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M.K. JERMAR

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WATER RESOURCES AND WATER MANAGEMENT

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ELSEVIER

Amsterdam – Oxford – New York – Tokyo 1987

ELSEVIER SCIENCE PUBLISHERS B.V.
Sara Burgerhartstraat 25
P.O. Box 211, 1000 AE Amsterdam, The Netherlands

Distributors for the United States and Canada:

ELSEVIER SCIENCE PUBLISHING COMPANY INC.
52, Vanderbilt Avenue
New York, N.Y. 10017, U.S.A.

Library of Congress Cataloging-in-Publication Data

Jermar, Milan K.
Water resources and water management.

(Developments in water science ; 28)
Bibliography: p.
Includes index.
1. Water-supply. 2. Hydrologic cycle. I. Title.
II. Series.
TD345.J47 1987 553.7 86-24114
ISBN 0-444-42717-1 (U.S.)

ISBN 0-444-42717-1 (Vol. 28)
ISBN 0-444-41669-2 (Series)

Printed in The Netherlands

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INTRODUCTION

Water is a substance which plays a crucial part in the existence of life on Earth. It forms the living mass and, together with the soil and the air, represents the living environment. The energy which is accepted by this system from the universe helps to sustain essential life processes. The hydrological cycle, or the process of permanent movement and transformation of water, connects the human being with all the elements of this environment in such a manner that any change results in a chain of consequences which spread throughout the ecological system.

For billions of years the development of the ecosystem was determined by the interplay of uncertain causes. A fundamental change occurred with the emergence of civilization. Man started to influence this system intentionally and systematically: gradually mankind's everyday existence came to have a more serious and detrimental effect on the environment. Up until now the energy which mankind used during his development has been negligible in comparison with the amount of energy used through natural processes. Nevertheless, even the water management and agricultural activities of ancient civilizations already had a drastic and irreparable impact on waste areas as a result of systematic efforts over long periods of time.

Today the march of technology appears irrepresible and irreversible throughout the world. The process of deforestation, land cultivation, urbanization and industrialization are rapidly changing the character of the earth's surface and the quality of the water, soil and air, as well as affecting the acceptance of solar energy. The scale of these human activities has now reached such a proportion that the impact of one single generation is comparable with the impact of all preceding generations. The amount of energy currently manipulated by man is no longer negligible in comparison with the total amount of energy used during natural processes. Civilization confines the world and mankind to monotonous, unambiguous structures which are very difficult to control effectively. Man alters the natural equilibrium without considering the global consequences of his actions. In the course of a few decades he is able to exhaust some natural resources and irreversibly pollute his environment. An unfavourable accumulation of the negative consequences of his activities, transferred in the framework of the hydrological cycle, threatens his own existence. Man has started to live at the cost of future generations.

The roots of this incomprehensible situation lie not only in mankind's misguided endeavour to achieve maximum economic benefits through minimum efforts and without considering secondary effects, but also in his traditional thinking processes. These were formed in the period when man still observed natural phenomena separately, without taking account of their interrelationship. In the past the observer of natural phenomena in one scientific discipline had no reason to follow up their inter-disciplinary relationships. The interrelationship of natural phenomena and the likely consequences of such a relationship were not taken into consideration.

This situation is also reflected in the field of water resources. The theoretical background to this field is traditionally formed by:

- hydraulics (the study of the physical regularities of water motion and function);
- hydrochemistry (the study of the physical, chemical, biological and bacteriological properties of water);
- hydrology (the study of the time and space distribution of various aspects of the hydrological cycle) and
- hydrogeology (the study of the occurrence and movement of subterranean waters and their geological environment).

The descriptive scientific disciplines are concerned with the study of two different categories of phenomena.

The first category comprises phenomena which are based on simple relationships among several variables. Here it is necessary to neglect those variables whose influence is unimportant and to derive the mathematical relationships among these variables whose influence is decisive.

The second category includes phenomena with a high degree of occurrence. Here it is not necessary to trace their mutual relationships, but rather to study the result of their interplay, when the relations between causes and consequences are to be determined and classified on the basis of statistical methods and the theory of probability.

However the size and number of water projects and other development activities which influence the hydrological cycle have reached such proportions that the majority of problems involved extend beyond the boundaries of the above traditional disciplines. These problems cannot be solved with the tools of the above methods. Present-day water management problems are inter-disciplinary in nature and as such include complex phenomena with complicated mutual interrelationships. These interrelationships are more important than the number of variables involved.

It is not enough to investigate these problems by researching selected important variables and relationships. Using statistical methods and the theory of probability for this purpose represents a complicated mathematical exercise with only little relevance to reality. Such an approach is unlikely to lead to the desired goal.

The solution of inter-disciplinary problems in water development and management practice on the basis of the traditional approach tends to ignore the key development and environmental factors. This leads among other things to:

- the separate development of either surface or groundwater resources,
- the use of high quality water for low quality requirements and vice versa,
- the over-excessive use of water for certain purposes, thus inhibiting or excluding more valuable uses,
- the neglecting of water re-use, water re-cycling, and waste material recovery possibilities and other water saving practices,
- the loss of nutrients or raw materials from the place of immediate or potentially easy utilization, and
- the neglecting of important secondary aspects, constraints and hazards of many water and other development projects.

The traditional approach is also one of the reasons of:

- over-excessive use of natural resources,
- the increasing deterioration of the natural environment, and
- the economic failure of many water development projects.

When investigating contemporary water development and management problems including their ecological, economic and social aspects, it is necessary to analyze a large number of elements whose interrelationships depend on the prevailing conditions. Such problems can be solved by limiting the problem area, simplifying it to the point of analytic tractability, and defining systems which preserve all vital aspects affected by various possible amendments. All important elements and dynamic interrelationships should be analyzed and not just generally, but also on the basis of their specific behaviour. It is necessary to employ a combination of different probabilistic and analytic methods, including modelling and investigating the sensitivity of the outputs to the assumptions made and to facets of the problem excluded from the formal analysis.

New scientific methods for the solution of the contemporary problems in water management include analogy, operation research, system analysis and cybernetics. The distinctive features of these methods are their emphasis on measurement and on the use of conceptual models described in quantitative terms, the verification of their theoretical predictions, and their awareness that concepts are conditional and subject to growth and continuous change.

This new approach should be defined within the framework of water resources management, i.e. within a complex of activities whose objective is the optimum utilization of water resources with regard to their quality and availability and the requirements of society. These water management activities should at the same time also ensure an optimum living environment, above all through protection of water resources against deterioration and exhaustion as well as through the protection of society against the harmful effects of water. In the course of these activities water resources management should avail itself of the entire spectrum of explicit sciences, gradually coming to form the sphere of its own theory.

The present monograph deals with the fundamental interdisciplinary problems of this complex sphere, an understanding of which is indispensable for successful water resources management in the widest sense of its social functions and environmental consequences.

Chapter 1

WATER OCCURRENCE AND ITS FUNCTION IN NATURAL SYSTEMS

1.1 SYSTEMS OF THE NATURAL ENVIRONMENT

Water exists as scattered humidity and as spatially limited water formations below, on and above the Earth's surface. Water resources are water formations which can be utilized by human society. Water and water formations are dynamic; they are always in motion and their state of aggregation is forever changing. These processes continue without interruption, change in space and time and transform the natural environment.

The natural environment is formed by a number of systems, or complexes of mutually interrelated elements, whose relationships within the framework of these complexes are more important than their relations with the elements of other systems. In the important part of the natural environment which constitutes the object of the present investigation it is possible to distinguish:

(a) abiotic systems, created by water, soil and air elements and characterized by:

- morphological (topographical) data
- pedological and geological data (soil is a mixed abiotic-biological element)
- hydrogeological and hydrometeorological data

(b) biotic-biological systems (ecosystems), originating with the development of living matter in a defined part of the abiotic environment and

(c) socio-economic systems, i.e. administrative, economic and technical systems (Fig. 1.1) originating with the formation of human society and possessing important interconnections with the above two systems.

The natural environment of Earth represents a semi-closed system. The input of matter into this system from outer space is negligible. The movement of matter inside this system is enabled by an input of energy, consisting mainly of solar energy and the internal energy of Earth itself. This system, due to its own homeostatic mechanisms and detectors, tends to achieve a state of equilibrium balancing accidental deflections from this state.

The material couplings which form interrelations among these systems include:

- biotic-abiotic couplings, e.g. the quantity of dissolved oxygen caused by the decay of a biomass
- abiotic-biotic couplings, e.g. the dependence of the intensity of biological processes on water temperature
- socio-abiotic couplings, e.g. as manifested especially by the impact of urbanization, industrialization and agricultural production on runoff and sediment transport

- socio-abiotic-biotic couplings, e.g. as manifested by the role of urbanization, industrialization and intensive agricultural production in polluting certain ecosystems.

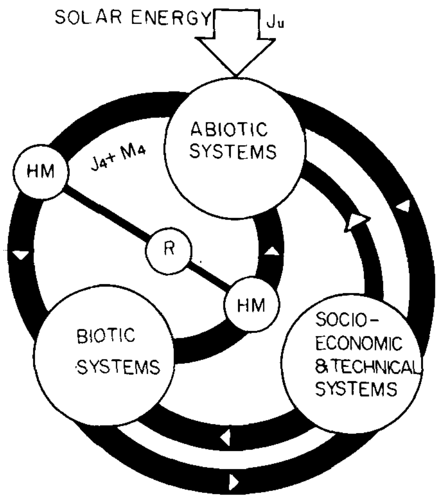


Fig. 1.1. The penetration of matter and energy through the abiotic and biotic (also socio-economic) systems. The equilibrium of relevant systems and its recovery depend on the energy and matter input: R - detector, HM - homeostatic mechanisms.

These material couplings also form complex interrelations, such as the socio-abiotic-biotic-social interrelation manifested by the influence of industrialization and the subsequent water pollution and eutrophication on water utilization.

The task of analyzing these interrelationships among the various systems is complicated not only by the complexity of the couplings and interrelations concerned, but also by the lack of data available (Fig. 1.2).

As only selected couplings are operationally controllable, only a few can be checked systematically. Moreover, because data monitoring is neither complex nor fully systematic, the relevant series of data in the different categories do not mutually correspond and are therefore inadequate. Furthermore, frequently undesirable secondary couplings occur and have a negative influence on the function of the system in question, sometimes bringing about a gradual change in the system's behaviour.

The movement of water and other matter within and between these systems changes in time and space: The importance of individual relations is variable. Regarded in this way the doctrine of water management concerns the structure and the function of systems, thus enabling the water to fulfill its natural functions and to be utilized for the various present and future requirements of society.

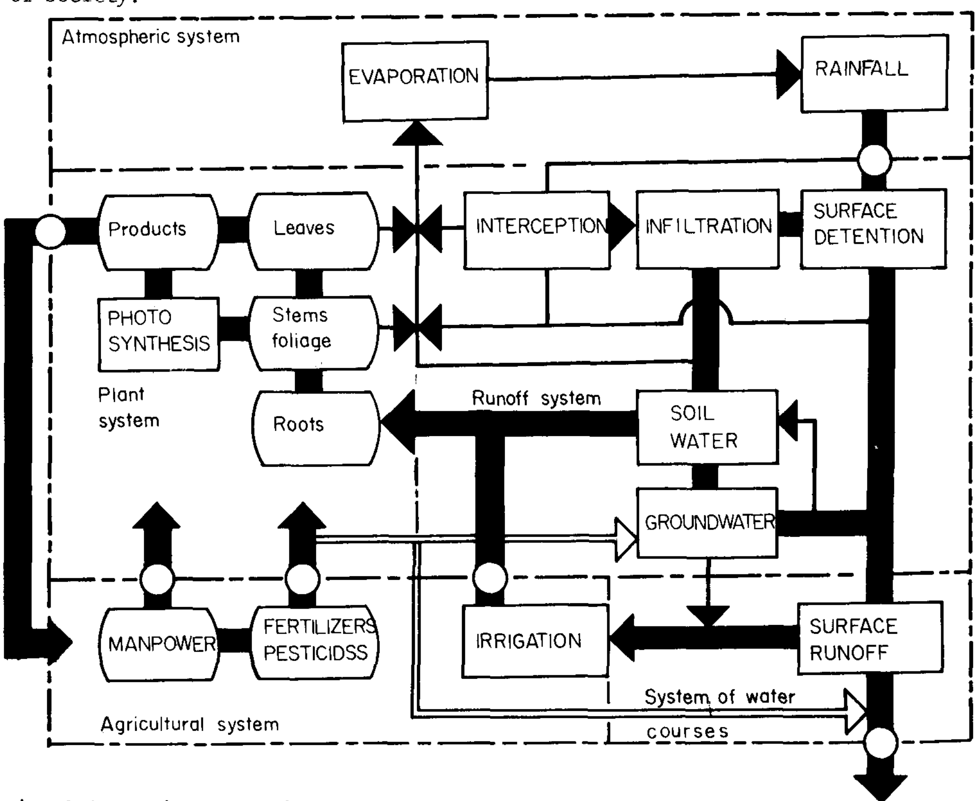


Fig. 1.2. Basic productive inputs and outputs of abiotic and biotic systems. Monitored, i.e. systematically checked inputs are marked by a circle; accidental, undesired outputs are marked by white arrows.

1.2 ENERGY INPUT AS A CAUSE OF THE HYDROLOGIC CYCLE

The Earth reflects a part of the external energy input which it receives, distributing the rest between the air, water, soil and geological formations and radiating part of it back into the Universe. The basic equation of the energy balance expresses the law of the conservation of energy (Fig. 1.3)

$$J_u \cdot (1 - \varrho) - J_g = \sum_{k=1}^{4} J_k \qquad (m^2.kg.s^{-2}) \qquad (1.1)$$

J_u - sun and other radiation from the Universe (short wave)

ϱ - albedo (coefficient of reflection)

J_g - global radiation (long wave)

J_1 - energy supply to the atmosphere

J_2 - energy supply to the hydrosphere

J_3 - energy supply to the pedosphere and lithosphere

J_4 - energy supply to the biosphere

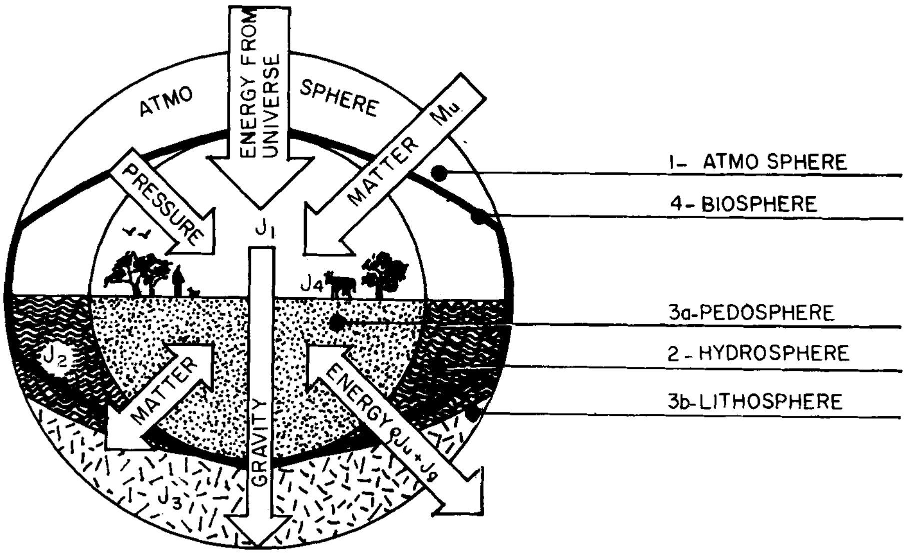


Fig. 1.3. Basic interrelations of the systems of atmosphere, lithosphere and pedosphere as well as the hydrosphere: movement of matter in the gravitational field, enabled by the supply of energy, forming the main input. The input of matter from the universe is negligible.

The Earth reflects on average 34% of the energy input. The coefficient of reflection, the albedo, depends essentially on the character and morphology of the surface, the state and quality of the atmosphere above, as well as on the angle of incidence of the rays. Stretches of water reflect 10% of the energy on average, lawns 15%, forests 20%, deserts 30% and snow 80%. The type of energy utilization changes with the character of the surface: 90% of the energy input is consumed by evaporation above oceans, while above continents the figure is only 50%.

The global average temperature of the air is not changing at present. The energy balance does not demonstrate any increment in the component: $J_1 = 0$. In average the basic equation of the energy balance, also taking into account the fact that the energy supply to the biosphere is relatively small, can be simplified as follows:

$$J_e = J_2 + J_3 \qquad (m^2.kg.s^{-2}) \qquad (1.2)$$

J_e - effective radiation

The result of the acceptance of the effective radiation are fluctuations in the soil and water temperature, accompanied by evaporation with sublimation.

These processes change the state of water aggregation into a gaseous one. The specific weight of water vapour is lower than that of air. Water vapour rises and in this way it acquires position energy. The thermal energy thus regenerates the mechanical energy of water and causes the circulation of water. The hydrological cycle is an uninterrupted process of water motion and changes of aggregation in the systems of the biological and abiotic environment. The difference between the specific and latent heat of fusion and vaporization, whose values are approximately two and three orders high respectively, balances this process during a higher or lower energy input.

The mechanical energy consists of the position energy, the pressure energy and the kinetic energy.

The position energy	$J_h = m.g.h$	$(m^2.kg.s^{-2})$	(1.3)
m - mass		(kg)	
g - gravitational constant		$(9.81\ m.s^{-2})$	
h - head		(m)	
Pressure energy	$J_p = m.\frac{p}{\varrho}$	$(m^2.kg.s^{-2})$	(1.4)
p - pressure		$(m^{-1}.kg.s^{-2})$	
- water density, unit mass of water		$(kg.m^{-3})$	
Kinetic energy	$J_k = m.\frac{v^2}{2g}$	$(m^2.kg.s^{-2})$	(1.5)
v - velocity of flow		$(m.s^{-1})$	

The quantity of water in water courses forms only 0.002% of the total global water reserves. The proportion of water power potential of water courses is only 0.4% of the $6.4 \cdot 10^{30}$ of energy which the Earth continuously receives from the Universe. But it is twenty times higher than the percentage of water courses volume in relation to total global water reserves because of the high head formed by geomorphological conditions.

Position energy acts as pressure energy and changes into kinetic energy, depending on the physical conditions. This kinetic energy together with chemical energy of water and changes in volume during ice formation, transforms soil and rock formations also forming and changing river beds. The growth and changes in ecosystems are also enabled by the effect of the mechanical, thermal and chemical energy of water.

By accepting and emitting energy, water molecules change their position and state of aggregation during their course through the biological and abiotic systems of the natural environment. The law of conservation of energy during this cycle expresses the equation of hydrological equilibrium:

$$\sum_{k=1}^{2} P_k = \sum_{k=1}^{3} Q_k + \sum_{k=1}^{4} E_k + \sum_{k=1}^{5} R_k \qquad (m^3) \qquad (1.6)$$

P_1 - vertical precipitation

P_2 - horizontal precipitation (see paragraph 1.3.2)

Q_1 - surface outflow (channel and overland flow)

Q_2 - subsurface outflow (groundwater runoff)

Q_3 - deep percolation and juvenile water inflow

E_1 - evaporation from bare soil surface

E_2 - evaporation from free water surfaces

E_3 - evaporation from snow and ice

E_4 - evapotranspiration

R_1 - water increment (or decrement) in soils and rock formations

R_2 - water increment (or decrement) in water courses and reservoirs incl. depression and detention storage

R_3 - water increment (or decrement) in the atmosphere

R_4 - water increment of the flora

R_5 - water increment of the fauna.

The area and period of application of this equation can be established in such a way that relevant increments or decrements in volume and the deep percolation or water supply from deep strata are negligible, thus simplifying the formula:

$$P_1 + P_2 = Q_1 + Q_2 + \sum_{k=1}^{4} E_k \qquad (m^3) \qquad (1.7)$$

This hydrological equation simply states that the total evaporation and the difference between the total inflow and outflow (concentrated and overland runoff, groundwater runoff) is formed by the precipitation and the dew deposit. Data on the earth's water reserves vary within a range of $\pm 10\%$. KORZUN and SOKOLOV (1976) estimated them at 1,386 mld. km^3, of which some 2.53% or only 35 mil.km^3, are fresh water reserves. The total annual evaporation is 577,000 km^3: 505,000 km^3 on sea surfaces, 72,000 km^3 on continental surfaces. Groundwater reserves exceed five thousand times the amount of water in all rivers, brooks and creeks. 50% of the groundwater is below the level of 1000 meters under the earth's surface (Tab. 1.1).

Of basic importance in this context is the recycling rate, which indicates the duration of the natural exchange of the relevant volume of water: in the case of water courses this rate is $3.4 \cdot 10^4$ times as high as for groundwater.

TABLE 1.1

Type of formation	Area (10^6 km^2)	Volume (10^3 km^3)	Layer (m)	Share (%) on total water	fresh reserves	Period of replenishment (years)
Ocean	361	1 338 000	3700	96.5	0	2500
Brackish groundwater	134.8	12 870	96	0.94	0	1400
Lakes	0.822	85.4	103.8	0.006	0	17
Total	497	1 351 000	3660	97.45	0	-
Groundwater	134.8	10 530	78	0.76	30.1	1400
Soil water	82	16.5	0.2	0.001	0.05	1
Icebergs:						
Antarctic	13.98	21 600	1540	1.56	61.7	9700
Greenland	1.80	2 340	1298	0.17	6.7	9700
Arctic	0.23	83	369	0.006	0.24	9700
Mountain	0.22	41	181	0.003	0.12	1600
Permafrost	21	300	14	0.022	0.86	10000
Fresh water:						
Lakes	1.236	91.0	73.6	0.007	0.26	17
Marshes	2.682	11.5	4.28	0.009	0.03	5
Watercourses	148.8	2.1	0.014	0.0002	0.006	16 d
Biosphere	-	1.1	0.002	0.0001	0.003	1 h
Atmosphere	510	12.9	0.025	0.001	0.04	8 d
Fresh water reserves	148	35 029	235	2.55	100	-
Total water reserves	510	1 386 000	2719	100	2.55	-

World water reserves and the share of different water bodies in the reserve of the total volume of water and in the volume of fresh water according to Sokolov (1981). The period of exchange of their volume by natural recharge (d - days, h - hour)

Of the 145.10^3 km^2 of continental surfaces only two thirds (100.10^3 km^2) are suitable for water development, 25.10^3 km^2 being permafrost, 14.10^3 km^2 icebergs and 6.10^3 km^2 extremely arid land.

1.3 HYDROLOGIC CYCLE SYSTEM

The complicated processes of the hydrologic cycle include evaporation, precipitation, interception and surface storage, infiltration and percolation, surface and groundwater runoff.

The catchment area, i.e. the area which drains into one place and thus contributes to the runoff in the profile in question, is an open system whose boundary crosses energy, water, air and soil/rock particles. Potential energy of position, thermal and chemical energy within this system, is transformed into kinetic energy and heat. Water, suspended, wash and bed load as well as floating debris are transported from the upper elevations towards the sea (and partially vice versa e.g. by sand dune movement) and transformed. Erosion, crushing, chemical and biochemical processes are an integral part of the water cycle (Fig. 1.4).

The system of the catchment area tends to achieve a steady state of operation, corresponding to the conditions of climate, topography, geology and ecology, characterized also by the fact that the water and debris output corresponds to a specific energy input. Any change e.g. by river training, reservoir construction, land cultivation, urbanization and industrialization, is a change of system elements and of the energy input, thus resulting in the change of output.

The state of this system is to be followed in its spatial elements (Fig. 1.4). Three equations of balance can be formulated for each of these elements:

- hydrologic balance (Fig. 4.1)
- fall-out, erosion and debris balance
- energetic balance.

In any spatial element due to the equilibrium of the atmosphere branch, the precipitation, the evaporation and the increment of atmosphere moisture equal to the difference of water vapour entering and leaving the element:

$$A_n - A_{n+1} = R_n + P_n - E_n \qquad (m^3) \qquad (1.8)$$

A_n - water vapour entering the spatial element n

A_{n+1} - water vapour leaving the spatial element n

P_n - precipitation and dew deposit in the element n

E_n - evaporation in the element n

R_n - air moisture increment in the element n.

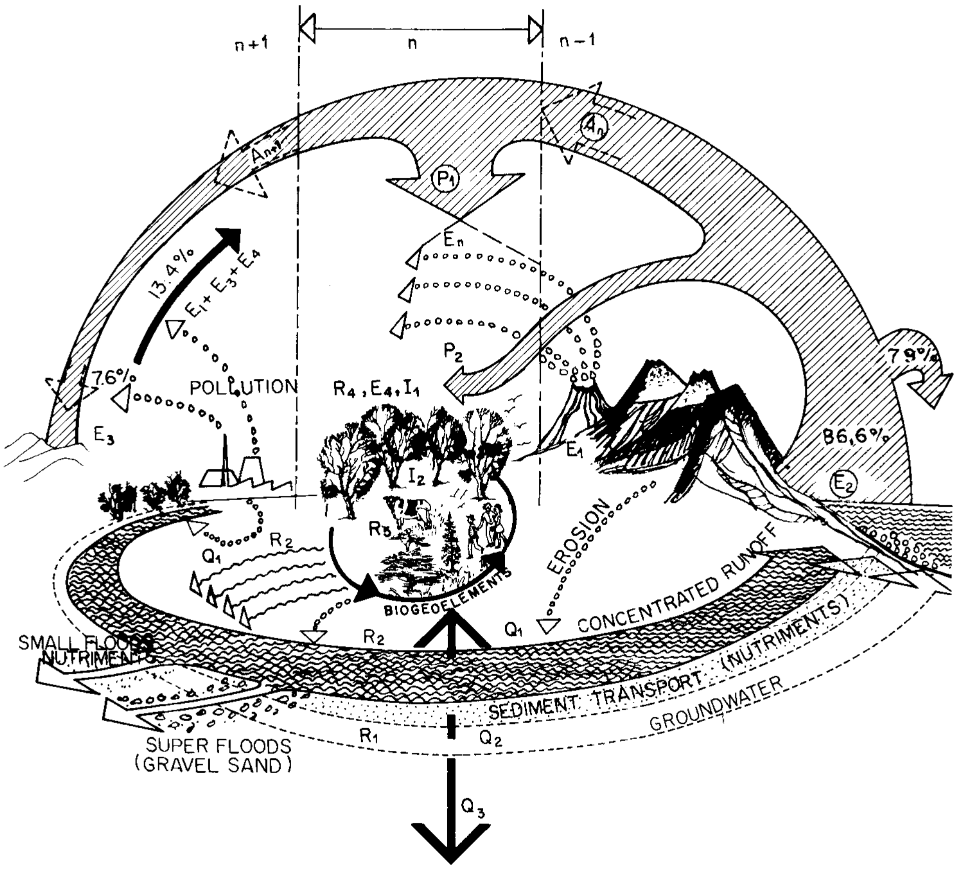


Fig. 1.4. Equation of hydrological equilibrium, the transport of mass and biogeochemical cycles as subsystems of the water cycle. Explanation of symbols and main equations is given in the text.

Precipitation is formed by external water vapour supply $A_n - A_n+1$ and by internal evaporation E_n:

$$P_n = A_n - A_{n+1} + E_n - R_n \tag{1.9}$$

but $P_n = Q_n + E_n$ (see equation 1.7) and, therefore,

$$A_n - A_{n+1} + E_n - R_n = Q_n + E_n$$

$$A_n - A_{n+1} = Q_n + R_n \tag{1.10}$$

Internal evaporation over continents is generally lower than the external water supply, requiring more energy and resulting in the generally prevailing evaporation on the sea surface. This fact can be expressed by the water circulation ratio, defined as

$$m = \frac{\sum_{n=1}^{N} P_n}{\sum_{n=1}^{N} A_n - A_{n+1}} = \frac{\sum_{n=1}^{N} P_n}{\sum_{n=1}^{N} Q_n + R_n} \qquad (1.11)$$

The value of this ratio over vaste areas is quite stable, e.g. for North America m_{na} = 1.25, Asia and Europe m_{ae} = 1.51.

1.3.1 Evaporation

Evaporation is a physical process by which water changes from the liquid state to the vapour state through the transfer of thermal energy. The change from solid state without passing the usual intermediate liquid aggregation is called sublimation.

Evaporation is the key process in the water cycle:

(a) it is the only one of the processes in this cycle during which the energy input exceeds the energy output,

(b) it accounts for the creation of living matter.

Evaporation takes place particularly on the boundary of the atmosphere and the hydro-, pedo-, and biosphere, thus making it possible to distinguish:

- evaporation from open water surfaces,
- evaporation from bare soil surfaces,
- evaporation from snow and ice,
- evaporation of water intercepted by vegetation,
- evapotranspiration from soil and vegetative cover,
- evapotranspiration of vegetative cover on water surfaces,
- evaporation from organic bodies and moist materials,
- evaporation in the atmosphere.

Evapotranspiration includes soil evaporation and the evaporation of water which is absorbed by crops, used in the building of plant tissue and transpired. The quantity of water evapotranspirated by plants and relevant soil surfaces per annum with the increment in plant tissue is the consumptive use of plants.

The hydrologic balance can be expressed generally or for a limited element of the lithosphere by the following equation:

$$ET = E + T = P + R_i + W - Q - F \; (m^3/year, M^3.s^{-1}) \qquad (1.12)$$

ET - evapotranspiration
E - evaporation
T - transpiration
P - precipitation
R_i - irrigation
W - increase of water moisture caused by capillary forces from the groundwater

(+) or decrease by water consumption of crops (-)

Q - deep percolation and drained water

F - water chemically and biologically absorbed and used in the building of the plant tissue (+), or eliminated from the organic matter (-), e.g. by guttation.

The rate of evaporation depends on the state of the systems whose interaction enables its course. The atmosphere influences this course by meteorological factors, namely by solar radiation, humidity and by air movement leading away water vapours. The relationship between radiation and evaporation can be expressed for a limited part of the hydro- or the lithosphere (reservoir, forest, field etc.) by the equation

$$J_e = J_h + (J_a + J_x) \quad (J.m^{-2} \text{ per day}) \tag{1.13}$$

J_e - effective solar radiation

J_h - heat accepted by the hydro- or litho- and biosphere

J_a - heat transferred back to the atmosphere

J_x - latent heat used for evaporation and evapotranspiration

The value and ratio of all these factors also change at the same place in the course of the year (Fig. 1.5)

$$\frac{J_a}{J_e} = \frac{\Delta T}{\Delta P} \tag{1.14}$$

Albrecht (1951) simplifies the equation for evaporation

$$E = \frac{J_e - J_h}{1 + \frac{\Delta T}{\Delta P}\cdot\alpha} \quad (mm) \tag{1.15}$$

ΔT - temperature increment (^{o}K)

ΔP - air pressure increment (Pa)

α - coefficient

The transfer of solar energy is greatly influenced by overshadowing and by meteorological factors, namely by the humidity of the air, precipitation, air temperature and pressure as well as the velocity of its movement. Temperature and air pressure do not influence evaporation directly. They characterize the quantity of accepted energy. The humidity and air flow which accelerate the evaporation by the exchange of saturated air strata above the evaporating surface are also incidental phenomena of the energy transfer to the atmosphere. They function as regulating factors of the evaporation and transpiration rate.

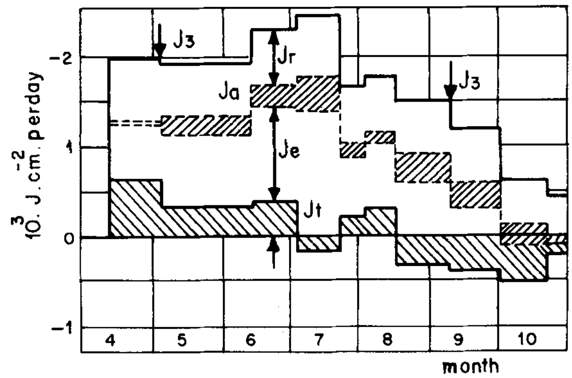


Fig. 1.5. The annual course of the energy balance (Lake Haussee according to measurements of Czepa and Schellenberger (1956). The energy input J_3 is partially radiated (J_r), partially transferred to the atmosphere (J_a) by the contact of the water table and the air mass. J_e is used for evaporation and J_t causes the change of water temperature.

The immediate cause of the evaporation process is the difference in humidity between the internal and external - or the saturated and unsaturated - system of environment. It can be characterized by the evaporation from surface as relative humidity, i.e. the ratio of the actual water vapour pressure e (Pa) and the maximum pressure E (Pa) which the air is able to accept at the actual temperature. The difference between these values is the saturation complement

$$d = E - e \qquad \text{(Pa)} \qquad (1.16)$$

Braslavskij and Vikulina (1954) assessed the following practical formula for the computation of the evaporation from open water surfaces on the basis of the air humidity and wind velocity

$$EV_a = 0.013 \cdot (e_o - e_2) \cdot (1 + 0.72\, v_2) \qquad \text{(mm per day)} \qquad (1.17)$$

EV_a - monthly average of evaporation

e_o - maximum water vapour pressure, corresponding to the average temperature of the water surface (m)

e_2 - monthly average of water vapour pressure 2 m above the water surface (m)

v_2 - average wind velocity at an elevation of 2 m above the water surface($m.s^{-1}$)

Šermer (1960) established the relation between the temperature and the evaporation from open water surface for the conditions of Central Europe as follows

$$EV_d = 10^{(0,0452\, T - 0.104)} \qquad \text{(mm per day)} \qquad (1.18)$$

T - average monthly temperature 2 m above the water surface (^oC)

Evaporation from snow and ice is five to ten times lower than evaporation from free water surfaces. Due to the lower temperature and solid state of snow and ice, much more energy is needed for the same intensity of its course. The evaporation rate from ice is about 50 to 100% higher than the evaporation from snow under the same conditions, because the heat conductivity of snow is lower. Therefore

$$EW > EI > ES \qquad (mm) \qquad (1.19)$$

EW - evaporation from open water surface

EI - evaporation from ice

ES - evaporation from snow surface.

The value of evapotranspiration from overgrown water surfaces depend on the kind and the total quantity of the vegetable matter. The evaporation from overgrown surfaces does not differ greatly from the evaporation from open water surfaces, when the water surface is only covered by floating leaves. But it exceeds it twice in the case of the densely overgrown edges of reservoirs. Therefore

$$EO \geqq EW \qquad (mm) \qquad (1.20)$$

EO - evapotranspiration from overgrown water surface.

Evaporation from bare soil does not depend on heat input only, characterized by meteorological factors, but also on the soil factors, namely on

- the structure and other physical properties of the soil,
- the soil moisture,
- the contact of the soil layer with the groundwater surface (Fig. 1.6).

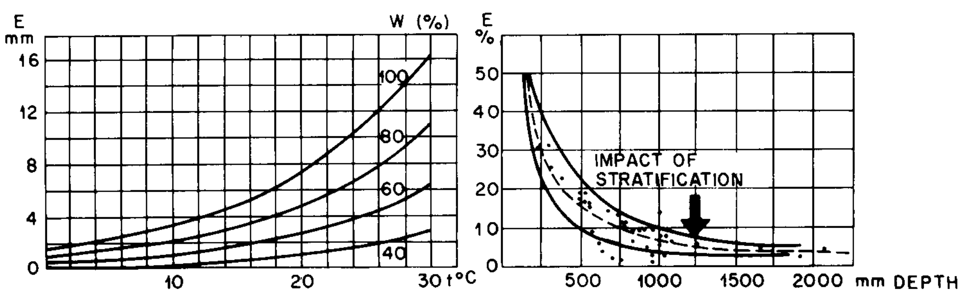


Fig. 1.6. (a) Interrelation of the evaporation from the free water surface, the air humidity and the air temperature according to Dub (1957). (b) Relation of the evaporation from the groundwater table on its depth, expressed as the ratio of the evaporation from free water surface. Derived according to White (1970).

These internal factors function clearly in the case of lower soil saturation. The evaporation from bare soils also depends on the velocity of water inflow to the surface. Inadequate water inflow lowers the evaporation rate.

Actual evaporation from bare soils is, therefore, lower than the potential rate, whose value depends on the energy supply only.

Values of the potential evaporation from bare soils almost equal those from open water surfaces, when water evaporates directly from the wetted topographic surface. Under conditions of a dry surface layers, as Penman (1940) proved, water vapour penetrates this layer by diffusion, which lowers the values of evaporation.

Evaporation from bare soils takes place

(a) in contact with the groundwater surface, regulating the soil moisture, or, more frequently,

(b) without outstanding contact with the groundwater surface, when the suspended capillary water of the soil profile is not connected with the capillary water supported by the groundwater level, and the root system does not penetrate into this space, i.e. when the groundwater level is influenced by the conditions of the soil surface by means of hygroscopic and osmotic forces and by the gas pressure only.

Evaporation from groundwater surfaces depends namely on the depth of the groundwater level. The course of groundwater level changes is not the same under the conditions of evapotranspiration: Relevant forces differ, especially during the day. They also depend on the kind of vegetation, its root system, stage of growth and quantity of leaves.

Evaporation within reach of a well can be calculated by neglecting the evaporation during the night, which is comparatively low, anticipating that the rise in water level is uniform:

$$E_1 = Q_1 \cdot (24 \cdot v - s) \qquad (l.s^{-1}) \qquad (1.21)$$

E_1 - evaporation from the groundwater surface within the reach of the measured well $(l.s^{-1})$

Q_1 - well yield during the decrease of water level by 1 m $(l.s^{-1})$

v - velocity of water level rising during night (m per hour)

s - total increase of water level per day (m per day)

In the most frequent case of evaporation from bare soils without outstanding contact with the groundwater level, the value of the evaporation rate in the initial stage is almost equal to the potential evaporation. The following stage, beginning with a substantial lowering of the moisture of the soil surface, is characterized by the decreasing velocity of evaporation, which stabilizes in the final stage at a low value. Anticipating a uniform distribution of the perpendicular velocity, Kutílek (1978) proves that

$$e = (W_i - W_o) \cdot \left(\frac{\bar{D}}{\pi \cdot t}\right) \qquad (m.s^{-1}) \qquad (1.22)$$

e - evaporation rate $(m.s^{-1})$

$W_i - W_o$ - difference of moisture content in the soil surface during time t (%)

$\bar{D}$ - average difussivity of the soil water, depending on the soil category and moisture $\bar{D} = \frac{k_f \cdot dh}{dW}$

k_f - hydraulic conductivity

h - pressure height

t - time

π - constant of soil properties.

Transpiration, the evaporation of water absorbed by a crop and not used in the building of plant tissue, may be above all stomatal but also appears as cuticular or as guttation or exudates from cut surfaces of the plant. Transpiration depends on physiological and environment (meteorological) factors, e.g. daytime. Physiological factors include

(a) the physiological structure of relevant plant types, the age of their organs and the nature of their cellular membranes,

(b) the actual state of the relevant individual plant, i.e. the degree of nutrition, namely water content of its cells and water vapour content in the transpiratory organs.

Under conditions of sufficient moisture and nutrition for the development of individual plants, the intensity of transpiration depends especially on environmental factors, namely on solar radiation, wind velocity and soil moisture. The temperature of the leaf exposed to the sun is higher than that of the air. In the case of an insufficient supply of water and nutrition, the intensity of transpiration depends more on the above-mentioned internal physical factors (Tab. 1.2).

The plant exercises a limited control on the transpiration rate. Stomata usually open in the light. They close with reduced moisture and when the sugar content decreases, changing to starch, as happens in the dark or at the end of the vegetation season, when leaves turn yellow. Transpiration is also reduced in the case of abundant water.

The movement of water from the root zone, through the stem and leaves, is enabled by diffusion and osmosis. The rate of both these processes is influenced by air moisture and energy supply, resulting in the removal of water vapour next to the leaf surface. Van Den Honert (1948) expressed transpiration by physiological analogy with OHM's law

$$T = \left(\frac{\psi_s - \psi_e}{r_s - r_p}\right) \cdot \gamma_v \qquad (m.s^{-1}) \qquad (1.23)$$

T - transpiration rate

TABLE 1.2

Term, sign	Definition	Usage
Potential evaporation (evaporativity) ET_1	Theoretical value derived from energy input $ET_1 = \frac{\Delta p}{\Delta p + \gamma} (J_s + J_g)$ Δp - saturated vapour pressure increment γ - psychrometric constant J_s - energy input J_g - energy transfer	Energy budget
Potential evapotranspiration ET_p	Evapotranspiration from soil and vegetation system, saturated with water and nutriments, derived from local hydrometeorological conditions.	Water balances for long term planning
Optimal evapotranspiration ET_{opt}	Evapotranspiration from a surface whose soil moisture is managed in order to increase agricultural and forestry production	Determination of plant water and irrigation requirements
Maximum evapotranspiration ET_{max}	Highest evapotranspiration that relevant vegetation system is able to achieve, dependent on its stage of growth and actual state	Resistance against moisture. Dimensioning of the drainage.
Minimum evapotranspiration ET_{min}	Evapotranspiration of a plot irrigated only for survival of relevant plant species	Resistance against drought
Actual evapotranspiration ET_a	Real evapotranspiration dependent on the growth stage and state of the plant, measured by soil-moisture sampling, large-size lysimeters, groundwater fluctuations	Determination of actual irrigation rates

Glossary of evapotranspiration.

TABLE 1.3

Cover	Bare soil			Grassland			Pine forest		
	mm	%	Share	mm	%	Share	mm	%	Ratio
October	9.6	5.4	1.00	18.2	5.1	1.75	28.6	6.6	2.98
November	2.6	1.5	1.00	7.0	1.9	2.69	13.0	3.0	5.00
December	0.6	0.3	1.00	2.0	0.5	3.33	8.5	1.9	14.20
January	0.2	0.1	1.00	3.7	1.0	18.50	12.1	2.8	60.50
February	4.2	2.4	1.00	5.1	1.4	1.21	13.4	3.1	3.18
March	10.2	5.7	1.00	16.7	4.7	1.64	25.4	5.8	2.49
April	23.1	13.0	1.00	37.6	10.5	1.63	41.0	9.4	1.78
May	23.9	13.5	1.00	62.6	17.5	2.62	69.9	14.7	2.92
June	24.4	13.7	1.00	51.6	14.6	2.12	58.6	13.4	2.40
July	29.9	16.8	1.00	57.4	16.4	1.91	61.5	14.2	2.05
August	27.0	15.2	1.00	55.2	15.5	2.04	61.1	14.0	2.26
September	22.1	12.4	1.00	39.5	11.1	1.78	48.4	11.1	2.18
Yearly total	177.8	100.0	1.00	355.6	100.0	2.00	435.5	100.0	2.44
Share from free surface evaporation	Loamy soil		50%	Loamy soil		87%	Depending on forest		70%
	Sand		26%	Sandy soil		26%	density and age		100%

Seasonal distribution of evaporation and evapotranspiration, its dependence on the soil surface and cover according to Wechman (1963, Eberswalde, GDR). The share of evapotranspiration compared with the free surface evaporation according to Krecmer (1980).

e_t - evaporation rate $(m.s^{-1})$

Ψ_s - soil moisture potential - suction pressure of the soil water $(J.kg^{-1})$

Ψ_e - moisture potential of the leaves $(J.kg^{-1})$

r_s - flow resistance of the soil $(Pa.s^{-1})$

r_p - flow resistance of the plant $(Pa.s^{-1})$

γ_v - unit mass of the soil water $(kg.m^{-3})$

The ratio of transpiration and evaporation from soil changes at one point in time, namely during the vegetation season. At the beginning of this season, the evaporation from bare soils dominates. Transpiration increases with the growing vegetation. Under the conditions of coherent plant cover, transpiration generally prevails. Overshadowing of the soil surface by the vegetative canopy decreases the soil surface temperature and the rate of water vapour removal, thus causing a decrease in the evaporation rate. Transpiration also drops during the period of ripening.

Evapotranspiration is a complicated phenomenon, explicable by a few values only (see Tab. 1.2) complying with the following unevenness

$$ET_l > ET_p > ET_m > ET_o > ET_a > ET_{min} \quad (1.24)$$

Under Central European conditions evapotranspiration by vegetation is generally higher than evaporation from bare soils, but lower than evaporation from open water surfaces. Evapotranspiration from arid zone plants is often lower than evaporation from bare soils. Gilimeroth (1951) and Kramer (1969) state that evapotranspiration from vegetation never exceeds evaporation from saturated soils at the same level of exposure.

1.3.2 Precipitation

The precipitation process is the transfer of water eliminated from the atmosphere system to the system of the hydro- and lithosphere, characterized by an output of the latent heat of vaporization.

The number of different forms of precipitation is very large, but basically precipitation can be

(a) vertical, i.e. precipitation from the upper part of the atmosphere system, characterized by a vertical movement of drops: drizzle, rain, snow, glaze, hail, sleet etc.,

(b) horizontal, i.e. water eliminated by condensation or sublimation on the ground: dew, hoar frost, rime, diamond dust etc.

Depending on its stage of agglomeration, precipitation is either liquid or solid. It is measured in terms of depth (mm), rainfall intensity in terms of mm per minute.

Rainfall is produced by a cooling of the air as the result of a decrease in the barometric pressure, by radiation, by contact with a colder land or sea surface or during mixing of air masses. Condensation of water vapour into cloud droplets takes place on condensation nuclei, formed by hygroscopic salt particles. The falling speed of droplets is a function of their size and of the speed of the air stream. The coalescence of the droplets to form raindrops is accounted for by the coexistence of the ice crystals and water droplets and by the differences in speed between large and small drops. The latent heat of evaporation regulates the process of condensation (Fig. 1.7).

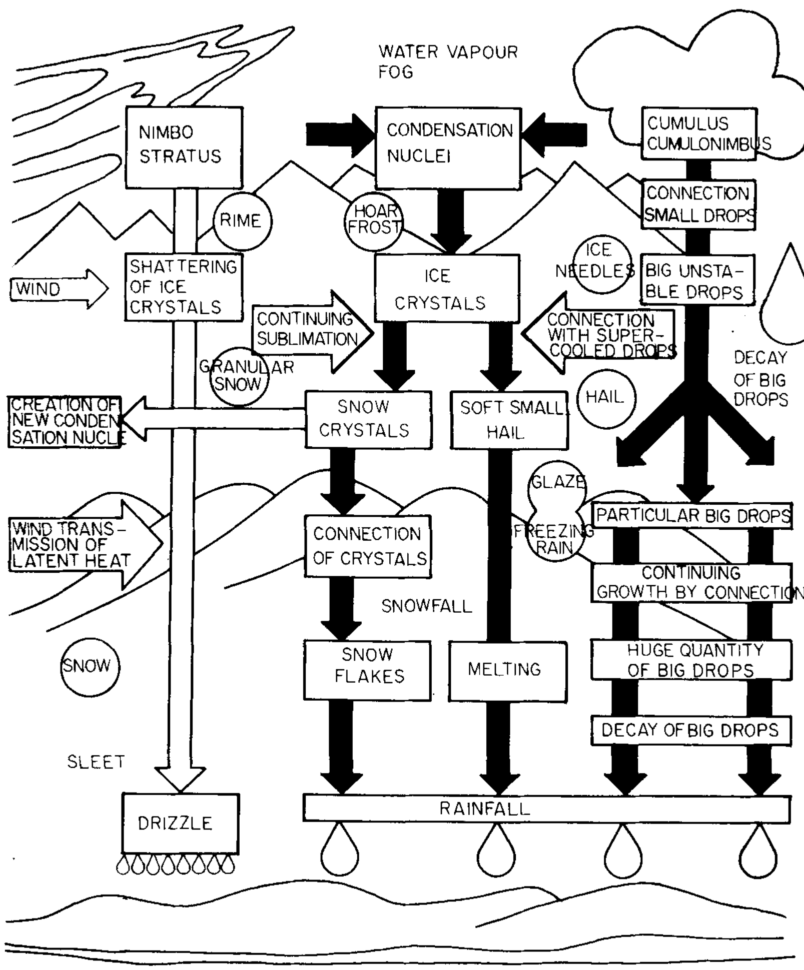


Fig. 1.7. The subsystem of precipitation and its processes in dependence on the altitude according to Mason (1957).

To summarize the tendency of rain to occur in definite patterns, it is possible to distinguish between:

(a) local convective rainfall - caused by the upward movement of air masses,

(b) orographic rainfall - influenced by the morphology of the exposed part of the higher mountain ranges and characterized by longer duration and lower intensity,

(c) cyclonic rain - caused by the air-mass contrast of cold and warm rain, i.e. by the excess of surface heating in lower latitudes and of cold in higher latitudes, characterized by moderate lasting rainfall over a large area, but also by heavy rain, hail or snowfall over a small area.

Rainfall often occurs as a combination of the above mentioned forms. Its occurrence, intensity and frequency depends on zonal, regional and local factors.

The contrast between surface heating in the equatorial and polar zones, or the difference in temperature between the continent and the sea, causes substantial movement of the air, which manifests the homeostasis of this system, i.e. its tendency to achieve a balanced, stable state. This movement of air is influenced by the rotation of the Earth and by regional thermal and orographic factors. Regions with a high horizontal inflow of water vapour and an upward movement of air masses are characterized by frequent precipitation.

The important influence of a region's latitude on the rainfall frequency is evident:

(a) the equatorial zone has the highest annual precipitation on average (50% of the global rainfall occurs between 20^{o} N.L. and 20^{o} S.L.),

(b) areas which have considerable rainfall cover middle and higher latitudes, oceans and the western parts of continents,

(c) areas with passat winds and strips along the tropics are rainless.

(d) polar areas are also rainless, obtaining 4 % of the total global precipitation.

In certain climatic regions, precipitation and its state of aggregation depends to a great extent on the altitude (Fig. 1.8). The increment in the rainfall total, corresponding to the difference in altitude, is the rainfall gradient.

Local factors which influence the spatial distribution of rainfall include geographical and morphological factors, such as the area exposure (to the direction of wind), the characteristic of its surface (roughness, vegetative canopy), and the gradient of the slope. Rainfall intensity, very often unevenly distributed in space and time, decreases on average with the areas affected and with the rainfall duration. The unevenness of the space-time distribution of the rainfall results in a fluctuation of precipitation during the year and in a fluctuation of annual average. During periods of defficient precipitation the deviation from average is greater for river runoff than for rainfall.

The complicated mechanism of precipitation can be influenced in particular by

- changes in the heat input,
- changes in the air mass movement,
- increasing or decreasing the quantity of condensation nuclei.

The result of any of these measures is not explicit, because the relevant interrelationships of the atmospheric system are complicated and a certain feedback exists, such as the atmospheric system's external relations with the hydro- and lithosphere and the solar system, whose energy supply is not uniform.

1.3.3 Interception

Interception is a process of precipitation transmission and redistribution on the boundary of the systems of the atmosphere and the lithosphere by the vegetative canopy. The quantity of precipitation which actually reaches the ground, effective rain- and snowfall, consists of the

- throughfall, which reaches the ground directly through intershrub spaces and drips from the leaves, twigs and stems, and of the
- stemflow which reaches the ground by running down the stems.

Interception loss is the part of precipitation retained by the vegetative canopy and then evaporated or absorbed. Therefore

$$P_e = P - I \qquad \text{(mm)} \qquad (1.25)$$

P_e - net precipitation
P - actual precipitation (above the vegetative canopy)
I - interception loss

$$I = I_1 + I_2 \qquad \text{(mm)} \qquad (1.26)$$

I_1 - interception by the aerial portion of the vegetative canopy

I_2 - interception of the layer of shedded leaves and needles

$$P_e = T + S - I_2 \qquad \text{(mm)} \qquad (1.27)$$

T - throughfall
S - stemflow

Interception loss during one single rainfall consists of the interception capacity of the surface of leaves, twigs etc. and the amount evaporated and absorbed by plants:

$$I = I_o + I_{ea} \qquad \text{(mm)} \qquad (1.28)$$

I_o - interception capacity of leaves, twigs etc.

I_{ea} - interception loss by evaporation and absorption

Absorption of water by plants during one single rainfall is negligible. For this reason Linsley derives the following equation for the interception during one single rainfall:

$$I = I_o + \alpha . ET . t \qquad (mm) \qquad (1.29)$$

α - ratio of the total evapotranspiration and the evaporation from the vegetation surface, depending on the ratio of the vegetative and non-vegetative surface (s^{-1})

ET - evapotranspiration (mm)

t - rainfall duration (s)

The interception capacity depends on the composition of the relevant levels of the vegetative canopy, its morphology and development stage. This capacity, which can be reduced by preceding rainfall, influences the net precipitation in dependence upon the actual rainfall intensity, duration and course as well as upon the wind velocity. An overfulfilling of this interception capacity is characterized by a remarkable increase of stemflow and throughfall (dripping). It goes without saying that the interception loss may exceed the interception capacity.

Zinke (1967) estimates, without including the capacity of the shedded leaves and needles, the average interception capacity of most grasses, trees and shrubs at 1.3 mm during one single rainfall and 3.8 mm during snowfall. He also states that the interception loss is twice as high in 20% of the observed cases. The average interception loss of a certain area depends not only on the composition of the vegetative canopy, its development stage and actual state, but also on the time distribution of the precipitation and the interplay of the rainfall occurrence with the course of temperature, humidity and wind velocity.

1.3.4 Depression and Detention Storage; Overland Flow

The effective precipitation reaching the earth's surface is partly stored

(a) after snowfall as snowpack, whose further effect on runoff depends on energy supply, i.e. on

- radiant heat from the sun
- latent heat of vaporization released by the condensation of water vapour,

(b) by depression storage in surface puddles and by surface detention formed by a sheet of water on the soil surface.

(c) as channel storage in stream channels, ponds, swamps, etc.

Depression storage is not directly measurable and even detention storage is usually derived from hydrograph analysis rather than from observation. Surface runoff usually commences from one part of a catchment area before the interception and depression storages in other parts are satisfied. Detention storage depends on the slope and surface roughness of the area, i.e. on the soil conditions, the vegetative cover and its state. The difference between types of vegetation are caused by the effects of the litter, which appears to be more significant than irregularities in the soil surface.

The surface runoff does not occur whenever the rainfall intensity does not exceed the infiltration and evaporation intensity. In this case the surface runoff does not occur only during the first part of the storm, when the interception, depression and detention storage capacities are not exceeded. As the rain continues, puddles become full and the soil surface becomes covered with a sheet of water and downhill flow begins towards an established surface channel.

A level plain can accumulate 3-18 mm of water, meadows and fields 12-42 mm and forests much more water, which gradually infiltrates and evaporates. When these limits are exceeded, spatially varied unsteady flow during rainfall occurs, in which the rate and depth of flow increase down the length of the flow path. This depth also increases with time, even when the intensity of the rainfall remains unchanged. For these conditions the relationship becomes

$$D_e = K \cdot L \cdot q \qquad (m^3) \qquad (1.30)$$

D_e - volume of detention when equilibrium flow condition is established (m^3)

L - length of flow (m)

q - discharge per meter width at equilibrium $(m^3.s^{-1})$

K - coefficient of rainfall intensity, slope and roughness of the surface

Where steady uniform overland flow is considered (Tab. 1.5), the following relationship between rate of discharge and depth of overland flow can be theoretically derived:

$$Q = K \cdot H^m \qquad (m^2.s^{-1})$$

Q - overland flow $(m^2.s^{-1})$

H - depth of flow (m)

m - coefficient of slope and roughness (involving viscosity,

m = 3 for laminar flow, m = 1.67 for turbulent flow)

1.3.5 Infiltration

Infiltration is a process of unsaturated or saturated flow during the movement of water into the pedo- and lithosphere, detructing the soil water and groundwater from the net precipitation. Water tries to achieve a state of minimum energy in these systems and moves from levels of higher energy to levels of lower energy.

Saturation depends on the porosity of soil or rock and the moisture content. When the moisture content is smaller than the porosity, the flow is unsaturated. When it equals the porosity, the flow is saturated. Its rate depends on the effective porosity, which is usually expressed as a percentage and defined by

$$n = \frac{V_v}{V_o} \cdot 100 \qquad (\%) \qquad (1.30)$$

n – effective porosity (%)

V_v – volume of water governed by gravity forces in the saturated soil or rock (i.e. the volume of all connected effective pores and voids) (m^3)

V_o – total volume of the soil or rock (the volume of all pores and voids plus the volume of all the grains and solids) (m^3)

The effective porosity is a part of the total porosity which enables the gravitational movement of water. It depends on soil texture and structure (grain-size distribution, mutually connected pores and cracks etc.) Infiltration also depends on the state of the soil surface incl. density of vegetation, moisture distribution in the soil layer, the air content in non-capillary pores, the temperature, the depth of the groundwater table and the intensity of the rainfall (high intensity rainfall causing compaction of the surface level).

The infiltration rate is the maximum rate at which the soil can absorb precipitation in a given condition. The initial high rate of infiltration decreases exponentially: rapidly at the beginning and then more slowly until it approaches a constant rate after a period of 20 to 120 minutes.

Philip (1958) expresses the actual infiltration rate by the formula

$$v_i = \frac{1}{2} \cdot S \cdot t^{-\frac{1}{2}} + v_k \qquad (m.s^{-1}) \qquad (1.33)$$

v_i – actual infiltration rate ($m.s^{-1}$)

S – sorptivity (m.s)

t – time of the beginning of infiltration (s)

v_k – final stable infiltration rate ($m.s^{-1}$)

Sorptivity can be defined by the equation

$$S^2 = 2\, k_f' \cdot (\mathfrak{R} + H) \cdot (W_o - W_i) \qquad (m^2.s^{-1}) \qquad (1.34)$$

k_f' – coefficient of the hydraulic (unsaturated) conductivity

$$k_f' = \frac{k_f \cdot W^3}{n^3} \qquad (m.s^{-1}) \qquad (1.35)$$

$\mathfrak{R}$ – soil characteristic (m)

W_o - final moisture content (%)

W_i - moisture content at the beginning (%)

H - depth of groundwater table (m)

Philip (1969) expresses the total value of infiltration by the sequence in which the first two component prevail

$$W_n = S \cdot t^{\frac{1}{2}} + v_k \cdot t \quad \text{(mm)} \qquad (1.36)$$

W_n - infiltration total (mm)

The following processes of unsaturated subsurface flow are interconnected with the infiltration

- redistribution, when soil water enters the layers with lower moisture content,
- percolation, when water leaves the saturated soil layers and enters the groundwater,
- capillary rise, when the moisture of the upper layers is supplemented from the lower ones, or from the groundwater.

1.3.6 Subsurface Water Movements

Subsurface water forms the subsurface hydrosphere in the heterogeneous environment of the soil and hydrogeological structures, which occurs in different forms (Tab. 1.5). The subsurface hydrosphere is formed by:

- soil water, occurring in the upper 2-4 m layer on the boundary of the atmosphere and the lithosphere. Water is retained in soil by surface-tension forces, which are molecular (electrical) by nature, i.e. other than those of gravity. The outflow of free water from soils occurs only if the pressure in the soil water exceeds the atmospheric pressure. Soil water is, therefore, unsuitable for water extraction, but indispensable for the photosynthesis of all plants.
- groundwater in the permeable formations of the Earth's crust, retained especially by gravitational forces and, therefore, usable for extraction (Fig. 1.8).

Permeable geological formations are known as aquifers and water occurs in their internal void space, forming

(a) voids or pores, i.e. subtle, microscopic spaces, which originated simultaneously with the associated rocks,

(b) cracks, i.e. breaches and other generally multi-directional spaces of secondary, tectonic origin,

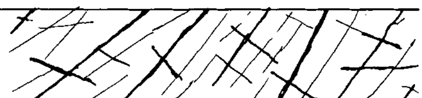
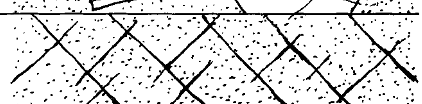
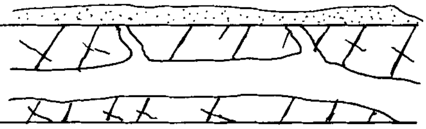
(c) cavities, or spaces of exceptional dimensions, originating mainly in carstic formations.

TABLE 1.5

Form	Prevailing forces	Occurrence	Movement
Water vapour	pressure	gaseous state	by pressure gradient, wind power
Ice, snow	gravity	solid state	by gravity, in soil after heat input
Gravitational	gravity	earth surface, pores, fractures, cavities	by gravity and tidal forces, pressure, osmotic and temperature gradient
Capillary	surface tension	- suspended - supported - no contact with gravitational	held in the interstices, available for plants
Adsorbed	attractive (surface potential)	hygroscopic viscous	oven-drying at 105°C
Structural	molecular	crystallic chemically combined	after disintegration/integration
	biochemical	biological	after disintegration

Modes of water occurrence above and under the ground.

TABLE 1.6

Types of interstices	Graphical interpretation
fractures-fractures	
fractures-pores	
pore-fractures	
pores-pores	
pores-cavities	
fractures-cavities	

Categorization of combined permeability according to Landa (1980).

Part of the water infiltrated into the soil flows laterally at shallow depths as interflow owing to less pervious lenses below the soil surface.

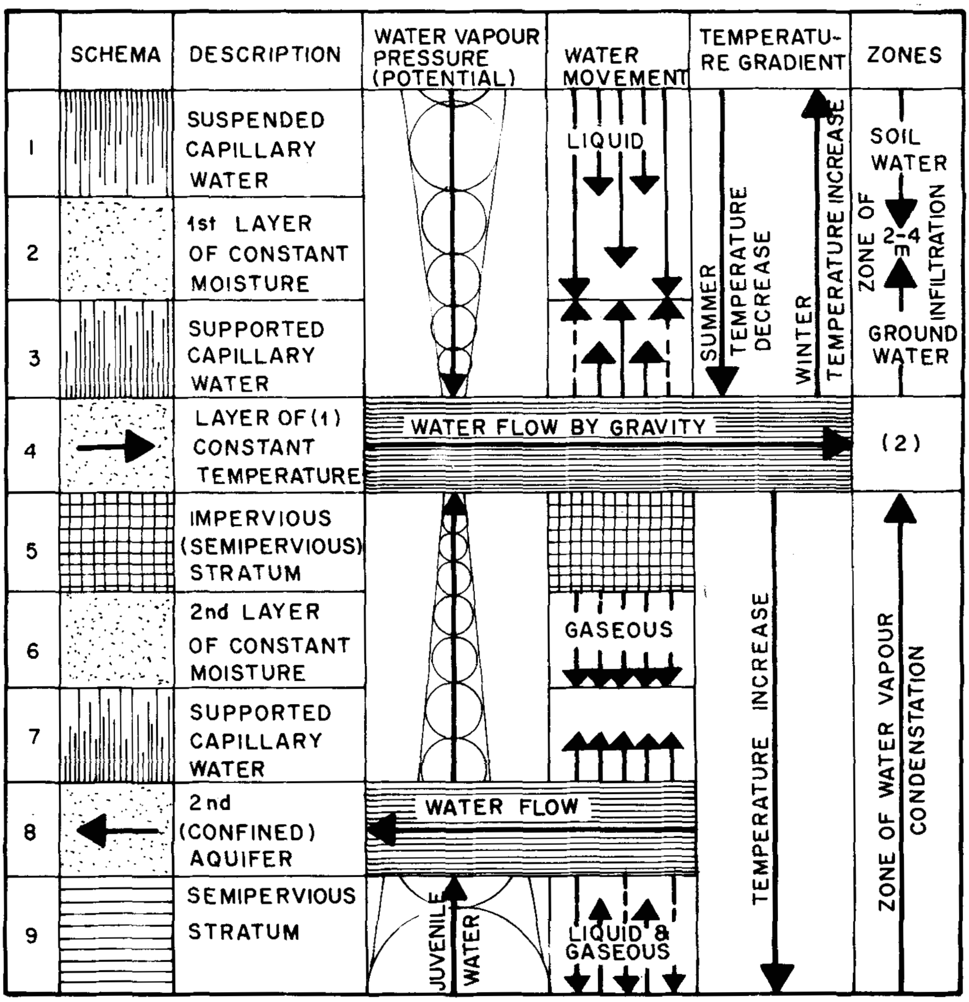


Fig. 1.8. Schematic representation of a characteristic arrangement of groundwater strata. (1) 1st (unconfined) aquifer, (2) depends on geographical length and geological structure. The size of circles is proportional to the pressure (potential).

Voids, cracks and cavities form extremely complicated underground spaces, which are separated or interconnected and which communicate effectively or non-effectively. Water in these internal spaces, whose permeability is combined (Tab. 1.6), is influenced by

(a) gravity - acting as the water weight, - acting as the pressure of surrounding geological formations,

(b) pressure of gases emitted by the water

(c) surface-tension forces (capillarity)

(d) molecular forces of the soil or rock particles (hygroscopic forces etc., primarily electrical in nature)

(e) osmotic forces, caused by the different quality (chemical composition) of water in different parts of the geological formations.

Unless these forces are in a state of equilibrium, groundwater is in movement and also influenced by

(f) friction forces, caused by the roughness of the surface of the soil or rock particles,

(g) internal friction forces caused by the fluid viscosity.

The flow in mutually communicating voids, cracks and cavities is in detail non-uniform and unsteady. For practical purposes it can be considered as uniform and steady on average. For groundwater movement Darcy's law is applicable within the laminar range of flow where resistive forces govern flow and the soil/rock environment is saturated

$$v_f = \frac{Q}{A} = k_f \cdot I \qquad (m.s^{-1}, \text{ m per day}) \qquad (1.37)$$

v_f - apparent velocity of flow

Q - flow rate $(m^3.s^{-1}, m^3$ per day$)$

A - cross-sectional rate

$I = \frac{dh}{dL}$ - hydraulic gradient

k_f - coefficient of hydraulic conductivity (Tab. 1.6)

As velocity increases, inertial forces change the linear relation to the apparent velocity of flow at the hydraulic gradient to the

$$v_f = k_f \cdot I^{\frac{1}{m}} \qquad (m.s^{-1}, \text{ m per day}) \qquad (1.38)$$

m - coefficient $\rightarrow 2$

Similar equations can be derived for unsaturated flow

$$v_f = - k'_f \cdot \text{grad}\,\Psi \qquad (m.s^{-1}, \text{ m per day}) \qquad (1.39)$$

$\text{grad}\,\Psi$ - gradient of the total potential of the groundwater

k'_f - coefficient of the unsaturated flow $(m.s^{-1})$

TABLE 1.6

Soil	Coefficient of hydraulic conductivity k_f ($m.s^{-1}$)	Capillarity (mm)	Average porosity
Clay	1.10^{-8}	2000 - 4000	50 - 95
Silt	$5.10^{-6} - 1.10^{-7}$	700 - 1500	40 - 60
Compacted loamy sand	$1 - 5.10^{-6}$	350 - 700	15 - 25
Fine and loose sand	$1 - 5.10^{-5}$	50 - 350	20 - 45
Coarse sand	$1 - 5.10^{-4}$	10 - 50	25 - 35
Sandy gravel	$2.10^{-4} - 1.10^{-3}$	-	20 - 40
Clean gravel	1.10^{-2}	-	25 - 35

Coefficients of hydraulic conductivity and average porosity and capillarity of different soils.

The total potential of the groundwater is the amount of energy needed to transfer a unit of water quantity from one place in the system water-rock/soil to another one:

$$\Psi = \sum \Psi_k = \Psi_k \cdot F_k \cdot dl \qquad (J\,.kg^{-1} = m^2.s^{-2}) \qquad (1.40)$$

Ψ - total potential of water in the force field $(J.kg^{-1})$

F_k - unit force of the force field $(N.kg^{-1})$

dl - distance

On the basis of the definitions and formulas in Tab. 1.7, the total potential of groundwater under isothermic conditions is

$$\Psi' = g\,.\,(x+z) + \frac{1}{\delta}\,.\,(\Delta P - \delta) \qquad (J.kg^{-1}) \qquad (1.41)$$

The groundwater movement is spatial in character. Depending on the governing potential, the regime of flow can be

(a) hydrodynamic - where gravitational and pneumatic forces are governing,

(b) hydrothermal - where the difference in temperature is governing,

(c) hydrochemical - where osmotic forces are governing.

The hierarchy of these groundwater movement regimes is interconnected with the values of the associated potentials, which used to be remarkably different. The regime of groundwater flow depends on the homogeneity of the geological formations. The ratio of permeability of the relevant formations and their integrated parts influences the creation of the flow regime. Several regimes e.g. local, areal and regional, can occur in a heterogeneous environment (Fig. 1.9).

TABLE 1.7

Symbol	Potential	Forces	Equation	Explanatory notes
Ψ_g	gravitational	gravity	$\Psi_g = g.dz = g.z$	g - gravitational constant z - head (m)
Ψ_c	capillary	capillarity	$\Psi_c = g.x$	x - capillary rise
Ψ_p	pneumatic	pressure gradient of soil gases, atmospheric	$\Psi_p = \frac{1}{\gamma}.\frac{\partial p}{\partial l} . dl = \frac{1}{\gamma}. \Delta P$	γ - unit weight of water ($kg.m^{-3}$) ΔP - pressure gradient ($Pa = kg.m^{-1}.s^{-1}$)
Ψ_t	thermic	water density gradient	$\Psi_t = \frac{1}{\gamma} .\Delta T$	ΔT - temperature gradient
Ψ_o	osmotic	difference in chemical composition	$\Psi_o = \frac{1}{\gamma} . \delta$	δ - osmotic pressure (Pa)

Categorization of soil water potential.

The function of different forces in the heterogeneous system of hydrogeological formations depends on external factors, including

- climatic and meteorological factors,
- surface run-off,
- variations and oscillations in the interconnected surface water levels of water courses, reservoirs, lakes and seas,
- external load.

Where the surface water is not in contact with an unconfined aquifer, the precipitation produces the governing influence. Seasonal variations in rainfall and changes of groundwater in storage, manifestated by changes in groundwater tables, are closely correlated. This correlation is heavily influenced by the surface run-off: the groundwater recharge depends on the rainfall intensity and distribution. The same monthly averages may produce different fluctuations in the water table.

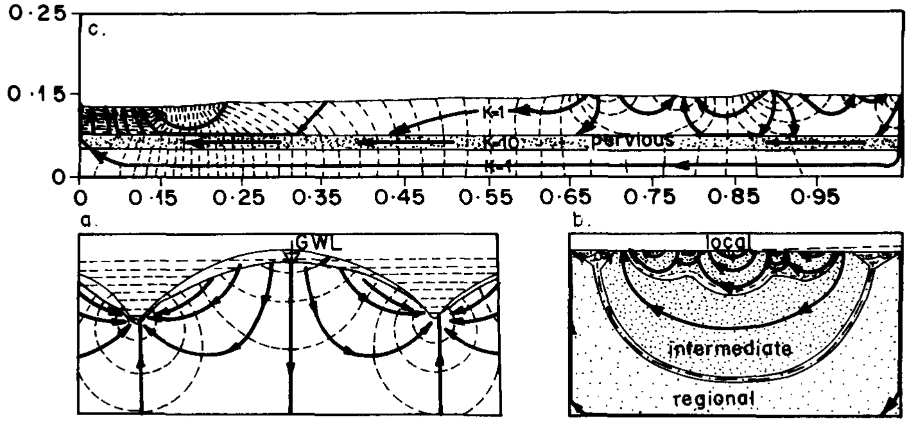


Fig. 1.9. Regional flow of groundwater (flow direction marked fully, equipotentials dashed, system boundaries dash- and dotted): a - homegeneous permeable strata according to Hubbert (1940), b - homogeneous isotropic strata according to Toth (1962), c - heterogeneous strata according to Freeze, Witherspoon (1966): local regimen dotted densely, intermediate medium, regional regimen dotted scarcely.

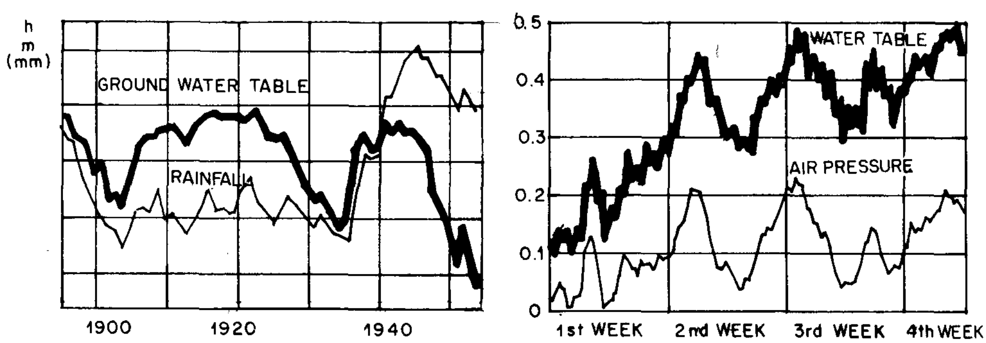


Fig. 1.10. Reduction of values and time delay of groundwater fluctuation in relation to the rainfall occurrence (deviation from the average) according to Todd (1970). Relationship of the air pressure and the water table fluctuation in an artesian well according to Robinson (1939).

Atmospheric pressure has no effect on unconfined aquifers. In the case of confined aquifers, increases in atmospheric pressure cause a decrease in water tables and vice versa (Fig. 1.10):

$$\Delta h = \eta . \Delta p_a \qquad \text{(m)} \qquad (1.42)$$

Δp_a - change in atmospheric pressure (m of water)

Δh - water level decrease or increase

1.3.7 Flow in Channel Network

Overland flow is gradually concentrated by the topography of the Earth's surface. Flow in natural channels whose profile and head is not stable due to erosion and siltation is generally non-uniform and unsteady. The discharge and the medium average velocity are functions of time and space.

The discharge in natural channels can for practical purposes be considered as gradually varied. In this case, the total head Δh at a channel section can be expressed as

$$\Delta h = \frac{v_s^2 \,.\, L \,.\, n^2}{R} + \frac{(v_2^2 - v_1^2) \,.\, k}{2g} \qquad (1.43)$$

$$v_s = \frac{v_1 + v_2}{2} = \frac{R^{\frac{2}{3}}}{\sqrt{2g.L}.n} \cdot \left[2g.\,\Delta h + k(v_1^2 - v_2^2)\right]^{\frac{1}{2}} \quad (m.s^{-1}) \qquad (1.44)$$

Δh - total head at a channel section (m)

v_1, v_2 - mean velocity in the upper and lower profile $(m.s^{-1})$

L - length of the channel section (m)

R - hydraulic radius ($= \frac{A}{0}$) (m)

A - area of the cross section (m^2)

0 - wetted perimeter (m)

k - reduction coefficient (≤ 1)

n - coefficient of channel roughness (smooth 0,01, variable sections 0,05)

Under conditions of a stable profile, uniform slope and roughness in a channel without barriers, the equation (1.43) can be simplified as follows

$$v_s = \frac{1}{n} \,.\, R^{\frac{2}{3}} \,.\, I^{\frac{1}{2}} \qquad (m.2^{-1}) \qquad (1.45)$$

$I = \frac{\Delta h}{L}$ - slope of the channel

The roughness coefficient depends on geomorphological conditions: the riverbed material, the unevenness of its surface, the character of the profile changes, the barriers in the riverbed, the riverside vegetation, the meandering and sediment transport (Tab. 1.8). The total roughness coefficient can be assessed on the basis of the supplemented formula of Cowan (1957)

$$n = m \,.\, s \,.\, \sum_{k=1}^{4} n_k \qquad (1.46)$$

TABLE 1.8

Coefficient of	Characteristics	Value	Coefficient of	Characteristics	Value
n_1 material roughness	earth rock fine gravel coarse gravel	0,020	n_4 barriers	negligible small medium high	0,000–0,010 0,010–0,015 0,020–0,030 0,040–0,060
n_2 bed roughness	smooth, plain small ripples medium ripples dunes	0,000 0,005 0,010 0,020	n_5 vegetation canopy	low medium high high and dense	0,005–0,010 0,010–0,025 0,025,0,050 0,050,0,100
n_3 cross section changes	gentle occasional frequent	0,000 0,005 0,010 -0,015	m meandering	low medium high	1,000 1,150 1,300
			s sediment transport	low high muddy discharge	1,000 1,500 2 - 100

Partial coefficient for estimation of the roughness coefficient for various boundaries according to Cowan (1957) supplemented by the coefficient of the sediment transport impact.

1.4 INTERRELATIONS OF SURFACE WATER AND GROUNDWATER RUNOFF

Runoff is a hydrologic process of rainfall distribution by the Earth's surface, which takes place in the system of the litho- and hydrosphere. This system consists of natural (morphological, geological, soil, vegetative) and anthropogenetic elements (urban, rural and other constructions, dykes, reservoirs, drainage and sewerage networks etc.). The output of this system depends on the input, which is characterized by

(a) meteorological data, especially rainfall distribution

(b) climatological data, or the supply of solar energy,

and on the actual state of this system, which depends on its previous function (degree of saturation) and anthropogenetic factors (water management activities).

Under natural undisturbed conditions, the surface outflow can be characterized by meteorological and climatological factors (Tab. 1.9).

Surface runoff equals precipitation minus interception, depression and detention storage, changing into infiltration and evaporation. The ratio of the sur-

TABLE 1.9

Category	Area (climate)	Sub-category	Characteristics of discharge occurrence
A. Rivers whose flow depends mainly on rainfall	arid and semiarid	1.	discharges only in rainfall periods
		2.	high discharges in winter, extremely low in summer
	tropical and subtropical	3.	high discharges during summer
	humid	4.	high discharges out of the summer season
B. Rivers whose flow depends mainly on snowmelt and glacier run-off	cool humid	1.	peak discharges especially in spring, influenced by rainfall
	hilly, northern	2.	high discharges influenced by rainfall
	high mountains	3.	high discharges from snowmelt in summer
	permafrost	4.	temporary streams downstream of glaciers

Categorization of rivers according to meteorological and climatological factors.

TABLE 1.10

Type of area			Slope	
		flat 1%	average 1-5%	steep 5%
Residential Appartment dwelling	closed blocks paved courts	0.70	0.80	0.90
	closed blocks with yards	0.60	0.70	0.80
	open blocks	0.50	0.60	0.70
	detached multi-units	0.40	0.50	0.60
Single-family houses with gardens	attached	0.30	0.40	0.50
	detached	0.20	0.30	0.40
Industrial	old type densely covered	0.60	0.90	-
	modern with laws	0.40	0.50	-
Parks, cemeteries, playgrounds		0.10	0.20	0.30
Streets, drives, walks, roofs		0.70	0.80	0.95
Railway areas		0.20	0.30	0.40
Unimproved areas		0.10	0.20	0.30
Grassland, fields	sandy soil	0.05	0.10	0.15
	heavy soil	0.17	0.22	0.35
Forests		0.00	0.05	0.10

Values of runoff coefficient in relation to the type of the drainage area.

face runoff and total losses (recharge and evaporation) does not change when the state of the elements and the energy supply into the system remains constant. For practical reasons this ratio is considered as stable even in the case of a single rainfall. Such hypothesis leads to the following simplified equations for each of the elements i:

$$Q_{si} = P_{gi} - (I_i + D_i) = P_i - (R_{gi} + E_i) \qquad (m^3) \qquad (1.47)$$

$$\frac{Q_{si}}{R_{gi}+E_i} = k \qquad (1.48)$$

and for the total area

$$Q_s = 1000.\sum_{i=1}^{n} C_i \cdot P_i \cdot A_i \qquad (m^3) \qquad (1.49)$$

Q_s - surface outflow (m^3)

G_g - groundwater/soil recharge (m^3)

P_i - precipitation in element i (mm)

C_i - runnoff coefficient of element

A_i - area of element (km^2)

This simplification neglects the time distribution of the input data and the changing state of the runoff system. The actual runoff coefficient is not stable, it is not only a function of the drainage area roughness r (which changes e.g. with the season), its shape and slope i, geology g but also a function of the soil state

$$C = \Phi\,(\, r\ ,\ i\ ,\ g\ ,\ s_f\,) \qquad (1.50)$$

Factors r, i, and g are relatively stable and are almost independent of meteorological conditions. Factor s_f depends on frost and saturation of soil. It determines the actual runoff in the specific hydrologic situation.

The total annual runoff can be determined on the basis of the climatological input data. Data on the left side of the simplified equation of the hydrologic balance i.e. precipitation P and surface runoff Q_s

$$P - Q_s = G_g + E \qquad (mm, m^3 \text{ per year}) \qquad (1.51)$$

can be measured quite easily and precisely. They are in most cases measured in the long term and systematically, and also analyzed statistically. Data on evaporation E and groundwater recharge G_g, on the right side of the equation, are difficult to measure and, therefore, not systematically followed up. Groundwater recharge and evaporation can be expressed as a function of the left side of the equation 1.51

$$E = f_1 \ (P - Q_s \ ) \qquad (mm,m^3) \qquad (1.52)$$

$$G_g = f_2 \ (P - Q_s \ ) \qquad (mm,m^3) \qquad (1.53)$$

The maximum possible evaporation for the measured long-term difference of rainfall and the surface runoff is

$$E_m \ = P - Q_s \qquad (mm,m^3) \qquad (1.54)$$

In this case $G_g = 0$, the groundwater is without recharge.

This phenomenon occurs in desert catchment areas, where all the infiltrated water evaporates. This can be graphically illustrated by a straight line with an angle of 45^o (Fig. 1.11).

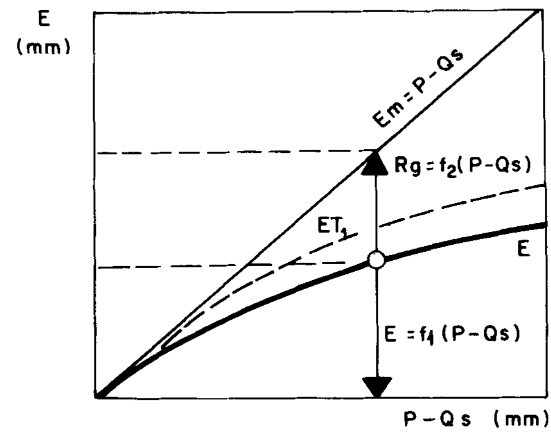


Fig. 1.11. Regional characteristics of the runoff: E - evaporation, ET_1 - evaporativity, P - rainfall total, G_g - groundwater recharge, Q_S - surface water runoff.

The second limiting stage could theoretically be reached when the difference of rainfall and surface runoff recharges the groundwater without any evaporation. This case is graphically illustrated by the horizontal axis. The practical values of the function f_1 migrate between these two limiting stages. They are also limited by the ET_1 value of potential evaporation corresponding to the supply of solar energy in the area. Curves f_1 and f_2 express the average influence of the input data of the relevant runoff system and can, therefore, be used as regional characteristics for the assessment of the groundwater runoff and evaporation.

The system of the rainfall/runoff process can be modelled on a physical or mathematical basis. The basis of the mathematical Tank Model assembled by SUGAWARA (1974) is hydraulic. This model represents the catchment area by a set of tanks, arranged vertically in a row. The number of tanks, their grouping and configuration depend on the catchment characteristics. Experience shows that the following two basic systems are suitable for any practical case

(a) four tanks arranged vertically for humid areas,

(b) several rows of four tanks arranged vertically for semi-arid and arid areas.

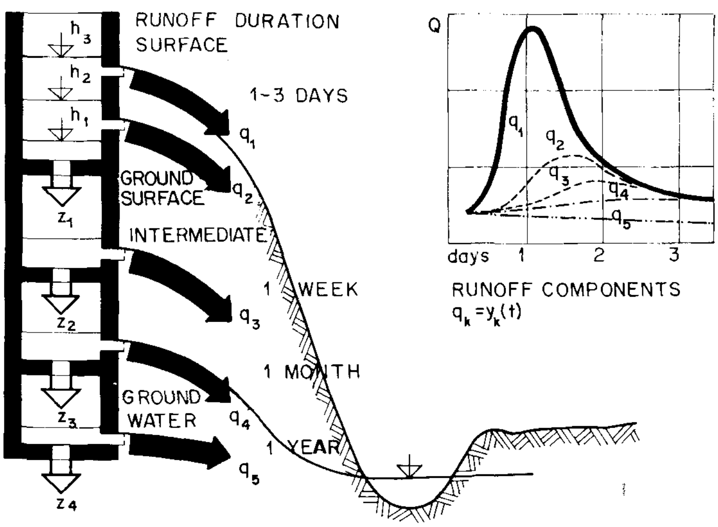


Fig. 1.12. Separation of the runoff components, its course and physical principles of the mathematical model of the runoff process according to SUGAWARA (1974): q_1 - surface runoff, q_2 - ground surface, q_3 - intermediate outflow (above the groundwater table), q_4 - groundwater runoff with short-term and q_5 - with long-term delay before penetration into the river, z_1 - infiltration, z_2, z_3 - percolation into groundwater, z_4 - deep percolation. Water tables: h_1 - at low, h_2 - at medium, h_3 - at high rainfall.

Tanks are equipped with side outlets and bottom outlets. The outflow from the side outlets simulates the following components of the surface runoff (Fig. 1.12):

- the top tank the surface and ground surface runoff, reaching the channel in one to three days,
- the second tank the intermediate runoff, reaching the channel in a week's time.
- the third and fourth tank the groundwater runoff, reaching the channel in one month, or in a year's time.

The top tank generally has two side outlets, while the other tanks are equipped with one side outlet only. The bottom outlets of all tanks simulate the infiltration or, in the case of the fourth tank, the deep percolation. The outflow from outlets is simply expressed by a linear or square relation on the storage amount:

$$q_k = \alpha_k \cdot X_k = f_k(t) \qquad (m^3.s^{-1}) \qquad (1.55)$$

q_k – outflow from the outlet $(m^3.s^{-1})$

X_k – storage amount (m^3)

α_k – outlet coefficient (s^{-1})

The following simple square relation is used whenever the linear relation does not generate satisfactory results:

$$q_k = \alpha_k \cdot X_k^2 = F_k(t) \qquad (m^3.s^{-1}) \qquad (1.56)$$

The nonlinear course of the output data is a consequence of a summarization of the partial results:

$$Q = \sum_{k=1}^{k} q_k = \sum_{k=1}^{k} \alpha_k \cdot X_k \qquad (m^3.s^{-1}) \qquad (1.57)$$

Low rainfall, not filling up the top tank up to the first side outlet, does not produce any runoff. Short floods with a rapid increase in discharge can be modelled more precisely by using more side outlets in the top tank: The saturation of the soil layer can be expressed by a restriction of the bottom outflow. Evaporation produces the decrease in the storage amount in the first tank. The number of tanks, their equipment and arrangement represent the behaviour of the catchment area. This arrangement has to be calibrated to achieve the desired relation of the input and collected output data.

Catchment areas in semi-arid and arid regions have to be divided into zones and represented by several rows of vertically grouped tanks. Evaporation in the period without precipitation has to be modelled by a space without an outlet in the top tank. Deformations of the discharge by river channels can be modelled by similar tanks.

The Tank Model is able to extend runoff data series or to complete missing data by simulation. The most important act to achieve the required accuracy is the assessment of mean precipitation: areal fluctuations in precipitation are high, both in small and large catchment area.

Purely mathematical models of the rainfall/runoff process can be derived from equations describing the physical substance of the hydrological process (Fig. 1.13, 1.14) and the hydrologic balance. Input data for such a model include rainfall records, catchment and meteorological characteristics, while the output data cover surface and groundwater discharges, i.e. entry data for the erosion process (Fig. 1.22).

Mathematical simulation models require detailed information about numerous coefficients (Fig. 1.14), which is very seldom available in the precise form required. These models are deterministic, but a stochastic approach has to be adapted to make them function reliably.

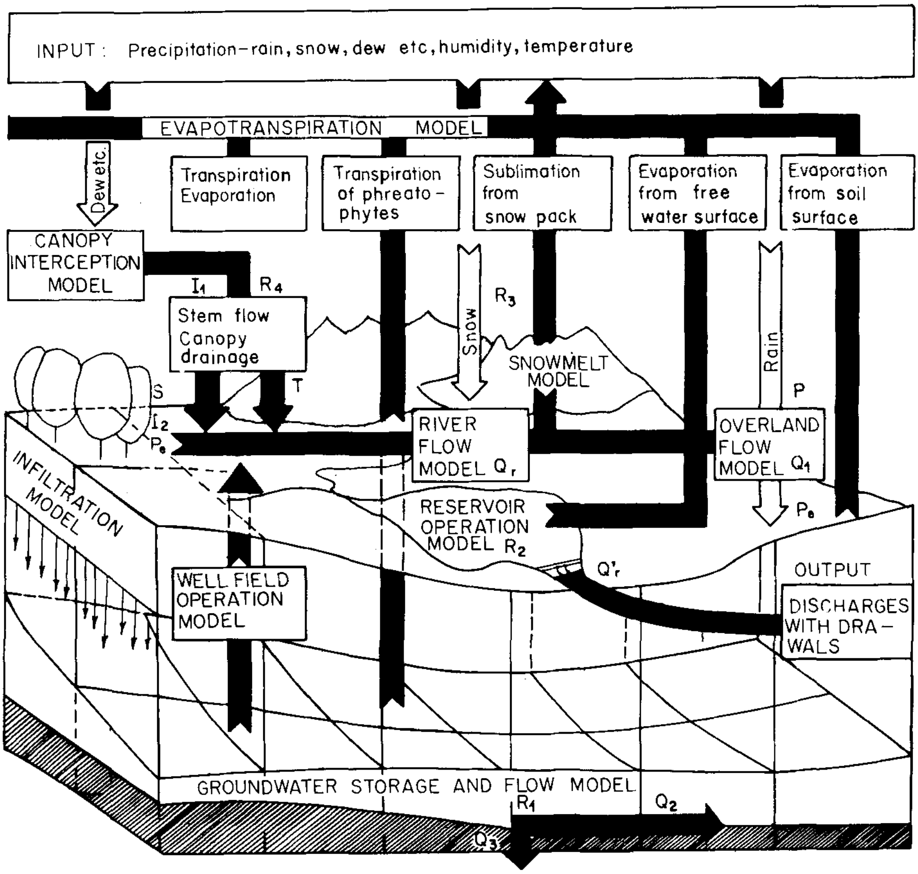


Fig. 1.13. Schematic representation of the model components of the hydrological cycle in rectangular grid: evaporation and canopy interception model, snowmelt (layered) and oveland flow model (two dimensional), river flow and reservoir operation model, root zone infiltration and recharge model (layered, one dimensional unsaturated flow for each grid element), groundwater model (layered, storage and saturated flow).

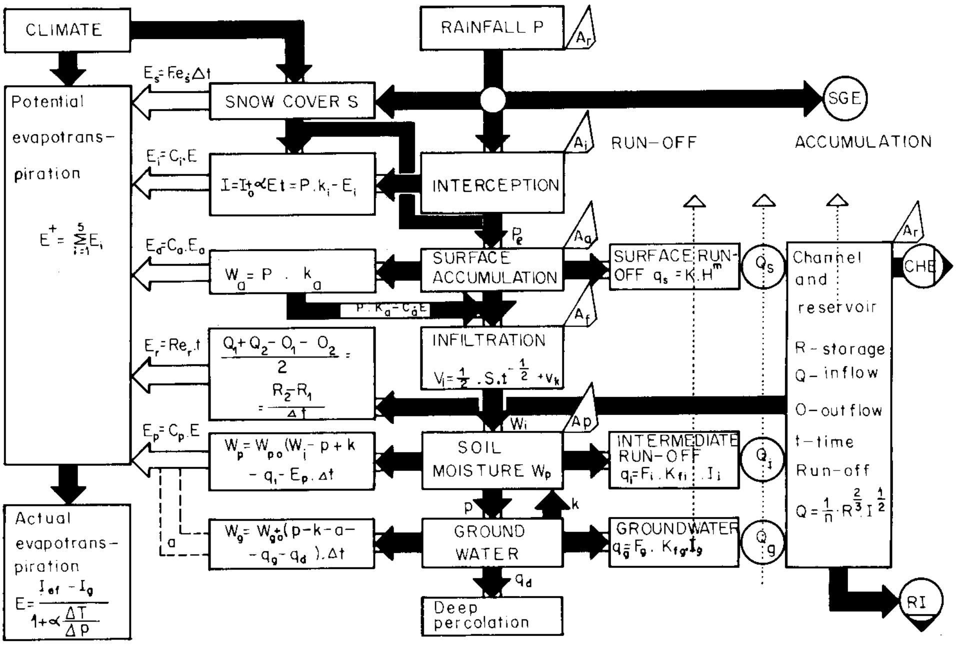


Fig. 1.14. Mathematical model of the water cycle. Explanation of main equations is given in text. Outputs of the run-off process form inputs of the erosion process model (Fig. 1.24). SGE - sheet/gully erosion, CHE - channel erosion, RI - recharge/infiltration, A_r, A_i, A_a, A_f, A_p - anthropogenetic factors.

1.5 GROUNDWATER LEVEL REGULATION, SOIL MOISTURE AND SOIL STRUCTURE FORMATION

Groundwater flow into streams/reservoirs, or vice-versa, depending on the relative altitude of the relevant water levels. In this case of the higher surface water level, infiltration i.e. water supply to aquifers occurs. Under conditions of the lower surface water level groundwater which drains into a stream forms its base flow.

Changes in this regime of infiltration or drainage can occur with time as stream or groundwater level shift (Fig. 1.15). The low rate of groundwater flow causes a shift in time and a reduction in the values of groundwater table fluctuation. The filtration results in a gradual improvement of the quality of the infiltrated water.

