

D. Wastewater disposal
1. Domestic and industrial wastewater flows and characteristics
2. Collection, transmission, treatment, disposal
    a. Centralized sewerage systems
        (1) Areas and populations served
        (2) Adequacy of collection, transmission, storage, treatment
        (3) Operator qualifications
        (4) Cross-connection
        (5) Costs
    b. On-site treatment and disposal systems
        (1) Areas and populations served
        (2) Soil and groundwater conditions
        (3) Performance and failure rates
        (4) Regulation
        (5) Costs
3. Water pollution
    a. Surface waters
    b. Groundwaters

E. Solid waste management
1. Sources, amounts, types and characteristics of wastes
    a. Managed refuse
    b. Industrial wastes
    c. Agricultural wastes
2. Storage, collection, transport, processing and disposal
3. Resource recovery, salvage, recycling
4. Hazardous wastes
    a. Handling
    b. Prevention of contact
5. Air, water, land pollution
6. Areas and populations served
7. Costs

F. Air resources
1. Air-quality conditions
2. Pollution sources

3. Emission standards
4. Effects on human, livestock, vegetation
5. Meteorological and topographic factors

G. Housing
1. Amount, condition, availability—historic and existing
2. Building, plumbing, electrical, heating and ventilating, occupancy codes and code enforcement
3. Overcrowding

H. Schools—elementary and secondary
1. Locations
2. Buildings and attendant recreation facilities
3. Adequacy of water supply, sewage and solid wastes disposal, food service, sanitary facilities, indoor air quality

I. Health care institutions
1. Type, location, capacity, adequacy
   a. Hospitals
   b. Clinics
   c. Nursing homes
   d. Rehabilitation centers
   e. Day care centers
2. Staffing, budgets, workloads

J. Recreational Facilities
1. Parks, pools, bathing beaches, marinas

K. Environmental Factors
1. Drainage, mosquito breeding
2. Noise and vibration
3. Insect, rodent, and other vermin control
4. Natural and manmade hazards slides, earthquakes, brush and forest fires, storms
5. Radiological hazard
6. Laws, codes, and ordinances
7. Health criteria and standards

IV. **Projected Conditions and Problem Identification**

A. Epidemiological and demographic
B. Water supply
C. Wastewater collection and disposal
D. Solid waste collection and disposal
E. Air-quality conditions
F. Housing
G. Schools

H. Healthcare institutions
I. Recreational facilities
J. Environmental factors

V. **Needed Public Health Facilities and Programs**
   A. Staffing
      1. Medical doctors
      2. Public health nurses
      3. Sanitary engineers
      4. Sanitation officers
      5. Laboratory technicians
   B. Facilities
      1. Office
      2. Laboratory
      3. Motor vehicle and support equipment
   C. Legal authority
   D. Programs
      1. Water supply and food inspection including restaurant and food service inspection
      2. Environmental monitoring
         a. Air quality including indoor
         b. Water quality including swimming pool and bathing beach
         c. Insect, rodent and other vermin
         d. On-site sanitary waste disposal and attendant ground and surface water pollution
         e. On-site water supply
         f. Health care institutions
      3. Code enforcement
         a. Housing
         b. Sanitation
         c. Health care institutions
      4. Health care monitoring
         a. Infant
         b. Elementary school pupils
         c. Secondary school pupils
         d. Immunization
      5. Emergency preparedness
         a. Water supply
         b. Waste disposal
         c. Toxic hazardous and radiological contamination
         d. Immunization

   e. Quarantine
   f. Medical services
6. Educational and training programs
   a. Personal hygiene
   b. Sanitation
   c. Nutrition
   d. Infant and child care
   e. Emergency response
7. Other

It should be noted that a number of the inventories required for operational public health emergency planning are identical to those required for comprehensive physical planning. Close coordination of and cooperation between the agencies involved in these kinds of planning effort is, therefore, high desirable.

The need for public health services, while clearly important in rich developed countries, is critical in poor, developing countries. Improving public health should be a high priority in such countries that have large populations lacking sufficient supplies of safe, potable water, adequate sanitation systems, and adequate electrical power and road systems. Primary environmental problems include insufficient water supplies and rapid rural to urban migration, which exacerbate waste management problems and constitute threats to human health. Contagious diseases, high infant mortality rates, and unsatisfactory life expectancy rates should make the provision of strong public health services and the promotion of good individual health in such countries a major objective. Many lives could be saved, and a great deal of human misery avoided, through the provision, at a relatively low cost, of simple measures to promote good sanitation, safe potable water, and pure food nutritional guidance and assistance, and immunization programs. Public health agencies should be ready to react promptly, efficiently, and effectively to potential epidemics, and pandemics and to abate, or eliminate, any endemic diseases such as malaria and cholera. The effectiveness of good public health services has been demonstrated historically by examples, such as the control of malaria and yellow fever that permitted the construction of the Panama Canal.

ROLE OF ENGINEERING

There is a need for sound engineering in the conduct of all types of planning for the physical development of an area, and more sensitivity to comprehensive planning in engineering, with emphasis on areawide metropolitan and regional approaches. Certain key elements of a comprehensive plan dealing with sewerage, stormwater management, water supply, and transportation should be prepared by competent engineers. Environmental protection and natural resource conservation must be successfully integrated into essential engineering efforts. Engineering factors that are essential for continued community survival and growth, and for the social and economic well being of the community residents, need to be carefully considered in the planning and engineering of any proposed development projects. Public awareness demands a quality environment that provides such fundamental needs as pure water, clean air, unpolluted land, the absence of traffic congestion, the availability of convenient public transit services; decent, safe, and sanitary housing; adequate recreational facilities, and the preservation of open space and historic values. These goals and objectives cannot be attained without the involvement in the planning and plan implementation processes of competent engineers.