The period of progression of the groundwater into the stream channel/reservoir depends on the coefficient of hydraulic conductivity, effective porosity, distance and head

$$t > \frac{n_e \cdot L^2}{k_f \cdot h} \qquad \text{(days)} \qquad (1.58)$$

t - period of progression (days)

n_e - effective porosity (%)

L - shortest distance from the stream channel (m)

k_f - coefficient of hydraulic conductivity (m per day)

h - head (m)

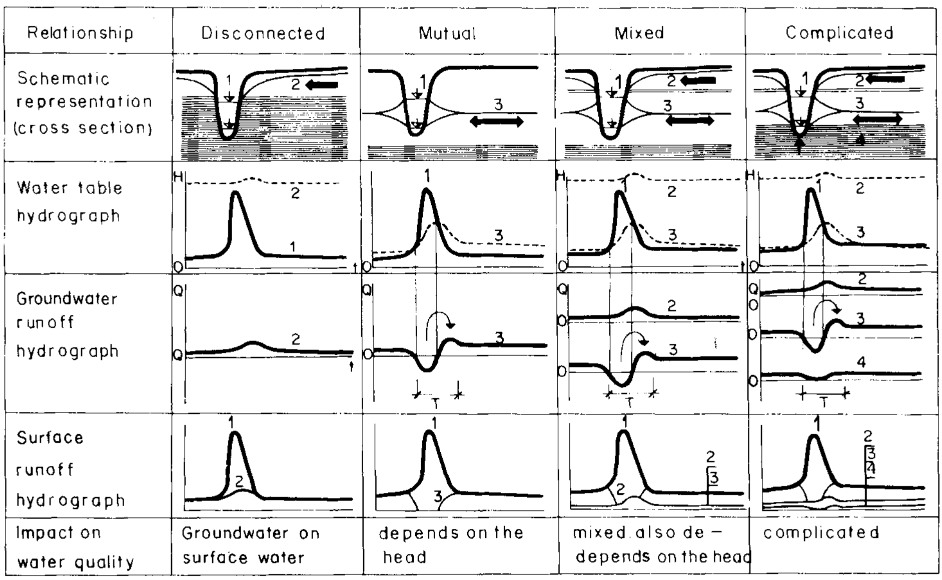


Fig. 1.15. Interrelationships of runoff, water tables and quality of the groundwater. Water tables: 1 - water course, 2 - independent aquifer, 3 - aquifer dependent on the stream, 4 - confined aquifer.

The direction of the flow between the surface and the groundwater influences the water quality: intruding water changes the water quality of the effluent. Both processes, and especially infiltration, the process of surface water penetration into the groundwater can be slowed down by clogging, i.e. the blocking of pores and cracks by suspended matter. During drainage, a reverse process occurs, suffusion, which gradually speeds up the groundwater movement.

Soil moisture, which is of basic importance for the water supply of plants, is less supplemented by groundwater than by precipitation. Gravitational potential is less important for its exploitation by plants than the capillary and osmotic forces, whose function can be measured as the total soil suction. This total soil suction consists of the matric suction, numerically equal to the capillary pressure, and the solute suction, numerically equal to the osmotic pressure. These depend on the soil texture and structure, on the interconnection of pores and cracks, on the chemical properties and temperature of the soil and water, but especially on the moisture content expressed by the ratio

$$w = \frac{V_w}{V_o} \cdot 100 \qquad (\%) \qquad (1.59)$$

w - moisture content (volumetric)

V_w - total volume of water in pores and voids (m^3)

V_o - total volume of the rock or soil (m^3)

The relationship of the moisture content and the total soil suction has to be expressed using the natural logarithm

pF = ln of the total soil suction = 3 + 981 Pa (mm of water) (1.60)

(Tab. 1.11)

TABLE 1.11

Hydrolimits	Suction pressure pF	Moisture content %	Definition
Full capacity (saturated)	0	25-60	State in which pores and cracks are filled up with gravitational and other water. Corresponds to the capillary porosity.
Field capacity FC	2.5-3.0	10-40	State in which water is held in the soil after the gravitational water has drained away.
Point of decreased availability	3.1-3.5	4-35	State in which the capillary conductivity was interrupted.
Wilting point WP	4.18	2-30	State in which evapotranspiration exceeds the water input (depends also on the plant species).
Adsorption water capacity	4.8-5.2	1-15	State in which the soil does not contain either gravitational or capillary water.

Categorization of soil state according to its suction pressure and moisture retention from plant cultivation.

The changing soil moisture and the total suction pressure form characteristics intervals. On the boundaries of these intervals the water supply of the plants changes in a way which qualitatively influences the development of the plants. The centre of these intervals has a characteristic value of the total soil suction and moisture, depending on the soil category (Fig. 1.16).

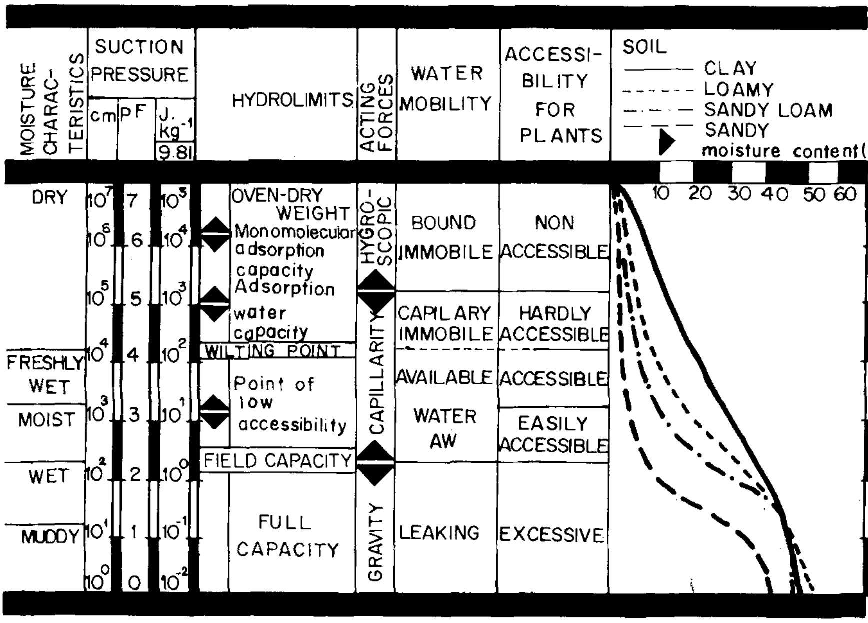


Fig. 1.16. Interrelations of the soil porosity and humidity with the suction pressure, potential and soil moisture retention data according to Kutílek (1979).

The water regime of soils depends on

- soil category, its texture, structure and permeability, characterized by the coefficient of the hydraulic conductivity, or by the course of the total soil suction,
- the position of the soil profile with regard to the groundwater level and the reach of the capillary zone,
- the root system of the plants,
- anthropogenetic factors, including especially changes in the soil texture, structure and moisture during its exploitation,
- climatological characteristics.

Rode (1956) classifies the water regime of soils on the basis of the annual ratio of the rainfall and evapotranspiration (Tab. 1.12). It is useful to add the swampy regime to this classification, which occurs when the water level permanently penetrates above the soil surface. The gradual development of soil is interrelated with the water regime and the action of climatological factors (Tab. 1.13).

TABLE 1.12

Regime	Characteristics	Ratio of annual precipitation and evaporation total
1. Permafrost	The soil water is permanently frozen	>1
2. Flushing	The soil is completely wetted several times a year	>1
3. Intermittent	Soil is not flushed every year	$\doteq 1$
4. Unflushed	Infiltration does not recharge groundwater reserves, the soil profile being only partially wetted	<1
5. Evaporative	Soil profile moisture is supplemented from groundwater	<1
6. Irrigation	Soil regularly wetted by irrigation	<1 $\frac{P + I}{E} \geqq 1$
7. Marshy	Capillary rise permanently reaches the soil surface, oversaturated by groundwater	-

Categorization of soil water regimes according to the ratio $r = \frac{P}{E}$ of the average annual precipitation total P and annual mean evaporation total E according to Rode (1956). I - annual irrigation rate

TABLE 1.13

warm °C

increase in temperature (↑)

<table>
<tr><td>Sierozem & desert soils</td><td>Chestnut soils</td><td>Chernozem</td><td>Degradated chernozem</td><td>Laterite soils
Red and yellow podzolic soils
Red-yellow podzolic soils
Podzolic soils</td></tr>
<tr><td colspan="5">Podzol soils</td></tr>
<tr><td colspan="5">Tundra soils</td></tr>
<tr><td colspan="5">Permafrost</td></tr>
</table>

0 increase in humidity 100%

drought wet

The impact of moisture and temperature on the formation of the soil profile according to BLUMENSTOCK and THORNWAITE (1941)

1.6 CLIMATOLOGICAL FUNCTIONS OF WATER

The water cycle is one of the basic processes which regulate the climate. The characteristic properties of water which influence the climatic conditions depend on its molecular structure. The climatological regulating functions of water depend on a number of unique physical characteristics: the high value of the specific heat, the high values of the latent heat of fusion and evaporation, the high coefficient of heat reflectance, the extremely low heat conductivity, and the anomalous density decrease below 4°C, differing from the fusion point (Tab. 1.14).

TABLE 1.14

Climatic impact of water	Fundamental cause
1. Accumulation and slow transfer of heat	High specific heat $I_s = 4.19 \cdot 10^3$ J.kg.K^{-1} (at 20°C) 4-5 times exceeding that of air and rocks High latent heat of fusion $I_f = 3.55 \cdot 10^5$ J.kg^{-1} (at 0°C) High latent heat of evaporation $I_e = 2.26 \cdot 10^6$ J.kg^{-1} (at 100°C)
2. Limitation of energy input from universe	High coefficient of heat reflectance $k_{hr} = 0.582$ W.m^{-1}.K^{-1}
3. Limitation of heat radiation	
4. Regulation of energy transfer between the lithosphere, hydrosphere and atmosphere	Low heat conductivity Fresh water (20°C) 0.557 W.m^{-1}.K^{-1} Sea water (18°C) 0.561 W.m^{-1}.K^{-1} Ice 1.173 W.m^{-1}.K^{-1} Snow Highest density at 4°C
5. Influence on temperature inversion	High specific heat and low heat conductivity
6. Influence on microclimate	High specific heat and high latent heat of fusion and evaporation. Irregularity of the highest density occurrence (at 4°C).

Climatic impact of water and its fundamental causes as a function of its exceptional molecular characteristics.

The coefficient of heat reflectance occurs in the reflectance of solar energy and in the heat transmissivity of the atmosphere. The Earth reflects 34% of the solar energy on average. Two thirds of this value, i.e. 23% of the total, is reflected by clouds, or accumulated vapour in the atmosphere. The increase in the water vapour pressure leads to a decrease in the heat transmissivity of the atmosphere. The difference between the average values of the heat transmissivity of the equatorial and the polar zone, with lower humidity, exceeds 13%.

Water vapour is the main cause of the hot-house effect of the atmosphere. It intercepts infrared radiation in the sphere of the wave length $4,4\mu < \lambda < 8,5\mu$ and $11\mu < \lambda < 80\mu$. The hot-house effect of the atmosphere consists in the input of radiation from the Universe to the Earth with small losses during daytime and in the output of the heat from the lithosphere to the Universe with high losses during nighttime. The atmosphere retains and reflects back to the Earth's surface the infrared radiation, forming 66 - 75 % of the radiated energy. Carbon dioxide CO_2 and ozone O_3 also take part in this effect, but in a very limited part of the spectrum, thus having far less influence.

Large water formations such as seas, icebergs, marshes and dambos, reservoirs and water courses act as thermal regulators. Evaporation and transpiration need a large quantity of thermal energy. This energy is released during condensation and accepted by the surrounding air, thus causing an equalizing of thermic differences. Due to the high specific heat of water, the process of its warming and cooling is slower than the process of the warming and cooling of soil. The differences in winter and summer temperatures, or day and night temperatures are, therefore, smaller in the vicinity of water formations. The local climate is influenced by the thermal inertia manifested by a slow transfer of heat to the environment. The degree of this influence depends on the volume of the functioning water mass and also acts over considerable distances, demonstrated by the continental nature of the climate.

Water reservoirs, marshes, dambos, snow and ice, also functioning as runoff regulators, thus propagate this thermal influence along water courses. The regulating function of marshes and dambos qualitatively differs from the influence of reservoirs. Marshes and dambos, containing 80 to 97% of water, bond on organic matter. The content of water in marshes cannot be decreased below 70% by drainage. Evapotranspiration from a marshy area forms 30 - 50% of evaporation from an open water surface, not taking away as much energy.

Snow and ice, thermal and runoff regulators, basically occur in two forms

(a) temporary snow and ice, thawing in the warm season,

(b) permanent snow and ice, especially Antarctic and Greenland icebergs, sea icebergs and mountain glaciers, permanent snow , permafrost.

Permanent or perennial ice and snow occur depending on the climate, altitude, latitude and morphology. If the climate is very rigorous, a layer of frozen ground, permafrost, may be formed, persisting from year to year. Thick snowpack tends to impede the formation of permafrost.

In areas where more snow and ice accumulate than actually melt and adjoining areas of lower altitude where the wastage of frozen water exceeds its accumulation, a slow movement of snow and ice mass from the upper area to the lower one may occur when the thickness of the glacier exceeds 15 to 30 m. The speed of this movement depends on the glacier thickness, its temperature and the slope of the ground. In this way, frozen water is transferred to areas with more favourable conditions for its participation in the hydrologic cycle (see also Tab. 1.1).

The hydrologic and microclimatic influence of snow and glaciers also functions by means of supplied rivers. Glaciers thaw more slowly than snow, thus offering high river discharges before the beginning of the summer season, when irrigation requirements may be expected to be highest (Tab. 1.9, Tab. 1.15).

TABLE 1.15

Season	Albedo	Snowpack thickness	Diurnal fluctuation	Runoff	Runoff after rainfall	Longterm storage impact
Spring	High	Highest	Slight	Moderate increasing	Subdued delayed	Dry & warm years = = Increase in total runoff
Summer	Moderate	Moderate	High	High	Slight delay	
Autumn	Low	Low	Moderate	Moderate	No delay	Wet & cool years = = Decrease in total runoff
Winter	Very high	Moderate	Nil	Slight	Stored	

Seasonal change in glacier-runoff characteristics according to MEIER (1964).

The regulating functions of water are also a consequence of its low heat conductivity. Heat flow is the most effective form of heat propagation in liquids. Under conditions of restricted flow below the ice cover, the heat losses of the water formation are low. The snowpack has an extremely low value of the heat conductivity. The insulating capability of water therefore appears in the winter season, remarkably enough, when this is urgently required for the maintenance of the temperature of the soil surface.

The low heat conductivity of the snowpack means that the heat output to the atmosphere does not exceed the heat input from the deeper formations. The soil temperature below the snowpack can be up to 15°C higher in comparison to the temperature of soils without the snowpack. The insulating effect of the snowpack does not only depend on its thickness, but also on the snow quality.

The snowpack has a cooling effect on the adjoining, warmer layer of atmosphere, thus causing ground inversion of temperature, especially in the spring season, and an associated increase in relative humidity. Such inversions above the open water surface are not as intensive and occur less often.

The air humidity can be characterized by the water vapour pressure. Its value oscillates between 0 and 40 milibars (0 - 4000 Pa) (Fig. 1.17). This pressure decreases with altitude: at 1750 m a.s.l. at one half and at 5000 m at one fifth of its original values at sea level. The content of water vapour in the atmosphere is on average 0.2% in the polar zone and 2.5% in rainy, tropical regions. It may, locally, exceed 4%.

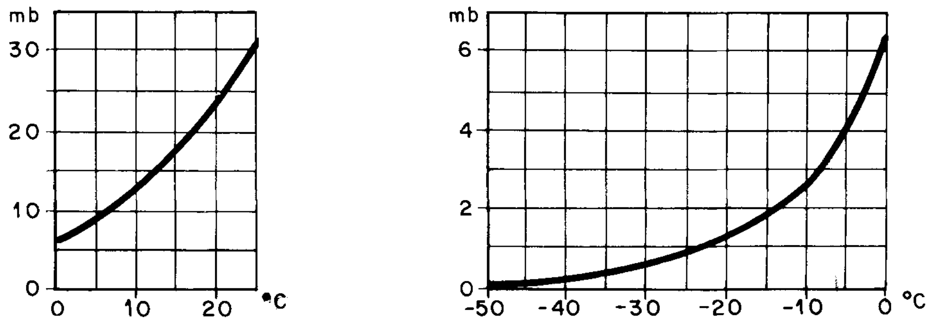


Fig. 1.17. Relation between temperature and saturation vapour pressure above and below 0°C.

The maximum amount of water vapour in the air depends directly on the temperature. The state in which water vapour can exist in equilibrium with a plane surface of liquid water at the same temperature is saturation. The relative humidity is the ratio of the actual vapour pressure to the saturation vapour pressure at the same temperature

$$U = \frac{e_w}{E_s} \cdot 100 \qquad (\%) \qquad (1.61)$$

U - relative humidity (%)

e_w - actual water vapour pressure (mb, 1 mb = 100 Pa)

E_s - saturation water vapour pressure (mb)

The air humidity is continuously changed by evapotranspiration, by the air flow and by temperature changes. The dew-point temperature is the temperature to which the air must be cooled at constant pressure to reach saturation with a given water content. Any further decrease in temperature thus causes condensation, occurring in different forms of the horizontal and vertical precipitation (Fig. 1.7) depending on the altitude, temperature and other conditions of the environment, e.g. morphology and temperature of the affected surface.

The daily minimum of the relative humidity occurs simultaneously with the daily maximum temperature at constant water vapour pressure. Changes in the water vapour content in the atmosphere cause changes in the relative amounts of the four principal gases (nitrogen N, oxygen O, hydrogen H and carbon dioxide CO_2) and minute traces of other gases, thus influencing its physical, chemical and biological characteristics.

The term drought (lack of rainfall), which negatively affects both the life of man and the development of plants, basically has two different connotations:

(a) climatic drought, caused by lack of precipitation or by its inadequate or irregular occurrence - particularly in the growing season or caused by high temperature, occassioning extreme evapotranspiration,

(b) local drought, which may also occur in areas with heavy rainfall during the growing season, occurring in regions with permeable soils, where excessive runoff impedes a sufficient water supply of plants.

The degree of the climatic drought depends especially on the average total rainfall or on its ratio to the mean annual temperature (Tab. 1.16).

TABLE 1.16

Climate	Mean annual precipitation total (mm)	Rainfall factor $r(mm/^{\circ}C.year)$
Wet	> 500	> 60
Semi-arid	400- 500	40-60
Dry (steppe and semi-desert)	200- 400	< 40
Extremely dry (arid)	< 200	$\ll 40$

Categorization of climate according to the mean annual precipitation total and in relation to the rainfall factor.

Climate is the average cycle of weather characteristic for given area. The course of humidity and temperature can be considered as factors which determine the type of climate. The climate can be categorized according to the mean annual total precipitation and in relation to the rainfall factor according to Koeppen (1920) (Tab. 1.16, 1.17)

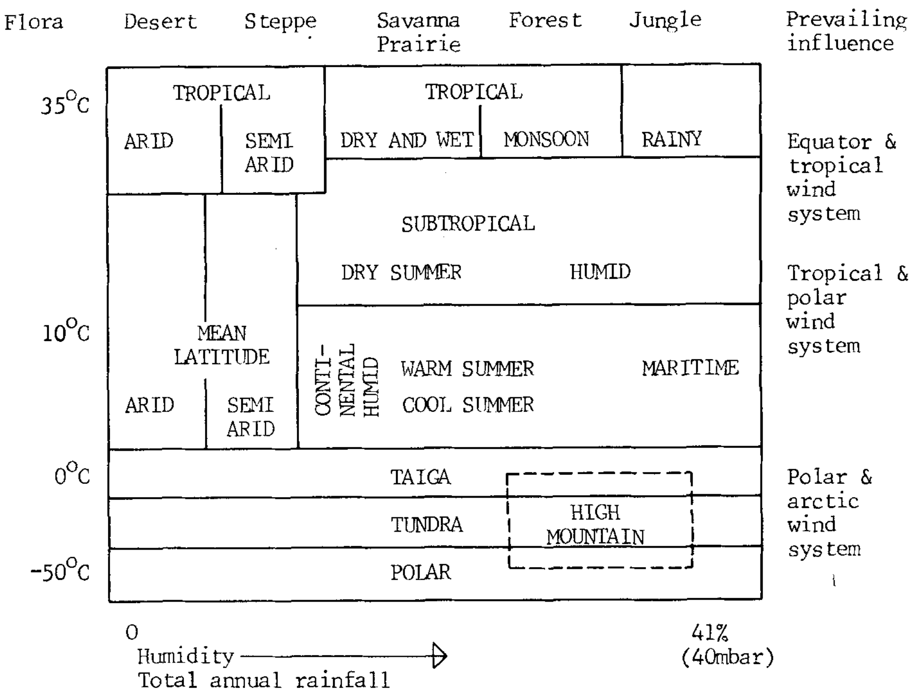
$$r = \frac{P}{T} \qquad (mm/\,^{\circ}C\,.\,year) \qquad (1.62)$$

r - rainfall factor

P - annual average precipitation total (mm per year)

T - mean annual temperature (^{o}C)

TABLE 1.17



Categorization of climate according to humidity and mean annual temperature, characteristic flora and prevailing factors of influence. Completed according to the structure of Critchfield (1960).

The regulating functions of water vapour, ice, snow and water act in dependance on the supply of solar energy, deciding e.g. on the predominant air circulation system. They are interconnected with numerous factors depending on the location, especially the exposure and altitude of the region. The annual and daily amplitude of temperature, upon which the continentality of the climate depends, increases with the distance from oceans. Regional and local morphology, water bodies, soils and vegetative canopy influence the characteristics of the meso- and microclimate.

1.7 BIOGEOCHEMICAL CYCLE SYSTEM

The mechanical and thermal energy which water acquires during the hydrological cycle, and its chemical energy, is consumed by

(a) the mechanical and chemical destruction of the land surface during rainfall, runoff and weathering, i.e. by hydrolysis, hydration, dehydration, leaching, dissolving , disintegration, absorption etc.,

(b) transportation and corrosion of sediments,

(c) deformation of banks and riverbeds,

(d) overcoming of different resistances during flow and undulation, internal and external friction, water hammer,

(e) biological processes of plant and animal production,

Water is the widespread agent of erosion, entrainment, transportation and deposition of sediment. The system of these complex processes forms the most important abiotic cycle in the environment of the water cycle in the proper sense. It enables the circulation of an organic and organic compounds of the biogeochemical cycle of elements. This cycle is characterized by a continuous, periodic or stochastic

(a) destruction and transfer of compounds and mixtures of different elements,

(b) dissolving, disintegration and integration of gaseous, liquid and solid mineral and organic matter,

(c) synthesis of new compounds, also enabling the initiation of new cycles.

This cycle regenerates nutriments and thus enables the course of the life process. Only a small part of the stock of elements and their compounds, existing in the pedo-, litho-, hydro- and atmosphere, is activated by the biotic and abiotic processes and takes part in the biogeochemical cycle. Erosion is the process of activation. Eroded matter, including bioelements, i.e. elements whose organic compounds form living matter, are entrained, transported and deposed as sediments (Tab. 1.18).

TABLE 1.18

Biogeoelements

Macrobiogenetic		Microbiogenetic				Oligobiogenetic (trace)			
Carbon	C	Calcium	Ca	Silicon	Si	Fluorine	F	Vanadium	V
Oxygen	O	Iron	Fe	Alluminium	Al	Arsenic	As	Chromium	Cr
Hydrogen	H	Magnesium	Mg	Manganese	Mn	Lead	Pb	Molybden	Mo
Nitrogen	N	Sodium	Na	Iodine	J	Titan	Ti	Nickel	Ni
Phosphorus	P	Kalium	K	Zinc	Zn	Cesium	Cs	Cobalt	Co
Sulphur	S	Chlorine	Cl	Copper	Cu	Selenium	Se	Galium	Ga
				Boron	B	Stroncium	Sr	Vismut	Bi
						Rubidium	Ru	etc.	

Categorization of biogeoelements.

Sediments are transferred from the higher altitudes with less favourable topographical and climatological conditions for cultivation to lower elevations of fertile plains and more favourable climate. The boulders, the gravel and partially also the sand move near the bottom as bed load. Fine sand and some organic particles float as suspended load; silt, clay swim as wash load and trees, plants, leaves as floating debris (Fig. 1.4).

During low floods coarse sediments remain in the channel: inundation contains fine particles, whose composition and size is more suitable for the formation of living matter. Suspended and wash load, partly of organic origin, and floating debris regenerate the bioenergetic potential, i.e. the fertility of soils. During superfloods coarse materials may also enter the flood plain and affect the soil fertility in a negative way.

TABLE 1.19

Continent	Catchment area mil.km^2	Mean annual sediment transport t.km^{-2}	10^9 t	Decrease of the land surface during 1000 years mm
Europe	9.3	34.8	0.32	23.2
Asia	26.9	591.0	15.91	394.0
Africa	19.9	27.0	0.54	18.0
North America	20.7	94.6	1.96	63.1
South America	19.4	61.8	1.20	41.2
Australia	5.2	44.4	0.23	29.6
Total/average	101.4	198.8	20.16	132.5

Annual sediment transport and decrease in the land surface according to Holeman (1968).

It is a basic prerequisite for intensive agricultural production that the production process should not be interrupted too often by floods and certainly not at harvest time. Intensive cultivation develops, therefore, in areas where the natural processes of inundation and regeneration of nutriments is already at least partially interrupted.

Wind erosion returns part of the sedimented matter from dry land to upper elevations. The greater part accumulates in seas and reservoirs. It is partially absorbed by the biomass. It also penetrates below the reach of the sun's rays, thus escaping from the biologic cycle.

Sediment represent a load on the geological formations of the Earth's crust and thus influence its balance. In such a way, they are one of the factors which have an impact on volcanic activities. New matter which occurs during volcanic activities on the Earth's surface enters the erosion process and thus closes the biogeochemical cycle.

Natural biogeochemical cycles, when not disturbed by human activities, are with some exceptions almost balanced. They reproduce 90 - 98% of the entering matter, thus maintaining the balance of quantity, structure and concentration, forming a stable basis for the biotic environment. All organisms conform to this state in the long term. The inequality of the biogeochemical cycle in the span of geological time leads to the migration and differentiation of species, to dispersion or concentration of elements and their compounds in different parts of the region and consequently to the formation of different abiotic environments and ecosystems.

An index of element migration, applied by Polynov (1936), is expressed by the ratio of the percentage quantity of the element in the hydrosphere to the percentage of its quantity in the lithosphere. Kovda (1975) proves on the basis of this index that chlorine Cl, sulphur S, iodine I, calcium Ca, natrium Na, magnesium Mg, fluorine F, strontium Sr, zinc Zn, uranium U and molybdenum Mb present high migration, while silicon Si, potassium K, phosphorus P, baryum Ba, manganese Mn, rubidium Rb, copper Cu, nickel Ni, kobalt Co, arsenic As, lithium Li and especially alluminium Al and iron Fe present low migration. Divergences occur locally, especially through changes in the conditions for oxidation or reduction and through the synthesis of integrated compounds.

The migration of biogenic elements is of crucial importance for the creation and growth of living matter. Of the macrobiogenetic elements only phosphorus creates an unbalanced cycle. Anorganic compounds of phosphorus are absorbed by plants. They serve as nutrition for animals, concentrate first of all in their bones and then enter the soil in their excrements as well as after extinction.

In the course of the erosion process 3-4 mil. tons of phosphates are transported annually to the sea. Only one thirtieth of this quantity returns to dry land as a product of fishing, or as guano etc. The natural processes supplement its active stock insufficiently. The circulation of phosphorus is activated by anthropogenetic measures: phosphates are a component of most fertilizers as well as of polluted waters. Blast-furnace slag also contains phosphorus. Nevertheless the stock of phosphorus is gradually diminishing, because this element is absorbed by plants (Fig. 1.18).

During the circulation of sulphur, bacteria, thiobacilli and desulphovibrions act in the soil, forming sulphates by oxidation and sulphides by reduction. The soil is enriched with sulphur by means of rainfall. Organic matter accepts sulphur from the soil and surrenders it again during decomposition. The erosion process transports part of the sulphur compounds to reservoirs and oceans, from which formations sulphur escapes to the atmosphere in the form of gaseous compounds (Fig. 1.19).

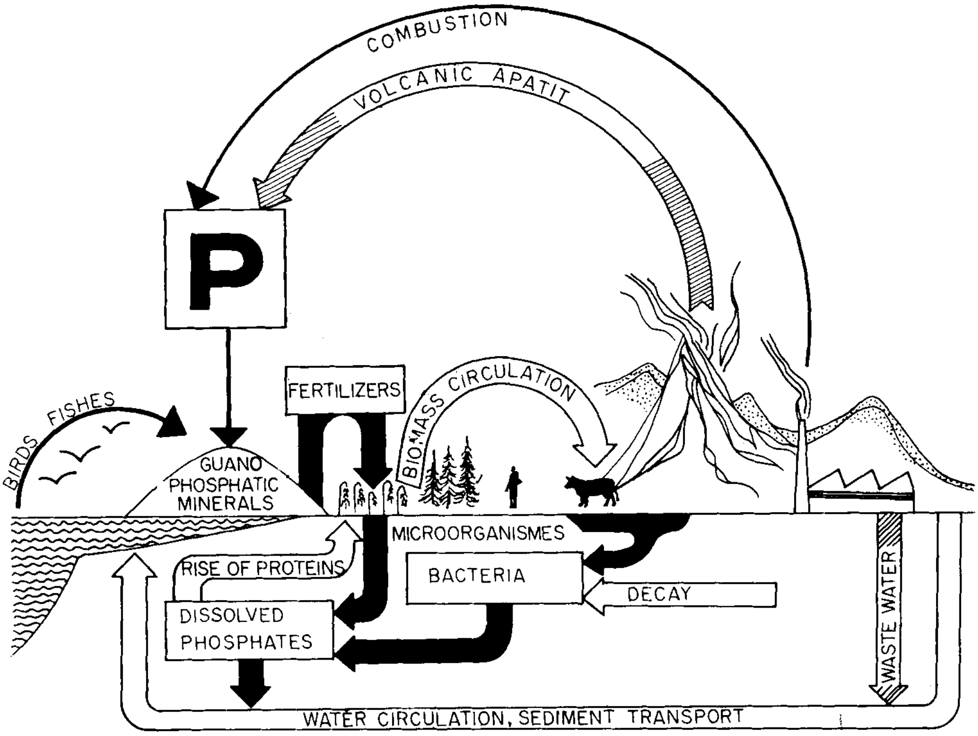


Fig. 1.18. Biogeochemical cycle of phosphorus as a subsystem of the hydrological cycle. The unbalanced cycle of phosphorus is controlled by volcanic and biological processes.

The amount of carbon dioxide CO_2 in the atmosphere is regulated 60% by oceans and 40% by the photosynthesis of plants. These processes also regenerate the stock of oxygen O. Carbonates are transported during erosion to the sea or enter organic matter from the soil. Carbon dioxide escapes from organic matter during respiration, burning, disintegration and from soil and water surfaces directly back to the atmosphere (Fig. 1.20).

The circulation of oxygen O, hydrogen H and nitrogen N, whose main stock is the atmosphere, is balanced. Forests, covering 9% of the Earth's surface, produce 48 mld. tons of oxygen annually, i.e. 47% of the total production. The rest is almost completely the share of oceans: the production of rivers and reservoirs is important from the point of view of meso- and microclimate only. Oxygen and hydrogen compounds, such as salts, oxides etc., forming soils, rocks and organic matter take part in the whole biogeochemical cycle.

The nitrogen N is a component of proteins, thus entering the waste from digestion, extinction and industrial processing. Saprogenic bacteria, acting during decay and ammonification, help to create ammonia NH_3. Under the action of nitrificating bacteria the ammonia changes into nitrites and than nitrates. Nitrates enter plant matter directly and, partly by denitrificating bacteria, are decomposed. Free nitrogen, the result of this process, is accepted by the atmosphere (Fig. 1.21). Goldschmidt (1954) states that 0.75 $g.m^{-2}$ of nitrogen enters into the circulation in zones with a mild climate and almost 3 $g.m^{-2}$ in zones with a humid, tropical climate.

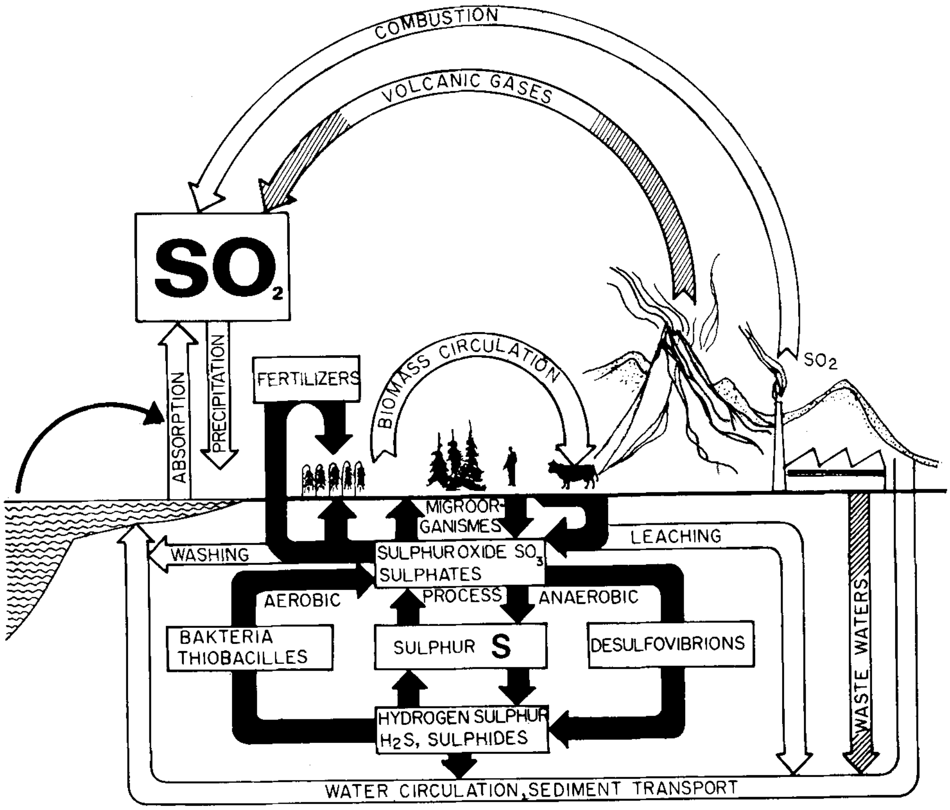


Fig. 1.19. Biogeochemical cycle of sulphur as a subsystem of the hydrological cycle. The cycle of sulphur is activated especially by microorganisms and volcanic activities.

1.7.1 Water Erosion as a Process Evoked by the Water Cycle

The chemical and mechanical energy of wind, ice, rainfall, runoff and sediments, acting during the hydrologic cycle in the system of the pedo- and lithosphere, results in the erosion, disintegration and wearing away of the land (Tab. 1.19). The interplay of acting forces depending on hydrometeorological factors, geomorphological conditions, namely of

- the density and composition of the vegetative cover,

- material and structure of the surface layer,

and of the duration of this process decides on its course and form. From this point of view, it is possible to distinguish

(a) sheet erosion - detachment and removal of the material from the entire land surface by wind, rainfall and overland flow, which may be either

- selective and change the soil texture together with the content of nutriments in the soil, or
- stratified, when the entire mould layer is washed away,

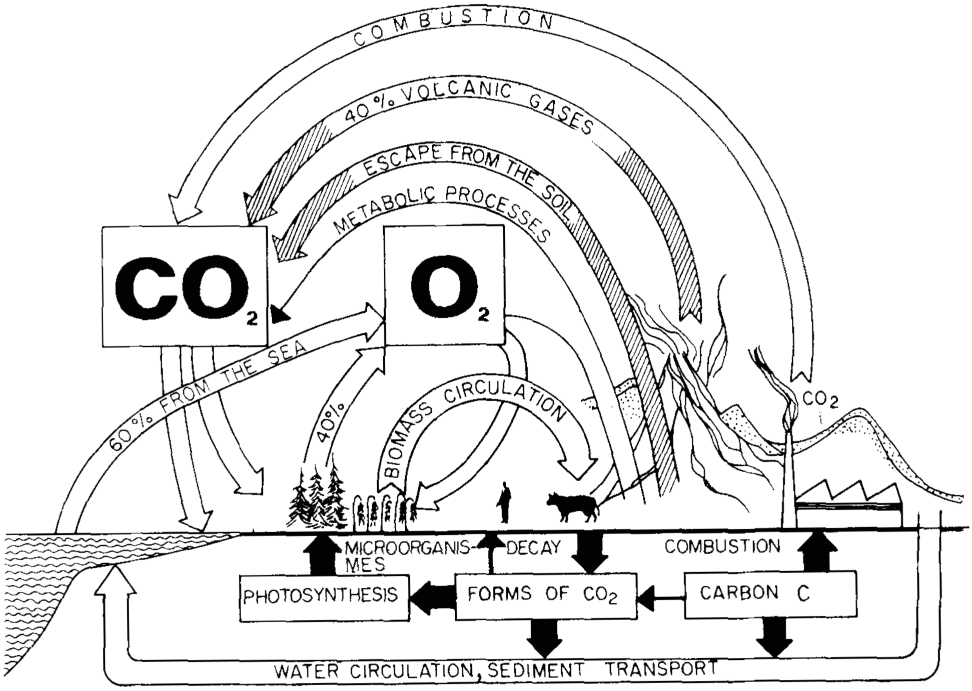


Fig. 1.20. Biogeochemical cycles of carbon and oxygen as subsystems of the hydrological cycle. The content of oxygen in the atmosphere is mainly controlled by oceans and by the photosynthesis of terrestrial flora.

(b) pre-channel erosion, exerted by forces of concentrated pre-channel flow, forming furrows, cuts, wash-outs, pot-holes and gullies,

(c) channel erosion, exerted by forces of concentrated water flow in stream beds, stream banks and flood-plains (Fig. 1.22).

NEAL (1938) connects the potential intensity of sheet erosion

$$G_s = K.\ I^{0.8}\ .\ i^{1.2} \qquad (t.ha^{-1}.min^{-1}) \qquad (1.63)$$

G_s - washed soil $(t.ha^{-1})$

I - gradient of the slope $(^{o})$

i - rainfall intensity (mm.min^{-1})

K - coefficient of local conditions

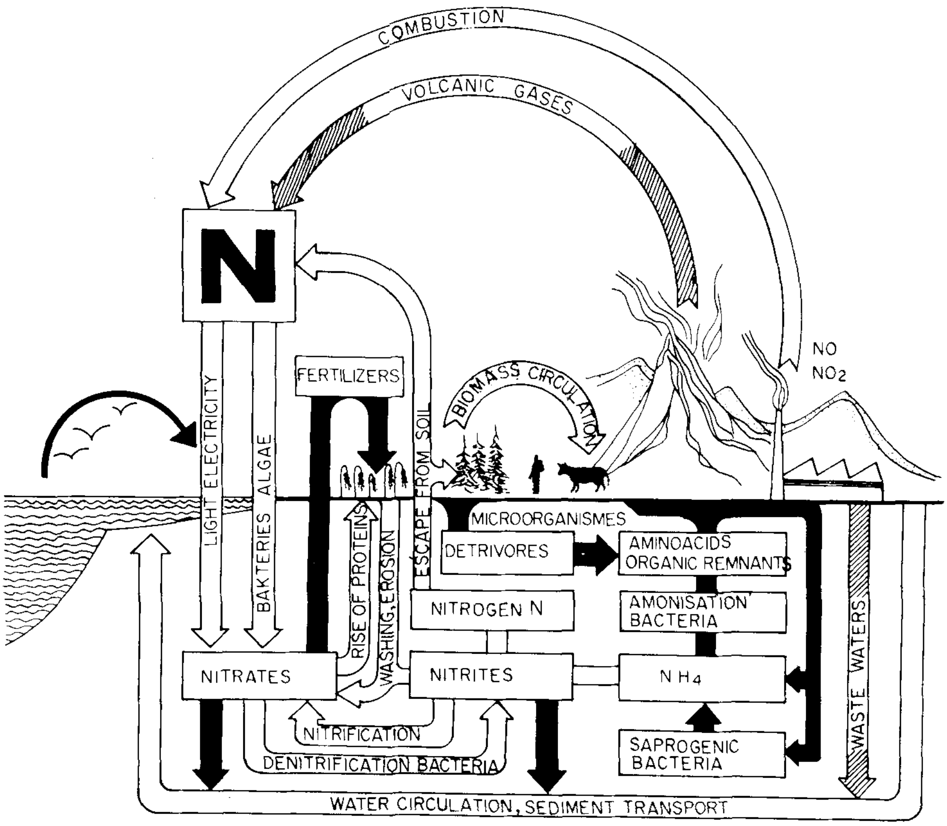


Fig. 1.21. Biogeochemical cycle of nitrogen as a subsystem of the hydrologic cycle. The main reserve of nitrogen is in the atmosphere.

From the chemical point of view, especially nitrogen N, potassium K, calcium Ca, magnesium Mg are washed away, while sulphur S, chlorine Cl and phosphorus P bond in the organic and anorganic soil particles. Washed soil particles may be intercepted by the grasslands, meadows and pastures, when eroded lands do not directly adjoin the stream channel. Plants in such grassland zones accept nitrogen N quite easily, potassium K, calcium Ca and phosphorus P are accepted only partially. Sulphur S, natrium Na and the rest of potassium K as well as of calcium Ca and phosphorus P are carried away by the surface runoff.

The energy of the overland flow increases with its depth and velocity. This flow is accelerated and its discharge grows with the length of course. The qualitative change of the sheet erosion into the pre-channel erosion depends especially on the combination of the soil surface characteristics, rainfall intensity, gradient of the slope and its length. The following formula can be derived for the critical length of the slope, i.e. the length where the less dangerous sheet erosion changes due to the concentrated flow and evoked forces into pre-channel erosion:

$$L = a \cdot f(i, r, t) \qquad (m) \qquad (1.64)$$

L - critical length of the slope (m)

i - gradient of the slope (%)

a - coefficient of soil characteristics (0.5-4,5 : 1 - levelled fields, 1.7-2.3 - meadows)

r - rainfall and climate factor

t - time factor, depending on the duration of rainfalls of high intensity

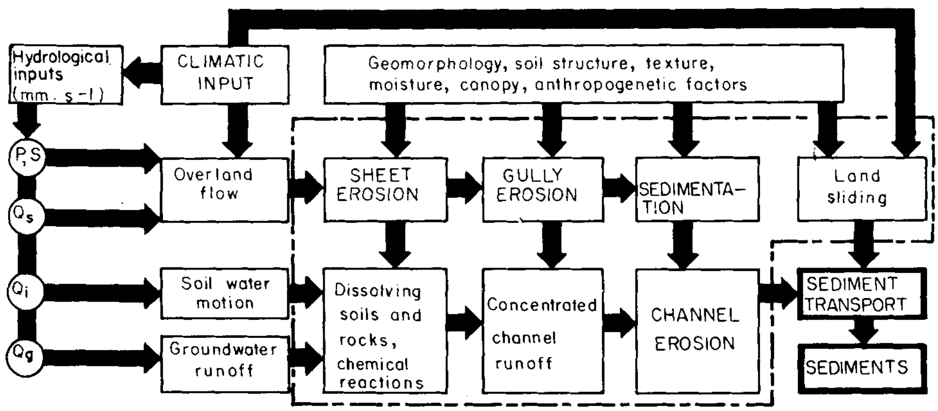


Fig. 1.22. Flow chart diagram of the erosion process. Rainfall and runoff, the output of the runoff system, are inputs of the erosion system. Output is: the sediment flow, settled sediments and the water quality.

Solid soil particles enter the movement of the concentrated overland flow at the moment when its speed achieves the value of the speed limit. This value depends on the weight, size and shape of the relevant particles, which can be expressed by a simple formula

$$v_c = s \cdot \sqrt{d} \qquad (m.s^{-1}) \qquad (1.65)$$

v_c - speed limit of sediment motion $(m.s^{-1})$

s - coefficient of shape

d - size characteristics (Tab. 1.20)

TABLE 1.20

Material	Grain size (mm)	Speed limit $(m.s^{-1})$	Material	Grain size (mm)	Speed limit $(m.s^{-1})$	Coefficient of shape Grain parameter value (s)	
Sand	3	0.108	Cobble rounded	27	0.650	round perimeter	4.46
	6	0.189	Cobble angular, sharp	60	0.975	elliptic long semi-axis	4.43
	20	0.325	Boulders	100	1.400	angular longest edge	3.45

Values of speed limits v_c and shape coefficients s.

Levi (1948) states for nonhomogeneous sediments

$$v_c = 1.4 \cdot g \cdot d_s \cdot \lg \frac{h}{7 d_s} \cdot \left[\frac{d_{max}}{d_{min}}\right]^{\frac{1}{7}} \tag{1.66}$$

d_{max}, d_{min}, d_s – maximum, minimum and medium size of sediment particles (m)

g – gravitational constant $(m.s^{-2})$

h – depth of flow (m)

A decrease in the flow rate below the speed limit causes a sedimentation of the soil particles. A stable sediment size is characterized by a stable gradient of the stream channel slope, as can be proved on the basis of Chézy's formula:

$$c \cdot \sqrt{R \cdot i_b} = v_c$$

$$c^2 \cdot R \cdot i_b = s^2 \cdot d$$

$$i_b = \frac{s^2 \cdot d}{c^2 \cdot R} = c_b \cdot \frac{d}{R} \tag{1.67}$$

i_b – balanced slope gradient (without erosion and sedimentation)

c_b – coefficient of the balanced slope

R – hydraulic radius (m)

Valentini (1893) stated c_b = 0,093 for the slope of the river bed up to 25% and

$$d = \sqrt[3]{\frac{V}{n}}$$

V – volume, n – number of cobbles

The balanced slope gradient for smaller grain sizes follows directly from Chézy's equation:

$$i_b = \frac{v_c}{c^2 \,.\, R} \qquad (1.68)$$

The current velocity is not uniform throughout the cross section and leads to the transport of particles of different size: For practical reasons the beginning of the motion of a considerable quantity of suspended matter is important i.e. the relevant critical discharge, whose occurrence is some 180 days per year under conditions of stable natural river beds.

Integrated processes of physical, chemical and biological character during wind, ice, water and gravity erosion, entrainment, transportation and deposition of sediments, forming the Earth's surface and enabling the circulation of biogeoelements, are greatly affected by human activities. The universal equation for predicting erosion rates can be expressed by the function

$$G_e = f\,(X_1, X_2, X_3, X_4, X_5, X_6, X_7, X_8) \qquad (1.69)$$

G_e - erosion rate $(t.ha^{-1})$

X_1 - climatic factor (rainfall and wind intensity, ice phenomena)

X_2 - hydrologic factor (concentration of the surface runoff)

X_3 - topographical factor (slope-length, steepness and exposure)

X_4 - soil factor (structure, texture, resulting in soil erodibility)

X_5 - geological factor (stability of the ground)

X_6 - vegetative cover factor (depending also on season)

X_7 - management practices factor (crop management, irrigation)

X_8 - anthropogenetic factor (effect of land development/disturbance and protection measures)

The analytic tractability of the function is complicated by the need to express the space-time characteristics of relevant factors, e.g. the coincidence of the rainfall occurrence and of different characteristics of canopy during relevant growth stages: harvesting, bed preparation and other management practices.

1.7.2 Water Quality as a Product of its Circulation

Water in nature is a multiconstituent compound whose substance is hydrogen dioxide H_2O containing dissolved and dispersed gaseous, liquid and solid cations, anions and nonionic constituents of anorganic and organic origin, as well as aquatic flora and fauna.

The unique chemical characteristics of the hydrogen dioxide H_2O, capillarity with other unique physical characteristics, are a consequence of the excentric position of oxygen with regard to the centroid of the water molecule. The very high dielectric constant of water permits it to decompose molecules of soluble compounds into ions and dissolve complicated matter, also forming soils and rocks.

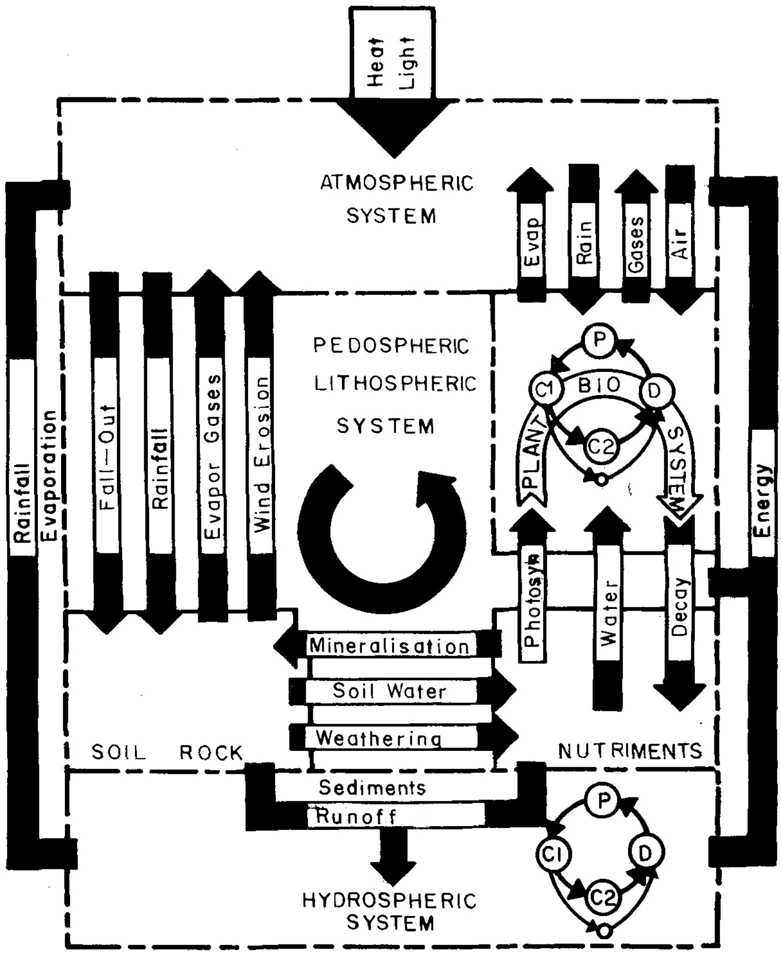


Fig. 1.23. Water and air as basic media of the geo- and biological processes as well as of the matter and energy transfer between continent and oceans.

Water quality consists of different properties, which are important when deciding about its possible utilization. These properties include temperature and colour, taste and odour, caused by the presence or absence of chemical substances and expressed by the alkalinity, acidity, hydrogen-ion concentration, content of carbonates (hardness), oxygen demand, sodium adsorption ratio, as well as by the presence of different ionic and nonionic constituents incl. microorganisms etc. Various physical, chemical and biological characteristics of water are formed by its contact with the environment during its circulation. Water quality changes most during its penetration through the soil and rock environment, but also during its contact with the atmosphere, vegetation, soil and rock during surface runoff and rainfall, further by mixing with water from deeper strata and by mixing and reacting with matter entering the system of atmosphere, hydro-, pedo- and lithosphere in the course of human activities (Fig. 1.23).

The complex of processes which create the characteristics, constituents and properties of water is called mineralization. The course of these processes depends also on the energy input, i.e. on the temperature, pressure and mechanical energy which crush the reacting particles, and on the concentration of acting components which come into mutual contact. Pores, cracks and cavities act as natural regulators of water quality: the rate of relevant processes also depends on the size of the acting surface, and on hydraulic parameters, especially on the flow rate, deciding about the duration of the contact of relevant constituents. Soil also functions as a natural filter, catching a substantial part of polluting matter and disposing it by subsequent biochemical processes (Tab. 1.21).

TABLE 1.21

Mineralization	Characteristics
Meteogenic	Mineralization in the atmosphere
Potamogenic (fluviogenic)	Mineralization in streams and rivers, dependent on the size, shape and geology of the river bed and on the velocity of the flow as well as on water temperature.
Limnogenic	Mineralization in lakes and other standing waters.
Litomorphic	Mineralization in groundwater, dependent on the petrographic and chemical characteristics and on the influence of the underground atmosphere on the infiltrated water and groundwater.
Bathymorphic	Mineralization in deep aquifers determined especially by temperature, pressure, migration, conservation and diagenesis of the groundwater in a way that is composition closely depends on the depth.

Categorization of the mineralization processes which determine water quality, in undisturbed natural conditions.

The following physical and chemical processes take part in the formation of natural water quality:

(a) transfer and diffusion of oxygen and other gases,

(b) destruction and crushing of matter and its diffusion in water,

(c) dissolving soluble and semi-soluble components of soil, rock and air,

(d) leaching of mineral and organic particles from the soil, rock and atmosphere,

(e) mixing, diluting and chemical reacting of waters of different qualities,

(f) separation of non-soluble precipitates and sedimentation,

(g) adsorption and desorption of soluted compounds on atmospheric, soil and rock particles and exchange of ions,

(h) radioactive decay of elements.

The intensity of the physical processes of dissolving and ion exchange, and also the chemical processes, especially those of dissociation and hydrolysis, depends on the saturation of the solution by the mineral components.

The saturation index

$$I_s = \frac{-[A]\ [B]}{S} \qquad (1.70)$$

[A] [B] - concentration of ions of the nonsoluble matter

S - constant

This saturation index indicates the direction of the reaction. $I_s = 1$ marks the balanced state, $I_s < 1$ dissolving, $I_s > 1$ separation of the insoluble component. The rate of relevant physical and chemical processes is proportional to the concentration gradient. This can be expressed by the equation

$$\frac{dc}{dt} = k \cdot (c - c_b) \qquad (1.71)$$

$\frac{dc}{dt}$ - rate of the adsorption and desorption processes ($mg.l^{-1}, s^{-1}$)

k - coefficient of the active surface (s^{-1})

c - concentration of the dissolving component ($mg.l^{-1}$)

c_b - balanced concentration ($mg.l^{-1}$)

t - time (s)

Integration offers

$$\ln \frac{c - c_b}{c_o - c_b} = - k \cdot t$$

c_o - initial concentration ($mg.l^{-1}$)

and consequently

$$\frac{c - c_b}{c_o - c_b} = e^{-kt} \tag{1.72}$$

With regard to the relatively small value s of the balanced concentrations, c_b can be neglected

$$c = c_o \cdot e^{-kt}$$

$$c' = c'_o \cdot (1 - e^{-kt}) \tag{1.73}$$

These equations prove that the rate of dissolving rock and soil particles, and also the rate of dissolving deposition of insoluble compounds in the rock environment of pores and cracks, is governed by exponential relations. The speed of these processes is higher in an environment where actual concentrations differ remarkably from the balanced concentration than in an environment where this difference is small (Tab. 1.22).

The balance of running dissolving and ion exchanging processes in the system soil/rock-water depends on the solubility of the rock, on the chemical composition of the water and its temperature, on the acting surface, depending on the porosity and size of the rock particles. The dependence between the solubility and the size of the soil particles can be expressed as

$$\ln \frac{c_k}{c} = \frac{a}{r} - \frac{b}{r^4} \tag{1.74}$$

c_k - solubility of small crystals (size 10^{-4}m)

c_r - solubility of particles with the size r

a,b- constants

Diffusion rate at the constant value of the concentration gradient

$$\frac{dn}{dt} = - f \cdot D \cdot \frac{dc}{dc_o} \tag{1.75}$$

$\frac{dn}{dt}$ = change of the number of mols passing through area f

$\frac{dc}{dc_o}$ = concentration gradient

D - diffusion coefficient

f - area

In most cases, the concentration gradient depends on time, which describes a partial differential equation, whose solution leads to the relation

$$c = c_s \cdot \left[1 - \frac{2}{\sqrt{\pi}} \cdot \int_0^{\frac{x}{2}\sqrt{DT}} e^{-y^2} \cdot dy \right] \qquad (1.76)$$

c_s – concentration of the saturated solution

y – integration variable.

TABLE 1.22

a) Dissolving of gases	b) Dissolving of minerals
$O_2, N_2, CO_2, H_2S, HCl, NH_3, Ar$ Kr, Xe, Ne, Hc	$CaCO_3, Fe(OH)_3, NaCl, FeCO_3$, $MnCO_3$ atd.
Mixing of waters: $q_1 \cdot c_1 + q_2 \cdot c_2 = 100 \cdot q_s$	
Chemical reactions:	
A) Oxygen O:	B) Calcium Ca
$O_2 + 4\,H^+ \rightleftharpoons 2\,H_2O$	$Ca^{2+} + CO_2 + H_2O \rightleftharpoons Ca^{2+} + 2\,HCO_3^-$
$H_2O_2 \rightleftharpoons O_2 + 2\,H$	$Ca^{2+} + CO_3^{2-} \rightleftharpoons CaCO_3$
$2\,H_2O_2 \rightleftharpoons H_2O + 2\,H^+$	
C) Iron Fe	D) Manganese Mn
$Fe^{2+} + H_2O \rightleftharpoons Fe(OH)^+ + H^+$	$Mn^{2+} + H_2O \rightleftharpoons Mn(OH)^+ + H^+$
$Fe(OH)^+ + H_2O \rightleftharpoons Fe(OH)2 + H^+$	$Mn(OH)^+ + H_2O \rightleftharpoons Mn(OH)_2 + H^+$
$Fe(OH)_2 + H_2O \rightleftharpoons Fe(OH)_3^- + H^+$	$Mn(OH)_2 + H_2O \rightleftharpoons Mn(OH)_3^- + H^+$
$Fe^{3+} + H_2O \rightleftharpoons Fe(OH)^{2+} + H^+$	E) Alluminium Al:
$Fe(OH)^{2+} + H_2O \rightleftharpoons Fe(OH)^{2+} + H^+$	$Al(OH)_3 + OH^- \rightleftharpoons AlO_2 + 2\,H_2O$
$Fe(OH)_2^+ + H_2O \rightleftharpoons Fe(OH)_3 + H^+$	$Al(OH)_3 + H_2O \rightleftharpoons Al(OH)_4^- + H^+$
$Fe(OH)_3 + H_2O \rightleftharpoons Fe(OH)_4^- + H^+$	$Al(OH)_4^- \rightleftharpoons AlO_2^- + 2\,H_2O$
G) Sulphur S:	F) Silicon Si:
$H_2S \rightleftharpoons S + 2\,H^+$	$CaAl_2Si_2O_8 + H_2O + 2\,H^+ \rightleftharpoons Al_2Si_2O_5(OH)_4 + Ca^{2+}$
$H_2O + H_2SO_3 \rightleftharpoons SO_4^{2-} + 4\,H^+$	H) Ammonia NH_4:
$S^{2-} \rightleftharpoons 2\,S^-$	$NO_3^- + H_2O \rightleftharpoons 2\,OH^- + NO_2^-$
$3\,H_2O + S \rightleftharpoons H_2SO_3 + 4\,H^+$	$NO_3 + 10\,H^+ \rightleftharpoons NH_4 + 3\,H_2O$
	$NO_3^- + 2\,H^+ \rightleftharpoons HNO_2 + H_2O$

Selected characteristic physical and chemical processes which form water (especially groundwater) quality.

Chemical reactions mostly take place when water of different origin is mixed. Where these reactions are missing, the resulting water composition is

$$q_1 \cdot c_1 + q_2 \cdot c_2 = 100 \cdot c_s \qquad (1.77)$$

q_1, q_2 - quantities of mixed waters (%)

c_1, c_2 - concentration of non-reacting components in mixed waters ($g.l^{-1}$)

c_s - resulting concentration ($g.l^{-1}$)

Solid particles suspended in water are affected by chemical and physical, especially hydraulic forces. Under prevailing hydraulic forces, the intensity of the interception of solid particles in rock formations is low: their function may even wash out rock particles, i.e. cause suffusion.

Under the prevailing influence of chemical forces there occurs a gradual clogging of pores and cracks, resulting in a decreasing coefficient of hydraulic conductivity.

The course of the groundwater flow depends, therefore, on the coincidental physical and chemical reactions. Slightly polar substances are intercepted quite easily and in the proximity of the infiltration point. More polar substances are difficult to intercept. The interception of basic, alkaline components depends to a remarkable extent on their chemical composition. Iwasaki (1974) states that the decrease in the concentration percentage is proportional to the actual concentration

$$\frac{c}{L} = (A + K \cdot s) \cdot c \qquad (1.78)$$

c - concentration percentage (%)

L - the thickness of the layer (m)

A,K - constants

s - the volume of suspended particles intercepted by the unit volume of the layer

The volume of intercepted particles

$$\frac{s}{t} = -v_f \cdot \frac{s}{L} \qquad (1.79)$$

v_f - apparent velocity of the groundwater flow (m per day)

The above-mentioned physical and chemical processes usually determine the quality of natural waters in the underground, on the Earth's surface and above it. These processes are often accompanied by biological, or bacteriological processes. These usually depend not only on the thermal energy input or output, but also on luminous energy.

From the biological point of view, the complex of local physical, chemical and other conditions is named biotope. The development of a biocoenosis, a community of organisms, depends on this biotope. Each type of biotope contains not only characteristic organisms, but also organisms which are usual in other biotopes and which have been brought in by chance.

The resulting water quality can be classified

(a) formally

(b) genetically

(c) in accordance with the possibilities of its utilization,

(d) in accordance with its influence on biological factors.

Systematic categorization, enabling an explicit genetic classification on the basis of formal physical and chemical factors, has not yet been developed. Different classifications are, therefore, used for the classification of surface waters and groundwaters.

Groundwater can, in accordance with its chemical composition, be classified as

(a) plain - containing less than 1 g of dissolved substances in 1 liter,

(b) brackish - containing 1 to 30 g of dissolved substances in 1 liter,

(c) brine - containing more than 30 g of dissolved substances in 1 liter of water.

Waters which contain more than 1 g of carbon dioxide CO_2 in 1 liter are denoted as acidic. Natural mineral waters contain either more than 1 g of dissolved substances or of carbon dioxide. Waters whose healing properties have been scientifically proved may be described as medicinal, or curative. The classification and terminology of mineral waters can be derived from partial classification according to the content of dissolved gases, quantity of dissolved solids, main ion components, biologically and pharmaceutically important components, chemical reaction, radioactivity, osmotic pressure and temperature. Thermal waters whose temperature generally exceeds 25°C can be classified as

- hypothermal	25-35°C
- isothermal	35-42°C
- hyperthermal	> 42°C.

The classification of groundwaters on the basis of their chemical composition is governed either by the prevailing ions or by the prevailing ion combinations. Jetel (1975) connects both these principles in the following way and differentiates:

- classes S, C, N, Cl - according to the representative anion SO_4, HCO_3, N, Cl,
- groups according to the representative cation Na, K, Mg, Ca.

Contents (r) of other ions a re to be added to the similar main ions: Mn^{2+} and Fe^{2+} to Ca^{2+}, NO_3 to Cl^- and alkalines to Na^+, CO_3^{2-} to HCO_3^-.

- species according to combinations of the main ions, marked by Roman figures (Tab. 1.23).

The symbol of groundwater quality forms marks of the main anions, cations, species and the value of the total mineralization, e.g. Cl^{Na}_{II} - 0,014 $g.l^{-1}$.

TABLE 1.23

Index	Hypothetical combinations of ions			Characteristic relationship
1	NaCl	Na_2SO_4	$NaHCO_3$ $Mg(HCO_3)_2$ $Ca(HCO_3)_2$	$rHCO_3 > r(Ca+Mg)$ $rNA > r(Cl+SO_4)$
II	NaCl	Na_2SO_4 $MgSO_4$	$Mg(HCO_3)_2$ $Ca(HCO_3)_2$	$rHCO_3 < r(Ca+Mg) < r(HCO_3+SO_4)$ i.e. $r(Cl+SO_4) > rNa > rCl$
	NaCl	Na_2SO_4 $MgSO_4$ $CaSO_4$	$Ca(HCO_3)_2$	
IIIa	NaCl $MgCl_2$	$MgSO_4$	$Mg(HCO_3)_2$ $Ca(HCO_3)_2$	$rCa < r(HCO_3+SO_4) < r(Ca+Mg)$ i.e. $r(Na+Mg) > rCl > rNa$
	NaCl $MgCl_2$	$MgSO_4$ $CaSO_4$	$Ca(HCO_3)_2$	
IIIb	NaCl MgCl $CaCl_2$	$CaSO_4$	$Ca(HCO_3)_2$	$rCa > r(HCO_3+SO_4)$ i.e. $rCl > r(Na+Mg)$
IV	NaCl	Na_2SO_4 $MgSO_4$ $CaSO_4$ H_2SO_4		$rHCO_3 = 0$
	NaCl MgCl	$MgSO_4$ $CaSO_4$ H_2SO_4		
	NaCl $MgCl_2$ $CaCl_2$	$CaSO_4$		

Groundwater categorization depending on ion combinations according to Alekin (1970). IV. species categorized according to Florea (1970).

The quality of surface waters depends to a great extent on hydrological, meteorological and antropogenetic factors and changes considerably with time. The chemical composition of these water is not the prevailing agent of their quality.

Their mineralization is remarkably lower than that of groundwaters. The quality of surface water, therefore, is to be defined on the basis of further characteristic indicators: oxygen regime, microbiological and other indicators (Tab. 1.24) and also with regard to its possible utilization.

Oxygen demand is the ability of substances to utilize the dissolved oxygen for their stabilization. Chemical oxygen demand (COD) is a measure (mg $O_2 . l^{-1}$) of the materials present in water which may be readily oxidized, in order to ascertain the amount of organic and reducing material. Biochemical oxygen demand (BOD) is the amount of oxygen used by aquatic microorganisms in their metabolic processes. The evaluation of the $\frac{BOD}{COD}$ ratio offers the basic information concerning the content of biologically degradable and resistant constituents.

The amount of dissolved oxygen ($mg.l^{-1}$) depends on the water quality. The difference between the maximum possible concentration of oxygen (depending on temperature - Tab. 1.24) and the actual concentration is termed oxygen deficit. Their ratio is marked as saturation ratio.

Very important indicators of the basic chemical composition include the value of total dissolved solids TDS ($mg.l^{-1}$) and the value of suspended matter: The concentration of ions is presently followed in multiples of the content of matter in a system, whose number of molecules is equal to the number of atoms in 12.10^{-6}kg of carbon isotope ^{12}C at 1 liter ($mmol.l^{-1}$). The ions Cl^- , SO_4^{2-}, Na^+ , Mg^{2+} are followed in particular.

Constituents which may significantly affect the application of water for beneficial purposes include cations, namely sodium Na^+, potassium K^+ , iron Fe^+ , and Mn^+ , calcium Ca^+ and magnesium Mg^+ , further anions, namely nitrate NO_3^- and ammonia NH_4^- , chloride Cl^- , and also bicarbonates HCO_3^- , carbonate CO_3^- and hydroxide OH^+ , are generally considered in the light of their influence on alkalinity and hardness. Nonionic constituents include especially detergents, oily substances, phenols, cyanides and silica (silicon dioxide SiO_2).

The sum of the calcium and magnesium, expressed as an equivalent amount of calcium carbonate, was in the past followed as water hardness and is presently replaced by a separate following up of both these cations.

An important integrated property of water is the hydrogen-ion concentration pH, the negative logarithm to the base 10 of the hydrogen-ion concentration. A balance between dissociated hydrogen and hydroxyl ions denotes a pH value of 7.0, but this value has no special significance as an expression of alkalinity and acidity.

TABLE 1.24

Class Characteristics		Ia very clean	Ib clean	II slightly polluted	III intensively polluted	IV deterio-rated
a) Indicators of the oxygen regime						
Dissolved oxygen	mg.l^{-1}	>7	>6	> 5	>3	<3
BOD_5	mg.l^{-1}	<2	< 5	<10	<15	>15
Oxidizability by permanganate	mg.l^{-1}	< 5	<10	<15	<25	>25
Saprobity		oligo-	β-meso	β- α-meso	α- meso	poly -
b) Chemical indicators						
Dissolved matter	mg.l^{-1}	<300	<500	<800	<1200	>1200
Suspended matter	mg.l^{-1}	< 20	< 20	< 30	< 50	> 50
c) Special indicators						
pH		>6.5 <8.5	6.5-8.5	6.0-8.5	5.5-9.0	<5.5 >9.0
Temperature 1)		<22	<23	<24	<26	>26
d) Indicators of the microbiological pollution						
Coli index	pc.l^{-1}	<10^3	<10^4	<10^5	<10^6	>10^6

Categorization of surface waters according to the basic indicators of water pollution. 1) in mild continental climate.

A pH value of less than 7.0 denotes an excess of hydrogen ions. Such water is called acid, when the value pH is below 4.5. Acidity is caused especially by free mineral and carbonic acids.

A pH value greater than 7.0 indicates an excess of hydrogen ions, the alkalinity, i.e. ability of this water to neutralize acids. Alkalinity is caused especially by hydroxide, carbonate and bicarbonate.

Sensoric properties such as temperature, colour, turbidity, odour and taste are very important indicators of water quality, influencing its utilization for drinking purposes. They depend on the chemical and biological composition of water.

A simple indicator of water quality is the electrical conductivity, which depends on the concentration of salts and refers to the conductivity of a one centimeter cube of water at 25°C.

On the basis of a set of graduated indicators, surface waters can be divided into several classes (Tab. 1.24). For a better appreciation several less favourable values should be collected uniformly throughout the year. The classification itself has to be carried out using arithmetic means after the exclusion of values influenced by heavy rainfalls.

On the basis of the utilization of water for drinking purposes three classes can be distinguished

(a) water requiring mechanical treatment and disinfection only, or not requiring treatment at all,

(b) water requiring chemical treatment,

(c) water not suitable enough or unsuitable for municipal water supply (high content of nitrogen N, iron Fe or manganese Mn, high mineralization, high content of calcium Ca and magnesium Mg, fluorine F, as well as chemically, radiologically, biologically or bacteriologically highly polluted waters.

1.8 HYDROLOGIC CYCLE AS REGULATOR OF BIOLOGICAL PROCESSES

The biosphere is an open system of anorganic and organic, living and withered matter on the Earth, transforming solar energy by means of biological processes.

Complicated water solutions of compounds of biogenetic elements formed by living environment before the gradual development of life (Fig. 1.24). The presence of bioelements in water as well as the presence of water in nutriments and organic matter has a basic importance for metabolic processes and the growth of living matter (Tab. 1.25).

Living matter, or biomass, consists of the three main components: proteins, fats and sacharids. During the decay of organisms, absorption and disintegration of nutriments, water is separated from all the mentioned components (Fig. 1.24). The circulation of matter can be followed as chains of nutrition in connection with the energy transfer. Organisms can be classified according to their relation to this circulation as producers, consumers and destructors.

Organisms which produce organic matter by consuming anorganic compounds (microorganisms, flora etc.) are termed as producers. Organisms which are not able to perform this function and consume organic matter, formed by producers and other consumers, are termed as consumers (animals etc.). Destructors are organisms which decompose organic matter, thus producing anorganic components (microorganisms etc.) (Tab. 1.26).

In ecosystems, subsystems of the biosphere, these biotic communities are interconnected with the biotic and abiotic environment, thus forming closed and independently functioning systems, whose biotic structure, cycle of nutriments and energy flow can be exactly determined (Fig. 1.25).

The energy in ecosystems basically has three forms:

- kinetic energy - whose manifestation is external motion,

- potential energy - accumulating in relation to the environment,
- internal energy - manifestated by internal movement and internal relations.

TABLE 1.25

Function	Description
Solution dissolving agent	Water dissolves partially or fully the prevailing part of anorganic and organic compounds, forming foodstuff and nutriments.
Chemical activator	Water fissure molecules, whose motion enables the approach and mutual reaction of molecules of different compounds.
Heat regulator	The high specific heat of water helps to maintain a stable temperature of organisms, without any excessive fluctuation. Its optimum value is kept by evaporation of water, which requires much energy because of the high latent heat of vaporization.
Regulator of pressure	The propagation of pressure in water is uniform in all directions, enabling the cellular pressure to be maintained and regulated.
Distribution agent	Water distributes nutriments to and takes away wastes from different parts of the living organisms. It also distributes thermal energy, transporting it from the place of its occurrence (muscles, liver) to cooler parts (skin).
Economizing agent for water organisms	The unit mass of these water organisms is the same as that of water, thus removing the effect of gravity and economizing their energy requirements.

Functions of water in the biomass.

The transformation of energy during its flow through the ecosystem takes place in accordance with physical laws, its manifestation is the motion and change of temperature. Apart from the law of conservation of energy, the law of degradation of energy also makes itself felt: during any process part of the energy changes into heat. According to Darwin-Lotke's rule, during a quick change of energy, heat losses form one half of the energy total. Due to these energy losses, any process in ecosystems is one-way. Heat losses are transferred to the environment.

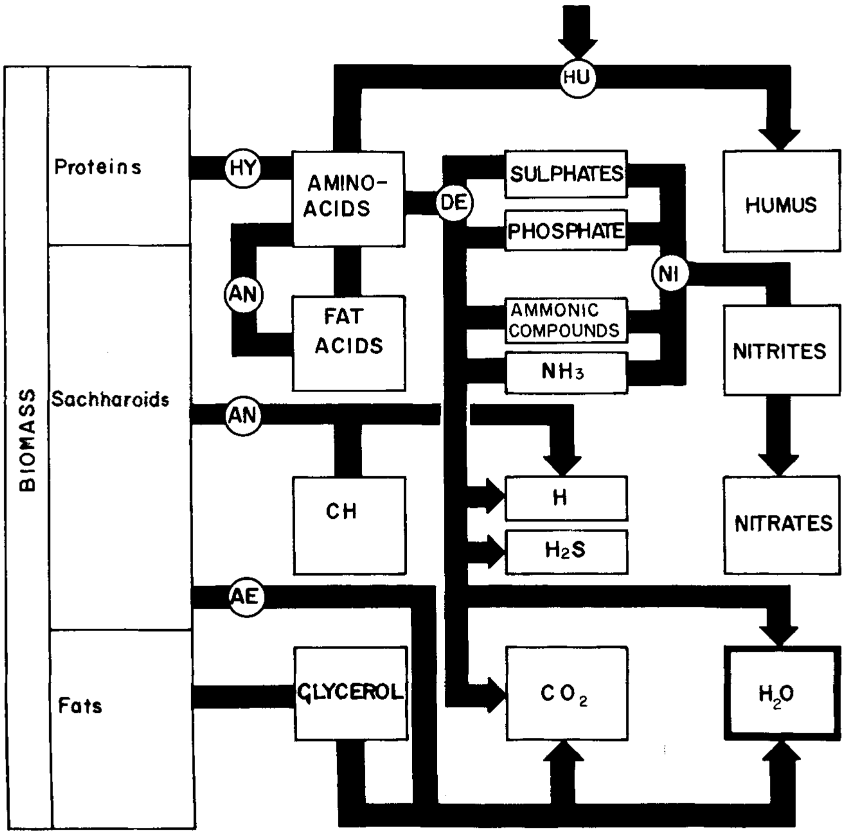


Fig. 1.24. Block diagram representing the decay of the basic components of the biomass. Processes: AE - aerobic, AN - anaerobic, HY - hydratation, HU - humification, NI - nitrification, DE - decarboxylation, dezamination, hydrolysis.

The ecosystem is a community, including all organisms of a certain space, and abiotic elements, acting in the climatic regime, whose relation with the environment is stable and determined, by the input and output of energy and matter.

The formation of regional ecosystems depends on topographical, soil and climatological conditions with the prevailing influence of solar radiation (temperature) and rainfall (Tab. 1.27). In natural ecosystems of forests, steppes, deserts, water formations etc. the input of matter is not significantly affected by human activities (pollution) and solar radiation is the sole source of energy.

In the framework of these regional ecosystems, depending on the macroclimate, local ecosystems exist, influenced especially by the local topographic, soil and moisture conditions and by the conditions of the meso- and microclimate. With regard to the wetness of their habitats, plants can be classified in four groups (Tab. 1.28).

TABLE 1.26

Organic groups (species)	Nutriment substance	Production	Process	Simplified formula
Producers (green plants, sulphur bacteria)	anorganic compounds of biogeo-elements	oxygen biomass	Photo-synthesis	$6\ CO_2 + 6\ H_2O + 1612\ kJ = C_6H_{12}O_6 + 6\ O_2$
			Chemosyn-thesis	$6\ CO_2 + 6\ H_2S + energy = C_6H_{12}O_6 + 6\ S$
			Biological uptake	$265\ CH_2O + 16\ NH_3 + PO_4 + 146{,}5\ O_2 + energy = C_{106}H_{180}O_{45}N_{16}P + 159\ CO_2 + 199\ H_2O$
Consumers (herbivore, carnivore omnivore)	organic matter: proteins, sachharoids fat	waste organic matter CO_2 H_2O	decomposition of sach-haroids	$C_6H_{12}O_6 + 6\ O_2 = 6\ CO_2 + 6\ H_2O + 161{,}1\ kJ$
Detrivore (fungi, bacteria)	Waste organic matter	CO_2, H_2O NH_3, SO_4 PO_3, salts	decomposition	

Categorization of nutrient relationships in terrestrial or aquatic ecosystem. Nutrients continually circle within the boundaries of the ecosystem. Fluxes across the ecosystem's boundaries link it with the environment, i.e. nutrient, soil and atmospheric compartment.

Four zones of plant communities can be distinguished along the water courses and reservoirs as a result of the impact of water level fluctuation (Fig. 1.26, Tab. 1.29).

Living processes and changes in ecosystems are managed by the transfer of matter, especially by means of water and air, and energy. Under the influence of human activities stable natural ecosystems change into (often unstable) anthropogenetic ecosystems

(a) agricultural ecosystems, where the dominant source of energy is solar radiation and the climate determines the type of cultivated agricultural plants, but the flow of matter and energy is significantly influenced hy human activities,

(b) industrial ecosystems, where in addition to the supplemented input of matter, the energy input is considerably supplemented by man-made energy,

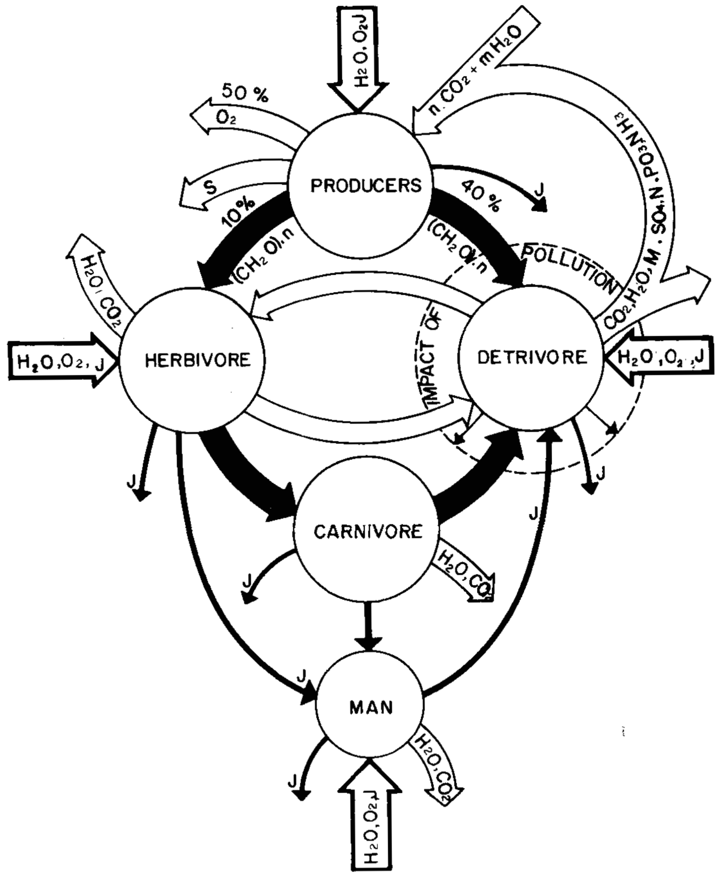


Fig. 1.25. Circulation of water and nutriments in ecosystems: the transfer of matter including water, proteins, sachharoids, fat etc. is represented by thick black arrows, energy input and output by thin arrows. The impact of pollution (dotted arrow) changes the input of nutriments, improving living conditions for detrivores, thus changing the ecological succession to the disadvantage of carnivores first. J - energy

TABLE 1.27

Temperature / Rainfall	Minimum	Optimum	Maximum
Maximum	-	steppe	desert
Optimum	tundra	mixed and coniferous forest	tropical monsoon forest
Maximum	-	salty marshes	tropical jungle

The dependence of the basic natural ecosystems on temperature and rainfall.

TABLE 1.28

Category	Characteristics	Selected species
Hydrophytes	grow in water swamps and bogs	water plants, phytoplankton, pondweed, rice, cattail
Hygrophytes	need moisture, not resistant against drought	ferns, moss
Mesophytes	medium water requirements survive both short periods of wetness and drought	grasses, wood
Xerophytes	low water requirements drought-resistant	cacti, haloxylon

Categorization of plants with regard to the relative wetness of their habitats.

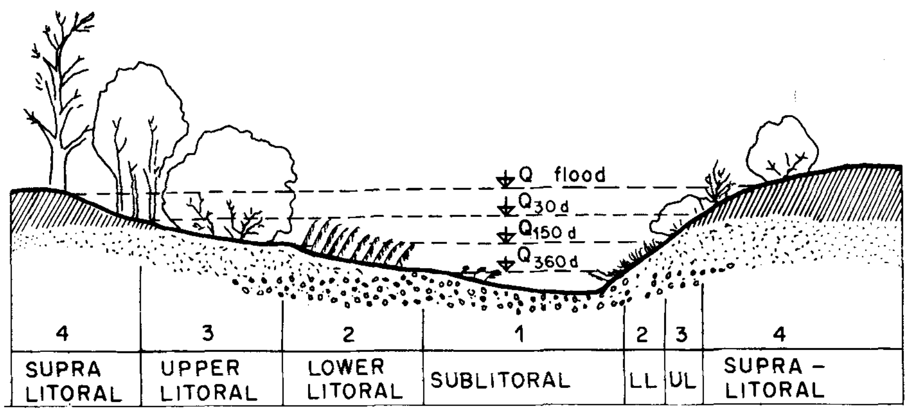


Fig. 1.26. The development of the flora in the sublitoral (1), litoral (lower - 2, upper - 3) and a supralitoral (4) zone along a stream or a reservoir shore depends on the frequency of flooding and on the groundwater table. Soft species occur especially in the litoral zone, hardwood species in the supralitoral zone.

(c) degradated ecosystems, where the additional input of matter (water, air and/or soil pollution) changes the input of energy and results in the disintegration of stable natural ecosystems.

TABLE 1.29

Zone	Characteristics or limitation	Characteristic wood	other species
Supra-litoral	flood only exceptionally	Hard: oak, maple, elm, ash-tree	grasses,
	water table Q_{30d}		
Upper-litoral	occasionally flooded	Soft: willow, poplar, alder	bramble, nettle, meadow-sweet, rush, willow-herb
	water table Q_{150d}		
Lower litoral	frequent water table fluctuation	Soft: willow, alder, hedge,	brooklime, bulrush, monkey flower, water celery, water mint, water forget-me-not, reed, reed-grass
	water table Q_{360d}		
Sub-litoral	permanently flooded	no trees	bog-pond weed, bulbous rush, floating clubrush, water-lilly, water crow foot, strapweed

Classification of shore zones according to the frequency of their flooding and characteristic representatives of relevant plant ecosystems.[1]

1.8.1 Interrelationship of Aquatic Ecosystems and Water Quality

An aquatic ecosystem, i.e. a system of organic communities in a certain water formation, where this community lives in a stable relation with its abiotic environment, represents an example of a closed chain of nutrition.

In this enviornment, Liebig's law of minimum is of particular significance: The missing energy or bioelement decides on the course of the production process. It is impossible to prove the presence of such limiting bioelements (usually phosphorus P, potassium K, nitrogen N etc.) in water, because it is changed into organic matter immediately after its entry into the system.

The production process is, in addition to this, also governed by the presence of matter stimulating the growth, primarily of vitamins: tiamin, biotin, cobaltamine etc. The consequence of a high content of nutriments and stimulating matter in water is eutrophication, manifestated by its biological overproduction.

Uhlmann (1975) expresses the circulation of matter in the aquatic ecosystem by the differential equation. The change in the concentration of biomass can be formulated as follows:

$$\frac{dZ}{dt} = {}_2k_{21}.P.Z + {}_2k_{24}.B.Z - {}_1k_{02}.Z - {}_1k_{42}.Z - {}_2k_{32}.F.Z \qquad (1.80)$$

Z - zooplankton

P - phytoplankton

B - bacteria

F - fishes

$_1k$ - coefficient of rate for reaction of the 1.range

$_2k$ - coefficient of rate for the reaction of the 2.range

The index on the right of the coefficients marks the receiver (1st number) and the supplier (2nd number).

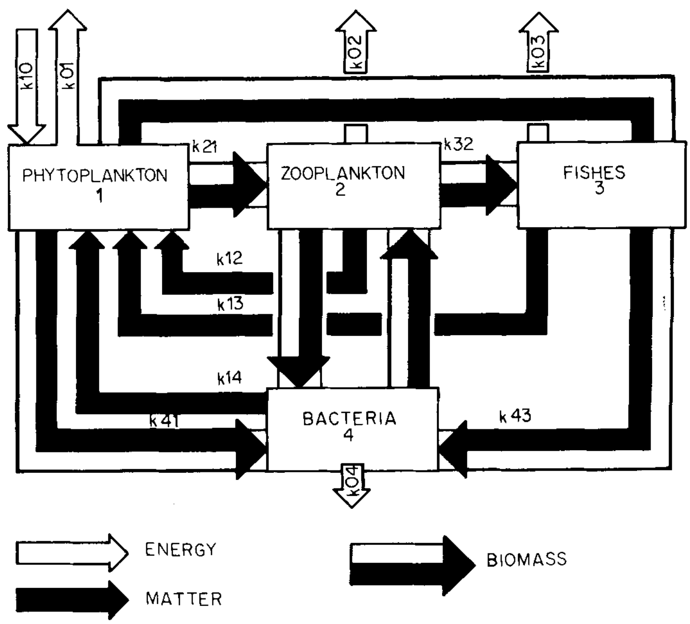


Fig. 1.27. Couplings of the aquatic ecosystem according to Uhlmann (1975): phytoplankton (1), zooplankton (2), fishes (3), bacteria (4). Index ij marks the transfer of matter or energy from the part j to the part i of the ecosystem, 0 - the abiotic environment.

The biomass in flowing waters is influenced by the inflow, as can be expressed by the differential equation

$$\frac{dX}{dt} = \mu \cdot X + Q \cdot X' - (i_1 + i_2) \cdot X \qquad (1.81)$$

X - biomass (g)

μ - daily increment ratio (d^{-1})

Q - water inflow $(l.d^{-1})$

X' - specific inflow of the biomass $(g.l1^{-1})$

i_1 - ratio of biomass outflow (d^{-1})

i_2 - ratio of biomass utilization by consumers and destructors (d^{-1})

In newly constructed river channels and after the flood

$$\frac{dX}{dt} \gg 0. \tag{1.82}$$

After this initial phase, the value of the biomass increment decreases to the value of the biological balance, characterized by

$$\frac{dX}{dt} = 0 . \tag{1.83}$$

The water quality with regard to its biological properties can be classified in terms of its saprobity or trophicity. The saprobity is the biological state of water, determined on the basis of the presence or absence of biocoenosis, that is characteristic for a certain degree of biochemical decay, i.e. in relation to the degree of pollution (Tab. 1.30).

The saprobity characterizes the changing properties of the water environment during a certain period, thus differing from the physical and chemical indicators, which characterize the actual state only. For this reason, an explicit relation between the saprobity and relevant physical and chemical indicators does not exist, though the classification system of saprobity is closely interrelated with the biological oxygen demand (BOD) of water (Fig. 1.28).

The trophicity is the ability of water to nourish water organisms. Nauman (1932) classified the trophicity on the basis of the surplus, average or undersized values of the basic physical and chemical preconditions of the development of different biocoenosis. Seven basic trophical types of stagnant and flowing waters follow as a consequence of combining these criteria (Tab. 1.31).

Some changes and combinations are chemically impossible, such as alkalitrophicity with siderotrophicity, acidotrophicity and dystrophicity, or acidotrophicity with eutrophicity. A practical classification is based on the mean annual values.

The views on the interrelationship of the saprobity and the trophicity have not yet been unified. Kolkwitz (1935), Sládeček (1961) and others state that the eutrophization and self-purification processes are only two directions of one natural process, relating in this way the degree of saprobity with the degree of trophicity. The scale of trophicity is then the ratio of the production of living matter to respiration, liberating the organic energy, bonded by living matter.

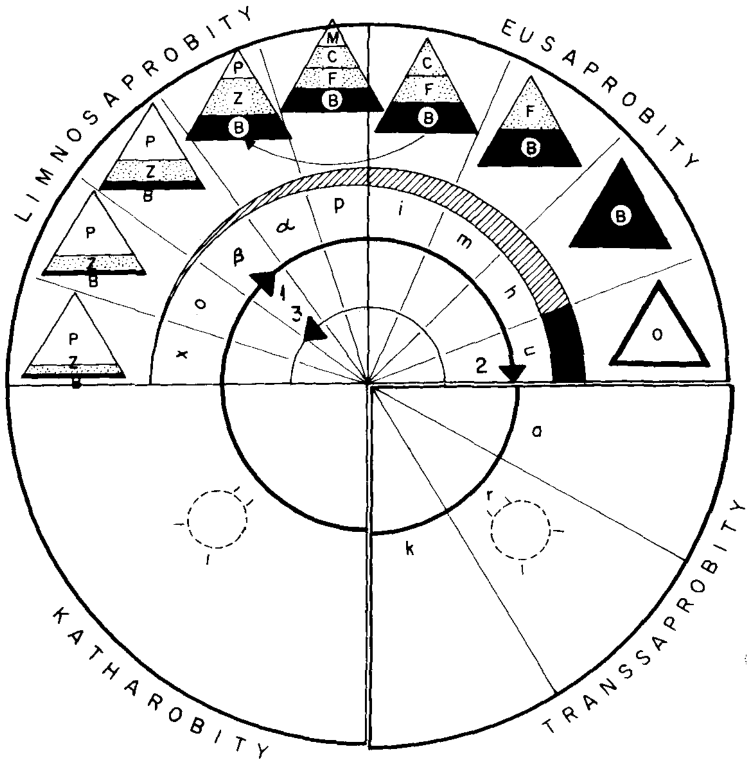


Fig. 1.28. Circular representation of water quality by degree of saprobity and relevant structure of aquatic ecosystems according to Sládeček (1972): Limnosaprobity: (x-xeno, o-oligo, β-betamezo, α-alphameso, p-polysaprobity), Eusaprobity (i-iso, m-meta, h-hyper, u-ultrasaprobity), Transaprobity (a-anti, r-radio, k-kryptosaprobity). Detrivore marked black: B-bacteria. Consumers-herbi-, carni-and omnivore marked dotted: Z-zooplankton, C-ciliata, F-zooflagellata. Producers- green plants and autotrophic bacteria marked white: P-phytoplankton, M-mixotrophic flagellata. O-no life. Arrows show the direction of eutrophization (1) and further pollution (2), decay and self-purification (3). Dsahed segment represents the increase in material input and output (and also the increase in the biological oxygen demand).

TABLE 1.30

Symbol Saprobity	Process		Symbol	Degree of saprobity	Pollution (degree)	BOD_5 $mg.l^{-1}$	Plankton (in ml^{-1})	Chlorophyle ($mg.m^{-3}$)	Primary production ($mg.m^{-3}.d^{-1}$)	($g.m^{3}.year^{-1}$)	Decomposition / Salts / Input output	Trophicity
K Katarobity	clean water	abiotic no life			without pollution	0	1	0	0	0		atrophicity
L Limnosaprobity	polluted water; self-purification/eutrophization	completed oxydation	x	xenosaprobity	very light	1	100	1	50	10	Decomposition, Salts, Input output ↓	ultra-oligotrophicity
		completed reduction	o	oligosaprobity	light	2,5	1000	5 (20)	100 (1500)	30 (500)		oligotrophicity
		starting oxydation	β	mesosaprobity	medium	5	10^5	300 (1500)	500 (12000)	150 (4000)		β-eutrophicity
			α	mesosaprobity	medium	10	10^6	1000	1500	300	↑	α-eutrophicity
		predominant reduction	p	polysaprobity	heavy	50	10^7	10000	12000	4000	growth	polytrophicity
E Eusaprobity	biologically degradable matter; self-purification ↑	biological	i	isosaporbity	(ciliatic)	400	1000	3	100	30		isotrophicity
		and	m	metasaprobity	(hydrogen sulfidic)	700	0	+	+	+	↓	metatrophicity
		chemical (see	h	hypersaprobity	(bacteriologic)	2000	0	0	0	0		hypertrophicity
		column 8)	u	ultrasaprobity	(abiotic)	12.10^4	0	0	0	0	↑	ultratrophicity
T Transsaprobity	biologically non-degradable matter; abiotic	chemical, abiotic, anorganic, no life	a	antisaprobity	toxic							
			r	radiosaprobity	radioactive							
			k	kryptosaprobity	physical							

Categorization of water quality according to its saprobity and trophicity. Relationships of the metabolism, self-purification processes and the trophicity. Values concerning chlorophyle and primary production are related to the result of the eutrophization process.