State and local health and environmental protection agencies have vital planning, plan approval, and regulatory responsibilities to ensure that the public health and welfare are protected. The performance of these responsibilities requires competent engineering staff to deal with such issues as water-quality management and pollution abatement; wastewater treatment and disposal; provision of safe and adequate water supplies; air-pollution control; solid hazardous and nonhazardous waste disposal; radiation protection; land subdivision development; disease vector control; and safe use of herbicides and pesticides. The responsibility of health and environmental protection agencies extends to issuance of permits and continual environmental monitoring to protect the public health and welfare, and to enhance the home, work, and recreational environments. Hence, such agencies have an important stake in all planning programs to ensure that the public does not inherit situations that are dangerous, costly, and difficult or impossible to correct.

Sound, comprehensive, community planning that gives proper attention to environmental health considerations, followed by phase, detailed planning, engineering, and capital budgeting, are among the most important functions a community can engage in for the immediate and long-term benefit of its residents. The potential environmental effects of projects such as new highway or industrial and housing developments should be considered in the planning and engineering design phases, and then during the construction and operational phases. Alternatives should be proposed and comparatively evaluated on the basis of costs, benefits, and environmental impacts. For major projects, the responsible engineers should seek the assistance, as necessary, of other professions, including, among others, landscape architects, soil and water conservationists, and fish and wildlife biologists.

It is also important to understand that environmental criteria and standards that implement laws and regulations and affect engineering will vary significantly with time and place. It is, therefore, essential that current criteria and standards be used in the planning, engineering, and environmental assessment processes. Sometimes, there will be proposed criteria and standards available that may have not yet been adopted, but that deserve careful consideration.

ENVIRONMENTAL ASSESSMENT AND IMPACT STATEMENTS

The preceding text has indicated that comprehensive plans, project plans, site plans—including land subdivision plans—and program plans should be accompanied by environmental assessments. An environmental assessment may also be related to an existing site or plant. The environmental assessment attempts to identify all existing and past activities that may have a deleterious effect on human health, the environment, or safety. In so doing, compliance with all applicable federal, state, and local laws, rules, and regulations, and required permit conditions are also determined.

An environmental assessment may be conducted for different purposes. It may be used to help validate comprehensive project and site plans. It may emphasize compliance with existing regulations and permit requirements, respond to a toxic or hazardous material spill, or relate to the existing or potential environmental risks and liabilities associated with the acquisition of a property.

An assessment to determine compliance with regulatory requirements may be referred to as an environmental audit. It may be carried out by regulatory personnel, in-plant personnel, or a consultant. The audit may relate to a single-purpose facility, such as an incinerator, wastewater treatment plant, hazardous waste operation, or water system, or to all operations and procedures at a plant or site. An assessment that is concerned with a property or its acquisition may be referred to as an environmental property assessment. It includes investigation for possible above-ground and subsurface contaminants and hazards, violations associated with structures on the property—including health and safety—and real property title searches.

At an existing operating site or facility, pollutant, emission, water, wastewater, solid waste, and soil samples may be collected, if indicated, for physical, chemical, and microbiological examinations and evaluations. Volume or weight measurements may be made. Materials balances of input versus output may be compared where possible. Raw-material and process changes to reduce and eliminate toxic or polluting discharges of product or wastes are considered. Deficiencies are identified, and a correction and prevention program is developed. In making an environmental property assessment, local residents, employees, and retirees may be interviewed regarding present and past products stored or manufactured, operations, practices, wastes produced, waste disposal methods, and previous land uses. Plant records, reports, and other documents may be useful.

A site investigation may include acquisition and analysis of old and recent land deeds, zoning district maps and ordinances, topographic maps and aerial photographs, historical reports, state archive records, regulatory agency and university reports, fire department and insurance files, and library files. Evidence of old mines, dumps, burial grounds, swamps, vegetation-free areas, wells, pipelines, buried tanks, impoundments, orchards, farmlands, laboratories, and factories may be found. Investigations and old reports and industrial directories may reveal types of waste materials generated and discarded at the site. Adjacent properties and uses may impact on the study site and should be explored. Site field surveys should be made at properties to be acquired and include—if indicated—soil, groundwater, waste, and air sampling for physical, chemical, radiological, and microbiological analyses and evaluation.

The value of an environmental assessment is dependent on the types and competencies of the professionals employed, the comprehensiveness of the survey, and the quality of the supporting laboratory results. Professionals who may be involved include engineers, land surveyors, geologists, hydrogeologists, archaeologists, historical geographers, chemists, biologists, health physicists, attorneys, toxicologists, and others who have the proper, specialized training and experience. Professional organizations, governmental agencies, institutions, and others may provide useful environmental assessment information, including guidelines, checklists, manuals, and texts that can be of value.

Purchasers of real estate, including plants and other properties, are advised to have an environmental site and facility assessment completed before purchase. The legal and financial liabilities assumed due to the presence of potentially hazardous contaminants on the site, or to building violations that may exist—structural, fire hazard, asbestos materials, polychlorinated biphenyls (PCBs), leaking underground petroleum and chemical storage tanks—should be understood and evaluated before ownership is finalized. Consultants performing environmental site assessments and audits may become involved in legal actions as a result of their studies and reports. They may be sued for having knowledge of the existence of hazardous conditions and not acting thereon. A consultant should be careful not to guarantee that a property is free of all contamination or what level of cleanliness a regulatory agency may require. Therefore, it is prudent for a consultant to limit liability in an agreement with a client, as the extent of the environmental assessment or audit to be prepared.

ENVIRONMENTAL IMPACT ANALYSIS

Concurrent with site selection and planning is the necessity to consider the effects of all proposed land uses, development activities, and required services and facilities on the environment or geography of the area concerned. It is extremely difficult to identify and evaluate in depth all possible factors that may affect, and be affected by, a particular development project or action. Good comprehensive regional, county, and municipal plans constitute a good source of pertinent data and greatly simplify preparation of an environmental impact assessment, and, if necessary, an environmental impact statement (EIS).

National Environmental Policy Act (NEPA)

Planning, design, and implementation of a project, without regard to its environmental effects, shirk the custodial responsibility and moral obligation of society to protect the environment for future generations and ensure their survival. Public concern over environmental pollution, aided by scientific and professional prodding and support, has led to federal and state legislation mandating consideration and documentation of the beneficial and adverse effects of proposed actions in the project planning stage for official and public scrutiny and indicated potential adjustments. This concept was given national recognition by the National

Environmental Policy Act (NEPA) of 1969, as amended. This act established a national policy that requires consideration of the effects of any significant federal actions on the environment. The act recognizes the impact of human activity on all components of the natural environment and the importance of environmental quality to public welfare. The act is intended to improve federal actions in order to achieve a number of objectives. Included among these are the following:

- To assure all Americans safe, healthful, productive, and aesthetically and culturally pleasing surroundings
- To attain the widest range of beneficial use of the environment without degradation, risk to health or safety, or other undesirable and unintended consequences
- To preserve important historic, cultural, and natural values

The act directs that all agencies of the federal government do the following:

- Utilize a systematic, multidisciplinary approach that will ensure the integrated use of the natural and social sciences and the environmental design arts in planning and in decision making that may impact on the environment.
- Identify and develop methods and procedures that will ensure that unquantified environment amenities and values may be given appropriate consideration in decision making, along with economic and technical considerations.
- Include a detailed environmental statement prepared by a cognizant official in every recommendation for legislation or other major federal actions significantly affecting the quality of the environment.

That statement is to set forth the environment impact of the proposed action, including any adverse environmental effects which cannot be avoided should the proposal be implemented; alternatives to the proposed action; the relationship between local short-term uses and the environment and the maintenance and enhancement of long-term productivity; and any irreversible and irretrievable commitments of resources involved in the proposed action. The NEPA also permits these statements to be prepared under specific conditions by state agencies or officials. The Act requires that prior to completing the required detailed statement, consultations shall be held with other federal agencies, and the views of appropriate state and local agencies obtained.

A number of states have also adopted legislation and prepared procedures for environmental assessment of proposed actions, and for the preparation of environmental impact statements similar to the federal legislation.

Terminology

The federal regulations for implementing the procedural provisions of the National Environmental Policy Act define certain terms. These definitions warrant inclusion here because of the important concepts contained within them.

The term *categorical exclusion* is defined to mean a category of actions that do not individually, or cumulatively, have a significant effect on the human environment, and for which, therefore, neither an environmental assessment nor an environmental impact statement is required.

The term *cumulative impact* is defined as the impact on the environment that results from the incremental impact of the action when added to other past, present, and reasonably foreseeable future actions, regardless of what agency—federal or nonfederal—or person undertakes such other actions. Cumulative impacts can result from individually minor but collectively significant actions taking place over time.

The term *effects* is defined with two parts:

1. Direct effects are caused by the action and occur at the same time and place.
2. Indirect effects are caused by the action, and are delayed in time or farther removed in distance, but are still reasonably foreseeable. Indirect effects may include growth-inducing effects and other effects related to induced changes in the pattern of land use, population density or growth rate, and related effects on air and water and other natural systems, including ecosystems.

The term *effects* and *impacts* as used in the federal regulations are synonymous. Effects include ecological—such as the effects on natural resources and on the components, structures, and functioning of affected ecosystems—aesthetic, historic, cultural, economic, social, and health, whether direct, indirect, or cumulative. Effects may also include those resulting from actions that may have both beneficial and detrimental effects, even if on balance the agency believes that the effect will be beneficial.

The term *environmental assessment* is defined to mean a concise public document, the preparation of which is the responsibility of a cognizant federal agency—or delegated state agency—and which serves to do three things:

1. Provide sufficient evidence and analysis for determining whether the preparation of an environmental impact statement or a finding of no significant impact is required.
2. Aid in compliance with the Natural Environmental Policy Act when no environmental impact statement is required.
3. Facilitate preparation of an environmental impact statement when one is required.

An environmental assessment is similar to an environmental impact statement but is not necessarily as comprehensive or in the same depth. It can be used to determine if a negative declaration is indicated, or if an environmental impact statement is required. An environmental assessment is not required if it has been determined in any case to prepare an environmental impact statement. An environmental assessment should include a brief description of the need for the proposed action concerned; of the alternatives thereto; of the potential environmental impacts of the proposed action, and of the alternatives thereto. It should also list the agencies and persons consulted in preparing the assessment.

The term *environmental impact statement* is defined as a detailed written statement required by Section 102(2)C of the NEPA.

The term *federal agency* is defined to include all agencies of the federal government. It does not mean the Congress, the judiciary, or the president. It also includes, for purposes of the federal regulations, states, units of local government, and Indian tribes assuming National Environmental Protection Act responsibilities under Sec. 104(h) of the Housing and Community Development Act of 1974 as amended.

The term *finding of no significant impact* is defined as a document prepared by a federal agency briefly presenting the reasons why an action, not otherwise excluded, is not expected to have a significant effect on the human environment and for which an environmental impact statement therefore need not be prepared. The term is intended to include the environmental assessment concerned with it and any other environmental documents related to it.