TABLE 1.31

Physical and chemical indicators			pH	Poly-typus	Meso-typus	Oligo-typus
Summer temperature just below the water table		^{o}C		> 20	15- 20	< 15
Calcium oxide	CaO	$mg.l^{-1}$		>100	25-100	3- 25
Nitrogen	N	$mg.l^{-1}$		> 40	1- 0	0
Phosphorus	P	$mg.l^{-1}$		> 25	1.5	0
Humus acids		$mg.l^{-1}$		80-100	25- 50	25
Biotypus	**Characteristics Occurrence**		**pH**			
alcalitrophic	poor plankton carst		> 7	Ca	-	N,P,Fe
siderotrophic	limonitic bed			Fe		
argilotrophic	high turbidity loamy and silt sediments			humus matter		
eutrophic	high content of nutriments rich phytoplankton mud, marshes bottom hydrogen sulphide		> 7	N,P	N,P	
oligotrophic	clear water, poor phytoplankton, poor flora in the neighbourhood new reservoirs, mountain lakes		$\doteq 7$			N,P,Ca
acidotrophic	turfic bed		$< 5,5$			Ca
dystrophic	browny water, poor phyto-plankton occasionally rich zooplankton marsh without odour		< 7	humus matter		Ca,P,N
hypertrophic	heavily polluted water, degradated aquatic life					

Categorization of water reservoirs, their trophic- and biotypes, physical and chemical indicators according to Nauman (1932), completed by Thienemann (1942) and Šrámek/Hušek (1948).

1.9 RUNOFF PROCESS AS REGULATOR OF THE LIVING ENVIRONMENT

Basic characteristics influencing the life and its environment gradually change with a characteristic gradient in the course of the longitudinal profile of the river. They also have an important impact on the utilization of water for different beneficial uses as well as on the ecosystems and the utilization of the neighbouring area.

Some of these characteristics, namely geomorphological and hydraulic, and also selected hydrological characteristics, are quite independent of the season. The course of the rest depends on the annual season and on the climate, especially in the case of rivers running through different climatological zones (Fig. 1.29).

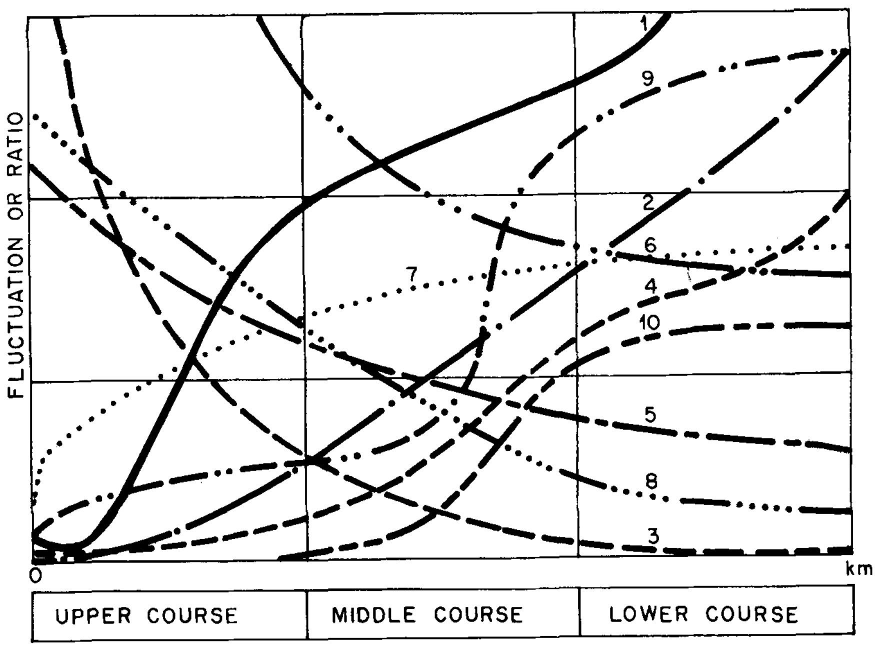


Fig. 1.29. The development of basic characteristics of a water course represented in its longitudinal profile, offering important information for the concept of agricultural, industrial and urban development: 1 - valley width, 2 - average discharge, 3 - river channel slope, 4 - river channel width, 5 - velocity of flow, 6 - fluctuation of discharge, 7 - water temperature, 8 - aeration, 9 - biochemical and chemical oxygen demand, 10 - sedimentation rate.

The suitability of a riverside area for different development purposes can be derived from the course of the mentioned curves by analysing the relevant interrelationships. Some relations appear to be contradictory: Lower and middle course areas are more suitable for the location of housing and industrial estates due to the necessary space. From the water supply point of view, upper courses are more suitable having more favourable conditions for reservoir construction.

Upper courses offer a high head and thus more favourable conditions for water power generation - with reservoirs as well for peak power production. Lower courses with high, sustained discharges offer conditions for the construction of run-of-river plants with lower heads. They offer only restricted possibilities for the construction of reservoirs, but favourable conditions for inland navigation.

Protection against floods can be achieved more economically by a proper location of the relevant estates out of the flood plain at the upper courses if relevant valleys are sufficiently wide, and by river training in the middle and lower courses.

The longitudinal proportion of the water course in an open area creates a natural traffic artery: not only its channel, but also the riversides on both banks. Fluctuations in the water table limit the beneficial utilization of the flooding area for communication, housing and industrial estates, which have to be protected from overflooding. Nevertheless, this zone usually has exceptional climatological and aesthetic conditions, extremely suitable for recreation. It is, therefore, useful to reserve this zone, especially in cities, for pedestrain communications or industrial quarters by a zone of plants or by a communication line (Fig. 1.30).

Communication, recreational, industrial and housing areas are mutually interrelated. The location of a housing estate in the second zone is aesthetically and functionally favourable when it corresponds to the topography, and provided that flood protection measures are realized.

The function of water courses for housing and industrial estates is twofold: they are used as sources of water supply and as recipients of waste disposal. These two functions are contradictory. Besides, the utilization of water courses for waste disposal is contradictory with their urban and aesthetic functions.

The aesthetic enjoyment of water as an intangible natural factor is manifestated in three dimensions

- in the water scenery, created by the synthesis of the water formation and its surroundings namely river banks,
- in the visual unit - i.e. the part of the landscape which is visually accessible from one place,
- in the landscape unit, i.e. formed by a geographically complex area.

The aesthetic properties of water are formed by its prominence, especially by its

- continuity and comprehensiveness,
- diversity,
- vivacity and variability.

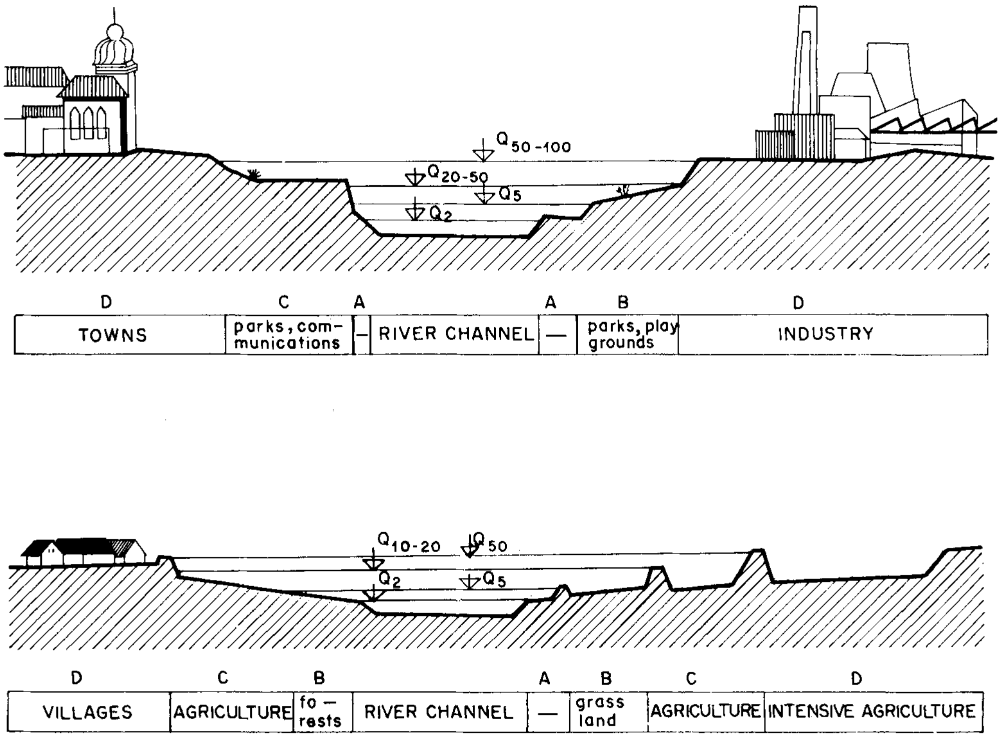


Fig. 1.30. Regulation of flood plain use derived from frequency of flooding and differing in the town and outside the town: A - floodway, B,C - partially protected zones, D - protected zone.

These properties depend on qualitative and quantitative factors. The aesthetic expression of a reservoir or a stretch of stream follows from its comprehensive continuous form, limited by the diversified banks, whose edges form limits between the water and riverside ecosystems. In a built-up area three categories can be distinguished on the basis of the dimension ratio of the housing, industrial, recreational etc. area to the width of the water level:

(a) dimensions of the water table are not remarkable with regard to the dimensions of the relevant area,

(b) dimensions of the water level do not differ remarkably from the dimensions of the relevant estate,

(c) dimensions of the water table exceed the dimensions of the relevant estate.

The resulting aesthetic enjoyment depends in any category on the quality of the architectural structure, but the medium category offers the most favourable conditions for an aesthetic and balanced effect of the water table in an urban setting. Architectural complexes in these conditions evoke the strongest aesthetic emotions.

Chapter 2

WATER AND ITS FUNCTION IN SOCIAL SYSTEMS

2.1 CATEGORIES OF WATER UTILIZATION

Water use includes all individual and collective activities of human society which affect water resources and change their quality and quantity. The beneficial utilization of water depends, as does its natural functions, on the water properties. Water uses include

(a) in-stream (navigation, hydropower generation etc.) and on-site (ponding etc.) uses, without withdrawing water from the resources,

(b) water withdrawal, i.e. diversion of water from the surface or groundwater resource

- local, i.e. on-site use in the neighbourhood of the resource,
- collective mass use by means of complicated supply, distribution and drainage (sewerage) networks.

The method of water use and distribution depends especially on the degree of development and organization of the social system. It becomes systematic as a consequence of agricultural, social and industrial development, gradually creating more extensive and complicated networks for water conveyance, distribution, use and drainage.

From the beginning water has been the basic need and precondition of human existence, but gradually it has also become a raw material which has been turned into a means of development in itself. An efficient water use in an organized society is managed by means of licences and concessions. Generally, no licence is required for non-organized small-scale water withdrawals and in-stream uses, especially individual, on-site washing, bathing etc., which is considered as a general use of water (Tab. 2.1).

Water supply includes all organized activities for the use of withdrawn water. Its purpose is to ensure the necessary water quantity of the required quality at the requested place in terms demanded by water users, i.e. by the

(a) population (municipal and rural demand),

(b) agriculture and forestry,

(c) industry and infrastructure (especially energetics and transport).

The functions of water can be categorized as natural and social i.e. water demands - in-stream, on-site uses and withdrawals. The relevant categories of water demands have a characteristic impact on water quality and quantity (Tab. 2.2).

TABLE 2.1

I Natural functions	II In-stream uses	III Withdrawals	
Soil moisture conservation, soil transformation	Groundwater table & soil moisture regulation HC	Drinking & cooking HQ	Urban and rural water requirements
Transport of biogeoelements	Waste transport & disposal HV, LQ, HP	Other domestic uses HQ, HP	
Biological functions	Fish and wildlife SR	Public uses HQ, HP	
Regulatory climatic functions	General utilization LC	Heating, steam power, boiling, climatization HP, HC	Industrial & infrastructural water requirements
Aesthetic enjoyment	Water transport public & goods	Processing HP	
Other environmental functions	Hydropower generation HV, LQ, LC	Cooling HV, LQ, HC	
	Recreation & water sports LC	Mining & hydraulic transport HP, LQ	
		Other industrial & agricultural uses LV	
		Irrigation HV, HC	Agricultural water requirements
		Processing HP	
		Livestock & poultry breeding HP	
		Fish & water fowl breeding	

Categorization of natural function of water and of water utilization. Abbreviations:

Consumptive use	HC - high	LC - low
Quality requirements	HQ - high	LQ - low
Impact on water quality	HP - high	LP - low
Volume requirements	HV - high	LV - low
High space requirements	SR - high	

2.2 WATER REQUIREMENTS AND WATER CONSUMPTION

The term water resources refers to the exploitable surface water and groundwater in a defined water management unit (e.g. catchment basin). Because of their periodic annual replenishment, the most suitable unit for their definition is the m^3 per year (dry, wet, mean) which leaves the relevant water management unit. The static interpretation is the amount of surface water or groundwater (m^3) within the water resource.

TABLE 2.2

Quantity	Water quality (properties)	Other factors
Volume	physical	water table width
(m^3)	chemical	riverbed width
Discharge	biochemical	channel depth
($m^3.s^{-1}$)	biological	groundwater table depth
Runoff ($m^3.s^{-1}$)	(physiological)	water table fluctuation
- total yearly	bacteriological	velocity of flow
- seasonal	radiological	sediment transport
- average	organoleptic	icebound regime
- minimum	(sensorial)	accessibility of shores
- maximum	psychic	utilization of the riverside
- minimum	medical (sanitary)	shore vegetation
- fluctuation		bank protection

Basic parameters of water occurrence and factors determining the possibilities of water utilization.

The amount of water diverted from the water resource in a given period is the water withdrawal ($m^3.s^{-1}$, m^3 per year). The water withdrawal is the input of the water supply system. The quantity of water returned to water resources after use (with a changed quality) is return flow. It forms the output from the supply and drainage system. The quality of the return flow is inferior in comparison with the quality of the withdrawal due to the processes of water use.

A given water requirement is the amount of water which is necessary for the undisturbed course of any natural or technological process. It includes water consumption (consumed flow), i.e. the difference between water withdrawal and the net return flow, that consists of consumptive use and losses. The consumptive use of water represents that part of the water consumption which, in the course of the natural or technological production process, becomes an integrated part of

(a) the product or

(b) the by-product or the waste matter.

The water loss represents that part of the water requirement, water consumption, water withdrawal or water resource which returns into the hydrologic cycle in the form of seepage, leakage, percolation, evaporation etc. Losses may be either

(a) productive, i.e. indispensable for the course of the production process (e.g. evapotranspiration for the agricultural production), or

(b) non-productive, a part of which is

- inevitable, i.e. losses which cannot be supressed in a rational or economic way, and the rest is
- the wastage, i.e. water that escapes from the resource, the supply system or the production process without being used.

The consumptive use (consumed flow) can be expressed by the following simple equation

$$C = W - (F - B) \qquad (l.s^{-1},\ m^3.s^{-1}) \qquad (2.1)$$

C - water consumption

W - water withdrawal

(F - B) - net return flow

F - return flow at the end of the sewerage system

B - undesired inflow into the sewerage system (drainage of groundwater, conveyed springs etc.)

From the foregoing terminological description it also follows that

$$C = \sum_{i=1}^{3} U_i + \sum_{i=1}^{4} \Delta_i \qquad (l.s^{-1},\ m^3) \qquad (2.2)$$

U_1 - consumptive use by means of the product (e.g. fruit)

U_2 - consumptive use by means of the by-product (e.g. trunk, branches, leaves)

U_3 - consumptive use by means of the waste material (e.g. weeds)

Δ_1 - productive losses (e.g. evapotranspiration) (Δ_p)

Δ_2 - non-productive inevitable losses (e.g. leaching, seepage in irrigation piping) (Δ_i)

Δ_3 - non-productive evitable losses caused by the state of system or by the insufficient technology e.g. seepage and evaporation in irrigation canals) (Δ_e)

Δ_4 - non-productive wastage caused by wrong operation (Δ_w)

The return flow, except for the undesired inflow into the system, which was used in the production processes and occasionally also water which was necessary to dilute this water from the production processes with the aim of achieving the desired water quality of the waste water before returning it into the water resources can be expressed as follows

$$F = F_1 (+ F_2) + B \qquad (l.s^{-1}, m^3) \qquad (2.3)$$

F - return flow (diluted waste water)

F_1 - waste water from the production process

F_2 - dilution water

B - undesired or occassional inflow into the system.

The consumptive use of water entering the product is thus the key constituent of water requirements. The quality of the product depends on the technology, which also determines the consumptive use of the water entering the by-product or the waste material, upon which the economy of the production also depends. The economy of the production process, from the water management point of view, can be improved by decreasing the amount of waste material, or by decreasing the size of the product, if possible.

From the point of view of the balance of water resources and needs the most important problems are the changes in the water quality and also the place of discharge of the return flow and the return of losses into the water resource (Fig. 2.1). Consequently losses can be classified in the following way:

(a) return losses which enter

- the same water resource from which the water was withdrawn Δ_{r1}
- other water resources in the same catchment basin Δ_{r2}
- water resources in some other catchment basin Δ_{r3}

(b) non-returnable losses (evaporation and evapotranspiration) which escape from the relevant resources and enter the atmosphere. Δ_n

Water consumption, defined as the difference between the withdrawal and the return flow, can thus be expressed as follows:

$$C = \sum_{i=1}^{3} U_i + \sum_{i=1}^{3} \Delta_{ri} + \Delta_n \qquad (l.s^{-1}, m^3) \qquad (2.4)$$

The mathematical definition of water consumption varies according to the water balance of different systems. From the point of view of the particular water resource, the water consumption C_r does not contain the first return loss - the return loss entering the water resource from which the water was withdrawn

$$C_r = \sum_{i=1}^{3} U_i + \sum_{i=2}^{3} \Delta_{ri} + \Delta_n \qquad (l.s^{-1}, m^3) \qquad (2.5)$$

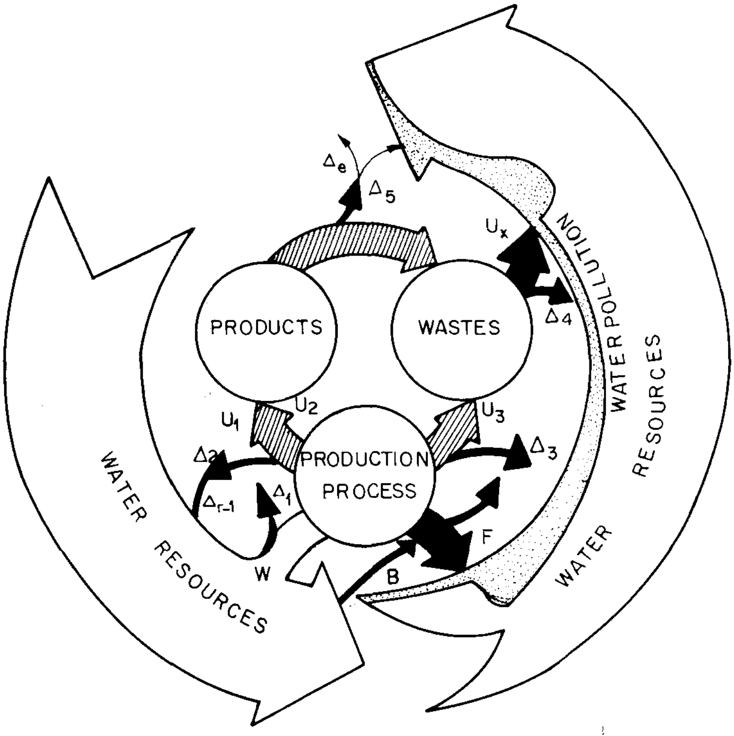


Fig. 2.1. Schematic representation of water use after physical diversion during an industrial or biological process, which results in production, accompanied by consumptive use by the product U_1, by-product U_2 and waste material U_3 as well as by water losses $\Delta_{1-n}t$. The use of the product, resulting in its change into wastes and the decomposition of wastes can lead to water recovery U_x: Waste waters from the production process as well as the leached wastes cause water pollution.

From the point of view of the catchment basin, the value of the water consumption C_b includes neither the first nor the second return loss

$$C_b = \sum_{i=1}^{3} U_i + \Delta_{r3} + \Delta_n \qquad (1.s^{-1}, m^3) \qquad (2.6)$$

From the point of view of the hydrologic cycle, the water consumption C_c is formed only by the consumptive use:

$$C_c = \sum_{i=1}^{3} U_i \qquad (1.s^{-1}, m^3) \qquad (2.7)$$

The consumptive use is

(a) short-term (transient, lasting several days or years)

(b) long-term (also from the point of view of geological time) or lasting (stable chemical links).

Therefore

$$C_c = \sum_{i=1}^{3} U_i \cdot f_i \cdot t^{-\frac{1}{n_i}} \tag{2.8}$$

f_{1-3} - variables

t - time

n_{1-3} - coefficients of the time effect

The mentioned general process not only occurs in the course of the municipal, rural, industrial and agricultural water supply, but also during the natural production process of different biological functions and during the development of cellular matter.

Waste matter from the natural and technological processes, also formed by the utilization of the products, usually disintegrates and releases water which also enters the hydrologic cycle. The growing of cellular matter such as wood, peat, coal, oil etc. causes long-term consumptive use. The increase in quantity of cellular matter may theoretically result in the consumption of all the water resources available in a certain area, but the homeostasis, i.e. the dacay of cellular matter etc. limits this undesired development.

Water requirements and water consumption in the course of agricultural and industrial processes may be distinguished as

(a) minimum,
(b) optimum,
(c) non-economic.

Minimum water requirements or minimum water consumption during a specific production process can be achieved under special conditions, e.g. in laboratories. The water-saving technology which achieves the minimum water requirements may differ from the technology which achieves the minimum consumption of water, and both can be unsuitable from the point of view of the total production cost.

An optimum water requirement and optimum water consumption are attained when the product of desired quality is produced under the conditions of minimum total social effort, i.e. from the point of view of the national economy, by applying an optimum technology. The non-economic water requirements and water consumption exceed this optimum value.

Low losses and optimum water consumption are indispensable preconditions for any efficient industrial technology. Low water requirements depend primarily on the degree of recirculation. An efficient water resources management policy is based on a decrease in water consumption and an improvement in the waste water quality.

The prevailing, productive, non-returnable losses form the indispensable precondition for the efficiency of agricultural processes. The efficiency of water utilization in agriculture can be followed up, first, on the basis of the ratio of the productive evapotranspiration and non-productive losses

$$x_e = \frac{\Delta_1}{\sum_{i=2}^{4} \Delta i} \qquad (2.9)$$

and, second, on the basis of the ratio of the consumptive use entering the product and the consumptive use of the other cellular matter:

$$x_u = \frac{U_1}{U_2 + U_3} \qquad (2.10)$$

2.3 IN-STREAM AND ON SITE WATER USE

On-site uses, such as soil moisture conservation, flood loss management, the maintenance of swamps, dambos and other wetlands are closely interconnected with the natural functions of water. In-stream uses such as hydroelectric power generation, navigation, recreation, water sports and waste disposal are closely connected with the social functions of water. In-stream uses are characterized by insignificant consumption. The only water consumption mainly consists of losses. For these uses the volume of water is important, and not the discharges. The applicable unit of measurement is m^3. The water consumption consists of return losses Δ_{r3} which enter other catchment basins and non-returnable losses n:

$$W = V + \int_0^t \Delta_{r3} + \int_0^t \Delta_n \quad (m^3) \qquad (2.11)$$

$$C = \int_0^t \Delta_{r3} \quad \int_0^t \Delta_n \quad (m^3) \qquad (2.12)$$

V - volume of water necessary for the in-stream or on-site use of water

W - total water requirements

These equations can be extended to express the natural functions of water in the following way

$$W = V + \int_0^t (U_1 + U_2 + U_3) + \int_0^t \Delta_{r3} + \int_0^t \Delta_n \; (m^3) \qquad (2.13)$$

$$C = \int_0^t (U_1 + U_2 + U_3) + \int_0^t \Delta_{r3} + \int_0^t \Delta_n \; (m^3) \qquad (2.14)$$

Losses due to the in-stream use of water should be considered as the difference between the values before use and the values of losses occuring during in-stream use. These losses consist of leakage and conveyance into other catchment basins as a result of beneficial operation, and of evaporation and seepage due to the extended water table and enlarged river channel, when necessary for the relevant use.

2.3.1 Waste Disposal

The hydrosphere is used for waste disposal and enables, primarily in water courses, the transportation and removal of wastes. Waste waters and waste materials which are conveyed into surface and groundwater bodies enter the natural processes of the generation of water quality, enabled by the thermal, chemical and kinetic energy of water, by the thermal and chemical energy of the riverbed, and by the thermal and luminous energy from the environment of this system.

TABLE 2.3

Physical	Processes Chemical	Biochemical, biological
warming - cooling	neutralization	aerobic disintegration
disintegration	oxidation	anaerobic disintegration
mixing, dispersion	reduction	assimilation
dillution	coagulation	dissimilation
sedimentation		biological filtration
adsorption,desorption		adsorption of low organism
washing away		by higher ones
oxygen exchange		decay of living matter
oxygen diffusion		

Categorization of basic processes of water self-purification.

The erosion, fall-out and waste disposal results in an increase in bed load, suspended load and dissolved matter along the water course. But a complex of other physical, chemical, biochemical, biological and bacteriological processes as a manifestation of the homeostasis in nature further changes the water quality. Self-purification processes accompany the water pollution process in the course of sediment transport and erosion processes, resulting in the destruction and melting of erosion products, waste material and fall-out (Tab. 2.3, Fig. 2.2).

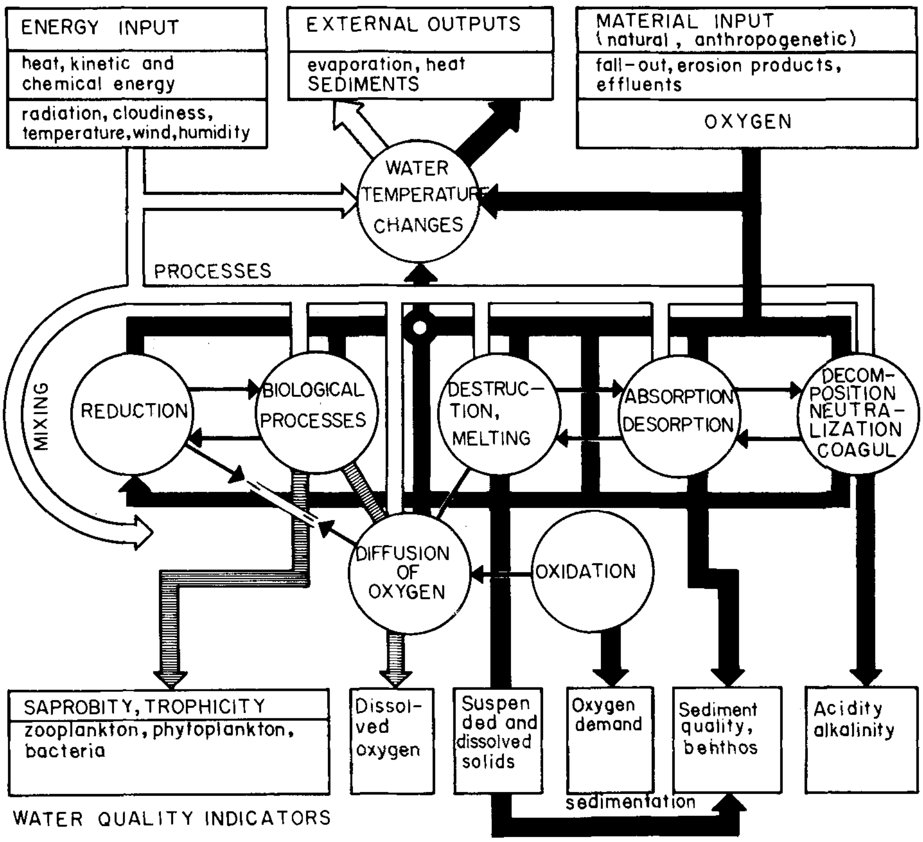


Fig. 2.2. Schematic representation of water self-purification process, a subsystem of biogeochemical cycles. Input consists of matter and energy, output is formed especially by sediments, benthos, water vapour, heat and water quality, characterized by a set of indicators.

The indispensable precondition for the destruction and transport of this material is a surplus of kinetic energy (see Chapter 1.6). A lack of kinetic energy causes sedimentation, the most basic of the physical self-purification processes. Sedimentation is governed by Stokes's law:

$$w = 0{,}01 \cdot \sqrt[n]{\frac{d \cdot (\gamma - 1000)}{a}} \qquad (m.s^{-1}) \qquad (2.15)$$

w - vertical sedimentation rate $(m.s^{-1})$

d - diameter of sedimented particles (m)

γ - unit mass of particles $(kg.m^{-3})$

a,n - coefficients of size, depending on the diameter of particles

d < 0.002 m - n = 1.2 ; a = 0.07

$d > 0.002$ m $-$ $n = 2$; $a = 0.064$

Sedimentation is accompanied by coagulation and melting and results in a decrease in the content of chemical matter in water and in an increase in the sediment volume.

Another basic process of self-purification to occur as a result of the contact of water with the air is the acceptance and diffusion of oxygen. Oxygen enters water not only from the air, but also as a product of the biological processes of plants and of phytoplankton. The content of dissolved oxygen in water is limited by temperature, barometric pressure and by the content of oxygen in the air above the water surface:

$$c_b = 0,373 \cdot \frac{B}{H} \qquad (g.m^{-3}) \qquad (2.16)$$

c_b - dissolved oxygen balance in water, when the oxygen content in the air equals 21%

B - barometric pressure (Pa)

H - Henry's constant, depending on water temperature (Pa- Tab. 2.4).

TABLE 2.4

Temperature (^oC)	0	5	10	15	20	25	30
H (10^3Pa)	2.57	2.95	3.32	3.69	4.05	4.44	4.81

Henry's constant H for the determination of the oxygen content in water in dependence on water temperature.

Chemical processes of self-purification, decomposition, coagulation, neutralization as well as absorption and desorption consume the dissolved oxygen, resulting in an oxygen deficiency, expressed by the difference between the actual oxygen content and the oxygen balance which corresponds to the relevant temperature.

The rate of the natural liquidation of this deficiency depends expressly on the temperature, and on the current velocity and depth of the water. Streeter-Phelps (1925) prove that the process of reaeration is quicker in shallow river beds with a higher current velocity:

$$\frac{D_t}{dt} = K_2 \cdot D_t$$

$$D_t = D_o \cdot e^{-K_2 T} \qquad (2.17)$$

$$K_2 = 1,047^{(T-20)} \cdot K_{2(20)}$$

D_c - oxygen deficiency at the beginning of the reaeration $(g.m^{-3})$

D_t - oxygen deficiency during the reaeration $(g.m^{-3})$

t - time (d)

K_2 - coefficient of reaeration at the temperature T (d^{-1})

$K_{2(20)}$ - coefficient of reaeration at the temperature of 20^oC (Tab. 2.5) (d^{-1})

T - temperature (^oC)

TABLE 2.5

Type of water course	Coefficient K_2 (d^{-1})
Shallow brook	0.50-0.80
River:	
velocity of flow>0.5 $m.s^{-1}$	0.30-0.80
<0.5 $m.s^{-1}$	0.20-0.25
Reservoir	0.05-0.15

Coefficient of reaeration K_2 at 20^oC according to Zhukov (1964)

In the course of physical and chemical processes the suspended matter is swallowed down by water organisms. The absorption of this matter into the nutrition chains of destruents, consumers and producers changes the living organic matter into anorganic matter and vice-versa. Most of the mentioned processes are aerobic, i.e. require the presence of oxygen. Anaerobic processes, i.e. processes without oxygen, occur especially near the bottom, in the mud.

The rate of the biochemical decomposition of organic matter depends on the enzymatic systems of the relevant organisms, i.e. their ability to decompose certain organic matter, or on their ability to create such systems after a short period of adaptation. The process of biochemical oxygen demand during biochemical decomposition can be described by the equation of kinetics of the 1st order

$$L_t = L_o.(1 - e^{-K_1 t}) \qquad (g.m^{-3}) \qquad (2.18)$$

$$K_1 = 1,047 (T -20) . K_{1(20)}$$

L_t - biochemical oxygen demand in the period t (BOD) $(g.m^{-3})$

L_o - the initial value of the biochemical oxygen demand $(g.m^{-3})$

K_1 - coefficient of deoxygenation at the temperature T (d^{-1})

$K_{1(20)}$ - coefficient of deoxygenation at 20^oC (d^{-1})

The change in the value of the oxygen deficiency during the processes of reaeration and deoxygenation, i.e. during the biochemical disintegration of organic matter, can be expressed by the differential equation

$$\frac{dD'_t}{dt} = k_d \cdot L_t - K_2 \cdot D'_t$$

$$D'_t = \frac{K_1 \cdot L_o}{K_2 - K_1} \cdot (e^{-K_1 t} - e^{-K_2 t}) + D_o \cdot e^{-K_2 t} \qquad (2.19)$$

D'_t - oxygen deficiency at the moment t for the simultaneous reaeration and biochemical disintegration of organic matter.

The decrease in the oxygen concentration and the increase in its deficiency as a consequence of the simultaneous reaeration and deoxygenation lasts until the critical moment at which the rate of the biochemical oxygen demand and the rate of the oxygen input become equal. After reaching this critical moment, the concentration of oxygen rises to the original value, following the curve of the oxygen content. If the concentration falls below the critical limit, the organisms die (Fig. 2.3).

The beginning of this process is accompanied by a decrease in the variety of biological species, characteristic for the degree of oligosaprobity, due to qualitative and quantitative changes in the littoral and benthic fauna, and in the plankton and fish species.

Consequent changes in the water properties include the change in its colour, the decrease in turbidity, the decrease in the oxygen content, especially in the hypolimnion of reservoirs etc. A further surplus of nutriment supply then causes a deterioration in the water quality as a result of the development of some organic species (Anabaena, aphanizomenon flos-aquae etc.). The result of their disintegration after extinction is an exhausted oxygen content.

Water pollution which occurs at the same place changes in time and depends on the pollution regime, the relevant discharges, the morphological factors of the river channel, the climatological factors and the coherent course of the self-purification processes.

Water pollution can also be defined as a complex of processes whose result limits or makes impossible the beneficial use of water. The natural pollution of surface water is generally low - the water quality varying within the limits of the 1st or 2nd class of water quality - unless it is severely deteriorated by higher quantities of suspended matter (especially by washed soil particles after heavy rainfall, or by high contents of salts as a result of salt plugs in the river channel or high evaporation - Tab. 1.24).

The character of water pollution which is caused by the industrial, agricultural and other activities of human society and by urban effluents differs from

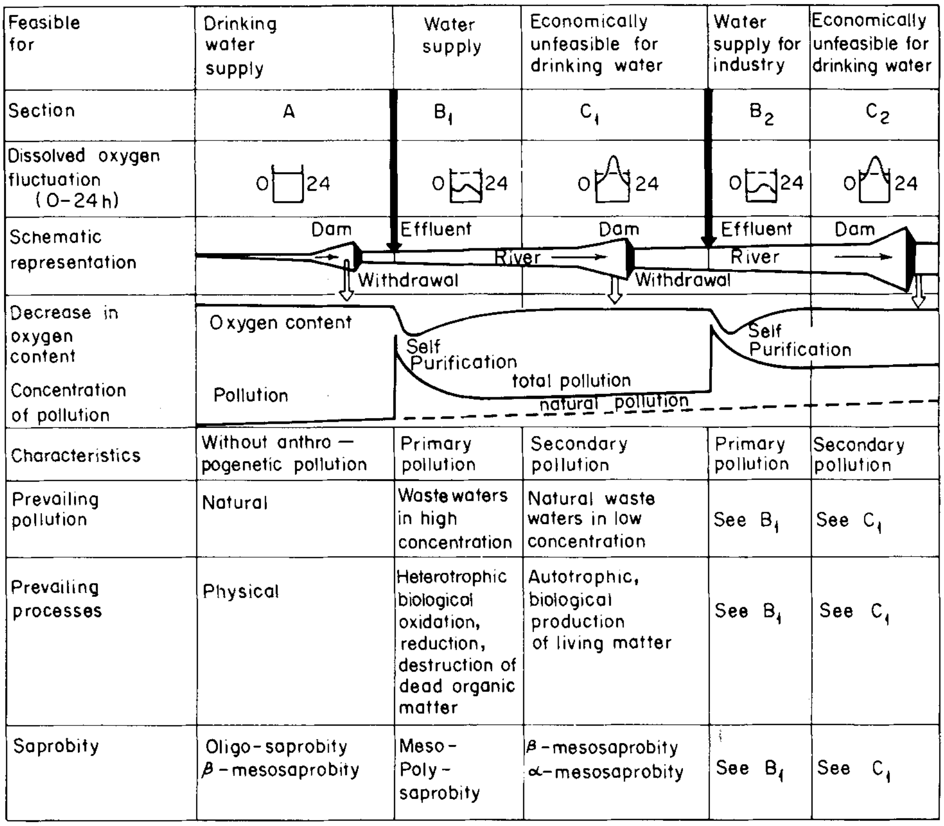


Fig. 2.3. Schematic representation of the course of the main characteristics of the self-purification process in the longitudinal profile of a water course with a cascade of reservoirs. Both natural and anthropogenetic pollution increases downstream. A characteristic curve of oxygen demand appears below the effluents.

that of natural pollution. This pollution considerably changes the chemical and biological properties of the water, and also the type of the relevant chemical, biological and other processes. A decrease in water quality below the 3rd or 4th class is a frequent consequence as well as eutrophosation, resulting in a decrease in the biological quality of water, reaching a maximum of β- mesosaprobity (Tab. 1.24, 1.30).

The self-purification process, like any manifestation of natural homeostasis, is stimulated by feedbacks. But the state to which the system returns is not necessarily the same as the original one. The lack of energy or matter makes such a return impossible and results in an irreparable change in water quality which may limit or exclude its beneficial use. The acceptable quality of water in a water resource can be expressed for any particular use by a set of indices.

All these chemical, biochemical and biological processes occur in the environment of the running water. Suspended matter and floating debris of both natural and anthropogenetic origin are carried away by tracting forces of the flowing water. Solid wastes in the stream channel and the bed load start to move when the drag forces exceed the friction forces. The balance of these forces is expressed by the equation

$$F_s \cdot \gamma \cdot g \cdot \frac{v_o^2}{2g} = V_s \cdot \gamma_m \cdot f \cdot g \qquad (2.20)$$

F_s – surface of the particle under the action of drag forces (m^2)

γ – unit mass of water ($kg.m^{-3}$)

v_o – bottom current velocity ($m.s^{-1}$)

V_s – volume of solid waste/sediment particle (m^3)

γ_m – unit mass of the particle ($kg.m^{-3}$)

f – coefficient of friction

g – gravitational constant ($m.s^{-2}$)

The current velocity, the size and shape of the particles of natural and anthropogenetic origin as well as their unit mass is not uniform throughout the cross section. For practical reasons the beginning of the motion of a significant quantity of sediments is important, which depends on a critical velocity corresponding to a critical discharge at which the above equilibrium (Eq. 2.20) is disturbed. The critical bottom current velocity which characterizes the start of the motion can be derived from the above equation as follows

$$v_c = \left[\frac{2g \cdot d_e \cdot (\gamma_m - \gamma) \cdot f}{\gamma}\right]^{\frac{1}{2}} \qquad (2.21)$$

v_c – critical bottom current velocity, characterizing the start of the sediment motion

$d_c = \frac{V_s}{F_s}$ – characteristic effective size of the particles

The discharge corresponding to this critical bottom current velocity in the conditions of most sustained river beds is often the discharge exceeded 50% of the time, i.e. Q_{180d}.

The water quality due to the course of sediment movement and the dilution of waste waters depends on the discharge but in direct relationship with:

(a) soil-erodibility rate, dependent on precipitation, and

(b) soil-solubility rate, dependent on the intensity of the surface runoff,

(c) geological, soil and soil surface factors incl. the type of the vegetative canopy, its state and season,

(d) hydrometeorological, seasonal and purely random influences, e.g. the changes in water temperature, the intensity of solar radiation, the intensity of the longitudinal mixing which determine the whirling and transport of sediments and wastes as well as the course of natural processes of self-purification,

(e) anthropogenetic activities, i.e. the pollution regime.

The pollution regime depends on the type of polluters in question, which may be

(a) accidental (pollution from pipelines, transport vehicles and their freight, breakdowns etc.),

(b) systematic

- spot pollution (point pollution), i.e. pollution from communities, localities, townships, towns, industrial and agricultural estates, infrastructure, sanitary, school, recreational and other facilities,
- areal pollution, i.e. washed soils and fertilizers, pesticides, dumps etc.

In addition to this organic and anorganic pollution may be distinguished, the first being mostly better coped with during natural processes.

Spot pollution, with the exception of dumps, occurs immediately. Areal pollution, which may also include pollution from dumps, is generally delayed and depends on the rainfall, and on the overland and groundwater flow occurrence. In this connection the relevant delay may depend on meteorological factors, but may also appear almost independently.

Water pollution which occurs at the same place changes, therefore, in time. The water quality in surface courses which results from the pollution and natural self-purification processes is a function of space and time

$$q_{1-n} = f\,(Q\ ,\ x\ ,\ y\ ,\ z\ ,\ t) \qquad (2.22)$$

q_{1-n} - water quality indicators ($g.m^{-3}$)

Q - discharge ($m^3.s^{-1}$)

x,y,z, - coordinates : x - distance in the longitudinal profile (from the point of pollution) (m)

y - location in the cross section of the river bed (m)

z - depth of the sampling (m)

t - time (date,hour)

Under a simplified approach primarily in the proximity of the sources of pollution the concentration of diluted matter can be considered as a representative factor of the water quality:

$$q_1 = a + \frac{b}{Q} \qquad (g.m^{-3}) \qquad (2.23)$$

q_1 - total concentration of dilluted matters in water

Q - discharge $(m^3.s^{-1})$

a - concentration of the basic natural pollution, often independent of the discharge $(g.m^{-3})$

b - pollution (input of wastes) $(g.s^{-1})$

In many practical cases pollution grows with discharges and the degree of dependence of the concentration of pollution on discharges is linear

$$q_2 = a + d \cdot Q \qquad (g.m^{-3}) \qquad (2.24)$$

or bilogarithmic

$$\log q_2 = \log a + d \cdot \log Q \qquad (2.25)$$

The changes of the organic pollution indicator, i.e. of the biochemical oxygen demand (BOD) and the chemical oxygen demand (COD), can be expressed by the regression formula

$$q_3 = q_b + \frac{A}{Q} + \frac{B}{Q} \cdot 10^{-K_1 t} \qquad (g.m^{-3}) \qquad (2.26)$$

q_3 - biochemical or chemical oxygen demand

q_b - basic value of the biochemical or chemical oxygen demand, dependent on the characteristic of the catchment basin $(g.m^{-3})$

A - organic pollution, non-degradable by self-purification processes $(g.s^{-1})$

B - organic pollution, degradable by self-purification processes $(g.s^{-1})$

K_1 - coefficient of deoxygenation (d^{-1})

t - regression time, i.e. the time of advancement of the pollution from the sources of pollution to the analysed profile, depending indirectly on the discharge

$$t = \frac{r}{Q^m} \qquad (d)$$

r , m - coefficient of the pollution advancement

Suspended matter and the bacteria (coli) can be quantified by the equation

$$q_4 = a + \frac{b}{Q} + d \cdot Q \qquad (g.m^{-3},\ pc.m^{-3}) \qquad (2.27)$$

a - quantity of suspended matter or bacterium coli from waste waters $(g.s^{-1}, pc.m^{-3})$

The changing inputs of the self-purification process and its changing intensity result in the changing intensity of the pollution and in variations in its concentration. The change in concentration may often be expressed by the equation

$$q_i = a + \frac{\beta \cdot b}{Q} \qquad (g.m^3) \qquad (2.28)$$

q_i - concentration of dilluted matter in the profile i

a - concentration of the basic natural pollution, independent of the discharge $(g.m^3)$

b - concentration of the spot pollution, changing with the discharge $(g.m^3)$

Q - discharge $(m^3.s^{-1})$

β - reduction coefficient $\beta = f(x, Q, T, h, v)$, depending on the distance x from the source of pollution, discharge Q, water temperature T, average water depth h in the river channel, flow velocity v.

On the basis of the foregoing formula the probable deviation of concentration at the same place for one single source of pollution is as follows

$$\varrho_i = \varrho_o + (c_Q + c + c_b) \cdot \beta^{-2} \cdot b^{-2} \cdot Q^2 \qquad (g.m^{-3}) \qquad (2.29)$$

ϱ_i - deviation of concentration in the profile i

ϱ_o - deviation of the basic pollution $(g.m^{-3})$

c_Q , c_β , c_b - coefficient of the variation of the discharge, of the reduction coefficient and of the spot pollution

The hydrometeorological and anthropogenetic inputs of the self-purification system are matter and energy. The output is not only the water quality and sediments, but also evaporation and external temperature, i.e. factors which influence the microclimate.

2.3.2 Inland Water Transport

Navigable or canalized water courses including reservoirs and canals form an infrastructure for the transportation of goods and passengers (public, occasional transport including recreation). The current importance of inland water transport is primarily a result of its energy and manpower saving technology, especially with regard to its role in conveying individual types of cargo, which is mainly general, liquid, bulk, heavy, spacious and containerized, such as grain, fodder, timber, cellulose, stone, gravel, sand, building materials, ore, coal and coke, oil and oil products, chemical products, fertilizers and piece goods.

European waterways can be classified into six classes depending on the size and capacity of goods-carrying inland-waterway vessels (Tab. 2.6). The parameters of waterways are derived from the size of the typical motor cargo vessel

TABLE 2.6

Class	Capacity (t)	Class	Capacity (t)
I.	250 - 400	IV.	1000 - 1500
II.	400 - 600	V.	1500 - 3000
III.	650 - 1000	VI.	> 3000

Classification of European waterways.

and motor-driven tug. Two categories can be distinguished on the basis of the biggest vessel

(a) European - vessel E (82 . 11.4 m)

(b) Local - vessel L (41 . 5.7 m)

The admissible draught on a canalized water course depends on the water stage:

$$T = H_g - H_d - M \qquad \text{(m)} \qquad (2.30)$$

T - admissible draught of the vessel (m)

H_g - gauged water stage (m)

H_d - difference between the maximum draught and the gauged water stage (m)

M - margin - safety distance between the vessel bottom and the channel bottom

In the case of inland waterways with a fluctuating water table, the draught characteristic corresponds to the draught secured during 240 days in a hydrologically mean year.

The network of inland waterways includes

(a) river channels (natural, improved - trained, canalized)

(b) canals (artificial water courses).

The basic parameters of these waterways, i.e. those which determine the carrying capacity, include the breadth and depth of the fairway, the corresponding minimum size of the cross section, and the velocity of the flow. The other main dimensions determine the fluency, methods of operation, speed and safety of transport.

The criteria for an assessment of the minimum dimensions are as follows (Fig. 2.4):

(a) minimum breadth of the fairway along straight stretches (at the level of bottom of the typical vessel):

$$B = 2\,b + 2\,b' + b'' \qquad \text{(m)} \qquad (2.31)$$

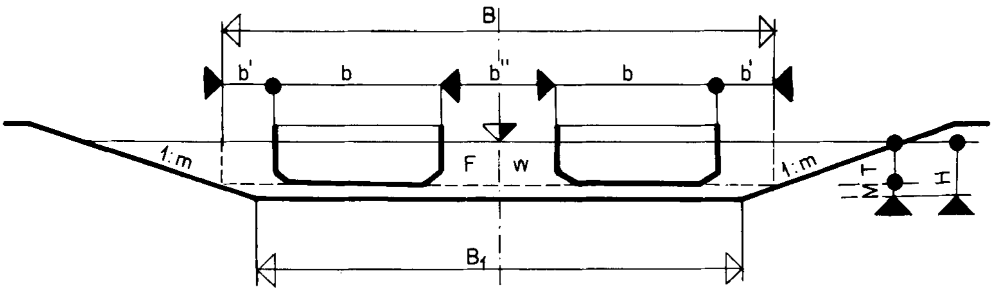


Fig. 2.4. Schematic cross section of an inland waterway. The relevant parameters are to be derived from the parameters of the typical vessel.

B - minimum breadth of the fairway

b - vessel width

b' - board space

b''- space between vessels

(b) minimum breadth of the fairway in a curved stretch

$B' = B + e$ (m) (2.32)

e - extension in curves

$c = \frac{L^2}{2R} - \frac{A}{R}$

L - overall length of the typical vessel formation

R - perimeter of the curve

A - coefficient of the extension ($= \frac{L^2}{2}$) (m^2)

(c) minimum depth of the fairway

$H = T + M$ (m) (2.33)

T - draught of the typical vessel

M - margin - safety distance between the vessel bottom and the channel bottom (0.3 - 0.5 m)

(d) minimum cross section, limited by the water level

$F = n_p \cdot p \cdot r \cdot T \cdot b$

n_p - hydraulic characteristic of the waterway $n_p = \frac{F}{f} = 5\text{-}7$

f - cross section of the typical vessel

p – number of vessels coupled side-by-side

r – reduction coefficient: two-way stretch $r = 1$
one-way stretch $r = 0.6$
waterway tunnel $r = 0.5$

(e) admissible velocity of the flow

$$v_{max} = \frac{Q}{F + \Delta F - p \cdot b \cdot T} \qquad (m.s^{-1}) \qquad (2.34)$$

Δ – enlargement of the minimum cross section corresponding to the discharge Q

v_{max} – velocity of flow

The design speed of vessels should be

$$w = 0.55 \cdot \sqrt{g \cdot H} \qquad (2.35)$$

The velocity of flow is limited by the following equations

$$v = 0.5 \cdot w \text{ , i.e. } v = 0.275 \cdot \sqrt{g \cdot H} \qquad (2.36)$$

but also by $v \leq v_{max}$

The flow velocity not only determines the speed when loaded (10 to 400 km per day), but also the operation capability and manoeuvrability of vessels and articulated formations, as well as the necessary energy input and fuel consumption. The required speed of vessels in relation to the channel cross section influences the backflow and thus the erosion rate.

(f) routing of the fairway:

The routing of the fairway including its extension in curves determines the speed, fluency, safety, method of operation and the energy consumption of the inland water transport. The straight route is most suitable: two limits exist for the value of the perimeter:

- the minimum perimeter, securing fluent and safe operation without any significant restrictions,
- the exceptionally acceptable perimeter, requiring limited speed and thus reducing the fluency of operation (Tab. 2.7).

The exceptionally acceptable perimeter has to be used in built-up areas, deep narrow valleys and natural river beds.

Secondary characteristics of water courses which have an impact on the course and safety of transport operation, the operation time and period, interruptions to operation, its restriction to some 220 to 340 days a year and the different technical measures employed include

- flood occurrence

- periods of low discharges in non-canalized rivers
- ice-bound regime
- meteorological factors, especially fog and strong wind occurrence
- maintenance, repair and reconstruction work, especially in the case of one-way stretches
- technologically unsuitable and obsolete constructions, such as locks and weirs.

The freight turnover of a waterway depends on the stretch with the lowest freight capacity, i.e. on the locks in the case of double-way canals. The capacity of a one-way canal is generally smaller than that of the lock. The freight turnover of the lock can be expressed by the formula

$$K_d = \left(\frac{24}{t_n} - n_d \right) . m . d . W . \frac{a}{b} . \frac{t}{24} \quad \text{(t per year)} \qquad (2.37)$$

t_n - duration of the operation cycle (lockage) (hours)

n_d - number of vessels per day

d - duration of the transport season (days)

m - number of simultaneously locked vessels

W - carrying capacity of one vessel (medium) (t)

a - coefficient of capacity utilization (0.7-0.9)

b - coefficient of the uneven utilization of the waterway (1.25-1.75)

t - average number of operating hours per day (12-24 h)

The volume of water needed for one lockage is

$$V_1 = F . h \pm W = s . d . h \pm W \quad (m^3) \qquad (2.38)$$

and for the slant walls of the lock

$$V_1 = (s + 2 h . tg\delta) . d . h \pm W \quad (m^3)$$

V_1 - volume of water needed for one lockage (m^3)

b - lock width (m)

a - lock length (m)

h - head (m)

δ - slope of the lock walls (^{o})

The plus sign before the value of the carrying capacity is used for the passage upstream, because water in the lock has to be replaced after its departure from the lock. The minus sign is used for the passage downstream. When technical measures safeguard reciprocal lockage in both directions, only 50% of the volume is needed

$$V_2 = \frac{1}{2} \cdot V_1$$

and, therefore for practical cases

$$V = k \cdot a \cdot b \cdot h \qquad (m^3) \qquad (2.39)$$

k - coefficient of operation coordination (1 k 0.5)

The freight turnover in a complicated network of inland waterways has to be expressed by a more complex formula

$$K_a = \frac{\eta \cdot d \cdot t \cdot m_s \cdot W_s \cdot (w_m + w_n)}{2 \cdot (p_m - p_n) \cdot t_1 + 2 p_n \cdot t_2} \qquad \text{(t per year)} \qquad (2.40)$$

η - coefficient of the uneven utilization of the waterway throughout the year

$m_s \cdot W_s$ - annual average of the carrying capacity of simultaneously locked vessels

w_m, w_n - utilization of the carrying capacity in either direction (%)

p_m, p_n - percentage of vessels in either direction

$p_m + p_n = 100\%$, $p_m - p_n > 0$

t_1 - duration of one lockage if lockage in the same direction follows $(=2 \cdot \sum_{i=1}^{6} t_i - t_3 - t_6)$ (hours)

t_2 - duration of one lockage if lockage in different direction follows $(= \sum_{i=1}^{5} t_i$ - Tab. 2.7)

Bearing this in mind, the annual water requirement for a lock is

$$R_a = \frac{2 \cdot K_a \cdot (p_n \cdot V_2 + /p_m + p_n/ \cdot V_1)}{m_s \cdot W_s \cdot (w_m + w_n)} \qquad (m^3 \text{ per year}) \qquad (2.41)$$

The operation of locks is an inherently in-stream use, but using water in this way results in a loss of its potential energy both in the passage upstream and in the passage downstream:

$$J_u = h \cdot (a \cdot b \cdot h + W) \cdot \gamma \qquad \text{(kgm)} \qquad (2.42)$$

$$J_d = h \cdot (a \cdot b \cdot h - W) \cdot \gamma \qquad \text{(kgm)}$$

J_u - loss of potential energy in the passage upstream

J_d - loss of potential energy in the passage downstream

γ - unit mass of water (kg.m^{-3})

The passage upstream decreases the energy consumption (i.e. also fuel consumption), the reverse operation of locks for the passage downstream has no effect on fuel consumption.

TABLE 2.7

Symbol	Operation	Duration (s)	Velocity (m.s^{-1})
t_1 t_5	drift in drift out $t_{1(5)} = \dfrac{L_k + (5-10).B_k}{r}$	see formula	r_1=0.6-1 r_5=0.8-2.2
t_2 t_4	opening and closing the upper gate opening and closing the lower gate	60-120 60-120	
t_3 t_6	filling the lock emptying the lock $t_{3(6)} = \dfrac{h}{v}$	300-900	v=0.02-0.06

Duration of one operation cycle of a navigation lock with two-way traffic. Symbols are in text.

The water requirements for inland navigation are determined by the size of the largest lock, i.e. in the case of unified horizontal dimensions by the volume of the lock with the highest head incl. relevant water losses. These water requirements can be reduced by

(a) two grouped locks

(b) water-saving tanks

(c) pumping

(d) vessel lifts, canal inclines, water slopes.

The first two technical measures reduce the water requirements and simultaneously increase the duration of lockage. Pumping and mechanical lifting equipment can shorten this operation, but, unless a counterweight is used, this is energy-demanding.

By grouping two locks, i.e. by emptying one lock into another, water requirements can be reduced by 50%. During routine operation of grouped locks, the duration of the lockage is shortened by closing the valve before equalizing the water levels, thus increasing the water requirements to the average value

$$R_a = 0{,}53 \cdot k \cdot a \cdot b \cdot h \quad (m^3) \qquad (2.43)$$

k - coefficient of the operation coordination $(1 > k > 0.5)$

The effect of water-saving tanks on reducing water requirements depends on their size, number and technical arrangement (Tab. 2.8). The water requirements of a lock with water-saving tanks of the same size

$$R_s = \left[1 - \frac{n}{n + 1 + x + \frac{2}{y}}\right] . a . b . h \qquad (m^3) \qquad (2.44)$$

n - number of water-saving tanks

$x = \frac{a.b}{U}$ - ratio of the size of the lock to the size of the tank

$y = \frac{h_n}{h_o}$ - ratio of the water strata h_n for particular tanks and of the difference of water tables h_o reached at the moment of the commencement of filling up from the next tank for time-saving reasons

TABLE 2.8

Number of reservoirs	Full levelling of water tables ($y = \infty$)		Partial levelling of water tables ($y = 10$)	
	requirements $V_s : V_o$	Ratio of duration $t_s : t_o$	requirements $V_s : V_o$	duration $t_s : t_o$
1	0.666	1.225	0.687	1.145
2	0.5	1.414	0.523	1.276
3	0.4	1.581	0.423	1.395
4	0.333	1.732	0.355	1.505

Decrease in water requirements and the extension in duration of one operation cycle of a navigation lock with water-saving reservoirs, their area being equal to that of the lock.

The following formula can be derived for the duration of the filling up of the lock with water-saving tanks

$$t_s = t_o \cdot \frac{1}{\sqrt{n + 1 + x + \frac{2}{y}}} \cdot \frac{n}{1 + x} \cdot \left[\sqrt{1 + x + \frac{1}{4}} - \frac{1}{2}\right] + \sqrt{1 + x + \frac{2}{y}} \qquad (hrs) \qquad (2.45)$$

t_o - duration of the filling up of the lock without water-saving tanks (hrs)

Water requirements for lockage restrict other in-stream uses, e.g. for hydropower generation, and should only be considered when the natural supply by river discharges is not sufficient. Water losses of navigation operation are caused by

(a) leakage of gates and valves

(b) seepage of the bottom and the banks of the canal

(c) evaporation from the free water surface and the increased evapotranspiration from banks affected by the impounded water.

The losses through the leakage of gates and valves depend on their construction, type of seal and technological state as well as on the lockage frequency. Their value fluctuates between 3 and 5 $l.s^{-1}$ for 1 m of head for locks 12 m wide. Higher values correspond to a higher frequency of lockage.

Inland water transport does not make any important requirements on water quality, except recreational passenger transport, whose success is closely interconnected with the quality of water. Water pollution from inland navigation is mainly caused by the liquid fuels used in vessels, chemical products incl. hydrocarbons and other dangerous substances transported as cargo, solid wastes, degassing, washing and ballast water, but especially by accidental spillage during loading, unloading and transloading.

2.3.3 Water Power Utilization

The potential energy of water can be converted into pressure energy by concentrating the head and discharge and into kinetic energy by passing the concentrated discharge through water engines. The value of the electric energy generated from this kinetic energy reaches

$$N = \frac{\eta \cdot \gamma \cdot Q \cdot H}{102} = 9.81 \cdot Q \cdot H \qquad (kW) \qquad (2.46)$$

Q - discharge $(m^3.s^{-1})$

H - net head (without intake losses) (m)

η - coefficient of efficiency (turbine, gears, generator)

γ - unit mass of water $(kg.m^{-3})$

N - power generated (kW)

To extract the maximum power and energy at the optimum cost the design criteria focus on the choice of the location, design discharge and head, lay-out, size and number of units etc. by suitable numerical techniques. This approach embodies an optimization of the power output/cost-benefit ratio etc. on the basis of a realistic operation of the plant, in the framework of the topographic/ hydrological situation and power market demands.

The specific advantages of hydropower plants open up favourable possibilities of application as

- run-of-river plants (in the original river bed or in a bypass canal, using discharges which are available without considerable storage),
- storage plants (using reservoirs for water accumulation and thus affording the possibility of peak power generation)
- pumped-storage plants (repumping accumulated water during a surplus of energy in the network and generating power during peak demand)

- tidal power plants (utilizing the head and flow produced by the tide)
- power stations using the energy of waves (not feasible yet).

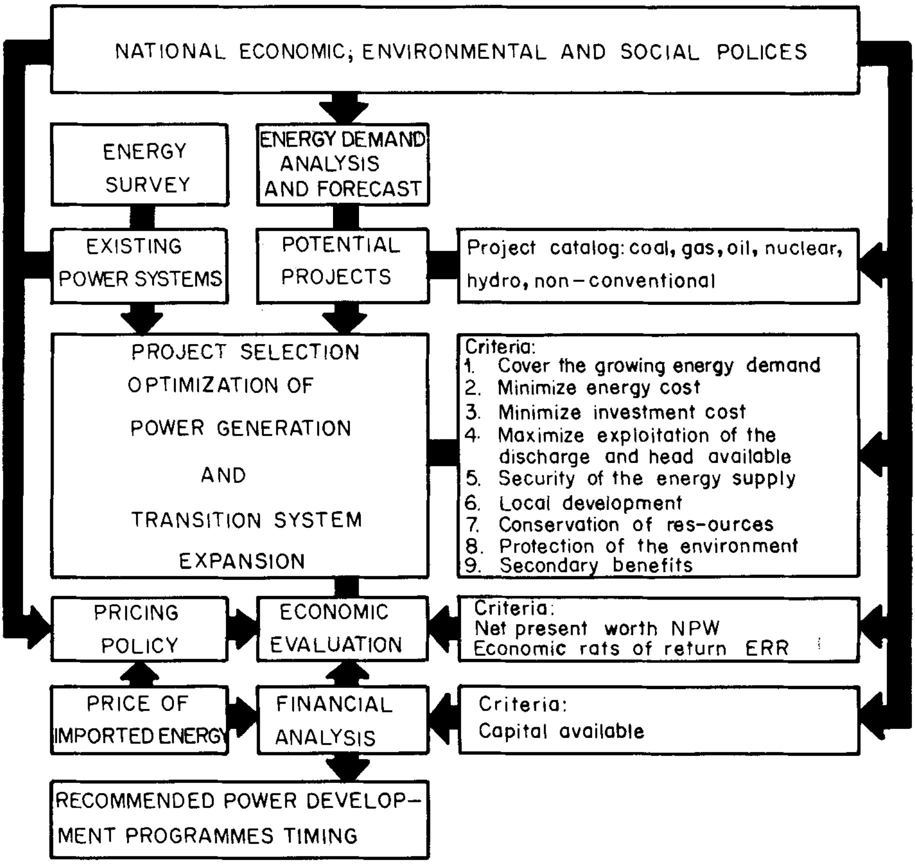


Fig. 2.5. Block diagram for the project selection, optimization of power generation and transition system expansion in the framework of national economic, environmental and social policies.

Hydropower is the only dependable renewable source of energy and offers, in addition in comparison with thermal and nuclear power, as well as with the unconventional energy options, the following basic advantages:

- flexibility of operation,
- possibility of multipurpose utilization,
- high reliability and long service life,
- positive or almost negligible environmental impact (if environmental factors are accordingly taken into account during the design and operation),
- low operating costs,
- possibilities of using local materials and labour.

The following indicators affecting the choice of the optimum design discharge and head have to be considered with a possible environmental impact of the power plant layout:

- unit cost of energy (kWh) should be competitive with other energy options,
- installed capacity (kWh) should be optimum for integration into the network power market,
- energy output in the period or season of maximum energy demand (kWh) should be optimum.

Available simulation models have the capability of simulating any hydropower plant or electrical system. Computations may be performed at a desired level of accuracy consistent with the availability of the input data. These programs may be used to determine hydropower potential, to optimize design discharges, heads, dam heights and reservoir sizes, to study the feasibility of new developments and their impact on existing systems, effects of changes in operational procedures in existing systems etc. (Fig. 2.5).

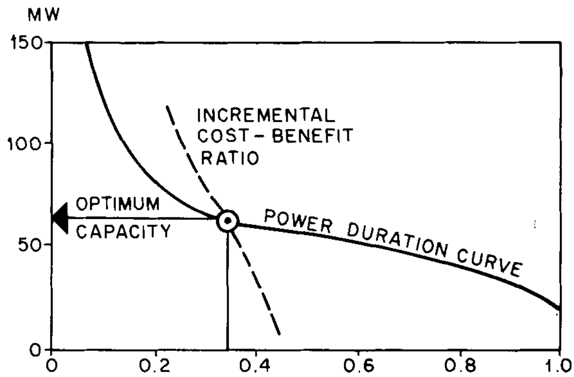


Fig. 2.6. Selection of the optimum capacity of a hydropower plant by superimposing the incremental cost-benefit ratio function on the power duration curve according to Fahlbusch (1983).

According to Fahlbusch (1983) the optimum capacity of a hydropower plant, if the objective is the maximum exploitation of energy and not the provision of peak capacity, is that value of theoretical capacity N for which the complementary cumulative distribution of power output equals the marginal benefit-cost ratio

$$\frac{\Delta C}{\Delta B} = \frac{C'(N)}{M.t_o} \qquad (2.47)$$

$$\int_{N^+_{opt}}^{\infty} f(x)dx = \frac{C'(N)}{M.t_o} \qquad (2.48)$$

Solving this equation for the optimum N_{opt} requires superimposing the marginal cost-benefit ratio function on the power duration curve (Fig. 2.6).

x – power output

f(x) – probability density of power output x

C(N) – annual cost as a function of capacity

M – value of energy per kWh

t_o – duration of one year in hours (8760 hrs)

ΔC – incremental costs

ΔB – incremental benefits

A hydropower development project may exhibit an incremental cost-benefit ratio of less than unity and still be uneconomical, requiring substantial investment for the construction of storage and diversion facilities, which may be largely independent of the design capacity.

The trouble-free and economic operation of power plants requires a low content of sediments (both bed load and suspended matter, especially hard minerals), a low content of floating debris and chemically non-aggressive water quality, which means that a low content of oxygen, low chemical aggressivity and a low temperature is required in order to restrict:

(a) cavitation and chemical disintegration of turbines,

(b) abrasion of pressure pipelines, spiral case, turbines, liner and other technological equipment,

(c) sedimentation in water conveyance structures.

The transport of bed-load and suspended matter requires the construction of special intake structures and silt basins. It also requires a minimum flow rate of some 1.0 $m.s^{-1}$, dependent on the characteristics of the prevailing particles, in order to avoid sedimentation in the conduit system. The design dimensions of these structures should be determined in the light of the size and density of the particles and their volume which can be allowed to enter the system.

No operational troubles caused by sediment transport occur in storage plants with a reservoir which has a sufficient trap efficiency. Run-of-river plants cope with serious sediment problem when the design discharge Q_i exceeds the critical discharge Q_s at which the bed load starts to move:

$$Q_i < Q_s \qquad (m^3.s^{-1}) \qquad (2.49)$$

In rivers with a heavy bed load transport it is useful to locate the off-take in an eroded section. If the off-take is located in a section where sedimentation prevails, it is necessary to narrow the river bed in this particular section.

The bed load transport normally needs the energy of some 50% of the discharge. To avoid sediment transport problems during a period of increased bed load transport ($Q_a > Q_s$), the hydropower station may utilize some 50% of the discharges available

$$Q_e = \frac{1}{2} \cdot Q_a \qquad (m^3.s^{-1}) \qquad (2.50)$$

even when the intake is well located.

The operation of a run-of-river plant in a river with a heavy bed load transport and fluctuating discharges is, therefore, limited in two time periods

- because of the lack of water during a period with actual discharges Q_a lower than the design discharge Q_i ($Q_a < Q_i$)
- for the transport of sediments in the period when the actual discharges Q_a exceed the critical discharge Q_s, but do not reach the double of this value ($Q_s < Q_a < 2Q_s$).

No limitation of such plant operation is required during high discharges ($Q_a \geqq 2Q_s$). But, under these conditions, the power generation is restricted by the decrease in head available:

$$Q_a \geqq 2Q_s \longrightarrow Q_e = Q_i \qquad h_a \ll h_i \qquad (2.51)$$

2.3.4 Water for Recreation

Recreation includes all activities whose social goal is to gain or recover physical and psychic forces. Water recreation does not only include bathing, swimming, fishing and other water sports, but also boating, yachting, some winter sports like skating etc., and sojourns beside the water such as camping, caravanning and other forms of short-term or weekend sojourn.

Areas rich in surface water substantially ameliorate the recreation conditions in arid, semiarid and humid climates, but do not have such a positive impact under conditions of rough climate. Water recreation may be classified as (Tab. 2.9, 2.10):

(a) everyday - reservoirs and accessible water courses, swimming pools in the proximity of dwelling areas (up to 20 km),

(b) weekend - reservoirs and water courses whose distance from relevant dwelling areas exceeds 20 km (up to 200 km)

(c) seasonal - areas of recreational character whose distance from relevant dwelling areas exceeds 200 km.

The quality of water recreation depends on

(a) water management factors,

(b) climatological factors,

(c) local factors incl. topographical and aesthetic factors.

The pre-condition for the recreational effect of a given area is the change of milieu: Relatively warm areas are pertinent for recreation in a mild climate, relatively cool areas in a semi-arid and arid climate.

TABLE 2.9

Type of recreation	Deciding factors	Type of recreation	Deciding factors
1 bathing	W1-6 & 8 K1-4, M1-6	7 yachting	W3-5, M3
2 water tourism	W1-3 & 5, K1-2, M5-6	motorboating	
3 rowing & paddling	W1, 3-5, K4, M6	8 recreational stay	W1, K1, M3
4 fishing	W1, 4-7, M4	9 skating	W6, 4, M3

Categorization of water recreation (basic characteristics of deciding factors see table 2.13).

Water quality incl. temperature is the most important factor which influences the quality of recreation in relation to the type of recreation activity (Tab. 2.10). Bathing and swimming is a supplementary activity for other recreation activities, distinguished by the highest requirements on most factors. Water temperature is not necessarily connected with climatological factors. Thermal waters may create extremely favourable conditions for recreation, especially in less favourable climatic conditions. Under such conditions the influence of climatological factors may appear of tertiary importance.

TABLE 2.11

Category of visitors	Required water depth (m)	Ideal share of the water table area (%)
Children	0 - 0.8	20%
Non-swimmers	0.8 - 1.3	40%
Swimmers	> 1.3	40%
Water jumping	3.4 - 5	min 16.25.14 m

Required water depth and the ideal share of the water table area for relevant categories of visitors to natural and artificial bathing pools.

The quality of natural bathing pools depends on the morphological and aesthetic conditions of the environment and on a favourable water depth for swimmers, non-swimmers, children and divers (Tab. 2.11, 2.12). The active area on big reservoirs is a zone near the shore, some 50 m wide.

The size of bathing and swimming pools should correspond to the length of race tracks, which are ratios of 50 m: 10 m, 12.5 m, 16.67 m and 25 m. In a swimming pool of 50.21 m, as recommended by FINA with a water depth above 1.8 m,

TABLE 2.10

Water management factors (W)	Excellent	Suitable	Marginally suitable	Unsuitable
1. Water pollution (class)	Ia	Ib	II	III
2. Water temperature °C	> 25	> 18	> 14	< 14
3. Water depth (m)	0.5 -1.6	< 1.6	> 1.6	< 0.5
4. Water table width (m)	> 20	> 10	> 5	< 5
5. Velocity of flow ($m.s^{-1}$)	< 0.5	0.5 -1.1	~1.5	> 1.5
6. Water table fluctuation (m)	< 0.5	< 2	≥ 2	≫ 2
7. Fish occurrence	plentiful		scarce	nil
8. Variance with other water management purposes	no	partially		yes

Climatic factors (C)	Excellent	Suitable	Unsuitable
1. Number of high summer days	> 70	> 50	< 50
2. Rainfall total in summer (mm)	< 250	< 450	> 600
3. Air temperature °C (% humidity)	21-26 (18-70)		< 18
4. Air pollution	no	no	yes
5. Noise	no	slight	yes

Morphological and aesthetic factors (M)	Suitable	Unsuitable
1. Riverbed material	sand	mud
2. Bank slope	< 1:3.3	> 1:2
3. Accessibility	good	diffi-cult
4. Insect occurrence	no	yes
5. Aesthetic of the environment	plea-sant	uninte-resting
6. Services (for mass recreation)	good	poor

Categories of parameters which determine quality of recreation.

it is possible to play water polo.

TABLE 2.12

Parameter	Limiting value (maximum or minimum)
Water table width	>10 m
Minimum area of the water table	200 m^2
Velocity of flow - for adults	< 0.5 $m.s^{-1}$
- for children	< 0.3 $m.s^{-1}$
Minimum discharge per visitor and day	1 m^3
Bottom slope	<30 %
Bottom material	sand, pebble, pavement, concrete
Water temperature	> 18 °C
Class of water quality	I (max II)
Area of water table per visitor	> 2.5 m^2
Total surface area per visitor	>10 m^2

Limiting values of basic parameters to ensure good conditions for recreating at natural bathing pools.

The optimum flow rate and fluctuation of the water table not only depend on the type of recreation, but also on the morphology of the terrain: on the material of the bottom, on the slope and accessibility of the banks. An optimum velocity of flow for most activities is below 0.5 $m.s^{-1}$. The permissible fluctuation of the water table also determines the water quality (Tab. 2.13).

The physical need to bathe appears when the daily temperature exceeds 25°C. A reservoir offers good conditions for bathing whenever the number of such days is higher than 50-70 annually and precipitation in this period does not exceed 450 mm. Conditions are favourable for a recreational stay near water when the average daily temperature is above 10°C, i.e. from April to October in a mild climate.

Last but not least, the quality of water recreation depends on the quality of the air, the noise and the occurrence of insects. The morphology may create a favourable climate in a natural milieu or in a housing estate. The climatic pleasantness depends on the relation of the amount of diffused and reflected solar radiation, which influences the air temperature and humidity (Fig. 2.7).

To maintain the water quality in swimming and bathing pools, an exchange of water is required, which may be

(a) continuous,
(b) immediate,
(c) achieved by the circulation of water.

TABLE 2.13

Water quality indicators	Bathing pool	
	natural	artificial
Physical properties:		
Temperature minimum	14 °C	14 °C
optimum	21 °C	21 °C
Visibility in water	>0.5 m	> 5 m
Turbidity (SiO_2- content)	-	
depth down to 1m	-	> 2 $mg.l^{-1}$
depth down to 2m	-	> 1 $mg.l^{-1}$
Chemical properties		
Factor pH	5.5 - 9.0	6.8 - 7.1
Organic matter	-	i + 30 $mg.l^{-1}$
Chloride	100 $mg.l^{-1}$	i + 0.3 $mg.l^{-1}$
Ammonia	1 $mg.l^{-1}$	i + 0.3 $mg.l^{-1}$
Nitrides		i + 0.2 $mg.l^{-1}$
Nitrates		i + 20 $mg.l^{-1}$

Water quality indicators for natural and artificial bathing pools. i - water quality indicator of the inflow.

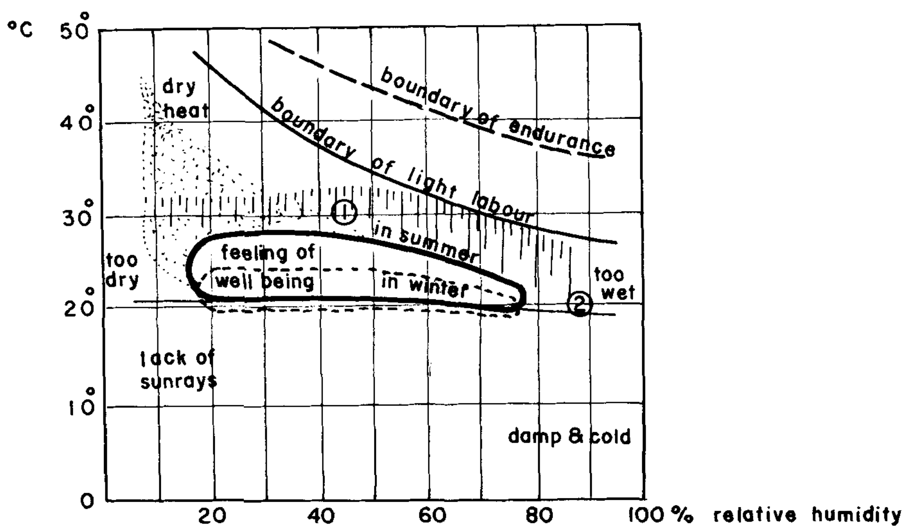


Fig. 2.7. Relation of temperature and relative humidity to attaining favourable feeling during water recreation in a mild climate. Sunshine and wind motion appear as important secondary factors: 1 - lack of air motion, 2 - lack of shadow.

Water quality standards for indoor and outdoor swimming pools approach the requirements for drinking water (Tab. 2.14). The relevant quantitative requirements include

(a) filling water R_f - its volume corresponds to the volume of the pool and of the relevant installations for water circulation etc. $R_f = V$.

(b) supplementary water R_s - compensating losses through spilling, seepage, leakage, evaporation etc.

(c) dilution water R_d - to ensure the required concentration of polluting substances, concentrated by the operation of the pool.

The quantity of dilution water for pools without water circulation can be derived from the permissible increment in the content of chlorides, measured to the permissible value of chlorides in the water resource. The specific daily pollution increment is

2 g per capita and day for outdoor and indoor swimming pools

1 g per capita and day for natural bathing pools, therefore

$R_d = \frac{2000}{30} = 66$ l per capita and day.

R_d - water requirements of dilution water for outdoor swimming pools.

During water circulation a 0.25 m layer of water has to be replaced in the course of one hour. The required capacity of the water treatment plant has to be

$$R_c = \frac{A \cdot 0{,}25}{3600} + R_s \qquad (m^3.s^{-1}) \qquad (2.52)$$

R_c - recycled discharge

A - area of the swimming pool (m^2)

When water is being circulated in a natural bathing pool, the recommended design discharge for the treatment plant is 0.5 m^3 per capita and day. Large swimming pools require a continuous process of circulation; an interrupted process is recommended for small pools with only a 4 hour cycle.

As a water-saving technique and in order to improve the water quality, the circulated water can be used for showers, flushing, filter washing and the cleaning of the recreational amenities.

2.4 MUNICIPAL AND RURAL WATER REQUIREMENTS

The amount and quality of water used in human settlements influences the social development of the society concerned and affects the biological development of the individual human beings. The quality and quantity of drinking water supplied to organisms has a direct effect on health.

Water supplies important minerals to organisms. The long-term utilization of the same water for drinking and cooking purposes by an individual influences the development of the organism and its hereditary signs. The amount and quality of water used for washing and bathing has a considerable influence on health conditions in human settlements.

The extent of these influences depends on the physiological adaptability and characteristic properties of man in the framework of the homeostasis of his own biological system, on the energy input and output of relevant individuals, on the supply of nutriments, vitamins and on other sanitary conditions.

The mode and frequency of the relevant organism's contact with water is a further important factor. Water demand in households, workshops and public services has different quality requirements for:

(a) drinking (and other uses resulting in internal contact of water with the human body: meal preparation),

(b) other domestic uses in contact with the surface of the human body

- physical care: washing, showering, bathing
- dish washing
- laundry

(c) using water in systems where contact with the body can be avoided

- laundry
- house cleaning and car washing
- yard and park watering, street cleaning, sewer flushing
- toilet rinsing
- fire extinguishing

(d) using water in closed systems

- heating
- air conditioning.

The supply of water of uniform quality for each of these technologically different purposes is the simplest method to safeguard all these requirements by means of one supply network. In practical cases this method may not appear as the most economic or suitable to positively influence the development of human organisms and their health.

2.4.1 Water Requirements for Drinking and Cooking Purposes

The physiological water requirements of a healthy individual reaches an average of 1.5 to 15 liters per day. The metabolic processes of each individual tend to achieve a balanced stage, depending on climatological conditions, personal weight and individual activities (profession, hobbies) and customs (drinking, eating, dressing), thus requiring a stable complementing of water losses.

The physiological water requirement of some 2.5 l per capita and day is covered 50% by food and 50% by beverages. In addition to this, a healthy organism produces some 0.3 l of metabolic water per day by processing the basic nutriments. The physiological water requirements per capita and day R_i can, therefore, be expressed by the following equation

$$R_i = f\ (w,\ a,\ c,\ h,\ f,\ m) - R_f \text{ (l per capita and day)} \qquad (2.53)$$

w - individual weight

a - activities (profession, hobbies, age)

c - climate (especially temperature and humidity)

h - personal habits (quality and quantity of drinking, dressing etc.)

f - food composition

m - metabolic function (less important)

R_f - content of water in food.

The human organism is influenced by the amount and quality of accepted water, especially if ancestors have been living in the same place for generations. The anorganic and organic constituents of water have a direct influence on the human organism, i.e. physiologically, and an indirect influence, i.e. psychically, both positively and negatively. The human organism generally, depending on its individual properties, may get accustomed to the influence of natural water constituents and their combination, or may produce relevant anti-matter. But some constituents of water, especially those coming from pollution through wastes from industry and agriculture, may cause diseases or morbid changes, namely

(a) teratogenic (may induce morbid changes of the organism)

(b) mutagenous matter (may produce hereditary changes)

(c) cancerogenous matter (may cause malignant tumours).

These matter and their function are not sufficiently known, because the reaction of any organism to such matter depends to a considerable extent on their quantity, combination and concentration, as well as on the organism's health and habits. The degree of resistance depends on the health standard, hereditary and personal resistance or disposition and age of the individual concerned.

Occasional drinking of unsuitable water may not be dangerous when the relevant harmful concentrations are low and when the relevant organisms does not contain potentially dangerous germs. The organism's own bacteria limit the development of the accepted bacteria. On the contrary, daily drinking of physiologically or sensorially unsuitable though sanitarily non-defective water which only corresponds to basic standardized indicators may cause unexpected consequences.

To achieve the healthy development of the population, it is essential to secure an everyday supply of physiologically beneficial and sensorially aggreeable water, at least for drinking purposes. If the quality of water in the pipeline system does not correspond to these criteria, it is vital to supply bottled water of physiologically beneficial quality, at least for sucklings. For this reason, it is also advisable to organise the production of all beverages using, without exception, groundwater resources of the best quality available.

The standards for water quality should be derived from the mode of contact of human organism with water, because this is

(a) regularly absorbed by the organism,

- without boiling
- after boiling, or

(b) in temporary contact with the whole surface of the organism (and may be accidentally swallowed during showering, swimming etc.)

(c) in restricted incidental surface contact with a part of the body (during washing, cleaning, sprinkling etc.)

(d) used in closed systems, excluding contact with the organism (air conditioning, heating, toilet rinsing, drip and subsurface irrigation).

In only one supply system is used for all the purposes of municipal or rural water supply, as is usual, the water quality should correspond to the highest quality requirements, i.e. to drinking water requirements. If such water is not available for all required purposes, sanitarily non-defective water should be used for such purposes, where contact with the organism cannot technically be excluded. The supply of the necessary amount of such water, whose value depends on local conditions, prevents the occurrence of water-borne diseases.

The level of knowledge about the biological importance of the different elements and components present in water and their combination is generally low, except the appreciation of the medical effect of some mineral waters.

Not even the effect of such basic components as calcium Ca or magnesium Mg has been sufficiently investigated. The knowledge on the effect of trace elements and especially of the synergetic or antagonistic effects of their combinations: iodin J and fluorine F, fluorine F and molybden Mb etc., is also low.

The reaction of the organism to the impact of these elements can have considerable individual or hereditary effects, also in combination with other external factors such as climate, overloading of the organism, the organism's stage of development, health state etc. Water of a different quality can be used for different purposes of domestic use and relevant quality indicators for any category of its particular use can be derived from the

(a) sanitary non-defectiveness,

(b) physiological benefit,

(c) sensorial agreeableness (Fig. 2.8).

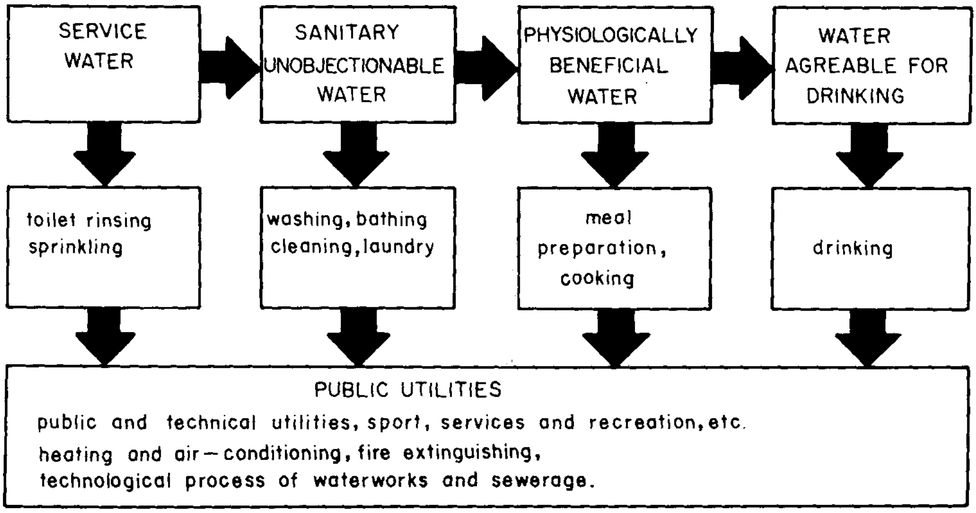


Fig. 2.8. Hierarchy of goals and requirements on water quality for municipal water supply and possibilities of water delivering water of different quality for relevant purposes.

The physiological benefit from water depends not only on its chemical and bacteriological composition, but also on its temperature, flavour and odour as the components of its sensorial properties. The quality of water in the supply network depends on the quality of raw water and can be defined by means of standards. The interstate coordination of these values is organized under the auspices of the World Health Organization and the International Standard Organization. The health and optimum development of the population can be permanently and effectively influenced through the utilization of appropriate water resources and through sophisticated water treatment (Tab. 2.14, 2.15, 2.16).

Water quality can be defined and standardized by means of indicators expressing the limiting concentrations of relevant components and other water properties with regard to their health effect. Their values have to be derived from the character and intensity of impact of the relevant components of the human organism. The number, type, methods and frequency of sampling and analytic methods are also standardized.

The relevant values can be standardized as

(a) maximum permissible values - water which exceeds these values may not be considered as drinking water (mandatory limits),

(b) recommended limits - the rate of their occasional or permanent excess has to be analyzed individually in consideration of local conditions (and officially approved).

Relevant drinking water quality requirements may differ for temporary or in-

TABLE 2.14

Selected indicators	Maximum permissible value ($mg.l^{-1}$)	
Physical: - colour	^{o}Pt 300	According to the platinum-cobalt scale
Chemical:		
a) matter influencing suitability for drinking:		
Total evaporation residium	1000	
Iron (Fe) total	50	Higher content when the ammonia content is below 0.5 $mg.l^{-1}$, due to the corrosion effect
Manganese Mn	5	
Copper Cu	1.5	
Zinc Zn	1.5	
$MgSO_4 + Na_2SO_4$	1000	
Sodium alkylbenzenesulphonate	0.5	
b) matter affecting health:		
Nitrates NO_3^-	45	Causing metahemoglobinanemia in sensitive individuals in concentration 100 $mg.l^{-1}$.
Fluor F^- derivatives	1.5	Higher concentration causes fluorosis, concentration 0.8.-1.0 $mg.l^{-1}$ are anticaretic prevention.
c) toxic matter:		
Phenol derivatives	0.002	gas works, chemical industry, volcanic waste from metal coating
Arsenic As	0.05	
Cadmium Cd	0.01	
Chromium Cr^{-6}	0.05	
Cyanids CN^-	0.20	
Lead Pb	0.05	
Selenum Se	0.01	
Total -activity	1000 $C.l^{-1}$	
d) matter indicating pollution:		
Oxidability	10.0	
Biochemical oxygen demand BOD_5	6.0	
Nitrogen N (total)	1.0	
Ammonia NH_3	0.5	
Extractable matter CCE	0.5	
Fat	1.0	

Maximum permissible content of chemicals in raw water that may be treated for drinking purposes, according to the recommendation of the World Health Organization.

dividual water supply and for permanent collective municipal and rural supply, where more strict criteria have to be applied with regard to possible infection, epidemics etc. From the metodological point of view it is possible to distinguish such indicators as

TABLE 2.15

Class	Bacteriological pollution	Bacteria coli per 100 ml	Required treatment
I.	slight	0 - 50	disinfection only
II.	medium	50 - 5000	current processes: coagulation, filtration
III.	high	500 - 50000	special treatment
IV.	excessive	>50000	water has to be used if inevitable only

Classification of raw water used for drinking purposes after its bacteriological pollution according to the recommendation of the World Health Organization.

TABLE 2.16

Indicator	Water course	Raw water	Drinking water recom.	max.
Chloride (CL^-)	400	200	20	30
Sulphide (SO_4^-)	300	200	60	
Calcium (Ca)	300	250	36	70
Magnesium (Mg)	200	125	30	60
Fluoride (F)	2.4	1.5	1.0	1.3
Ammonia (NH_3)	3	0.5	0	0.2
Nitrate (NO_3^-)	50	25	20	30
Nitride (NO_2^-)	-	-	-	0.05
Sulfate (SO_4^{2-})	-	-	25.0	50.0
Phosphate (PO_4^{3-})	-	-	0.01	0.02
Iron (Fe- total)	1.5	0.5	0.05	0.1
Manganese (Mn)	0.5	0.2	0.01	0.03
Cyanide (CN)	0.2	0.01	0.01	0.05
Zinc (Zn)	2	2	1	2
Nickel (Ni)	0.1	0.05	0	
Lead (Pb)	0.1	0.04	0	0.04
Chromium (Cr)	0.1	0.05	0.05	
Arsenic (As)	0.5	0.04	0.04	
Copper (Cu)	0.2	0.05	0	0.05
Selenium (Se)	0.1	0.05	0.003	0.01
Mercury (Hg)	0.005	0.001	0.0001	0.004
Cadmium (Ca)	0.3	0.005	0	0.005
Alluminium (Al)				0.05
Free Chlorine (Cl)			0.1	0.3
Oxygen (O_2) (min 5.0)			8.0	10.0

Selected admissible values of ion content ($mg.l^{-1}$) in water courses, surface water used for municipal water supply and in drinking water (recommended and maximum admissible values).

(a) bacteriological and biological indicators

(b) chemical and physical indicators.

Drinking water may be defined as sanitarily non-defective water when it does not cause any health troubles or diseases, even after long-term utilization.

In addition, water delivered for municipal and domestic purposes should be wholesome and palatable. Water from underground sources is preferred to surface-water delivery. Groundwater contains more bioelements important to human organism, has a stable temperature, and is less subject to contamination than surface water resources. But the very high demand for municipal water frequently precludes the exclusive use of groundwater for municipal water supply because of the limited capacity of groundwater resources.

Bacteriological non-defectiveness is an indispensable requirement. Physical and chemical indicators tend to demonstrate possible pollution in the water resource or during water purification and transport.

The term raw water refers to water from the surface or underground resource, whose quality only depends on natural factors and possible anthropogenetic pollution. Water treatment or water purification is a combination of technological processes aimed at changing the quality of raw water to the required level (Fig. 2.9).

The quality of treated water depends on the quality of raw water: not only on the content of undesirable matter not removed during water treatment, but also on the content of desirable matter which was removed during treatment or which does not appear in the raw water. For example, the lack of minerals in drinking water, characteristic for treated water from surface resources, incidentally causes heart and vessel diseases.

The basic requirement for the quality of raw water intended for municipal water supply is its non-defectiveness from the toxicological point of view and the safe running of technological processes during its purification.

The values for the maximum permissible concentration of harmful matter are gradually being defined with more precision. Particularly important is the quantity of harmful bacteria and of organic matter, whose concentration increases the probability of noxious effects. The harmfulness of this matter also depends on its combination. Unpleasant flavours and odours which are difficult to remove are another important factor.