The term *human environment* is defined to include the natural and physical environment, and the relationship of people with that environment. This means that actions having purely economic or social effects are not intended by themselves to require preparation of an environmental impact statement. However, when an environmental impact statement is prepared and economic or social and natural or physical environmental effects are interrelated, then the environmental impact statement is to describe all of these effects on the human environment.

Scoping

Scoping is an important element of all planning processes because it defines what will and what will not be included in the process. Scoping must be conducted early in the planning process, preferably at the beginning of the public participation effort. The federal regulations relating to environmental assessments and environmental impact statements address scoping. Under those regulations, scoping is defined as an early and open process for determining the scope of issues to be addressed, particularly the significant issues related to a proposed action. As soon as practicable after a decision is made to prepare an environmental impact statement, and before initiation of the scoping process, the lead agency must publish a notice of intent in the Federal Register. As part of the scoping process the lead agency shall take these steps:

1. Invite the participation of affected other federal, and of state and local agencies, any affected Indian tribe, the proponent of the action, and other interested persons—including those who might not be in accord with the action on environmental grounds.

2. Determine the cope and the significant issues to be analyzed in depth in the environmental impact statement.
3. Identify and eliminate from detailed study the issues that are not considered to be significant, and explain why those issues are not expected to have a significant effect on the human environment.
4. Allocate assignments for preparation of the environmental impact statement among the lead and cooperating agencies, with the lead agency retaining responsibility for the statement.
5. Indicate any public environmental assessments and other environmental impact statements that are being, or are expected to be, prepared, that are related to, but are not a part of, the scope of the impact statement under consideration.
6. Identify other environmental review and consultation requirements so the lead and cooperating agencies may prepare other required analyses and studies concurrently, and in an integrated manner with, the environmental impact statement.
7. Indicate the relationship between the timing of the preparation of environmental analyses and the agency's tentative planning and decision-making schedule.
8. The lead agency may hold an early scoping meeting, or meetings, which may be integrated with any other early planning meetings the agency holds. Such a scoping meeting, or meetings, will often be particularly appropriate when the impacts of a particular action are confined to a specific site or sites.

Recommended Format for Environmental Impact Statement

A format should be used for environmental impact statements that will encourage good analysis and clear presentation of the alternatives, including the proposed action. The following standard format for environmental impact statements may be followed unless the agency determines that there is a compelling reason to do otherwise:

1. Cover sheet
2. Summary
3. Table of contents
4. Purpose of and need for action
5. Alternatives including proposed action
6. Affected environment
7. Environmental consequences
8. List of preparers
9. List of agencies, organizations, and persons to whom copies of the statement are sent
10. Index
11. Appendices

Content of an Environmental Impact Statement

The environmental impact statement (EIS) required under the National Environmental Policy Act is intended to be a detailed written statement prepared by a responsible official on every proposal for legislation, or other major federal action, significantly affecting the quality of the human environment. Guidelines for the preparation of an EIS have been published by the Council on Environmental Quality, and a number of states have adopted similar guidelines. A draft EIS is generally first prepared and circulated for comment. The EIS may be for a proposed legislative act, program, planning study, or construction project. The comments received are then evaluated and considered in the decision-making process.

The EIS should include a description of the proposed action; a statement of the purpose or purposes of the action; and a description of the environment affected, including summary technical data, and maps and diagrams, as may be required. The description should be adequate to permit an assessment of the potential environmental impacts by commenting agencies and the public. Highly technical and specialized analyses and data should be avoided in the body of the draft impact statement. Such materials should be attached as appendices, or footnoted with adequate bibliographic references. Importantly, the statement should succinctly describe the environment of the area affected as it exists prior to the proposed action. The interrelationships and cumulative environmental impacts of the proposed action and other related federal projects should be presented in the statement. The amount of detail provided in such descriptions should be commensurate with the extent and expected impact of the action, and with the amount of information required at the particular level of decision making—planning, design, construction. Agencies should also take care to identify, as appropriate, the following:

- Population and growth characteristics of the affected area
- Any population and growth assumptions used to justify the project or programs
- Growth impacts resulting from the proposed action and its alternatives
- Sources of data used to identify, quantify, or evaluate any and all environmental consequences

The relationship of the proposed action to land-use plans, policies, and regulations for the affected area should be described, including the plans developed in response to the Federal Clean Air Act, Federal Water Pollution Control Act, and Federal Transportation Act. Where a conflict or inconsistency exists, the statement should describe the extent to which the agency has reconciled its proposed action with the plans, policies or regulations concerned, and the reasons why the agency has decided to proceed notwithstanding the absence of full reconciliation.

The statement should contain a clear description of the probable impact of the proposed action on the environment. This requires assessment of the positive and negative effects of the proposed action on the environment. The attention given to different environmental factors should vary according to the nature, scale, and location of the proposed actions. Among factors to consider should be the potential effect of the action on these aspects of the environment:

- Air quality, water quality, shellfish sanitation
- Stream flows and stages, fish and wildlife, solid waste, noise, radiation, toxic and hazardous substances, contamination of foodstuffs, herbicides and pesticides, transportation and handling of hazardous materials
- Energy supply, renewable resource development, natural resource conservation
- Land use and management
- Protection of environmentally critical areas—floodplains, wetlands, beaches and dunes, unstable soils, steep slopes, aquifer recharge areas
- Land use in coastal areas, redevelopment, and construction in built-up areas
- Density and congestion mitigation
- Neighborhood character and continuity
- Impact on low-income populations
- Historic architectural and archeological preservation
- Soil and plant conservation, hydrology
- Outdoor recreation

Primary attention should be given in the statement to those factors most evidently impacted by the proposed action. Secondary, or indirect, as well as primary or direct, consequences for the environment should be included in the analysis. Many actions, in particular those that involve the construction of infrastructure investments, stimulate or induce secondary effects in the form of changed patterns of social and economic activities and related land-use patterns. Such secondary or indirect effects—through their impacts on existing community facilities and activities, through inducing new facilities and activities, or through changes in natural conditions—may often be more substantial than the primary effects of the proposed action itself. The effects of the proposed action on population growth and land-use development may be among the most significant secondary effects.

Alternatives to the proposed action, including, where relevant, those not within the existing authority of the responsible agency, should be described. A rigorous exploration and objective evaluation of the environmental impacts of all reasonable alternative actions, particularly those that might enhance environmental quality, or that might avoid some or all of the adverse environmental effects, is essential. Examples of such alternatives include the following:

- The alternative of taking no action, or of postponing action pending further study
- Alternatives requiring actions of a significantly different nature that would provide similar benefits with different environmental impacts—as, for

example, nonstructural alternatives to flood control projects, or mass transit alternatives to highway construction

- Alternatives related to different designs or details of the proposed action that would present different environmental impacts—as, for example, cooling ponds, in place of cooling towers for an electric power generation powerplant or alternatives that will significantly conserve energy
- Alternative measures to provide for compensation of fish and wildlife losses, including the acquisition of land, waters, and interests therein

In each case, the analysis should be sufficiently detailed to reveal the comparative evaluation of the environmental benefits, costs, and risks of the proposed action and of each reasonable alternative thereto.

Any probable adverse environmental effects that cannot be avoided—such as water or air pollution, undesirable land-use patterns, damage to life systems, urban congestion, or threats to public health—should be described. Included for purposes of contrast should be a clear statement of how avoidable adverse effects will be mitigated.

The trade-offs between short-term environmental gains at the expense of long-term losses, or vice versa, should be described, together with the extent to which the proposed action forecloses future options. In this context, the terms *short-term* and *long-term* should be viewed in terms of the environmentally significant consequences of the proposed action, without reference to any fixed level period.

Any irreversible and irretrievable commitments of resources that would be involved in the proposed action, should it be implemented, should be described. Construing the term *resources* to mean only the labor and materials devoted to an action should be avoided. Resources should also be defined as the natural and cultural resources committed to loss or destruction by the action.

An indication of other considerations that are thought to offset the adverse environmental effects of the proposed action should be described. The statement should also indicate the extent to which these countervailing benefits could be realized by following reasonable alternatives to the proposed action that would avoid some or all of the adverse environmental effects. In this connection, agencies that prepare cost–benefit analyses of proposed actions should attach such analysis, or summaries thereof, to the environmental impact statement, and should indicate the extent to which environmental costs have not been reflected in such analyses.

Every effort should be made to convey the required information succinctly in a form easily understood, both by members of the public and by public decision makers, giving emphasis to the substance of the information conveyed rather than to the particular form, length, or detail of the statement. Each of the points of attention need not always occupy a distinct section of the statement if an action is otherwise adequately covered in the descriptions of the impact of the proposed action and of the alternatives thereto. The statements should indicate at appropriate points in the text any underlying studies, reports, and other information obtained and considered in preparing the statement, including any available cost–benefit analyses. A suggested outline for the content of an EIS follows:

I. **Project Description**
    A. Purpose of action
    B. Description of action
        1. Name
        2. Summary of activities
    C. Environmental setting
        1. Environment prior to proposed action
        2. Other related federal activities
II. **Land-Use Relationships**
    A. Conformity or conflict with other land-use plans, policies, and controls
        1. Federal, state, and local
        2. Clean Air Act and Federal Water Pollution Control Act Amendment of 1972
    B. Conflicts and/or inconsistent land-use plans
        1. Extent of reconciliation
        2. Reasons for proceeding with action
III. **Probable Impact of the Proposed Action on the Environment**
    A. Positive and negative effects
        1. National and international environment
        2. Environmental factors
        3. Impact of proposed action
    B. Direct and indirect consequences
        1. Primary effects
        2. Secondary effects
IV. **Alternatives to the Proposed Action**
    A. Reasonable alternative actions
        1. Those that might enhance environmental quality
        2. Those that might avoid some or all adverse effects
    B. Analysis of alternatives
        1. Benefits
        2. Costs
        3. Risks
V. **Probable Adverse Environmental Effects that Cannot Be Avoided**
    A. Adverse and unavoidable impacts
    B. How avoidable adverse impacts will be mitigated

VI. **Relationship Between Local Short-Term Uses of Man's Environment and the Maintenance and Enhancement of Long-Term Productivity**
   A. Trade-off between short-term environmental gains at expense of long-term losses
   B. Trade-off between long-term environmental gains at expense of short-term losses
   C. Extent to which proposed action forecloses future options

VII. **Irreversible and Irretrievable Commitments of Resources**
   A. Unavoidable impacts irreversibly curtailing the range of potential uses of the environment
      1. Labor
      2. Materials
      3. Natural
      4. Cultural

VIII. **Other Interests and Considerations of Federal Policy that Offset the Adverse Environmental Effects of the Proposed Plan**
   A. Countervailing benefits of proposed action
   B. Countervailing benefits of alternatives

Selection and Analysis of Alternatives

The selection and analysis of alternatives is an important element of all planning processes and of the impact analysis process. It is important to make sure that the alternatives that are studied are reasonable. This means that the group of alternatives that will be considered is not selected so as to make a favored alternative "look good." This is important and suggests that the "preferred" alternative not be identified as proposed in the regulation. It is also important that alternatives are discrete, which means that each alternative can on its own fulfill the objectives of the plan or project concerned. The analysis of the *null*, or no-action, alternative is also important from a policy point of view to show the value of the project or plan. Finally, it is important to identify the specific criteria, such as cost, environmental impact, and feasibility, by which each alternative is to be analyzed. The proposed alternatives and the criteria for their analysis are important elements of the early public participation process.