Water treatment decreases the content of undesirable components to below the level of maximum permissible concentrations and increases the suitability of the water for transport in the pipeline network. All pathogenetic organisms, in particular the large group of Salmonella-Shigella bacteria and viruses, have to be removed by disinfection. Viruses are often resistant to current disinfection methods, including:

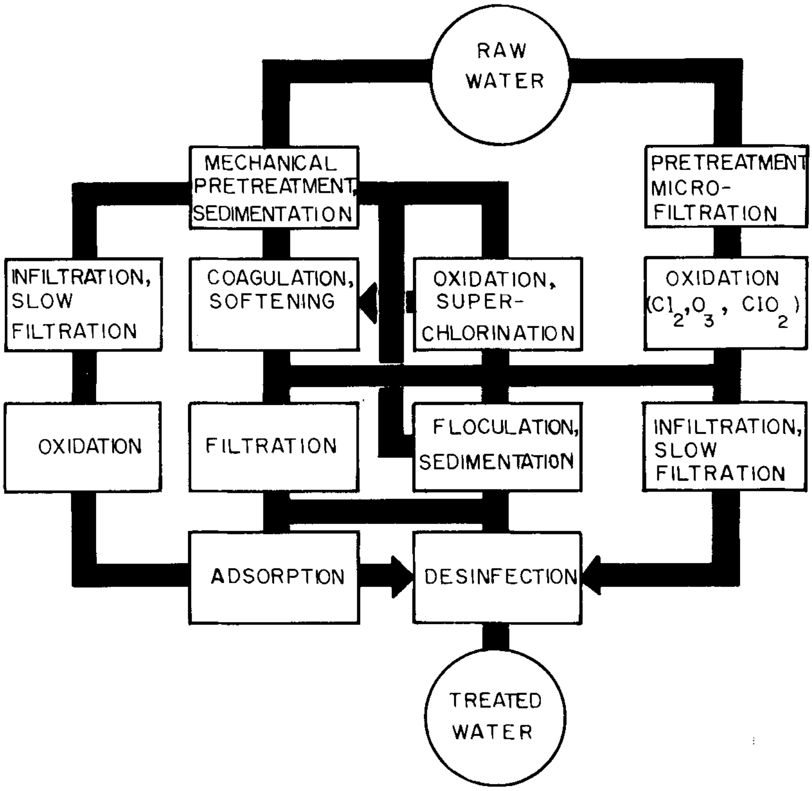


Fig. 2.9. Basic combinations of methods of water treatment for municipal water supply.

(a) physical (light-ultraviolet rays, radioactivity - γ-radiation, heat, ultrasound, electricity)

(b) mechanical (filtration, clarification, sedimentation, ultramicrofiltration, reverse osmosis, capable of removing 95-99% of bacteria)

(c) chemical (chlorination, i.e. adding of its compounds, other halogens, oxygen etc.)

(d) oligodynamic (katadynisation and other disinfection methods using various heavy metals: silver, copper and their salts).

An excess of disinfection matter, e.g. chlorine, forms a protection against pollution during transport in the pipeline network. Its extinction at the end of the network may indicate relevant pollution, which may be of pathogenetic origin. But chlorination may also produce adverse effects: trichlorine methane derivatives, produced by reacting chlorine on humine acids, currently occurring in surface waters, cause the dissemination of cancer according to Maugh II (1981).

Apart from sanitary requirements, the quality of drinking water should correspond to the requirements of economical and continuous transport in the pipeline system, not causing corrosion or clogging. The optimum water quality for this purpose depends especially on the degree of over-saturation and under-saturation with calcium carbonate $CaCO_3$. This state can be characterised by Langelier's index, i.e. by the difference between the actual pH factor of water and balanced pH_s, when the protecting alkalinity corresponds to the concentration of carbon dioxide CO_2

$$I_s = pH - pH_s \tag{2.54}$$

TABLE 2.17

Material	Concrete	Asbesto-cement	Steel & cast iron	Glass & plastics
Saturation index	0	0	0	0
Oversaturation with calcium carbonate				
- as $CaCO_3$	5-10 $mg.l^{-1}$	5-10 $mg.l^{-1}$	5-10 $mg.l^{-1}$	5-10 $mg.l^{-1}$
- as Ca	0.05-0.1 $mmol.l^{-1}$		0.05-0.1 $mmol.l^{-1}$	
Aggressive CO_2	5 $mg.l^{-1}$	5 $mg.l^{-1}$	5 $mg.l^{-1}$	-
Calcium Ca	-	-	16 $mg.l^{-1}$	-
Total alkalinity	0.8 $mmol.l^{-1}$	0.8 $mmol.l^{-1}$	0.8 $mmol.l^{-1}$	-
Factor pH	6,7	6.0	-	
Sulphates SO_2^{2-}	250 $mg.l^{-1}$	250 $mg.l^{-1}$	-	
Suspended matter	15 $mg.l^{-1}$	15 $mg.l^{-1}$	1000 $mg.l^{-1}$	15 $mg.l^{-1}$
COD (by permanganate)			75 $mg.l^{-1}$	

Degree of aggressivity	Rate of uniform corrosion μm per year (water temperature below 25°C)
I. mild aggressivity	50
II. medium aggressivity	50 - 150
III. high aggressivity	150

Indicators for safeguarding the stability of water quality during its transport and limiting the corrosion rate in pipeline systems. Degree of aggressivity for determining the efficiency of the water treatment process to limit the corrosion rate.

The protection of metallic pipelines has to be achieved by a certain degree of oversaturation with calcium, forming a thin internal protective. This can be achieved under conditions of a high content of the total components of carbonic acid H_2CO_3. According to Stumm (1962), in the case of a low content of these components, a granular porous matter appears instead of a compact film. The aggressivity of water depends on the character of the material it contains, and has to be evaluated on the basis of the limiting values of the pH factor, sulphates SO_4^{2-} and chlorides Cl^-. Pipes made of plastic materials and glass are chemically far more resistant (Tab. 2.17).

For the most part domestic water requirements have to be covered by warm water supply. The mass supply of warm water is often accomplished by a special pipeline network. The quality requirements for mass supply of warm water is a complex subject. Such water should correspond to drinking water standard and must not cause excessive corrosion or clogging of the supply network. The temperature of warm domestic water should be about 60^oC, because higher temperatures increase the corrosion rate. Chemical indicators for warm water quality are, therefore, more complicated means of achieving the desired balance for limiting corrosion and clogging (Tab. 2.18). These criteria also include the content of magnesium Mg before warming and the maintenance of the diphosphorus oxide P_2O_5 concentration above 2 mg. l^{-1} to 3 mg. l^{-1}.

TABLE 2.18

Temperature	< 60^o C	Total alkalinity		> 1.5 $mmol.l^{-1}$
Dissolved solids	<1000 $mg.l^{-1}$	$CaCO_3 + MgCO_3$		> 1.5 $mmol.l^{-1}$
Factor pH	< 8.6	P_2O_5		2 - 5 $mg.l^{-1}$
Content of chlorides in dependence on $CaCO_3$+$MgCO_3$				
$CaCO_3 + MgCO_3$	< 4,18 $mmol.l^{-1}$	→		75 $mg.l^{-1}$
	> 4,18 $mmol.l^{-1}$	→		150 $mg.l^{-1}$
Content of magnesium Mg^{2+} in dependence on pH and total alkalinity +)				
pH	<8,6	total alkalinity 1.5-4 $mmol.l^{-1}$		<105 $mg.l^{-1}$
	>8.8	4-8 $mmol.l^{-1}$		< 42 $mg.l^{-1}$
Content of free CO_2 in dependence on Ca^{2+}, and total alkalinity +)				
$0 \leq (Ca^{2+}-a) \leq 0.5$	$0 \leq (a-Ca^{2+}) \leq 0.5$	$0.5 < (a-Ca^{2+}) \leq 1$		$0.5 < (Ca^{2+}-a) \leq 1.5$
$mg.l^{-1}$				$mg.l^{-1}$
≤1		1.5-3.6 $mmol.l^{-1}$		≤1.8
≤5	←	3.6-7.2 $mmol.l^{-1}$	→	≤7
≤16		> 7.2 $mmol.l^{-1}$		≤18

Basic criteria for the quality of warm water supplied by a special pipeline network for ma$s supply: +) before warming, a - alkalinity.

2.4.2 Water Requirements for Other Domestic Uses

Water requirements for other domestic uses depend on the local conditions, especially on the

- life-style
- standard of equipment
- ratio of income and water rates
- number and age of household members.

In developed countries, the standard of equipment has the greatest influence (Tab. 2.19).

TABLE 2.19

Household equipment	Average daily water requirements (l per capita and day) block of flats	family houses
Mass delivery of warm water, central heating, bathroom	280	170
Warm water heated locally bathroom	230	140
Cold running water, shower	150	90
Outdoor wells, street faucets (without running water or flush toilets)	40	25

Average urban and rural water requirements per capita and day and their relation to the standard of household equipment.

Water withdrawals for domestic water supply generally exceed the relevant water requirements and also depend on the technical equipment and state of the supply network, as well as on its operation and maintenance. Water rates have a regulating effect, depending on the ratio of the family or individual income and its value, but only if payments are derived from current metering. It is useful to apply water pricing as a regulating factor of water withdrawals, when the total water demand reaches the capacity of the constructed supply systems, or when the water balance of the relevant area tends to be passive. Under such circumstances, lower water withdrawals decrease operating costs and delay the extension of the old supply system or the construction of a new one.

Domestic water requirements also depend on the structure of the family, on the age, sex and activities of the family members. Nevertheless, the prevailing factor is the standard of equipment. The crucial moment of a rapid increase in water requirements is reached when water use is not restricted by availability, a low standard of equipment or high rates influencing living standards.

The availability of free time may appear as the next crucial factor for a further rapid increase in water requirements. According to Holman (1961), the structure of time utilization in developed countries during the period 1950-2000 will not change considerably (except annual leave, which may restrict requirements in the critical summer period). For this reason, future water demand will not differ from present requirements, which correspond to high living standards.

Domestic water requirements (including drinking water demand, forming 2-2.5% of its value only) have to be derived from the standard of equipment, occupation and general customs, sex and age and simply defined as a function for the individual

$$R_1 = f (s , o , g) \qquad \text{(l per capita)} \qquad (2.55)$$

and for the household (family) members.

Defining the average per capita and day water requirements R_d as the optimum value which corresponds to the customary style of life, not including excess wastage, previous equations can be simplified by using coefficients as follows:

for the individual $\quad R_1 = R_d \cdot k_a \cdot k_x$ (l per capita)

for the household $\quad R_f = m.R_d \cdot k'_a \cdot k_x$ (l per household)

k_a, k'_a – coefficient of activity (profession and free time)

k_x – coefficient of unavoidable wastage

m – number of household (family) members.

The total domestic water demand is expressed by the sum

$$R_s = k_s \cdot k_x \cdot \sum_{k=1}^{N} k_a \cdot m_{ak} \cdot R_d \qquad (m^3 \text{ per day}) \qquad (2.56)$$

k_s – coefficient of losses in the supply system (< 1.15)

k..... N – category of the dwelling standard including subcategories of activities

m_{ak} – number of inhabitants in relevant subcategories

R_d – optimum water demand which corresponds to the style of life (household equipment and activities).

When analysing the necessity and economy of domestic water supply for different purposes of utilization it is possible to distinguish four categories of water quality:

A_1 – physiologically beneficial water agreeable in smell and taste (can be supplied by a special network or bottled)

A_2 – physiologically beneficial water (if not available, can be replaced by category B)

B – drinking water, as defined, i.e. sanitarily non-defective water, which cannot cause health troubles or diseases, even after long-term utilization.

C – sanitarily non-defective water. The use of water of lower quality for flushing, water and other purposes requires strict technical and hygienic measures to exclude any contact with the human organism.

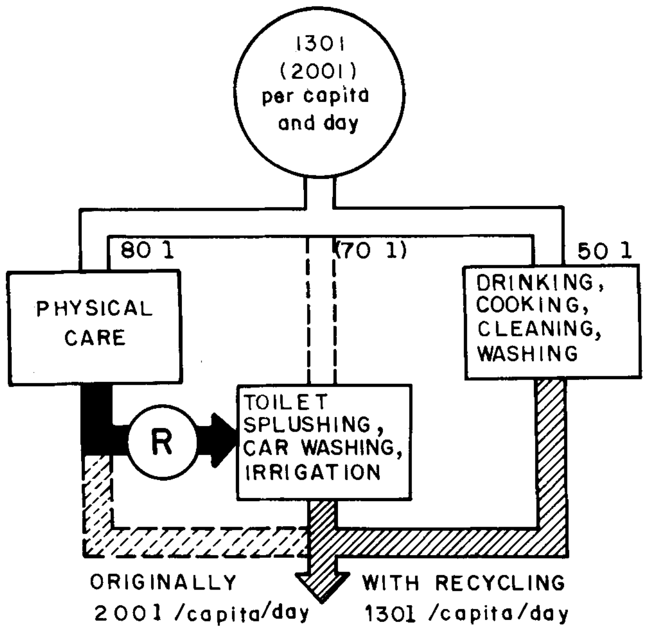


Fig. 2.10. Water-saving technologies for households. Schematic representation of possibilities of waste water segregation in household and subsequent feasibility of domestic water re-use. Traditional system in black and dotted, data in brackets.

The basic precondition for a high standard of life can be ensured by supplying 250 l per capita and day (Tab. 2.20), if used in a proper way. Supplying higher quantities only forms favourable conditions for water wastage. The same standard can be achieved by applying unconventional water-saving techniques to lower water withdrawals and/or by recycling segregated waste waters: Waste water from personal washing, bathing and laundry can be used without any treatment for toilet rinsing, garden watering and outdoor washing (Fig. 2.10).

Pollution by detergents may restrict the use of such water for irrigation. This can be precluded by using suitable detergents, namely by using detergents which have fertilizing effects and do not form carcinogen remnants. Waste water re-use in households may decrease the per capita water requirements of the highest standard of life to some 130 l per day, thus enabling the growing water demands for irrigation and street washing to be covered, in many cases without an extension of the existing water supply network.

TABLE 2.20

Component		Water requirements per capita and day (l)	(%)	Total per capita and day (l)	(%)	Water quality Harmless	Health bene-ficial	Agree-able to drink
Drinking	A_1	2				+	+	+
Meal preparation	A_2	3	2	5	2	+	+	−
Dish-washing	B	15	6			+	−	W
Physical care		60	24			+	−	W
Laundry (washing)		20	8			+	−	W
Cleaning		10	4	105	42	+	−	W
Toilet rinsing	C	50	20			−	−	−
Garden watering		10	4	60	24	−	−	−
Unavoidable losses	A–C	30	12	30	12			
Household total		200	80	200	80	+	+	+
Public utilities & heating		50	20	50	20	+	+	+
Urban water requirements total		250 l per capita and day						

Ideal structure of per capita and day urban water usage respecting modern style of life, but not including unnecessary wastage which does not improve the living standard. Corresponds to water requirements of garden cities in a humid climate.
Symbols: + yes, − not necessary, W warm water

2.4.3 Urban Public Water Requirements

Urban public uses of water include

(a) public and technical utilities

(b) heating and boiling (steam, heated and warm water networks) - see paragraph 2.4.2, Tab. 2.18.

(c) fire extinguishing

(d) water and waste water treatment, cleaning of water supply and sewer system.

Public and technical utilities embrace all services including cultural, schools, hospitals and other sanitary services and administration, but not industrial and agricultural production. Water use for this purpose also includes street washing and watering of gardens and parks, playgrounds and graveyards, and cleaning of transport vehicles (Tab. 2.21).

TABLE 2.21

Water requirements	Per employee daily	Water requirements	Per visitor daily
Shops, stores	60	Theatres, cinemas	5
Bar	300	Nurseries, creches	120
Restaurant, canteen	450	Kindergarten	60
Snack bar, canteen	400	Schools	25
Café, wine cellar	300	Universities	40
Services not using water for processing	80	Youth clubs	25
		Gymnasium	60
Dirty and dusty workshops	180	Sauna	250
Hairdressers	200	Match auditorium	3
Photographic laboratories	800	Travellers by rail or bus	3
Sales rooms	60		
Butchers' shops	80		Per one washing
Chemists	100		
Sanitary services	80		
Railway stations	60	Car washing	500 - 1000
Offices	60	Lorry, bus washing	900 - 3000
	per bed daily		per sq.m. daily
Hotels de lux	1200	Communications 1)	3 - 5
second class	500	Public spaces 1)	3 - 5
Guest houses hostels	200	Playgrounds	1 - 2
Hospitals	700	Tennis, basketball	10
Convalescent homes	250		$m^3.ha^-$ per season
Social care homes	500		
		Parks 2)	1200
		Gardens 2)	3000
		Graveyards 2)	200

Urban public water requirements: 1) 240 days a year, 2) in humid climate.

The quantity of water used for heating is relatively small and relatively unimportant for water balance computations. The quantity of water used for water treatment and cleaning the water supply and sewer system can be derived as a percentage of the total amount supplied. When using water for fire extinguishing, temporary troubles or breakdowns in the public water supply may be permitted.

Water requirements for public uses therefore depend

(1) on the area of the community (washing and watering of communication lines and other public areas)

$$R_a = \sum_{k=1}^{K} A_k \cdot R_{ak} \qquad (m^3) \qquad (2.57)$$

A_k - area washed and watered (m^2)

R_{ak} - specific water demand per square unit $(l.m^{-2})$

(2) on the number of inhabitants (per capita and day water demands in public utilities)

$$R_b = n \cdot \sum_{k=1}^{L} R_{bk} \qquad (m^3 \text{ per day}) \qquad (2.58)$$

n - number of inhabitants

R_{bk} - average per capita and day uses in relevant public utilities $(m^3$ per capita and day)

(3) on the number of public, cultural and other social utilities (on the number of outdoor visitors, requirements not included in the number of inhabitants - hotels, hostels, selected schools, sanitary, sport, cultural and transport utilities etc.)

$$R_c = \sum_{k=1}^{M} m_k \cdot R_{ck} \qquad (m^3 \text{ per day}) \qquad (2.59)$$

m - number of visitors in relevant utilities

R_{ck} - per capita and day uses of visitors in relevant public utilities.

The per capita and day requirements of the inhabitants and visitors can be estimated as the fictitious uses of relevant personnel.

The quality of water for public utilities theoretically corresponds to the mentioned four categories for domestic water uses. The quantity requirements depend on the climate, on the size of the relevant localities and on the standard of the relevant public utilities. Their total reaches some 10% of the domestic water demand for unimportant townships, 30% for big municipalities and some 50% for large cities and spas.

Water for fire extinguishing has to be withdrawn from the water supply network, from special reservoirs and/or directly from a water resource. The quality requirements for such water should safeguard the uninterrupted operation of the extinguishing equipment - i.e. preclude clogging - and also secure the basic sanitary postulates.

TABLE 2.22

Fire load (kg)	Specific water requirements ($l.s^{-1}$)	Period between the alarm and extinguishing (min)	Distance of the fire brigade (km)	Surface affected by fire (m^2) Minimum	Collective dwelling	Industry with combustible products
5	0.128	3	0.5	16	44	95
50	0.170	10	3–6	28	72	148
100	0.220	20	10–13	45	112	224
120	0.240	30	18–22	62	152	300
180	0.300	40	28	79	192	337

Parameters for determining fire water requirements: specific water requirements for different fire load and surface assumed to be affected by fire at the beginning of fire extinguishing.

A minimum volume of at least 75 m^3 or a maximum daily withdrawal of 3 hours should be reserved for fire extinguishing purposes in the reservoirs of the relevant supply network. The capacity of the water resources and intake must allow a supplementation of this volume for 12 hours in industrial estates, for 24 hours in big towns and for 36 hours in small townships.

The theoretical requirements for fire extinguishing correspond to the size of the area attacked by fire at the beginning of extinguishing. The specific water requirements, corresponding to 1 m^2 of the area attacked, depends on the structure and material, expressed as fire load. This load has to be determined by converting the amount of combustible matter present in the volume of wood of the same heating value. It is neither advantageous for economical to safeguard water for extinguishing single family houses, simple and small buildings, or small localities with water requirements which do not exceed 5 $l.s^{-1}$.

Water requirements for fire extinguishing are determined by the following formula

$$R_e = \delta \cdot A_e \cdot R_{se} \quad (l.s^{-1}) \qquad (2.60)$$

R_e – water requirements for fire extinguishing ($l.s^{-1}$)

A_e – area attacked at the beginning of the fire extinguishing (m^2)

δ – coefficient which expresses operational difficulties during fire extinguishing (1 to 1.3, max. 1.5, depending on ventilation, evacuation of persons, types of combustible matters etc.)

R_{se} – specific requirements of water for fire extinghishing ($l.s^{-1}.m^{-2}$)

The size of the area attacked depends in part on the type of building and then on the time it takes the fire to flare up and the time it takes the fire-brigade to arrive, i.e. on the distance of its headquarters (Tab. 2.22) and on the method of the fire alarm signal. For storage tanks, silos and reservoirs the theoretical value of this area is at maximum 150% of the area which can be attacked by fire. The water pressure in hydrants should be at least 0.2 MPa.

The water requirements for water treatment cover

(a) filter washing

(b) sludge discharge of defecators and settling basins.

The water requirements for filter washing are expressed by the formula

$$R_w = \frac{f \cdot t \cdot x \cdot 100}{K \cdot V \cdot (1-e^{-It})} \quad \text{(\% of treated water)} \quad (2.61)$$

f - filter surface (m^2)

I - washing intensity ($m^3.m^{-2}.s^{-1}$)

t - time of washing (s)

x - content of suspended matter in raw water ($mg.l^{-1}$)

k - sludge capacity of the filter ($m^3.m^{-3}$)

V - volume of the filter (m^3)

Leaving aside the quantity of suspended matter in the filter, this equation can be simplified to

$$R_w = \frac{230.3 \cdot \log vt}{v \cdot t} \quad \text{(\% of treated water)}$$

v - filtration rate (%)

t - duration of the filtration cycle (hrs)

The water requirements for the cleaning of defecators or settling basins without pumping are

$$R_u = \frac{x'}{c} \cdot 100 \quad \text{(\% of treated water)} \quad (2.62)$$

x' - concentration of suspended matter which enters the space for thickening ($g.l^{-1}$)

c - concentration of suspended matter in the thickened sludge ($g.l^{-1}$)

Pumping changes the previous formula to

$$R_u = \frac{Q_w \cdot t \cdot 100}{Q_t \cdot t_1} \quad \text{(\% of treated water)} \quad (2.63)$$

Q_w - output of the sludge pump $(m^3.s^{-1})$

T - duration of sludge pumping (sec)

t - period of sludge pumping (sec)

Q_t - treated water quantity $(m^3.s^{-1})$

2.4.4 Management of Water Delivery and Disposal

The flow chart for an assessment of water requirements, as well as their projection for the evaluation of alternative scenarios and for the operational management of water withdrawals in the mass supply network, also embraces industrial and agricultural water supply including infrastructure (Fig. 2.11).

The value of the optimum water demand for population, enabling the development of a high standard of living, was derived in the previous paragraph fixed at 200 l per capita and day for domestic purposes and 50 l per capita and day for urban public uses (without recycling). These figures include a reasonable percentage of water wastage and are to be regarded as planning and operational limits which must not to be exceeded. They also contain a reasonable reserve for an increase in present water demands through

- the extended use of washing-machines,
- more frequent bathing, showering and general physical care,
- the extended use of dish washers,
- the extended practice of garden irrigation and out-door washing (Tab. 2.20).

These figures do not include water requirements for home swimming-pools or air coolers. Using the flow chart for the management of withdrawals (Fig. 2.11), these have to be reduced hierarchically depending on the socio-economic losses which occur as a consequence of the reduced water deliveries.

The course of water withdrawals which fulfill municipal and rural water demands is non-uniform. This course depends on the cycle of economic and social activities, in particular on

- the organisation of production, services and other social activities,
- the living standard, customs and cultural standards which serve to form the relevant life-style.

In the course of the year, minimum municipal water requirements occur during holidays - with the exception of holiday resorts. In Central European conditions, a noticeable minimum can be observed at the end of July and beginning of August and there is also a periodic depression during February. Maximum water requirements, which differ less from the average values than the minimum values, occur very often during October or November and sometimes also before Christmas. The weekly minimum occurs on Saturdays and Sundays. The course of water deliveries depends on economic activities on weekdays, and on the life-style during holidays. The daily minima occur at night, and the maxima in the evening, with a

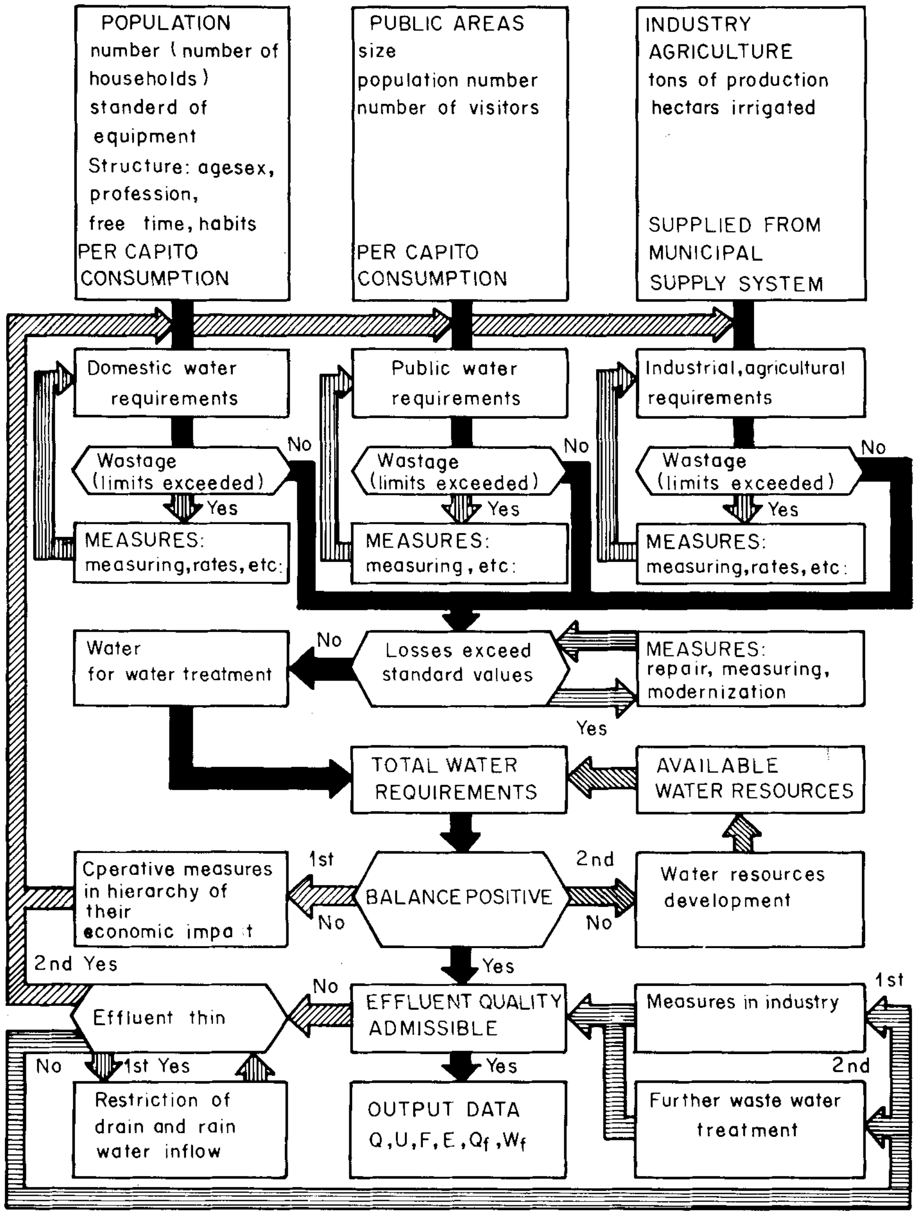


Fig. 2.11. Block diagram for determination of municipal water requirements and management of water delivery during periods of a passive balance of water resources and needs.

less considerable maximum values in the morning and at noon (Fig. 2.12).

The maximum and minimum values of water withdrawals from the municipal water supply network can be derived from the average values by using coefficients as follows:

Maximum and minimum total daily average water requirements:

$R_m = R_d \cdot c_d$ (m^3 per hour) (2.64)

R_d – average daily requirements (total of the domestic and public uses) (m^3 per hour)

c_d – coefficient of the daily non-uniformity (= 0.9 for minimum, 1.05 – 1.5 for maximum, lower values correspond to big cities, higher to small communities)

Maximum and minimum water requirements per hour

$R_h = R_m \cdot c_h$ (m^3 per hour) (2.65)

R_h – maximum daily average demand (m^3 per hour)

c_h – coefficient of the per hour non-uniformity (c_h = 0.15 – 0.6 for per hour minima, 1.5 – 2.9 for per hour maxima, likewise depending on the size of the settlement).

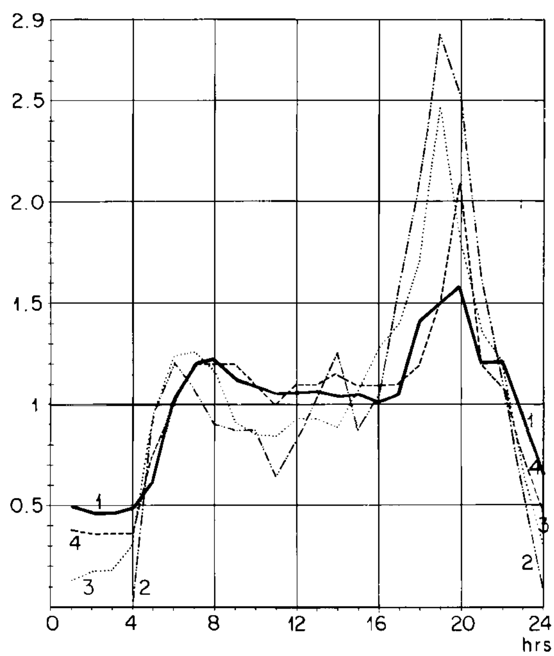


Fig. 2.12. Graphic representation of diurnal fluctuation of water deliveries in a municipal supply network and coefficients of per hour fluctuation: 1 – town with 50,000 inhabitants, 2 – district of workers, 3 – district of clerks and salesmen, 4 – average district.

Water losses which occur during mass water supply for the population are caused by

(a) wastage – i.e. in the unused release of water from the network,

(b) technical shortcomings and defects of the private indoor installations,

(c) the operation, technical shortcomings and defects in the public network incl. water reservoirs.

These losses can be classified as

(a) technically removable,

(b) inevitable losses.

The percentage of water wastage depends not only on the suitability of the relevant technical equipment, but also on the economic tools and the degree of official and personal responsibility and discipline. Technical shortcomings and defects depend especially on the technical state of the water supply network, which in itself depends on the quality of the material, fittings and other equipment, on the state and utilization of measuring equipment as well as on the quality of the workmanship, maintenance, method and duration of the operation, i.e. the age of the system.

The average water losses of the pipeline network should not exceed 10%, and at the end of the service life of the system not more than 15% of water withdrawals.

From the economic point of view water losses have two basic aspects:

(a) the general economy of water resources utilization, which can be analyzed on the basis of water balances,

(b) the cost-effectiveness of the operation of the water supply network depending on the water pricing and water metering system.

These two aspects differ in detail and often generally, as well:

A substantial part of the withdrawn water is not used beneficially, although paid for, and does not, therefore, contribute to the solution of relevant water balance problems. On the other hand, withdrawn water, although not paid for, may be beneficially used. The loss from the cost-effectiveness point of view is formed by the difference between the quantity supplied and the volume paid for. Water used for fire extinguishing, street watering and emergency water supply in cisterns is often not subject to invoicing, yet cannot be considered as a loss from the balance point of view.

Mass water supply is metered

(a) directly - by means of measuring instruments, mainly gauges and water meters,

(b) indirectly - on the basis of the energy consumption for its supply, or pump output.

The course of water delivery and water losses cannot be followed up in the necessary detail, because water supply networks are not equipped with a sufficient number of measuring devices. The manner of invoicing and water pricing, often lump sums which bear no relation to the water quantity really delivered, is not sufficiently bound to the desired real economy to supply water for beneficial uses only. The goal of the assessment of lump sums and other charges is to cover the operation and maintenance costs including profit, if required. Incoherent metering, accompanied by imperfect measuring equipment and the insufficient quantity and wrong location of this equipment, serves to create fictitious losses. Under such circumstances, water pricing does not form an effective tool for economising on water utilization.

Measures for limiting real losses in water tanks, pipelines and indoor installations include

(a) a well-equipped, prompt maintenance and breakdown service for the immediate repair of apparent and discovered troubles,

(b) the execution of repairs, reconstruction and modernization of the network in harmony with the technological development and with its technical state, especially with its corrosion, clogging and ageing,

(c) the limiting of overflow by an effective signalling and blocking system,

(d) the systematic measuring of all important withdrawals and the systematic checking of lump sums and excessive withdrawals,

(e) the utilization of water meters in a quantity which corresponds to the delivered water quantity,

(f) the adherence to the recommended terms for the callibration of water meters and periodic maintenance,

(g) the systematic checking of water losses in the supply system,

(h) the equipping of the network with really watertight valves and closures,

(i) the introduction of an effective system for checking their locking mechanism.

The measures for limiting water wastage are simple, but effective. They include:

(a) systematic water metering and the limiting of anonymous non-metered withdrawals by the installation of water meters not only for the main users, but also for housing units,

(b) an effective water pricing system, introducing water prices which increase with over-excessive water deliveries,

(c) the utilization of water meters in a quantity which corresponds to the delivered water quantity,

(d) the automatic controlling of non-metered escapes of water,

(e) the instalment of automatic stop and discharge valves, locking gear, self-activated timing devices etc.,

(f) the systematic checking of water losses in and automatic checking of escapes from the supply system,

(g) the application of devices for waste water segregation and accumulation, and secondary using of water polluted by washing and showering for toilet flushing, outdoor washing and garden watering.

Domestic sewage is to be accumulated and/or treated in order to avoid the contamination of surface and groundwater resources. It may be, under appropriate environmental conditions and depending on the required degree of control (Fig. 2.13), discharged into a body of water if a sufficient discharge with adequate dissolved oxygen is available, so that the self-purification processes would not cause any nuisance. The appropriate method of domestic waste water disposal depends, therefore, on effluent quantity and quality as well as on local environmental constraints.

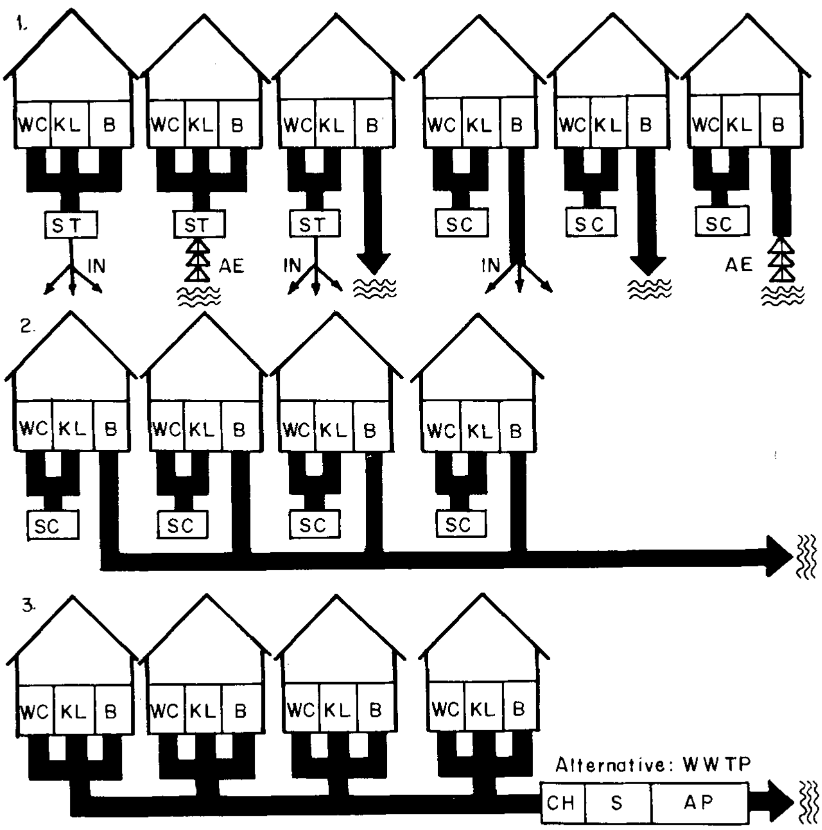


Fig. 2.13. Basic systems of domestic waste water disposal, resulting in a moderate local (scheme 1), moderate semi-centralized (scheme 2), and strict pollution control (scheme 3): KL - kitchen, scullery, laundry, B -bathroom, showers, washbasins, WC - toilet, ST - septic tank, SC - sludge container, S - sedimentation tank, CH- chemical treatment, IN - infiltration, AE - aeration, biological filter etc., AP - aerobic pond, WTP - waste water treatment plant.

2.5 INDUSTRIAL WATER SUPPLY AND RE-USE SYSTEMS

Industrial supply is enabled by industrial water supply and disposal systems, i.e. sets of structures, technological equipment such as measuring and controlling devices with associated feedbacks which secure the withdrawal and treatment of water, its distribution and circulation, as well as waste water treatment and recycling, sludge disposal and the harmless discharge of polluted water into appropriate recipients.

Process water in industry includes all water needed for

(a) processing, i.e. water entering the product and serving functional purposes,

(b) mining and hydraulic transport,

(c) cooling and air conditioning,

(d) boiling and heating,

(e) general use (cleaning, showering, drinking and other personal uses in industry).

Process water does not include water used for water power generation.

The use of water in industry is heterogeneous, and the relevant supply and disposal systems are complicated; these include

(a) open circuit operations - in one process

(b) successive re-use operations -

- of used water in other processes of the same industrial plant,
- of waste water in other plants or in agriculture,
- of municipal waste water in industry,

(c) recycling operations

- partial circulation (e.g. of cooling water)
- closed circuit operation, i.e. circulation and recycling of all waste waters (Fig. 2.14).

In the open circuit system the water withdrawal is discharged into recipient water resources after use in one process. The value of the water withdrawal W corresponds to the water requirement R, i.e. to the sum of the water entering the product or serving other functional purposes, return flow and the water losses

$$R = W = C_1 + \sum_{k=1}^{n} \Delta_k + F \qquad (l.s^{-1}) \qquad (2.66)$$

Water consumption in the open circuit system is

$$C = C_1 + \sum_{k=1}^{n} \Delta_k = W - F \qquad (l.s^{-1}) \qquad (2.67)$$

F - return flow (effluent)

C_1 - water consumption for functional purposes incl. water entering the product

Δ_1 to Δ_k - water losses in the supply, distribution and disposal system

Δ_m , Δ_n - water requirements for water/waste water treatment

The successive re-use of waste waters is characterized by the supply of water in qualities which differ from the quality requirements of the relevant produc-

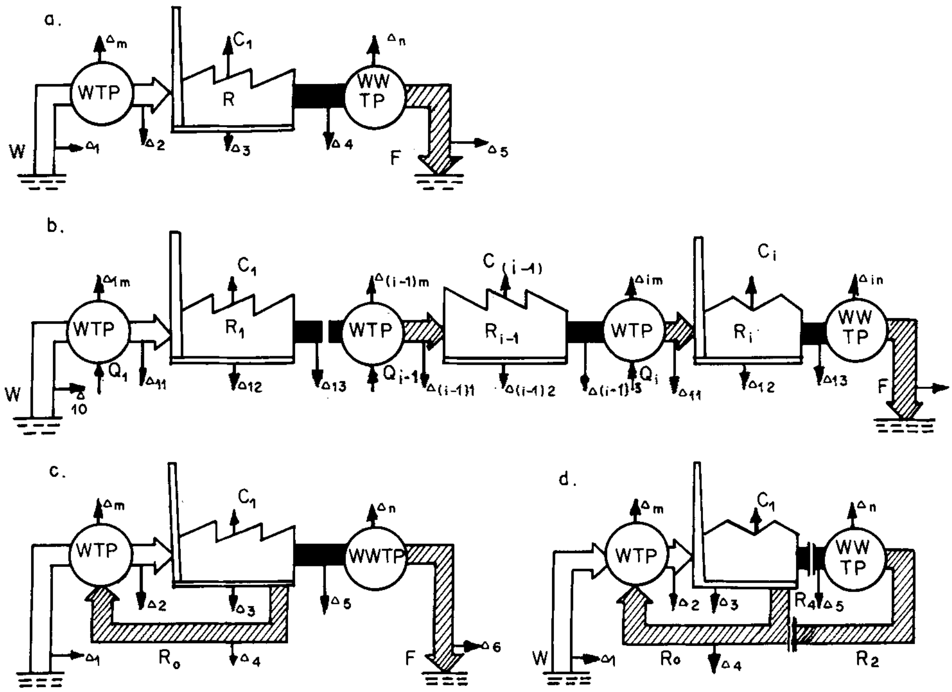


Fig. 2.14. Industrial water supply, distribution and waste water disposal systems: (a) open circuit system, (b) successive re-use system, (c) partial recycling system, (d) closed circuit system. WTP - water treatment plant, WWTP - waste treatment plant.

tion process. The basic problem of the direct re-use of water is:

(a) securing the quantity of water for successive technological processes taking into account the time schedule and hierarchy of water requirements,

(b) safeguarding the quality of the water for the following process, which depends on the quality of the preceeding one, and their schedule on the basis of the decreasing water quality, in order to economize on the water treatment e.g. by segregation of waste waters, re-use of important substances of waste waters etc.

During industrial processes, water is used

- in contact with the material or product without a thermic impact (category A) or without a thermic impact (category B)
- in closed systems without any contact with the raw material or product (category C), (Fig. 2.15, Tab. 2.23).

The criteria for water quality which safeguard successful water re-use and re-cycling are summarized by Appleyard and Shaw (1974) as follows:

(a) low content of suspended matter,

(b) low aggressivity,

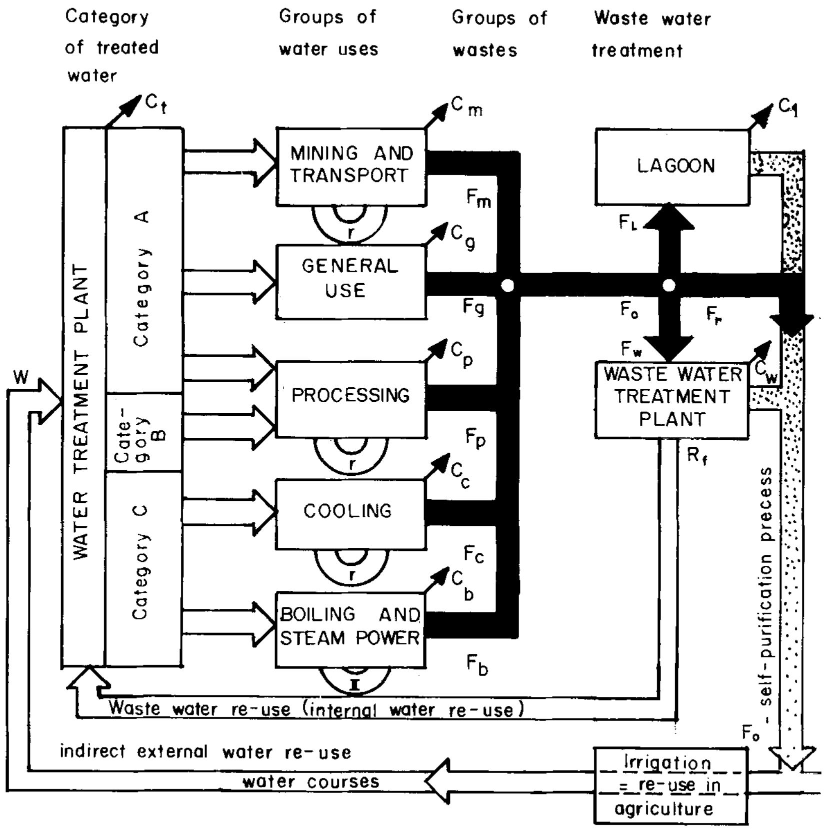


Fig. 2.15. Schematic representation of heterogeneous water quality requirements necessary for relevant groups of industrial processes. These processes result in heterogeneous quality of waste waters, that are to be treated in one waste water treatment plant and subsequently disposed of or re-used, both in industry and agriculture: r - water recycling, F_i - waste waters, C - water consumption, F - effluent, W - water withdrawal.

(c) no tendency to separate salts which are difficult to dissolve,

(d) bacteriologically reliable,

(e) no tendency to create biological deposits,

(f) suitable pH, suitable content of dissolved matter and acceptable odour.

Current water treatment processes are often inadequate when it comes to gaining water of such quality from waste water. The treated waste water contains excessive quantities of salts, including ions of ammonium and phosphorus, and a lot of organic matter, dissolved or suspended, which is bacteriologically dangerous and forms foam. If the current simple treatment processes are not capable of attaining water of suitable quality, the following physical and chemical processes should be applied:

TABLE 2.23

Water quality indicator		Water in contact with the product or with the raw material		Water without any contact with the product		
		without heating	with heating	Temperature of the medium 80°C	80-400°C	400°C
Temperature	°C	-	-	25-28	<28-40	<40-45
Suspended matter	$mg.l^{-1}$	200[1)] 1000	30-45	20-30	10-20	5-10
Fat and oil products	$mg.l^{-1}$			20	10-20	10
pH		-	6.5-9	6,6-8,5	6,5-8,5	6,5-8,5
Total content Mg + Ca	$mmol.l^{-1}$	-	-	-	< 7	< 5
Carbonate content Mg + Ca	$mmol.l^{-1}$	-	-	1,2-3,5 1,5-2,5[+]	1,5-3 1-2[+]	1,5-2,5 0,5-2[+]
Dissolved matter	$mmol.l^{-1}$			<4	<3,5	< 3
Chlorides Cl^-	$mg.l^{-1}$	-	-	<2000	<1300	< 800
Sulphates SO_4^{2-}	$mg.l^{-1}$	-	-	< 350	< 350	<150
Iron Fe	$mg.l^{-1}$	-	-	< 500	< 600	<250
Chemical oxygen demand						
by permanganate	$mg.l^{-1}$	10[1)]	-	< 20	< 20	< 20
by bichromate	$mg.l^{-1}$	-	-	100-150	-	-
Total biochemical oxygen demand BOD	$mg.l^{-1}$	-	-	15-20	10-15	10-15
Bioelements						
Nitrogen N	$mg.l^{-1}$	-	-	50-80	50-80	-
Phosphorus P	$mg.l^{-1}$	-	-	2,5	2,5	-

Quality indicator for circulation water (+ supplementary water) according to information from COMECON (1976): 1) for flotation

(a) coagulation with low doses of ingredients in order to decrease the content of the suspended matter,

(b) sorption with active charcoal - in the case of high quality requirements,

(c) using ion exchanges - especially to eliminate the salinity and metallic ions in exchange for sodium, hydrogen and hydroxyl,

(e) reverse osmosis - for an efficient removal of organic matter and bacteria as well as of suspended and dissolved anorganic matter,

(f) electrodialysis - for the separation of dissolved matter, including acids, bases and salts,

(g) separation of foam - especially for the separation of detergents,

(h) ozonization - for disinfection and decrease in turbidity and content of organic matter,

(i) using immobilized enzymes - in order to remove dissolved organic matter including phenols and in order to decrease the content of pathogenic germs,

(j) fermentation and sterilization - to remove sulphite waste liquors etc.

The basic equations for successive water re-use are (Fig. 2.14b)

$$R_i = R_{i-1} - C_{i-1} - \sum_{k=1}^{n} \Delta_{(i-1)k} \pm Q_i \quad (m^3.s^{-1}) \qquad (2.68)$$

$$C = \sum_{i=1}^{i} C_i + \sum_{i=1}^{i} \sum_{k=1}^{n} \Delta_{ik} = W + \sum_{i=1}^{i} Q_i - F \ (m^3.s^{-1}) \qquad (2.69)$$

$$F = R_i - C_i - \sum_{k=1}^{n} \Delta_{mk} \quad (m^3.s^{-1}) \qquad (2.70)$$

Q_i - excessive inflow that is to be diverted without use or deficit that is to be made up from other sources.

C - total water consumption

C_i - water consumption for functional purposes including water entering the product in the single process i.

Apart from the mentioned direct internal successive waste water re-use, indirect external water re-use also exists, i.e. repeated use of the same water along a river by different users, formed by the discharge of waste waters into water courses and by its successive withdrawal (Fig. 2.15). The ratio of the internal successive water re-use is as follows:

$$r_i = \frac{R}{W} \quad \text{or} \quad r_i = \frac{\sum_{k=1}^{k} R_k}{\sum_{k=1}^{k} W_k} \qquad (2.71)$$

R - the total water requirements needed for relevant technological purposes $(m^3.s^{-1}, m^3)$

W - the total water withdrawals $(m^3.s^{-1}, m^3)$

The ratio of the external water re-use is expressed by the formula

$$r_e = \frac{\sum_{k=1}^{k} W_k}{Q_b} \qquad (2.72)$$

Q_b - the guaranteed stream flow used for the compilation of water balances

The total ratio of water re-use is expressed by their product

$$r_t = r_e \cdot r_i = \frac{\sum_{k=1}^{k} R_k}{Q_b} \qquad (2.73)$$

Generally:

$$Q_b = Q_m + Q_r - \left[\sum_{k=1}^{k} W_k - \sum_{k=1}^{k} F_k \right] \qquad (2.74)$$

Q_m - minimum monthly discharge (98% of guarantee)

Q_r - guaranteed yield of reservoirs

The expression in brackets equals the total water consumption.

The repeated use of the same water inside a closed circuit is called water recycling. Water quality requirements call for water to be treated, at least by cooling after each cycle. In the case of an open system, part of the water quantity enters the circulation system and the rest is used once only or successively (Fig. 2.14c). Water requirements in a system with partial circulation are expressed by the sum

$$R = W + R_o \qquad (m^3.s^{-1}) \qquad (2.75)$$

The actual water requirements are substantially lower and are covered by the water withdrawal, which replaces the effluent of waste waters and feed water in order to replace losses and regenerate the water quality of the circuit

$$W = C_1 + \sum_{k=1}^{n} \Delta_k + F \qquad (m^3.s^{-1}) \qquad (2.76)$$

The water consumption is

$$C = C_1 + \sum_{k=1}^{n} \Delta_k = W - F \qquad (m^3.s^{-1}) \qquad (2.77)$$

The volume of water in the circulation system depends on the recycling rate and, therefore

$$V_o = R_o \cdot t_c \qquad (m^3) \qquad (2.78)$$

V_o - volume of water in the circulation system, whose regular exchange safeguards the regeneration of water quality

t_c - recycling rate (s)

In the closed circuit operation the effluent is limited to that quantity which enables the regeneration of the water quality (Fig. 2.14d)

$F \doteq 0$

The water withdrawal W in such case only covers the water consumption, i.e. the consumptive use incorporated in a product, by-product and waste material plus water losses

$$W = C_1 + \sum_{k=1}^{n} \Delta_k \qquad (m^3.s^{-1}) \qquad (2.79)$$

The intensity with which water is recycled or successively re-used depends on the type and degree of pollution. The closed circuit operation often requires complicated and expensive equipment. Water consumption in industry consists of the consumption during processing C_p , the consumption required to regenerate the water quality C_q and losses during treatment, distribution and recycling.

$$C = C_p + C_q + \sum_{k=1}^{n} \Delta_k \qquad (m^3.s^{-1}) \qquad (2.80)$$

The regeneration of the water quality includes water treatment and waste water treatment, clearing, sludge blow-off etc. During water recycling in industry, water requirements are covered by the sum of the recycled water R_o and by the supplementary water W abstracted from the resource.

The internal recycling coefficient is the ratio

$$r_i = \frac{R_o}{W + R_o} = \frac{R - W}{R}$$

The ratio of the water consumption is expressed by

$$r_c = \frac{C}{W} = \frac{C_1 + \sum_{k=1}^{n} \Delta_k}{C_1 + \sum_{k=1}^{n} \Delta_k + F} \qquad (2.82)$$

The ratio of the water consumption for closed circuit systems equals almost 1.

As was mentioned already, water consumption consists of the consumptive use by a product U_1, a by-product U_2 and by means of wastes U_3 as well as by returnable and non-returnable losses $_n$ and, therefore

$$r_c = \frac{\sum_{i=1}^{3} U_i + \Delta_r + \Delta_n}{W} \qquad (2.83)$$

The ratio of the water consumption has to be analyzed separately for the supply, water treatment and recycling system and for water entering the product, by-product and serving other functional purposes. The relevant values often depend on the season, being higher in summer due to the higher evaporation rate.

The water consumption during water supply, recycling and water treatment consists of non-productive losses only. The consumptive use during the technological process of water treatment is a pure loss from the production point of view. These losses can be reduced by technological and operational measures including maintenance, as well as by a decrease in water requirements in the production processes.

The beneficial use of water in industry can also be expressed by the ratio of withdrawal utilization

$$w_1 = \frac{W - F}{W} \qquad (2.84)$$

and by the ratio of losses

$$w_2 = \frac{W - F}{R} = \frac{W - F}{W + R_o} \qquad (2.85)$$

Basic indicators of the economy of water use in industry are the water requirements per unit of product and the water consumption per unit of such a product as well as the waste load generated per unit of production. Their values depend on each other, on water recycling and on the technology of production and of water supply. The basic interrelationships can be expressed conceptually in the form of a joint function:

$$^1R\ ,\ ^1C\ ,\ ^1N\ ,\ r_i = f_{1-4}\ (A\ ,\ B\ ,\ C\ ,\ D\ ,\ E\ ,\ P_1\ ,\ M_{1-6})$$

^1R - water requirements per unit of production $(m^3.t^{-1})$

^1C - water consumption per unit of production $(m^3.t^{-1})$

^1N - waste load generated per unit of production $(t.t^{-1})$

r_i - internal recycling coefficient

A - combination of production process and product mix

B - nature of raw material used, which also influenced by-product production and waste material processing incl. material recovery

C - production technology including technology of waste material processing, operating rate

D - water quality (water quality indicators $q_1, q_2, \ldots. q_n$)

E - law and order, administration, the efficiency of their function

M_1 - water rates and cost of water treatment

M_2 - cost of waste water treatment and effluent disposal rates.

Water consumption, with the exception of cooling water, water for mining and the use of water in the food industry, does not generally form a substantial part of industrial water demand. Limiting water requirements serves to decrease the quantity of waste waters and water consumption, but need not necessarily lead to a decrease in the waste load generated, which depends more on the production technology.

The interrelationship between water requirement and water consumption is complicated, not only in terms of the quantity of waste water, but also of its quality, e.g. the environmental need to dilute waste water. The selection of a suitable technology from the water resources point of view requires an analysis of the combinations of water requirements, water consumption and waste loss generated per unit of production. The decision has to be taken on the basis of an economic evaluation of the environmental aspects of relevant production scenarios (Fig. 2.18).

2.5.1 Water for Processing, Mining and Hydraulic Transport

In the course of mining and hydraulic transport water comes into direct contact with the intermediate or final product without any thermic impact. During processing water comes into contact with the product or enters the product mainly as a cooling or heat-carrying material.

The quality requirements for water which comes into contact with other products without any thermic changes depend substantially on the nature, quantity and maximum size of the solid particles, which should be specified for the relevant use.

No treatment is required for some industrial uses, e.g. for the hydraulic transport of slag or coke cooling. Simple pretreatment, e.g. mechanical, is often sufficient for a considerable number of technological processes, especially for cooling, mining and hydraulic transport. During this pretreatment the content of iron Fe, manganese Mn and aluminium Al has to be reduced. Pretreatment should include processes aimed at removing ingredients which may interfere with further water treatment processes.

Water which comes into direct contact with the product by mining, beneficiation of ore, transport of ashes and coal, cleaning of gases etc., accepts pollution from the raw material or the intermediate product. It has to be treated before the new cycle of use.

Heterogeneous quality requirements on water for processing, which also depend on its transport in the pipeline system, often require the application of multigrade treatment technologies, including

(a) mechanical processes,

(b) thermic processes,

(c) magnetic processes,

(d) chemical processes,

(e) biological processes.

Chemical water treatment includes softening, decarbonization, deionization, demineralization and other processes aimed at decreasing the content of organic matter and dissolved oxygen, especially by using macromolecular ion exchangers.

TABLE 2.24

Interference agents	Negative impact on
Iron (Fe) Manganese (Mn) Humines	taste and/or colour of tee, coffee, yeast, dough, malt, beer, milk, cheese, starch, sugar, tinned food cathalytic disintegration of fats, reduction in durability of food
Calcium/magnesium 1) carbonate ($CaCO_3$ + $MgCO_3$)	taste/floculation of cacao taste of butter, other milk products, and beer turbidity/colour of alkoholic beverages, bottom sediments
Chlorides (Cl^-) 1)	taste of coffee and tea
Natrium (Na) Hydrogencarbonate	stability of vitamins
Nitrates	production processes
Oxygen (O_2) 1)	oxidation of fats, decomposition of proteins (acceleration)
Putrefactive and iron bacteria, mold fungi, dregs etc.	negative impact on taste, cause of health difficulties, disturbance in production processes

Negative impact of selected agents on food products: 1) high content

Multigrade water treatment processes combine cheap processes for removing a substantial part of the undesirable components with more expensive processes aimed at achieving the desired quality for a limited volume of water for certain single, specific process. The final product of this treatment is water of different qualities which is suitable for certain specific technological processes.

During the use of water in contact with the product and as a cooling and heat carrying medium, it is possible that carbonates, other salts, gases and organic matters may separate. In this way water is used during catching, cooling and cleaning of gases, extinguishing of coke etc. also in the food industry. The quality requirements in this group are complex and should correspond not only to the previous ones, but also to the requirements for cooling and heat carrying matter. These requirements, which are peculiar to each production process, have to be determined separately.

For the pharmaceutical and food industry drinking water is used and additional quality requirements applied for in order to safeguard the appropriate standard of these products (Tab. 2.24).

2.5.2 Cooling Water

Cooling water, which accepts and removes the excess heat during industrial production, forms some 60-80% of the water quantity needed in industry. This water undergoes thermal changes and often requires thermal treatment, including all the processes of water warming, cooling, distilling, mixing with vapour and degasifying. Cooling by water in contact with the semi-finished product as contact cooling is a part of processing.

TABLE 2.25

Losses through	Requirements of cooling water ($m^3.s^{-1}$)	Water consumption (losses)	Type of losses
Once-through systems	R ($m^3.s^{-1}$)	$\Delta_e = c_e \cdot (T_2 - T_1) \cdot R$ $\Delta_e = 0.001.(T_2-T_1+10).R$	evaporation leakage
Open circuit systems	$\frac{0.241.J}{T_2 - T_1}$	$\Delta_e = 0.002.(T_2-T_1+13).R$	evaporation (concentration) wind impact spreading, leakage, mud discharge
Closed circuit systems		$\Delta_e = 0.01.R$	evaporation (concentration) leakage mud discharge

Losses through
I. wind impact
II. spreading $\quad \Delta_{I-IV} = c_{I-IV}.R$
III. leakage
IV. mud discharge (sludge)

J - heat diverted ($J.s^{-1}$)
T_1- water inflow temperature
T_2- water outflow temperature (^oC)
R - cooling water requirements

Water requirements and losses in different cooling systems. Water requirements in once-through systems are permanent, in circuit systems once per operation cycle.

Systems for cooling without any contact with the product are like other industrial water systems, namely

(a) open circuit systems,

(b) recycling systems

- open, when the heat is removed by the direct contact of water and air,
- closed, when the heat is removed without any direct contact with air, i.e. in a closed heat exchanger.

Cooling is needed e.g. in steam and nuclear power plants, during vapour condensation, bearing and oil cooling, as well as for the indirect cooling of gases and liquids, furnaces, kilns etc.

Water requirements depend primarily on the technological process and its temperature, i.e. on the quantity of heat J ($J.s^{-1}$) to be removed and, secondly on the type of cooling system (Tab. 2.25, 2.26). They are substantially lower in recycling systems. Closed systems prevent evaporation, thus further decreasing both water consumption and water requirements. Between 80 and 400°C air cooling is more advantageous than water cooling.

TABLE 2.26

Cooling systems	Evaporation losses at the air temperature 0° C	10° C	20° C	30° C	Losses through wind impact
Cooling towers					
- with natural draught	0.0010	0.0012	0.0014	0.0015	0.001-0.003
- air blowers					0.005
Outdoor sprinklers	0.0020	0.0024	0.0028	0.0030	0.015-0.020
Cooling ponds and tanks	0.0007	0.0009	0.0011	0.0013	0

Water loss coefficients through wind impact c_I evaporation c_e and their dependence on air temperature and type of the system.

The quality requirements for water used as a cooling medium without any contact with the product are derived in such a way as to ensure the safe and efficient operation of the system (Tab. 2.27). They may be low for open circuit systems and must be high for recycling systems, preventing especially their corrosion and clogging. The quality requirements for water used in heat exchangers should safeguard its thermostability, i.e. eliminate the growth of biomass, the separation of carbonates and other salts and gases, etc., even under conditions of multiple cycles of warming and cooling (Tab. 2.23).

A cumulation of the following suspended matter occurs in the recycled water:

(a) crystals of salts, especially of calcium carbonate $CaCO_3$ which are difficult to dissolve,

(b) the products of corrosion,

(c) microorganisms,

(d) dust and soot (especially in open systems).

Cooling water has to be treated mechanically by filtration, by alkaline clarification, by ion exchangers, or magnetically, in order to decrease the sedimentation, especially of the calcium carbonate. The sedimentation rate in a closed system is essentially lower than in an open system.

TABLE 2.27

Velocity of water flow ($m.s^{-1}$)	Permissible concentration of pollution ($mg.l^{-1}$) Continuously	Short-term
<0.01	< 5	<20
0.01-0.2	10 - 20	50
0.2-0.5	30 - 50	100

Permissible concentration of pollution in cooling water and its dependence on the cooling water flow velocity.

For the treatment of water for cooling, it is necessary to remove organic components, which are able to form porous deposits in a warm environment, thus clogging the cross profile of the pipeline system, increasing the flow rate and decreasing its heat conductivity. In the closed circuit recycling system it is not necessary to remove the infectious bacteria: this is only indispensable when the water comes into direct contact with the product or with the staff in some industrial branches, especially in the food and pharmaceutical industries.

2.5.3 Boiling and Stream Power Water

Boiling water is used as a heat carrying medium without any contact with the product and undergoes similar changes as cooling water. Boiling water and steam is used

(a) during processing,

(b) for heating and ventilation,

(c) for power generation,

(d) as warm service water.

The temperature of water in the supply network of warm water systems generally depends on the energy input and often reaches 150°C. Temperatures not exceeding 100°C are admissible in networks whose output does not exceed 1.7 GJ per hour. Warm water for industrial purposes is seldom supplied by the municipal supply system.

The water quality requirements follow

- the decrease in corrosion
- the decrease in clogging.

Corrosion is supported by free CO_2, low pH factor (< 8), iron Fe and copper Cu content, and by a higher oxygen content (> 0,02 mg $O_2 . l^{-1}$). Clogging is caused mainly by $CaCO_3$, $MgCO_3$, H_2SiO_3, sediments, organic colloids and oil.

The quantity of water in power generating systems is formed by feed water to fill the system and supplementary water to cover water losses, caused especially by leakage and evaporation:

$$V_o = R_f + R_s - \int_0^t \Delta dt \qquad (m^3) \qquad (2.86)$$

V_o - volume of water in the recycling system (m^3)

R_f - feed water (for the first filling up) (m^3)

R_s - supplementary water (m^3)

Δ - water losses $(m^3.s^{-1})$

t - time (s)

After the first filling of the system $V_o = R_f$ and, therefore,

$$R_s = \int_0^t \Delta dt \qquad (m^3) \qquad (2.87)$$

Total water requirements, corresponding to the water withdrawal, are

$$W = R_f + R_s \qquad (m^3) \qquad (2.88)$$

The quality requirements of the feed and supplementary water should also safeguard its thermostability, limiting the content of suspended matter, oil and chemically aggressive components to almost nil. Such water should be clear and without any colour. The total content of ions is limited to 10-14 $mmol.l^{-1}$, ions of calcium Ca^{2+} and total carbon dioxide CO_2 to less than 3.6 - 7.0 $mmol.l^{-1}$. Lower values correspond to the density of the energy output above 23 $kW.m^{-2}$ (Tab. 2.28).

The content of gases and organic matter in condensed steam depends on the nominal pressure and on the thermal scheme of the system - it exceeds the water content. The feed water of these systems is a mixture of the returned condensed steam and the supplementary water.

Methods of treating the condensed steam include filtration, demineralization and deoxygenation. Steam treatment in heating plants and power plants often includes the softening and removal of organic matter and oil. Steam systems have to be protected from the aggressivity of water by maintaining the protective alkalinity, which can be achieved by dosing solid or volatile deoxigenation or other agents. This protection can also be achieved under a neutral regimen by the removal of corrosive gases, salts and other aggressive particles, i.e. by the treatment of the condensed steam and by the demineralization of the supplementary water.

TABLE 2.28

Water quality indicator	Unit	Evaporators	Steam exchangers	Boilers with nominal pressure 0.15 MPa <23 kW .m^{-2}	>23 kW .m^{-2}	Discharged boilers <6.5 MPa	>6.5 MPa	Drum boilers 6.5 MPa	9.6 MPa	13.9 MPa	17.8 MPa
$Ca^{2+} + Mg^{2+}$	$\mu mol.l^{-1}$	15	15	50	15	1.5	0.25	2.5	1.5	1	0.5
C_2	$\mu g.l^{-1}$	50	50	500	100	20	10	20	10	10	10
CO_2	$mg.l^{-1}$					1	0.5	5	1	0.5	0.5
Fe	$\mu g.l^{-1}$					20	20	30	20	20	20
Cu	$\mu g.l^{-1}$					5	5	10	5	5	5
Oxidizability COD_{Mn}	$mg\ O_2.l^{-1}$						1	5	3	2	2
Suspended matter	$g.l^{-1}$						50	-	50	50	50
Specific electrical conductivity	10^3 $\mu S\ cm^{-1}$	9+	9+	13+	10+	0.5	0.3				
SiO_2	$\mu g.l^{-1}$					20	20	6+	2.5+	0.6+	0.3+
p-apparent alkalinity	$mmol.l^{-1}$							0.05-1.5		< 0.05	
Surplus of P_2O_5	$mg.l^{-1}$							2-10	1-3	0.5-2	0.3-1
Oil	$mg.l^{-1}$	3	3	3	3						

Water quality indicators for feed and boiler water (+) depend on the type and output of the thermal economic system.

Heated water and steam form a medium which enables the transformation of chemical and nuclear energy into electrical energy in thermal and nuclear power plants. According to Minasian et al. (1977), the water requirements reach

	At present	in 2000	
- in a thermal power plant	0.127	0.104	$m^3.kWh^{-1}$
- in heat and power plants	0.101	0.050	$m^3.kWh^{-1}$
- in nuclear power plants	0.200	0.125	$m^3.kWh^{-1}$

The ratio of water consumption in this case reaches 0.01 to 0.02. Davis and Wood (1974) estimate water consumption during power generation at 10 km^3yearly. The water demand for this purpose in developed countries is gradually reaching the water demand for irrigation. But the use of water for power generation purposes is not as consumptive.

2.5.4 Water Losses in Industry and Flow Chart of Water Use

Because of the prevailing percentage of water used for cooling purposes, the prevailing losses of water in industry are formed by

		Percentage of the volume of water used
(a)	evaporation	1.5 %
(b)	escape and spreading	0.2-0.8 %
(c)	leakage and leaching	1 - 2 %
(d)	mud discharge	up to 6 %.

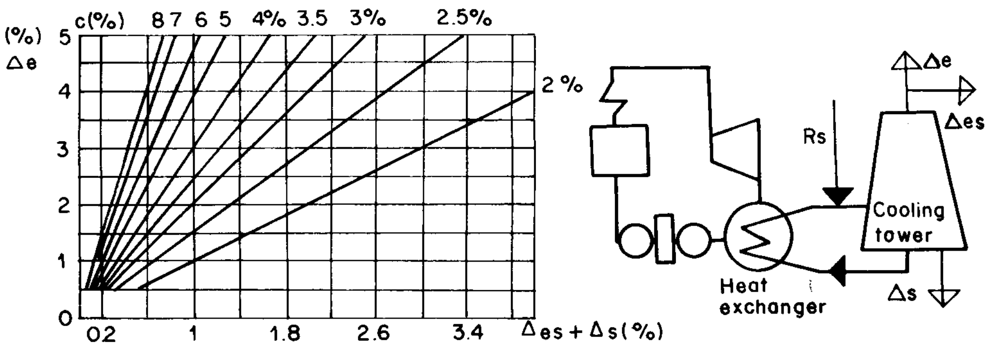


Fig. 2.16. Interrelations of evaporation, spreading and wind action losses and of the concentration of salts in a water cooling system: e - evaporation, es - spreading and escape, s - sludge, c - concentration of salts.

The prevailing losses are those caused by evaporation. They depend not only on the type of the system and its equipment, but also on the method of its operation. Minimum losses can be achieved in closed recycling systems by uninterrupted operation. Losses through evaporation and corrosion cause the concentration of salts which may exceed the relevant maximum permissible values in the recycling system (Fig. 2.16). This concentration is defined by the following concentration ratio (for a cooling or similar system)

$$c = \frac{\sum_{i=1}^{3} \Delta_i}{\sum_{i=1}^{2} \Delta_i} \qquad (2.89)$$

Δ_1 - losses through escape (Δa) (m^3)

Δ_2 - losses through spreading (Δes) (m^3)

Δ_3 - evaporation losses (Δe) (m^3)

Losses through water escape may arise in open systems only when the air flow takes away droplets and carries them outside the cooling system. The value of this loss depends on the air flow rate, i.e. on the gradient of temperatures and the type of system.

Losses through spreading arise as a result of the influence of wind, i.e. again in open systems only. The value of this loss depends on the construction of the spray cooler and on the velocity of the wind. Its value is not constant and, therefore, cannot be replaced by an estimated average.

Unproductive leakage may not only arise in cooling systems, but also in lagoons, oxidation ponds etc., i.e. after processing. They do not necessarily increase the relevant water requirement. Their values reach a maximum after the first filling up of the reservoir and then gradually decrease due to clogging.

Losses during water purification or waste water treatment are caused by using water as a medium for collecting waste material and sludge. They occur periodically or permanently, depending on:

N - the volume of removed waste material (m^3)
w - the moisture content of the waste material (%)
t - the time period of their accumulation (s)

$$F_m = \frac{N \cdot w}{t \cdot 100} \qquad (m^3.s^{-1}) \qquad (2.90)$$

Water consumption and mud discharge water in a recycling system has to be replaced by supplementary water R_s

$$R_s = C + F_m = \sum_{i=1}^{3} U_i + \sum_{i=1}^{n} \Delta_i + F_m \qquad (m^3.s^{-1}) \qquad (2.91)$$

F_m - mud discharge water, replaced for improving water quality ($m^3.s^{-1}$)

U_{1-3} - consumptive use by a product, by-product and by means of wastes ($m^3.s^{-1}$)

The function of industrial water supply and disposal systems using water in contact or without any contact with the product can be analyzed by means of modelling. The model using water without any contact with the product includes e.g. a spray cooler, treatment plants for the recycled and feed water and for mud discharge.

Inputs of such a model include (Fig. 2.17)

- feed (supplementary) water, characterized by

R_o - discharge ($m^3.s^{-1}$)

c_o - concentration of dissolved solids ($mg.l^{-1}$)

T_o - water temperature (^oC)

- liquid and solid particles entering the system from the air characterized in the same way, Q_a, c_a, T_a
- thermal energy: J_o, J_a, J_m. (J)

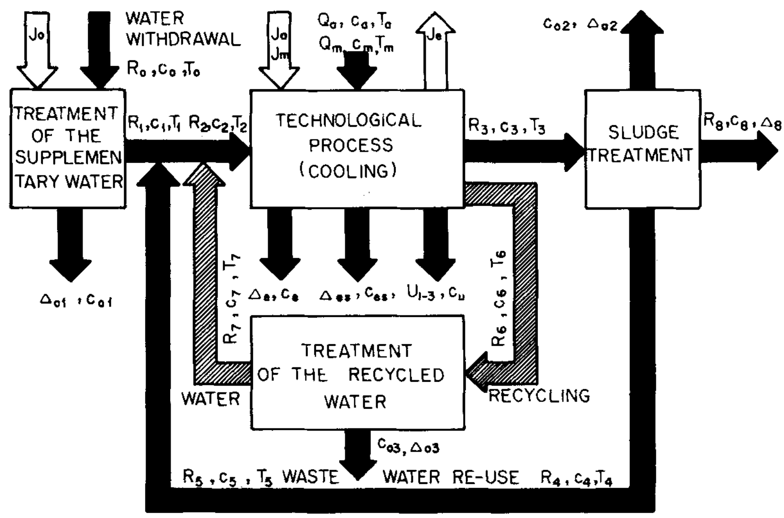


Fig. 2.17. Simple model of water usage in industry with one water recycling and one water re-use circuit, illustrating the balance of water quantities, of the diluted and suspended matter and of the energy input and output.

Inputs in a system using water in contact with the product include, in addition to this,

- liquid and solid particles entering the system from the raw material and semi-finished product (Q_m, C_m, T_m)

Outputs of a model of industrial water supply and disposal system without any contact with the product include:

- waste water, characterized by

R_8	- discharge	$(m^3.s^{-1})$
c_8	- concentration of dissolved solids	$(mg.l^{-1})$
T_8	- water temperature	(^oC)

- mud discharge (from the treatment of the recycled water, sludge treatment etc.)
- water losses through evaporation Δ_e, escape and spreading Δ_{es}
- losses of energy (e.g. by evaporation J_e)

Outputs in a system using water in contact with the product include, in addition to this,

- consumptive use U_1 , U_2 , U_3.

Using such a model, the balance

(a) of the water quantities (water delivery, recycling and disposal),

(b) of the diluted and suspended matter

(c) of energy input and output

can be analyzed in different parts of the system.

(a) The volume or discharge of the supplementary water can be determined on the basis of the balance

$$R_1 = \sum_{i=1}^{8} \Delta i + \sum_{k=1}^{3} U_k + R_8 - Q_a - Q_m \qquad (m^3.s^{-1}) \qquad (2.92)$$

Apart from the supplementary water R_1 the recycled water R_7 and re-used water R_5 also enter the subsystem, thus

$$R_2 = R_1 + R_5 + R_7 \qquad (m^3.s^{-1}) \qquad (2.93)$$

$$R_2 = \Delta_{es} + \Delta_e + \sum_{k=1}^{3} U_k + R_3 + R_6 - Q_m - Q_a \qquad (m^3.s^{-1})$$

The outfall from the industrial water system is the waste water

$$R_8 = R_3 - R_5 - \Delta_{02} \qquad (m^3.s^{-1}) \qquad (2.94)$$

and mud discharge

$$N = \Delta_{01} \cdot c_{01} + \Delta_{02} \cdot c_{02} + \Delta_{03} \cdot c_{03} \qquad (2.95)$$

(b) The chemical balance can be analyzed by equations of the following type:

$$R_2 \cdot c_2 = R_3 \cdot c_3 + R_6 \cdot c_6 + \sum_{k=1}^{3} U_k \cdot c_k + \sum_{i=1}^{n} \Delta_i \ c_i + Q_m c_m + Q_a c_a \qquad (2.96)$$

The water quality in the system changes as a result of the input of energy and matter. In the case of a cooling system ($U_{1,2,3} = 0$), the rate of disintegration, caused by different chemical and biochemical processes resulting in changes in water quality, depends on the discharge to volume ratio in the cooling plant. This can be expressed by a differential equation

$$\frac{dc_i}{dt} = \frac{R_3 \cdot c_{3i}}{V} \qquad (2.97)$$

c_i - concentration of the water quality indicator i ($mg.l^{-1}$)

V - volume of water in the system

The rate of concentration changes in the component i depends on the original maximum concentration $c_{i(0)}$ at the moment t_o

$$c_{i(t)} = c_{i(0)} \cdot e^{-\frac{R_3}{V}(t-t_o)} \qquad (2.98)$$

The trouble-free operation of an industrial water supply, and re-cycling and disposal, system requires a stable water quality, which should be maintained by

- a sophisticated water recycling and re-use system
- appropriate delivery of the supplementary water
- maintenance of water quality by an appropriate dosage of relevant chemical substances.

The dose of the chemical substance to maintain its required concentration (to protect the water supply and recycling system or to maintain the quality required for processing) is, therefore,

$$c_t = \frac{R_1 \cdot c_1}{R_3} + \left[\frac{c_{i(0)} - R_1 \cdot c_1}{R_3}\right] \cdot e^{-\frac{R_3}{V}(t-t_o)} \qquad (g) \qquad (2.99)$$

The influence of water losses on water quality differs: evaporation losses change the concentration of most water quality indicators, while seepage, escape and spreading do not. To maintain the required water quality, the necessary input of the supplementary water is to be derived from evaporation losses Δ_e and the differences in the input and output concentration

$$R_1 = \Delta_e \cdot \frac{c_3}{c_3 - c_2} \qquad (m^3.s^{-1}) \qquad (2.100)$$

When the water treatment plant of both the supplementary and the recycled water are able to maintain a constant water quality, the changes in concentration depend mainly on the evaporation rate and on the matter input from the water re-use circuit. The quality of water that can be recycled depends on the permissible concentration of the suspended matter and on the efficiency of filtration in the treatment plant of the recycled water. High efficiency of filtration helps to increase the ratio of the recycled water

$$\frac{R_6}{R_3 + \Delta_{es}} = \frac{f}{1-f} \qquad (2.101)$$

f - efficiency of filtration

(c) The water temperature in different parts of the system and the temperature of the waste water can be determined from different equations of the energetic balance, e.g.

$$J_8 = J_o - J_e - \sum_{i=1}^{n} \Delta J_i + J_a + J_m \qquad (J.s^{-1}) \qquad (2.102)$$

Water recycling and re-use require higher funds to be allocated by the user for the investment, enabling him to make savings in operation costs. The application of these technologies results in a reduction of water withdrawals with a subsequent improvement of water balances and of the water quality in surface and groundwater resources.

2.5.5 Waste Waters and Waste-free Technologies

Waste water which is discharged into streams constitutes an ever-increasing proportion of water supply. With regard to the self-purification and water treatment process, the relevant waste particles can be considered as

(a) biologically degradable,

(b) biologically undegradable.

In effect, the contamination caused by industrial waters can be categorized as

(a) chemical - diluted and suspended chemicals,

(b) biological - bacteria, viruses and other pathogenic organisms,

(c) thermal.

Industrial waste waters are generally mixed. The contamination is mostly toxic; but the harmfulness of the wastes depends not only on their toxicity, but also on their ability to slow down or to stop the processes of self-purification in rivers, or of biological water treatment in relevant plants.

TABLE 2.29

Waste water groups		Origin	Suitability for re-use and re-cycling
Cooling	F_c	cooling systems	good, occasionally without specific treatment
Mining and hydraulic transport	F_m	lagoons, settling tanks	good, simple treatment technologies
Processing incl. rinsing	F_p	quality depends on raw material and technology applied	generally demanding treatment technologies; food, paper and pulp industry waste waters suitable for irrigation; possibilities for material recovery
Sewage	F_g		not suitable for industrial re-use, suitable for irrigation
Other waste waters	F_b	feed water, precipitation	not suitable, accidental occurrence, requires accumulation

Classification of industrial waste waters with regard to possibilities of their re-use and re-cycling. See Fig. 2.15.

The possibilities of waste water re-use or recycling depend on the quality of the waste waters concerned, i.e. on their origin and on the type of the industrial process (Tab. 2.29). The outfall of the system is treated waste water:

$$F_o = \sum_{i=1}^{5} F_i - \sum_{i=1}^{e} \Delta_i \qquad (m^3.s^{-1}) \qquad (2.103)$$

This quantity, or part of it can be re-used, thus decreasing the quantity of waste waters discharged into water resources (Fig. 2.15):

$$F_o' = F_o - R_w - \sum_{i=f}^{m} \Delta_i \qquad (m^3.s^{-1}) \qquad (2.104)$$

Data on the chemical and biological composition of waste waters can be derived by an analysis of the relevant technological processes on the basis of the material balance. The degree of pollution of industrial waste waters can be compared with domestic sewage by means of population equivalent values. The population equivalent value of industrial pollution corresponds to the number of inhabitants producing pollution whose biological oxygen demand BOD_5 has the same value as waste waters from the relevant industrial production processes. This population equivalent value E can be related to the daily production or to the production unit:

$$E = \frac{BOD_5(g.m^3) \ . \ Q(m^3)}{54 \ g \ BOD_5} \ \text{(per unit of production, per day)} \qquad (2.105)$$

The sewerage system normally discharges different kinds of sewage water, or discharges different types of sewage waters separately. Nevertheless it is necessary to prevent the penetration of aggressive substances into the sewerage system, or to prevent the penetration of waters containing

(a) matter which destroys sewerage structures or damages the materials of the sewerage system,

(b) matter which causes breakdowns in the waste water treatment processes.

(c) matter which is infectious, contaiminated, poisonous, narcotic or radioactive to such a degree that it threatens the health of the staff in the treatment plant or of the population, or forms these substances in admixture with waste waters from other processes,

(d) explosive or combustible substances, or compounds which form such substances with water or air or other substances which can penetrate into the system,

(e) substances with an extremely offensive odour or which cause such an odour in admixture with waste waters from other production processes.

These waters are also not suitable for re-use or recycling. The penetration of waste waters into water resources leads to a deterioration in their quality, as well as in the quality of the other compounds of the biosphere.

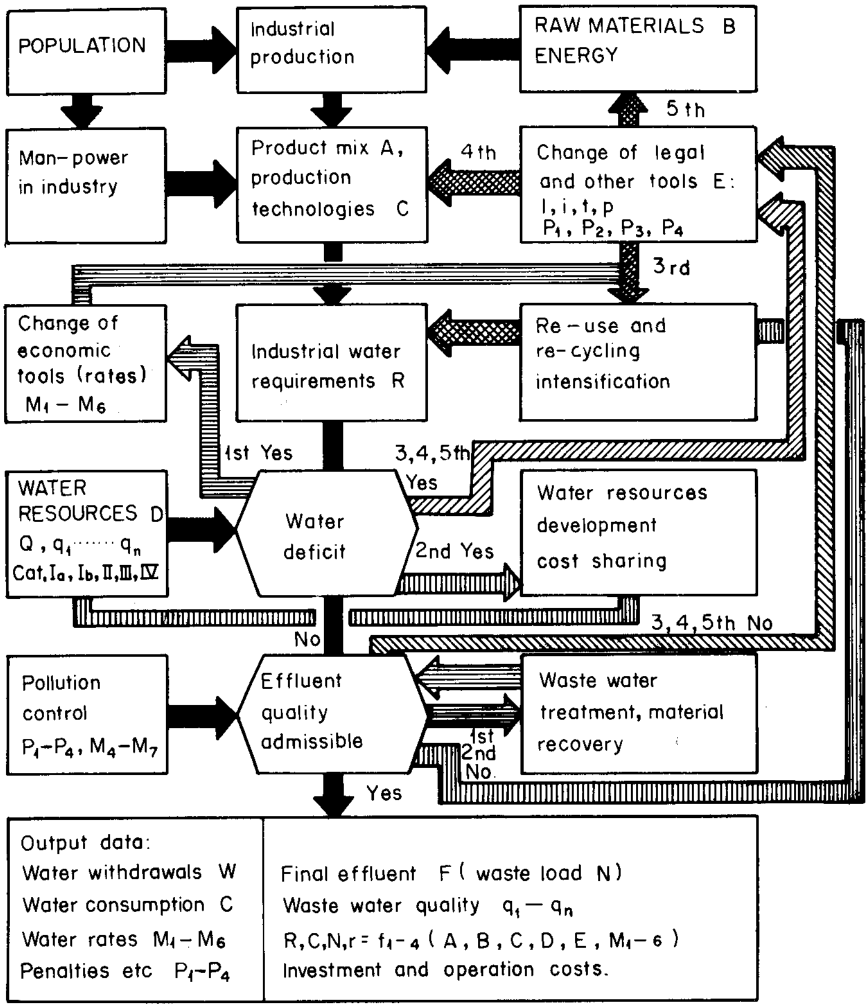


Fig. 2.18. Block diagram for the determination of water requirements and management of water deliveries as well as waste water disposal in industry in accordance with the hierarchy of goals and the basic limitations.

In order to reduce the negative impact on future development, the utilization of water in industry should be rationalized, especially by means of the following water-saving measures (Fig. 2.18):

(a) reducing water wastage,

(b) limiting the duration of water utilization during technological processes to the absolute minimum,

(c) selecting processes which entail minimum water consumption and minimum water pollution,

(d) applying internal recycling and waste water re-use,

(e) decreasing the requirements on water quality to the technologically permissible limit and by using available resources of low quality,

(f) using industrial waste waters in other branches of the national economy, especially in agriculture.

A decrease in the volume of wastes in industrial production can be achieved by

- a change of technological processes,
- a change of product mix, enabling the utilization of waste material as raw material for other products,
- a reduction in the weight of products
- water recycling and waste water re-use,
- using selected waste material as fertilizers in agriculture.

Liquid, solid and gazeous wastes are often suitable

- as raw material for other production processes,
- for material recovery,
- for soil regeneration,
- for power generation.

These problems are interdisciplinary, having an impact not only on water management, but also on the biogeochemical cycles and the exhaustion of the natural resources. To moderate this problem, the production processes should be gradually, as far as possible, incorporated into natural biogeochemical cycles.

Production processes which are aimed at the maximum utilization of all raw materials on the one hand and at the re-use of material products after their utilization on the other hand gradually lead to waste-free technologies. Their introduction requires the variety of products and the system of their utilization to be changed, in order to enable their return into the production cycle or their unexceptional coalescence with the environment. This goal can partly be achieved by the higher service life of products, if their repair is economically feasible. The issue of energy consumption is also interconnected with these problems, because power generation likewise leads to the over-utilization of available natural resources and to environmental pollution (Fig. 2.19).

The necessary reorganization of production can be achieved by grouping relevant production processes into integrated schemes. In such a way it is possible to apply continuous technologies, which may be financially less feasible, but restrict the negative impact on the environment. But there are limits to production concentration. A high concentration, even in the case of a low production of wastes per product, causes such a high concentration of waste material and waste waters that this cannot be locally and economically disposed of without harmful effects on the environment.

The step-by-step introduction of waste-free technologies requires a systema-

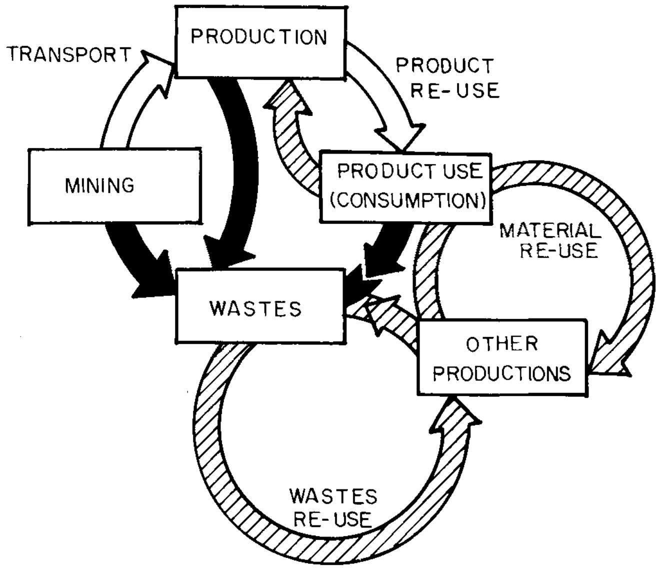


Fig. 2.19. Schematic representation of the conventional natural resources-demanding production and consumption process which leads to accumulation of wastes (black arrows) and to an excessive environmental pollution. Unconventional waste-free technologies (hatched arrows) decrease the environmental pollution and the natural resources exhaustion.

tic approach, which must consider all the scientific, technical, economic, structural and social aspects of human development: industrial production, transport and power generation, covering the sphere of all users: in short, the everyday life of all inhabitants. The transition to this prospective technology is an integrated and gradual process aimed at closing the circle between the sphere of production and the sphere of users.

2.6 WATER IN AGRICULTURAL SYSTEMS

Agricultural production is a result of the function of agricultural systems and has to be managed within their framework. An agricultural system can be defined as a set of interconnected soil and microbiological, plant, mechanical and human elements whose interaction produces organic matter for the nourishment of man on the basis of the supply of solar, mechanical and human energy and matter including water, fertilizers and agrochemicals (Fig. 2.20). This system can also be expressed as the intersection of plant ecosystems, the microbiological system of soil and the livestock breeding as well as agrochemical producing system

$$AS = PE \cap MS \cap IA \qquad (2.106)$$

AS - agricultural system

PE - plant ecosystems (t)
MS - microbiological system of soil (t)
LA - livestock breeding and agrochemical producing system (t)

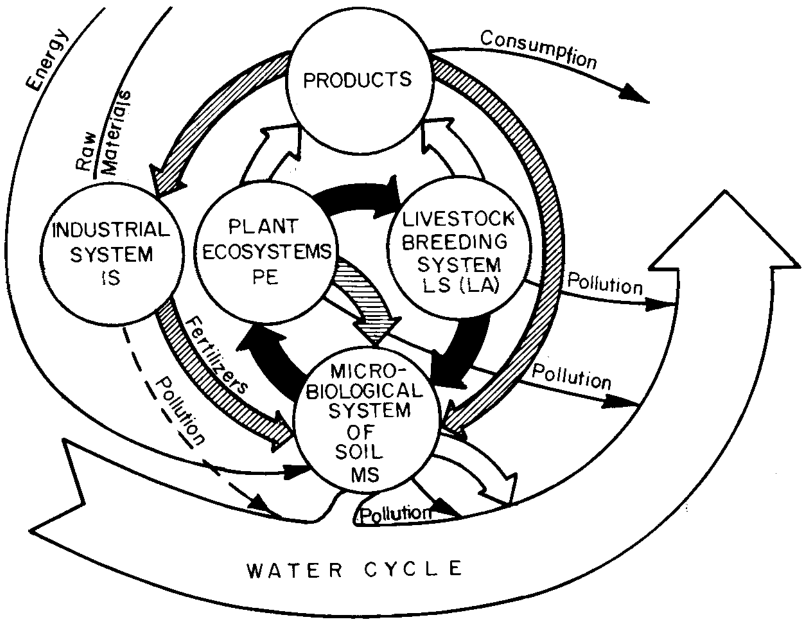


Fig. 2.20. Agricultural system, its environment and basic interrelationships of its subsystems (microbiological soil system, plant ecosystem, livestock breeding system). Basic inputs (energy and labour, sediments and fall-out, fertilizers and pesticides) and outputs (plant and animal products, eroded and leached material).

The process of the accumulation and transformation of solar, mechanical and human energy and matter takes place especially on the active surface of soil minerals, in their microbiological communities, in the roots, stems, leaves and fruits of plants and in the digestive organs of livestock. Plant ecosystems transform solar energy, water and nutriments into organic matter. This plant matter, decomposed especially by the digestive organs of polygastric livestock, is transformed into more complicated proteins, sacharides and animal fat.

Waste matter which has not been incorporated into the resulting animal matter contains mainly carbon and nitrogen. It returns into the soil in the form of manure, dung-water etc. and is subsequently transformed into polymolecular matter, or humus, by the microbiological communities in soil.

This process regenerates the bioenergetic potential of the soil, which depends on the extent of the active surfaces and the structure of the soil components and may be characterized as

$$E = \frac{\sum Y}{\sum N} \tag{2.107}$$

$\sum Y$	- dry weight of yield	(t)
$\sum N$	- weight of main nutrients (nitrogen N, phosphorus P, potassium K)	(t)

The stability of the agricultural system and the permanent course of the agricultural production process depend on the equilibrium of the relevant soil, plant and animal subsystems and on the equilibrium of the agricultural system and its environment within the framework of the natural biogeochemical cycles: Basic input factors, i.e. energy, water and labour, must safeguard a permanent and sufficient supply of relevant matter from one subsystem to another. In the case of an insufficient or interrupted supply, the system becomes unstable and can enter an uncontrollable state.

Two of the existing feedbacks in an agricultural system are particularly important and regenerate the bioenergetic potential E

$$PE \longrightarrow MS \tag{2.108}$$

$$LA \longrightarrow MS \longrightarrow PE \longrightarrow LA \tag{2.109}$$

The agricultural production gradually takes away, for the sake of human society, a certain amount of matter in the form of plant and animal products, thus destroying the natural balance. Where this production is very intense, the missing matter is not sufficiently replaced by the biogeochemical cycles. It has, therefore, to be replaced artificially, by means of fertilizers and irrigation.

A positive biogeochemical development of the territory sets in whenever the functions of the agricultural system gradually bring more and more matter into the biogeochemical cycles. This process, which results in an extension of the biological productivity of the territory, can be achieved

(a) extensively - by the extension of agricultural land,

(b) intensively - by the intensification of the agricultural and agro-industrial processes, i.e. by an increased input of energy and matter, especially water, fertilizers and forage.

Agricultural water requirements are frequently satisfied by a combination of on-site and external supplies. The regulating function of water has to be achieved by an external water supply for

(a) regulating the soil moisture by means of irrigation and drainage,

(b) livestock and poultry breeding,

(c) fish and water poultry breeding,

(d) processing, boiling, cooling, heating, waste disposal,

(e) public uses in agricultural settlements.