The analysis concerned should present the environmental impacts of the proposal and the alternatives thereto in a comparative form, thus sharply defining the issues and providing a clear basis for choice among the options available by the decision makers concerned and the public. The analysis should rigorously and objectively evaluate all reasonable alternatives including, importantly, the alternative of no action. For alternatives that were eliminated from the detailed study, the analysis should set forth the reasons for elimination. The analysis should also include appropriate potential mitigation measures not already included in the proposed action or alternatives thereto.

Comprehensive Assessment

To be comprehensive, the environmental assessment should include, to the extent possible, a description of all of the environmental impacts of the alternatives considered, including the proposed action; any adverse environmental effects which cannot be avoided should the proposal be implemented; the relationship between short-term uses of the environment and the maintenance and enhancement of long-term productivity; and any irreversible or irretrievable commitments of resources that would be involved in the proposed action. The assessment should include eight factors:

1. Direct effects and their significance
2. Indirect effects and their significance
3. Possible conflicts between the proposed action and the objectives of federal, regional, state, and local—and in the case of a reservation, Indian tribe—land use plans, policies and regulations for the area concerned
4. The environmental effects of alternatives including the proposed action
5. Energy requirements and conservation potential of various alternatives and mitigation measures
6. Natural or depletable resource requirements and conservation potential of various alternatives and mitigation measures
7. Urban quality, historic and cultural resources, and the design of the built environment, including the reuse and conservation potential of various alternative and mitigation measures
8. Means to mitigate adverse environmental impacts

Various methods and techniques have been devised to assist in making a comprehensive impact analysis. Each method needs to be adapted to the particular plan, project, or action under consideration to properly reflect the action and assess its impact. It is unlikely that any analysis, no matter how carefully made, will satisfy everyone, but it is important to describe the method or criteria used in the analysis early in the public participation process in order to attain consensus.

The methods used for analysis have certain steps in common. The first involves identification and grouping of the environmental categories or factors involved. One possible grouping is by social and physical factors as illustrated in Table 6.2.

Another category grouping used might be physical/chemical, ecological, aesthetic, social, with appropriate subcategories under each as illustrated in Table 6.3.

The second step in the method used for analysis includes selection of criteria, or standards within each subcategory that will measure the quality of the category. The third step involves measurement and interpretation of the significance of the criteria or standards and effect on each of the categories. These may include value judgments—that is, evaluation of scientific knowledge by an expert—and assessment of the value that society places on a factor.

TABLE 6.2 Social and Physical Factors Grouping

Social Services	Safety	Sense of Community
Education facilities	Structures	Structural organization
Employment	Materials	Homogeneity and diversity
Commercial facilities	Site Hazards	Physical stock and facilities
Health care/social services	Circulation conflicts	
Liquid waste disposal	Road safety and design	Psychological well being
Solid waste disposal		Physical threat
Water supply	Physiological well-being	Crowding
Stormwater drainage	Noise	Nuisance
Police	Vibration	
Fire	Odor	Historic value
Recreation	Light	Historic structures
Transportation	Temperature	Historic sites and districts
Cultural facilities	Disease	
		Visual quality
		Visual content
		Formal coherence
		Apparent access
Physical Geology	Special Features	Biota
Unique features	Sanitary landfill	Plant and animal special lists
Resource value	Wetlands	Vegetative community types
Slope stability/rockfall	Coastal zones/shorelines	Diversity
Foundation stability	Mine dumps/spoil areas	Productivity
Depth of impermeable layers		Nutrient cycling
Subsidence	Water	
Weathering/chemical release	Hydrologic balance	Climate and air
Tectonic activity/volcanism	Aquifer yield	Macroclimate hazards
	Groundwater recharge	Forest and range fires
	Groundwater flow direction	Heat balance
Soils		
Slope stability	Depth to water table	Wind alteration
Foundation support	Drainage/channel form	Humidity and precipitation
Shrink-swell	Sedimentation	Generation and dispersion of contaminants
Frost susceptibility	Impoundment leakage and slope	
Liquefaction	failure	Shadow effects
Erodibility	Flooding	
Permeability	Water quality	Energy
		Energy requirements
		Conservation measures
		Environmental significance

TABLE 6.3 Physical/Chemical, Ecological, Aesthetic, and Social Factors Grouping

Physical/Chemical

Water
Biochemical oxygen demand
Groundwater flow
Dissolved oxygen
Fecal coliforms
Inorganic carbon
Inorganic nitrogen
Inorganic phosphate
Heavy metals
Pesticides
Petrochemicals
pH
Stream flow
Temperature
Total dissolved solids
Toxic substances
Turbidity

Land
Soil erosion
Floodplain usage
Buffer zones
Soil suitability for use
Compatibility of land uses
Solid waste disposal

Air
Carbon monoxide
Hydrocarbons
Nitrogen oxides
Particulate matter
Photochemical oxidants
Sulfur oxides
Methane
Hydrogen and organic sulfides
Other

Noise
Intensity
Duration
Frequency

Ecological

Species and populations
Game and non-game animals
Natural vegetation
Managed vegetation
Resident and migratory birds
Sports and commercial fisheries
Pest species

Habitats and Communities
Species diversity
Rare and endangered species
Food chain index