2.6.1 Agricultural Production and Agricultural Yield

The subsystem of the lithosphere and atmosphere where plant production takes place includes

(a) 2 - 4m deep and, exceptionally, deeper soil layer with the root system and microbiological communities,

(b) 2 - 6m high and, exceptionally, higher layer of the atmosphere containing the upper part of the plants.

Present-day agricultural production is becoming a more and more complicated process with industrial character, which has, inter alia for economic reasons, to take maximum advantage of natural factors and must not be allowed to adversely affect the environment. The agricultural yield in a given area is a function of eight factors

$$Y = f(S, W, C, F, M, H, Q) \qquad (t.ha^{-1}) \qquad (2.110)$$

Y - yield

S - soil type, its texture and structure, its water holding capacity (relatively stable)

W - weather, supply of energy and water (variable, controllable only in hot-houses)

C - quality and suitability of plants and their seeds (controllable in advance)

F - quality and suitability of fertilizers (controllable in advance)

M - machinery and its proper utilization (operatively controllable)

H - human labour (operatively controllable)

Q - water supply and its appropriate timing, water quality and appropriate irrigation practices.

Weather and soil, stable within the framework of crop rotation cycles, are key factors in this equation. The other factors, especially these controllable in advance, have to be adapted to their characteristics. Operatively controllable factors have to be managed with particular regard to the weather, which is a variable and uncontrollable factor.

The exploitation of soil and water demand closely depends on both these key factors. Fertile soils generally have higher water requirements per hectare of land, permitting higher specific yields to be achieved (t per hectare). Their specific water demand per unit of product (m^3 per t) is, therefore, absolutely lower. These soils permit the achievement of higher yields with a lower dose of fertilizers (Fig. 2.21). Under the conditions of a warmer climate, evapotranspiration is more intensive due to the higher input of solar energy. Resulting yields are higher as far as relevant higher water requirements are satisfied.

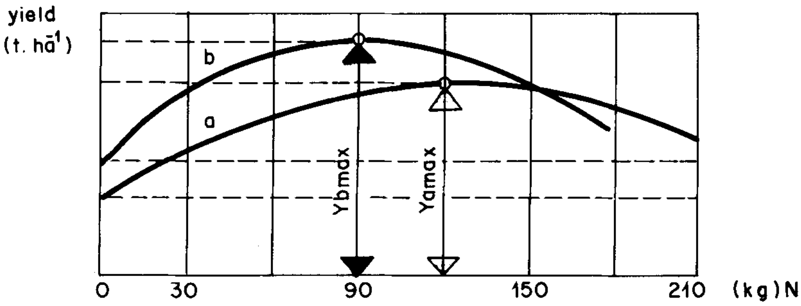


Fig. 2.21. Interrelations of yield, soil quality and the quantity of fertilizers according to Buliček (1976): higher yields are achieved by lower fertilizing rates under better soil conditions (a - medium quality soil, b - high quality soil). An increase in fertilizing rates above the optimum value increases water resources contamination, thus reducing both the yield and economic efficiency.

The water requirements R_a of plants are primarily controlled by the prevailing weather and also depend on the soil conditions when water supply is unlimited. Transpiration is proportional to radiation and can be quantitatively assessed from the relevant weather elements. The water requirements R_a consist

- of the transpiration T of the physiologically active plant and
- of the evaporation E from the adjoining soil surface

$$R_a = T + E = k_e \cdot T \qquad (m^3.ha^{-1}) \qquad (2.111)$$

k_e - soil quality coefficient, also depending on agricultural practices, overshadowing, the presence of weeds, generally $k_e = 1.2 - 1.5$.

The growth of plants in terms of net assimilation or dry-matter increment, also depends on the energy input, but does not commence until radiation reaches a certain minimum intensity. It reaches a maximum rate at moderate radiation intensities, increasing only a little at high intensities.

Yet yield does not only depend on a sufficient and adequate supply of energy and water, but also on a sufficient supply of air to the root zone. This fact is expressed by the interplay of the factors S - soil quality and Q - water supply - of the yield equation (Eq. 2.110). Under efficient agricultural practices the amount of water supplied corresponds to the actual evapotranspiration; losses are negligible. Water consumption is almost equal to water requirements. Irrigation is an inherently consumptive use, largely reducing the possibilities for the multiple utilization of water.

Maximum yields can be achieved under soil moisture conditions of the field capacity FC. When the value of humidity is higher, the aeration is insufficient. In heavy soils, the aeration is already insufficient in the conditions of the field capacity, thus decreasing yields considerably. The size of the pores is too small to enable the necessary degree of aeration. Light soils are far more tolerant to an increase in soil humidity above the limits of the field capacity. The size of the pores enables a sufficient supply of both water and air (Fig. 2.22).

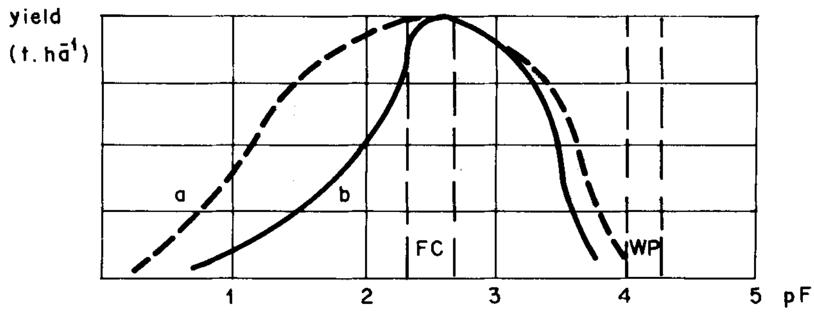


Fig. 2.22. Interrelations of yield, soil humidity (expressed as the suction pressure pF), and soil type according to Kutílek (1963): (a) sandy soils form better conditions for achieving higher yields at lower soil humidity due to the better aeration, i.e. the same yield is achieved with lower water requirements. – (b) heavy clayey soils.

The maintenance of the moisture capacity between the limits of the field capacity under the variable conditions of weather especially of uneven precipitation and evaporation, has to be achieved not only by irrigation, but also by drainage. Yields depend on the maintenance of adequate soil moisture levels during the various stages of plant growth.

The water requirements of plants depend

(a) on the interplay of the transpiration rate and the supply of water from the root zone, i.e. on the resistance of the plant body to the penetration of water from the soil to the atmosphere,

(b) on the accessibility of the soil profile to water, depending on the development of the root system,

(c) on the evapotranspiration rate, depending on weather conditions.

The water requirements of plants R_a and their consumptive use U_a are a combined function

$$R_a = U_a = f\ (S\ ,\ C\ ,\ A\ ,\ W) \qquad (m^3.s^{-1}) \qquad (2.112)$$

S – soil type, its texture and structure, its water-holding capacity

C – plant type: morphology of leaves, stem, root zones etc.

A – agricultural and irrigation practices (see Eq. 2.110 – M, H, Q)

W – weather conditions (solar radiation, temperature, wind etc.).

The actual water requirements of plants depend on weather: on the variable energy input or output from the atmosphere, water and soil, i.e. mainly on the intensity of the sunlight, but also on the irrigation water temperature, air humidity and wind velocity. Their characteristic course shows a maximum during the summer months in all the climatic zones of the northern hemisphere. As transpiration after sowing is almost nil, water requirements cover evaporation from the soil surface in order to maintain sufficient soil moisture. In the next period transpiration increases, reaching a maximum shortly before the period of maximum growth (Fig. 2.23).

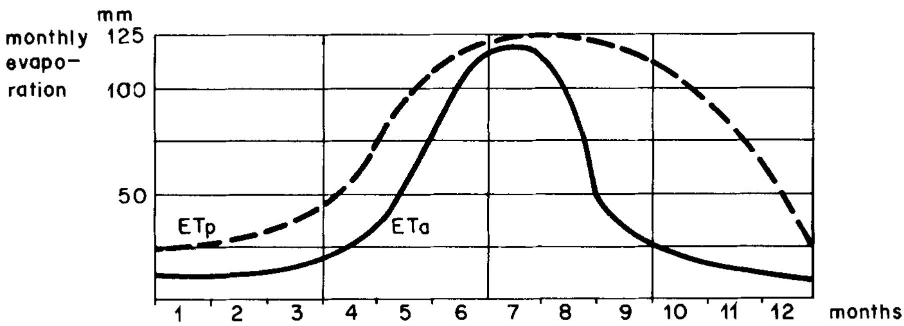


Fig. 2.23. Representation of the evapotranspiration of an annual plant. The actual evapotranspiration ET_a approaches the value of the potential evapotranspiration ET_p in the period of maturing: FC - field capacity, WP - wilting point.

Water is the regulating factor of energetic processes during the transformation of the organic matter in agricultural systems. These energetic processes are controlled by thermodynamic laws. The expected yield of the dry matter can be derived from the characteristics of the change of the internal energy y

$$y = \left(\frac{T_n}{T} - \frac{h_n}{h} \right) . Y_{max} \qquad (2.113)$$

T_n - temperature total in the relevant period (^oC)

T - temperature total during the year of the maximum yield (^{o})

h_n - precipitation in the relevant period (mm)

h - precipitation total during the year of the maximum yield (mm)

Y_{max} - long-term maximum yield of the dry matter ($t.ha^{-1}$ / year)

The course of the change of the internal energy is characteristic for the periods of growth and the plants in question. Thermodynamic curves limit the critical periods in which the lack of water considerably decreases the yields.

Different plants require different amounts of soil moisture in different periods of growth and seasons of the year. They show a preference for a particular soil texture, structure and other physical conditions. Some plants thrive on well-drained soil, coarse-textured and with a poor water-holding capacity. Others show better development in more finely textured soil, with a higher degree of moisture.

The root system of plant species is adapted to accept

- the rain from the surface (shallow, dense, vast root system)
- the soil water
- the groundwater (deep-rooted species, phreatophytes)

The arrangement and the density of the root system varies from species to species. A relationship between root systems and the water regime can be traced: species which prosper in rainfall may have a comparatively poor and shallow system, while species in an area where the rainfall does not penetrate to a greater depth have a vast surface system. Other species develop two to three root systems, which are supplied from rainfall, groundwater and the soil moisture. The root depth of one single species depends on the structure and depth of the soil profile and is influenced by the moisture conditions and groundwater table, which are interconnected with the climate.

In deep well-drained soils in humid countries plants are able to accept water from a depth ranging from 0.3 to 1.8 m, depending on the particular species and local conditions. The root depth of semi-arid to arid areas exceeds the root depth in humid areas by up to two times. Seeds and seedlings are able to accept water from their proximity only. With the development of the plant, the roots penetrate into deeper layers and spread horizontally.

A decrease in the groundwater table has an important effect on the yield in the case of light and medium soils. Under conditions of heavy soils, this influence is not so substantial (Fig. 2.24). But heavy soils do not allow a sufficient water supply in dry seasons - yields are then considerably affected by weather conditions. Light soils, requiring high water tables, because of their low capillary rise, do not allow the necessary development of the root system. A decrease in the water table under conditions of a shallow root system restricts yields because of the lack of water, while an increase has the same impact because of the lack of air.

Yields cannot be expected when the upper soil layer, whose depth is 0.1 m in the case of light and 0.4 m in the case of heavy soils, is completely wetted - because of the lack of air in the root zone. It is rare for an uninterrupted supply of soil moisture from groundwater to occur. But when the capillary rise and the suction pressure ensure an adequate supply of groundwater even in dry periods, not limiting a sufficient supply of air, the groundwater table is in the optimum position for the species of plant in question to achieve the maximum yields. To achieve higher yields under these conditions, the fluctuation of the groundwater table must be restricted (Fig. 2.24).

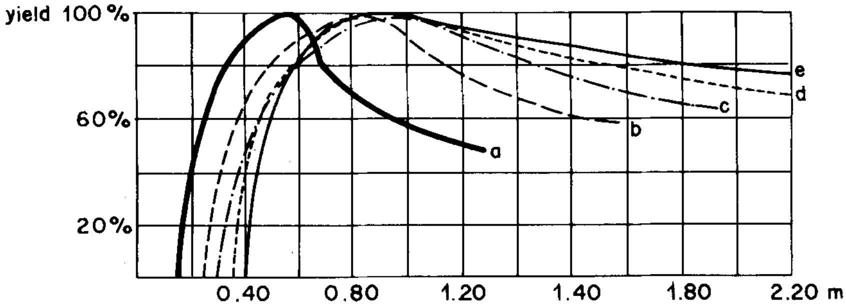


Fig. 2.24. Interrelationship of yield, soil quality and depth of groundwater table according to Benetín (1963): a - sand, b - sandy loam, c - loamy clay, d - clayey loam, e - clay. A fall in the groundwater table has a greater effect on yield from soils with lower capillarity.

At the same location, characterized by the soil quality, the weather conditions, the suitability of plants and the quality of seeds the relationship between the water supply and the yield can be expressed under simplified conditions, not taking into account agricultural practices including the suitability, quality and quantity of fertilizers, as follows:

$Y = f(D)$ $(t.ha^{-1})$ (2.114)

Y - yield
D - water delivery (natural and artificial) and its timing $(m^3.ha^{-1})$

The course of this function (Fig. 2.25) proves that maximum yields can only be achieved with an optimum water supply. A decrease below or an increase above this optimum value cuts yields. Lowering the water supply below the mentioned optimum value can increase the cost-benefit ratio, i.e. the financial or the economic yield. Taking into account economic reasons, it is necessary to mention that a long term oversupply of abundant water not only causes economic losses, but also the gradual degradation of the soil layer.

Under these simplified conditions, for the purpose of water balances compilation only, total water requirements can be derived directly from the yield

$R_a = m_e \cdot Y$ $(m^3.ha^{-1})$ (2.115)

m_e - coefficient of water requirements $(m^3.t^{-1})$(Tab. 2.29)
Y - total yield $(t.ha^{-1})$

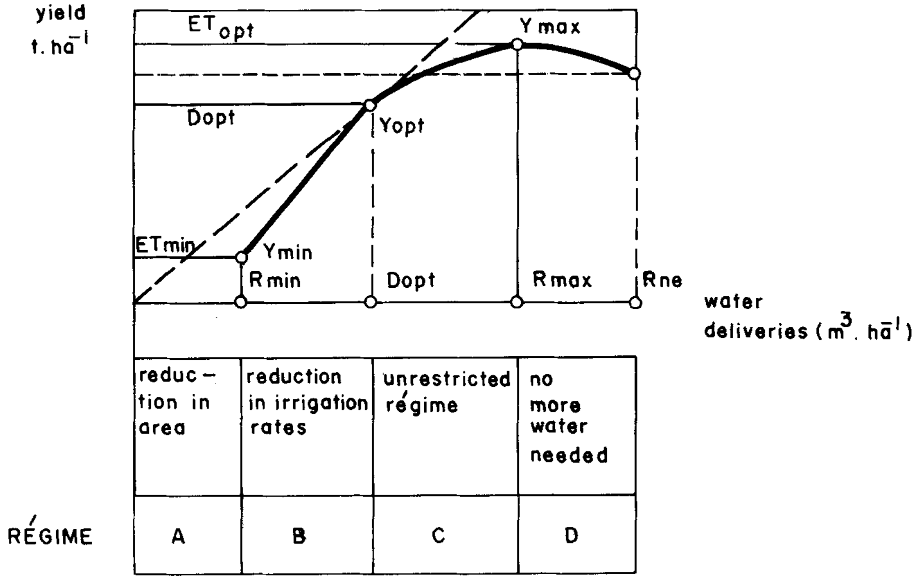


Fig. 2.25. Interrelationship of the yield and the adequacy of the water delivery. The decrease in water delivery below minimum water requirements results in no yield. Regime: A - reduction of the area irrigated, B - reduction in irrigation rates, C - unrestricted regime, D - no more water needed. Symbols: Y_{max} - maximum yield, Y_{min} - minimum yield, ET_{opt} - optimum evapotranspiration, D_{opt} - optimum water delivery, R_{min} - minimum (unavoidable) water requirements.

The coefficient of water requirements depends on climatic factors. The equation was adapted for practical application and coefficients derived e.g. Cherkasow (1950) (Tab. 2.30)

$$R_a = 0.1 \cdot m_e \cdot k_t \cdot y_e \cdot Y \qquad (m^3.ha^{-1}) \qquad (2.116)$$

k_t - coefficient of transpiration $(l.kg^{-1})$

y_e - coefficient of yield

Under the same climatic conditions the transpiration/assimilation ratio of different species varies considerably. Some species are more efficient producers of dry matter than others, with the same expenditure of water. This difference depends on the given morphological characteristics, e.g. on the leaf, stem and root arrangement.

As was shown above, the rate of the physiological processes, i.e. the transpiration/assimilation/production processes depends mainly on the supply of energy and moisture, and on the wind speed. But it also depends on the duration

TABLE 2.30

Products	Coefficients k_t $(l.kg^{-1})$	y_e	$m_e(m^3.kg^{-1})$	Yield $Y(t.ha^{-1})$
Cereals:				
wheat	271-639	2.14	0.8-1.1	3 - 6
rye	431-634	2.25	0.8-1.1	3 - 6
barley	404-664	1.77	0.8-1.1	3 - 6
oats	432-876	1.35	0.8-1.1	3 - 6
corns	239-495	1.28	0.7	5 - 8
Root crops:				
sugar beet	304-377	0.35	0.8-0.9	50-90
potatoes	285-575	0.25	0.8-1.0	40-80
Vegetables:				
Cucumbers	713	0.08	1.2-1.3	30-70
Tomatoes	500-650	0.10	1.0-1.2	30-60
Cabbage	250-600	0.15	0.7-1.0	40-90

Table of transpiration coefficients k_t, yield coefficients y_e, water requirement coefficients m_e according to Cherkasow (1950) and relevant yield depending in addition on soil quality, fertilizing and adequate solar radiation.

of the daylight. The course of water requirements can, therefore, be derived from astronomic and meteorological factors. The Hargraeves (1955) formula is based on an optimum simplification of internal plant and external environmental factors:

$$R_{opt} = 45.7 \cdot k \cdot d \cdot T \cdot (0.38 - 0.0038\ h) \quad \text{(mm)} \qquad (2.117)$$

k - monthly consumptive-use coefficient

d - monthly daytime coefficient dependent upon latitude

T - mean monthly temperature in ^{o}C

h - mean monthly relative humidity at noon in per cent (Tab. 2.31).

To achieve optimum crop yields

(a) in climatic conditions, where the relevant plants can be cultivated without artificial watering, irrigation supplements the natural water supply,

(b) in adverse climatic conditions, where plants cannot be cultivated without an artificial water supply, irrigation safeguards the undisturbed growth of plants. Under such conditions, irrigation rates should be adequate to achieve at least minimum yields. If the water quality available is not sufficient to cover these minimum requirements, it is vital to reduce the extent of the area irrigated.

TABLE 2.31

Consumptive use coefficients

Crop/Month	3	4	5	6	7	8	9	10	11	Seasonal
Pasture	0.11	0.25	0.29	0.33	0.31	0.32	0.32	0.22	0.14	0.25
Alfalfa	0.41	0.70	0.64	0.67	0.74	0.67	0.64	0.40	0.41	0.41
Corn				0.12	0.38	0.42	0.26	0.10		0.26
Rice		0.32	1.34	1.42	1.40	1.44	0.51			1.07
Potatoes early	0.55	0.72	0.73	0.62						0.66
Onions early	0.28	0.45	0.30	0.31	0.28					0.32
Carrots	0.16	0.18	0.19	0.52	0.64	0.28				0.33
Peas	0.28	0.36	0.49	0.31						0.36
Beans				0.15	0.28	0.66	0.51			0.40
Tomatoes				0.32	0.41	0.71	0.67	0.81		0.58
Sugar beets	0.19	0.27	0.55	0.87	0.69	0.36	0.15	0.10	0.03	0.36
Water melons				0.15	0.18	0.25	0.51			0.27
Prunes	0.17	0.34	0.34	0.50	0.48	0.32	0.42	0.48	0.24	0.37
Peaches	0.22	0.45	0.43	0.46	0.51	0.51	0.38	0.60	0.41	0.44

Monthly daytime coefficients

N latitude	1	2	3	4	5	6	7	8	9	10	11	12
5^o	1.01	0.91	1.02	0.99	1.03	1.00	1.03	1.03	0.98	1.02	0.98	1.00
25^o	0.91	0.86	1.01	1.03	1.12	1.11	1.13	1.09	1.00	0.97	0.89	0.89
50^o	0.72	0.76	0.99	1.11	1.28	1.32	1.32	1.20	1.01	0.89	0.73	0.68

Consumptive use coefficients at Davis, California and monthly daytime coefficients in the Hargreaves (1955) equation for the determination of the potential evapotranspiration.

The actual water requirements depend on the field conditions, which change with the weather conditions. A plant requires different quantities of soil moisture, depending on the species and the soil, during its different stages of growth. Maximum transpiration rates appear in a developing crop before assimilation has reached its peak. The actual problems of how to supplement these requirements by irrigation and of how to overcome adverse climatic, soil and water conditions should be worked out on the basis of daily measurements in the course of the irrigation season.

Basic decisions include

- amount of water required to moisten the desired depth of soil (not smaller and not greater)
- appropriate method and timing of irrigation (also to reduce evaporation and percolation losses)
- the coordination of other agricultural treatment processes with the irrigation method and the timing of rations.

2.6.2 Efficiency of Irrigation Water Use

The efficiency of irrigation water utilization is presently the key problem of water management, because

(a) irrigation water forms the main element in water requirements on a global scale. The extent of both the irrigated land and the irrigation intensity is increasing because of the increasing demand for food, caused partly by the world population boom and partly by improving living standards;

(b) irrigation is an inherently consumptive use which considerably reduces the possibility of further re-use or recycling;

(c) irrigation networks and their supply systems have a substantial and lasting impact on the natural environment.

The economy of irrigation is characterized by the ratio of the water withdrawal and the market unit, i.e.

$$i_1 = \frac{W_i}{Y - Y_o} \qquad (m^3.t^{-1}) \qquad (2.118)$$

Y - yield under conditions of irrigation $(t.ha^{-1})$

Y_o - yield under the same conditions, but without irrigation

W_i - water withdrawal for irrigation purposes $(m^3.ha^{-1}$ per year)

From the point of view of the population's nourishment this economy can be expressed by the ratio of the water withdrawal and the nutritive value of the product

$$i_2 = \frac{W_i}{I \, . \, (Y - Y_o)} \qquad (m^3.J^{-1}) \qquad (2.119)$$

I - nutritive value of 1 t of the produced plant $(J.t^{-1})$

The benefits of all investments in irrigation projects depend on proper water use in the field in conjunction with other agricultural inputs and cultural practices.

The planning and design of water development projects in agriculture should therefore be based on a water-use concept and should reflect the planned development of agriculture resulting from the need for a further intensification and diversification of production, and the resulting changes in agricultural practices.

Human society can determine only two out of the four input variables of the equation 2.112 namely: C - plants (seeds) and A - agricultural and irrigation practices. However, the mutual relationship of these variables is complex and can be solved reliably enough on the basis of system analysis alone. This complex relationship is often not reflected by current practice. The structure of agricultural systems and crop patterns is often still the result of

- the traditional food pattern,
- the given economic interests,
- the traditional agricultural practices,
- the local degree of relevant know-how etc.

The equation of water balance and the optimum use of the soil moisture available in the absence of irrigation, or the optimum use of natural discharges available without storage are seldom included among the relevant decision criteria in agriculture and irrigation development projects. The results of such a routine approach are excessive irrigation requirements without sufficient cause and exaggerated claims on water withdrawal and storage.

A change in the relevant engineering approach is needed, including an optimization of cropping patterns and a harmonization of the resulting total water requirements with the course of natural water supply: soil moisture, precipitation, discharges and groundwater resources available during the vegetation season. This harmonization of irrigation requirements with availability of water without storage may also require changes in the traditional food pattern: e.g. in arid countries with heavy rainfall and high river discharges at the beginning of the vegetation season, the introduction of precocious potatoes instead of rice cultivation can help to ensure the food supply without extensive water storage, which results in high evaporation losses (Fig. 2.26).

Arrangements for increasing the efficiency of water utilization during agricultural production include

- the creation of an optimum structure of agricultural systems, i.e. the optimum ratio of the producers and consumers of carbonic matter,
- the optimization of the crop pattern, preferring plants and seeds with lower water requirements corresponding to the pattern of water occurrence, thus ensuring an optimum utilization of the soil moisture, rain water and natural surface water discharges,
- the appropriate preparation of the land, including efficient measures to increase infiltration and transform overland flow into subsurface runoff,

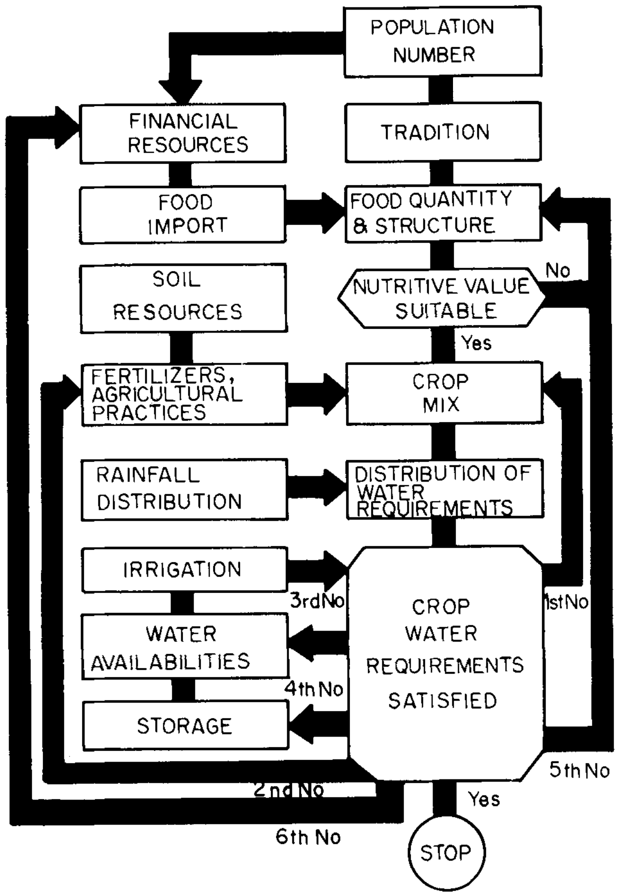


Fig. 2.26. Block diagram depicting the hierarchy of necessary basic measures for safeguarding of food for population.

- the construction of small reservoirs, diversion dams etc. in order to decrease the slope of the terrain and slow down the surface runoff.
- the utilization of appropriate water-saving irrigation methods, corresponding to the species of the crops cultivated and the relevant cultivation practices,
- the reduction of water losses during conveyance by adapting the design of conveyance structures to local conditions e.g. lined canals in pervious soils, closed culverts in arid climate and by appropriate maintenance and by economical operation,
- the management of agricultural systems on the basis of daily agrohydrometeorological data, i.e. by watering only in periods of a substantial decrease in soil moisture below the optimum value, without any overirrigation,
- the drainage and re-use of excess irrigation water,

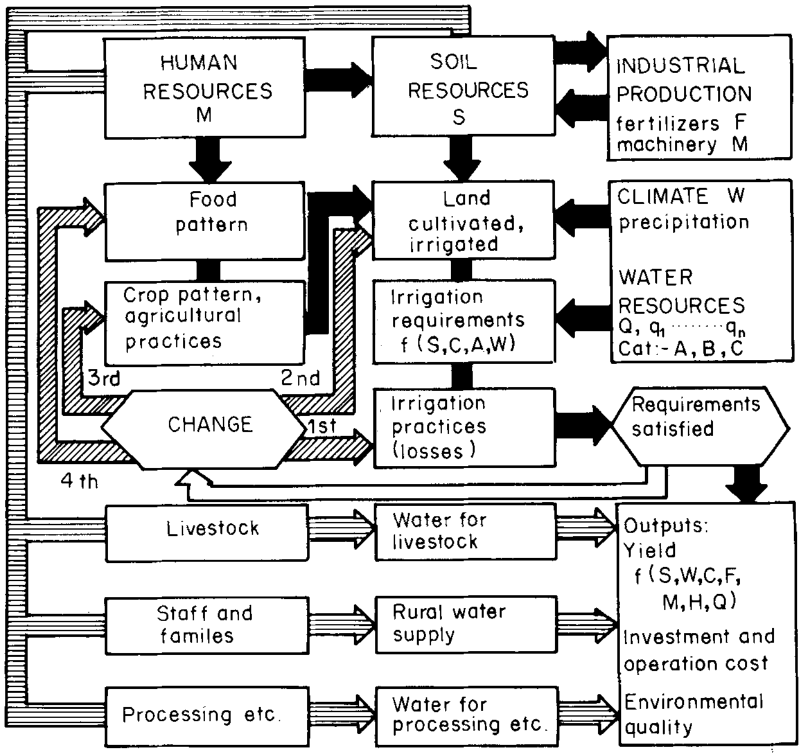


Fig. 2.27. Block diagram of water delivery management in agriculture to safeguard the environmental equilibrium of the agricultural system.

- the reduction of evaporation losses, e.g. by protecting the soil surface by means of wind-breaks, irrigation at night etc.,
- the re-use of municipal, industrial and agricultural waters for the purpose of irrigation,
- the observation of optimum agricultural practices during fertilizer and pesticide application.

There are essentially three ways of ensuring the adequate nourishment of the population:

(a) self-sufficiency across the entire range and assortment of necessary agricultural products,

(b) over-production and export of selected agricultural goods, thus forming financial resources to supplement the lacking varieties by means of import,

(c) exporting industrial goods or raw materials with the same goal.

The over-intensification of agriculture, namely the over-application of fertilizers and chemical substances in plant pest control as well as insufficient protection measures resulting in soil wash,the wastes from farm machinery and repair shops and highly concentrated livestock production results in surface and groundwater pollution and threatens the quality of products and of the environment.

The scientific coordination of the crop pattern with both the agropedological and the hydrometeorological conditions results in an increase in yields without a substantial increase in water requirements for irrigation, as well as in an increase in the total nutritive value per hectare cultivated. It helps to maintain the equilibrium of the biogeochemical cycles in the agricultural system, whose lasting function is possible only under the conditions of the stability of energy and matter input and output, and under the conditions of an equilibrium of the system and its environment (Fig. 2.27).

2.6.3 Water for Irrigation and its Quality

The supplementation of soil moisture to satisfy crop water requirements is the main, but not the single purpose of irrigation. By means of irrigation bioelements and other matter which improves plant production or soil conditions can either be naturally or artificially supplied, favourable microclimatic conditions to support plant growth maintained, and matter including pests which jeopardizes the soil structure and texture or the health of plants removed. From this point of view, irrigation can be categorized as follows

(a) proper irrigation (supplementary watering),

(b) fertilizing and remedial (plant health promoting) irrigation,

(c) protective irrigation,

(d) soil leaching irrigation.

The quality of the water used for irrigation depends on the required purpose, on the soil properties and on the irrigation operation. The basic requirements affecting the quality of water used for irrigation can be summarized as follows:

(a) it should favourably influence plant growth and the quality of the products grown,

(b) it should not cause breakdowns during the irrigation operation,

(c) it must not cause sanitary complaints, either during its operation or during the processing and consumption of the relevant agricultural products,

(d) it should not endanger the quality of the surface water and the groundwater,

(e) it must not deteriorate the structure, porosity and other agrochemical properties of the soil profile.

The quality of the water used for irrigation has to be categorized on the basis of its relevant physical, chemical, biological and bacteriological properties (Tab. 2.32). An important property of water, deciding on its suitability for irrigation, is the salinity, frequently expressed as the sodium percentage, the amount of sodium Na present in respect of the cationic concentration. But generally more important is the sodium- adsorption ratio SAR, which expresses

TABLE 2.32

Indicators			Categories A good	B conditioned		C marginally admissible
Oxygen content ($mg.l^{-1}$) at $10^{o}C$			> 11			50%
at $20^{o}C$			> 9			saturation
Dissolved matter ($mg.l^{-1}$)			<800	800-1200		>1200
Chlorides ($mg.l^{-1}$)			<300	300- 400		> 400
Sulphates ($mg.l^{-1}$)			<250	250- 300		> 300
Toxic matter				traces Cl		CO_2, Cl H_2S, F ($1mg.l^{-1}$)
Radioactivity Ra^{220} (Curie)						3.10^{-12}
Sr^{88} (Curie)						3.10^{-11}
Odour			slight	mediocre		offensive
Temperature in spring ^{o}C			10-15			
in summer ^{o}C			15-20	15-35		>35
Sediment size (mm)			0.005-0.1	0.001-0.005[1]		0.1[2]
Water pollution class			Ia,Ib,II	III		IV
Degree	Salinity	Electrical conductivity ($mmhos.cm^{-1}$)	Alkali hazard S1 Low	S2 Medium	S3 High	S4 Extreme
C1	Low	0 - 0.25	<9	9 - 17	17-24	>24
C2	Medium	0.25 - 0.75	<7	7 - 14	14-20	>20
C3	High	0.75 - 2.25	<5	5 - 11	11-16	>16
C4	Extreme	2.25 - 6.0	<3	3 - 8	8-12	>12

Categories of water quality for irrigation purposes and of its suitability according to the alkali and salinity hazard (derived from the graphical representation of the US Salinity Laboratory in Riverside).
1) fine sediments have a positive impact on the fertility of highly pervious soils, but decrease the quality of heavy soils, restricting the perviousness and aeration
2) cause sedimentation in the canal and pipeline network.

the relative activity of sodium ions in exchange reactions with soil, in which calcium Ca and magnesium Mg in the soil are replaced by the sodium in the water. The SAR is calculated from the ionic concentrations in millimoles of relevant bioelements according to the following formula:

$$SAR = \frac{Na^{+}}{\sqrt{\frac{Ca^{2+} + Mg^{2+}}{4}}} \qquad (2.120)$$

The second basic property of irrigation water is the alkali hazard, measured as electrical conductivity, which refers to the conductance of one centimeter cube of water on a side measured at 25 °C. Depending on these two criteria, which possess dividing points for low, medium, high and very high values, irrigation water can be characterized by sixteen combinations of salinity, i.e. sodium adsorption ratio and alkali hazard (Tab. 2.32). Water with a low alkali hazard and low salinity can be used for irrigating almost all crops with any type of soil. Water with high salinity or a high alkali hazard is not suitable for irrigation under normal conditions.

TABLE 2.33

Species	Salt tolerance high	medium	low
Fruit trees	dates	grapes, citrus fruit	pears, apricots, peaches, plums, apples
Field crops, vegetables	sugarbeet, beetroot, savoy, rape	barley, rye, oats, rice, flax, tomatoes, asparagus, melons, lettuce, carrots, spinach, capsicum, garlic, gourds, sunflowers, wheat, corn	peas, celery, cabbage, potatoes
Fodder crops		clover	alfalfa

Salt tolerance of crops, i.e. their ability to survive under conditions of increasing salinity.

When irrigation with water which has medium or high salinity, salt-tolerant crops should be cultivated (Tab. 2.33). Measures to counteract against the salination of the soil profile include especially good drainage and leaching. When irrigating with water whose utilization for this purpose is conditional, due to the sanitary hazard (Tab. 2.36) special measures are required.

In addition, protecting zones without irrigation by such water should be established around dwelling areas and communication lines for pedestrians.

2.6.4 Irrigation as Supplementary Watering

Soil moisture can be controlled by means of an irrigation and/or drainage system. An irrigation system consists of five subsystems: storage, transmission, distribution, soil moisture and, exceptionally, also underground aquifers.

Irrigation basically safeguards the supplementation of the water which escapes from the vegetative system, especially by evapotranspiration, thus contributing to its undisturbed development. Its feasibility depends on soil and land conditions (Tab. 2.34). The total water supply required for one irrigation season is the sum of uses and losses, derived from seasonal consumptive use and leaching requirements, less the amount of rainfall and groundwater input in the vegetation period which contributes to the moisture of the soil layer in question and less the utilizable moisture-holding capacity of soil at the beginning of this period.

TABLE 2.34

Class		Simplified characteristics
I	Good irrigable land	No erosion or gravel problem, adequate permeability, good soil structure and texture
II	Moderately	Slight erosion, gravel problem, low permeability, slightly undulated, slight salinity etc.
III	Marginally irrigable	Moderate gravel, slope, erosion, deep soil, wetness problem etc.
IV	Irrigable special conditions	Steep slope, shallow soil, gravel, undulated surface etc.
V	Undetermined suitability for irrigation	Salinity, etc.
VI	Non-irrigable land	Rocky land, marsh, flooding problem etc.

Simplified FAO classification of land according to its suitability for irrigation.

$$R_a = \sum_{i=1}^{n} \frac{1}{e_f} \cdot (E_{ei} + R_{li} - \alpha_i P_v - W_{wi} - W_{gi})\, A_i \quad (m^3 \text{ per year}) \quad (2.121)$$

R_a - total annual irrigation demand

E_{ei} - seasonal consumptive use of the pland i in the vegetation period ($m^3.ha^{-1}$ per year)

R_{li} - leaching requirements, approximately 0 to 50% of E_{ei} (see paragraph 2.6.7) ($m^3.ha^{-1}$ per year)

P_v - decisive total rainfall in the vegetation period (for planning and design purposes the rainfall of the vegetation period in a medium dry year should be used) ($m^3.ha^{-1}$ per year)

α_i - coefficient of the rainfall efficiency (depends on the soil quality: 0.5 for heavy soils, 0.6 for sandy soils, 0.7 for clay soils, 0.75 for loamy soils)

W_{wi} - utilizable moisture-holding capacity of soil at the beginning of the vegetation period, formed in the winter period ($m^3.ha^{-1}$)

W_{gi} - the groundwater input in the vegetative season, depending on the capillarity of soils and the groundwater depth ($m^3.ha^{-1}$)

e_f - coefficient of field efficiency, depending mainly on the irrigation method (Tab. 2.35)

A_i - area of crop i (ha)

It goes without saying that the value of the total withdrawal is

$$W_o = R_a + \sum_{i=1}^{n} \Delta_{c_i} = \frac{1}{e_d} \cdot R_a \qquad (m^3) \qquad (2.122)$$

A - area (ha)

Δ_{c_i} - delivery losses (see paragraph 2.6.8) (m^3)

e_d - coefficient of water delivery

TABLE 2.35

Methods of irrigating	Definition	Coefficient of field efficiency e_f
Basin (level-border) irrigation	Flooding of level plots surrounded by small dikes. Water layer 0.15-0.3 m is held until complete infiltration.	0.4 - 0.6
Border irrigation	Water delivery at the high end of long strips, e.g. from ditches running along contours, drainage at their low end, depth of the overland flow 0.03-0.07 m.	0.6 - 0.7
Furrow irrigation	Controlled flooding from furrows or corrugations running between crop rows.	0.7 - 0.8
Subsurface irrigation	Creation of artificial groundwater table, e.g. by delivery of water by means of underground pipes.	(a) 0.6 - 0.8
Sprinkler irrigation	Artificial rainfall from overhead sprinklers supplied e.g. from pipes.	0.7 - 0.87
Drip (trickle) irrigation	Nozzles discharge the water from pipes in drips along the length of the plant row.	0.85-0.92

Categorization of irrigation and irrigation field efficiencies: (a) coefficient depends on the hydraulic conductivity of soils and on the surface runoff caused.

The total rainfall with an 80% frequency of occurrence in the vegetation period may be considered as decisive, depending on local climatic conditions and yield. The efficiency of the rainfall utilization depends on evapotranspiration and outflow, i.e. on climatological, geomorphological, soil and vegetation factors.

The crop irrigation depth which has to be penetrated by watering, and thus the crop water requirements too, depends on the depth of the root system (Paragraph 2.6.1).

The utilizable moisture-holding capacity W_{wi} of soil at the beginning of the vegetation period also depends on the root depth and on the capillary rise of the soil structure. Its value can be derived according to Holý (1976) from the formula

$$W_{wi} = 25 \; . \; n_c \; . \; h_i \qquad (m^3.ha^{-1}) \qquad (2.123)$$

n_c - average value of the capillary porosity (%)

h_i - effective depth of the root system (m)

This value fluctuates between 150 $m^3.ha^{-1}$ in light sandy soils and 350 $m^3.ha^{-1}$ in clay soils for cereals, root-crops and fodder crops with the exception of corn and beetroot, whose moisture holding capacity is some 30% higher. Higher values can be also expected for alfalfa and in orchards, when they fluctuate between 200 and 250 $m^3.ha^{-1}$.

The groundwater input in the vegetative season W_{gi} depends mainly on the groundwater table depth and on the soil structure. According to Kostjakov (1951), the value of the groundwater input to the seasonal consumptive use of plants does not exceed an average of 5% when the groundwater table depth exceeds 2.5 m, reaching 25% for deep root systems and smaller groundwater table depths. Under normal conditions, the capillary rise does not exceed 3 m, i.e. the groundwater cannot supplement the water requirements of current plants when deeper than 3 m below the land surface.

The economy of plant production and the efficiency of irrigation water application are closely interconnected. The actual irrigation rates are to be determined and irrigation operation managed on the basis of the measured actual evapotranspiration. The water rates must not overload either the plant or the soil, which results in a degradation of both, and they should not harmfully affect the underground biosphere.

Useless losses through unused outflow, deep percolation and excessive unproductive evaporation should also be avoided. Irrigation rates can further be derived from the actual soil moisture, capillary rise and the necessary depth of water. The capillary porosity practically corresponds to the full field capacity FC. The irrigation rate also depends on the method of irrigation and on the conditions of operation, which have a basic impact on losses, i.e. on the coefficient of irrigation efficiency

$$R_r = \frac{100}{e_f} \cdot (FC - W_a) \cdot h_r \qquad (m^3.ha^{-1}) \qquad (2.124)$$

R_r - irrigation rate

FC - field capacity (%)

W_a - actual soil moisture (%)

h_r - effective depth of the root system (m)

e_f - coefficient of irrigation efficiency

2.6.5 Fertilizing and Remedial Irrigation

Fertilizing irrigation serves to supplement important nutriments. For the purpose of fertilizing irrigation the following solutions are used:

(a) solutions of fertilizers,
(b) flood waters,
(c) municipal, industrial and agricultural waste waters and sludges,
(d) dung and dung-water.

The annual irrigation requirements and the irrigation rates depend and are to be determined on the basis of the prevailing purpose of the irrigation which can be either supplementary watering or fertilization or waste water disposal. When irrigation is expected to be the prevailing purpose of the irrigation by waste waters, the water requirements are expressed by the following function

$$R_f = f\ (S\ ;\ C\ ;\ A\ ;\ W\ ,\ N\ ,\ M\ ,\ t) \qquad (m^3.ha^{-1} \text{ per year}) \qquad (2.125)$$

For an explanation of factors S, C, A, W see equation 2.112

N - nutriment requirements $(t.ha^{-1})$

M - suitability of waste waters, i.e. quality and exploitability of nutriment contents

t - period from the beginning of the vegetation period.

When waste water disposal is expected to be the prevailing purpose of irrigation, the seasonal irrigation requirements R_f are to be determined with a view to the annual production of waste waters

$$R_f = R_a - \frac{1}{e_{fo}} \cdot R_{ao} \qquad (m^3 \text{ per year}) \qquad (2.126)$$

R_a - annual irrigation requirements (m^3 per year)

e_{fo} – off-season coefficient of farm losses

R_{ao} – average useful irrigation rate off-season (m^3 per year)

When fertilization is expected to be the prevailing purpose of irrigation, the annual irrigation demand is to be derived on the basis of the requirements of the main nutriment

$$R_f = \frac{N_m}{n_o \cdot C_o} \quad (m^3.ha^{-1} \text{ per year}) \quad (2.127)$$

N_m – average requirements of the relevant nutriment, nitrogen N, phosphorus P or potassium K, derived from the cropping pattern (t.ha^{-1})

n_o – average coefficient of the exploitability of the nutriments from waste waters

C_o – average concentration of the nutriment in waste waters (t.m^{-3})

Before being used for irrigation, sewage effluent should be

(a) treated mechanically or at least strained by fine racks, or

(b) treated biologically, if necessary, and

(c) accumulated in the medium term or in the short term for balancing the inflow of the waste water and the required irrigation rates.

$$f = \frac{N_o - N_a}{N_a} + \frac{P_o - P_a}{P_a} + \frac{K_o - K_a}{K_a} \quad (2.128)$$

f – indicator of the fertilizing efficiency

N_o, P_o, K_o – content of the main nutriments: nitrogen N, phosphorus and potassium K in 1000 m^3 of the sewage effluent (kg)

N_a, P_a, K_a – average demand of nitrogen N, phosphorus P and potassium K for 1 hectare of cultivated land, derived from the cropping pattern and the required yield.

The positive impact of these basic nutriments can be increased by the presence of other compounds and elements, namely trace elements, by the presence of organic matter, matter forming humus or matter supporting the growth of plants. But they can also, through the presence of toxic matter, considerably limit such an impact.

The sanitary efficiency of these forms of irrigation, characterizing the effect of the filtration through the soil layer on the quality of the return flow, can be expressed by the indicator of the sanitary hazard

TABLE 2.36

Crops:	Indispensable measures
For direct consumption:	
a. eaten raw:	a. mechanical, biological and tertiary water treatment
	b. bacteriological checking of water quality (<100 bacteria coli per ml)
	c. protecting period of 21 days without irrigation before harvest
	d. sprinkler irrigation prohibited
b. not eaten raw	a. and b. as above
	c. protecting period of 14 days without irrigation before harvest
Fodder crops:	
a. grazing	a. mechanical, biological and tertiary water treatment
	b. bacteriological checking of water quality (<1000 bacteria coli per ml)
	c. grazing allowed after drainage and evaporation of irrigation water
	d. grazing of milk cows prohibited
b. consumed dry	a. as above
	b. no grazing allowed (fences)
Parks and sports fields:	a. mechanical, biological and tertiary water treatment
	b. bacteriological checking of water quality (<1000 bacteria coli per ml)
	c. pipeline is used for the primary and secondary network
	d. access of public is prohibited during watering with the exception of subirrigation
Lumber, industrial crops incl. flax and hemp:	Mechanical and biological treatment

Indispensable measures for irrigation with waste waters.

$$s_h = 1 - \frac{Q_s \cdot q_s + Q_g \cdot q_g}{R_f \cdot q_f} \qquad (2.129)$$

Q_s - volume of the surface outflow from irrigation (m^3)

Q_g - volume of groundwater outflow from irrigation (m^3)

R_f - volume of water applied (m^3)

q_s - quality indicator of surface outflow (eg. BOD_5)

q_g - quality indicator of groundwater outflow

q_f - quality indicator of irrigation water applied

When applying the solutions of mineral fertilizers, concentrations of 0.1 to 0.5 % and sprinkler or drip irrigation methods should be used. Sprinkler irrigation can also be applied to spread solutions of pesticides, stimulators and agrochemicals which protect against pest and plant diseases, i.e. as irrigation which improves plant health.

If the layers of soil above the groundwater level are uninjured and strong enough, it is possible to eliminate all dangerous forms of bacteria before penetration into surface and groundwater resources, but not to eliminate some chemical substances which might represent acute or potential health hazards.

Water which is hazardous from a sanitary point of view cannot be used on land whose soil depth is not deep enough to guarantee the necessary biological filtration needed to safeguard the groundwater from contamination. Irrigation with such waters must be prohibited for this reason e.g. in the flood plain of water courses whose water is used for the supply of the population.

The application of not only toxic or infectious matter, but also high concentrations or overdoses of generally harmless chemicals, might represent acute or potential health and environmental hazards, jeopardizing

(a) the health of the service personnel,
(b) the air and water quality,
(c) the soil quality,
(d) the quality of agricultural products.

They also have a negative impact on the irrigation operation and act aggressively on structures and technological equipment. When looking for the origin of current mass diseases, it is necessary to take the factors of the environment into account, as well as the long-term consumption of products treated by this feasible, but unnatural method, which has not yet been sufficiently investigated, especially from the point of view of its long-term impact.

2.6.6 Protective Irrigation

Protective irrigation is used to safeguard the optimum conditions for the undisturbed development of plants. It includes climatizing and purifying irrigation.

The temperature and humidity in plant systems can be controlled by climatizing irrigation in order to achieve favourable conditions for further development: Anti-frost irrigation protects the plant system against the impact of freezing temperatures. This type of irrigation is applied exclusively by means of sprinklers, delivering heat energy to the air, the soil and the plants.

The impact of this irrigation is based on the physical properties of water, especially on its high heat capacity, the high value of the latent heat of solidification and its low heat conductivity. The temperature of the water applied generally fluctuates between 5 and 12°C. When it drops to 0°C , the ice may cover the leafs and blossoms, thus forming an insulating layer and supplying them with its latent heat of solidification. By sprinkling, the humidity of the air increases, thus decreasing the air albedo and slowing down the cooling of the plant system.

The efficiency of this anti-frost irrigation depends not only on the intensity of the water application and its temperature, but also on the wind velocity, the relative humidity of the air, and on the plant species and its stage of growth. Anti-frost irrigation has proved sufficient down to - 6°C. Irrigation rates for this purpose range between 1 and 3 mm per hour, depending on the above conditions.

According to Achtnich (1957), the water requirements for anti-frost irrigation can be determined as follows:

$$R_{af} = \frac{11.15 \cdot h_p \cdot v_w \cdot (T - 2)}{K \cdot (80 + T_w)} \qquad \text{(mm per hour)} \qquad (2.130)$$

h_p - height of the plant (m)

v_w - wind velocity ($m.s^{-1}$)

T - temperature of the surface air layer (°C)

T_w - water temperature (°C)

K - coefficient corresponding to the area of irrigated leaves and stems

2.6.7 Soil Leaching Irrigation

The goal of leaching irrigation is the protection of the soil quality, i.e. its chemical composition, texture and structure. The basin method is generally used for leaching, aiming at the removal of excessive salts from the soil surface and root zone, especially of carbonates, chlorides, sulphates and nitrates, which may gradually result in a decrease in yields as well as in soil degradation.

Leaching increases the original crop water requirements at

$$R_{al} = R_a \frac{c_w}{c_a - c_w} \qquad (m^3.ha^{-1} \text{ per year}) \qquad (2.131)$$

R_a - irrigation requirements without leaching

c_w - concentration of salts in the irrigation water $(g.l^{-1})$

c_a - permissible limiting concentration of salts in soil water $(g.l^{-1})$

The water requirements for a decrease in the salinity of soils consist of the volume needed for the solution and washing away of salts R_1, the volume needed to supplement the soil moisture R_2 at the value of the field capacity FC, and the losses

$$R_{a1} = R_1 + R_2 + \Delta_1 + \Delta_2 - P - W_s \qquad (m^3.ha^{-1}) \qquad (2.132)$$

R_1 - volume needed for the solution and washing away of salts $(m^3.ha^{-1})$

R_2 - volume needed for the supplementation of the soil moisture at the field capacity FC $(m^3.ha^{-1})$

Δ_1 - losses caused by inactive penetration through the soil profile $(m^3.ha^{-1})$

Δ_2 - losses caused by evaporation $(m^3.ha^{-1})$

P - precipitation during the period of leaching $(m^3.ha^{-1})$

W_s - surplus moisture which remains in soil after completed leaching $(m^3.ha^{-1})$

Losses caused by inactive penetration through the soil profile and evaporation losses depend on the regime of leaching. The volume needed for the solution and washing away of salts can be derived according to Legostajev (1965) as follows:

$$R_1 = 100 \cdot h_s \cdot \gamma_s \cdot \frac{s_o - s_a}{s_1} \qquad (m^3) \qquad (2.133)$$

s_o - original content of salts in soil (% of weight)

s_a - admissible content of salts in the soil profile (% of weight)

s_1 - amount of salts which can be removed by 1 m^3 of water (% of weight)

γ_s - unit mass of soil $(kg.m^{-3})$

h_s - depth of the soil profile in question (m)

The quantity of salts which can be dissolved and washed away by 1 m^3 of water depends on the water quality, the chemical composition of the salts, the soil structure and texture, the temperature and the groundwater level.

The quantity of water needed for the supplementation of the soil moisture at the field capacity should only be delivered in well drained soils, i.e. when the water remaining in the soil layer does not reach the field capacity. In this case

$$R_2 = 100 \cdot h_s \cdot \gamma_s \cdot (FC - W_o) \qquad (m^3) \qquad (2.134)$$

FC - field capacity (% of weight)

W_o - soil moisture before leaching (% of weight)

The effect of leaching depends on the efficient drainage of the leaching water by means of a permeable subsoil layer or a drainage network. After leaching the water polluted by leached salts returns to the groundwater or surface resources. The loss which decreases the capacity of the water resources is caused by evaporation and deep percolation.

The irrigating schedule of leaching generally consists of several irrigation rates in the off-season period. It is useful to apply the leaching rate in the period of drought, and especially, during the drop in the groundwater table, in order to preclude an oversaturation of the soil layer and possible washing up of the salts. A high groundwater table and insufficient drainage increases the evaporation losses and carries the salt up to the soil surface.

An excessive drop in the groundwater table may considerably increase the losses caused by inactive penetration through the soil profile. Leaching by groundwater decreases the groundwater table, thus deplenishing the groundwater resources. Leaching by surface water can result in a recharging of the groundwater resources. But in both cases the quality of the groundwater is negatively affected, especially when the ratio of leaching requirements to the volume of groundwater resources is high.

2.6.8 Irrigation Losses

It is possible to distinguish the following water losses during irrigation operation (Fig. 2.28):

1. Delivery losses (losses of water diverted for irrigation before applying to irrigated land):
   - (a) canal and reservoir seepage losses
   - (b) leakage of gates, unused spills and other escape losses,
   - (c) evaporation losses,
   - (d) unused water in the irrigation network,
2. Farm losses (losses of water applied to irrigated land):
   - (a) supplementation of the soil moisture, not used by plants,
   - (b) surface and groundwater outflow of the unused water,

(c) deep percolation into subsoil layers,

(d) inefficient evaporation from the soil surface and evaporation in the atmosphere during sprinkler irrigation,

(e) evapotranspiration of weed plants,

3. Off-farm losses, i.e. by irrigation of areas where irrigation is not planned or where it is not feasible.

Farm and delivery losses in irrigation networks which have been overaltered and are badly maintained as well as not properly operated frequently exceed the consumption of plants. The losses can also be caused by water wastage, i.e. by wrong operation or by using improper irrigation methods and techniques. They can be significantly limited by technical and operational measures including proper maintenance, controlled operation on the basis of flexible operating schedules, by the modernization and automatization of the operation and by the management of irrigation rates on the basis of the continuously measured agro-hydrometeorological data and weather forecast.

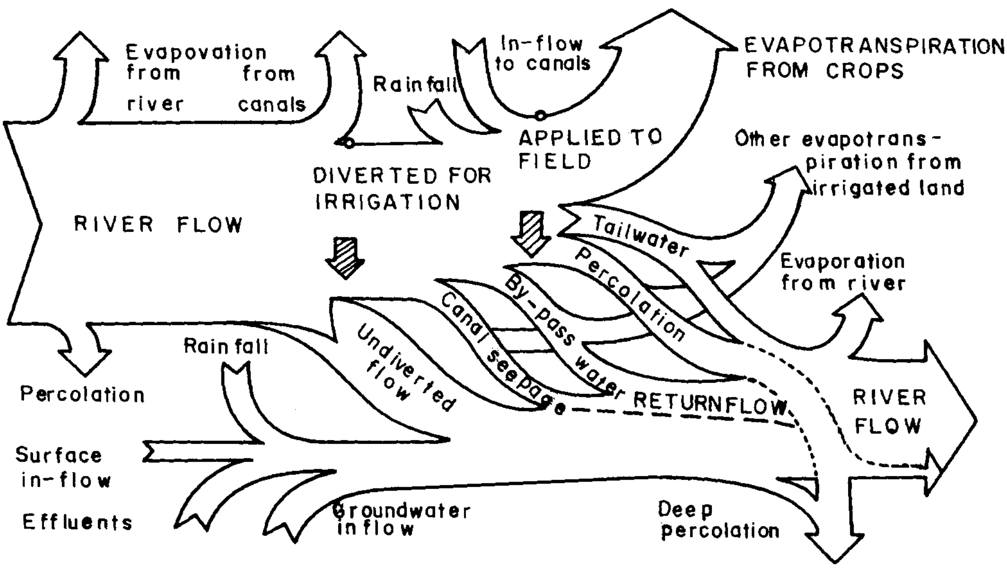


Fig. 2.28. Model of the irrigation return-flow system according to Law and Denit (1972), completed.

The coefficient of water delivery i.e. of the e_d efficiency of the irrigation network, is expressed by the ratio of the amount of water delivered to the farm field to the water withdrawal

$$e_d = \frac{R_a}{W_o} = \frac{W_o - \sum_{i=1}^{m} \Delta_{d_i}}{W_o} \qquad (2.135)$$

e_n - coefficient of water delivery

R_a - amount of water delivered to the farm field (m^3)

W_o - water withdrawal (m^3)

Δ_d - delivery losses (losses in the delivery network) (m^3)

The coefficient of the field efficiency e_f is expressed by the ratio of the amount of water actually consumed by the irrigated plant to the amount of water delivered to the farm field

$$e_f = \frac{R_c}{R_a} = \frac{R_a - \sum_{j=1}^{m} \Delta_{fi}}{R_a} \tag{2.136}$$

e_f - coefficient of water actually consumed by the irrigated plants

Δ_f - farm losses (m^3)

It goes without saying that the amount of water actually consumed should correspond to the irrigation requirements of the plants

$$R_a - \sum_{j=1}^{m} \Delta_{f_i} = \sum_{i=1}^{n} (E_{ei} + R_{1i} - \alpha_i P_v - W_{wi} - W_{gi} \quad (m^3.ha^{-1} \text{ per year}) \tag{2.137}$$

The total losses of irrigation water can be derived from the coefficient of the total efficiency, i.e. from the ratio of water withdrawals to the actual consumption of plants, corresponding to the product of the coefficients of water delivery and field efficiency

$$e_t = \frac{R_c}{W_o} = e_d \cdot e_f \tag{2.138}$$

2.6.8.1 Delivery Losses

An irrigation distribution system consists of open or covered canals, culverts, pipelines, ditches and corrugations; water can be transported in tanks, cisterns or by combinations of all these possibilities. Delivery losses depend mainly on the type and length of the distribution system, on its equipment, operation and maintenance.

The value of losses and the possibility of an economic operation of the irrigation network depend on its design, which is interconnected with the irrigation method and on its state.

Modern irrigation methods such as sprinkler or trickle irrigation, which have small farm losses, are often supplied from pipeline networks.

The precision of pipelines, the dimensional accuracy of their fittings result in very low seepage and leakage losses in this type of delivery network. Seepage losses in concrete pipes are very low and metal, asbestoscement and plastic pipes are almost without seepage.

With regard to the evaporation losses of pipes, they are almost nil under pressure operation and are also extremely low during free surface flow, due to the high humidity inside. Higher losses may occur through the leakage of untight pipes under pressure or during the operation of incorrectly erected portable pipes.

TABLE 2.37

Method	Probable drop (%)
Spontaneous clogging	40 - 50
Compacting	50 - 60
Sprinkling with chemicals	50 - 75
Floating with clay or loam	40 - 75
Clay layer	70 - 85
Concrete, asphalt membranes	80 - 95

The impact of different methods of decreasing seepage losses in unlined channels.

The amount of water which remains in the pipeline network is also very small compared with that in the open channel network. Generally, losses in the pipelines of an irrigation network are relatively lower than those of the municipal water supply system. They should not exceed 3 - 5 % for small-scale networks consisting of pipes with small diameters and not more than 8 - 10 % for large-scale networks and for portable ones.

Water losses in open channels are comparatively higher: they consist mainly of seepage, leakage and other escape losses, which are relatively bigger due to the perviousness of the construction material, low dimensional accuracy, higher roughness and bigger cross sections.

Seepage losses in open channels depend

(a) on the length of the wetted perimeter and the water depth,

(b) on the hydraulic gradient and the roughness of the canal, which determines the flow velocity,

(c) on the bank and bottom lining, i.e. on its perviousness, (Tab. 2.37).

(d) on the water quality, especially on the content of suspended matter, its grain size distribution, which in combination with the flow velocity decides on the sedimentation rate and on the clogging of the pores,

(e) on the soil properties of the bottom and banks, i.e. on their saturation and hydraulic conductivity,

(f) on the difference in the water level altitude and the groundwater table altitude,

(g) on the duration of the operation and its schedule.

The formula for seepage losses according to Davies and Wilson (1965) includes basic parameters only. The results of computations according to other formulas, including more entry data influencing seepage, do not produce more reliable results. The problem is the coincidence of the relevant entry data with the real data of the particular case. More precise values of seepage can be determined by analytical methods only or by electrical analogy, which is more reliable for the selection of alternatives and the design of the irrigation network and for the relevant economic analysis.

Reliable data on seepage in an existing network can be gained by measuring only. Delivery losses per 1 km from unprotected earth canals per 1 km exceed 10 % of the discharge provided the operation is permanent and the discharges are relatively low (below 0.1 $m^3.s^{-1}$). In the case of higher discharges, interrupted operation and pervious ground, these losses range between 10 and 20% of the discharge at 1 km length, dropping to half this value in the case of permanent operation. These values can be used for a first orientation only: the problem of water savings by means of a change in the operating schedule from continuous to iterrupted operation and vice versa is complex and depends on local conditions, and not only on the duration of the operation.

Delivery losses in open channels can be decreased by increasing the velocity of flow, by minimizing the canal cross sections, by optimizing its shape, and lining the banks and bottom of these canals. By lessening the roughness of the bottom and of the banks, it is possible to reduce seepage not only because the increased velocity of flow, but also due to the generally lower perviousness of the fine materials used for this purpose. All these measures should be analyzed taking into account the interrelated problems of canal operation, e.g. with a view to the resulting waterlogging, erosion and sediment transport problems.

Evaporation losses of open channels in humid areas are relatively low. But in semi-arid and arid areas the impact of evaporation is relatively high. These losses can be reduced by operation at night, which is feasible only for relatively small networks that can be operated for a just a few hours per day.

To reduce delivery losses by this interruption of the operation during high evaporation rates, seepage losses resulting from new filling must not exceed evaporation losses during the period that was excluded from operation. Interrupted operation reduces the total delivery losses, providing that the seepage losses are relatively low. A substantial decrease in evaporation losses can be achieved by covering the canal, by constructing closed culverts, or by overshadowing its water table with a protecting canopy, as well as by minimizing the water table width by forming a semi-circular or semi-eliptic or rectangular cross section with a longer vertical axis.

Water losses through evapotranspiration, caused by the bank canopy, are negligible in humid areas only. In semi-arid and arid countries, these losses may play an important role. Nevertheless, the protecting canopy makes it possible to increase the slope of the banks and overshadow the water table, thus limiting the evaporation from open water surfaces. This positive impact of the canopy may prove prevailing, also having a favourable influence on the microclimate.

Evaporation, seepage, leakage as well as waste water and other losses should be considered as losses in the balance of water resources and needs, if not recovered in streams or under the ground. These losses may produce problems of oversaturation, waterlogging and salinity, thus decreasing not only the yields but also the soil fertility and causing environmental problems as well as sanitary hazards.

2.6.8.2 Farm Losses

The selection of the irrigation method depends on cultivation practices, which are closely interconnected with the crop pattern and plant species. Modern methods of irrigation are characterized by substantially lower farm losses, but also by lower delivery losses, because modern irrigation practices require modern methods of water conveyance.

These methods also require higher investments and operation costs; furthermore, they are energy-consuming, as well as frequently being labour-demanding, thus requiring skilled workers. The change from traditional irrigation to modern irrigation often requires a basic change in cultivation practices, replacing primitive labour by skilled installation and operation. Local forces may not always be available to overcome the gap in manpower needs.

Farm losses depend not only on the irrigation method, but also on the technical level of its operation its control and regular checking, as well as on the reliability of the manpower or of the automatic equipment.

At the beginning of the application of the irrigation rate water losses caused by supplementation of the soil moisture can occur, which cannot be recovered by the suction pressure of the plants. These losses can be substantial, especially in dry heavy soils. Another farm loss is the percolation into subsoil layers which have no capillary interconnection with the soil profile. This percolation loss, which recharges the groundwater resources, can only be determined by local metering.

Losses through overland flow occur during overirrigation, namely after the accumulation of the surplus water on the soil surface, unless the subsequent runoff can be utilized for the effective irrigation of the adjacent land. The accumulation of water on the land surface, which is also caused by water-logging, increases the evaporation losses.

The value of evaporation losses depends on the area of the water accumulated on the land surface. During basin, graded-border or contour-ditch irrigation, the whole irrigated area is flooded and unproductive evaporation occurs from the entire irrigated strip. During furrow or corrugation irrigation, the flooded surface is remarkably restricted, resulting in a substantial decrease in evaporation losses. This depends on the density and width of the furrows, and on the soil structure.

The flooding of the entire strip can also occur during sprinkler irrigation, by exceeding the appropriate irrigation rate. The efficiency of sprinkler irrigation depends on the harmony of the irrigation rate with the suction pressure of soil, which decreases the evaporation.

Losses during sprinkler irrigation are also caused by the irrigation of unproductive land and by evaporation in the atmosphere. The value of evaporation losses in the atmosphere depends on the temperature and air humidity, on the wind velocity, on the size of the water drops and the duration of the penetration through the atmosphere. Evaporation losses during wind of velocity 4 $m.s^{-1}$ exceed these recorded during calm periods by four times and more. When the wind velocity does not exceed 1 to 1.5 $m.s^{-1}$, the total field losses through sprinkler irrigation are lower than those during traditional irrigation methods, even in arid areas.

The size of the water drops and the duration of their penetration through the atmosphere depend on the operation pressure of the sprinkler, on the shape and diameter of the nozzles, i.e. on the type of the sprinkler, as well as on the arrangement of the irrigation rate and on the sprinkling intensity, which should be harmonized with the given climatological conditions.

Operation should be controlled according to the meteorological conditions, i.e. the conditions of the local microclimate; e.g. air temperature at night are lower, the wind velocity is milder and relative humidity higher. These favourable conditions usually result in a 10 to 15% decrease in evaporation losses in comparison with sprinkling operation in the morning or afternoon. The relative evaporation losses decrease with the increase in the irrigation rate, due to the influence of the humid microclimate formed by this operation provided the actual infiltration rate is not exceeded.

Maximum irrigation efficiency is achieved by drip/trickle irrigation. This high efficiency follows from the limitation of the area irrigated to the immediate vicinity of the plant, controlled by its suction pressure. In this way not only are evaporation losses effectively restricted, but percolation into unproductive subsoil layers is also correspondingly reduced.

This irrigation method, also used to add fertilizers, is characterized by high investment and operation costs and therefore is feasible for fruit trees and shrubs and for selected types of vegetables, such as tomatoes, peas, lettuce, cucumbers, gourds, aubergines, water-melons, peppers etc.

The advantages of trickle irrigation include in particular:

(a) water savings, resulting in a 10 to 20% increase in yield and, under special conditions, even by a high 60% and higher increase without any rise in water requirements or water consumption,

(b) the possibility of also using low quality water for irrigation, i.e. brackish and even sea water, because in the course of the trickle irrigation the soil and plant accept the minimum physiologically indispensable water quantity, which consequently restricts the input of salts. Trickle irrigation with low quality water requires appropriate operation including regular leaching.

(c) the possibility of fertilizing irrigation, which can be dosed depending on the actual growing stage and nutriment requirements of the relevant plant species,

(d) larger size, higher quality and better colour of plants, restricted occurrence of pests, weeds and plant diseases,

(e) shortening of the vegetation period.

2.6.9 Water for Livestock and Processing

Livestock breeding is an important component in the balance of biogeochemical cycles. During livestock breeding and agricultural processing, water is used

(a) to water cattle (including pressure cooking, dilution of fodder mixtures etc.)

(b) as service water (for waste disposal, washing and cleaning)

(c) as process water

(d) as drinking water (for newly born calves and sucking-pigs, for personnel etc.)

With regard to the quality of water for livestock, the relevant requirements are relatively lower in comparison with the drinking water quality, especially in terms of the chemical and bacteriological indicators. But the reaction of different species of domestic animals varies and depends on their age. (Tab. 2.38, 2.39).

Horses require high water quality, while sheep can take relatively low quality. The quality requirements of newly born and sucking animals are relatively high, resulting in the use of drinking water to supply young calves and sucking pigs.

The health stage and yield of livestock and poultry depends on the quality and quantity of the water delivered. A 30% decrease in water supply in large-scale breeding results for example in a 40% decrease in milk yield and in a 30% decrease in pork yield.

TABLE 2.38

Indicator		Livestock	Man mass supply	Man individual
Oxidizing	$mg.O_2.l^{-1}$	5	3	3
Sulphates	$mg.l^{-1}$	< 450	< 25	< 50
Bacteria coli 0 per		10 ml	100 ml	10 ml
mezophyllic per ml		< 500	< 20	< 100
psychrophyllic per ml		< 2000	< 200	< 500
Temperature (minimum)	^{o}C	6 10a), 14b)	8-12	8-12

Differences in water quality requirements of drinking water for man and livestock. a) for calves, b) for sucking-pigs. For newly born calves drinking water standards and minimum temperature 25°C.

TABLE 2.39

	Evaporation residium	Chlorides	Sulphates
Cows	< 2400 $mg.l^{-1}$	< 600 $mg.l^{-1}$	< 800 $mg.l^{-1}$
Calves	< 1800	< 400	< 600
Pigs	< 1200	< 400	< 600
Sucking-pigs	< 1000	< 350	< 500
Horses	< 1000	< 400	< 500
Foals	< 1000	< 350	< 500
Sheep	< 5000	< 2000	< 2400
Lamb	< 3000	< 1500	< 1700

Indicators, characterising the sensitivity of different livestock species to water quality requirements and the feasibility of livestock breeding under different water quality conditions.

The requirements of watering livestock and of service water necessarily depend on the breeding technology. Modern breeding technologies result in a 50 to 100% increase in water requirements compared with small-scale breeding, because higher sanitary standards are necessary to cope with the increased probability of diseases due to high degree of cattle accumulation. Furthermore, replacing human labour by mechanical processes results in an increase in service water requirements: removing litter results in a 20% increase in water requirements (Tab. 2.40).

The total daily water requirements of livestock production consist of watering and processing as well as service water for waste disposal, washing and cleaning:

$$R_b = \sum_{i=1}^{k} n_i \cdot r_i + R_p + \sum_{k=1}^{k} A_k \cdot r_k \qquad (m^3 \text{ per day}) \qquad (2.139)$$

R_b – total daily water requirements of a cattle breeding farm

r_i – specific requirements per head of cattle or poultry (m^3 per pc)

n_i – number of heads in category i (pc)

R_p – daily requirements of processing water, if not included in specific requirements per head (m^3 per day)

A_k – area of relevant operational space k (m^2)

r_k – specific water requirement per square meter (m^3 per m^2)

TABLE 2.40

Species	Water requirements per pc and day Average	Maximum	Excrements liquid (l per day)	solid (kg per day)
Livestock:				
under fattening	10-40 a)	60	10	30
milk cows	15-60 a)	140	20	35
calves	15	20	2	5
horses	40	60		
mares and stallions	60	80		
sheep	8	10		
lambs	4	6		
fattened hogs	1,5-15	25	8	9
Poultry and small animals:				
Hens	0,25 b)-0,75 c)	1,5 d)		
Broilers	0,25 b)	0,35		
Geese and ducks	1,2	1,5		
Guinea-hens and turkeys	0,8	0,9		
Rabbits	3	5		

Water requirements for livestock and poultry breeding
a) lower value piped water, higher one rinsing system,
b) drip and self-filling drinking bowls,
c) flow drinking bowls,
d) during long summer days

The actual requirements for watering depend on the season, temperature, duration of the daylight, on the real weight of the relevant species, and on the particular breeding practices (stable and walk, hen-roost or run, outdoor breeding, small-scale or large-scale, type of equipment etc.). A remarkable fluctuation in requirements depending on the duration of the daylight occurs especially on poultry farms.

The maximum daily and per hour requirements can be derived with the aid of simple equations

$$R_d = R_b \cdot k_d \qquad (m^3 \text{ per day}) \qquad (2.140)$$

$$R_h = \frac{1}{24} \cdot R_d \cdot k_h \qquad (m^3 \text{ per hour}) \qquad (2.141)$$

R_b - total daily water requirements

R_d - maximum daily water requirements

k_d - coefficient of daily fluctuation ($k_d = 1.6 - 2.4$)

R_h - maximum per hour requirements (m^3 per hour)

k_h - coefficient of per hour fluctuation ($k_h = 1.8 - 3.5$)

Process water in agriculture, as in industry, includes all water needed for

(a) processing (including milk production)

(b) hydraulic transport (of manure, potatoes, beets, cereals etc.)

(c) cooling (of milk and other products) and air conditioning,

(d) boiling and heating,

(e) sorting, washing, rinsing and cleaning (of potatoes, vegetables, fruits, cereals, meat etc.)

Water in agriculture is used either as matter entering the product, as matter which comes into direct contact with the intermediate or final product or as a cooling or heat carrying medium. Relevant water quality requirements can be, therefore, classified in the same manner as the industrial water use.

2.6.10 Water Pollution from Agricultural Production

There are three main groups of pollutors in agricultural production:

(a) pollution from plant production (mainly areal): washing away of the eroded soil particles, applied and stored fertilizers, wastage of plant products, drainage waters and waste waters from irrigation polluted by extraction of salts due to overirrigation etc.,

(b) pollution from livestock and poultry breeding (mainly local): wastes from small and large-scale cattle, sheep and poultry breeding, including areal pollution from cattle walks, hen runs and pastures, escape of dung water and waste water from stables, escape of silage etc.,

(c) pollution from agricultural processing (mainly local): waste water from processing, dairies, from washing of agricultural machines, escapes of oil and oil products, stored agrochemicals etc.

Agrochemicals can be categorized according to their solubility, toxicity, possibility of decomposition or accumulation in organic matter, and their migration properties, which influence the water quality (Tab. 2.41, 2.42).

TABLE 2.41

Category	Characteristic	Lethal dose for warm-blooded animals a) X_k	Coefficient of accumulation for warm-blooded animals K_k	of aquatic organisms K_n	Stability b) in soil (days)	in water (days)
1	slightly dangerous	>1000	> 5	<50	<30	<5
2	dangerous	201-1000	4-5	51- 200	1-6 month	6-10
3	highly dangerous	51-1000	1-3	1000	0,5-2 years	11-30
4	extremely dangerous	< 50	<1	>1000	> 2 years	>30

Classification of chemicals, especially pesticides, after their threatening of surface and groundwater according to the COMECON proposal for standard (1981).
a) mg per kg of weight, peroneal dosage
b) duration of degradation on harmless constituents

$$K_k = \frac{LD_{50}\ \text{chronica}}{LD_{50}\ \text{acuta}}$$ – coefficient of accumulation for warm-blooded animals

Average dose for warm-blooded animal, peroneal dosage, mg per kg of weight:

LD_{50} chronica – by repeated dosage

LD_{50} acuta – by single dosage

$$K_n = \frac{C_g}{C_v}$$ – coefficient of accumulation in aquatic organisms

C_g – concentration in aquatic organisms

C_v – concentration in water

The quantity of excrements from livestock and poultry breeding can be derived from the weight of the relevant animal species. The ratio of the daily production of excrements fluctuates between 3.6 and 10% of the given weight. Poultry is characterized by lower, pigs by higher values. The daily average production of liquid excrements rises almost three times, and the maximum daily production to 250%, when water delivery by cisterns is replaced by a waterworks.

The prevailing pollution of water resources by agricultural production depends on local conditions and so any of the mentioned three groups of pollution may predominate in a given locality. Under conditions of intensive plant production the areal mineral and synthetic pollution by fertilizers and pesticides generally predominates. The influence of this areal pollution may substantially exceed (up to several times) the total pollution of water resources caused by industrial and municipal pollution.

TABLE 2.42

Class	Characteristics	Application	Species of pesticides
0	Non-poisonous	without limitation	sulphur fungicides (except barium polysulfide), zincous oxide, iron sulphate
1	Slightly dangerous	Application limited in protection zones for drinking water resources	Zincous sulphate, zonepion acid, hexachlorbenzol, acid substituted by halogens, fungicides with copper content, engine oil
2	Dangerous (easily degradable, non-accumulative)	Application prohibited in protection zones for surface resources and restricted in protection zones for groundwater resources used for municipal and rural water supply	derivatives of phenoxiacid, carbamate, triazin, dithiophosphorousacid (except metidation), heterocyclic fungicides, amid acids, analides, trichlorfon, dichlorfos, fenytrion, fenthion, bromfos, 1,4-dichlorpropane, zincous phosphide, baryum polysulphide
3	Highly dangerous (poisonous, easily degradable, accumulative)	Application prohibited in protecting zones for surface resources, exceptional usage in protecting zones for groundwater resources used for public water supply	derivatives of bipyridin, morkaptan (except forat), other chlorinated hydrocarbons (except endosulphane), carbamin acid, derivatives of ureas, all combinated herbicides
4	Extremely dangerous	Strict prohibition of usage in protecting zones for water resources	nitroderivatives, derivatives of dinitrophenol, forats, endosulphane, poisonous grain, matter containing mercury Hg or arsenic As

Classification of chemicals used during plant production according to their suitability for application in public water supply protecting zones.

The production and physiological processes of plant production take place in a pervious soil environment. Precipitation and surface irrigation washes away soil particles and agrochemicals, especially under conditions of large-scale production, thus causing their leaching and extraction and the consequent contamination of surface and groundwater resources.

The inconsistency of fertilizer and pesticide application with protecting water resources occurs when these agrochemicals escape from the root zone of the plants. Plants accept selected chemical elements only, especially nitrogen N, potassium K , phosphorus P - partially also calcium Ca, magnesium Mg and microbioelements. They do not accept any elements which are present in the soil in surplus.

The aim of maximizing agricultural yields with a minimum of human labour (unfortunately coupled with a lack of technological discipline) leads to an overapplication of agrochemicals. The application rates of chemicals frequently exceed 1.5 to 2 times and more the output of relevant bioelements during plant production. The contamination of water resources by intensive plant production is a problem of balancing the nutriment input and output. The resulting surface and groundwater pollution indicates not only overapplication and improper application practices, but also an uneconomic way of production, i.e. the wastage of agrochemicals.

Chapter 3

WATER SYSTEMS AND WATER BALANCE

3.1 CHARACTERISTICS OF SURFACE AND GROUNDWATER RESOURCES

The development of water resources and water management, i.e. management of all activities which influence the location and the course of water occurrence, quality and utilization, serves to satisfy social requirements by water availability, both depending on natural, historical and economic factors. The relevant water development stage can be characterized by the innovative utilization of water in the key branch of the developing economic structure (Tab. 3.1).

TABLE 3.1

Stage	Innovation Characteristics (prevailing utilization)	Innovation Tool (means)	Period in Europe
1.	individual consumption	jug	?
2.	collective usage	well	5.mil.B.C.
3.	river navigation	boat	3.mil.B.C.
4.	irrigation	irrigation canal	2.mil.B.C.
5.	human power	bucket wheel	
6.	water power	water wheel	10.c.A.D.
7.	fish breeding	fish pond	10.-15.c.A.D.
8.	minicipal water supply	pipeline networks	12.-16.c.A.D.
9.	mine drainage	pump, driven gears	15.-18.c.A.D.
10.	inland navigation	canals	16.-19.c.A.D.
11.	industrial development	steam engines	19.c.A.D.
12.	hydropower	water turbines	19.c.A.D.
13.	mass usage	reservoirs	19.-20.c.A.D.
14.	multipurpose usage	multipurpose reservoirs	20.c.A.D.
15.	large-scale usage	water systems	end of the 20.c.A.D.
16.	rational usage	water-saving	21.c.A.D.

Characteristic stages of water resources development.

Surface water and groundwater are frequently developed as separate resources. The reason for this rests in the historical and economic conditions, as well as in their physical diversity. This diversity requires not only different modes of utilization but also diverse methods of investigation. Surface water is used and investigated as a dynamic resource depending on natural factors, and groundwater as a renewable raw material. This results in different degrees of cognizance of their physical parameters, having a feedback on their utilization.

Surface water resources are characterized by their shape and size, i.e. volume (m^3) and discharge ($m^3.s^{-1}$). Aquifers, permeable geological formations containing water, are characterized not only by their shape and size, but also by their effective porosity. The effective porosity is usually expressed as a percentage and corresponds to the specific yield, the volume of water which can be removed by the force of gravity.

In addition to this, an aquifer has a specific retention and contains a certain amount of water governed by forces other than gravity. The sum of the specific retention and the specific yield corresponds to the total porosity.

The coefficient of permeability or hydraulic conductivity k_f is defined as a quantity of water flowing in one unit of time through a face of unit area ($m^3.m^{-2}.s^{-1}$) under a driving force of one unit of hydraulic head change per unit length. It depends upon the porosity: Upon grain size, shape and distribution of pores, and compaction of the formation. The product of the hydraulic conductivity and the saturated thickness is the transmissivity

$$k = \int_0^h k_f \, . \, dz \qquad (m^2.s^{-1}) \qquad (3.1)$$

h - saturated thickness

This value characterizes unconfined aquifers. A confined (artesian) aquifer is characterized by the storage coefficient or storativity S. This storativity is dimensionless and corresponds to the volume of water released from the aquifer (or taken into storage) per unit surface area of aquifer and unit change of the piezometric head ($m^3.m^{-2}.m^{-1}$).

Hydraulic phenomena should be assessed over a long period of time on the basis of probability. The likelihood of their recurrence is established without reference to any specific time interval. Reservoirs and aquifers modify the distribution of water resources in time by accumulating water during periods of excess flow and by augmenting natural discharges during periods of low flow.

Their effect can be characterized by the storage coefficient , i.e. by the ratio of the storage capacity of the reservoir or the volume of interstices forming the effective porosity of the aquifer and the long-term mean total annual flow/annual recharge.

$$\beta = \frac{V_e}{Q_a} \qquad (3.2)$$

V_e - useful storage capacity (volume of effective pores) (m^3)

Q_a - long-term mean total annual flow (long-term mean natural recharge) (m^3 per annum)

The development of water resources for maximum utilization requires the co-ordination of surface and groundwater management. Aquifers should be managed in the same manner as surface reservoirs. Depending on the relation between the storage capacity, the fluctuation of natural discharges and water requirements, flow regulation is confined to seasonal redistribution and/or to between-year regulation to satisfy water requirements during years with insufficient water flow.

The guaranteed delivery of a reservoir is the ratio of the minimum discharge secured by the reservoir to the long-term average yearly (monthly, seasonal) discharge

$$\alpha = \frac{Q_{min}}{Q_a} \qquad (3.3)$$

Q_{min} - minimum (yearly, monthly seasonal) discharge secured by the reservoir ($m^3.s^{-1}$)

Q_a - average natural discharge ($m^3.s^{-1}$)

The ratio of the surface yield (m^3 per annum) to the average annual recharge (m^3 per annum) of the aquifer expresses the similar characteristics of the groundwater resources.

3.2 SAFE YIELD

Unlike other mineral resources, water resources form a continuous flow which is renewed within the natural hydrologic cycle. Man uses water in that part of its hydrologic cycle which corresponds to the flow of water over the land masses. Any utilization of water changes the course of this cycle quantitatively and qualitatively, and also influences the rate of the relevant hydrological processes (recharge).

Various attempts have been made (see paragraph 5.5) to influence the hydrologic cycle and to increase the quantity of usable water resources. When compiling water balances a distinction has to be made between

- the traditional, conventional water uses and
- the non-conventional uses of water.

Water resources are dynamic and, therefore, the interrelationships between surface and groundwater restrict the number of categories which can be treated separately for the compilation of water balances: Through an accumulation of the dynamic component on the surface or under the ground, the static stock is formed to supplement the lack of the dynamic components, if the need arises (Tab. 3.2).

TABLE 3.2

Component	Physical interpretation	Dimension	Definition
Static	volume	m^3	Amount of water on the surface or under the ground, in the given water management unit, subsequently recharged
Dynamic	discharge (flow)	$m^3.s^{-1}$	Amount of water leaving the relevant water management unit during a given unit of time

Basic interpretation of quantitative aspects of water resources in a defined water management unit.

Interpreted in this way, the surface water resources consist of two parts: the first originating from precipitation and groundwater, the second coming from other water management units. The withdrawn water is partially replenished by increased input of groundwater and reduced evaporation caused by the decrease in water level.

The exploited groundwater resources of a given territory are replenished by increased infiltration from neighbouring aquifers, by increased infiltration from surface waters, as well as by increased infiltration after rainfall and reduced evaporation as ground water level sinks. The safe yield of an aquifer is defined as the amount of water which can be withdrawn annually from the aquifer and which is replenished naturally, without bringing about some undesired environmental legal or other result. To remove some of the ambiguity in meaning of this term, the American Society of Civil Engineers (1961) defined four concepts of yield as follows:

(a) Maximum sustained yield is the maximum rate at which water can be withdrawn perenially from a particular source.

(b) Permissive sustained yield is the maximum rate at which water can economically and legally be withdrawn perenially from a particular source for beneficial purposes without bringing about some undesired result.

(c) Maximum mining yield is the total volume of water in storage that can be extracted and utilized.

(d) Permissive mining yield is the maximum volume of water in storage that can economically and legally be extracted and used for beneficial purposes, without bringing about some undesired result.

In assessing water resources a distinction has to be made between natural and usable water resources. Natural water resources are, on average over a period of years, equal to the mean multi-annual runoff from the defined water management unit, i.e. to the volume of the natural replenishment. The usable water resources of the given water management unit are characterized by the amount of water in a longer time unit (m^3 per year) or by the flow-rate ($m^3.s^{-1}$), which can, with an adequate degree of certainty, continuously supply the relevant water users.

For a precise assessment of usable water resources, the following factors should be taken into account, as they influence the natural recharge rate:

(a) the additional recharge caused by the lowering of the water table: additional infiltration of rainwater, decrease in evaporation, increase or reduction in the groundwater inflow into water courses, infiltration from adjoining aquifers etc.

(b) anthropogenetic influence, caused by land and water development, water utilization etc. and especially by return flow.

Taking into account the natural availability of water and the technical and economic limitations for increasing its supply, water yield, the amount of water which can be withdrawn from the water resource, has different qualities:

Natural yield is the amount of water (m^3 per year) which is supplied by the water resource that is not influenced by anthropogenetic activities. The natural yield of surface resources corresponds to natural discharges. Its minimum value is, therefore, the minimum natural discharge Q_{min}. The natural yield of groundwater resources, the maximum sustained yield, corresponds to the natural recharge and enables water withdrawals which do not decrease natural groundwater deposits in the long term.

Theoretical yield is the amount of water (m^3 per year) which it would be possible to harness in the long term by modifying the occurrence of water in the long term, namely through storage, artificial infiltration and overdraft of groundwater. The theoretical yield of a surface resource corresponds to the average long-term annual runoff. The theoretical sustained yield of a groundwater resource corresponds to the average value of maximum withdrawals under a steady regime of flow, i.e. when the natural groundwater deposit is decreased (development overdraft), thus enabling the maximum recharge from surface and rainwater, also by an artificial recharge, as well as from other aquifers.

The technically utilizable yield of water resources is that portion of the theoretical yield (m^3 per year) which is defined by the possibilities of regulating the flow regime, by the possibilities of locating reservoirs, as well as by the recharge and overdraft possibilities of the relevant aquifers etc. The technically utilizable yield is limited by topographical, hydrogeological and environmental factors, the possibilities of constructing dams, reservoirs and

TABLE 3.3

Classification	Form of interpretation	Measuring unit
Aquifers (water-bearing formations) 1) exploitable en mass 2) local and unimportant 3) utilizable for other purposes 4) unsuitable for any use	Groundwater reserves-volume of water stored in the aquifer, i.e. statistically expressed in the same manner as other mineral resources. Groundwater flow-groundwater resources expressed in the same manner as surface runoff.	m^3 $l.s^{-1}$ ($m^3.s^{-1}$)
Induced recharge	Water entering the aquifer from other aquifers and from the surface as a result of water withdrawal.	$l.s^{-1}$ ($m^3.s^{-1}$)

Basic characteristics	Categories according to the cognizance of basic characteristics		
	A	B	C
	explored	under investigation	followed up
Aquifer boundary	exactly determined	under investigation	known, not exactly laid down
Source of data	observation network pumping	drilling and short-term pumping	archives
Quantity evaluation	prognosis of the future development	interplay with hydrometeorological factors	hydraulic and hydrological methods
Quality indicators		technology of water treatment, pollution effect	basic information
Protection measures	proved by investigation	determined	not yet laid down
Environmental impact and economy of operation	determined in detail	optimum operation regime	not yet laid down

Groundwater resources offered by a hydrogeological unit, i.e. by a geographically and physically limited system of aquifers and aquicludes. Categories of groundwater according to the adequacy of cognizance of basic data.

structures for artificial recharge etc. It also depends on the flexibility of water management in the sphere of water users.

The economically utilizable yield is a portion of the technically utilizable yield and is defined by the economic criteria (e.g. maximum cost per m^3 of supplied water) accepted by or given to water users in the relevant stage of economic development.

The economic and social development of human society affects and reduces the natural and theoretical yield of water resources, both qualitatively (e.g. by pollution) and quantitatively (e.g. by decreased recharge). On the other hand, technical development results in an increase in the technically and economically utilizable yield (e.g. through bigger reservoirs, or an increase in acceptable costs).

Catchment boundaries (dividing lines) form the natural geographical framework for the compilation of water balances, unless the groundwater straddles the relevant dividing line. The following sum defines, without storage factors, the natural yield $\bar{Q}_n$ for a short term period, whose duration depends on natural retention capacities, and, with storage factors included, the theoretical sustained yield $\bar{Q}_t$, provided the relevant period is a long-term one:

$$\bar{Q}_n = \int_0^t Q_s \, dt + \int_0^t G_g \, dt \qquad (m^3) \qquad (3.4)$$

$$\bar{Q}_t = \int_0^t Q_s \, dt + \bar{Q}_{sr} + \int_0^t G_g \, dt + \bar{G}_{gr} \qquad (m^3) \qquad (3.5)$$

Q_s - total surface runoff $(m^3.s^{-1})$

$\bar{Q}_{sr}$ - total storage in reservoirs (m^3)

G_g - total groundwater runoff $(m^3.s^{-1})$

$\bar{G}_{gr}$ - groundwater reserve (m^3)

t - time (s)

The preceding equation corresponds to the natural state of the catchment without any anthropogenetic influences. But the harnessing of water resources can never be considered independently of water withdrawals, water pollution and other anthropogenetic activities whose influence can be expressed as follows:

$$\bar{Q}_t = \int_0^t Q_s \, dt + \bar{Q}_{sr} + \int_0^t W \, dt + \int_0^t F \, dt + \int_0^t L \, dt + \int_0^t G_g \, dt + \bar{Q}_{gr} + \int_0^t G_{gi} \, dt - \int_0^t I \, dt - \int_0^t Y \, dt - \bar{Y}_r \qquad (3.6)$$

W - water withdrawals $(m^3.s^{-1})$

F - waste water disposal - return flow $(m^3.s^{-1})$

L - water conveyance from (+) and to (-) other catchments $(m^3.s^{-1})$

G_{gi} - induced groundwater reserves $(m^3.s^{-1})$

I - decrease in groundwater recharge, if not recovered in surface resources $(m^3.s^{-1})$

Y - irreversibly polluted portion of runoff $(m^3.s^{-1})$

$\bar{Y}_r$ - irreversibly polluted stored volume (m^3)

The determination of the safe yield is also a problem of the adequacy of the cognizance of resources (Tab. 3.3), categorization, investigation, measurability and a knowledge of the interrelationships of different categories of water occurrence, especially of surface water and groundwater. Water resources can generally be considered as

(a) conventional - i.e. traditional surface and groundwater resources which are withdrawn, pumped, transported, regulated by reservoirs, distributed etc.

(b) non-conventional - geothermal resources, collected (harnessed) dewfall, sea-water, icebergs etc.

Under the second category it is also necessary to consider the increase in conventional resources by non-conventional water use techniques such as artificial rainfall etc. (see paragraph 5.5).

For an assessment of usable groundwater resources it is indispensable to know the hydrodynamic parameters of all the relevant aquifers. The extent to which these resources can be used depends especially on the spacing between wells or galleries (ghanats etc.). To reduce the negative environmental effects, it is necessary to determine the most suitable operating conditions such as pumping rates, draw-down limits etc.

The theoretical yield $\bar{G}_g$ of groundwater resources can be expressed by the formula

$$\bar{G}_g = \int_0^t G_g \, dt + \bar{G}_{gr} + \int_0^t G_{gi} \, dt \qquad (m^3) \qquad (3.7)$$

Groundwater can be deliberately overpumped in the period of high water demand in the knowledge that it will be recharged naturally or artificially in the period of abundant water supply. Such an overdraft has the character of mining minerals and is limited by the volume of the groundwater reserves and by the duration of the overpumping:

$$G_{gm} = \int_0^t G_g \, dt + \int_0^t G_{gi} \, dt + \frac{\bar{G}_{gr}}{t_m} \qquad (m^3.s^{-1}) \qquad (3.8)$$

G_{gm} - overpumping $(m^3.s^{-1})$

t_m - duration of overpumping (overdraft) (s)

The difference between the theoretical $\bar{G}_g$ and the economically utilizable yield $\bar{Q}_{ge}$

$$\bar{G}_g - \bar{G}_{ge} = \bar{G}_{go} \quad (m^3) \qquad (3.9)$$

forms the non-utilizable reserve $\bar{G}_{go}$. This reserve consists mainly of low-quality groundwater resources and resources of unstable or low yield. The economically utilizable yield is thus

$$\bar{G}_{ge} = \int_0^t G_g \, dt + \bar{G}_{gr} + \int_0^t G_{gi} \, dt - \bar{G}_{go} \quad (m^3) \qquad (3.10)$$

The equilibrium of input and output of water within a natural geographical area (catchment) over a long period forms suitable conditions for the environmental equilibrium, i.e. for the stability of regional ecosystems. Such a balance of water resources and natural needs can be expressed by the equation

$$\int_0^t Q_s \, dt + \int_0^t G_g \, dt + \int_0^t P \, dt + \int_0^t L \, dt = \int_0^t 0_s \, dt + \int_0^t 0_g \, dt + \int_0^t E \, dt + \int_0^t C \, dt \quad (m^3) \qquad (3.11)$$

Q_s, G_g - surface and groundwater inflow $(m^3.s^{-1})$

P - precipitation

L - water conveyance from (+) and to (-) other catchments

0_s, 0_g - surface and groundwater outflow

E - evaporation

C - water consumption (of Q_s, G_g, P, L) $(m^3.s^{-1})$

The majority of these data is measured, systematically collected and processed. Data concerning evaporation E and water consumption C are generally incomplete. Groundwater inflow and outflow cannot be measured directly and have to be determined from the changes in the groundwater reserve. Any inaccuracy in the estimate of relevant values should correspond to the possibilities of regulating the outflow.

The degree of environmental changes and damages depends not only on the degree of disturbance of this balance, on its duration, and period, but also on the tolerance of the relevant ecosystems to changes in relevant components P, G_g, Q_s and L as well as on an induced or hazardous deterioration of water quality.

3.3 BALANCE OF WATER RESOURCES AND NEEDS

The balance of water resources and needs compares the quality and quantity of available water resources, i.e. the economically utilizable yield, with the water requirements, so that the measures which are necessary to satisfy the demands can be analysed. These balances evaluate the actual or planned utilization of water, its localization, course and necessity.

Each balance of water resources and needs relates to a certain geographical unit. The most suitable units for this purpose are catchments, which offer available hydrological data and the possibility of synthesizing surface and groundwater data, as well as partial results from the various neighbouring catchments.

From the hydrological point of view aquifers, reservoirs or their systems are also suitable. Practical purposes require water balances to be compiled for different administrative areas, towns, counties, but also for large farms and industrial estates.

When demarcating the boundaries of such a water management district, the relations to the neighbouring water management units have to be considered in order to incorporate these data hierarchically into those of larger geographical units.

The operational management of water resources utilization requires

(a) a current evaluation of the actual state of the water balance,

(b) a periodic (yearly) evaluation of the balance of the previous year.

Apart from this, medium-term (five years) and long-term (twenty to fifty years) balances should be determined for planning purposes.

In the framework of the planning and investment process long-term, medium-term and short-term water needs arise, i.e. quantities of water intended for a particular use in industry, agriculture, infrastructure or for the population. These needs call for planning or, if short-term, for immediate action. They should be revised as they change and become water demands after their official approval and after the construction of the relevant project. These water needs and water demands exceed the real water requirements (Fig. 3.1).

The water requirement represents that part of water demand which must be supplied for the given technological process. An inevitable water requirement represents that part of the water requirement which must be supplied by applying an optimal water-saving technological process. The water withdrawal and the

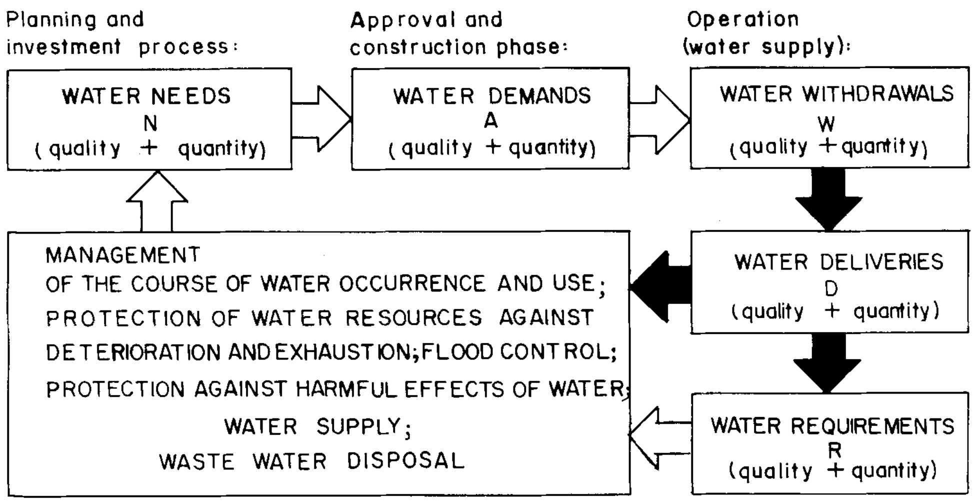


Fig. 3.1. Schematic representation of water needs, demands, withdrawals, deliveries and requirements in the framework of the planning, investment and operation process.

water delivery generally exceed water requirements differing from the amount of water paid for.

The relation between the mentioned categories can be expressed in this way:

$$N \gtreqless A \gtreqless W \gtreqless D \gtreqless R \gtreqless R_i \gtreqless U \gtreqless Q_p \qquad (3.12)$$

The relation between the water quality indicators in these categories can be expressed in a similar way:

$$n_i \gtreqless a_i \gtreqless w_i \gtreqless d_i \gtreqless r_i \gtreqless r_{ii} \gtreqless u_i \gtreqless q_i \qquad (3.13)$$

N, $n_{1 \ldots n}$ - planned water needs and planned water quality indicators,

A, $a_{1 \ldots n}$ - officially approved water demand and approved quality indicators,

W, $w_{1 \ldots n}$ - water withdrawal, amount of water diverted from a stream or a groundwater resource and its water quality indicators,

D, $d_{1 \ldots n}$ - water delivery, amount of water supplied to the water user and relevant water quality indicators,

R, $r_{1 \ldots n}$ - water requirement, the amount of water required by the water user under the given economic and production conditions,

R, $r_{i1 \ldots in}$ - indispensable water requirement, the amount of water which is indispensable to ensure the technological process, by applying all known water-saving techniques,

U, $u_{1...n}$ - water use, the amount of water really used for the relevant purpose and actual water quality indicators,

Q_p, $q_{p1...n}$ - amount of water paid for and corresponding water quality indicators.

The economy of the water development process depends on the mutual relations between the above values. The necessary water supply can be determined from the (indispensable) water requirements with a reserve for losses etc., deducing the amounts supplied from in-plant resources such as water re-use and re-cycling, storage etc.

A certain reserve, marked by the sign $>$ between water demand, water withdrawal, water supply and water requirements forms the conditions for a future extension of the production. When the sign $<$ occurs between these values, operational troubles may occur. With regard to water quality indicators, a reserve is necessary in each case for manifold and multipurpose water use, or to treat water for any of these different purposes.

The problems with the present practical compilation of the balance of water resources and needs mainly arise from their inadequacy in respect of the following points:

(a) relevant surface and groundwater resources are not analyzed from the point of view of their economic feasibility, but in the hierarchy of their cognizance/present utilization, depending mainly on the inertia of the past development and on the external influences of other braches of the national economy,

(b) the motivation of relevant water needs is not sufficiently analysed, resulting in the approval of the excessive water demands and in an extensive development of industrial or agricultural production on account of the water (and overall) development, financed generally from state financial resources,

(c) different methodological conditions of occurrence and statistical interpretation of the surface water and groundwater (e.g. groundwater and surface water including re-use of waste waters both from surface water and groundwater are analysed separately. The overdevelopment of one of these resource categories may be a consequence of or the reason for this practice).

(d) non-conventional water resources are not taken into account sufficiently.

The problem of the compilation of the balance of water resources and needs does not concern surface and groundwater resources only, but also soil water and rainfall. Soil water safeguards the majority of plant water requirements. In arid and semi-arid areas, the problem of the maintenance of the vegetative canopy has to be included in the relevant water balance considerations.

The water requirements of the vegetative canopy can be included in the framework of the irrigation water requirements. Soil water including the stock of the capillary rising groundwater can also be excluded at the beginning of the compilation process, because the water which is available for the evapotranspiration depends on local conditions, thus forming a closed system of local water supply and production, and water balances are generally compiled for superior land complexes.

The heterogeneity of the available data, the differences in the extent and frequency of measuring, and the different methods of data recording and statistical evaluation all tend to complicate the common compilation of surface and groundwater balances.

The basic inequation for the compilation of water balances and needs is

$$Q \gtreqless N \qquad (m^3.s^{-1},\ m^3) \qquad (3.14)$$

Q - available water resources $(m^3.s^{-1},\ m^3)$

N - water needs (water withdrawals W) $(m^3.s^{-1},\ m^3)$

This basic inequation can be formulated for both the surface and groundwater resources of a certain geographical unit for a limited period in the following way

$$Q_s + Q_{sr} + G_g + G_{gr} + L + F \gtreqless W + MQ + G_{go} \quad (m^3 \text{ per period}) \qquad (3.15)$$

Q_s - surface water inflow

Q_{sr} - surface water in reservoirs

G_g - groundwater inflow

G_{gr} - groundwater reserve

L - water conveyance into the area

F - return flow - waste water

W - water withdrawals including water conveyance from the area

MQ - required minimum discharge

G_{go} - groundwater outflow

The balance for surface water is expressed as follows:

$$Q_s + Q_{sr} + L - I + F = W_s + MQ \qquad (m^3 \text{ per period}) \qquad (3.16)$$

and for groundwater resources

$$G_g + G_{gr} + I = W_g + G_{go} \qquad (m^3 \text{ per period}) \qquad (3.17)$$

I - infiltration into groundwater resources from surface resources, waste water and water conveyance

W_s - water requirements covered by surface water resources

W_g - water requiremets withdrawn from groundwater resources.

TABLE 3.4

Class	Water quality	Characteristic suitability	Usage
I.	a. very clean	drinking water	urban and rural supply, food and pharmaceutical
	b. clean	domestic uses	industry, swimming pools
II.	slightly polluted	livestock breeding	livestock breeding, water sports and recreation
III.	intensively polluted	other uses	industrial supply, irrigation
IV.	deteriorated	selected in-stream uses	not suitable for withdrawal uses, only for navigation, hydropower generation, waste disposal

Categories of water quality according to its efficient usage (see Tab. 1.24).

TABLE 3.5

Group	Characteristics
A.	Water acceptable for relevant purposes of usage without treatment or after simple pre-treatment
B.	Water acceptable for relevant purpose of usage after inexpensive, simple treatment
C.	Water acceptable for relevant purpose of usage after special, but economically feasible treatment
D.	Water acceptable for relevant purposes of usage after an economically unfeasible treatment

Groups of water quality according to the feasibility of water treatment for the required purpose of usage.

The purpose of the compilation forms the basic difference between the hydrological balance and the balance of water resources and needs: The hydrological balance analyses the quantity of water in the hydrologic cycle, i.e. the inflow into and the outflow from certain geographical unit and simultaneously the increment or decrement of water inside.

The balance of water resources and needs analyses the quality and quantity of available water resources and their seasonal fluctuation, comparing them with the course or development of the relevant water needs (demands, withdrawals, requirements) in relevant categories of water quality (Tab. 3.4).

In addition to this available water resources can for water development purposes be categorized according to the feasibility of water treatment for the required purpose of usage (Tab. 3.5).

3.4 MINIMUM WATER TABLE AND MINIMUM DISCHARGES

The functions of water are manifold and any utilization of water resources must not be allowed to hinder either the natural functions of water or its general utilization by human society. It is, therefore, of paramount importance to safeguard the social functions of water and its essential ecological functions, especially for

(a) the conservation of the natural ecosystem in the rived bed,

(b) the conservation of the sediment transport,

(c) the conservation of the hygienic and aesthetic functions of water,

(d) the conservation of the natural vegetative canopy within the sphere of influence of groundwater withdrawals,

(e) conservation of the groundwater table and the natural ecosystems along water courses.

The water regime has a basic influence on the biological balance in ecosystems. Changes in the water regime occur as changes

- in flooding, the season of its occurrence, its duration and frequency, the depth and velocity of flow in the flooded area, the water and sediment quality,
- in the groundwater regime: in the groundwater recharge, groundwater level fluctuation and quality, especially if this water supplies the soil moisture of the superficial layer.

The occurrence of a minimum water table in a river, and a minimum groundwater table along its course, depends on the occurrence of minimum discharges, provided that the water table is not impounded artificially.

Therefore, during minimum discharges a criticial situation occurs, whose long-term influence on the existing natural conditions determines the composition of the relevant ecosystems. When the values of water discharges influenced by human activities such as reservoir operation or water withdrawals exceed the yearly minimum, the balance of ecosystems may not be disturbed, even in the case of an increase in the frequency of the occurrence of low discharges or in the case of an extension of their duration.

In many cases, depending on the natural conditions and adaptability of ecosystems, even a decrease in natural discharges below the value of the yearly minimum need not necessarily have a significantly harmful effect. Taking this into account, the value of the admissible minimum discharge can be derived from the minimum yearly discharges in the following way:

$$MQ = r \cdot Q_{min} \qquad (m^3.s^{-1}) \qquad (3.18)$$

MQ - minimum admissible discharge (minimum acceptable flow)

Q_{min} - the natural minimum yearly discharge, usually Q_{355d}

r - the rate of minimum discharge reduction ($r \leqq 1$)

In this way the minimum acceptable flow can be derived from the minimum monitored discharges only (Tab. 3.6).

In many cases such an oversimplification does not lead to appropriate results. The rate of minimum admissible discharge reduction is a function of

- climatic factors X_c
- geomorphological factors X_m
- biological factors (adaptability, drought resistance) X_b
- groundwater regime and surface water regime X_w
- water quality (natural pollution) X_q
- anthropogenic factors (artificial pollution, required water utilization etc.) X_x

It goes without saying that the minimum admissible discharge often depends on the season and may, therefore, differ for each month

$${}^{m}Q_{min} = f_m (X_c , X_m , X_b , X_w , X_q , X_x) \cdot {}^{m}Q_{min} \; (m^3.s^{-1}) \qquad (3.19)$$

m - month (1,2,3,.......12) $(t_m$

Furthermore, the maximum admissible duration of the minimum discharges also depends on the season and can be expressed as a function of the degree of the discharge reduction

$$t_m = F_m (X_c , X_m , X_b , X_w , X_q , X_x) \; \frac{{}^{m}Q_m}{{}^{m}Q_{min}} \quad \text{(days)} \qquad (3.20)$$

${}^{m}Q_{min}$ - natural minimum discharge in the month m

The above factors or the rate of the minimum discharge reduction and its admissible duration has, therefore, to be derived on the basis of three groups of criteria:

(1) criteria of environmental protection,
(2) criteria of in-stream water utilization,
(3) criteria of withdrawal priorities.

The criteria of environmental protection include:

(a) the criterion of biological equilibrium in the stream channel, i.e. complicated problems with regard to the undistrubed development of aquatic life,

(b) the criterion of the external equilibrium in the landscape, i.e. conservation of natural terrestrial ecosystems,

(c) the criterion of the physical equilibrium i.e. determination of minimum discharges which do not upset the balance of the erosion and sedimentation processes in the river bed,

(d) the first criterion of water quality, i.e. not allowing it to exceed the maximum admissible chemical, biological and heat pollution levels, in order to protect groundwater resources

(e) the first criterion of water table altitude, required for aesthetic enjoyment.

The criteria of in-stream water utilization include:

(a) the criterion of hydrological balance, i.e. determination of minimum discharges which limit excessive drainage of groundwater or permit the inevitable infiltration,

(b) the second criterion of the water table, required for the general water utilization in the river channel, as well as for navigation and recreation.

(c) the first criterion of discharges, necessary for power generation,

(d) the second criterion of water quality, i.e. determination of the necessary dilution of waste waters to safeguard the undisturbed course of natural self-purification processes and enable general water utilization, fishery, recreation etc.,

The criteria of withdrawal priorities include:

(a) the second criterion of discharges to cover relevant downstream water withdrawals,

(b) the third criterion of water quality, i.e. determination of the waste water dilution which would permit safe and economic water treatment processes for further water utilization by the pollution and industry.

All these criteria depend on local conditions. The established values may differ, depending on the above factors ($X_c, \ldots X_x$). The problem of minimum admissible discharge is generally considered as a hygienic and economic one. In such a way, the environmental factors are not accordingly taken into account. The appropriate determination of the minimum admissible discharge is hampered by inadequate information, in addition to the economic obstacles, legislative and institutional problems and the lack of responsibility of the authorities towards the needs of the society.

Depending on the given economic possibilities, the approved minimum admissible discharge can be used to serve environmental purposes, or to cover essential withdrawals, i.e. to fulfill only some or all the above-mentioned criteria. Taking mainly economic factors into account, minimum admissible discharges are determined on the basis of a compromise between the cost of waste water treatment on the one hand and the economic losses which may occur as a result of the deterioration in water quality and the subsequent limitations of water supply to lower riparian users on the other hand.

A practical assessment of the minimum acceptable flow depends inter alia on water requirements for effluent dilution to achieve the requested water quality, characterized e.g. by 8 mg of the biological oxygen demand BOD_5 in effluents, whose quality depends on the admissible waste water pollution in the area in question. Discharges within the limits of Q_{355d} to Q_{270d} can also be assessed, depending on the type and state of geological formations which do not destroy the groundwater regime and/or which safeguard the conservation of the characteristic ecosystem etc. (Tab 3.6).

TABLE 3.6

Water course	Minimum discharge
Mountain creeks	0.2 Q_{min}
Water courses with a relatively steady flow	0.5 Q_{min}
Other water courses	0.8 - 1.0 Q_{min}

Minimum acceptable discharges MQ according to the recommendation to the Economic Commission for Europe of the United Nations (1970).

When the minimum admissible discharge is established, not respecting the criteria of in-stream water utilization and the criteria of withdrawal priorities, practical discharge limits should be determined for each stream sector to safeguard all essential requirements for in-stream water utilization and essential water withdrawals.

In such a way a minimum value of not less than Q_{355d} can be accepted as limiting just below the dam profile. Corresponding to this in a sector of a stream not influenced by the effect of a reservoir the minimum admissible discharge may be assessed within the limits

$$\frac{1}{2} Q_{364d} < MQ < Q_{364d} \qquad (3.21)$$

In the intermediate sectors, the relevant values decrease down to the profile, where the reservoir impact is not apparent. In any case, the minimum admissible discharge should also depend on the water quality, i.e. be higher for low water quality, e.g. Q_{355d} instead of $\frac{1}{2} Q_{364d}$.

An assessment of the minimum admissible discharge may make it necessary to take measures to change existing reservoir operation and to limit water withdrawals so as to respect this value etc. Authorities might approve of a drop below these values in exception cases, but limit it to some lower values. Every appropriate measure should be taken to safeguard the necessary minimum discharge including the construction of reservoirs or conjunctive use of groundwater and surface water discharges whenever the possibility of further water withdrawals occurs.

3.5 ACTIVE AND PASSIVE WATER BALANCE

The equilibrium of water balances and needs signifies that no action has to be taken to satisfy existing needs if no further uses are planned. For such a state an interval of $\pm$ 10% has to be introduced to make allowances for the elasticity of demand and its adaptation to water shortages and also for the uncertainties of data collection and processing. Water demands can be cut by up to 20% without any important negative operational and economic consequences (Fig. 3.2).

The minimum admissible discharge for environmental protection and in-stream water utilization (not including any withdrawals) has to be regarded as an indispensable water need. Bearing this in mind, the balance of water resources and needs may be considered to be in equilirbium if

$$0.9\,Q - MQ \leqq \sum_{i=1}^{n} W_i - \sum_{i=1}^{n} F_i \leqq 1.1\,Q - MQ \qquad (3.22)$$

in each of the localities (river sectors) considered

W_i - water withdrawals ($W_i < Q - MQ$) (daily - m^3 per day)

Q - daily discharges/groundwater yield (m^3 per day)

F_i - outlet discharge (return flow)

MQ - minimum admissible discharge (m^3 per day)

$(Q - MQ)$ - usable water resources (m^3 per day)

This balance is therefore favourable (active) if

$$\sum_{i=1}^{n} W_i - \sum_{i=1}^{n} F_i < 0.9\,Q - MQ \qquad (3.23)$$

and unfavourable (passive) if

$$\sum_{i-1}^{n} W_i - \sum_{i=1}^{n} F_i > 1.1\,Q - MQ \qquad (3.24)$$

A favourable balance of water resources and needs indicates that abstraction for existing water uses can be extended and new uses can be satisfied, including water conveyance into neighbouring areas with passive balances. The unfa-

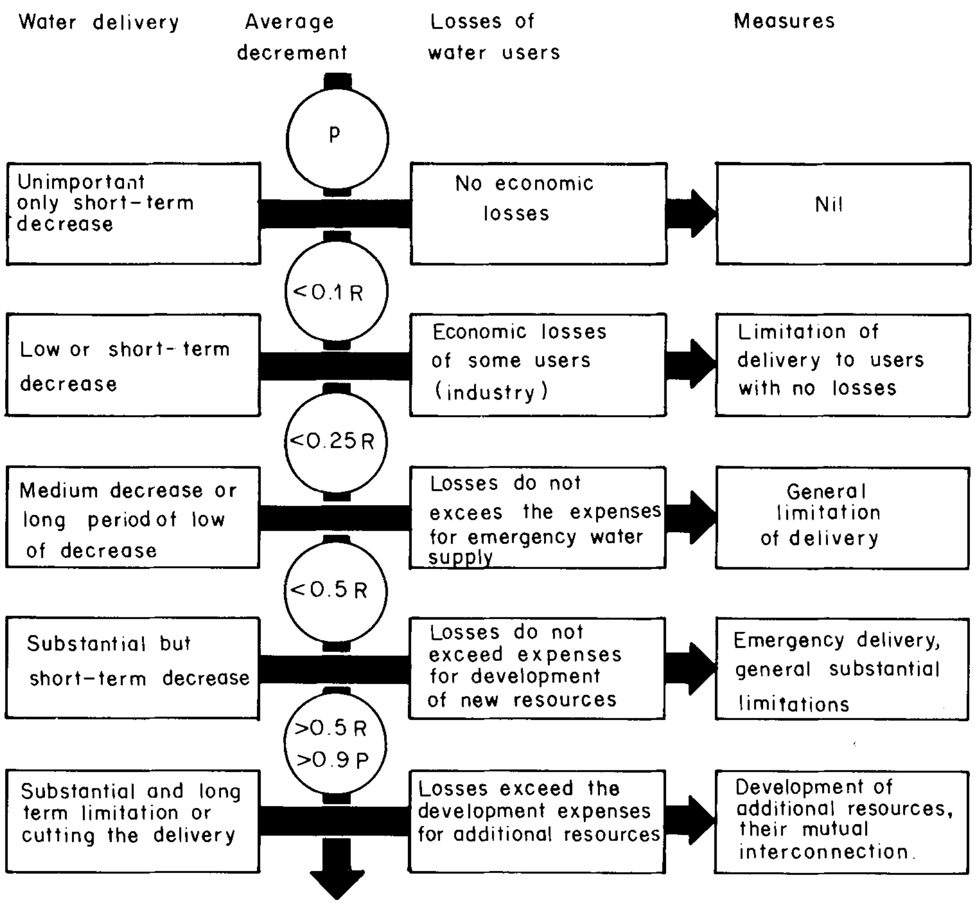


Fig. 3.2. Consequences of a decrease in water delivery and necessary operational or investment measures (p - rate of guarantee, R - water requirements).

vourable (passive) water balance indicates the need for a development of new water resources or for water conveyance from neighbouring catchments with an active water balance. From the operational point of view it indicates the need for restricting present water uses and for cutting down existing water uses e.g. by excluding inefficient uses and through the introduction of water-saving techniques.

When compiling balances of water resources and needs, the balancing effect of outlet discharges should be taken into account

$$F = W - C \qquad (m^3) \qquad (3.25)$$

C - water consumption (m^3)

The compilation of statistics of the interrelationships between water supply (amount of water supplied) and water consumption gives a basic picture of development possibilities by the application of water re-use and recycling techniques in the sphere of water users. Nevertheless, it does not mirror the possibilities of other water-saving techniques which are to be considered separately, in connection with relevant technological processes (Tab. 3.7).

TABLE 3.7

Balance of water resources and needs	Basic equation	Water surplus or deficit	Coefficient of usage of water resources	Measures
Favourable (active)	$Q > 1.1\ W$	$X > 0$ $X > 0.1\ Q$	$\mu < 0.9$	New water uses can be developed
In equilibrium	$0.9W \leq Q \leq 1.1W$	$\lvert X\rvert < 0.1\ Q$	$0.9 \leq \mu \leq 1.1$	No action necessary
Unfavourable (passive)	$Q < 0.9\ W$	$X < 0$ $\lvert X\rvert > 0.1\ Q$	$\mu > 1.1$	Water use restriction, water resources development

Quantitative indices of the balance of water resources and needs.

In practice, the difference between usable water resources and demands is often used as an important quantitative indicator. It is called water surplus if positive, or water deficit if negative, and is to be derived from statistical records in the following manner

$$X = Q - W + F \qquad \text{i.e.} \qquad (3.26)$$

$$X = Q - C \qquad (m^3,\ m^3.s^{-1})$$

X - water surplus (+), water deficit (-) $(m^3,\ m^3.s^{-1})$

On this basis, the rate of usage of a water resource is to be defined by the ratio

$$r_u = \frac{\sum_{i=1}^{n} W_i - \sum_{i=1}^{n} F_i}{Q} \qquad (3.27)$$

The ratio $$r_r = \frac{\sum_{i=1}^{n} W_i}{Q} \qquad (3.28)$$

expresses the degree of water re-use of relevant resources. The reversed value of this ratio, applied to the whole country and covering an average year, was introduced by Balcerski (1968) for comparing water resources utilization in different countries:

$$c_{wm} = \frac{\sum_{j=1}^{k} Q_i}{\sum_{j=1}^{n} W_i} \tag{3.29}$$

c_{wm} - index of water management

$\sum_{j=1}^{k} Q_i$ - mean annual surface and groundwater runoff of the whole country (m^3 per year)

$\sum_{i=1}^{n} W_i$ - annual water needs of the whole country (m^3 per year)

This index of water management does not express the activity or passivity of water balances and needs. It characterises the ratio of surface and groundwater resources development and utilization

- at the beginning of economic development and
- the re-use of water at further stages of development.

This index does not include the internal recycling, i.e. the repeated use of the same water inside a closed circuit of different water users. It characterizes the development of water management in the relevant country/area and the coordination of the repeated use of the same water by the different users, but does not characterize the efficiency of water use by relevant water users.

Quantitative indices of water utilization depend on the season, especially if irrigation requirements prevail. This unevenness can be expressed by the ratio of a summer r_s (April to September) and winter r_w (October to March) withdrawals or by the ratio of summer c_s and winter water consumption c_w:

$$r_s = \frac{\sum_{i=1}^{n} W_{si}}{\sum_{i=1}^{n} W_{ai}} \qquad r_w = \frac{\sum_{i=1}^{n} W_{wi}}{\sum_{i=1}^{n} W_{ai}} = \frac{\sum_{i=1}^{n} (W_{ai} - W_{si})}{\sum_{i=1}^{n} W_{ai}} \tag{3.30}$$

$$c_s = \frac{\sum_{i=1}^{n} (W_{si} - F_{si})}{\sum_{i=1}^{n} (W_{ai} - F_{ai})} \qquad c_w = \frac{\sum_{n=1}^{n} (W_{wi} - F_{wi})}{\sum_{i=1}^{n} (W_{ai} - F_{ai})} \tag{3.31}$$

W_{ai} - annual water withdrawals (m^3)

W_{si}, W_{wi} - water withdrawals in the summer and winter season (m^3)

F_{ai} - return flows (m^3 per year)

F_{si}, F_{wi} - return flows in the summer and winter season (m^3 per season)

3.6 PROBABILITY OF THE SATISFACTION OF WATER REQUIREMENTS

The course of water availabilities Q and of water consumption C can be expressed as a function of time

$$Q = f_1(t) \qquad C = \sum_{i=1}^{n} (W_i - F_i) = f_2(t) \tag{3.32}$$

Their difference water surplus or deficit X is, therefore, also a function of time

$$X = Q - C = f_1(t) - f_2(t) = f_3(t) \tag{3.33}$$

The points of intersection of the time function of available water resources and the time function of their consumption divide the period of the active and passive water balance. The duration of the passive balance, i.e. of non-guaranteed water supply, depends not only on the quantitative variation of water resources in time, but also on the course of water withdrawals and consumption, i.e. on the structure of water users. Similar structures of water users under the same climatic conditions produce similar time functions of water consumption.

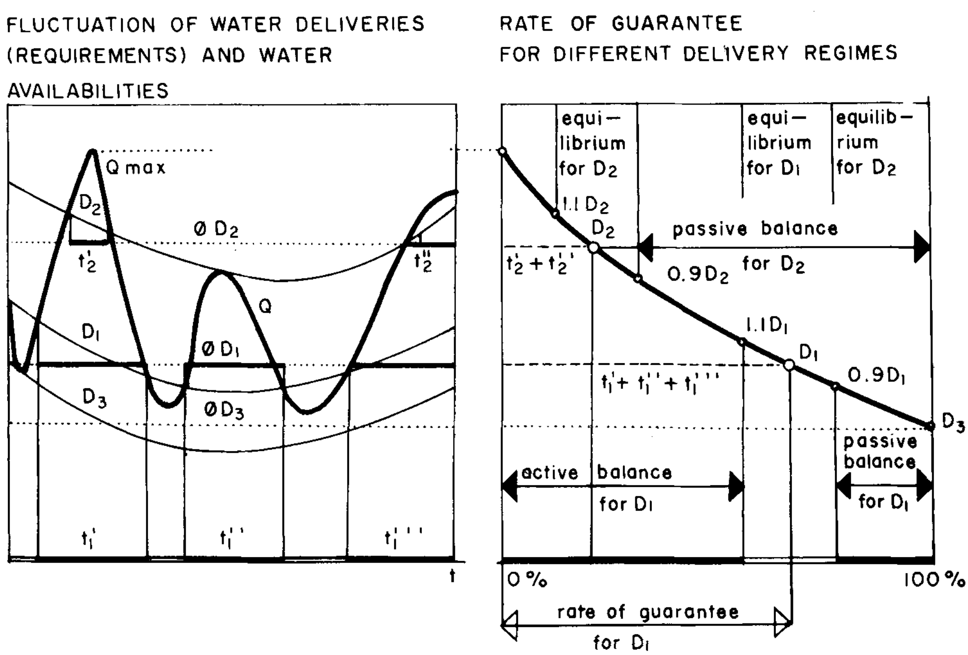


Fig. 3.3. Chronological representation of the course of water deliveries (requirements), water resources availability and the duration curve of relevant water balance states: D_{1-3} - water deliveries (requirements), $\phi\ D_{1-3}$ average values, Q - available water resources, t - time.

Fluctuation in water consumption can therefore be characterized by average values and by the rate of the non-guaranteed water supply evaluated in the same manner as the course of discharges in hydrology: by the duration curve. Such a duration curve indicates the duration of the non-guaranteed water supply (%) in the given long-term period for the relevant course of the water consumption, characterized by the average value (Fig. 3.3). The decrease in water requirements increases the rate of guarantee and extends the duration of the favourable balance of water resources and needs (requirements).

Practically, the interval $\pm$ 10% for the equilibrium of water balances and needs has to be considered and relevant curves derived from values corresponding to the increased values of water availability by 10% and average values of water consumption (or for characteristic water resources data and water consumption) decreased by 10%.

The rate of guarantee of the water supply has to be economically considered from the point of view of

- the water user,
- the water supply organisation,
- the national economy.

The cost of water for its user can be expressed as the function

$$M = f(W) \qquad (3.34)$$

M - cost per unit of production ($ per t)

W - amount of water supplied to the water (per unit of product m^3 per t , m^3.etc. water withdrawal W, delivery D, or water demand A, depending on methods of payment and masurement)

Agriculture and industry can operate without restriction or interruptions, i.e. at full capacity, when

$$D \geqq R_i \leqq R \qquad (m^3.s^{-1},\ m^3.t^{-1}) \qquad (3.35)$$

R_i - the minimum discharge with which the user is able to operate without limiting the production (indispensable water requirement) ($m^3.s^{-1}$, $m^3.t^{-1}$)

D - water delivery (D < W) ($m^3.s^{-1}$)

R - the discharge which meets the user's requirements without using water-saving techniques ($m^3.s^{-1}$)

A limitation or interruption of the water supply causes economic losses in industry and agriculture. A decrease in the water supply beneath the lower limit R_i results in an immediate, non-proportional increase in costs per unit of production (M_2). The production rate decreases, also often influencing the quality of production, both in agriculture and in industry. A further decrease in water supply can result in a similar non-proportional increase in costs (M_3), because production can be ensured e.g. by an emergency water supply only, and in agriculture by cutting down the area under irrigation. It is quite obvious that a decrease in water supply below a certain limiting value definitely interrupts the production process, but a minimum discharge R_{min} may still be required for the maintenance of some processes in industry and for conservational purposes in agriculture (Fig. 3.4).

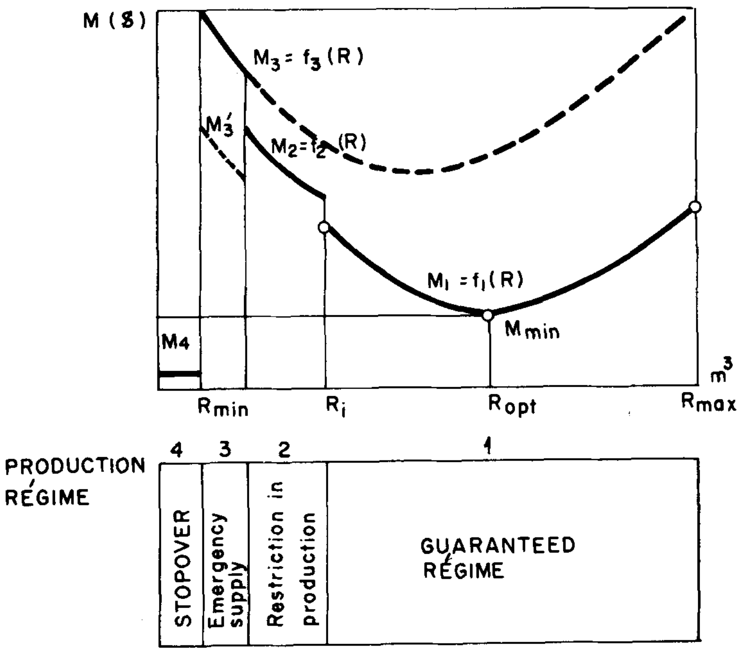


Fig. 3.4. Graphical representation of the influence of limiting water deliveries on operating cost: R_{min} - indispensable water requirements (e.g. with maximum recycling), R_{max} - water requirements with no recycling, R_{opt} - optimum discharge to be abstracted from the users viewpoints, M_1 - M_4 - operating costs under different production and water delivery regimes, M_{min} - minimum cost for the user.

The guarantee rate of water requirements satisfaction is simply the probability of satisfying the quantitative conditions of water requirements

$$p = \frac{t_1}{t} \, . \, 100\% \qquad (3.36)$$

p - the guarantee rate of water requirements satisfaction

t_1 - the duration of the satisfaction of water requirements (days)

t - the analysed long-term period (days)

By optimizing water use in agriculture and industry, an optimum discharge can be determined, thus safeguarding the required production at minimum cost for the user, i.e. optimum discharge to be abstracted from the user's viewpoint, or for the national economy, i.e. from the superior nation-wide point of view (R_i). The overall efficiency of the water supply does not depend on the water cost borne by the water user, but on the relevant cost of the water resources development and operation and on the losses resulting from the cutting down of production borne by the national economy.

But the economic relations between the water users and organisations responsible for the water supply are one-way. Relevant economic and legal feedback is not sufficient to project accordingly the losses to the water supplier: These organisations are only affected by the decrease in income from restricted water supply or by the possible duty to safeguard a compensatory emergency water supply. A decision on the rate of guarantee has to be taken from the over-all point of view of the national economy: Supplementary water resources development, generally borne by the national economy, is economically feasible if the total losses cause by the interruption or the decrease in the water supply exceed the total construction and operation costs.

TABLE 3.8

Water user	Rate of guarantee (%)	Water user	Rate of guarantee (%)
Population:		Power production:	
Big cities	95	Interstate system	99
Small centres	80	Local system	90
Agriculture:		Industry:	
Field crops	75	Interstate importance	97
Intensive cultivation	85	Local importance	90
Water transport:		Recreation	80
International	95		
National	85		
Local importance	60		

The recommended guarantee rate of water requirements satisfaction for basic categories of water users.

The full satisfaction (100%) of water requirements for the national economy is completely uneconomic, requiring a disproportionate development of water resources, in certain cases also emergency reservoirs and networks. It is very important that an increase in the guarantee rate of a few per cent within the limits from 80 to 95, and especially from 95 to 99 per cent results in a disproportionate increase, in a doubling or even in a higher increase of construction and operation costs. It is therefore indispensable to accept that the water supply could be decreased and even interrupted during periods of a lack of water or during necessary maintenance and reconstruction works. The limits of this guarantee rate depend on the relevant economic and social losses (Tab. 3.8).

The rate of guarantee does not only depend on quantitative, but also on qualitative parameters. The conditions for satisfying the quality requirements with the necessary degree of probability are of two types; i.e. for quality indicators, which must

(a) be greater than the necessary concentration

$$q_i \geq q_{io} \qquad \text{(oxygen content etc.)} \qquad (3.37)$$

(b) not be greater than the allowable concentration

$$q_i' \leq q_{io}' \qquad (3.38)$$

($i = 1,2\ldots, n-1,n$ thermal, chemical, biological and bacteriological pollution).

The rate of guarantee for qualitative conditions represents the probability of exceeding the necessary and not exceeding the admissible indicators.

The guarantee rate of water requirements satisfaction is therefore a function of many random variables

$$f(R) = \text{probability } (Q \geq R\ ,\ q_i' \geq q_{io}\ ,\ q_i' \leq q_{io}'). \qquad (3.39)$$

To determine this probability with the necessary accuracy requires daily records of quantitative data concerning water resources and water requirements. The density of water quality data need not be even, but must embrace any occurrence of pollution which exceeds the accepted limits.

The guarantee rate of water requirements satisfaction may be practically expressed in three ways:

(a) guarantee of duration x_t

(b) guarantee of volume x_v

(c) guarantee of frequency x_f

The guarantee of frequency, expressed by the ratio of the number of years (or days) with active balance or balance in equilibrium and the total number of years of the given period, defines neither the real frequency of the interruption of the water supply, nor the depth of the water deficiency, nor its real duration.

The economic effect is quite different if these days are spread or accumulated. The rate expressed by the ratio of the number of years, though used quite often, is almost without practical use (Tab. 3.9).

TABLE 3.9

Rate of guarantee	Formula	Remarks
Guarantee of duration	$x_t = \frac{t'}{t}$	t – total duration of the period t' – accumulated duration of the periods in which the use is satisfied
Guarantee of volume	$x_v = \frac{W'}{W}$	W – total volume of water requirements W' – volume of water actually supplied
Guarantee of frequency	$x_f = \frac{Y'}{Y}$	Y – total number of years in the period Y' – number of years in which the water use is completely satisfied

Rate of guarantee for qualitative water requirements expressed as a percentage or fraction of the whole according to the Economic Commission for Europe (1973).

The guarantee of duration and of volume have the same disadvantage, namely that of expressing neither the frequency nor the duration of the relevant disturbances of supply. The relation between the three mentioned rates is:

$$x_f < x_t < x_v \tag{3.40}$$

The rate of guarantee of volume may exceed 1 (one), exceeding the guarantee of duration in all cases. The guarantee of frequency, expressed by numbers of years, represents the smallest value, illogically accepting the total annual period as passive, if only a few days occur with a passive water balance.

To characterize the guarantee rate of water requirements satisfaction by mostly appropriate figures, it is necessary to determine the characteristics interrelations between the three indicators mentioned in the following way:

- to find the year with the highest number of days with a passive water balance,
- to select the longest period of the passive balance within this year,
- to determine the guarantee of volume during this period,
- to check whether a lower value of guarantee does not occur in some other period.

The appropriate value of the guarantee rate of water requirements satisfaction is expressed by the figure selected in this way.

3.7 FLOW CONTROL AND OPERATING SCHEDULES

The desired daily equilibrium or active balance of water requirements and water availabilities has to be achieved by flow and groundwater abstraction control. Schedules and guides for both surface and groundwater withdrawal and the regulation of flow and reservoir operation should be developed in advance in order to determine the most effective methods of water utilization.

Operating procedures form a complex of fixed and conditioned rules, whose aim it is to influence the location and the time distribution of water occurrence and its quality. These operating procedures include rules for surface and groundwater withdrawal, the storage of excess water in reservoirs and aquifers, its infiltration, pumping and conveyance, the release of stored water, the control of its quality by the control of the return flow and its beneficial use for the sake of the society.

Surface water bodies differ from underground water bodies by their flood detention effect. River beds, reservoirs, polders and river valleys offer storage for the immediate accumulation of water discharges, prism storage and, during the advance of a flood wave, also wedge storage. The degree of flood control offered by the reservoir depends on the ratio of the flood volume to the detention storage offered at the moment of any harmful overtopping of the natural and artificial banks in a given reach of stream. The degree of flood control can be characterized by the frequency of the flood volume occurrence, when the storage

$$V = \int_0^t (Q_f - Q_o)\, dt \qquad (3.41)$$

V - storage volume of the reservoir (m^3)

Q_f - flood discharges ($m^3.s^{-1}$)

Q_o - maximum discharge, not causing harmful overtopping of river banks ($m^3.s^{-1}$)

t - time (duration of the flood)

Almost all modern reservoirs are multipurpose. The effective storage capacity of such a reservoir can be theoretically divided into the flood-control storage and the storage capacity reserved for beneficial use. It is essential that the reservoir capacity reserved for the storage of flood water should be emptied as soon as practicable after a flood. Insufficient flood-storage capacity may result in a concentration of maximum discharge from tributaries, thus increasing the maximum flood discharge instead of decreasing it. The storage filled up before the arrival of the peak flood reduces the duration, but not the extent of inundation.

To optimize the operating procedures for the multipurpose utilization of reservoirs, the modifying effects on discharges including floods passing through a reservoir, polder etc. have to be determined by routing on the basis of

(a) collected chronological sequences of hydrological data and data on water use,

(b) chronological sequences of synthetic hydrological data and water needs,

(c) general probabilistic data on water requirements and water availabilities,

(d) frequency analysis of the storage volume at the boundary of the time intervals.

Operating schedules, rules and guides depend on the lay-out and technical equipment of relevant projects and systems. Depending on the relevant lay-out and equipment, the function of water development projects and systems is

(a) controllable and thus controlled or uncontrolled,

(b) uncontrollable, i.e. rigid and not dependent on the decisions of the operating personnel.

Consequently, the operating rules are either rigid or flexible. Rigid schedules depend mostly on ungated structures or on unconditional binding operations. The day-to-day operation is often based on semi-rigid schedules, on conditional rules dependent on the flow and the water requirements, on their current and forecasted state. The decision can be determined beforehand and expressed in the form of graphs and tabulation, formulated by the operating centre or done on site by relevant decision-makers or by the operating personnel, as this should be laid down beforehand on the basis of the theoretical studies or of previous experiences.

To increase the flood control effect of a reservoir, the active storage capacity reserved for beneficial use may be partially emptied, depending on the flow forecast. Such a release and beneficial use of water is also useful for limiting the expected but not beneficially usable spill (for power generation), which may occur especially when the reservoir is full before the beginning of the new cycle of reservoir operation.

Under such circumstances, the release of water is economically feasible if the economic effect from the beneficial utilization of such water balances the risk of losses which may occur in the next period of reservoir operation (Fig. 3.5). According to Hugh-Blair Smith (1960), this condition may be formulated as follows:

$$O_{k+} = Q_{m-k} - (V - V_k) - O_{m-k} \qquad (m^3) \qquad (3.42)$$

O_{k+} - additional release of water during the month k (m^3)

Q_{m-k} – forecasted inflow in the remaining (m-k) month period of the operation cycle (m^3)

V – total active storage (m^3)

V_k – volume available in the reservoir in the month k

O_{m-k} – outflow from the reservoir according to the basic operation (m^3)

When $O_{n+} < 0$, the additional release of water = 0. An additional limitation for water power generation is

$$O_{k+} \leqq V_k \qquad Q_{ke} \geqq O_{k+} \leqq V_k \qquad (m^3) \qquad (3.43)$$

Q_{ne} – unused capacity of the power plant according to the basic operation

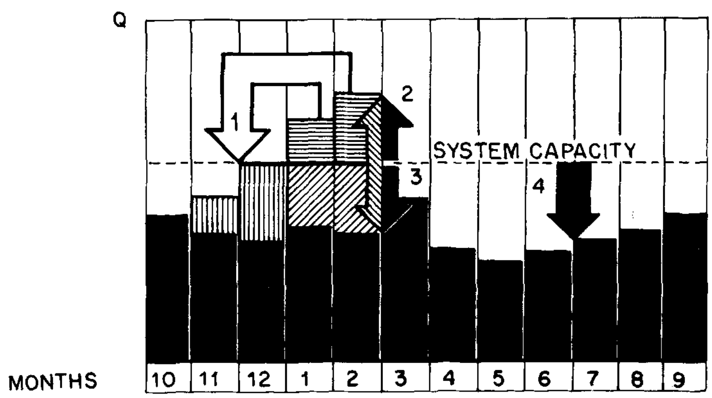


Fig. 3.5. Supplementary outflow from a reservoir on the basis of a medium-term inflow forecast increases the efficiency of water utilization in comparison with a rigid operating schedule, based on actual water availabilities.
1 – supplementary outflow, 2 – water surplus (nonavailable operatively),
3 – water surplus available operatively, 4 – unused capacity of the system (reserve for seasonal increase in requirements).

The additional release of water is not economically feasible if the economic effect from the filled reservoir exceeds the economic effect from the beneficial utilization of water downstream.

The economization of reservoir utilization can also be achieved by the reduction of withdrawals to safeguard water in storage for later use. The feasibility of such a decision has to be proved on the basis of the benefits arising from the decreased risk of a water lack in the next period. The efficiency of such operation can be proved when the function of the economic losses is not linear. Under such circumstances, the lowering of water withdrawals in the period preceding the period of the expected water deficiency is motivated by the higher benefits to accrue from the same amount of water.

Such a reduction of water withdrawals is justified in the period of reduced useful storage (Fig. 3.6) and is useful in the course of a short-term period, because hydrological and meteorological forecasts for longer periods are not sufficiently reliable.

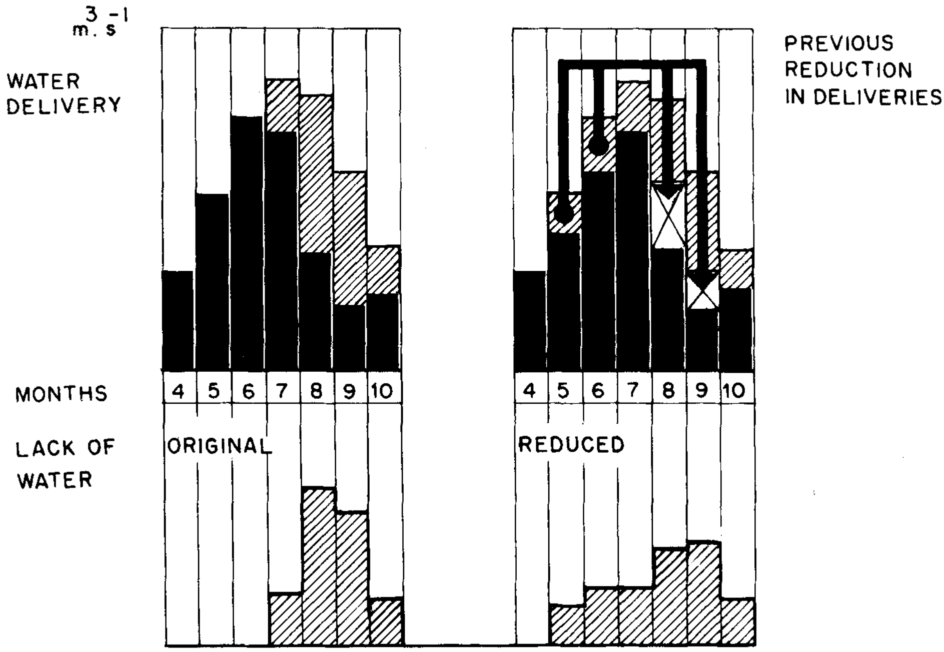


Fig. 3.6. The decrease in economic losses from water deficiency by reducing water deliveries before the period of unfavourable balances of water resources needs: a. original values without previous reduction in water deliveries, b. reduced values of water deliveries before the period of the forecasted drought, resulting in a reduction in the lack of water in the period of water deficiency. (Water deliveries marked black, deficiency hatched).

For the optimum utilization of the maximum volume of water in water reservoir systems it is necessary to distribute the release of water among the relevant reservoirs, so that the empty part of the useful storages is in relation to the inflow expected on the basis of a statistical and probability analysis in the remaining period before the beginning of the next operation cycle.

Shoemaker (1960) expressed this principle mathematically on the basis of the quality of the ratio of the empty storage of one reservoir to the empty storages of all the reservoirs, and the ratio of the expected inflow of one reservoir to the expected inflow of all the reservoirs in the system as follows:

$$\frac{V_j - \bar{V}_{jk} - Q_{jk} + O_{jk}}{\sum_{j=1}^{n} (V_n - V_{jk} - Q_{jk}) + O_r} = \frac{Q_{j(m-k)}}{\sum_{j=1}^{n} Q_{j(m-k)}} \tag{3.44}$$

n – number of reservoirs

m – number of months in the operation cycle

V_j – useful storage of the reservoir j (m^3)

$\bar{V}_{jk}$ – the volume of water in the storage of reservoir j in the month k (m^3)

Q_{jk} – the inflow of water into reservoir j during the month k (m^3)

O_{jk} – outflow from the reservoir j during the month k (m^3)

O_r – controlled increase of runoff in the rest of the period (m^3)

$Q_{j(m-k)}$ – the expected inflow into the reservoir j in the rest of the cycle of the reservoir operation (m^3)

Supposing that

$$Q_r = O_{jk} = (\bar{V}_{jk} + Q_{jk}), \tag{3.45}$$

the release from reservoir j during the month k is

$$O_{jk} = \bar{V}_{jk} + Q_{jk} - V_j + \sum_{j=1}^{n} \left[(V_j - \bar{V}_{jk} - Q_{jk}) + O_r \right] \cdot \frac{Q_{j(m-k)}}{\sum_{j=1}^{n} Q_{j(m-k)}} \tag{3.46}$$

The benefits from operation on the basis of this principle arise in practice only if the hydrological forecast is sufficiently reliable, i.e. mainly during spring discharges caused by the melting of snow.

The formulation of a similar analog for water power generation requires programming, because relevant dams offer different heads, resulting in the differences in the benefits to arise from a utilization of the same amount of water by the power stations of different dams.

For the efficient use of the useful storage capacity it is indispensable

(a) to release water either for beneficial uses or to increase the flood-control storage in the period of the expected surplus of water, to decrease the extent of floods or the amount of water not beneficially used,

(b) to decrease water withdrawals in the period before the water deficiency, carefully balancing the restricted benefits against the decrease in expected losses,

(c) to manage the operation of all reservoirs which are capable of controlling and increasing the discharges in the relevant water management profile in such a way as to balance their empty storage against the inflow expected in the next period,

(d) to increase the yield by a conjunctive use of surface and groundwater resources, to meet most needs in normal and wet years by surface storage, to retain groundwater for use during years of low surface runoff and also recharge this artificially in periods of excess surface flow.

In reality, reservoirs and water resources systems are managed on the basis of incomplete knowledge. Operational decisions are taken on the basis of what the future state is expected to be, rather than of what it is known to be. The optimal control of the outflow depends

(a) on the ability to forecast future flow sequences,

(b) on the influence of the intermediate catchment: the prism and wedge storage of the river bed, inflows from unmeasured tributaries, gains and losses due to groundwater drainage, losses and evaporation, water withdrawals etc.

(c) on the useful storage available at the right moment,

(d) on the control of the reservoir sluices.

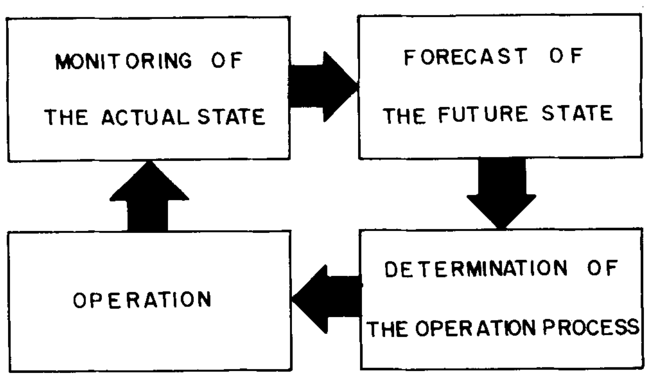


Fig. 3.7. Schematic representation of a cycle for tuning the reservoir operation on the basis of results achieved by single steps of operation.

Success in managing a multi-purpose reservoir or a reservoir system in real time depends on a minimal delay between the measured change of state and the implementation of the appropriate control decision implemented (Fig. 3.7).

This delay depends above all on the equipment and the state of

(a) the signalling system (hydrological and meteorological)

(b) the decision making system (programming, simulation or brain-trust only),

(c) the operation system (communication, press-button control on site or remote, centralized remote-control etc.)

The degree of water losses arising from current control in comparison with the data of computerized centralized remote-control often exceeds 20%. The extent and technical standard of the signalling, decision-making and operation system safeguarding the real flexibility of operation schedules should be determined by analyzing the relevant purchase and operation costs. The sum of these costs should exceed neither the increase of the induced benefits, nor the investment and operation costs of the emergency water supply.

3.8 SYSTEMS IN WATER RESOURCES MANAGEMENT

The framework in which water management activities exist forms a complex of river network systems, groundwater strata systems, water supply systems, irrigation systems, drainage and water disposal systems, flood control systems, water transport systems, water power generation systems etc., but also the abiotic, biological, legal, economic, administrative, informational and other systems of the environment (Fig. 3.8). This complex can be characterized by and subdivided into

(a) the natural systems of catchments and aquifers,

(b) technical systems of inlet works, wells and galleries, reservoirs, canal and pipeline networks etc. with relevant signalling and control systems,

(c) water supply, distribution and disposal systems of water users, situated either inside or outside water resources systems,

(d) economic and administrative systems of water management,

(e) natural, technical and socio-economic systems of the environment.

A system is a set of elements whose interrelationship is far more important than their relations to the elements of the other systems which form its environment. The set of elements and links forms the structure of a system (Fig. 3.9). Important links in water resources systems can be distinguished as

- material (hydraulic and hydrological - Fig. 3.11)
- energetical (enabling the operation)
- immaterial (economic, legal, informational etc.)

n elements of a system can be connected mutually by not more than n . (n-1) links of the same type. An open system has at least one link with the environment. A closed system has no links with the environment and can be characterized by the Cartesian product

$$S = \{X * R\} \qquad (3.47)$$

$X = \{X_1 \quad X_2 \ldots \quad \ldots X_n\}$ X_i - sets of elements x_i

$R = \{R_1 \quad R_2 \ldots \quad \ldots R_n\}$ R_i - sets of elements r_i

$(x_1 \in X_1, x_2 \in X_2, \ldots \qquad \ldots, x_n \in X_n)$

$(r_1 \in R_1, r_2 \in R_2, \ldots \qquad \ldots, r_n \in R_n)$

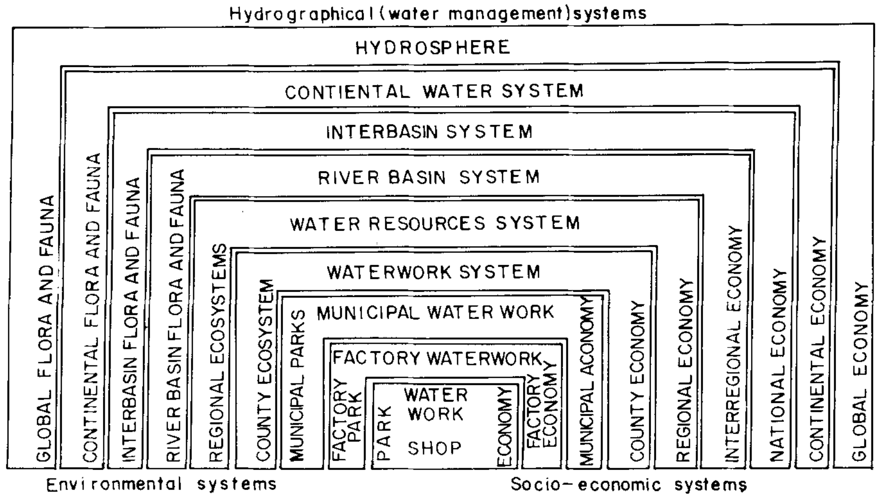


Fig. 3.8. Hierarchy of basic systems for water supply in relation to the natural and social systems which form the environment of the water supply and disposal systems.

To achieve the optimum satisfaction of the defined objectives of water resources systems, to find their most economic lay-out and function and to achieve their harmony with their environment, water resources systems and their function should be optimized at three different stages of their development:

(a) at the planning stage - to identify the optimum structure of the system which satisfies the needs within the constraints imposed, i.e. to allocate resources so that relevant preconceived goals are attained as far as possible,

(b) at the design stage - to optimize the size of the components mainly on the basis of the topographic and hydrological data, e.g. to select the least-cost solution imposing minimum constraints on the future development, or the solution of creating an integral component of the final development stage,

(c) at the operational stage - to manage a system in such a way that the actual needs are satisfied up to the design standard and the economic losses (sometimes also operational costs) are minimized and the maximum benefits achieved.

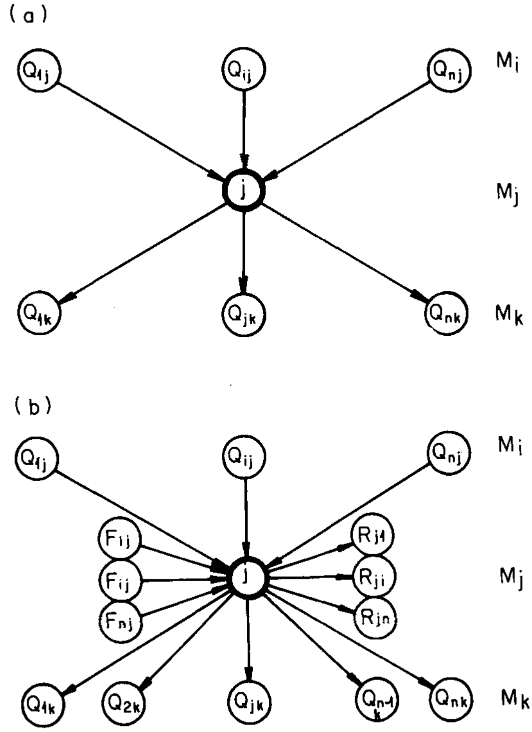


Fig. 3.9. Schematic representation of hydraulic interrelations of one element in a water resources system: a) with the water users who form the environment of the system, b) with the water users incorporated into the system. Q - water resources, R - water withdrawals, F - effluent.

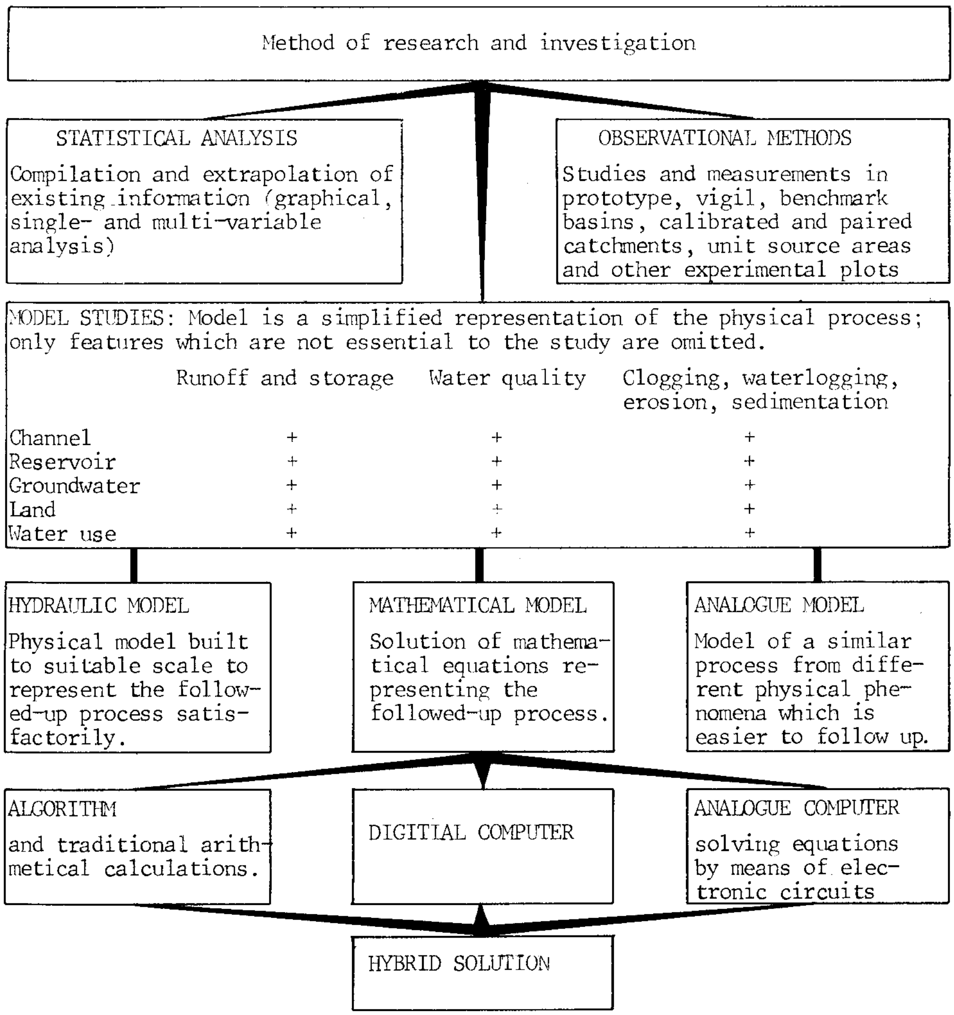
3.9 ANALYSIS AND MODELLING OF WATER RESOURCES SYSTEMS

Desirable functions of water resources systems can be achieved in balanced interrelations in their subsystems only, simultaneously fulfilling different functions in other systems, especially in the technical and economic ones and in the administrative system of water resources management.

To achieve these desired goals in an optimum way, heuristic methods have to be used. These methods, restricting the extent of searching and helping to formulate the solution, include scientific appraisals in the first extreme and exact algorithms in the second. In this specific case it is unlikely that any algorithm, a prescription for a series of calculations to be performed one after another, or any similar analytical technique, would be capable of leading from the entry data to the optimum solution.

A hierarchical approach is needed, enabling many alternative solutions to be considered without attention to detail, in order to examine the best of them in detail during subsequent stages. The complex problems of water resources require the use of different research and investigation methods (Tab. 3.10) and various other techniques such as probability theory, modelling and mathematical programming, operation research/systems analysis etc.

TABLE 3.10



Research methods and models in water resources management.

Relevant methods are appropriate to different circumstances: Simulation methods use mathematical systems analogous to the physical systems under study, which may be manipulated to produce output data similar to observed data. The variables of interest in the former correspond to physical variables. Mathematical programming is a technique for finding the optimum way to accomplish the given purpose.

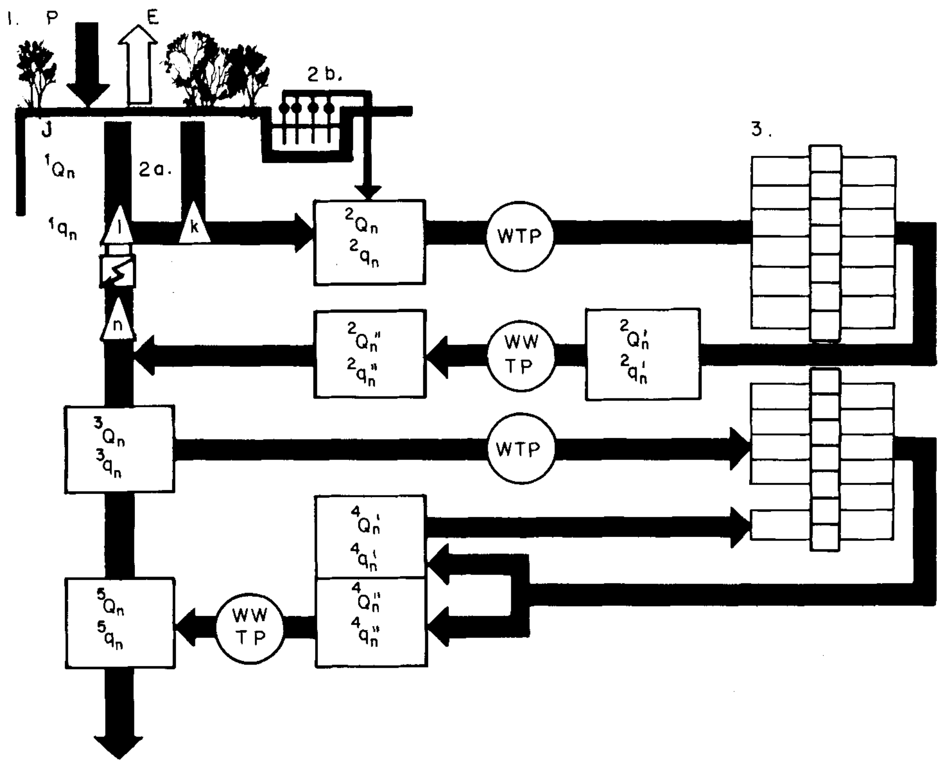


Fig. 3.10. Basic inputs and outputs in systems of water resources and users: P - precipitation, J - energy, Q - runoff, q - water quality indicators, E - evaporation, WTP - water purification plant, WWTP - waste water treatment plant. 1 - natural systems, 2 - water resources systems: a) channel and reservoir network, b) well systems, 3 - distribution and waste water disposal systems of water users.

The linear programming method is a systematic procedure for trying various combinations of elements in such a way that the control variable comes nearer to each goal at each try, always keeping within the established limit when all the relationships are linear. Integer programming is used when the quantities involved are limited to integer values. Dynamic programming is the application of the theory of multi-stage decision processes. It leads to an optimal policy by steps, in ways that often correspond to methods by decisions are made.

Models afford a deep understanding of the behaviour of the real system, providing the possibility of introducing the necessary changes in the structure and operation of the system to produce higher benefits, decrease the relevant costs and reduce the relevant negative effects.

The model of a water resources system is a combination of rivers, canals,

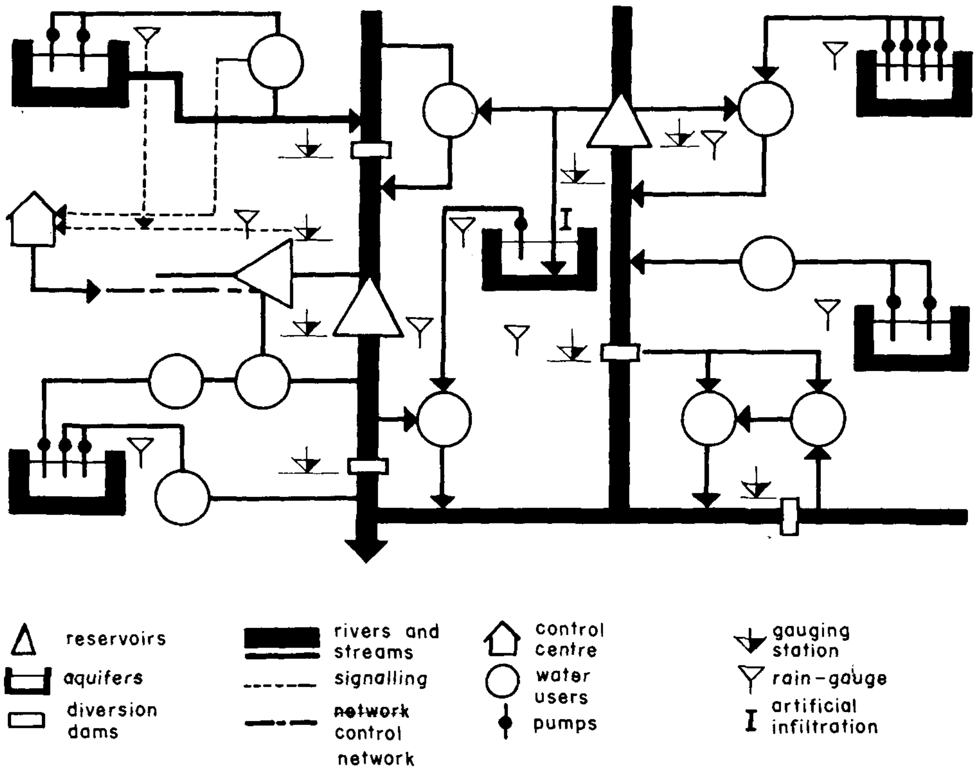


Fig. 3.11. Schematic representation of a system of surface and groundwater resources. The monitoring and control systems are depicted for two water resources and one of the water users only.

and pipelines, pumping, water purification and water treatment plants, hydropower stations (and their design heads) etc. Utilization variables concern the water supply for population and industry, areas under irrigation, power production etc. and are mainly expressed in cubic meters, kilowatt hours etc. per year. Constraints relate mainly to the volume of water available in reservoirs at the beginning of the operation season or at the beginning of each month, as well as to minimum flow, the monthly demand of energy etc. and to the nonnegativity of flow.

The iterative computations with different combinations of components and different operating schedules make it possible to select the optimum solution. The capacity of computers as well as practical reasons of the natural regulation of flow in reservoirs and channels make it possible to use ten daily or monthly averages as entry data for the analysis of the water supply, power generation

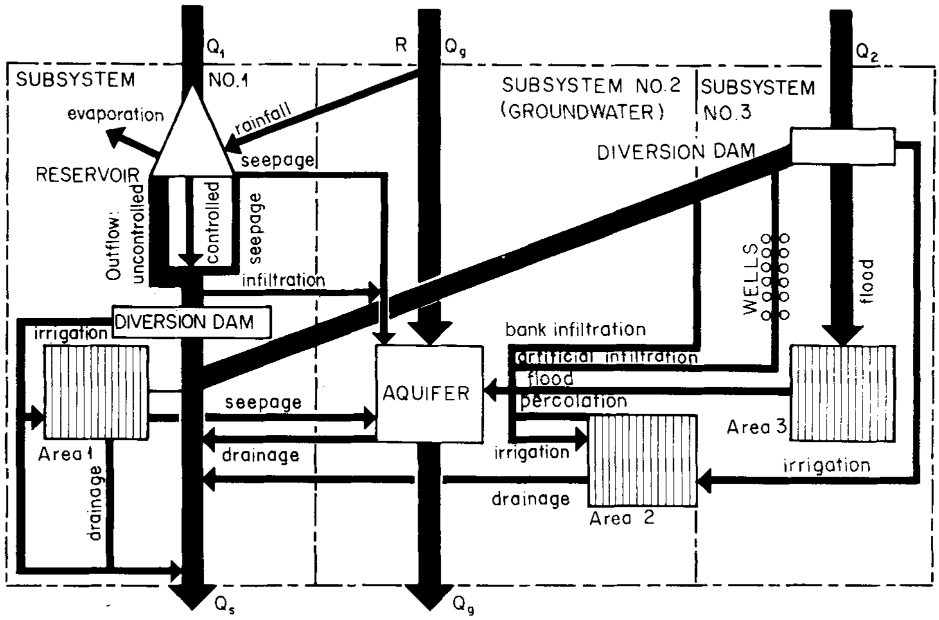


Fig. 3.12. Schematic representation of a surface and groundwater system for irrigation supply at the confluence of two rivers.

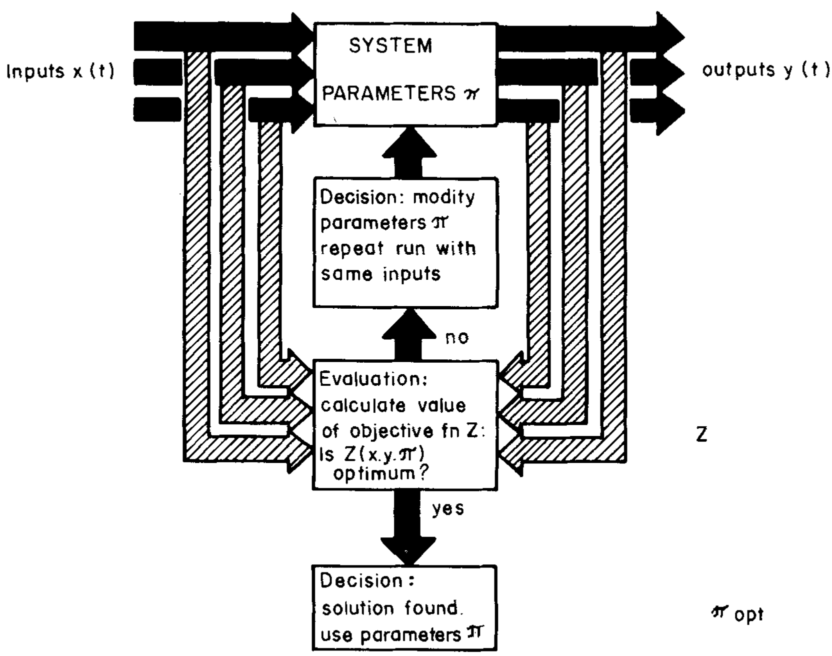


Fig. 3.13. Flow chart diagram for the selection of the optimum combination of project parameters according to Plate (1975).

etc. The break-up data for flood protection purposes should be in more detail, at least for six hour intervals, depending on the size of the catchment and the course of floods (Fig. 3.13).

An increase in the reliability of the results of optimization can be achieved by:

(a) a systematic selection and construction of alternatives, not by trial and error,

(b) formulating and programming operating schedules in such a way as to form the variable part of the model, or selecting the optimum operating schedule on the basis of a systems approach,

(c) generating a long-term series of synthetic hydrological data (e.g. for five hundred years), or probable characteristic hydrological situations which did not occur in the series observed, improving in this way the reliability of these entry data for future situations, especially in periods of minimum and maximum runoff,

(d) evaluating the benefits of relevant water resources systems on the basis of data whose stability and reliability or progressive increase or decrease can also be specified precisely enough in periods to come. These reliable data have to be derived from the population growth and development of living standards, based on the optimum needs of one individual,

(e) employing a sensitivity analysis, whose goal it is

- to define the dispersion interval of the entry data, safeguarding the generation of the output data in the sphere of the optimum solution,
- to identify the group of criteria which has the most important influence on the selection of the optimum solution and to analyse their interrelationship,
- to maximize the functional stability of the system by optimizing its structure, links and management.

Benefits and losses arising from the operation of different water resources systems can be characterized by the set of affected hydrological data, by a set of geographical and economic data, or by financial indicators. Benefits and losses, as well as the pay-off, are functions of the parameters of the system (Fig. 3.14).

$$B_i = F_i \quad (X_1 , X_2 ....X_n) \tag{3.48}$$

$B_1 , B_2 , ...,B_n$ - benefits and losses

$X_1 , X_2 , ...,X_n$ - parameters of the system

On the basis of the decision criteria for any combination of the entry data and elements of the analyzed system a set of outcomes may be determined, each outcome with a determined degree of probability.

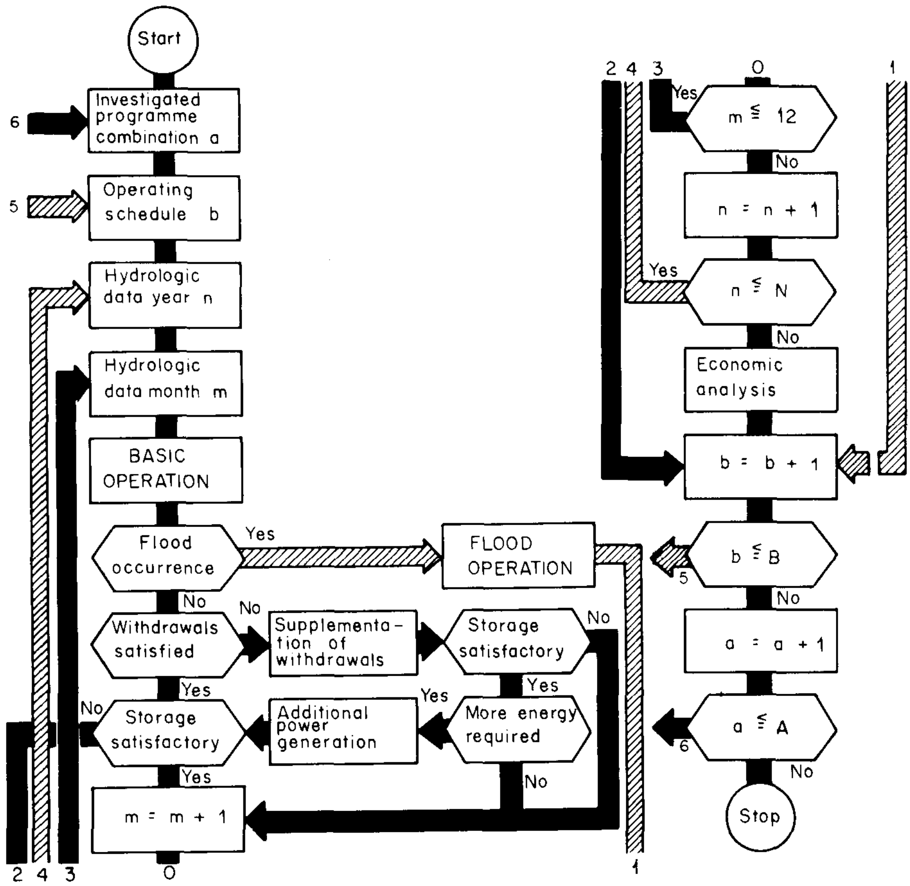


Fig. 3.14. Simplified flowchart diagram for modelling of a system of multipurpose reservoirs: A - number of investigated combinations a, B - number of investigated operating schedules b, C - number of analysed years n.

System analysis is a rational approach entailing any of the following steps (Fig. 3.15):

(a) Analysing the problem area, identifying its boundary and basic interconnections to other problems,

(b) Simplifying the problems to the point of analytical tractability, preserving all important aspects affected by various possible solutions, defining the system,

(c) Defining the hierarchy of objectives and goals,

(d) Identifying criteria for decision-making, employing feedback mechanism,

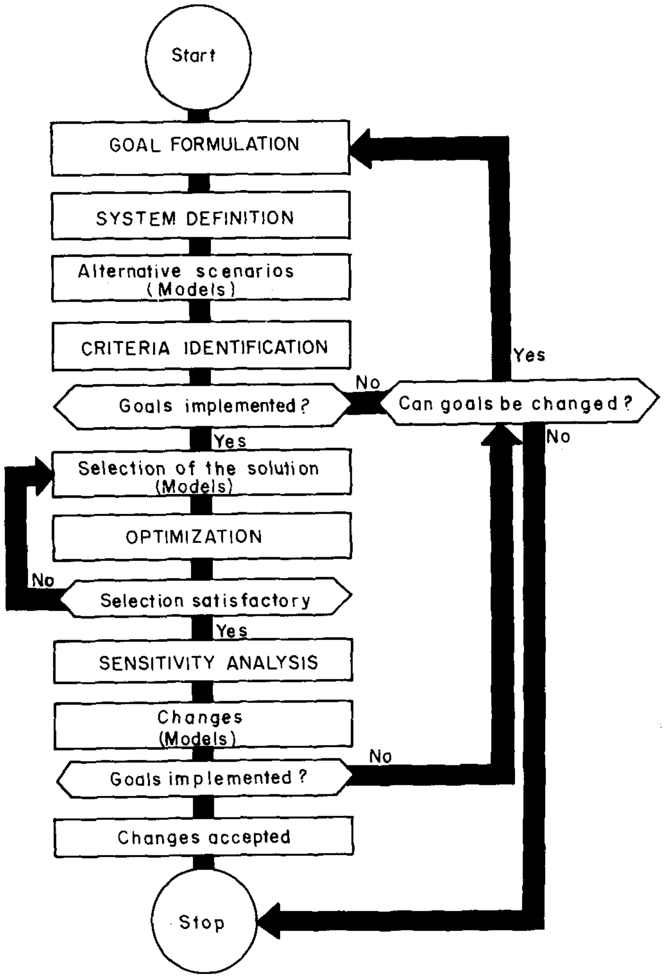


Fig. 3.15. Flowchart diagram for the selection and optimization of water resources systems.

(e) Modelling the system, examining appropriate alternatives, in order to optimize the structure of the system,

(f) Optimizing the function of the system, not omitting any dynamic interrelationships among the various components,

(g) Investigating the sensitivity of the results to the assumptions made, including the inclusion or exclusion of the problem components,

(h) Verifying that the selected solution satisfies the defined objectives and goals.

The hierarchy of decision criteria for development goals mainly includes

(a) political criteria, such as full employment, higher income and its better distribution, increased standards of life, promotion of industrial/agricultural development, electrification etc.,

(b) water management criteria, e.g.

- the increase of the rate of guarantee of water delivery for different categories of water users,
- the increase of the rate of guarantee of flood protection,
- economic utilization of resources available,

(c) economic criteria, e.g. fixed target at least cost, benefit maximization, cost-benefit optimization.

(d) environmental criteria etc.

The identification of these criteria determines the relevant political, water management, economic, environmental and other consequences: e.g. the minimization of relevant costs, expressed and realized as the minimization of present costs to achieve the requested goals, forms obstacles to future development trends.

Systems analysis with adequate entry data is to be used for solving problems of multipurpose projects and in conditions with a lack of data to identify problems. The possibility of a successful optimization is threatened by

(a) not including the really optimum solution among the selected alternatives,

(b) not identifying the really optimum function of the system,

(c) the possibility that the hydrological data are not sufficiently representative for the given task,

(d) the low reliability of the economic data for the future period of the functioning of the system,

(e) unexpected environmental consequences, especially those with a substantial economic impact.

The most common errors leading to the failure of systems analysis include

- selecting the wrong models,
- neglecting important components, links and feedbacks
- constructing models which are too detailed and exhaustive, making it difficult to select the optimum solution,
- using the process too rigidly or using the wrong criteria, i.e. those which do not lead to the requested decision,
- analysing relationships in the selected solutions which will be altered in the real situation or if a problem solution is obvious.

3.10 ECONOMIC OPTIMIZATION AND FINANCIAL ANALYSIS

Economic evaluation/optimization is a method of selecting the optimum solution for a useful utilization of limited resources such as capital, labour, land, water and other natural resources for different uses in the interests of human society. It consists in the selection of such a combination of structural variables as to minimize losses and maximize benefits. Its replacement by a minimization of investment costs is not adequate. Investment costs should be used as one of the criterion functions (Tab. 3.11).

TABLE 3.11

	Economic evaluation	Financial analysis
Goal	Growth of national income Better income distribution	Financement Money profit
Objective	Select the project, enabling maximum efficiency in using capital and natural resources available	Assessment of financial viability of economically optimum project
Viewpoint	(National) economy	Capital available to the project-undertaking entity
Input	1. Costs and benefits to the economy 1.1 directly to the project-undertaking entity 1.2 affecting other entities and individuals 2. secondary effects (transfer payments, sunk costs and inflation excluded)	Expenditures and revenues to the entity, external and secondary effects excluded. Transfer payments, taxes, custom duties, subsidies and depreciation, interest and amortization, sunk costs and general inflation excluded.
Prices	Shadow prices used, if market prices do not reflect the true values of projects effects	Market prices used.
Result	Net present worth (NPW): Discounted costs and benefits, subtracted former from the latter. Economic rate of return (ERR): The discount rate equalizing the present worth of benefits and costs.	Estimation of total capital requirements, split up into - local currency, - foreign exchange. Income statement, statement of financial sources, cash flow, balance sheet. Financial rate of return (FRR). Financial ratios: - return of fixed assets, - debt service coverage by internal cash generation, - debt/equity ratio.

Characteristics of economic evaluation/optimization and financial analysis.

Financial analysis is a method of assessing whether or not the relevant entity or entities intending to undertake the project is capable of financing its construction and operation.

The investment costs of a multipurpose project financed by several participants are generally expected to be less than the total of the costs of the single-purpose project that would produce equivalent outputs. In multipurpose projects there are

(a) separable costs which can be clearly separated and allocated to one of the participants $S_1, S_2 \ldots . S_n$

(b) common costs which are also to be shared equitably by these parties $O_1, O_2 \ldots O$

The total cost of a multipurpose project is, therefore

$$T = \sum_{k=1}^{n} (S_k + O_k) + I \qquad (3.49)$$

I - irrecoverable subsidies.

TABLE 3.12

Activities	Input or output	Methods and tools	Other effects and criteria
Identification of benefits and costs	1. Direct costs and benefits - of the project-undertaking entities, - of other entities and persons 2. Transfer payments (taxes, subsidies and custom duties, interest and amortization, - inflation and depreciation excluded) 3. Secondary effects	Comparison of situation with and without project (no status quo since even without the project development is likely)	Secondary effects stemming from - project inputs (during construction) - project outputs (after completion) expressed - explicitly by multiplicators applied to prices, - implicitly by using shadow prices
Measurement of benefits and costs	Shadow prices based on opportunity cost principle OCC (if marked prices are distorted) - efficiency shadow prices - to achieve income growth and its improved distribution between consumption and investment, - social shadow prices - to distinguish between costs and benefits accrued to poor and rich to achieve improved income distribution		
Comparison of benefits and costs	Net present worth (NPW) = difference between present worth of benefits and that of costs using discounting technique. Economic rate of return (ERR) = discount rate at which NPW = 0 Discount rate = opportunity cost of capital (OCC) defined by Authority.	Criterion of economic viability: Absolute merit (single project) NPW at OCC $\geqq$ 0, ERR $\geqq$ OCC Relative merit (several projects) Max NPW at OCC NPW $\geqq$ 0 low tariff leading to waste High NPW - impedes economic growth	Sensitivity analysis to deal with uncertainties affecting input data. Risk analysis using probability distributions for important projects. Qualitative assessment of intangible aspects.

Identification, measurement and comparison of benefits and costs.

There are a number of cost sharing methods, but the practical cost sharing is a result of negotiations. Participants in multipurpose projects are prepared to pay their separable costs and their share of common costs provided that their sum does not exceed the cost J_m of an equivalent single-purpose project $(S_m + O_m < J_m)$ and provided their benefits exceed or equal the costs

$$(B_m \geq S_m + O_m). \qquad (3.50)$$

In many countries tariffs are not well related to costs of production and investment is often subsidized. Under such circumstances the expected net benefits of the relevant undertaking cannot therefore be used as a scale for sharing the common costs.

The participants should, therefore, share the common costs in proportion to their saving, resulting from the joint project, i.e. in proportion to the equivalent single-purpose costs less their separable costs in the multipurpose project. The range within which it is reasonable to negotiate the share of common costs is therefore

$$O_m = \sum_{k=1}^{n} O_k \frac{(J_m - S_m)}{(J_m - S_m) + \sum_{k=1}^{n} (J_k - S_k)} \qquad (3.51)$$

$J_1, J_2, \ldots, J_n$ - costs of equivalent single-purpose projects

Costs and benefits must reflect the true value of project inputs, outputs and other effects on the economy as a whole. When the tariffs do not refer to the actual costs of resources used or saved by consumer decisions, they are based on sunk costs and the backward-looking pricing approach of calculating accounting costs is used. Price system distortions, namely

- price control imposed by the government,
- under- and overvalued currencies,
- protectionist measures by import quota and customs duties,
- taxes and subsidies hidden in prices,
- monopoly or government control over certain markets,
- interest rates distorted by inflation etc.

may lead to the failure of the law of supply and demand to operate freely. The valuation of resources requires a forward-looking pricing approach for calculating future marginal costs, reconciling the tariff and cost structure (Tab. 3.12).

3.11 PLANNING MODELS BASED ON PHYSICAL PARAMETERS

Physical parameters can already be adopted as a criterion in the planning stage. A simple planning model in which surface water and groundwater interactions are explicitly included in the project screening and sequencing process consists of a set of run-of-river diversions, reservoirs, well fields, water treatment plants and water conveyance projects (Fig. 3.16). The area may be divided into N planning districts. Water balances are to be analyzed in T years.

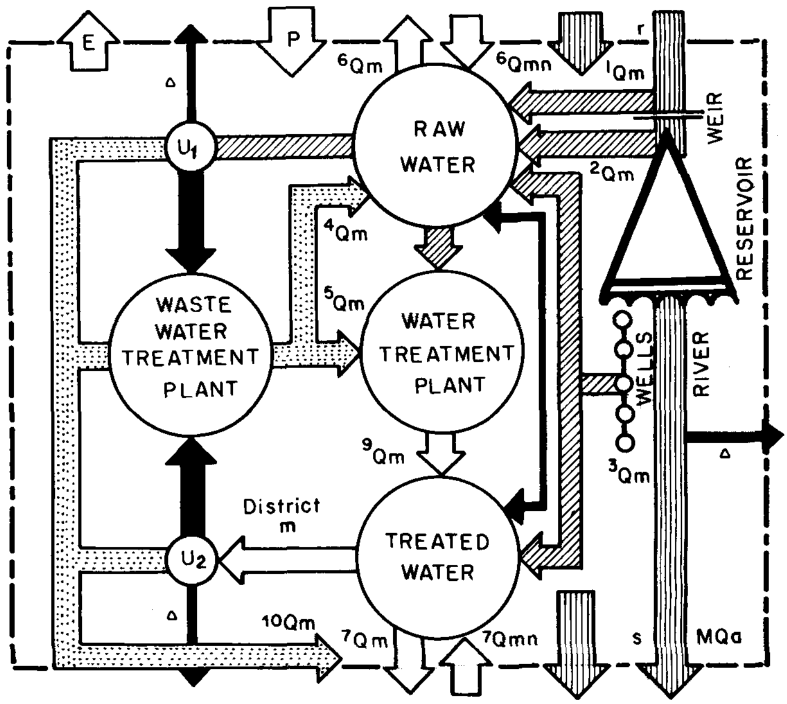


Fig. 3.16. Schematic representation of the m-th region in the planning model according to Maddock and Moody (1973); completed:
^{1}Q - withdrawal of uncontrolled discharges, ^{2}Q - withdrawal of controlled discharges, ^{3}Q - groundwater withdrawal, ^{4}Q, ^{5}Q - water re-use, ^{6}Q, ^{7}Q - conveyed water, ^{8}Q - groundwater inflow, ^{9}Q - treated water, ^{10}Q - waste water, water losses, U - water users, E - evaporation, P - precipitation.

The planning process can be modelled by a mixed-integer programme whose objective functions minimize

- the volume and distance of water conveyed,
- the volume and lift of water pumped (or maximize the head and volume used for power generation).

The first objective function may be written

$$\sum_{t=1}^{T} \sum_{m=1}^{N} \sum_{a=1}^{A_c} \left[\sum_{c=1}^{C} Q_{ctma} \cdot d_{mac} + \sum_{n=1}^{N} Q_{ctman} \cdot d_{cman} \right] \rightarrow \min \quad (3.55)$$

c - category of the resource

a, A_c - index and total number of projects in the category

t,T - index and total number of planning periods

m,n, N - indices and total number of planning districts

Q_{ctma} - volume of water supplied by project c during the period t in district from resource a

d_{mac} - distance of water conveyance by project c from the resource a in district m

Q_{ctman} - volume of water conveyed from (+) the resource a district n to district m by project c during the period t

The second objective function differs only in the variables T representing head

$$\sum_{t=1}^{T} \sum_{m=1}^{N} \sum_{a=1}^{A_c} \left[\sum_{c=1}^{C} Q_{ctma} \cdot H_{mac} + \sum_{n=1}^{N} Q_{ctman} \cdot H_{cman} \right] \rightarrow \min \quad (3.56)$$

Adopting the minimum cost as a criterion, the objective function minimizes the present value of the capital costs and operating costs over the planning period. According to Moody and Maddock (1972) the objective function may be adopted

$$\sum_{t=1}^{T} \sum_{n=1}^{N} \sum_{a=1}^{A_c} \left[\sum_{c=1}^{5} Q_{ctma} \cdot O_{ctma} + \sum_{c=1}^{5} I_{ctma} \cdot K_{ctma} + \sum_{n=1}^{N} Q_{ctman} \cdot O_{ctman} + \sum_{m=1}^{N} I_{ctman} \cdot K_{ctman} \right] \rightarrow \min \quad (3.57)$$

O_{ctma} - operating, maintenance and replacement costs per unit of water supplied by project number a of the resource c in planning district m per planning period t

O_{ctman} - ditto from planning district n

I_{cma} - the present value of construction costs of project number a of the resource c in planning district m

I_{cman} - ditto in planning district n

K_{cma} - integer column variable - if K = 1, the construction of project number a of the resource c in planning district m is completed at the beginning of the planning period t. Otherwise, K = 0.