Ecosystems
Productivity
Biogeochemical cycling
Energy flow

Aesthetic

Land
Geologic surface material
Relief and topography

Air
Odor
Visual
Sounds

Biota
Animals—wild and domestic
Vegetation type
Vegetation diversity

Manmade Objects
Consonance with environment

(*continues*)

TABLE 6.3 (*continued*)

	Composition
Water	Composite effect
Flows and stages	Unique composition
Clarity	Mood atmosphere
Interface of land and water	
Floating materials	
Social	
Individual Interests	Individual well being
Educational/scientific	Physiological health
Cultural	Psychological health
Historical	Safety
Leisure/recreation	Hygienic
	Community well being
	Social Interactions
	Political
	Socialization
	Religious
	Family
	Economic

To ensure proper consideration of potential impacts requires an interdisciplinary approach. Among the disciplines required may be the following:

- Land related: geography, geology, soils, geomorphology, land resources economics
- Air related: meteorology, bioclimatology
- Water related: hydrology, limnology
- Plant related: botany, forestry, microbiology
- Animal related: zoology, wildlife
- Human related: anthropology, sociology, medicine, economics, geography

The more significant or critical parameters or variables affected by the proposed actions or activities are identified for further study. This should include measurement of the effects—primary and secondary, or indirect—of the activities of humans on themselves and on the environment, and of the environment on humans. The effects of the actions or activities are evaluated as positive or negative and summarized as in Figure 6.6. The results are weighed and the total effects noted as none, moderate, or significant. Tables 6.4 and 6.5 can be helpful in this regard. Evaluation and interpretation of the data assembled, including methods to mitigate adverse effects, can then assist in making the environmental impact assessment and in preparing the environmental impact statement, if found necessary.

Category		ATTRIBUTE NUMBER	Attribute	*Net Positive Impact +	Net Negative Impact X
Air		1	Diffusion factor		
		2	Particulates		
		3	Sulphur oxides		
		4	Hydrocarbons		
		5	Nitrogen oxide		
		6	Carbon monoxide		
		7	Photochemical oxidants		
		8	Hazardous toxicants		
		9	Odor		
Water		10	Aquifer safe yield		
		11	Flow variations		
		12	Oil		
		13	Radioactivity		
		14	Suspended solids		
		15	Thermal pollution		
		16	Acid and alkali		
		17	Biochemical oxygen demand		
		18	Dissolved oxygen (DO)		
		19	Dissolved solids		
		20	Nutrients		
		21	Toxic compounds		
		22	Aquatic life		
		23	Fecal coliform		
Land		24	Erosion		
		25	Natural hazard		
		26	Land-use patterns		
Ecology		27	Large animals (wild and domestic)		
		28	Predatory birds		
		29	Small game		
		30	Fish, shellfish, and waterfowl		
		31	Field crops		
		32	Threatened species		
		33	Natural land vegetation		
		34	Aquatic plants		
Sound		35	Physiological effects		
		36	Psychological effects		
		37	Communication effects		
		38	Performance effects		
		39	Social behavior effects		
Socioeconomic	Human	40	Lifestyles		
		41	Psychological needs		
		42	Physiological systems		
		43	Community needs		
	Economic	44	Regional economic stability		
		45	Public sector revenue		
		46	Per capita consumption		

☐ No significant impact

▨ Moderate impact

▒ Significant impact

Project Name ____________________

Project Number ____________________

Alternative ____________________

*Positive impacts are shown above the attribute number and negative impacts below.

FIGURE 6.6 Summary form for the potential environmental effects of proposed actions.

TABLE 6.4 Air Quality Parameters

Pollutant	High	Moderate	Poor	Federal Air Quality Standards	Notes
Particulates (μg/m^3)[a] $PM_{2.5}$ PM_{10}	0 to 80	80 to 230	230 to 500+	15[b] 35[c] 150[d]	Visibility affected as low as 25 μg/m^3; human health effects begin at about 200 μg/m^3; condensation nuclei less desirable in concentrations less than 25 μg/m^3.
Sulfur oxides (ppm)[e]	0 to 0.10	0.10 to 0.17	0.17 to 0.25+	0.03 0.24[f]	The minimum SO_2 concentration for vegetation damage is 0.03 ppm; less than 0.03 ppm can denote a safe environment; increased mortality observed at 0.2 ppm SO_2.
Hydrocarbons (ppm)[g]	0 to 0.19	0.19 to 0.27	0.27 to 0.40+	—	Conditions for smog development approached at 0.15 to 0.25 ppm.
Nitrogen oxides (ppm)[h]	0 to 0.025	0.025 to 0.075	0.075 to 0.20+	0.05	Nitrogen dioxide is about four times more toxic than nitric oxide. Nitrogen dioxide below 0.05 ppm does not pose a health problem, but above that level begins to act as a toxic agent.
Carbon monoxide (ppm)	—	—	—	9[i] 35[j]	Concentrations of 10 to 15 ppm for 8 hours or more can cause adverse health effects; 30 ppm can cause physiologic stress in patients with heart disease; 8 to 14 ppm correlated with increased fatality in hospitalized heart patients.
Photochemical oxidants (ppm) ozone	—	—	—	0.08[k]	Ozone can irritate lung airways and cause inflammation. Even at very low levels, ground-level ozone triggers a variety of health problems including aggravated asthma, reduced lung capacity, and increased susceptibility to respiratory

					illnesses like pneumonia and bronchitis. Leaf injury in sensitive species after 4-hour exposure to 0.005 ppm. Polymers and rubber adversely affected. Smog develops at concentrations of 0.15 to 0.25 ppm.
Asbestos	0.0	None visible	Visible	—	Long-term exposure to high concentrations of asbestos dust can cause asbestosis.
Beryllium (mg/m^3)	0.01	0.10	>0.10	—	Above 0.01 $\mu g/m^3$ produces disease; at 0.10 or above larger number develop disease; should not exceed 0.01 $\mu g/m^3$ over 30-day period.
Mercury (mg/m^3)	0.0	0.1	>1.0	—	Mercury should not exceed 1.0 $\mu g/m^3$ over 30-day averaging period.
Odor	No odor to odor threshold	Odor threshold to slight odor	Slight odor to strong odor	—	Odor threshold can be detected by 5 to 10 percent of panelists. Moderate odor can be detected by about 40 percent; strong odor by 100 percent.