This objective function is subject to the following constraints:

(a) Total water demand constraints: Total volume of water supplied and the imports minus the exports must be greater or equal to the total water demands in planning region m during the planning period t.

$$\sum_{a=1}^{A_c} \left[\sum_{c=1}^{5} Q_{ctma} + \sum_{c=6}^{7} \sum_{n=m}^{N} (Q_{ctman} - Q_{ctman}) \right] \geqq D_{tm} + MQ_{at}$$

D_{tm} - water needs in planning district m during the period t

MQ_{at} - volume of the minimum runoff of the resource c during the period t

(b) Project initiation constraint: No water may be supplied from project a of the resource c in planning region m until the project has been completed. Once constructed, it cannot provide more water than its yield.

(c) Processing constraints: The volume of treated water produced by well fields and water treatment plants and the volume of treated water imports must be greater or equal to the treated water demands.

(d) Flow requirement constraint: The sum of unregulated upland stream flows in planning district m which discharge to a stream segment rs, minus the withdrawals by diversions and reservoirs upstream of this segment and the volume of water lost from the stream to the underlying aquifer due to groundwater pumping, must be greater or equal to the required flows downstream of the segment rs.

The values in the flow requirement constraint imply certain seasonal patterns of surface water flows and downstream flow requirements, i.e. a set of operating rules which may be used to alter the timing of surface water withdrawals due to groundwater pumping.

Chapter 4

IMPACT OF DEVELOPMENT ACTIVITIES ON THE HYDROLOGIC CYCLE

4.1 CHANGES IN THE HYDROLOGICAL DATA

The long-term geomorphological development has formed stable, but seasonally variable conditions for the life of typical ecosystems in different parts of the natural environment. A family of these stabilized, local ecosystems forms the regional ecosystem, which is characteristic for the relevant landscape and climatological conditions.

Inputs to and outputs from the ecosystem are moved by the hydrologic cycle. This cycle also serves as the principal vehicle of matter and energy inside the ecosystem. The set of links of the hydrologic cycle, influencing the life and development of ecosystems, is formed by the hydrometeorological regime, which is characterised mainly by precipitation, water quality, groundwater table, runoff, ice and sediment drift data, temperature and sunshine.

Human activities which take place in the framework of the natural environment influence the different components of this system. If this influence on the different components of the ecosystem does not exceed the limits of the homeostasis of the system, the system is able to achieve the original equilibrium again in the long-term. But often human activities also influence the structure of the system. These structural changes, above all the change in the water regime (water quality, runoff, groundwater table, ice and sediment drift), result in sudden or long-term negative changes, i.e. in the degradation of local or regional ecosystems.

The effects of human activities on the hydrologic cycle can be distinguished as

(a) purposeful, i.e. requested consequences of water development projects and measures,

(b) non-requested, i.e. the secondary effects of activities which have another purpose or unintentional effects.

Both these effects can be either desirable or undesirable. Because of the as yet uncoordinated economic development on a global scale, the undesirable effects often prevail. The effects of human activities cause a change in both the quantitative and the qualitative aspects of the hydrologic cycle. The quantitative and qualitative aspects are mutually interconnected. A change in the volume of water in one process of the hydrologic cycle results in a change in the concentration of dissolved and suspended matter as well, i.e. in the water quality. Changes in water quality influence the course of these hydrological processes (water pollution decreases the infiltration and evaporation rate etc.), thus

TABLE 4.1

Phenomenon Simplified equation	Remarks	Influenced factors and causes of their change
Rainfall $P = k_c \cdot E$	k_c - coefficient of condensation E - evaporation	k_c - changes in energy balance changes in the quantity of condensation nuclei changes in air motion E - see evaporation and evapotranspiration
Interception $I = P - P_e$ $P_e = R + S - I_2$	P_e - effective rainfall T^e - throughfall S - stemflow I_2 - litter interception loss	I,T,S,D - by changes in the land surface and in the vegetative canopy and litter
Depression and detention storage $D = k_d \cdot A$	k_d - detention coefficient A - area surface	k_d - changes in the land surface construction of channels and reservoirs, surface drainage A - changes in the area surface
Infiltration $v_f = \frac{1}{2} \cdot S \cdot t^{-\frac{1}{2}} + v_k$	v_f - actual infiltration S^1 - sorptivity v_k - constant infiltration rate t - time from the beginning of the process	S - changes in the hydraulic conductivity and in other soil properties including the moisture content and in the overland flow depth v_k - Changes in permeability
Subsurface runoff $G_g = A \cdot v_f$ $v_f = k_f^1 \cdot \mathrm{grad}\,\Psi$ $v_f = k_f^1 \cdot I$	k_f' - coefficient of the unsaturated flow k_f - coefficient of hydraulic conductivity Ψ - soil water potential	I - by changes in the head resulting from water withdrawals, irrigation k_f - by clogging etc.
Evaporation and evapotranspiration $ET = k_x \cdot EW$	k_x - coefficient of the land surface EW - evaporation from free water surface	k_x - changes in the land surface including canopy
Overland flow $Q_s = K \cdot H^m$	K - coefficient of rainfall intensity, slope and roughness H - depth of flow m - coefficient of flow	K - changes in the land roughness and slope m - resulting changes in the flow H - resulting changes in the flow depth
Concentrated surface runoff $Q_r = A \cdot v_s$ $v_s = \frac{R^{\frac{2}{3}}}{\sqrt{2gLn}} \cdot \left[2g\Delta h + k(v_1^2 - v_2^2)\right]^{\frac{1}{2}}$	R - hydraulic radius L - length of the stream stretch n - coefficient of channel roughness h - difference in water tables k - reduction coefficient	v_1, v_2,R,k,Δh - change in the channel cross section L - changes in the length of the channel stretch n - changes in the channel roughness

Hydrological processes and factors of their equations, influences of human activities.

influencing the relevant quantity of water (Tab.4.1).

The quantitative influence on the course of the hydrologic cycle is a result of

(a) an acceleration, extension or facilitation of any process of the hydrologic cycle in the particular space,

(b) a retardation, limitation, suppression or discontinuation of any of the hydrologic processes in the particular space.

Such an extension or suppression results in the absorption or release of energy, thus influencing the course of other hydrological processes in situ and/or in another affected space.

The qualitative influence on the course of the hydrologic cycle is a result of

(a) an increase or decrease in the compounds of the hydrologic cycle, which have also previously been its natural component,

(b) the introduction of such new elements and compounds into the cycle and a contingent increase of their content in the cycle.

These compounds or elements may become

(a) an enduring or temporary accessory component of all the processes of the hydrologic cycle, their content being thinned or decomposed during these processes,

(b) an enduring component of water resources, the air mass or the living matter, their content being gradually accumulated.

The change in any value of the hydrological data, including the change in water quality indicators, can be expressed by the equation

$$q_1 = q_o + \sum_{k=1}^{n} \Delta_k \qquad (m^3,\ m^3.s^{-1},\ m.a.s.l.,\ g.m^{-3}) \qquad (4.1)$$

q_o – the natural value of any parameter of the hydrologic cycle not influenced by human activities

q_1 – the actual value of the hydrometeorological parameter influenced by human activities

Δ_1, Δ_n – increments/decrements arising from different human activities 1, 2, ..., n

It is rather difficult to determine the exact values of these increments or decrements. They can be separately measured or assessed by some mathematical method, or by modelling in exceptional cases only. They are provoked by many factors, whose influence is long-term, variable and sometimes also erratic. Their interplay is extremely difficult to follow up in detail and appears to be stochastic. Their usual determination is therefore based on a comparison of the natural and transformed values

$$\sum_{k=1}^{n} \Delta_k = q_1 - q_o \quad (m,\ m^3.s^{-1},\ m.a.s.l.,\ g.m^{-3}) \qquad (4.2)$$

The increments/decrements have to be assessed by

- methods of water balance
- research on experimental river basins
- methods of hydrological analogy
- statistical methods
- mathematical or physical modelling
- comparing data of the affected and non-affected period
- comparing data of the affected and non-affected similar catchment.

4.2 CHANGES IN THE HYDROLOGICAL BALANCE

To ascertain the quantitative effects of human activities on the hydrologic cycle, it appears practicable to subdivide the area in question into elements which correspond to, for example, relevant sub-catchments and to separate the atmospheric and lithospheric branch of the hydrologic cycle (Fig. 4.1.).

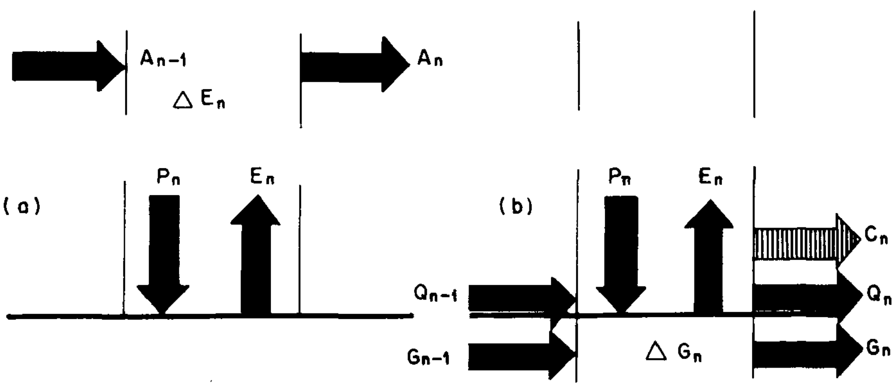


Fig. 4.1. Schematic representation of the atmospheric (a) and terrestrial (b) branch of the water cycle: A - input and output of water vapour, P - precipitation, E - evapotranspiration, Q - surface water discharge, G - groundwater discharge, ΔG, ΔE - storage, C_n - water consumption

Elements of the hydrological balance which represent the deep percolation and storage in flora and fauna can be omitted to simplify the problem. Bearing this in mind, the hydrological balance in the atmospheric branch of the hydrologic cycle can be modelled by the equation

$$A_{n-1} + E_n = A_n + P_n + \Delta E_n$$

$$P_n - E_n = -E_n + A_{n-1} - A_n \qquad (4.3)$$

P_n - vertical and horizontal precipitation in the element n

E_n - evaporation in the element n

ΔE_n - increment in the water vapour content in the atmosphere of the element n

A_{n-1} - water vapour input of the element n

A_n - water vapour output of the element n.

The balance of the lithospheric branch of the hydrologic cycle can be expressed as follows:

$$P_n + Q_{n-1} + G_{n-1} = E_n + Q_n + G_n + \Delta G_n + C_n \tag{4.4}$$

Q_{n-1} - surface water inflow

Q_n - surface water outflow

G_{n-1} - groundwater inflow

G_n - groundwater outflow

ΔG_n - increment or decrement in the groundwater content

C_n - water consumption inside the area in question

Depending on the hydrological conditions, the terms of the equation 4.4 G_{n-1} and G_n, which express the groundwater inflow and outflow, can be omitted because their difference is not important. The water consumption C_n may also often be omitted, being mainly the component of the evaporation E_n. In this way, the equation 4.4 can be simplified to

$$P_n - E_n = Q_n - Q_{n-1} + \Delta G_n \tag{4.5}$$

Analysing a long-term period, the increment in the groundwater storage does not change: In this way

$$E_n = P_n - Q_n + Q_{n-1} \tag{4.6}$$

This equation, expressed for the overall catchment area, can be expressed very simply:

$$E_n = P_n - Q_n \tag{4.7}$$

because in this case $Q_{n-1} = 0$.

The exact average value of the evaporation (and also of the soil moisture) cannot be measured and evaluated directly, because it changes considerably during the day and from place to place. They can therefore be derived from the long-term average values of precipitation and surface flow, which are measured daily and are reliable enough.

The equations of the hydrological balance make it possible, therefore, to check the reliability and accuracy of the characteristic averages of the hydrological parameters.

Connecting the equations 4.3 and 4.5 it follows that

$$-E_n + A_{n-1} - A_n = Q_n - Q_{n-1} + G_n \qquad (4.8)$$

and for a closed catchment area

$$G_n = -E_n + A_{n-1} + A_n - Q_n \qquad (4.9)$$

Bearing in mind the stable water content in the lithosphere and atmosphere over waste areas in the long-term, the direct relation of the long-term averages for a big catchment is

$$Q_n = A_{n-1} - A_n \qquad (4.10)$$

Under these conditions, which are not applicable for short-term data, the soil water increment equals the decrease in the humidity in the atmosphere and vice-versa.

Analysing the above equations, the following conditional conclusions can be derived for large catchments:

(a) As a result of an increase in the outflow from the catchment, the water vapour outcome is decreased, causing a decrease in the probability of precipitation occurrence in the area affected, whose position depends on the direction of the prevailing air mass movement. A decrease in the water outflow causes an increase in the mentioned probability (Eq. 4.10).

(b) As a result of an increase in evaporation in the catchment, the probability of precipitation occurrence in this catchment is increased, as far as the conditions for its condensation have not changed, i.e. the increase in evaporation does not necessarily lead to a decrease in outflow (Eq.4.7).

(c) An increase in outflow decreases the average precipitation of the area in question. A decrease in outflow increases the probability of its occurrence.

Equations of the hydrological balance make it possible to define a lot of similar conditioned relations, but the resulting hydrometeorological situation also depends on the influence of the neighbouring areas.

The factors ΔE - the increment in water vapour in the atmosphere - and ΔG - the increment in the soil and groundwater - act as regulators. The increase in the vapour content of the air leads to its oversaturation. The increase in the water content of reservoirs and soil may have the same result when the supply of energy enables an increase in evaporation.

Changes in the hydrologic cycle do not, therefore, depend on the hydrological balance alone. They are also determined by the basic laws of physics. An analysis of the quantitative influence of man on the hydrologic cycle has to be based on the equations of the relevant hydrological processes and on changes in the relevant entry data (Tab. 4.1).

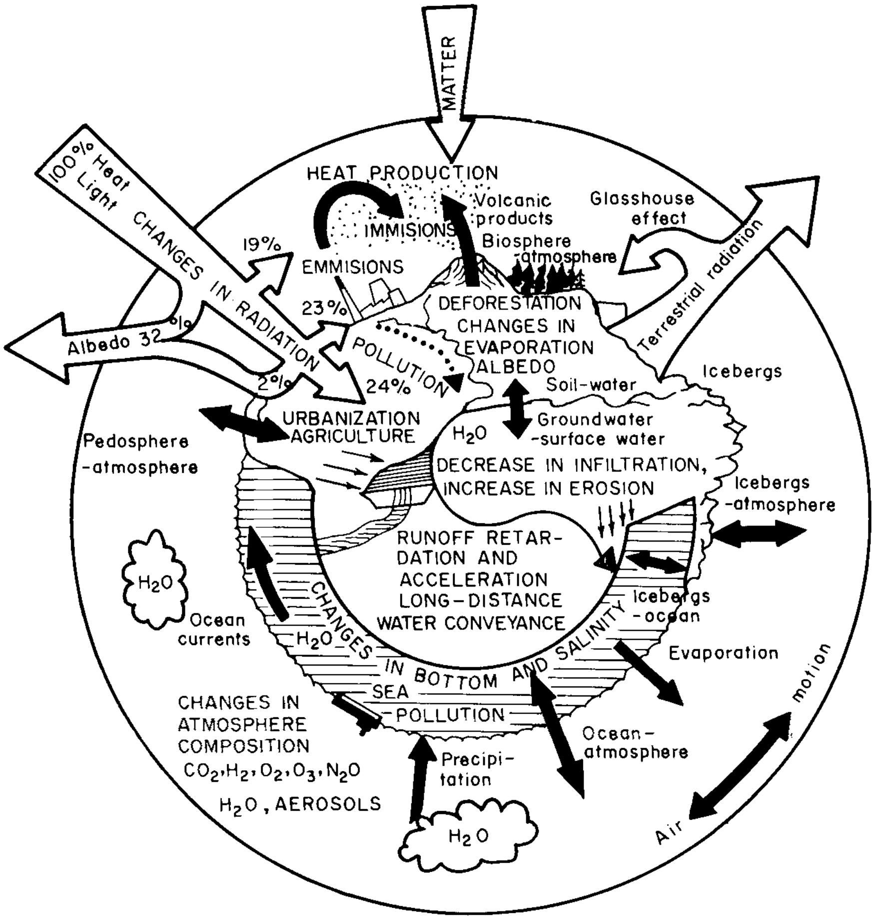


Fig. 4.2. Basic interrelationships of the main processes in the atmospheric, litho (and pedo)spheric and hydrospheric system

The changes which influence the elements of the hydrologic cycle can be categorized into mutually interconnected

(a) changes in the Earth's surface,

(b) changes in the energetic balance,

(c) changes influencing the process of precipitation (Fig.1.2).

The changes in the Earth's surface - as the consequences of clearing, agricultural production, urbanization, industrialization and transport - influence the distribution of the volume of water among the different processes of the hydrologic cycle: interception, depression and detention storage, evaporation, infiltration, groundwater runoff, dispersed and concentrated surface runoff. They also influence their intensity and pace.

The changes in the energy balance as a result of human activities occur within the framework of the natural processes, whose intensity is enormous. In the past there have been fairly regular transitions between warm inter-glacial and glacial years about every 100,000 years. Inter-glacial periods have been relatively shorter, lasting some 10,000 years. The present epoque seems to start in next glacial period. The average global temperature is at present + 14.8°C.

Man's activities increase the energy input into the atmosphere through

(a) the increasing hothouse effect of the atmosphere as a result of the increasing quantity of carbon dioxide in the air and through pollution of the air by other gases and aerosols,

(b) the heat production (Tab. 4.2).

TABLE 4.2

Mankind' influence	Time period	Estimate of the increment	Relevant surface temperature increment °C	Rate of change towards the end of the time period (°C/decade)
Carbon dioxide content of the athmosphere	2000 AD 2050 AD	+ 25% + 100%	+0.5 to 2 +1.5 to 6	0.2 to 0.8 0.3 to 1.2
Adding chlorofluorocarbons to the troposphere	2000 AD 2050 Ad	0.8 ppbv 2.5 ppbv	+0.1 to 0.4 0.25 to 1	0.04 to 0.2 0.02 to 0.1
Nitrous oxide N_2O content of the athmosphere	2050 AD	+ 100%	0.25 to 1	0.02 to 0.1
Direct addition of heat	2100 AD	50-fold increase	0.5 to 2	0.05 to 0.2
Adding aerosols, patterns of land use	?	?	?	?
Total expected changes	2000 AD 2050 AD	-	+ 1.2 + 4.0	+ 0.5 + 0.7

Summary of anthropogenetic influences on the global mean surface temperature according to Kellogg (1977).

The changes in the energy balance are interconnected with air mass movement. They influence not only the evaporation rate, but also the water vapour condensation. During this second process, the latent heat of vaporization/fusion is released . Thus, precipitation is conditioned not only by the presence of condensation nuclei, but also by the transfer of this latent heat to other air masses.

The changes in the energy input also depend on changes on the Earth's surface. Changes in the solar radiation absorbed by the surface have an effect on the heat balance, as well as on the local climate. They are completely heterogeneous, as are their consequences, too, resulting from the influence of other factors.

TABLE 4.3

Land surface	Albedo (%)	Land surface	Albedo (%)
Snow: fresh	85	Forest:	
old	70	deciduous in autumn	33-38
melting	30-65	in spring	16-27
Water (depending on the angle of incidence)	2-78	oak in spring & summer	18
		pine forest	6-19
Soil and rocks:		spruce	14
		fir	10
Chalk and limestone (white)	45	Grassland:	
Granit and similar rocks	12-18	dry	16-30
Siliceous sand(white,yellow)		green	8-27
dry	34-25	Fields:	
wet	29	Cereals(depending on ripeness)	10-25
Clay dry	29-31	ploughed dry	12-20
wet	16	ploughed wet	5-14

Albedo, the coefficient of the reflectance of solar energy according to Lamb (1972).

An increase in the surface moisture and a change in the colour of the earth's surface from bright to dark, for example, causes a decrease in the albedo (Tab. 4.3). Flooding may cause by its water table an increase in the albedo, depending on the angle of dip of the heat rays. Agricultural activities influence the albedo not only through the type of plant, but also through relevant agricultural practices. Thus, man's activities both increase and decrease the value of the albedo. The chain of consequences (Fig.4.4) depends on many local factors, while the resulting consequences may be quite different. In the case of their important influence on the heat balance of the Earth, they may even cause important changes in distant areas.

The third category of changes to affect the hydrologic cycle includes factors which directly influence the process of precipitation, such as:

(a) changes in the soil and air humidity,

(b) a rise in the number of condensation nuclei, resulting in increased precipitation in the direction of the air mass movement from the entry of the pollution,

(c) radioactive elements (Krypton Kr, Tritium Tr, Radon Rn and other products of Uranium U), entering the atmosphere not only as a result of the generation of nuclear power and enriching the nuclear fuel, but also through the incomplete combustion of low-quality coal.

An ionization of the mentioned elements increases the electrical conductivity of the atmosphere, decreasing its electrical charge. Rain can occur under a strong electrical charge of clouds only. The occurrence of radioactive gases in the atmosphere decreases the probability of rain occurrence and its intensity.

The effect of the mentioned factors may also be contradictory: the air pollution aggravates the condensation of the water vapour by increasing its temperature, but simultaneously forms the condensation nuclei which facilitate this process. Owing to these complicated relationships and feedbacks, the course of hydrological processes and the influence of anthropogenetic factors are remarkably stochastic: Different consequences correspond to identical causes, each of them having a different probability of occurrence, depending on the influence of the other elements of the system.

4.3 INFLUENCE OF FORESTRY AND AGRICULTURE

Vegetative canopy as a component of the structure of the hydrologic system influences the availability of water resources and the negative effects of water occurrence. Different types of vegetation, the density and structure of the growth, the topography of the surface, the quality and quantity of the litter, humus and soil layer have a considerable effect on

(a) the short-term retention, whose consequence is a decrease in flood discharges,

(b) the long-term accumulation, whose consequence is a decreased fluctuation in runoff and increased minimum discharges,

(c) the protection of the land surface against erosion,

(d) the water quality.

This effect consists in

(a) decreasing the concentration of the surface runoff and its velocity,

(b) changing the dispersed surface runoff from the natural recharge of precipitation to groundwater runoff,

(c) slackening the pace of the melting of snow,

(d) causing water losses through high evapotranspiration,

(e) catching the horizontal rainfall in mountainous areas.

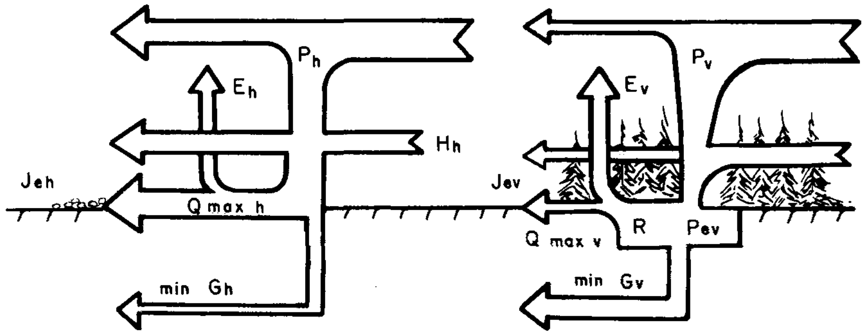


Fig. 4.3. Retention, retardation and anti-erosion effect of the biosphere and its influence on rainfall and evaporation: (a) region with vegetative cover, (b) region without vegetative cover: $P_{ev} < P_h < P_v$; $Q_{maxv} \ll Q_{maxh}$; $E_v > E_h$; $I_{ev} < I_{eh}$; $H_v > H_h$; $\min G_h < \min G_v$.

In this way vegetative canopy influences, in particular, (Fig.4.4)

- flood discharges Q_{max}
- minimum discharges Q_{min}
- total annual runoff Q_a
- the groundwater regime G_g
- the erosion process and its intensity I_e
- the water quality q_{1-n}
- total annual rainfall P_a
- and the rainfall occurrence p

The interrelationship of these entry data of the runoff process and of the rainfall can be expressed by the equation

$$Q_{max}, Q_{min}, Q_a, G_g, I_e, q_{1-n} = P \cdot f_{1-6}(X_c, X_v, X_s, X_m, X_g, X_x) \qquad (4.11)$$

X_c - climatological factor, including the energy input,

X_v - factor of the vegetative canopy, depending on its composition, age and state

X_s - soil factor, depending on the soil type, structure and permeability, characterized by the course of the suction pressure or by the saturation and the coefficient of the hydraulic conductivity,

X_m - morphological factor, including the shape of the slope and its position, but also the location of erosion rills and channels,

X_g - geological factor, including the structure and permeability of the geological formations and their communication with the land surface,

X_x - water management factor, including all other positive and negative influences to arise from human activities, e.g. from the production of heat, land and soil management, mining, thus having an impact on all previous factors.

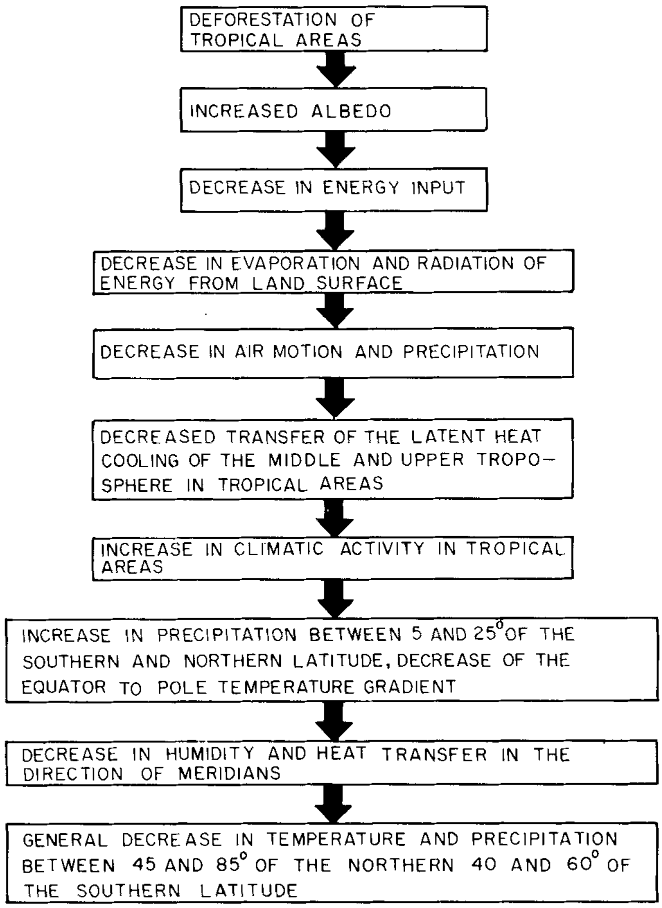


Fig. 4.4. Chain of consequences of deforestation in tropical regions according to Potter et al. (1975).

The intensity of hydrological processes on the boundary of the pedosphere and atmosphere can also be derived from the material and energy balance of the relevant ecosystems. Interception is also important, depending on the composition of the vegetative canopy, its age, density and state and on climatological factors, especially on the rainfall regime. Transpiration, depending on the biomass quantity and also on the characteristics of the vegetative canopy, is far less important.

The influence of the vegetative canopy on the hydrologic cycle can be characterized by simple parameters such as its composition, density, height and volume in the system of the atmosphere and by the density and depth of the root system in the pedosphere. But other interrelated factors, such as pedological, geological and topographical factors, may exceed their importance under specific local conditions of change in the vegetative canopy. Due to these complex interrelationships, changes in the vegetative canopy over vast areas may also provoke global consequences (Fig. 4.5).

4.3.1 Interception, Evapotranspiration and Infiltration

The extent of interception depends very much on the characteristics of the vegetation. The difference between the summer and winter values and their averages depends on the type of precipitation, rainfall and snowfall. In forests at low altitudes interception is an important negative component of the water balance. Under conditions of prevailing evaporation, interception decreases the total runoff. At higher altitudes, when horizontal precipitation from mountain fogs prevails, interception increases the total precipitation: drip and stemflow exceeds the value of evaporation of the intercepted water. (Tab. 4.4).

TABLE 4.4

Precipitation (season)	Interception (%) Young growth	Pole tree	Timber tree	Noble tree
650 mm (summer)	12	20	30	39
550 mm (winter)	10	22	26	32

Rainfall intensity	Spruce	Beech
Low	81.7	71.9
Medium	54.8	24.8
High	24.1	17.7

Increase in average interception with the age of the vegetative canopy according to Delfs (1956) and values of the actual interception in coniferous and deciduous forests (%) according to Eidman (1968).

The actual transpiration of the vegetation depends on the rainfall, the availability of water in the soil, the energy input, and the quantity and function of the biomass. Different species of vegetation, e.g. agricultural products have different water requirements, depending on their structure, especially on the ratio of their underground and surface parts.

The water requirements of wood species do not differ as much. The difference between the water requirements of hardwood and softwood, of quickly and slowly growing local wood species in Central European conditions is reported to be comparatively small, for water requirements depend on the density and development stage of the relevant wood: they increase noticeably with age. Only some exotic species are reported to have low water requirements, but not exotic industrial wood, which is more likely to be planted in these conditions.

The level of evapotranspiration in forests is, under current climatological conditions, higher than that of other types of vegetative canopy, depending not only on the wood species and the variety of different stories of other plants, but also on forestry practices. Actual evapotranspiration from highly productive agricultural land is lower, under the same climatological conditions, than the evapotranspiration of a forest with little wood production. The evapotranspiration ratio of forest and agricultural land depends to a significant extent on the energy input required to evaporate the total yearly rainfall (Fig. 4.5).

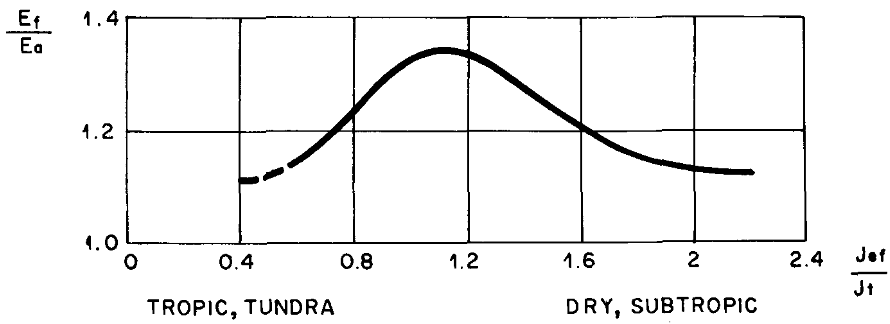


Fig. 4.5. The ratio of evaporation from forests E_f and from fields E_a in relation to the ratio of the energy input J_{ef} and the energy J_t needed to evaporate the total yearly rainfall P according to Budyko (1973).

Two basic theoretical, but contradictory cases of the water management function of soil and vegetative canopy can be distinguished:

(a) The infiltration increases with the growing accumulation capability of the soil and the vegetative canopy,

(b) The infiltration rate decreases with the growing accumulation capacity of the soil and vegetative layer.

In the first case of a simultaneous increase in the infiltration and accumulation capacity, the amount of the evaporated rainfall grows with the increasing accumulation capacity, thereby reducing the surface runoff. In such soils the highest groundwater runoff occurs at medium values of infiltration and accumulation, and runoff for both high and low values of infiltration and accumulation decreases to almost zero. In such soils, given sufficient supply of energy, the high infiltration rate enables almost all soil water to be evaporated. The surface runoff, whose values decrease with the increase in evaporation (Fig. 4.6), is supplemented by the groundwater runoff mainly for medium values of infiltration and accumulation.

In the second case, where the infiltration rate of the soil cover is low, although its accumulation capacity is high, most of the rainfall flows away as

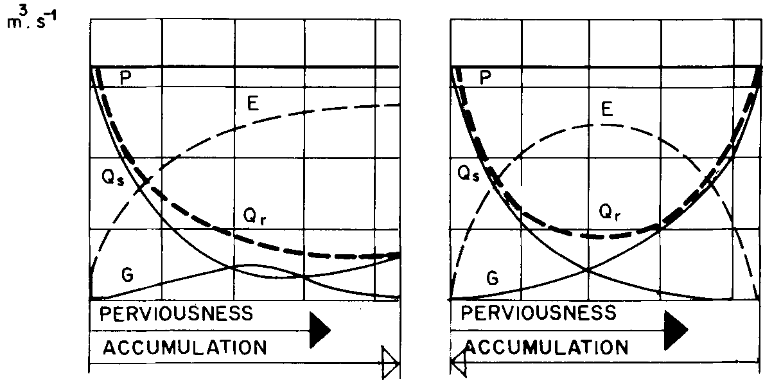


Fig. 4.6. The theoretical impact of perviousness and of the accumulating effect of the soil layer on the distribution of the rainfall P at surface runoff Q_s, groundwater runoff G_g and on the formation of river discharges Q_r and evaporation E according to Lwowitch (1970).

dispersed or concentrated surface runoff. The values of both groundwater runoff and evaporation are low for low infiltration rates. With the growing infiltration rate and simultaneously decreasing accumulation capacity, the dispersed surface runoff decreases and the groundwater runoff increases. Evaporation is low for both high and low values of infiltration: the rainfall changes into surface runoff or percolates into lower geological layers. The highest evaporation values and the lowes values of the concentrated runoff occur at medium values of infiltration and accumulation.

Under conditions of a low infiltration rate of the soil, the surface runoff concentrates without any important influence of the groundwater runoff. Under conditions of a high infiltration rate, the surface runoff concentrates with an important influence of the groundwater: the fluctuation of its values is smaller, provided the accumulation capacity of the soil is sufficient.

The above analysis was based on a theoretical hypothesis of stable physical, chemical and biological properties of the soil layer and the vegetative canopy. In reality, these properties depend on the soil structure and its state, as well as on the development stage of the vegetation and its state. Cultivated agricultural land undergoes comparatively more important and more frequent changes than forest land, which undergoes basic changes during clearing. The changes of the agricultural land are seasonal, depending on the particular cultivation practices.

The infiltration properties of agricultural land are affected especially by ploughing, and depend to a large extent on the duration of the period between ploughing and rainfall. Primitive ploughing loosens the soil till down to a depth of 0.12 m, horse ploughing to 0.16 m, and mechanized ploughing to 0.3 m. Mechanized autumn ploughing slows down the winter runoff, changing a substantial part of the surface runoff into groundwater runoff, simultaneously increasing the volume of the stored rainfall and snowfall. This positive influence can be reduced or distorted by the weight of tractors packing the lower soil layers.

The extent of the influence of mechanized ploughing on the infiltration rate depends not only on the state of aggregation, but also on the climate and the nature of the precipitation.

It appears to be more important in areas with a low total yearly rainfall and a low soil humidity. Concerning the influence of plant species, the continuous cultivation of cereals decreases the infiltration rate to a minimum value. The effect of the cultivation of cereals in rotation is more favourable from this point of view, and the cultivation of fodder crops in rotation most favourable of all.

The infiltration rate of pastures and forests tends, on average, to exceed this property of agricultural or urbanized land. These lands distinguish themselves from the agricultural land by their extensive and dense root system. In forests, not only species of the lower plant stories and the litter layer contribute to this property, but also the favourable biochemical properties of the forest soil, which generally has a good structure and a high humus content.

The infiltration properties of forest land also depend on the plant species and their age, as well as on cultivation and clearing practices. The highest infiltration rate is produced by the soil of mixed forest cultures. This positive property in comparison with agricultural and pasture land is further helped by the less significant effect of freezing, which penetrates into the upmost soil layer only.

4.3.2 Influence of the Vegetative Canopy on Floods and Erosion

The rate of surface runoff depends especially on the topography, the infiltration rate and, to a lesser degree, also on interception losses. On agricultural lands these properties depend on the agricultural practices, especially on the depth and method of ploughing, as well as on the plant species and their development stage. In forests surface runoff is almost imperceptible, even after heavy rains. In spruce and deciduous forests surface runoff may appear under extreme topographical and soil conditions and during heavy rains, when the soil and litter layer is destroyed by improper clearing practices.

The protective effect of the vegetation canopy form of accumulation and retardation. The accumulation effect, or storage of water, is also aided by the root system and the depth of the soil layer. The retardation of the runoff is caused by the change of the surface runoff into groundwater runoff, by the interception of the plants and litter, and by the roughness of the land surface. This effect also decreases the erosion rate and the concentration of the surface runoff. In forests the concentration of surface runoff into rills and channels occurs later than on pastures and agricultural land (Fig. 4.8).

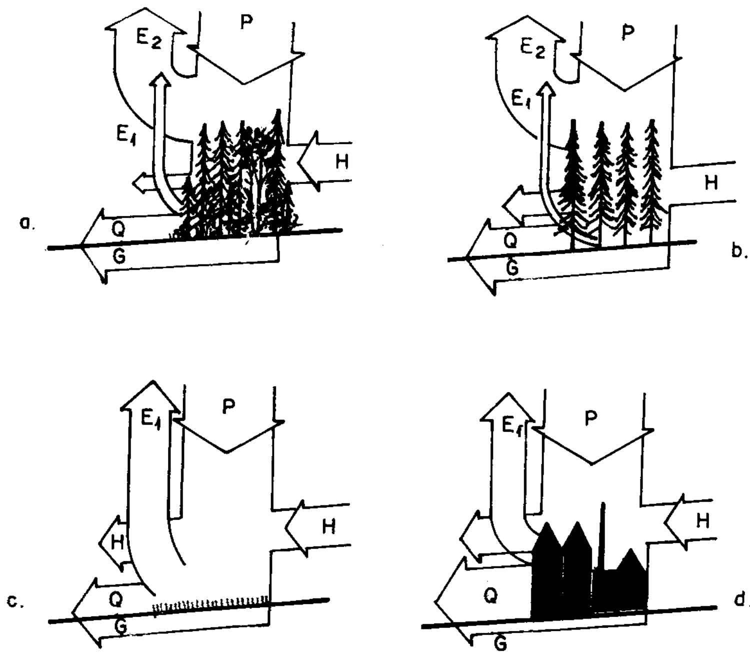


Fig. 4.7. The impact of vegetative canopy on the rainfall-runoff process: (a) multistage forest, (b) single stage forest, (c) grassland and fields, (d)urbanized area. The values of the relevant hydrological phenomena are proportional to the width of relevant arrows:
$P_a = P_b > P_c < P_d$; $E_a > E_b > E_c > E_d$; $Q_{sa} < Q_{sb} < Q_{sc} < Q_{sd}$; $G_a > G_b > G_c > G_d$
$Q_b < Q_a < Q_c < Q_d$; $H_a > H_b \gg H_c > H_d$
P - precipitation, H - vapour condensation, E - evaporation, Q_s - surface runoff, G_g - groundwater runoff, Q - total runoff and maximum discharges.

Accumulation on afforested land occurs to a more significant extent during lower rainfall and runoff than during extreme rainfall and maximum floods. Floods with a one year frequency of occurrence may increase after clearing more than ten times and floods with a hundred year frequency of occurrence several times, in inherent dependence on the size of the catchment, the depth of the soil and its moisture before the rainfall. Forests with shallow soils have no important influence on the decrease in discharges in comparison with deforested areas. The accumulation and retardation effect largely depends on the saturation of the soils, i.e. on the frequency of rain occurrences and on the interval between them. If the accumulation capacity is exceeded, this causes an immediate increase in the surface runoff.

The water management function of forests depends considerably on human activities and especially on forest management. Undisturbed forest cultures are characterized by their important protection effects against floods and erosion. Multi-storey forests cultures transform floods more effectively than cultivated single storey monocultures, and far more efficiently than pastures or cultivated agricultural land (Fig. 4.8).

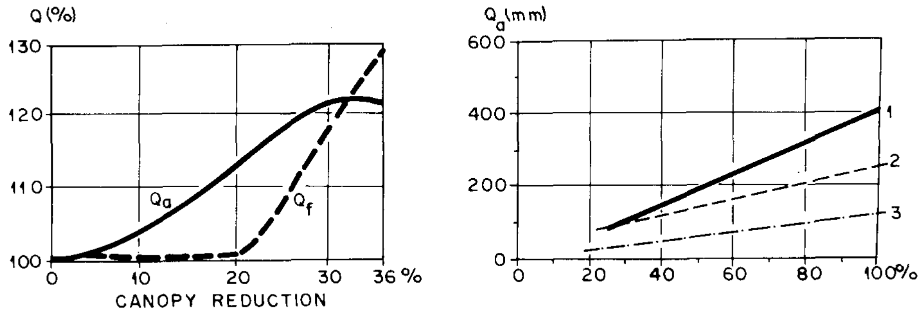


Fig. 4.8. (a) The increase in the total annual surface runoff and in the fluctuation of discharges as a consequence of clearing an afforested catchment according to Zelený, Křeček and Krečmer (1979); p - the decrease in the biomass (%), Q_r - total yearly runoff, Q_f - flood discharges.

(b) The increase in the total annual runoff Q_a as a consequence of clearing according to Bosch and Hewlett (1982): 1 - coniferous, 2 - deciduous, 3 - bush.

Mechanized clearing, the transport of timber and the network of transport communications decrease this positive function. The activities of clearing, harvesting, transport and other machines tend to compact the soil, destroying its structure, which is conducive to infiltration, both in forestry and agriculture. The movement of transport machines, such as for towing logs, form rills, gullies and channels for the concentration of surface runoff, whose increased tractive force accelerates the erosion process.

The direct relationship between the runoff coefficient and soil wash and transport was proved by means of measurement. Murzaev (1977) indicates that the land grading for the mechanized afforestation increases the runoff coefficient of forest land by up to 0.8 (Tab. 4.5).

Vegetative canopy forms an effective protection against erosion for the land surface. The best protection is formed by natural ecosystems. The resistance of cultivated forests without comprehensive anti-erosion measures is relatively smaller, because of their geometrical arrangement, monotonous plant species and human activities during their cultivation. Nevertheless, forests generally form an efficient protection against erosion, if not destroyed by harvesting (Tab. 4.6).

TABLE 4.5

Group	Characteristics	Water managemetn function	Timber production	Purpose
I	Forests of catch ments used for municipal water supply	superior	inferior	Exclude soil erosion, not to restrict runoff, safeguard the water quality
Ia	Forest in zones of sanitary protection of water quality	exceptional	conditioned	
II	Forests in upper catchments	balanced		Balance the runoff fluctuation, protect the land against erosion
III	Local protecting canopy			Soil protection, river bed stabilization, bank protection, sanitary protection of local water resources, transformation of surface water into groundwater runoff
IIIa	Bank canopy	exceptional	conditioned	
IIIb	Canopy protecting local water resources	exceptional	conditioned	
IIIc	Infiltration forest belts	exceptional	conditioned	

Categorization of forest canopy as a function of its water management function according to Krečmer and Běle (1975).

Pastures have similar positive effects, if not destroyed by being overgrazed or trampled down by herds. The resistance of cultivated fields against erosion is substantially lower.

The anti-erosion effects of the vegetative canopy have a favourable effect on the quality of the surface water. Its high infiltration capability similarly influences the groundwater quality. The decreased erosion decreases the volume of eroded material in water, thereby reducing the duration of water turbidity in brooks, creeks and rivers. The content of sediments may increase five to seven times due to deforestation. Also important are other changes in water

TABLE 4.6

Land use	t/ 10^6 km^2/yr	Relative to forest = 1
Forest	8.5	1
Grassland	85	10
Abandoned surface mines	850	100
Cropland	1700	200
Harvested forest	4250	500
Active surface mines	17 000	2000
Construction	17 000	2000

Representative rates of erosion from various land uses according to Canter (1983)

quality after clearing, caused by the decay of organic matter and by the increased leaching of nutriments:

- the increase in the concentration of nitrides e.g. from 1mg/l to 60-80 mg/l (Hubbard Brook - USDA Forest Service 1975)
- the increase in the phenol concentration to 0.6 mg/l (Wyoming, Hart et.al., 1981).
- five to thirty fold increase in the calcium, magnesium and potassium content in the outflow (Sopper, 1975).

The influence of agriculture and silviculture on floods, erosion and water quality can be managed, in particular:

(a) by the selection of suitable plants and woods and by the arrangement of relevant cultures and plots, and of the communication and drainage network, by suitable cultivation practices, namely by ploughing along isohyets and horizontal furrows, by sowing without plouging, by the restriction of land cultivation, by a rational crop rotation, by cultivation in strips, by infiltration strips arranged along water courses, by the protective cultivation of grass, by wind belts, infiltration and overshadowing of forest belts, cultivation of rills, by terraces, dikes, channels and by protecting the destructed land surface to limit erosion,

(b) by measures which limit the compacting of the soil surface and improve the soil quality and humus content so as to increase the rate and the degree of exploitation of mineral fertilizers,

(c) by the cultivation of resistent forest cultures, which remain stable in winds and difficult snow and ice conditions, by preffering selective and partial clearing, and by the immediate recultivation of clearings in vast areas.

4.3.3 Influence of the Vegetative Canopy on Rainfall and Runoff

The roughness of the forest cover, higher in comparison with deforested areas, has an important influence on the precepitation process. It decreases the rate of motion of the lowest layer of the atmosphere and causes turbulence of the air, thus improving the conditions for the condensation of the water vapour. This influence has been proved not only theoretically, but also statistically, however for extremely vast forest areas only. Kalinin (1968) mentions that the influence of large pine forests increases the level of precipitation by about 20% in the summer season and by some 8-10% in winter. The impact of deciduous and mixed forests can be estimated at about one half of the above values. The influence of spruce forests is higher, assessed at a roughly 30% increase in precipitation in the summer season in comparison with deforested areas. This positive influence on rainfal cannot be considered in areas with scattered, relatively small forests.

In addition to this, forests increase horizontal precipitation, depending on the altitude and distance from the sea. Fojt and Krečmer (1976) estimated, for central European conditions and mountanuous humid areas, the influence of forests as having a supplement of almost 400 mm to the values of vertical rainfall in comparison with deforested areas. Karpov (1962) estimated the value of annual horizontal precipitation by a 13% increase in the yearly total rainfall (Fig. 4.7).

The influence of forests on air motion has a remarkable effect on snowfall distribution. Snow accumulates in forests to the detriment of deforested plots. Boughton (1970) mentions the following fundamental points:

(a) Snow accumulates mainly in small openings in forests, especially at lower altitudes. The optimum size of opening for snow accumulation is about one to ten times the height of the surrounding forest cover. Large openings do not have such a positive influence because of the wind effect.

(b) The effect of forests on snowfall is more a redistribution of the snow, rather than any overall increase in precipitation. It appears as a positive supplement to the water balance in small catchments only.

(c) The redistribution of snow into deeper falls over smaller areas attenuates the runoff from the melting of the snow, thus decreasing the spring peak discharges.

Forests with intermittent deforested plots have a favourable effect on extending the duration of the snow melt. The decreased rate of melting contributes to the good accumulation and retardation function of forests, manifestated by a more stable regime of groundwater, springs and surface water.

The runoff from afforested areas is greatly influenced by the high evapotranspiration of ecosystems, generally exceeding the contribution of the increased precipitation. The increase in the total yearly runoff from aforested areas in comparison with areas without forest has been statistically determined only for extremely large catchments with moderate evapotranspiration as a consequence of higher vertical and horizontal precipitation.

In the case of small afforested areas a lower yearly runoff has been statistically documented in comparison with areas of the same size and character, but without forests, as a consequence of higher evapotranspiration. Mc Arthur and Cheney (1965) have measured an increase in the total yearly runoff of between 43 and 235 % of the hypothetical runoff of the afforested catchment after a forest fire. Higher values have been measured in the first years after a conflagration.

The values of the increase in the total yearly runoff due to deforestation depend not only on the percentage of the reduction in the forest cover and its type (coniferous, deciduous, bush), but also on the total annual precipitation and its state of aggregation (Fig. 4.9).

The impact of the silvicultural activities on the runoff coefficient c depends on the following groups of factors

$$c = \varphi_s (L , S_1 , S_2 , B_1 , B_2 , P) \qquad (4.12)$$

L - stable local factors, especially the drainage area shape and slope i, soil depth and type s and geology g,

S_1 - silvicultural practices and conservation services, namely the stand density, type and density of forest roads, movement and type of transport mechanisms,

S_2 - ratio and type of deforested plots, extending the duration of snow melting,

B_1 - type of culture, its root system and the amount of biomass,

B_2 - the ratio of middle-aged tree classes, which have the highest interception and transpiration losses,

P - the state of aggregation of the precipitation and its coincidence with the season and saturation periods.

The decrease in ratio on the area surface by 30% in dependence on other conditions causes an increase in flood discharges of six times or even more. The fact that rain forests are being destroyed by man at the rate of about 11×10^6 ha every year appears also as a warning in this connection.

But under conditions of an intensive forest exploitation and forest management, the ratio of afforested areas is not the only decisive factor of the water regime. This depends substantially on the depth of the soil, the age, species and condition of the forest, and on cultivation practices (Tab. 4.7). Fully afforested areas may have an insufficient influence to balance the water regime as a consequence of wrong forestry practices which concentrate the runoff.

To increase the total yearly runoff from afforested areas where spruce is the main wood, without increasing the flood discharges, Perina and Krecmer (1973)

TABLE 4.7

Class	Years	Clearing period 100 years decreased forest density: Area (%)	Biomass concentration	Annual water consumption ($m^3.ha^{-1}$)	Clearing period 120 years full forest density: Area (%)	Biomass concentration factor	Annual water consumption ($m^3.ha^{-1}$)
I.	0-20	20	1.0	360	10	1.0	180
II.	20-40	20	0.8	520	20	1.0	560
III.	40-60	20	0.8	730	20	1.0	800
IV.	60-80	20	0.8	670	20	1.0	720
V.	80-100	20	0.9	560	20	1.0	600
VI.	100-120	0	0.0	0	10	1.0	260
Total annual consumption		100	-	2840	100	-	3300

The impact of forest density (biomass concentration measured in t per hectare and compared with theoretical values of full density according to Schwabach (1890) on total annual runoff. Pine forest in area with total annual rainfall 1200 mm.

recommend the following biotechnical measures:

(a) The cultivation of forests with a low stand density in areas with low horizontal precipitation in order to decrease the interception losses.

(b) To increase the ratio of younger tree classes and the ratio of clearing (opening) surfaces, and to limit the ratio of the middle-aged tree classes, which have highest interception and transpiration losses, i.e. to shorten or to extend the period of clearing in areas with low horizontal precipitation.

(c) The change of tree species in areas with low horizontal precipitation, i.e. to replace species with high interception and transpiration losses with species which have low interception and transpiration, to substitute deciduous trees for spruces.

(d) A considerable increase in the ratio of the old spruce forests in areas with high horizontal precipitation and high stand density, and a decrease in the ratio of the youngest growth and clearings destined for afforestation.

(e) The deforestation of suitable areas in accordance with the planned extension of the cultivated land, pastures, towns, industry and recreation development.

The runoff coefficient on agricultural lands depends on the cultivated species, their root system: deep, shallow, intermittent, surface etc., their stage of

TABLE 4.8

Month	4	5	6	7	8	9	10
Grassland	6	13	37	11	12	16	16
Winter rye	2	4	17	25	8	0	0
Spring wheat and barley	0	3	10	24	16	0	0
Potatoes	0	0	2	9	26	30	14

The impact of field crops on water accumulation in soil (%) according to Bulavko (1971).

growth and on the course of the growth depending on the soil thickness and type, the agricultural practices and the state of aggregation of precipitation. Measurements on agricultural soils document a considerable loss of water accumulation in comparison with grassland, whose value depends on the season (Tab. 4.8). The change of pastures with a deep root system into agricultural fields may result in a 30% increase in the total yearly runoff, when the rainfall occurs mainly in the vegetation period. Also important are agricultural practices: crop rotation, weed removal, the depth and period of ploughing, agricultural conservation services. Lwowitch (1968) shows that deep ploughing can decrease the yearly runoff depending also on the rainfal distribution by some 25 to 75%. Nevertheless compacting of the deeper soil layers by heavy tractors and other agricultural machinery increases the surface runoff.

The intensification of agricultural production, resulting in an increased yield:

- is either accompanied by a growing evapotranspiration, enabled by an increased infiltration rate and higher moisture content in the root zone due to agricultural practices loosening the soil layer, thus limiting the interflow and decreasing the recharge of the groundwater, which results in a decrease in the total annual runoff and a decrease in low discharges in water courses,
- or caused by better utilization of water by plants.

In this second case, the change (increase or even decrease) of the evapotranspiration is less important, because the infiltration rate enables an adequate recharge of groundwater and hence has no significant impact on the total annual runoff.

The impact of agricultural activities on the runoff coefficient depends on four groups of factors

$$c = f_a (L, A, B, P) \quad (4.13)$$

c - runoff coefficient

L - stable local factors, especially the drainage area shape and slope i, soil depth and type d, geology g,

A - agricultural practices and conservation services, e.g. contour or other method of ploughing, its depth and period,

B - plant species, the depth and type of their root system, the intensity of cultivation, e.g. the yield-biomass ratio,

P - the precipitation aggregation, occurrence, intensity, duration and coincidence with plant growth, soil processing and saturation periods etc.

TABLE 4.9

Area	Decrease in total annual runoff
Steppe (cultivated land)	66 - 74
Fields and forests	40 - 66
Southern edge of forests	20 - 40

The decrease in total annual runoff as a result of deep ploughing of fields, expressed as a percentage of original values, according to Lwowitch (1965).

The selection of the plant species and variety also depends on agricultural practices and on the possibility of conservation services, which have a basic impact on the runoff coefficient.

An evaluation of the influence of the vegetative canopy on runoff leads to the following conclusions:

(a) The consumption of water by plantations, forests and other plant communities depends mainly on the amount available in the soil.

(b) Plant communities of the same ecological order use approximately equal volumes of water. Fast-growing tree species do not use more water than slow-growing ones.

(c) The decrease in the volume of the biomass increases the total yearly runoff in the same way as the change of deep-rooted species into shallow-rooted ones.

(d) The afforestation of grassland or cultivated land decreases both surface runoff and infiltration into the groundwater.

(e) The changes of the water regime as a consequence of the forest and agricultural practices are heterogeneous and depend on soil, geomorphological and climatological conditions.

The vegetative canopy also has a significant influence on the altitude of the groundwater table. A developed forest can cause it to drop to some ten meters below the land surface. Clearing and thinning results in a rise in the groundwater table, depending on the geomorphological, hydrogeological, climatological and soil conditions. The deep root system of the forest cover takes off the water from the lower soil layers. After clearing a forest the groundwater table may rise over the land surface. Such a rise, in the case of low water quality or if the water rises through salty layers, affects the quality of the soil, increasing its salinity.

4.4 INFLUENCE OF URBANIZATION AND INDUSTRIALIZATION

Urbanization and industrialization influence all the factors in the equation (4.10), determining peak discharges Q_{max}, total runoff Q, minimum discharges Q_{min}, erosion intensity I_e, groundwater regime G, water quality q and the total rainfall P i.e. climatological factors X_c, the factor of the vegetative canopy X_v, soil factor X_s, morphological factor X_m, geological factor X_g, and the water management factor X_x.

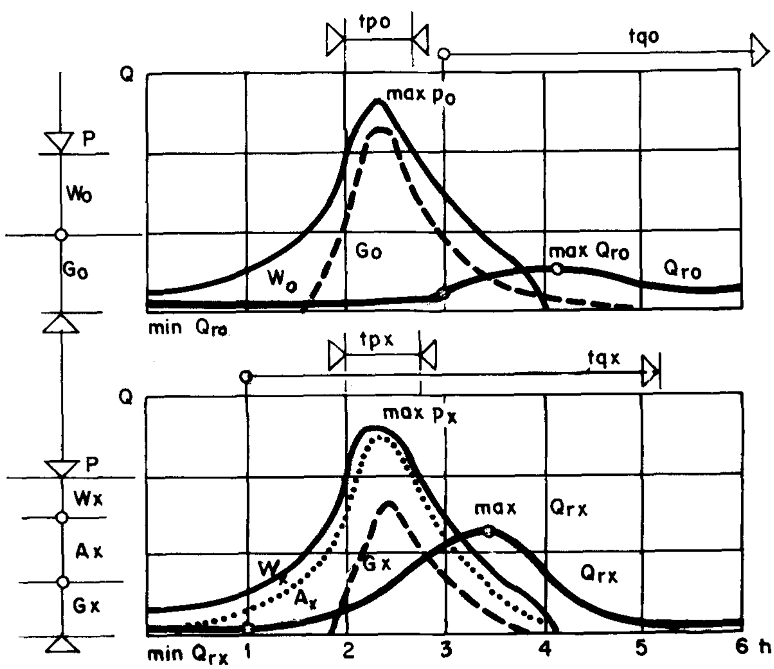


Fig. 4.9. The increase in flood discharges as a consequence of urbanization: P - rainfall curve, Q - river discharge, W - detention storage and water accumulation in the soil layer, G - groundwater accumulation, A - accumulation in the sewerage network. $P = W_o + G_o = W_x + A_x + G_x$. $maxP_x \doteq maxP_o$; $t_{px} > t_{po}$; $minQ_x < minQ_o$; $G_x < G_o$; $t_{qx} < t_{qo}$; $q_{10} \cdots q_{no} < q_{1x} \cdots q_{nx}$ (pollution).

The basic hydrological consequences of urbanization and industrialization are as follows:

(a) a rise in water requirements, whose total may exceed the capacity of the water resources of the area in question, necessitating the diversion of water from upstream sources or from external river basins (Fig. 4.11)

(b) a decrease in infiltration on account of the built-up areas

(c) a fall in the groundwater table and a decrease in the natural groundwater outflow

(d) a concentration of and acceleration in the surface runoff as a result of the change in the natural system of drainage, and a concentration of flow in the sewerage system

(e) a rise in peak discharges, and an increase in the yearly total of surface runoff

(f) a rise in erosion on land stripped by construction activities (Tab.4.6)

(g) increased pollution of streams, also caused by waste disposal, which exceeds the capacity of the natural self-purification processes and causes a steady increase in groundwater pollution

(h) a decrease in the natural flow capacity of river beds due to the urbanization of the flood plain and increased sediment transport, thus exacerbating flood damage

(i) a decrease in evapotranspiration owing to the restriction of bare soil and vegetation-covered surfaces by built-up areas, and an increase in evaporation due to industrial production

(j) heat production and a rise in temperature in the urbanized area

(k) change of the albedo, owing to the change of the quality of the landscape surface

(l) an increased probability of rainfall occurrence as a result of the increased number of condensation nuclei, owing to the air pollution

(m) a change in ecosystems as a consequence of the previous changes.

The increase in surface runoff results not only from the decrease in infiltration, especially through the reduced surface permeability of the built-up, communication and other surfaces, but also from the decline in surface roughness. This is caused by the replacement of the original vegetative canopy by the smooth materials of buildings and communication lines. The topography of the area in question also undergoes drastic changes, simplifying the complicated conditions of the original unconcentrated flow by more straight and short ways. The rise in slope increases the velocity of the overland flow and leads to a higher concentration of runoff. Land grading and the increase in velocity reduce the detention storage.

The underground storage has been reduced by the decline in the infiltration rate. Because the surface and underground storage are drastically decreased, this results in an increase in the frequency of flood occurrence and an increase in the values of relevant peak discharges. In such a way, even rainfalls occurring during dry periods may cause high peak discharges and not sufficiently supplement the groundwater storage.

Urbanization and industrialization increase the total yearly runoff, proportionally with the unpermeability of the land surface and with the concentration of the outflow by the sewerage system. According to Costin and Dooge (1972), peak discharges increase five to ten times with a corresponding reduction in their duration, depending on the frequency of their occurrence. The runoff coefficient also rises three to four times. The average increase in the total runoff (5-15%) is thus comparatively lower than the rise in peak discharges (Fig. (4.7).

The development of changes in the hydrologic cycle depends on the expansion of the urbanized area, and on its development phase, interconnected with the agricultural development of the adjoining region (Tab. 4.10).

Urbanization and industrialization greatly influence the water regime as well as the values of low discharges. The reduced infiltration leads to a fall in the groundwater table and to a decrease in the volume of the groundwater reserve, occasionally causing terrain settlements. Low discharges in river courses are decreased by water withdrawals and by the reduced water recharge from groundwater resources.

Building and the resultant overshadowing of plots decreases the air motion and hence the evaporation rate. Concerning the total yearly evapotranspiration, it may be either decreased, in areas with low evaporation losses, or increased, especially in industrial areas by evaporation from cooling systems and in tropical and subtropical regions by intensive irrigation of municipal parks and gardens.

The development of vast industrialized and urbanized areas also affects the total yearly rainfall. Costin and Dooge (1973) estimate its increase at some 10%. This rise is a consequence of the higher intensity of air mass motion above the covered area, its increased temperature, caused especially by heat production, air pollution and sometimes by the increased evaporation, especially from industrial production processes. The increase in the total yearly rainfall has been proven statistically, but not the rise of maximum values of precipitation. The increase in the frequency of storm occurrence has also been recorded. The increased rainfall contributes to the frequency of flood occurrence and their duration.

The most threatening effect of urbanization and industrialization is the production of heat energy, which is increasing by some 5% yearly on a global scale. This advancement means an increment of 500% in 35 years. In the year 2000 many huge areas with a surface of some 10^3 to 10^5 sq. km will emerge, where their own artificial heat production will exceed the acceptance of solar energy.

TABLE 4.10

Changes in land or water use	Hydrological effect
Clearing, removal of vegetation	Decrease in transpiration, increase in evaporation. Increase in overland flow, flood frequency and peak floods. Increased soil erosion and sedimentation of streams. Raised groundwater table. Change in albedo.
Ploughing	Change in soil structure. Increased infiltration and evaporation. Escape of carbon dioxide.
Large-scale production, mechanization	Liquidation of small streams and dry beds, increase in overland flow and erosion rate, increase in sedimentation of streams, environmental pollution.
Irrigation	Stream clogging. Rise in groundwater table. Increase in in evapotranspiration rate. Cooling of soil surface and air air temperature. Change in albedo. Change in soil structure and quality (increased salinity).
Drainage	Drop in groundwater table. Decrease in evapotranspiration warming of area, change in albedo. Increased infiltration. Change of soil structure and quality (decrease in salinity). Impact on the quality of the surface water.
Well erection	Decrease in groundwater table.
Sewage disposal	Local increase in soil moisture. Increasing pollution of wells and streams.
Mass construction: Land grading and excavations	Increased erosion and sedimentation of streams. Liquidation of small streams - flooding of land during high rainfall.
Communication and stom drainage system construction	Decrease in infiltration rate, drop in groundwater table and land surface. Increase in surface runoff and flood occurrence. Lower base flow. Increased pollution of streams. Change in albedo.
Construction of the mass water supply and distribution system	Increased water wastage. Rise of the groundwater table around wells of the previous local water supply, lowered water table in location of the mass water withdrawal. Decrease in runoff at point of withdrawal and downstream. Problems of waste water disposal

TABLE 4.10 (Cont'd)

Changes in land or water use	Hydrological effect
Construction of sewage system	Land drainage, decrease in groundwater recharge. Increased pollution of streams, especially during low discharges and when system also used for the disposal of industrial waste water. Degradation of water for downstream users, loss of aquatic life.
Waste water treatment plant construction	Decrease in pollution of streams, improvement of water quality downstream, improved conditions for aquatic life.
Late urban stage	Boom in water requirements. Decrease in water quality.
Long-distance water transfer	Increased runoff in affected streams. Increased evaporation from the catchment.
Deep large capacity wells	Overdraft results in land subsidence.

Checklist of impact of urbanization activities and of interconnected land and water use on the hydrologic scale and water availabilities.

This will lead to an unproportional increase in the temperature over these scattered areas and also influence the global climate. The rise in temperature in the atmosphere will increase evaporation from the oceans; thus the hydrologic cycle will be more intense. There will be weakened equator-to-pole temperature gradient, so the general atmospheric circulation will be less vigorous, resulting in more precipitation in the region of the present subtropical deserts.

The greatest change may occur in polar regions. The arctic Ocean ice pack, presently highly reflecting, can, after pollution of its surface, absorb more solar energy. It may happen that the warming effect described above might remove this ice pack completely. The relatively fresh water from its melting has a lower density than normal sea water. Wave action and water currents can mix it with sea water, decreasing the probability that this water will freeze again. This will lead to a further intensification of evaporation and precipitation.

Concerning the relatively larger ice sheets of the Antarctic and Greenland, any small change in their immense volume would affect the mean sea level. Their melting has been one of the reasons for the rise in mean sea level of about 0.2 m from the beginning of this century. A complete melting would increase the

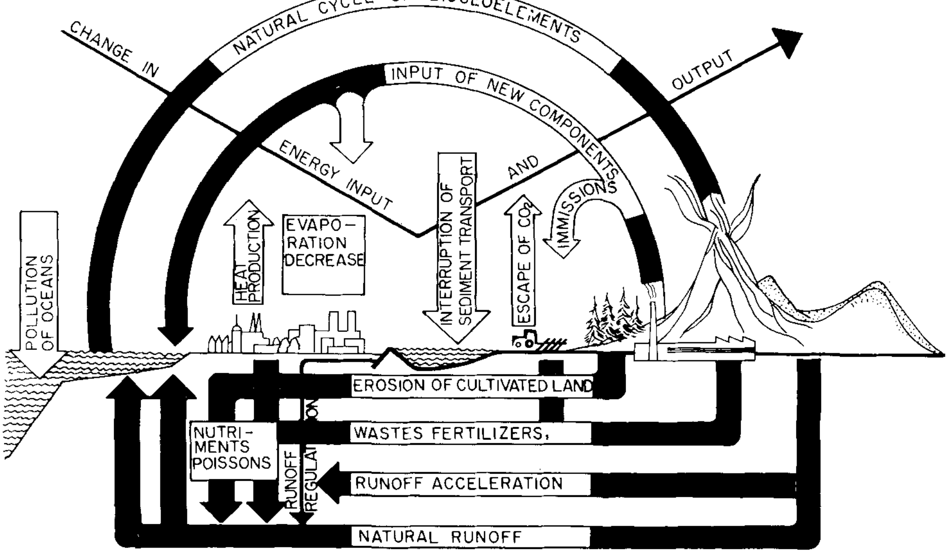


Fig. 4.10. Schematic representation of the impact of human activities on erosion, water quality and selected hydrological processes.

mean sea level by about 70 m. But such an event would appear to be very unlikely during the next 10 to 100 thousand years. The rise in the average global temperature may not even decrease their volume because of the increased rain and snowfall, which will supplement their ice pack.

The changes in the energy balance are likely to increase the temperature in polar regions by about + 10°C in the year 2050, also extending the local vegetation period: at the latitude of 50° by about 15 days, at 70° by about some 30 days on average, depending on precipitation occurrence.

4.5 CHANGES IN WATER QUALITY

The physical, chemical and biological characteristics of water are formed not only during its penetration through the atmosphere, soil and rock environment, but also during its contact with the vegetative canopy. Forests and other cultures therefore have an important effect on the bacteriological and chemical quality of water, and on its turbidity. This quality also depends on the plant species, the composition of ecosystems, the stage of growth and season; also important are the impact of pollen and the changes caused by harvesting, ploughing etc. Changes in the ecosystem of the vegetative canopy, i.e. changes in the plant species or cultivation practices, result in a change of water quality.

Waters from afforested areas are generally of good quality,which also depends on the heterogeneity of the ecosystems: the replacement of forest polycultures by monocultures leads to an increase in acidity. But in areas with high rainfall decaying vegetation causes water contamination, depleting the dissolved oxygen and increasing the acidity etc., especially in tropical and subtropical conditions of high temperatures. Water from afforested catchments can also become bacteriologically contaminated by wildlife, and particularly by birds.

The pollution of water resources is a consequence of

- natural processes: erosion, volcanic activities and biological processes,

and by human activities, especially by

- increasing erosion owing to deforestation, wrong cultivation practices and urbanization,
- washing of agrochemicals from agricultural and silvicultural production (fertilizers and pesticided),
- accidents during the transport of fuel and other chemicals,
- disposal of gaseous, liquid and solid wastes from industry, thermal and nuclear power generation, agriculture, dwelling areas etc.
- subsequent leaching of wastes deposited on the surface, under the ground or in water,
- infiltration of polluted water from or to groundwater resources etc.

The ratio of these processes to the total water pollution depends on the natural conditions, the development stage and relevant practices. Erosion forms the prevailing part (90% or even more) of pollution in countries with traditional intensive agriculture. The washing of agrochemicals may contribute by more than 50% to the total pollution of surface and groundwater resources, even in highly industrialized countries. Municipal pollution, due to its partly organic origin, is less harmful than the pollution from industry and the stocking of chemicals. Hazardous accidents during the transportation and stocking of fuel and other chemicals can be particularly dangerous, owing to their quantities or chemical properties, as well as accidents in nuclear power plants.

The term pollution refers to undesirable changes in the physical, chemical and biological properties of air, surface water, groundwater and the natural environment which prejudice the living conditions of human beings and desirable biological species and imperil these conditions in future, as well as lead to a deterioration in natural resources and negatively affect production processes, aesthetic or cultural values and endanger them in future.

The atmosphere and the quality of precipitation has been polluted by carbon dioxide CO_2, nitrous oxide N_2O, sulphur dioxide SO_2, other gases, sulphates, chlorofluoromethanes and aerosols produced by industry, thermic power generation, transport, space heating, slash-and-burn and other agricultural practices etc. Within the framework of the hydrologic cycle pollution passes from air to water and from one element of the environment to another.

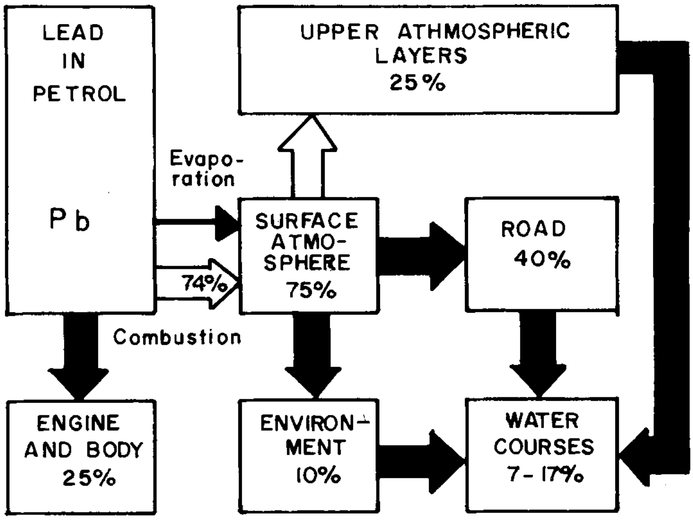


Fig. 4.11. Penetration of lead Pb, produced by combustion engines used in public transport, into the hydrologic cycle accorddng to Fishbein (1976).

Pollutants can be categorized as:

(a) harmless matter, which can easily be removed from water through filtration and other self-purification processes,

(b) toxic matter and matter causing sensorial (organoleptic) problems for organisms (Fig. 4.11).

(c) matter influencing the oxygen demand of water,

(d) anorganic pollutants, dissolved or insoluble, increasing the salinity of water.

Toxic matter can cause problems or breakdowns in the various biological functions of an organism and its diverse organs (e.g. cancerogens), as well as further physiological and psychical and evolutional changes (mutagens and teratogens) depending on the concentration and accepted quantity of this matter, the influence of other matter and on the age and health stage of the organism. These problems may occur not only shortly after the contact, but also in the long term over a period exceeding even 40 years (Fig. 4.12).

Research into the impact of different kinds of toxic matter and, especially their synergetic effect, is still in an early stage. This effect can therefore be neither qualitatively nor quantitatively established. The problem is very complicated, especially because of the varying resistance of the same organisms under similar conditions, because of the effect of other factors, and because of

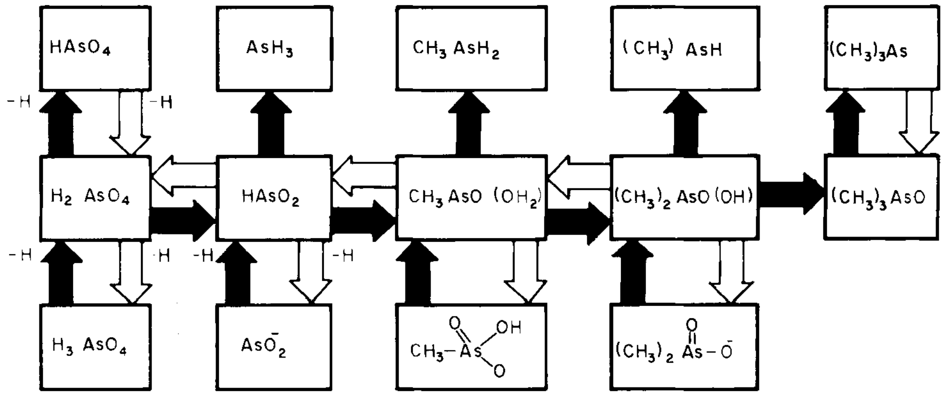


Fig. 4.12. Changes in arsenate compounds during the course of the hydrologic cycle.

the changes in these matters during their passage through the environment.

Some chemicals are chemically stable and pass through various biological and physical processes without change (e.g. DDT - Fig. 4.13), endangering especially higher organisms by their accumulation, i.e. remaining in their organs in a substantially concentrated form in comparison with their concentrations in lower elements in the biological chain.

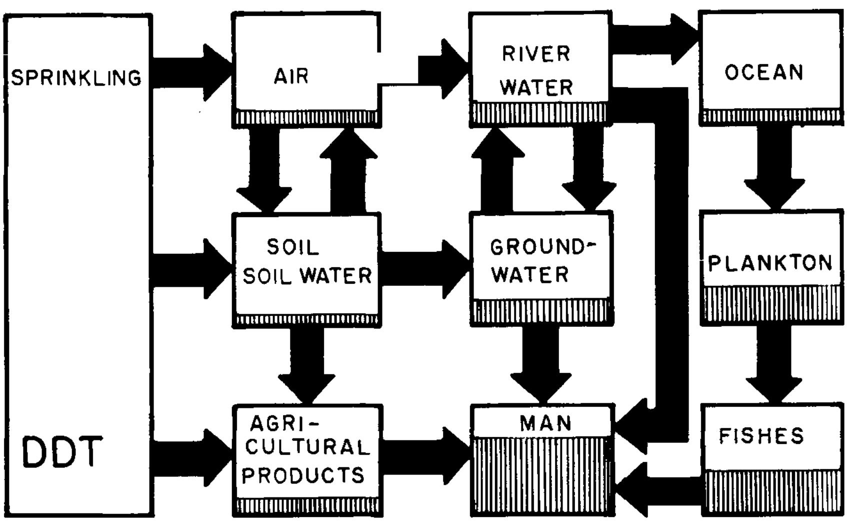


Fig. 4.13. Penetration of the insecticide DDT into the hydrologic cycle and its accumulation in higher organized organic matter according to Woodwell (1965). Concentration is hatched.

The harmfulness or harmlessness of relevant pollutants depend on many factors such as their mutual effect, their duration, the prevailing health standards, individual resistance etc. The general level of knowledge about these factors is still unsatisfactory. It is e.g. presumed that 50 to 90% of the cases of cancer are a consequence of the synergetic influence of cancerogens.

The highest concentration of the matter supposed to have an undesirable effect is the sanitary admissible concentration. These concentrations can be distinguished for

(a) indirectly harmful consequences,
(b) sensorial (organoleptic) consequences,
(c) toxic consequences.

TABLE 4.11

Categories of waste water	Comments
1. Intensively acid or intensively alkaline	Contain acids or bases in high concentrations.
2. With high degree of mineralization	Not sufficiently suitable for further utilization in industry or agriculture.
3. With high content of suspended matter	Produce secondary pollution by its biological decay. Injurious for fishes.
4. With matter influencing the oxygen input	Tenzids, oil products, grease etc.
5. With high content of biologically degradable matter or matter consuming oxygen chemically	Domestic sewage. The change of aerobic processes to anaerobic ones. The lack of oxygen causes perishing of fishes.
6. With matter influencing the sensorial properties	Chlorphenols, oil products, solvents etc.
7. With toxic matter	Heavy metals, pesticides, nitrogenic and radioactive matter.
8. With pathogenic germs	Water from sanitary services, tanneries etc.
9. With predominant nitrogen and phosphorus compounds	Fertilizers, detergents. Eutrophic influence.
10. Warm waters	Decrease in oxygen content, increase in metabolism of water fauna and its oxygen requirements, resulting in a decrease in the self-purification capacity, providing the aeration is not predominant.

Categories of waste water depending on the predominant type of pollution according to Pitter (1972).

Waste waters can be categorized on the basis of their main components, which also characterize their prevailing harmful effects (Tab. 4.11). Pollution directly caused by waste disposal is primary pollution. If it does not exterminate all organic life, a development of some undesirable organisms, namely detruents, occurs. The mass decay of these organisms causes secondary pollution.

Human activities draw new, mostly harmful components into natural cycles and thus influence the natural circulation rate of the main biogeoelements. In such a way the volume of the nitrogen circulation is increased, especially by

(a) gazeous emissions and aerosols from burning and other chemical processes,

(b) liquid wastes from industrial estates,

(c) the use of nitrate fertilizers, accelerating the biological production of nitrous oxide.

Nitrides are quickly soluble and therefore mobile, i.e. it is difficult to keep them in the soil and very easy to wash them away. Losses by washing reach some 20 - 40% on average. Only ammonia salts can be bound in the soil, but they are not stable, changing into nitrides in soil.

A direct relation exists, therefore, between the content of nitrogen in surface waters and in the intensity of fertilizing. A substantial part of such contamination comes from the groundwater, polluted by percolation nitrides from fertilized fields.

Five hundred million tons of nitrous oxide N_2O enters the atmosphere annually, mainly by biological decay and denitrification processes taking place in soils and oceans. Human activities presently account for some 10% of this figure. The rate of the denitrification process by soil organisms depends on the soil's acidity. The ratio of N_2 to N_2O produced by soil bacteria increases from 0.05 to 0.2 in acid soil. The rate of nitrogen and nitrous oxide production depends, therefore, on the production of sulphur dioxide and sulphates, i.e. the interrelationships of the biogeoelements' circulation are complex.

Human activities also change the unbalanced circulation of phosphorus, namely by means of the waste water disposal and by fertilizer wash from agricultural areas. The compounds of phosphorus are difficult to dissolve. They are fixed as ferrum phosphates in acid soils and as calcium phosphates in alkaline soils. Nevertheless, especially through the long-term application of phosphates on light or organic soils with a low absorption capacity, they escape and pollute the groundwater.

The increase in the carbon oxide CO and carbon dioxide CO_2 concentration results mainly from

(a) agricultural production processes, especially as a consequence of ploughing,

(b) the continued rise in the burning of fossil fuels.

Six billion tons of carbon oxide enters the atmosphere per annum through in-

TABLF 4.12

Potential impact (diseases)	
Pulmonary	Beryllium Be, Cadmium Cd, Chromium Cr, Selenium Se, Manganese Mn
Liver	Selenium Se, Nickel Ni, carbon chloride CCl_4, chlorinated phenols
Kidney	Lithium Li, Lead Pb, Stroncium Sr, Selenium Se, Nickel Ni, Cadmium Cd - especially cadmium sulphate $CdSO_4$, ethylenglycol
Nervous system	Mercury Hg, Stroncium Sr, Manganese Mn, Lead Pb, Calcium Ca, Cadmium Cd
Metaheamoglobin-anemia	nitrites and nitrates
Fluorisis	Fluorides
Canceerogens	tar, asphalt and combustion gases, Chromium Cr, Nickel Ni, Beryllium Be, nitrides and nitrates, nitrosamins, polychlorinated biphenyles, petroleum, triazin, polyuretan, polyvinylchloride, benzene, polynuclear aromatic hydrocarbons, chlorophorm, bromophorm, asbest, pesticides endrine, dieldrine, chlordane, endring, DDT etc.)

Selected toxic matter, occuring especially in waste water and their possible impact on human health.

complete combustion in conditions of a restricted access of oxygen - the share of combustion engines in transport is more than 75%.

The carbon dioxide in the atmosphere has risen from 0.028% in 1860 to the present 0.033% and may double by the next mid-century. Its content in the atmosphere increases especially as a result of the change of afforested areas into agricultural land. According to Wilson (1975) the percentage of the carbon dioxide in the atmosphere has risen by about 10% in the period 1860-90 by ploughing vast areas in America, South Africa, Australia and Eastern Europe. The burning of fossil fuels increases this content by about 0.0001% yearly , but the combustion of all fuels available would increase this figure almost twenty times.

Obvious additions to the atmosphere, produced by a combination of burning and the photochemical reactions in the presence of ultraviolet radiation, are aerosols, a combination of soot particles, sulphur dioxide SO_2, sulphates and unburned hydrocarbons. An important influence is had here by sulphur dioxide SO_2 and sulphur trioxide SO_3, which occure especially as a product of low quality fuel burning. The natural vulcanic production of sulphur dioxide is some 140 mil. tons yearly, while power generation, space heating and other human activities add some 50% more to this figure.

Air pollution influences water circulation in an important way, because

(a) carbon dioxide, chlorofluoromethanes, nitrous oxide and other infrared absorbing gases absorb terrestrial infrared radiation in several infrared bands, thereby warming the Earth's surface,

(b) aerosol particles over a dark surface such as oceans increase the net albedo, but lower the albedo over the land, although their overall influence is not known yet,

(c) aerosols produced by burning and industry act as good condensation and freezing nuclei, thus increasing the probability of rainfall occurrence.

The pollution from the air enters the soil and water especially through

(a) washing-out of gases and aerosols from the atmosphere by rainfall,

(b) absorption of gases by the soil, vegetation and water,

(c) settling of solid particles on the vegetation and soil and in the water.

One of the obvious results is an increase in the acidity of rainfall and surface waters including natural lakes. The course of air pollution is uneven, and that of the air motion too, so the acidity of rainfall at one place fluctuates in time. But the overall result on the surface water quality is a rise in its acidity, caused namely by

(a) the inflow of acid rainfall,

(b) the leaching of acid geological layers,

(c) the inflow of acid waste waters,

(d) the supply of salts from the sea water through the atmosphere.

The increased acidity of surface water causes changes in the relevant ecosystems, manifested first by a reduction in their diversity. The decrease of the pH factor below 5.5 is also critical for most fish species, decreasing the overall biological activity and changing the nutrition chains. A similar influence occurs on soils. But the rise in the soil acidity is often artificially neutralized by liming in order to increase yield.

On the whole, the effects of pollution are remarkably negative (Tab. 4.11). The relevant interrelationships are complex, and not yet fully quantified. The result of anthropogenetic influences on the climate , environmental quality and the hydrologic cycle, also influencing living conditions and human life, cannot yet be sufficiently quantified.

4.6 ENVIRONMENTAL IMPACTS OF WATER DEVELOPMENT PROJECTS

The exploitation of water resources is inevitably accompanied by a disturbance of the natural balance. The extent of the influence of these projects on the environment depends on the extent of the changes in the water regime in the area concerned (Tab. 4.13).

TABLE 4.13

Environmental factors (external)		System factors (internal)		
Stable	Variable	Stable	Variable	
			abiotic	biotic
climate geographical position altitude morphology geology soil factors natural water quality	weather discharges ice phenomena human activities	project size purpose operation	hydrological meteorological microclimato- logical other physical chemical progress of the project	ecosystems social systems

Categorization of basic factors which determine the impact of water development on the environemnt and on human society.

The identification of environmental impacts should be an early activity in the planning porcess. Environmental studies are needed to restrict undesirable effects and identify appropriate mitigation measures. An assessment of the environmental impacts requires

- a general knowledge of the impacts of similar water development projects under similar geomorphological and climatological conditions,
- a systematic approach based on the use of checklists, intersection matrices and networks,
- a quantitative approach based on mass balance and environmental dilution calculations,
- the use of mathematical models for multiple environmental factors,
- case studies and pilot projects.

The purposes of constructing water development projects can be classified as

(a) regulating - provision of water for different purposes and safeguarding of its supply, also in periods of low natural discharges and high water requirements, by accumulating water in surface and underground reservoirs during periods of surplus, or by its conveyance.

(b) control - reduction of high discharges and high water tables, runoff retardation, soil conservation, reduction of erosion, control of silt load in streams by conservation storage, river training, water conveyance etc.

(c) distribution and drainage - water supply for municipal, industrial and agricultural use, sewage collection and removal etc.

(d) quality control - pollution abatement, improvement of water quality, prevention of contamination for the protection of the environment and of public health.

(e) beneficial use of land/water space - urbanization, improvement of agricultural and industrial production, transport including inland navigation, water power utilization, recreational use of water and aesthetic enjoyment.

Currently water development projects are planned for several purposes (Tab. 4.14). The sum of all the benefits of a multi-purpose project exceeds the maximum benefit of any one individual function, but the value of any one of its functions is seldom the maximum one. Some of its functions may even be contradictory (Tab. 4.15). These contradictions may occur after the construction of reservoirs, for example because they affect an extensive area and their effects differ

(a) in the space of the reservoir and its environment (Tab. 4.16),

(b) along the water course downstream of the dam (Tab. 4.20),

(c) along the headrace or tailrace (Tab. 4.21),

(d) in the area under supply (Tab. 4.17).

TABLE 4.14

	Water supply	Hydropower generation	Navigation	Flood Control	Water quality control	Environmental and aesthetic aspects	Recreation	Fish breeding
Water supply	-	1,2	2	1,2	0	2	2,3	2,3
Hydropower generation	1,2	-	2	1,2	2	2	2	2
Navigation	2	2	-	0	3	3	0	0
Flood control	1,2	1,2	0	-	2	0	3	0
Water quality control	0	2	3	2	-	0	3	3
Environmental and aesthetic aspects	2	2	3	0	0	-	0	0
Recreation	2,3	2	0	3	3	0	-	3
Fish breeding	2,3	2	0	0	3	0	3	-

0 - no or non-important variance
1 - variance in reservoir volume requirements
2 - variance in reservoir operation requirements
3 - variance in water quality requirements

Matrix of variances for basic purposes of reservoir construction and operation.

TABLE 4.15

	Water supply	Hydropower generation	Navigation	Urbanization	Decrease in flood losses	Water table regulation	Landscape formation	Soil erosion	Agriculture	Recreation	Fishery	Environmental protection	Protection of monuments	Number of positive impacts	Number of negative impacts
Reservoirs in populated areas	1	1	1	2	1	3	2	0	2	1	1	0	3	6	3
Reservoir in abandoned areas	1	1	1	1	1	3	0	0	2	1	1	2	0	7	2
Flood control dikes	0	0	0	1	1	0	3	0	1	0	0	0	1	4	0
River training	0	3	3	1	1	2	2	0	1	2	2	2	3	3	5
Bank stabilization	0	0	0	1	1	0	0	1	1	0	0	0	1	5	0
Water ways	0	3	1	1	1	0	2	0	2	2	2	2	3	3	5
Irrigation projects															
Irrigation	0	0	0	1	0	2	2	1	1	2	0	2	0	3	4
Drainage	0	0	0	1	1	3	1	0	1	0	0	3	0	4	0
Fishponds	1	0	0	1	3	3	1	0	3	1	1	3	3	5	0
Sanitary eng. projects															
Waterworks	1	0	0	1	0	2	0	0	0	0	0	0	0	2	1
Sewarage	0	0	0	1	0	2^+	0	1	0	0	0	0	0	2	1
Groundwater development	1	0	0	1	0	0	3	0	3	0	0	3	0	2	0
Water recycling	1	0	0	1	0	1	0	0	0	0	0	0	0	3	0
Water management measures	0	0	0	3	1	1	1	1	2	1	0	1	0	6	1
Afforestation	0	0	0	3	1	1	1	1	2	1	0	1	0	6	1
Managed agriculture	0	0	0	1	0	0	1	1	1	2	0	2	0	4	2

Divergencies in the impact of selected water projects and measures: 0 - no or unimportant influence, 1 - positive impact 2 - negative impact, 3 - depends on local conditions, + with a waste water treatment plant

4.6.1 Effects of Reservoirs and Irrigation Systems on Climate

The flooding of an area after putting a reservoir into operation changes the character of the landscape. A uniform, compact water table takes the place of diverse surfaces of different character. In such a way the reservoir affects all the natural processes which took place within its area of influence.

The original evapotranspiration of ecosystems and the evaporation from bare soils are replaced by the increased evaporation from the free water surface, whose share was originally far less important. This process is thus released from a dependence on soil, hydrogeological and physiological factors.

TABLE 4.16

Impact of reservoirs on their surroundings				
Flooded land	Flora and Fauna	Water quality	Microclimate	Dwelling value
Rise in water table, increased fluctuation	Change in aquatic life	Abrasion	Rise in air humidity	New scenery
Loss of agricultural and forest land	Development of plankton organisms	Sedimentation	Equalizing temperature differences	Improvement of living and recreational conditions
Flooded mineral resources	New predominant fish species	Production of new organic matter	Increased wind velocity	Increase in insect density
Rise in ground water table and increase in infiltration	Change in coastal vegetation	Temperature changes	Change of albedo, energy input and radiation	Increase in population density and in pollution
Increased probability of earthquake occurrence	Change in wildlife species including fowl	Mineralization, zones of different water quality	Decrease in local rainfall	Flooding of landmarks and monuments

Checklist of the probable impact of reservoir construction and operation of the surroundings.

The rise in altitude of the surface at which evaporation occurs, its less protected position and its smoothness all accelerate this process and affect the air flow. The increased input of solar energy, i.e. the change of the albedo and the increase in the water temperature, may also contribute to the rise in the evaporation rate. The simplification of surface characteristics, the decrease in evapotranspiration, the increase in air humidity change reversely the conditions which influence the run of this process.

Depending on meteorological and other conditions, the evaporation from the free water surface mostly exceeds the evapotranspiration from afforested or cultivated soils. Both evaporation and evapotranspiration from the adjoining shore areas increase, due to the raised groundwater table being sufficiently supplied by the impounded water table of the reservoir. A similar increase in evapotranspiration is recorded along irrigation canals.

The increase in evaporation also influences the water quality, causing non-productive water losses and raising the concentration of suspended and dissolved matter. This fact is extremely important in arid and semi-arid areas because of the extremely high evaporation rate there. The fall in water quality occurs as a consequence of high evaporation, especially in shallow reservoirs. It may result in a drop of water quality below the limits of utilization for the required purpose, or limit the economic feasibility of the relevant project.

The increase in the mean evaporation from an area affected by the construction of a reservoir can be estimated on the basis of the following equation:

$$E \cdot A = EW \cdot A_w + ET \cdot (A - A_w) \quad (m^3) \qquad (4.14)$$

$$E = r \cdot EW + ET \cdot (1-r) \quad (m)$$

$$E = ET + r \cdot (EW - ET) \quad (m) \qquad (4.15)$$

A – area surface (m^2)

A_w – water table surface (m^2)

E – total mean evaporation

ET – mean evapotranspiration from the soil surface (m)

EW – mean evaporation from free water surface (m)

$r = \frac{A_w}{A}$ – the ratio of the water table surface A_w and the area surface A

Leaving aside the change of the precipitation total and the change of mean evaporation, the decrease in the total yearly runoff from a catchment resulting from the increased evaporation reaches

$$\Delta Q_a = d \cdot (EW - ET) \cdot A \quad (m^3) \qquad (4.16)$$

$d = r_1 - r_o$ – the difference between the ratio of the water surface and the surface of the catchment after (r_1) and before (r_o) the construction of the reservoir

The decrease in the total yearly runoff due to the impact of the construction of an irrigation network can be estimated in a similar way, in accordance with equations 4.14 and 4.16. In this case

TABLE 4.17

Impact of irrigation (drainage)				
Soil profile	Chemical impact	Biological impact	Hydrological impact	Microclimate
Rise in the (drop in the) groundwater table	Change in acidity or alkalinity of soil	Increase (decrease) in the root depth	Increase in runoff	Change in the albedo (in both cases)
Wetting (aeration) of the soil profile	Increase (decrease) in the salination rate	Increase (decrease) in respiration of roots	Increase in (suppression of) evaporation	Increase (decrease) in the air humidity
Change in the soil temperature	(Escape of nutriments, especially nitrogen)	Plant diseases provoked by higher humidity	Decrease (increase) in infiltration	Cooling (warming)
Change in the soil structure		Change in the plant species (in both cases), weed occurrence		Decrease in the daily fluctuation of temperature
		Increase in (suppression of) insect occurrence		

Checklist of the probable impact of irrigation and drainage (in brackets) on the water cycle and the environment.