[a] Based on 24-hour annual geometric mean.
[b] Based on a 3-year average of the weighted annual mean $PM_{2.5}$ concentrations.
[c] Based on a 3-year average of the 98^{th} percentile of 24-hour $PM_{2.5}$ concentrations.
[d] Based on a maximum PM_{10} concentration not to be exceeded more than once a year
[e] Based on 24-hour annual arithmetic mean.
[f] Based on maximum 24-hour concentration not to be exceeded more than once a year.
[g] Based on 3-hour average annual concentration.
[h] Based on average annual concentration.
[i] Based on maximum 8-hour concentration not to be exceeded more than once a year.
[j] Based on maximum 1-hour concentration not to be exceed more than once a year.
[k] Based on 3-year average of the 4^{th} highest daily maximum 8-hour average.

Source: Information abstracted from *Environmental Quality handbook for Environmental Impact Analysis*, Department of the Army, April 1975, pp. A-1 to A-1. Superintendent of Documents, GPO, Washington, D.C., 2402 and United States Environmental Protection Agency.

TABLE 6.5 Selected Attributes (Variables) and Environmental Impact Categories—Water Quality

Selected Attributes	Observed Condition	1[a]	2[a]	3[a]	4[a]	5[a]
Physical aquifer safe yield[b]	Changes occurring in physical attributes of aquifer (porosity, permeability, transmissibility, storage coefficient, etc.)	No change	No change	Slight change	Significant change	Extensive change
Flow variations[c]	Flow variation attributed to activities: Q_{max} /Q_{min}	None	None	Slight	Significant	Extensive
Oil[d]	Visible silvery sheen on surface, oily taste and odor to water and/or to fish and edible invertebrates, coating of banks and bottom or tainting of attached associated biota	None	None	Slight	Significant	Extensive
Radioactivity[d,e]	Measured radiation limit 10^{-7} μci/ml 5pCi/l	Equal to or less	Equal to or less	Exceed limit	Exceed limit	Exceed limit
Suspended solids[c]	Sample observed in a glass bottle	Clear	Clear	Fairly clear	Slightly turbid	Turbid
	Turbidity in Jackson Turbidity Units	3 or less	10	40	60	140
	Suspended solids mg/l	4 or less	10	15	20	35
Thermal discharge[c]	Magnitude of departure from natural condition	0	1	2	4	6
Chemical	Departure from natural condition	0	1	2	3	4
	pH units					10
Acid and alkali	mg/l	1	2	3	5	Low
BOD[d]	Percent saturation	100	85	75	60	High
DO[c]	mg/l	300 or less	400	500	1,000	Large

Dissolved solids[d]						
Nutrients[c]	Total phosphorus, mg/l	0.02 or less	0.05	0.10	0.20	Large
Toxic compounds[e]	Concentration, mg/l	Not detected				
Pharmaceuticals and personal care products	Concentration, mg/l	Not detected	Traces	Traces	Small	Large
Synthetic organic compounds (pesticides and herbicides)[d]	Concentration, mg/l	Not detected	Traces	Traces	Small	Large
Biological fecal coliforms and E-coli[d]	Number per 100 ml	50 or below	200	1,000	20,000	Large
Aquatic life[c]	Green algae	Scarce	Moderate quantities in shallows	Plentiful in shallows	Abundant	Abundant
	Gray algae	Scarce	Scarce	Scarce	Present	Plentiful
	Delicate fish; trout, grayling	May be plentiful	Plentiful	Probably absent	Scarce	Absent
	Coarse fish; chub, dace, carp, roach	May be present	Plentiful	Plentiful	Scarce	Absent
	Mayfly naiad, stonefly nymph	May be plentiful	Plentiful	Scarce	Absent	Absent
	Bloodworm, sludge worm, midge larvae, rat-tailed maggot, swage fly larva and pupa	May be absent	Scarce	May be present	Plentiful	Abundant

[a]Environmental Impact Category. Category 1 indicates most desirable condition; Category 5 indicates an extensive adverse condition. Because all attributes are related to environmental quality between 0 and 1, it is possible to compare attributes and five categories on a common base. Each category is equivalent to approximately 10 percent of the overall environmental quality. In the physical sense, water quality for five categories will be very clean, clean, fairly clean, doubtful and bad. Environmental impact may be adverse or favorable. Adverse impact will deteriorate the environmental quality while favorable impact will improve the quality. Proper signs and weights must be used to achieve overall effects.
[b]Applies to groundwater systems only.
[c]Applies to surface water systems only.
[d]Applies to both the groundwater and surface water.
[e]Surface combined radium—226 and radium—228.

Source: Adapted from *Environmental Quality Handbook for Environmental Impact Analysis*, Headquarters, Department of the Army, April 1975, Supt. Of Documents, GPO, Washington, D.C.

Since the goal is to measure the impact of the project being considered on the environmental attributes, a great deal of expert professional judgment is needed to identify, evaluate, and weigh the significance of the information assembled. Engineering is one of the important areas of expertise required.

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