ET_o - mean evapotranspiration from the dry-farmed and other non-irrigated land (m)

ET_i - mean evapotranspiration from irrigated land (m)

$r_i = \frac{A_i}{A}$ - the ratio of the irrigated land A_i and the total area surface A

$r_o = 0$ and therefore

$$\Delta Q_{ai} = r_i \cdot (ET_i - ET_o) \cdot A \quad (m^3) \qquad (4.17)$$

The increased yield after irrigation is often achieved less by the growth in the overall evapotranspiration rate, but rather by the different and more efficient evaporation distribution: by its increase in the period of plant growth and by its decrease out of the vegetation season, i.e. by the increase in efficient and decrease in inefficient evaporation. This phenomenon has been confirmed statistically by long-term measurements, e.g. the water table of the Aral Sea did not change in the period 1910-60, in spite of the extension of the irrigated area from 2 to 4 mill. ha in the catchment of its tributaries. From this point of view an appropriate cropping pattern, correct irrigation timing and appropriate economic irrigation practices are also important. In the step-by-step development of irrigation,therefore, two stages can be distinguished

- stage of evaporation redistribution, not affecting the total annual runoff to a significant extent,
- stage of increased total evaporation, decreasing the total annual runoff.

The increase in the extent of free water surfaces in the catchment owing to the construction of reservoirs often results in a reduction in precipitation. This decrease in precipitation is a consequence of lower temperatures above the water surface in the summer season in comparison with the original temperatures above the non-wetted soil surface. The decrease in the total yearly runoff may, therefore, be higher than the value established according to equation (4.16).

An inversion often occurs above an open water surface: the air temperature does not fall with increasing altitude, but rises. This inversion causes a vertical air motion, decreasing the ratio of its saturation - and hence the probability of rainfall occurrence, too. This probability is also reduced by the reduced roughness of the reservoir surface in comparison with the roughness of the original land surface. The decrease in the total rainfall has been recorded statistically, but only in the case of extremely big reservoir surfaces.

This also signifies a decrease in the water exchange in the total annual runoff of affected water courses, especially in the case of big carry-over storages, which has an important impact on water quality. This effect of the operation of big carry-over storages has already been recorded on a global scale.

The construction and consequent operation of reservoirs and irrigation networks also influences the values of other meteorological phenomena, in comparison with the original state without any reservoir or irrigation. The heat capacity of water is four to five times higher than that of air or soil and rocks, and the latent heat of solidification and evaporation is also comparatively high. Water bodies act, therefore, as a cooler part of the environment during a rapid increase in air temperature, e.g. in spring and during the morning hours. During a fast fall in air temperatures, e.g. in the evening or in autumn, they function as a warmer part of the environment. Likewise, they warm the adjoining air layer during cool summer nights. The heat of the water body limits the fluctuation of the temperature of the surface air layer, also influencing the thermic zonation of the air on the reservoir shore.

This influence can be measured especially in deep valleys, and has a different impact depending on the radiation situation. During radiation back to space, which occurs particularly during bright nights, the lowest temperatures in a valley without a reservoir are at the foot of the slope, when calm. Lower minimum nightly temperatures also occur in this zone. In the middle part of the slope a warmer zone with higher values of minimum nightly temperatures appears. At the top of the slope, the temperature decreases again (Fig. 4.14 a,b).

In a valley with a reservoir the night temperature decreases upwards to the top of the slope. The difference between day and night temperatures in a valley with a reservoir is higher at the top of the slope, but at its foot in a valley without a reservoir. In a valley with a reservoir, a more intensive wind motion occurs, because warmer air above the water table is replaced by cooler strata which descend from the top of the slope.

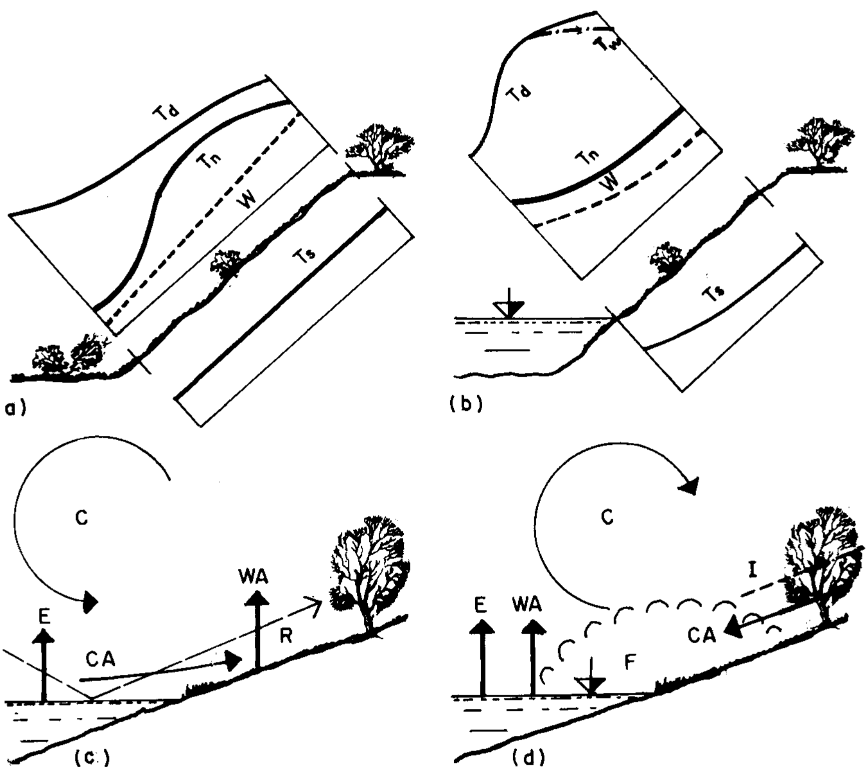


Fig. 4.14. The course of air temperatures (daily) T_d, nightly T_n) the temperature of the soil surface T_s and of air humidity W in a valley (a) before and (b) after the construction of a reservoir during radiation situation according to Malý (1979). Air motion above the reservoir shore during calm; (c) clear day, (d) clear night. The occurrence of the inversion I and fog F: R - reflected radiation, CA - cool air, WA - warm air, C - air circulation, E - evaporation.

On a bright day, the highest temperatures occur at the foot of the slope in a valley without a reservoir and decrease upwards to the top of the slope. In a valley with a reservoir, the heat capacity of the water body reduces the morning temperatures. Their decrease to the top of the slope is measurable when windy (T_w), and negligible when calm (T_d).

The air flow depends on the changes of temperature. The lower roughness of the reservoir surface promotes horizontal air movement. The influence of big reservoirs therefore changes the shape of the relevant wind rose, increasing the occurrence of strong winds from the reservoir to the shore, namely along its longest dimension. The wind rose is extended in this direction.

The air movement is more marked in shallow valleys, while in deep valleys this only applies in the case of a coincidence in the direction of the valley and the prevailing strong winds. During calm and during radiation back to space in the spring season in daytime, the warmed air rises above the reservoir's shores, being replaced by the cooler air coming from the expanse of the reservoir itself. This cooler air is replaced by the still cooler air from the upper layer of the atmosphere (Fig. 4.14 c).

The air humidity depends on the evaporation rate. In a flat area an influence of some 10 - 15% of the relative humidity reaches to a distance of some 100 m in the direction of the wind, even in the case of relatively small reservoirs. The highest air humidity is at the reservoir surface, and this decreases towards the top of the slope in deep valleys. The course of the air humidity in valleys without reservoirs is the reverse: its values are about 3% lower at the foot of the slope than at its top.

The high air humidity at the water table and the occurrence of the inversion layer result in fog formation where the cool air flows in, thus increasing the frequency of fog occurrence in valleys with reservoirs - or large headrace, tailrace and diversion canals, especially during periods without winds (Fig. 4.14 d).

The degree of influence of a reservoir on the local climate therefore depends on the frequency of wind occurrence and on its intensity. The change of the microclimate also depends on the change of the solar radiation input and on its reflectance, derived from the change of the area surface. Different species of the vegetative canopy are replaced by the uniform water table, whose reflectance depends on the angle of incidence.

Changes of the absorption and reflectance of solar radiation, together with changes of temperature and humidity, also influence the ecosystems on the shore in question. The energy input increases, producing favourable effects on the relevant canopy, as long as the limits of its heat tolerance are not exceeded.

The extent of the measurable effect of reservoir operation on climatological factors depends on the local conditions. It is a compensating effect, occurring more noticeably in areas with a rough climate than in areas with a mild climate.

The distance of reach of the climatological influence of reservoirs and irrigation networks depends on their size: It does not exceed a few hundred meters in the case of small reservoirs. Big reservoirs influence the climate within a reach of some 1 to 3 km from their shores. The biggest reservoirs in the world, according to Avakyan et al. (1977), can under extraordinary meteorological conditions occasionally influence the climate up to a distance of 30 to 60 km, their average effect generally occurring within a reach of 10 to 15 km. The change of mesoclimate and sanitary hazards caused waterlogging, wrong irrigation practices etc. are more important, because of inhabitants living inside the affected area.

4.6.2 Effect of Reservoirs and Dams on Sediment Transport

Dams, diversion dams and weirs inhibit and disrupt bed-load, suspended and wash load transport. They also change the course of the erosion process both downstream and, within the reach of their swelling effect, upstream. The process of sedimentation in reservoirs occurs as a consequence of the decrease of the velocity and kinetic energy of flow in the estuaries of tributaries running into the reservoir. The increasing depth and extension of the cross section results in a reduction in the sediment transport capacity of the flow. The difference in the original q_o and the resulting transport capacity, q_r, must be deposited, or

$$\Delta q_r = (q_o - q_r) \qquad (m^3) \qquad (4.18)$$

Δq_r – the difference in the transport capacities, deposited within the reach (m^3)

This deposition process takes place by affecting the coarse particles of the sediment mixture and those particles with the highest unit mass first, the finest ones with a low unit mass last. This leads to segregation of sediments of different size and density.

The gravel, the boulders and partially also the sand which move as bed load form deltas, sometimes referred to as backwater deposits, at a relatively short distance from the estuary. Deltas extend to the point where the maximum water level intercepts the original river bed. Borland (1971), after investigating the depositional pattern of delta formation, concluded:

- the topset slope approximates one half of the original slope,
- the foreset slope is 6.5 times the topset slope,
- the topset and foreset slopes meet at the normal or mean pool where the reservoir is operated most of the time.

Seasonal drawdown causes the formation of multi-deltas.

Suspended load, mostly sand and other anorganic and organic particles, wash load, i.e. silt, clay, agrochemical particles and colloids, which move predominantly in suspension and have the kinetic energy of the flowing water, become more and more affected by gravitational forces with the decreasing velocity of flow.

Finer material forms the bottom sediments, spreading throughout the reservoir. The average thickenss of the deposition h_{di} per unit time of deposition t_d was specified as:

$$h_{di} = \frac{\Delta q_{ri} \cdot t_d}{A_i} \qquad (m) \qquad (4.19)$$

A_i - area between the successive sections, corresponding to the difference in transport capacities Δq_{ri}.

The finest particles of silt, clay, colloids etc. (often flocculated) are also affected by the dynamic viscosity of water and, therefore, sink to the bottom very slowly. They have a tendency to form density currents, which have been found to move towards the spillways, turbines and outlets.

In addition to this, thixotrop gel often forms the mass which acts as a solid when a force is not applied but will flow when a force is applied. Floating debris rest in the zone where the tracting forces are in equilibrium with the resistance of wind. (Fig. 4.18)

The grain size, its unit mass and shape are the basic factors which influence its mobility and determine whether particles will settle or not. The water density in the reservoir is heterogeneous, also depending on temperature. The relevant particles sink until they reach a water layer with the corresponding density or right down to the bottom. Depending on the density, stratification and flow velocity, some particles which are not able to float in the upper layers of the reservoirs, cannot settle near the bottom.

The theoretical distance of deposition L_s for a particle with a settling velocity w, derived for a stable depth and width

$$L_s = H \frac{v}{w} \qquad (m) \qquad (4.20)$$

w - vertical sedimentation rate, depending on the unit mass, size and shape of the particle s (see eq. 2.15) $(m.s^{-1})$

v - flow rate $(m \cdot s^{-1})$

H - depth of the reservoir in a given place (m)

For a reservoir with varying depth and width the distance is

$$L_s = \frac{1}{w} \cdot f(L) \qquad (m) \qquad (4.21)$$

because both the depth and the flow rate are functions of the distance of the entry of the sediment particle into the reservoir.

When the flow rate increases, e.g. in the period of the decrease in water table in a reservoir or during floods, particles of the same size settle at greater distances, destroying in this way the homogeneity of the grain-size distribution, which is also influenced by the surf. Only those particles cross the dam profile which happen to be in the reach of the kinetic effect of the outlets, off-takes and spillways (Fig. 4.18)

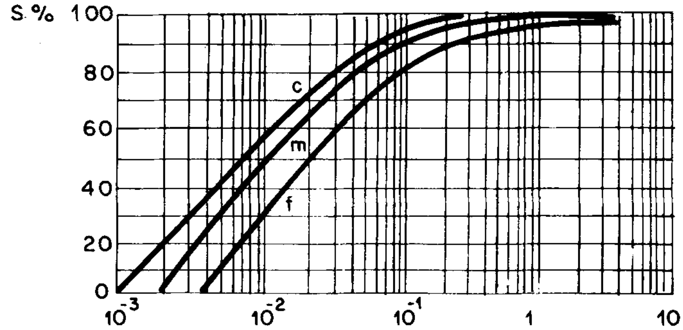


Fig. 4.15. Trap efficiency curve according to Brune (1979): s - sediment trapped as a percentage, r - ratio of reservoir capacity to mean annual flow, v - envelope curves; c - coarse sediment, f - fine sediments, m - medium curve.

The deposition of transported bed-load, suspended load and wash load in reservoirs results in the storage loss. Trap efficiency, the ability of a reservoir to trap and/or retain the sediment which enters it, can be expressed as a percentage of the total load. (Fig. 4.15). For very large reservoirs, the trap efficiency is almost 100 per cent, because only very fine sediments can pass the barrage. To determine the sediment deposit volume Rooseboom (1975) recommends the expression

$$V_t = V_{50} \cdot 0.376 \cdot \ln \frac{t}{3.5} \qquad (m^3) \qquad (4.22)$$

for $t > 8$ years.

V_t - the average sediment volume after t years

V_{50} - the arbitrary estimated sediment volume after 50 years.

The reservoir operation also influences the density, i.e. the average unit mass of deposits. The average unit mass for a deposit over a period of t years is given by Pemberton (1980)

$$\gamma_t = \gamma_i + 0.43 \cdot K \cdot \left[\frac{t}{t-1} \cdot \ln t - 1\right] \qquad (kg/m^3) \qquad (4.23)$$

γ_i - initial unit mass (kg/m^3)

γ_t	- resulting unit mass over a period of t years	(kg/m^3)
K	- Lane-Koelzer factor (Table 4.18)	
t	- period	(years)

TABLE 4.18

Type of reservoir operation	Initial mass, W_i			Lane-Koelzer factor K		
	clay	silt	sand	clay	silt	sand
Sediment submerged	416	1120	1550	256	91	0
Moderate to considerable drawdown	561	1140	1550	135	29	
Normally empty	641	1150	1550			
Rivered sediments	961	1170	1550			

Initial unit mass, W_i and K factors ($kg.m^3$) according to Lane and Koelzer (1975).

Formulas for the estimation of the trap efficiency of reservoirs often have an exponential form, considering that, in the final stage, the arrangement of the reservoir and the flow rate do not allow further sediment deposition. According to Gontcharow (1960)

$$V_t = V_o \cdot \left[1 - (1 \frac{V_y}{V_o}) \; t \right] \qquad (m^3) \qquad (4.24)$$

V_t	- the decrease in reservoir volume through sediment deposit during T years	(m^3)
V_o	- original volume	(m^3)
V_y	- mean annual sediment deposit volume in the reservoir	(m^3 per year)
t	- period	(years)

The mean annual sediment deposit V_y in a reservoir is simply

$$V_y = \frac{S \cdot B_{sw}}{\gamma_s} + \frac{B_b}{\gamma_b} \qquad (m^3/year) \qquad (4.25)$$

B_{sw}	- medium total annual transport of the suspended and wash load	(t per year)
S	- coefficient of the trap efficiency	
B_b	- medium total transport of the bed load	(t per year)

γ_s - unit mass of the suspended and wash load ($\sim 0.7\ t.m^{-3}$)

γ_b - unit mass of the bed load ($\sim 1.7\ t.m^{-3}$)

The medium total annual transport B_{sw} of the suspended and wash load from a catchment can be derived on the basis of the main catchment characteristics

$$B_{sw} = s_s \cdot A_c \cdot s_e \cdot i_e = 31536 \cdot c_a \cdot Q_a \qquad \text{(t/year)} \quad (4.26)$$

A_c - catchment area (m^2)

i_e - annual erosion rate in the catchment area ($t.km^{-2}/year$)

c_a - average content of suspended and wash load in the discharge ($t.m^{-3}$)

Q_a - mean annual discharge ($m^3 . s^{-1}$)

s_e - share of the eroded matter forming the suspended and wash load (< 1)

s_s - share of the suspended load that has not settle in the mediate river stretch (< 1)

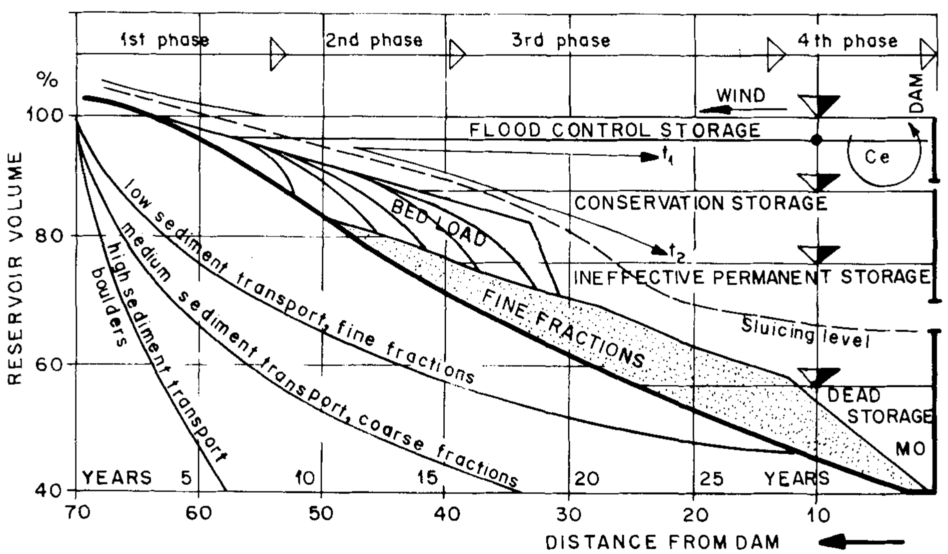


Fig. 4.16 Geographical representation of sediment deposition in reservoirs and the decrease in settling rate. Sediments are built up to an elevation depending on sluicing level, but channel is maintained through these. MO - monolimnion, c_e - circulation in epilimnion.

It is very important from the operational point of view that the rate of storage reduction is higher in the initial period of the reservoir's operation and depends on the grain size distribution (Fig.4.15). The bed load and coarse fractions of the suspended load at that time enter the upper parts of the storage only, reducing first the volume of the storage zone reserved for flood control and then, in the second stage, also the conservation storage. Under these circumstances only fine fractions are able to reach the ineffective permanent storage. For rivers with a regular sediment transport the course of the decrease in the total storage may be considered as linear:

$$V_t = V_y \cdot t \qquad (m^3) \qquad (4.27)$$

In the third phase of the storage reduction process, the movement of the bed load reaches the ineffective permanent storage and then the dead storage, decreasing the rate of reduction in the active (flood control and conservation) storage. In the fourth phase, the sediment transport enters the storage and the space of the dynamic influence of the turbines, outlets and spillways, resulting in a further decrease in the rate of diminuation of the reservoir volume (Fig. 4.16).

The rate of storage reduction by sedimentation depends especially on the proper design of a project. Depending on the sediment transport regime and on the requirements on reservoir and dam operation, an optimum desigh, i.e.

- the size of the reservoir and
- a lay-out of the project,

can be selected and realized in such a manner that almost no suspended and wash load is kept back, whilst storing water in the reservoir. In such a way only the transport of the bed-load contributes to the storage reduction. The sediment-laden water of the early flood is passed through low-level openings. This condition requires a relatively shallow reservoir and a relatively short reservoir lake, not filled except in late flood, when the flood water contains less sediments. The dynamic influence of relevant spillways and outlets must reach the sediment flow. Their capacity, arrangement and relevant operation with the gates must not permit a division of the streamline, resulting in a reduction in the tracting forces. An appropriate size, lay-out and equipment of the project enables the reservoir to interfere to some 10% with the regime of rivers with a high level of suspended matter transport, thus greatly contributing to the efficiency of the project.

Other control measures can be grouped in

- control of watershed (proper soil conservation, farming and foresting techniques, protection of river banks etc.)
- control of inflow (by settling basins, by-pass canals, provision of vegetative screening, favourable location of intake structures for off-channel reservoirs etc.)

- removal of deposits (flushing, sluicing, dredging, which is economic in exceptional cases only).

The decrease in reservoir volume not only results from the sediment of the reservoir's tributaries, but also from the fall-out from the atmosphere, plankton, washed up soil and agrochemical particles from the adjoining shores and material from the eroded reservoir banks. The abrasion and landsliding of shores is a process of their destruction which is caused by the effect of water, wind, by the fluctuation of the water table, by water flow, by the effect of waves and ice and by the effect of human activities.

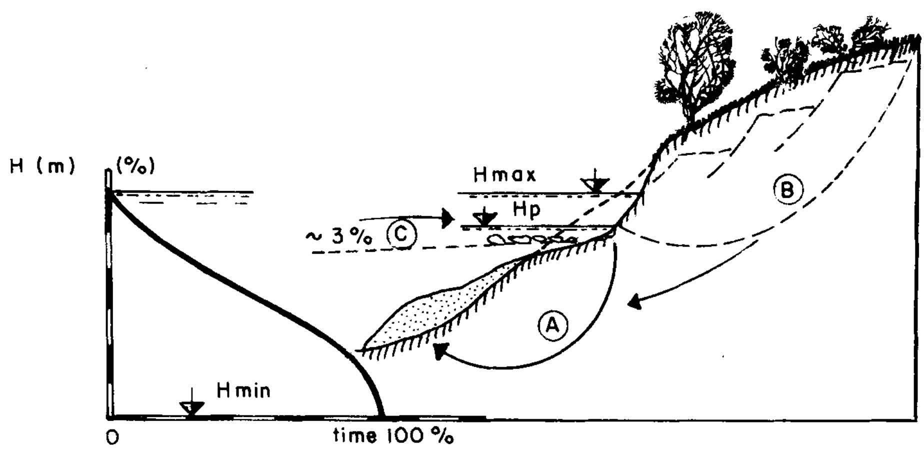


Fig. 4.17. The erosion of reservoir shores in relation to the fluctuation of the storage level. Redrafted according to Bayer (1954), H_p - pond level, H_{max} - maximum water level, A - abrasion shore, B - sliding abrasion shore, C - shore with accumulation of sediments, B+C - abrasion and accumulation shores.

An important destructive effect is exerted especially by variable phenomena. The abrasion of the shores of a reservoir starts shortly after the first filling-up of the reservoir. The rate of this process increases step-by-step in the first years of operation, reaching a peak after some three to five years and then gradually decreasing again. In this phase, the shape of the shores almost reaches a state of geomechanical equilibrium.

The wetting of the shores results in a change in their geomechanical characteristics, especially in their cohesive strength and coefficient of friction. New forces acting on the wetted material destroy the original balance, which may, under unfavourable geomorphological conditions, also result in the sliding of whole rock formations.

Depending on the slope of the shores, their exposure, their geological and soil characteristics and their vegetative canopy, the result of the process on the shore formation are

- abrasion watersides, generally having a steep slope, whose material is eroded, transported and then deposited (Fig. 4.17 A)
- abrasion and sliding watersides, when the change of geomechanical factors results in landsliding (Fig. 4.17 B)
- accumulation watersides, formed in flat areas, especially in shallow coves, where the material from tributaries was deposited by wave action (Fig. 4.17 C)
- abrasion and accumulation watersides, which are steep, with a platform formed by the eroded material.

Abrasion phenomena do not occur whenever the slope of the shore is below 3^{o}. Under such conditions the acting forces, because of their almost parallel direction, are not able to destroy the surface layer.

4.6.3 Effect of Reservoirs on Water Quality

The sedimentation process in a reservoir is accompanied by many other physical, chemical and biological processes of self-purification, which causes mixing and thinning. The influence of the water level fluctuation on the mean concentration of dissolved matter in the reservoir can be determined on the basis of the following formula

$$q_t = \frac{q_o \cdot V_o + Q_t \cdot k_t - Q_t \cdot q_o}{V_t} \quad (g \cdot l^{-1}) \qquad (4.28)$$

q_t, q_o – concentration of dissolved matter in the moment 0 and t_o $(g.l^{-1})$

V_t, V_o – volume of storage in the moment 0 and t_o (m^3)

Q_t – water inflow in the period from 0 to t-1 (m^3)

k_t – concentration of dissolved matter in the inflow water $(g.l^{-1})$

O_t – outflow from the reservoir in the period from 0 to t-1 (m^3)

In this formula a constant concentration of outflow is assumed during the period in question.

Chemical and biological processes, running simultaneously with the physical processes, result in

(a) the mineralization of organic matter

(b) the production of new organic matter.

Some chemical substances, e.g. chlorides, do not change during these self-purification processes. Their concentration depends then on the rate of water exchange. The concentration of other matter increases or mostly decreases and can thus be expressed by a dropping exponential function, e.g. in summary by means of the biological oxygen demand BOD.

The course of the physical, chemical and biological processes is influenced not only by the input of sediments, but also by the input of solar energy and by the oxygen and carbon dioxide from the air. The content of organic matter depends on the rate of the mineralization processes and on the production of organic matter. The dependence of the concentration of organic matter in the outflow on the rate of water exchange is hyperbolic. This concentration depends on the concentration of the organic matter in the inflow, on the average water depth, on the biological oxygen demand BOD_5 in the reservoir and on the rate of the water exchange. According to Straškrabová (1976)

$$q_t = q_r + 0.66\, q_o \,.\, t_e^{-0.21} + 0.66 \,.\, p \,.\, h^{-1} \,.\, t_e^{0.79} \quad (mg.BOD_5.l^{-1}) \qquad (4.29)$$

q_t - concentration of organic matter in the outflow $(mg.BOD_5.l^{-1})$

q_r - concentration of non-disintegrable matter $(mg.l^{-1})$

q_o - concentration of organic matter in inflow $(mg.l^{-1})$

t_e - rate of water exchange in the reservoir (days)

h - mean depth of the reservoir (m)

p - BOD_5 production in the reservoir $(g.m^{-2}$ per day)

The rate of mineralization process in reservoirs with a high rate of water exchange is higher than the production of organic matter during the first five days after the inflow of organic matter. In shallow reservoirs, with a depth down to 5 m and a rate of water exchange in excess of 20 days, the production of organic matter exceeds the rate of mineralization. A shorter rate of water exchange results in a higher decomposition rate. The longer rate of water exchange results in an increase in concentration of organic matter in the outflow in comparison with the inflow, especially when the BOD_5 concentration in the inflow is lower.

The concentration of organic matter in the outflow depends on the rate of production of the organic matter in comparison with the rate of the mineralization process:

$$q_p < q_m \longrightarrow q_t < q_o \qquad (4.30)$$

$$q_p \doteq 0 \longrightarrow q_t \ll q_o$$

$$q_p > q_m \longrightarrow q_t > q_o$$

q_p - rate of organic production $(mg. \quad .l^{-1})$

q_m - rate of the mineralization process $(mg.l^{-1})$

For longer periods of water exchange than 14 to 16 days the share of dis-

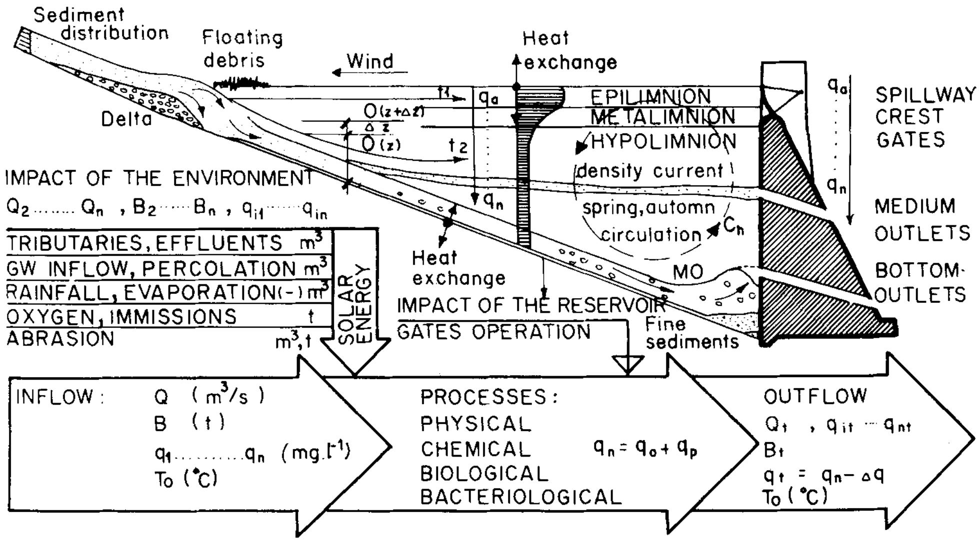


Fig. 4.18. The impact of thermal stratification and operation with spillway gates, bottom and medium outlets on water quality in reservoir. River flow t_1, t_2 and water circulation c_e during stagnation, circulation c_h during the period of homothermicity is dotted. The seasonal changes in thermal stratification.

integrated organic matter does not depend on the depth of the reservoir. The efficiency of the mineralization process increases with the duration of the water exchange and in reservoirs with a rate of water exchange of 14 to 16 days increases substantially with their average depth.

The upper layers of the reservoir are trophogenic, i.e. nutritive. Assimilation is their prevailing process, while dissimilation occurs only partially. Lower layers are trophylitic, i.e. they support the disintegration of organic matter. The prevailing process there is dissimilation, when destruents disintegrate the dead plankton and other dead organisms. Owing to the water flow a certain development of physical, chemical and biological processes is observed from the estuary of tributaries to the dam.

The rate of the relevant biochemical processes depends largely on the course of water temperatures. The unit mass of water depends on the temperature, chemical composition and content of sediments and results in thermal stratification. The pattern of thermal stratification in reservoirs depends on the

- reservoir depth and geometry
- solar radiation and air temperature
- wind velocity
- reservoir operation, i.e. on the flow to volume ratio.

The degree of stratification depends on the densimentric Froude number Fr which can be approximated by

$$Fr = 320 \frac{L}{H} \cdot \frac{Q}{V} \qquad (4.31)$$

L - reservoir length (m)
H - mean reservoir depth (m)
Q - discharge ($m^3 . s^{-1}$)
V - reservoir volume (m^3)

According to Canter (1983) if Fr is less than $\frac{1}{\pi}$, stratification is expected, with the degree of stratification increasing with the decreasing densimetric Froude number.

The thermal stratification in reservoirs is more marked in deeper reservoirs. The difference in temperature between the surface and the bottom layers may exceed 15°C during high summer and 10°C during spring. This difference is about 4-5°C during winter.

Temperature gradients, i.e. the difference of temperature in the vertical direction, are not regular. When the temperature regime is stable, a characteristic zone called the metalimnion or thermoclina occurs at a depth of some 5 to 15 m. Its thickness varies and may even reach 6 m. This layer is characterized by a quick decrease in water temperature with the depth, exceptionally reaching 8°C at 0.3 m. (Fig. 4.18

The upper layer, above the metalimnion, is the epilimnion, where the effects of solar radiation are intensive, especially in the summer season. This layer extends to a depth of some 4 to 15 m. In this layer, the stock of oxygen is supplemented from the atmosphere by diffusion as well as by the photosynthesis of the water organisms. During the summer season the water temperature of this upper layer is higher, and in winter lower, than the temperature of the lowest layer, the hypolimnion. The temperature of the surface of the epilimnion is decreased from the surface by evaporation, thus causing an upward flow of water. The wind pressure on the water surface results in a turbulent flow, causing together with the water inflow from tributaries a mixing of water and a downward transfer of heat and kinetic energy.

The changes of water quality may result in the creation of a comparatively heavier, cooler layer at the reservoir bottom, enriched by products from the mineralization and decomposition processes. The chemical composition of this layer causes this water to reach its highest density at a temperature slightly above 4°C. This layer, the monolimnion, mostly does not take part in the process of water circulation.

Local circulation flows may occur in any part of the reservoir, but the overall circulation is a result of the destruction of the balance which arises from stratification by external forces. The probability of the occurrence of an overturn is, therefore, greater at the time of a non-marked stratification. This time occurs mostly in spring or autumn, when the upper and lower layers of the reservoir have the same temperature, i.e. during the period of homothermicity (Fig. 4.19). Such a state occurs once or several times during spring or autumn. During these periods of spring and autumn circulation, the flow caused by the wind effect mixes the whole volume of the reservoir, mostly with the exception of the monolimnion.

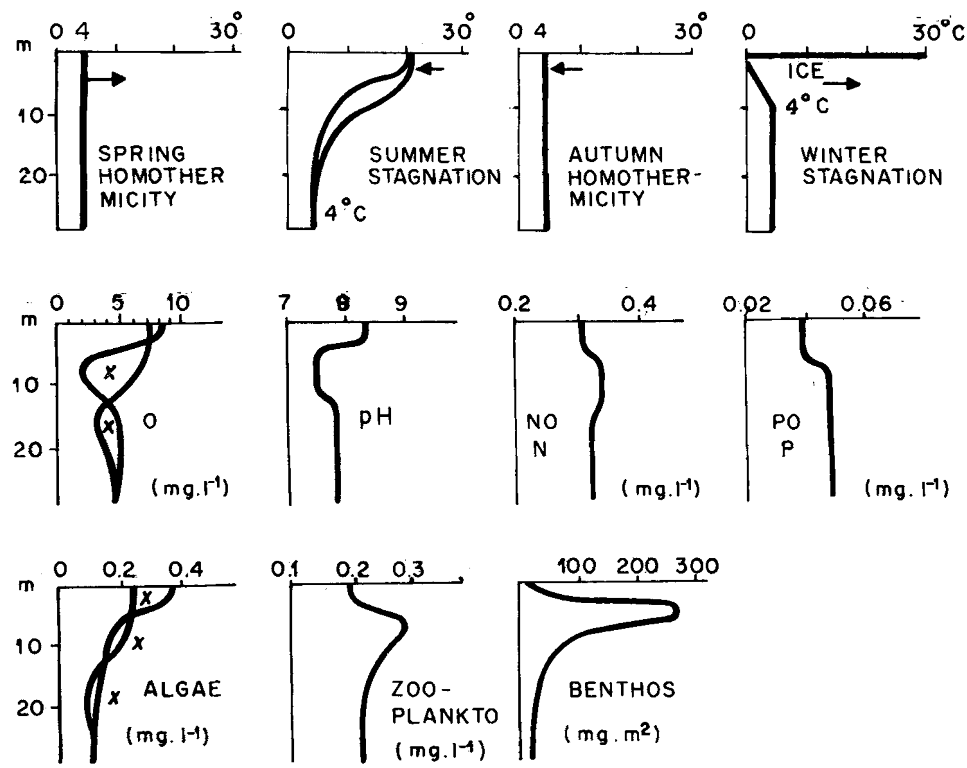


Fig. 4.19. Seasonal changes in thermal stratification in deep reservoirs. Oxygen content and other quality indicators depend on depth and reservoir operation (x). According to Chen and Orlob (1980).

In summer and also during winter, when the reservoir is not covered by ice, winds cause water circulation in the layer of the epilimnion only. During these periods of stagnation, the heat balance of the reservoir is influenced by the heat exchange between the bottom and water and by the heat input or output from the water level or ice cover, i.e. not by overall water circulation. The motion of the suspended matter, their floating and sedimentation, depends on these circulation phenomena.

In summmer water from tributaries, usually cooler than the water in the reservoir, penetrates below the warm epilimnion, following the direction of the original river channel. During this season the water temperature in a single, deep man-made lake is comparatively higher than it would be in a natural lake under the same topographical and climatological conditions. The outflow of the cooler water from the hypolimnion through turbines and bottom outlets results in an increase in the average temperature of the reservoir.

During winter, the bottom outlets and turbines release water which is warmer in comparison with the upper layers, resulting in a decrease in the water temperature. The average water temperature of man-made lakes is, during the winter season, therefore lower than that of natural lakes. Flow conditions resulting from the inflow of tributaries are substantially more complicated as compared with the simple penetration of the cooler inflow below the equilibrium in summer. After the spring circulation a substantially lower flow occurs in the reservoir.

The situation is quite different in a cascade of man-made lakes. The temperature in the second and further reservoirs is greatly influenced by the input of cool water from the upper reservoir. It changes not only vertically, but also in the longitudinal profile. The average of this temperature, and the temperature of the surface layer, is also lower than it would be in a natural lake under similar conditions.

The surface temperatures and often also average temperatures reach their minimum in summer just downstream of the upper dam. The location of a rapid increase in temperature, corresponding to a drop of the streamline and the formation of an epilimnion, changes with the values of inflow from the upper reservoir. Increased discharges upset the upstream zone of the metalimnion in the direction of the flow and extend the zone with low surface temperatures, thus restricting the possibilities of bathing. For similar reasons, the surface temperature decreases in the direction of the main flow downstream of the upper reservoir.

The quality of water in reservoirs is determined by the interplay of

- the water exchange rate,
- the quality of water entering the reservoir,
- the climate and weather,
- the hours of sunshine,
- the resulting water temperature,
- the morphological characteristics of the reservoir, especially its depth,
- the material of the reservoir bottom,
- the aquatic ecosystem and ecosystem of the surroundings
- the impact of human activities.

The quality of the water entering the reservoir varies considerably with the season, being considerably influenced in dry periods by the quality of effluents from industrial and agricultural enterprises. In arid countries, the salinity of the inflow may increase considerably in this period. In high-flow periods, the quality of the inflow depends to a great extent on the erosion rate, i.e. on the material of the riverbed and wash from cultivated and fertilized land, depending on the season, agricultural practices and on the rainfall intensity.

The self-purification process in reservoirs with the exception of sedimentation is negatively influenced by the greater depth of water, resulting in lower oxygen content and lower temperature in comparison with the original conditions of the riverbed. Reduced flow velocities result in higher sedimentation with a long period of settling, hence reducing the turbidity of water. The increased detention time leads to increased biological activity. A higher nitrogen content, entering the reservoir mainly as a result of wrong cultivation practices, and higher surface temperatures with slower water flow in the epilimnion result in the over-development of algae. The decay of these organisms causes secondary pollution, decreasing the oxygen content, poisoning other organisms and disrupting the biological balance. Serious trouble may be caused by the over-development of weeds in the shallow parts of the reservoir.

The thermal stratification results in the formation of zones of differing water quality (Fig. 4.19). These zones differ not only chemically, but also in the content of various water organisms and can be modelled mathematically (Fig.4.20).

The hypolimnion may be, and the monolimnion certainly is characterized by anaerobic conditions and high concentrations of iron Fe, manganese Mn and sulphides; this causes quality deterioration, especially during the natural autumn overturn or during excessive water withdrawals. This deterioration may occur as a low level of dissolved oxygen, high Fe, Mn and hydrogen sulphide concentration and in organic and inorganic tastes and odours.

When a cool water input or circulation does not destroy the natural thermal stratification, a decrease in the oxygen content of the epilimnion occurs in the summer season. During that period this layer loses, owing to circulation, up to 50% of the oxygen content acquired in spring.

The character of the biochemical changes in the water quality in the epilimnion depends mainly on the course and type of processes, especially those which occur in the summer season. Nutriments enter the free space of the reservoir, also from its bottom, by means of the circulation, thus contributing to the activation of the biological process.

Oxygen losses are balanced by the decrease in temperature in autumn. The hypolimnion, having no contact with the atmosphere, loses its oxygen content as a result of decomposition processes, which occur especially in the bottom sediments. The decrease in oxygen content may result in an oxygen deficit, and in the decay of aerobic organisms. The thermal stratification influences all the

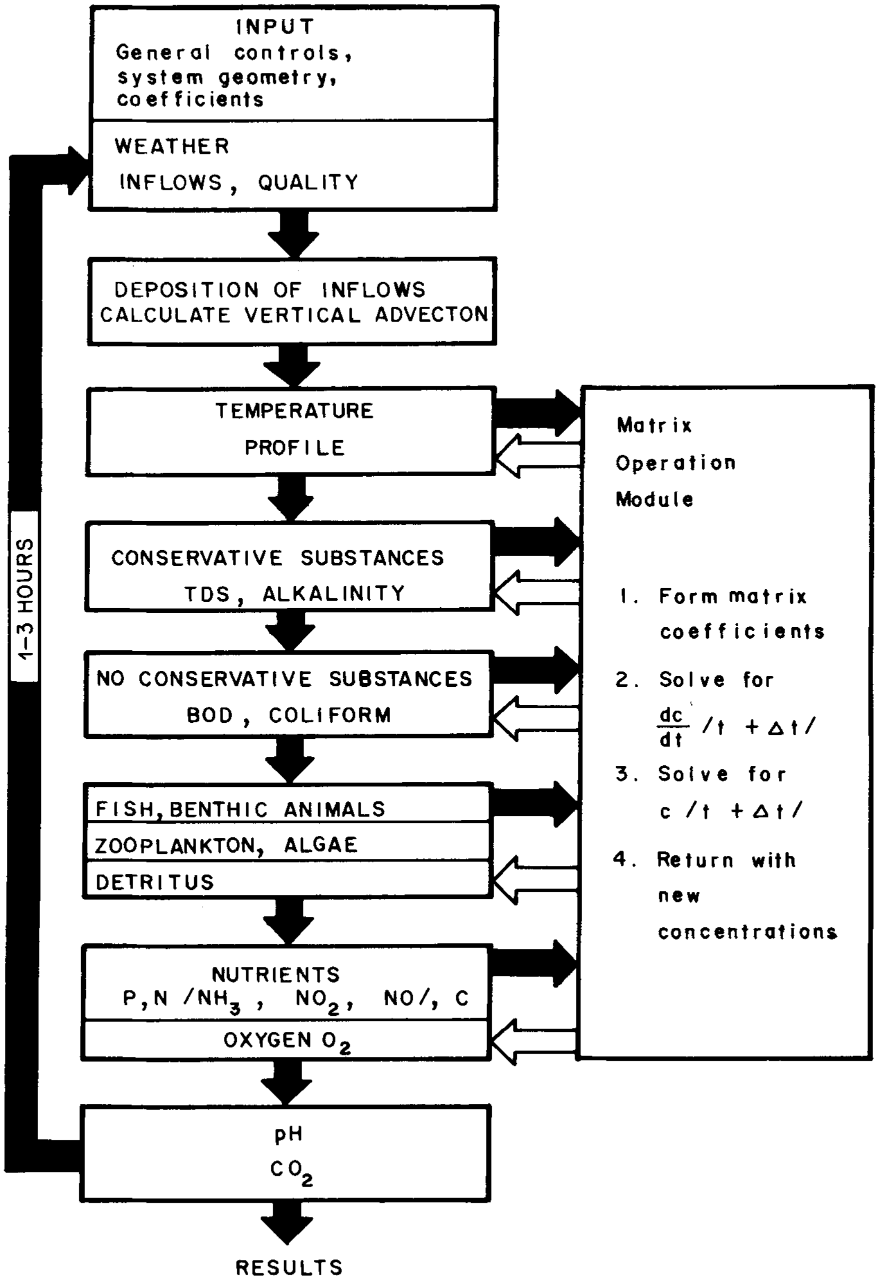


Fig. 4.20. Flowchart diagram (the lake ecological model) for determining the changes in water quality and the biomass production according to Chen and Orlob (1973).

chemical and biological processes, determining the water quality and the rate of biological production (Fig. 4.20).

Human activities also contribute to the occurrence of zones with an oxygen deficit, especially effluents, pits and dikes at the bottom of the reservoir, impeding the water circulation. Similar effect has the inexpediency of the reservoir operation, e.g. its emptying by upper outlets and spillways, which is required not only during floods but also to increase the water temperature in summer for bathing downstreams.

The thermal stratification is less significant, or does not occur at all, in shallow reservoirs (see Eq. 4.31). The cooler water is generally at the end of the backwater. The temperature increases in the direction of the main flow, i.e. to the dam, spillweir or outlet. The heat inertia of shallow reservoirs is low. The decrease in temperature at night may result in the formation of homothermicity, enabling intensive water circulation.

The higher day temperatures result in the formation of an inexpressive metalimnion. As it grows in size, the metalimnion reaches the bottom, and gradually disappears. The resulting homothermicity permits frequent circulation, thereby increasing the biological production of shallow reservoirs.

An improvement in water quality in reservoirs can be achieved by mechanical destratification, by the use of air and mechanical pumps or by treatment with copper sulphate $CuSO_4$ with or without citric acid, lime and alum. The control of algae growth can also be achieved by limiting the nutrient input in the major tributaries, especially by limiting the input of phosphorus.

4.6.4 Influence of Man-made Lakes on the Biosphere and Society

The development of aquatic life in a new reservoir is greatly influenced, and the water quality is determined, by the following factors:

- topographical, geological and soil conditions of the locality and its vegetative canopy
- climatological conditions of the site, especially the duration of sunshine
- water quality of its tributaries and the resulting water temperature
- the original ecosystems in the river and on the shore
- clearing, removing of stamps, litter, humus, cleaning and other measures undertaken by man to decrease sanitary hazards
- measures taken by man to accelerate the development of desirable species in the ecosystem of the new reservoir
- operation of the reservoir, often causing a periodic daily, weekly and seasonal draw-down and rise of the water table
- appropriate human activities during the reservoir's operation, namely those resulting in water pollution. (Tab. 4.19).

TABLE 4.19

Category	Factor
Terrestrial:	
Population	Crops Natural vegetation Herbivorous mammals Carnivorous mammals Upland game birds Predatory birds
Habitat/land use	Bottomland forest(a) Upland forest (b) Open (non-forest)lands(c) Drawdown zone Land use
Land quality/ soil erosion	Soil erosion Soil chemistry Mineral extraction
Critical community relationships	Species diversity
Air:	
Quality	Carbon monoxide Hydrocarbons Oxides of nitrogen Particulates
Climatology	Diffusion factor
Human Interface:	
Noise	Noise
Aesthetics	Width and alignment Variety within vegetation type Animals-domestic Native Fauna Appearance of water Odor and floating materials Odor and visual quality Sound
Historical	Internal & external sites
Archaeological	Internal & external sites

Category	Factor
Aquatic:	
Populations	Natural vegetation Wetland vegetation Zooplankton Phytoplankton Sport fish Commercial fisheries Intertidal organisms Benthos/Epibenthos Waterfowl
Habitats	Stream (d) Freshwater lake (e) River Swamp (f) Non-river Swamp (g)
Water quality	pH levels Turbidity Suspended solids Water temperature Dissolved oxygen Biochemical oxygen demand Dissolved solids Inorganic nitrogen Inorganic phosphate Salinity Iron and manganese Toxic substances Pesticides Faecal coliforms Stream assimilative capacity
Water quantity	Stream flow variation Basin hydrologic loss
Critical community relationships	Species diversity

Checklist of bio-physical and cultural environment factors for impoundment projects according to Canter (1983). Explications follow.

(a) A composite of the species associations; percentage mast-bearing trees; percentage covered by understory; diversity of understory; percentage covered by groundcover; diversity of groundcover; number of trees $\geq$ 0.5 m diameter per ha; percentage of trees $\geq$ 0.5 m diameter; frequency of inundation; edge (quantity) and edge (quality).

(b) A composite of the following: species associations; percentage mast-bearing trees; percentage coverage of understory; diversity of understory; percentage coverage of groundcover ; diversity of groundcover; number of trees 0.5 m diameter/ha; percentage of trees $\geq$ 0.5 m diameter; quantity of edge; and, mean distance to edge.

(c) A composite of the following: land use; diversity of land use; quantity of edge; and, mean distance to edge.

(d) A composite of the following: sinuosity; dominant centarchids; mean low water width; turbidity; total dissolved solids; chemical type; diversity of fishes; and diversity of benthos.

(e) A composite of the following mean depth; turbidity; total dissolved solids; chemical type; shore development; spring flooding above vegetation line; standing crop of fish; standing crop of sport fish;diversity of fish;, and, diversity of benthos.

(f) A composite of the following: species associations; percentage forest cover; percentage flooded annually; groundcover diversity; percentage of groundcover; and, days subject to river overflow.

(g) A composite of the following; species associations; percentage forest cover; percentage flooded annually; groundcover diversity and percentage of groundcover.

Non-influenced ecosystems in the man-made reservoir tend in the long term to achieve biological equilibrium, corresponding to a natural lake under similar conditions. Man-made reservoirs can therefore be categorized in the same way as natural lakes (Tab. 1.31).

As soon as the filling up of a reservoir begins, the original ecosystem of flowing river water changes, gradually being replaced by a new ecosystem of stagnant water. Within a period of several weeks, an over-development of some plankton species usually occurs. This boom affects the species, which do not encounter important life concurrence and first find the rich stock of nutriments in the newly flooded soil layers and their partly removed vegetation canopy.

The development boom of this species is interrupted in the next stage by an overdraw of the original nutriments, leading to the development of other species. This situation gradually tends towards a biological equilibrium, with a more rich aquatic life in the area of the estuariaes of the reservoir tributaries, where the nutriment input is more intensive.

The aquatic life of man-made lakes is greatly influenced by a frequent draw-down and rise of the water level. This results in the poorer heterogeneity of ecosytems in the upper littoral zones of man-made reservoirs in comparison with natural ones: these ecosystems do not include species which are not resistant to the fluctuation of the water level and which cannot follow the water level or find a temporary shelter in the denuded surface cover.

This is the reason why a number of current species are disappearing as a result of the action of the fluctuating water level, including weed, rush etc., and there only remain some unwanted species of insects (some midges and gnats) and worms (e.g. leeches). The occurrence of mosquitos can be significantly reduced by a managed draw-down and rising up of the water level.

The occurrence of aquatic species depends mainly on

(a) critical physical and chemical factors, i.e. on the occurrence of nutriments which are indispensable for the relevant species in quantities exceeding the necessary minimum,

(b) the ecological valency, i.e. on the extent of the tolerance of the relevant organisms to these factors and to the occurrence of other unwanted components of their living environment. Critical limits and optimum conditions are specific for the species in question. Approaching these limits, living phenomena become more demanding, especially energetically. Under favourable conditions, less energy is required, leaving aquatic animals the necessary reserve for finding and consuming food. A sufficiency of food and energy supply and an appropriate environment form the optimum living conditions for the species in question.

The existence of relevant fish species depends on the water quality, - mainly on its temperature and oxygen content, on the water depth, rate of flow, morphology and material of the bottom and the banks, and on the occurrence of aquatic flora. The construction and operation of a reservoir changes all these conditions. A dam or a weir forms an invincible obstacle for the draw of migratory fishes, e.g. eels, salmon.

Fish traps, elevators and other equipment constructed to enable the migration of fishes do not form an adequate substitute for such a purpose. There are also problems with the optimum location of such equipment and their capacity, especially in the period of the draw, is often not sufficient. The migration of fishes is already restricted during the construction period. The development of some fish species is even curtailed. Fish species that are not able to accept the changed conditions die out, changing in this way the structure of the ecosystem and conditions for the development of other herbivores, carnivores and detrivores. The conditions for fish occurrence in fish-ponds differ completely from those in reservoirs used for water supply and flow control. High inflow and outflow result in a high rate of water exchange and in water quality which is characterized by a lack of nutriment content. Fresh water fishes usually live near shores, and not in the free space, where a lack of nutrition occurs. This results, together with the lack of solar radiation, low temperature and lack of oxygen, in a substantial drop in productivity in reservoirs deeper than fifteen meters.

The water level fluctuation reduces the production surface and destroys zooplankton, the basic component of the fishes' food. The productivity of a reservoir does not depend on the extend and frequency of the water level fluctuation only, but also on the period of its occurrence. Shores covered by a dense vegetative canopy form favourable conditions for fish shelters, spawn deposition and foetus development. The decrease in the water level usually destroys spawn and foetus, especially in its early stage of development. The drop in the water table also has certain positive effects on fish production, forming suitable conditions for fauna development in the uncovered surface. The inundated grasses create a favourable environment for the development of some fish species, as well as offering them food.

The population boom of some fish species, e.g. of pike, after the first filling of the reservoir is also caused by the abundance of nutriments in the newly inundated soil surface and by the number of shelters. This population boom lasts several years, then gradually diminishes.

Ichthyofauna of man-made lakes can be categorized as follows:

(a) fishes which occur in the reservoir from the original ecosystem of the stream and which are able to adapt to the changed environment and breed naturally,

(b) fishes which have extremely favourable conditions for their natural breeding and development and are able to exterminate other fish species,

(c) fishes of the original ecosystem which are able to adapt to the changed conditions only in restricted areas of stream estuaries, where conditions have not been changed drastically,

(d) fishes which are able to live in the reservoir, but do not have the ability to breed naturally, thus requiring artificial breeding for replenishment of their occurrence,

(e) fishes which are imported artificially from other ecosystems and, being adaptable to the reservoir conditions, are able to fulfill the required function in the reservoir ecosystem: weed reduction, maintenance of ecosystem equilibrium, meat production etc.

The ecosystem of a reservoir includes

(a) fishes intended for breeding,

(b) supplementary fishes, using food which is not utilized by the raised fishes.

The extent and intensity of changes in the landscape caused by the reservoir depend not only on the topography, character and accessibility of the area and on the density of population and communication lines, but also on the size of the reservoir, especially on its surface area. The following occurs after the construction and operation of a reservoir:

(a) changes in the inundated area:

- flooding of forests, cultivated and urbanized land, communications, buildings and other engineering works, landmarks and historic places,
- flooding of mines and mineral deposits etc.,
- the extinction of the original ecosystems, the destruction of dry land species of flora and fauna, including the rare ones,
- the inception of aquatic flora and fauna, as well as the extension and change of its environment, including that for fowl and insects.

(b) changes in the reservoir environment

- creation of new scenery, influenced by the water level fluctuation,
- changes in the hydrogeological and hydropedological conditions, new ballast of the Earth's crust,
- changes in the groundwater level, soil moisture and air humidity, changes in temperature, resulting in a change of ecosystems,
- changes in the living environment of man; change in dwelling environment, in health and recreational conditions, and a severing of communication lines,
- change in the conditions for economic development: the economic impact of the dam construction and reservoir operation causes a construction boom, as the equipment used on the building site offers possibilities for further utilization, and the construction of new communications increases the accessibility of the area and its consequent utilization for recreation purposes, which leads to a modernization of the life style of the population.

The reservoir's environment is negatively affected by the water level fluctuation, especially at the end of backwater and in flat areas. When the banks are steep, landsliding may occur. The negative consequences of the water level fluctuation should be restricted by overflow dams, dikes, banks, ramparts, and by excavation in shallow flooded areas etc.

Dry land ecosystems are affected not only by the rise in the groundwater level and by an increase in soil moisture and air humidity, but also by the flooding of pastures and dens, by complications associated with the access of shy animals to water, by the worsening in the living conditions, especially of rare species, through the increase in population density and economic activities. In sparsely populated areas reservoir shores form favourable conditions for nesting and resting places for migratory birds.

The social, group and personal interests of the population are affected by the creation of new shores, by the increase in soil moisture, by changes in the microclimate etc. The increase in dwelling value of areas not adversely affected by water level fluctuation waterlogging or other negative effects results in an increased density of habitation. The change in the dwelling value has an important impact on the life style, supporting its recreational aspects. The reservoir creates or supports favourable conditions for fishing, camping, hunting, and other types of weekend and vacational recreation. The space for water tourism increases, but the recreational value is sometimes prejudiced by the change of the flowing water into stagnant water.

The increased density of habitation has as a secondary effect a breaking down of the natural vegetative canopy, an increase in the erosion rate. a rise in the transport density, an increase in noise density, a gradual pollution of the environment, with the concomitant need for a mass water supply, organized waste and waste water removal.

Depending on the water quality and prevailing sanitary conditions, the reservoir operation can create or strengthen the conditions for the dissemination of germs or their bearers, esepcially in tropical and subtropical areas. Negative circumstances may result in economic, cultural and social losses, either permanent or temporary, especially in the period during and shortly after the construction.

Some of the expected economic effects may be not achieved due to various planning, financial and organizational obstacles or due to the unexpected reaction of the population. This mainly concerns the immediate surroundings of the reservoir, which sometimes fail to attract sufficient interest among potential investors.

Uncoordinated planning and lack of investment in further construction activity or institutional gaps may cause discrepencies in the area in question, restricting or even cancelling the positive impact of the reservoir in the border areas, or even altogether.

4.6.5 Effect of Flow Control and Water Withdrawals

Downstream of the dam profile the reservoir operation and water withdrawals affect, especially,

- the water and ice regime, the transport of sediments, and the water quality,
- the aquatic flora and the riverside canopy,
- the aquatic fauna including fishes,
- the dwelling value of the relevant area (Tab. 4.20).

Changes in the water regime are manifestated mainly by changes in discharges, dependent on the reservoir operation, and on the time distribution of water withdrawals and effluents. These changes result especially in

(a) a decline in peak discharges and relevant water levels downstream, usually with the exception of superfloods and floods of long duration, because these often exceed the capacity of the reservoir,

(b) an increase in low discharges,

(c) a water deficiency in the case of excessive water withdrawls.

TABLE 4.20

Impact of reservoir operation and water withdrawl on downstream water course					
Water quantity		Water quality		Flora/Fishes	Dwelling
Decrease in higher discharges	Increase in low discharges	Decrease in sediment transport	Decreased salinity of low discharges	Change in water table and ground-water table	
Restricted flooding	Improved water supply	Decrease water table of floods	Increase in salinity by evaporation	Change in aquatic flora	Improved flood control
Restricted natural fertiliza-tion	Improved navigation and power generation	Decrease in sedimenta-tion flooded land	Increase in nitrogen, iron and mangan content	Change in coastal flora	Restricted soil re-generation
Restricted erosion	Decrease in sedimentation		Decrease in oxygen content	Increase in yield	Changes in pattern of watertourism
Restricted groundwater recharge	Increase in infiltration	Decrease in clogging	Decrease in water tem-perature in summer	Interrupted draw of fishes	Restricted summer recreation
Restricted waste disposal	Improved sanitary conditions		Increase in water tem-perature in winter	Restricted migration of fishes	Restricted skating in winter
Decrease in evaporation	Slight increase in evaporation	Extended period of high turbidity	Change in ince forma-tion and flow	Change in zones of fish occurrence	
Decrease in water table and discharge fluctuation Periodic fluctuation of water table and dischar-ges in case of hydro-power generation					

Checklist of the probable impact of reservoir operation and water withdrawal on downstream water course.

Water withdrawals do not generally result in a substantial decrease in flood discharges, as they are usually comparatively small. Big withdrawals, such as those used for irrigation purposes, reduce the value of low discharges in the summer season, thus causing an increase in these discharges in the winter season on account of the greater groundwater outflow from irrigated land at that time. Irrigation may also increase flood discharges, because watered land has a limited infiltration capacity, thus causing an intensive outflow of the rainwater.

The flood control effect of the reservoir results in

(a) a decline in the flooded area,

(b) a decline in the extent and frequency of irrigation by flood water spreading and soil regeneration by silt sediments,

(c) a decline in the rate of natural riverside infiltration,

(d) a decline in the erosion rate, and an increase in the sedimentation rate.

The decline in the flooded area results in a reduction in flood losses. Nevertheless, irrigation by flood water spreading is restricted, thus reducing the regeneration rate of the soil profile. In this case, the natural watering and soil regeneration process has to be replaced by artificial irrigation and fertilizing, which results in high operation costs and also requires appropriate operation skill, as well as being connected with a change in irrigation methods and in the cropping pattern.

The necessary measures for this purpose require the supply of artificial fertilizers, energy for their production, manpower and skill and may appear to be operationally, financially or organizationally unsuitable, especially in developing countires. They are feasible for intensive production, but are not satisfactory from the environmental point of view, as they may supply the requested quantity of anorganic nutriments, but not the necessary volume of organic matter.

Flood control results in the decline in the natural riverside infiltration, reduction in the groundwater recharge and subsequent negative influence on agricultural production, especially in flat river valleys. In the case of the low quality of river water, the drop in the infiltration rate results in an improvement of the groundwater quality.

The decline in the erosion rate and interrupting of the sediment transport which result from the flood control functions of the reservoir serve the maintenance of riverbeds. As a consequence of the reduction in high discharges, an increase in the sedimentation rate may occur resulting in a decrease in the channel capacity downstream of the dam profile and thus influencing water level hydrographs, navigation conditions etc. As a result of the decreased discharges and attendant higher sedimentation, the rate of the self-purification processes falls, thus causing a deterioration in the water quality. The decrease in the erosion, and increase in the sedimentation rate negatively influence the occurrence of fish shelters, thus limiting the fish population.

Depending on the given conditions, the reservoir with a low impact on flood discharges may on the contrary, owing to its trap efficiency depriving the downstream flow of its sediment content, increase the erosion rate downstream.

The increase in low discharges is caused not only by the reservoir operation, but also by the influence of water utilization processes between the water withdrawal and effluent, the second process having a negative effect on the water quality.

The increase in low discharges, being accompanied by a raising of minimum water levels, creates more favourable conditions for water withdrawals, navigation and water power generation, as well as having a favourable impact on the groundwater regime, and therefore also on agriculture and forestry. Such a raising of the water table may sometimes result in advancing percolation and evaporation, i.e. in growing water losses. The flow rate increases, augmenting sediment transport and the rate of self-purification processes, and thereby improving the sanitary conditions and the aesthetic value. Under certain circumstances the flow rate may exceed the relevant limiting values of the river bottom stability, thus causing erosion.

Water withdrawals and subsequent utilization frequently increase the concentration of dissolved or suspended matter in the remaining discharges. Water utilization decreases the oxygen content especially and increases the nitrogen content. The regulating effect of the reservoir with a longer rate of water exchange mostly reduces the level of water pollution. The augmentation of low discharges also dilutes the pollution in water from tributaries and effluents.

The sedimentation and self-purification processes in the reservoir generally have a favourable effect on the quality of the water outflow, even in the case of a low quality inflow. In semi-arid and arid areas the concentration of dissolved and suspended matter can nevertheless be increased by passing through the reservoir with a high evaporation rate.

The value of the water pollution downstream of the reservoir, at the confluence or at the estuary of effluents, can be determined or its course modelled on the basis of the mixing formula

$$^{i}q_3 = \frac{Q_1 \, ^{i}q_1 + Q_1 \, ^{i}q_1}{Q_1 + Q_2}$$

$^{i}q_1$, $^{i}q_2$ - the concentration of relevant indicators before the confluence or before the estuary of effluent
resulting concentration downstream

$^{i}q_3$ - resulting concentration downstream

i - 1, 2, 3.....,n order of water quality indicators

Q_1 - Q_2 - discharges upstream of the confluence.

The real course of the water pollution in the longitudinal profile of the water course differs from the computed on account of the self-purification process including sedimentation. The relevant computed values should, therefore, be checked and corrected in the sequence from the upper profile to the estuary. On this basis, the course of the water quality can also be controlled and its improvement during critical periods achieved by reservoir operation. Such an emptying of the storage is to the detriment of the water supply. The feasibility of such operation depends on the course of the decomposition processes and on the evaporation rate in the reservoir, and resulting water quality.

The changes in water temperature downstream of the dam site arise from the reservoir operation. With the power generation or with the bottom outlet open, the deep water layers, i.e. the hypolimnion, are emptied, which results in a cooling of the river water in the summer season and its warmimg during winter, in comparison with the original state before the reservoir operation. This water also contains more nitrogen and iron and less oxygen. The difference in water quality, including temperature, is substanional, especially in the case of a cascade of reservoirs. The water of the epilimnion, whose temperature does not differ as much from the original one, enters the river channel downstream of the reservoir by means of spillways, mainly during floods, i.e. not so frequently.

Temperature changes have an influence on, especially,

(a) water utilization after its withdrawal

(b) fish occurrence and fish breeding

(c) other in-stream water uses, especially water sports, recreation, navigation, and also waste disposal.

The decrease in water temperature is favourable for both municipal and industrial water supply, namely for cooling purposes. For irrigation purposes, warmer water is more convenient. Changes in water temperature and water quality also influence the ichthyofauna. They may cause a change in the zones of fish occurrence. The changes in water temperature mostly have a negative effect on recreation and water sports; the cool water in summer spoils the conditions for bathing and other water sports; while the increase in winter temperature restricts the freezing of the water pool and skating in winter, but tempers the ice bound regime, thus creating more favourable conditions for water transport.

Water temperatures are also affected directly by water withdrawals, decreasing water discharges, water depth and flow rates with consequent temperature increase, also caused by the high temperature of effluents from cooling systems. These temperature changes depend to a great extent on the ratio of discharges and withdrawals and on the quantity and temperature of effluents. Water withdrawals also increase the concentration of sediments in the remaining discharge, aggravated by material input from effluents, increasing the sedimentation rate and causing the filling of riverbeds.

The drop in the sediment content in discharges caused by the sedimentation in the reservoir reduces the course of water levels in comparison with the state prior to the reservoir operation. The fall in the water table reduces the potential energy, and augments the kinetic energy of water. This intensifies the erosion process, entailing a gradual increase in sediment and bed-load transport downstream, where, depending on the conditions, the water level may gradually approach the original one of the same discharge. Downstream of the reservoir, the period of turbid water discharges is usually longer because of the gentle sedimentation of fine particles in the reservoir.

The natural river channel downstream of the reservoir is also affected by the construction of many offtake and outlet structures, some stretches being regulated or paved in this connection. The natural riverside canopy, whose development and state depends on climatological conditions, altitude, soil and geomorphological conditions, bank slopes, exposition of the location and the water regime changes under the long-term influence of the water level alterations and consequent changes in groundwater table. Vegetation species which are not adaptable to the new conditions gradually expire, affecting the scenery and the relevant dwelling and recreational conditions.

The living conditions for fishes in the stretch which is affected by the operation of the reservoir and especially by

- changes in water quality, including temperature
- increase in the minimum and decrease in the maximum flood discharges and their occurrence,
- changes in the riverbed and associated flora,
- construction of obstacles for the movement of fishes upstream,

are drastically changed. These consequences include a decrease in the heterogeneity of the prevailing ecosystems, including the expiring of migratory fishes. The improvement of the water quality and the decrease in water temperature may result in the formation of a trout zone in the stretch downstream of the dam site. Intensive sport fishing is often recorded in these stretches, especially when this activity is not permitted on the reservoir, e.g. because its water is used for drinking purposes.

The flood control, water supply or multi-purpose effect of the reservoir operation increases the dwelling value of the affected area. But, downstream of the reservoir, there obtains the risk of a possible dam destruction. The probability of such an event is very low, but its consequences may be catastrophic, destroying economic values and threatening the population.

The effects of very large reservoirs appear even as far down as the estuary of the river into the sea, or where it expires in an area without outflow. The drop in the nutriment input and possible deterioration in water quality by human activity may limit the extent and heterogeneity of the quatic fauna including fishes, as well as restricting fish production in the coastal zone. The decrease in sediment transport may result in erosion, deepening the estuary and aggravating sea-wave action.

The decrease in discharges caused by the reservoir operation or by water withdrawals results in an increased penetration of seawater upstream, with a consequent increase in soil salinity, also leading to a degradation of salt-resistent plant species including e.g. date palms. The saline effluents from irrigation schemes may also contribute to this degradation, a process which is more evident in the dry period of low river discharges.

The resulting stage in the estuary largely depends on the operation both of the reservoir and the associated water users. The increase in low discharges may cause a decrease in the average salinity, i.e. it may shorten the period of upstream penetration of the salty back water, which reduces the acreage of the affected area. Another consequence may be the raising of tracting forces, and the intensification of the self-purification process. In this way, a balanced reservoir operation can also improve the conditions for coastal flora, thereby augmenting both agricultural and fish production.

4.6.6 Effect of River Training and Open Channel Water Conveyance

The formation of riverbeds depends on hydrometeorological, hydrogeological, geomorphological and soil conditions. It is also affected by the occurrence and species of the vegetative canopy on the river banks. The basic natural functions of streams consist of

(a) drainage and water conveyance

(b) ice transport during the winter and spring season,

(c) sediment and bed-load transport, soil quality regeneration,

(d) groundwater table and soil moisture regulation, i.e. maintenance of conditions for the riverside vegetation,

(e) maintenance of conditions for aquatic life and of environmental balance.

Incidental phenomena of these natural functions, such as floods, restrict the possibilities of utilizing the adjacent area for the various activities of human society, e.g. for intensive settlement, industrial and intensive agricultural production, mining, uninterrupted in-stream water utilization e.g. navigation and water power generation. The variability of the channels of natural water courses, their fluctuating water levels, changing discharges and also ice phenomena negatively influence the socioeconomic functions of water. For this reason water courses are trained and canals for water conveyance constructed with the aim of

(a) improving the conditions of water supply and drainage, in-stream and on-side water use,

(b) restricting inundations and consequent economic losses,

(c) adapting the riverbed to the changing discharges, inland water transport requirements, power generation, sediment transport or ice regime phenomena,

(d) increasing the dwelling value of the adjacent area,

(e) stabilizing the river banks and river bottom, achieving directional stabilization, restricting the erosion process and removing its consequences,

(f) improving the groundwater regime,

(g) adapting the riverbed to the consequences of diversion dams and weir construction, as well as of the construction of communication lines, urban, industrial and agricultural development,

(h) improving the water quality, safeguarding the desired sanitary conditions and the requirements of aeathetic enjoyment(Tab. 4.21).

The unavoidable precondition for ensuring the desirable effect of river training is that natural functions of the stream must not come into conflict with the desired goals. The flow of natural rivers and streams is frequently almost steady, i.e. changes very slowly with time. Unsteady flow occurs as flood waves or travelling surges. In natural riverbeds, this flow is non-uniform, changing slowly or suddenly in the magnitude and direction of the velocity along the streamline. Strictly uniform flow rarely exists in such channels. The cross section of a trained stream usually has a simple geometric shape. The flow in such a canal is generally considered to be uniform, only having slow changes of direction and no changes with distance in the value of the velocity along a streamline, with the exception of stretches upstream of drops, weirs and diversion dams, where non-uniform flow occurs.

The natural riverbed, though often not sufficiently stable in the short-term, is a result of the activities of external natural forces, and may be considered to be in long-term equilibrium with them. The prismatic channel of a trained river with a uniform flow cannot correspond to the complicated conditions of the original state and, destroying this long-term balance, frequently has a negative effect on some of the basic natural functions of the stream or river.

The biological equilibrium in the original ecosystems on the banks is a result of an interplay of the original groundwater level and corresponding soil moisture fluctuation. The conditions for the equilibrium of aquatic ecosystems depend on the interplay of water depth, flow rates, the morphology and material of the channel, and on the aquatic flora. Ecosystems, both aquatic and on the banks, generally need heterogeneous conditions for their development or survival. These conditions are unified by river training, or newly and uniformly established by the headrace or tailrace construction. Unified conditions are not acceptable for many relevant species. This results in a decline in their heterogeneity, signalizing the disturbed biological balance. These changes occur gradually from the beginning of the construction work.

River training, if not accompanied by the construction of weirs and dams to

TABLE 4.21

Impact of river training					
Hydraulic parameters	Discharges	Water Table Increase	Water Table Decrease	Flora and Fauna	Dwelling value
Increased slope of the channel	Limited flooding	Change of sedimentation and erosion		Change in water quality	Increased flood control
Extended cross section	Restructed natural fertilization	Change in water temperature		Change in water flora	Improved agriculture
Increased velocity of flow	Restricted groundwater recharge	Increase in infiltration	Decrease in infiltration	Change in water fauna including fish species	Deteriorated soil regeneration
Increased drainage rate	Decrease in base flow during vegetation period	Rise in groundwater table	Drop in groundwater table	Change of riparian vegetation	Improved navigation and hydropower generation
	Increase in winter discharges	Waterlogging	Excessive drainage		Improved accessibility. Negative impact of water tourism

Checklist of the probable impact of river training on the water cycle and riparian environment.

swell the water table, results in a substantial drainage effect. Such an effect may be supported by the associated irrigation network and result in a 10-20% increase in annual outflow in the first 4-5 years after construction. In the next period, the drainage impact on the annual outflow is not as substantial and mainly occurs as a regulating effect, increasing low discharges. Its effect on flood occurrence is controversial. Decreased moisture content in the upper soil layer increases the infiltration capacity, thus lowering the surface runoff. The increased flow capacity of the riverbed, and especially of the associated drainage network, increases the flow velocity and contributes to the increase in flood discharges. The drainage effect of river training and associated network increases the probability of flood occurrence and the value of flood discharges, depending on the soil and moisture conditions, i.e. depending on the share of the balancing effect of the increased infiltration capacity of the drained soil layer.

River training drastically changes the conditions for sediment transport. This can also be analyzed on the basis of the following simple formula, derived from the water depth, the flow rate and the grain size of the bed-load mixture

$$d_e = \frac{v_x^3}{K \cdot h} \qquad (4.33)$$

d_e - characteristic grain size of the bed-load mixture (m)

h - water depth (m)

v_x - minimum flow rate causing the onset of bed-load transport $(m \cdot s^{-1})$

K - coefficient of the sediment transport $(m^{1.5} \cdot s^{-3})$
(almost stable and = 216 according to Schamow)

River training influences both the water depth and the flow rates, and in this way changes also the characteristic size of the bed-load mixture and the intensity of the bed-load transport. This change in the bed-load transport may result in demands for further river training in the stretch downstream. River training usually has a positive influence on the ice regime in the regulated stretch, but due to its accelerating effect has negative impact on unregulated stretches downstream;

The negative impacts of river regulation result mainly from the reduction of the stream length, from the extension of the cross section and from the removal of the riverside vegetative canopy. This augments the drainage effect, increases the flow rates, accelerates the outflow and, limiting groundwater recharge, results in the reduction of evaporation nad evapotranspiration.

River training may result in curtailing the duration of runoff from the source to the estuary, even to the extent of reducing it to half the original duration. The decrease in groundwater recharge limits the regulating effect of groundwater on surface water discharges, resulting in a decrease in average discharges during the summer period and in an increase in discharges in winter, thus causing a drop in agricultural production in the adjacent area.

The impact of headrace, tailrace and feeder, link and other conveyance canals is more drastic: They change the groundwater regime and associated ecosystems, they may cause waterlogging with associated salinity hazards in vast areas, they change the infrastructure of the area - severing the communication network and restricting the accessibility of certain areas both for the population and the wildlife. Their construction restricts wildlife occurrence, worsening the living conditions, especially of rare species, and permits fish to escape from reservoirs and rivers.

Conveyance canals enable the transfer of pollution and under certain circumstances form favourable conditions for the occurrence of insects and for desease dissemination. Nevertheless, an improvement in the conditions for water transport, power generation, other multi-purpose utilization of water, settlement, agricultural and industrial production, recreation form the precondition for a development boom in the adjacent area (Tab. 4.20).

River training has to be realized only as an integral part of an improvement in the water regime in the adjacent area. It is, therefore, indispensable

(a) to simultaneously accept measures for changing the surface runoff into groundwater runoff, especially on the forest and agricultural lands,

(b) to simultaneously accept measures for achieving a biological equilibrium in the ecosystems of the river valley and the catchment, especially by determining the ecologically optimum ratio of arable land,

(c) to solve river training problems not only hydraulically, technically and economically, but also from an environmental point of view.

Streams and river channels are formed by the long-term impact of hydrometeorological, geological and biological processes. Substantial changes in the original river bed, in its route and in the accompanying vegetative canopy during river training may disrupt the balance which has been established by natural forces and endanger the course of natural functions.

Only when the construction respects the original state, the main natural functions and basic interrelationships, as occurs after minor amendments to the original river bed and through the construction of protection dykes adapted to the topography of the terrain, can the consequent state be predicted with satisfactory accuracy and therefore be managed to offer maximum benefits with minimized environmental losses.

Chapter 5

WATER DEVELOPMENT AND MANAGEMENT POLICY

5.1 WATER MANAGEMENT ACTIVITIES AND ORGANIZATIONS

Water management is a complex of activities, designed to meet the demands of economic development and aiming at an optimum development and utilization of water resources, depending on their quality and availability in space and time, and at the creation of an optimum living environment, through the conservation of water resources, their protection against exhaustion and deterioration, and through the protection of human society against the harmful effects of water.

The rational management of water resources utilization has as its aim, in common with development generally, an enhancement of the conditions for human life and must, therefore, be recognized as an integral part of social and economic development.

In periods of predominantly single-purpose water utilization, in areas with abundant water resources, low population density, scattered small-scale irrigation networks and a low degree of industrialization, social and individual water requirements can be satisfied by the activities of water users or different local organizations. To achieve a higher production and a better water utilization, various specialized organizations are formed with the aim of ensuring water supply, and/or disposal, irrigation development, power generation, inland navigation, protection against floods etc.

In the next development stage, river boards and other authorities are formed in order to achieve a greater efficiency in the management of water development to coordinate the multipurpose water utilization and protect the society against the harmful effects of water.

The supreme regulatory action concerning water, in order to meet the demands arising out of human activities and the necessary protection of the environment, is a government right and obligation. The delegation of authority from the centre varies from country to country and, in the case of federalized and developing countries, even within the same country, depending on the given social and political framework, the legal regime of water management, the availability of water in relation to its use, and other regional diversities.

Legal and institutional factors play an important role in the organization of the responsibilities for water resources management. The institutional framework is aimed at satisfying the different interests of all water users, and also at facilitating the correct implementation of all water-related policies and programmes. Decision-making is invariably closely linked with the relevant political, economic and social processes which are the result of the interaction of a number of bodies (Tab. 5.1).

TABLE 5.1

LAW - MAKING	constitution civil law public works law labour law taxation law	water law water uses law flood control law pollution control law	WATER MANAGEMENT water law enforcement registry of water rights cadaster of water rights rights of way for water uses	national water policy international waters policy water management strategy	national objectives and goals international policy sectoral development policy	POLICY-MAKING & PLANNING
INTERIOR	municipal development	urban & rural water supply waste water treatment and disposal water pollution control	water pricing legal tools reimbursement of costs water administration	waterway development and maintenance hydrographical services water pollution control	inland navigation timber flotation railway, highway and air transport development	TRANSPORT
INDUSTRY & MINING	water supply and use waste water disposal	water supply for industry water pollution control	rights of way for water uses granting of water rights water disputes decisions	hydropower generation water for thermal & nuclear power generation water pollution control	thermal and nuclear power development distribution networks	ENERGETICS
AGRICULTURE	agricultural development irrigation drainage fisheries river training watershed management	water supply for irrigation livestock, processing and fish breeding water pollution control	approval of water development projects project design project construction project operation technical assistance	water supply for timber industry forest irrigation water pollution control	forest management watershed management erosion control training of brooks and creeks	FORESTRY
ENVIRONMENT PROTECTION	natural resources zoning landscape protection	flood control erosion control siltation control pollution control	hydrological services hydrogeological services data monitoring & processing hydraulic and hydrologic research	water supply for recreation waste water treatment and disposal	recreation services national parks administration tourism promotion sport promotion	RECREATION

Interrelationship between water management and other sectors.

Four basic groups can be distinguished among water management activities:
(a) legal administration,
(b) development activities,
(c) economic activities (Tab. 5.2),
(d) other management activities (incl. services - Tab. 5.3).

Depending on the individual characteristics of a given country, the institutional framework for water resources management includes the agencies with political and regulatory functions, working e.g. under regional authorities, and legislative bodies, working under a centralized water or other national authority. In order to restrict possible conflicts and provide a view which unifies nation-wide interests, the supreme coordination is usually entrusted to a special national authority, to one of the ministries responsible for the various water development aspects such as the Ministry of Water and Energy / Agriculture / Forestry / Public Works or to a multi-sectoral commission or special institute. To avoid any ambiguity, the exercising responsibility has to be separated from the administering and controlling/monitoring responsibility.

The diversity of institutional integration in water management depends on the separate consideration of such specific problems as municipal and industrial water supply and waste water disposal, groundwater development, irrigation and drainage, forest management, hydropower generation, inland navigation etc., and may be reflected by the existence of various organizations for some of these purposes.

Nevertheless, all matters relating to water should be regarded as forming part of an integral whole based on the unity of the relevant catchments. The structure of river boards corresponds to this territorial principle, whereas the institutional structure of water supply and waste water disposal organizations often depends on the particular in-house political arrangements.

In order to achieve the economic and social goals of a country in consideration of its environmental limitations, existing surface and groundwater resources have to be assessed, their quality, natural functions and present uses for all purposes identified, the future demands in the medium and long-term estimated, and both the medium and long-term plans formulated on the basis of an optimization process.

Water resources planning as an integral part of water development and management is a continuous process, whose implementation basically requires:

(a) a fixed strategy of water resources development and environmental protection,

(b) a flexible tactics of water requirements and withdrawals management,

(c) an operational control and checking of water quality and occurrence, water withdrawals, effluents and their quality, in-stream water uses and of measures of environmental protection.

5.2 PARADOXES OF WATER RESOURCES DEVELOPMENT

The course of water requirements and water withdrawals is generally deterministic, whereas the course of water availability is deterministic only within the limits of the realistic forecast of groundwater and surface water availability, which greatly depends on weather (rain) forecasts. It is, therefore, basically stochastic in the long term. The occurrence of water requirements and surface availability is usually contradictory: this leads to the first paradox which has to be dealt with in water resources development:

IN THE PERIOD OF HIGH WATER REQUIREMENTS A SUBSTANTIALLY LOWER WATER QUANTITY EXISTS IN NATURAL UNREGULATED RESOURCES THAN IN PERIODS OF LOW WATER REQUIREMENTS.

A gradual increase in total water requirements frequently results in a situation where, during water utilization, a point is reached when water requirements cannot be satisfied by an increase in water withdrawals from groundwater or unregulated discharges only. The water availability has to be regulated by artificial water accumulation.

Daily and weekly fluctuations can easily be balanced by small reservoirs or water tanks. Seasonal fluctuations in water requirements manifest a comparatively high dispersion of minimum and maximum values, which call for an overutilization of available water resources and claim a substantial increase in the parameters of relevant development projects.

As the number of reservoirs increases, gradually less and less feasible localities or less feasible arrangements for supplementing the required supply availability have to be used, including distant water resources, deep groundwater strata, and, in the last stage of development, even resources with low quality and unconventional water resources.

This is the reason for the rise in the average investment, operational and maintenance costs for water resources withdrawal, conveyance, purification and distribution. In addition, effluents depreciate the quality of available water resources and waste water treatment becomes necessary, thus further increasing relevant costs. This leads to the second paradox which has to be dealt with in water resources development:

THE AVERAGE INVESTMENT AND OPERATIONAL COSTS PER CUBIC METER OF WATER SUPPLIED GROWS EXPONENTIALLY, EVEN THOUGH THE SPECIFIC COST OF WATER SUPPLY FOR INDIVIDUAL WATER DEVELOPMENT PROJECTS DECREASES DOWN TO A CERTAIN LEVEL WITH THE INCREASING QUANTITY OF WATER SUPPLIED.

Problems associated with a lack of water or inadequate water quality are solved by the construction and subsequent operation of water projects. Water development projects which have in good time been implemented create a temporaty surplus of water that cannot be fully utilized immediately after their completion. This leads to the third paradox which has to be dealt with in water resources development:

THE TEMPORARY SURPLUS OF WATER OFFERING AN INTERLUDE FOR WATER OVERUTILIZATION WITHOUT ANY IMPORTANT NEGATIVE ECONOMIC EFFECTS, FORMS PRECONDITIONS FOR A SUBSEQUENT WATER SCARCITY.

Any period of temporary surplus of water ends by achieving an equilibrium between water resources and over-excessive water requirements. Any further lack of water is again solved by constructing a new project (Fig. 5.1). This cycle is to be repeated, extending the water resources development to more distant areas, until a stage of a utilization of economically feasible water resources is achieved. This leads to the fourth paradox that has to be dealt with in water resources development:

ALL AVAILABLE WATER RESOURCES ARE USED BEFORE EFFICIENT WATER-SAVING TECHNIQUES ARE APPLIED.

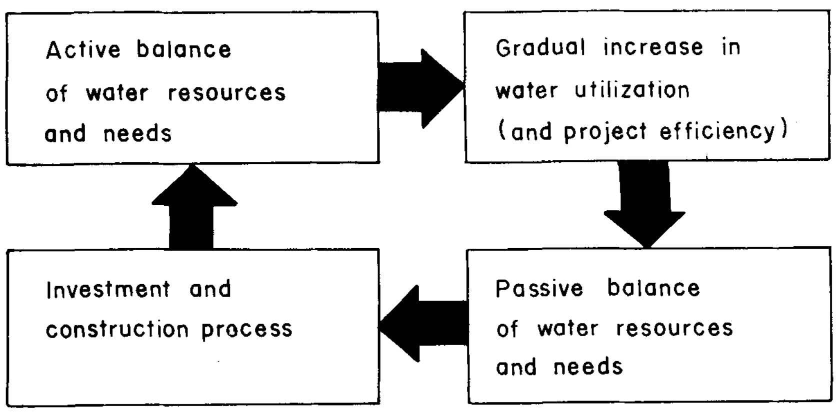


Fig. 5.1. Schematic interpretation of the cycle of water resources development and water use rationalization.

A society should form pre-conditions for its sound development by adapting its water requirements to water availabilities. But this rule functions under extreme situations only: When water availabilities are sharply restricted, water is used for indispensable uses only. The increased availabilities cause water to be used for less and less necessary uses. Under the situation of a long-term water surplus, growing water withdrawals differ more and more from the indispensable water requirements. This fact, accompanied by an exponential increase in specific investment and operational costs caused by utilizing less and less feasible project sites for growing total water withdrawals, leads to the fifth paradox that has to be dealt with in water resources development:

GRADUALLY INCREASING DEVELOPMENT COSTS GRADUALLY SAFEGUARD LESS AND LESS IMPORTANT WATER REQUIREMENTS.

5.3 STRATEGY OF WATER RESOURCES DEVELOPMENT

By formulating the desired water resources development objectives, it is possible to establish a strategy for the rational conservation and step-by-step development of those resources: i.e. to establish procedures for increasing the availability and subsequent utilization and disposal of water resources. A common objective is for example the conservation of the natural functions of water resources within the framework of the natural environment, especially of the quality and optimum allocation of these water resources among present and potential water users, i.e. their optimum multi-purpose utilization within the framework of the existing and expected social and economic structure (Fig. 5.2).

Long-term planning, a basic tool for helping to achieve these objectives, consists of the following steps:

(a) identification of available surface and groundwater resources, evaluation of their quality and uses in relevant categories of water utilization, which requires an information system or its establishment;

(b) evaluation of water demands in the medium term (five years) and of water needs in the long term, to match the physical and socio-economic conditions, national and regional development plans; treating inter-regional and international problems in the context of national interests;

(c) compilation of balances of water resources and needs, detecting critical areas, present and future problems;

(d) formulation of alternative scenarios and strategies, appropriate for solving particular national, regional and local problems;

(e) optimization and evaluation of these scenarios and strategies, with respect to their advantages and disadvantages, environmental and socio-economic after-effects, other implications and unavoidable repercussions, benefits and losses, and, last but not least, the investment, operation and associated costs required for the full completion and successful operation of the project or complex implementation of required arrangements in the framework of the present and future socio-economic structure;

(f) selection of the optimum scenario and strategy, i.e. the most appropriate for solving particular regional and local problems, capable of being pursued on a phased and flexible basis, taking into account environmental and socio-economic limitations incl. the lack of skilled human resources and the inertia of local customs, obsolete social structure, traditional labour methods, jeopardizing especially the successful introduction of modern agricultural practices, and the implementation and operation of modern irrigation systems;

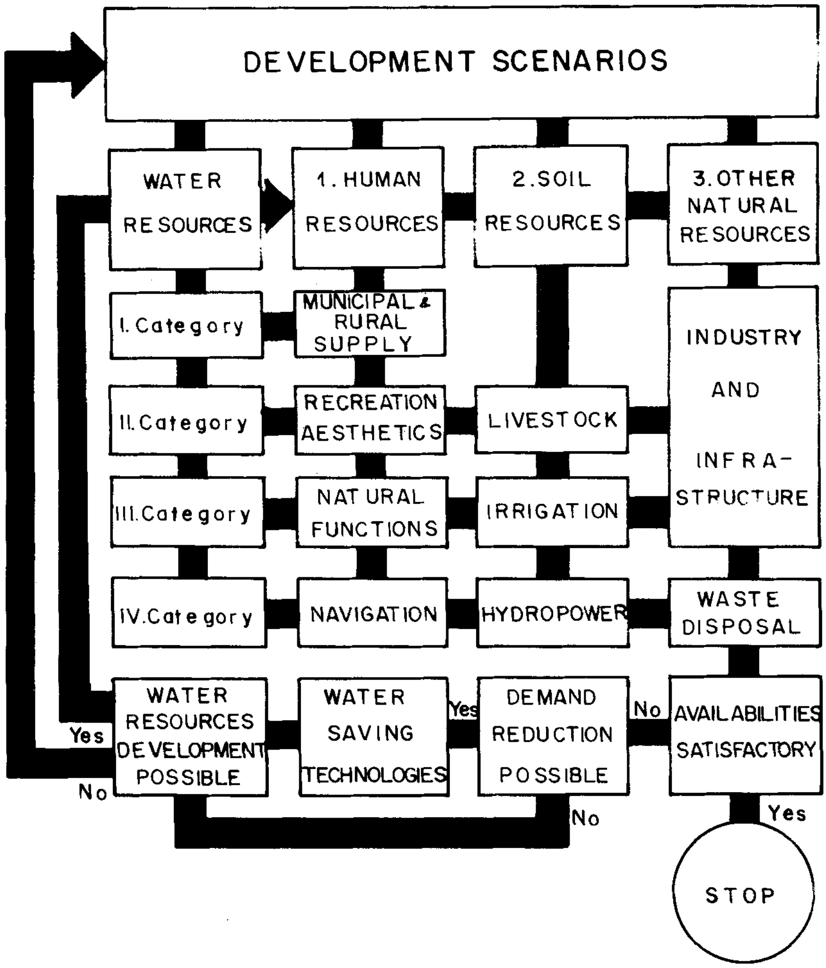


Fig. 5.2. Block diagram for allocation of water resources in line with development of the soil resources and industry. Any rational development tends to the ultimate stage of a sustained utilization of the natural potential by using the minimum matter and energy, which should be checked in relevant time horizons.

(g) approval and acceptance of the preferred scenarios and strategy by all central and regional authorities, involving the existence of an appropriate legal and institutional framework and two-way co-ordination among all levels of responsible authorities during the planning process;

(h) budgeting the gradual implementation within the framework of medium-term plans, whose aim is to integrate planned programmes of different sectors, define in financial terms the annual national, regional and local objectives, and to allocate funds for achieving those medium-term objectives;

(i) monitoring the performance of the plan, modifying it, if required by changed circumstances, needs and priorities.

Significant goals in medium-term plan implementation include the harmonization of:

(a) the development of the natural environment, balancing the needs of the utilization of natural resources and the necessity of environmental protection in order to decrease the negative impact of water utilization on the hydrological cycle, which reduces the volume of water available and leads to a deterioration in its quality,

(b) the water needs of present and potential water users with a view to the required water quality and quantity and to the optimum economic conditions.

To achieve the above goals, the following three principles have to be respected:

First principle of water development strategy:

KEEPING THE DEVELOPMENT OF WATER RESOURCES IN LINE WITH THE OVERALL SOCIO-ECONOMIC DEVELOPMENT BY RESPECTING THE DIVERSITY OF THE OCCURRENCE OF WATER RESOURCES UNDER NATURAL CONDITIONS.

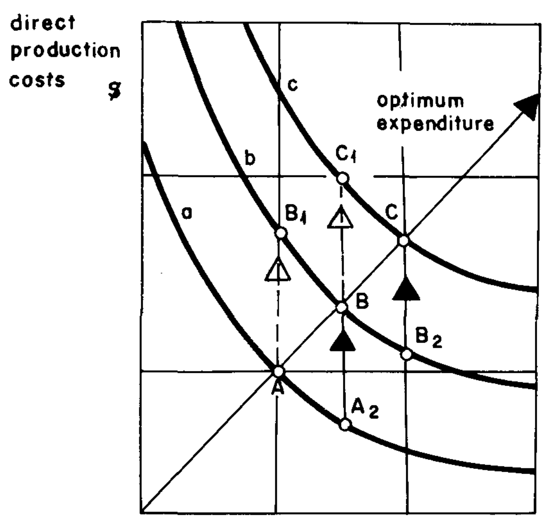


Fig. 5.3. Graphic representation of the relation of the total direct production cost and the expenditure on infrastructural investment and operation according to Czuka (1975). Excess infrastructural capacity (path A A_2 B B_2 C) enables lower production costs.

Economic development requires a proportional development in the fields of both productive and infrastructural projects. Expenditures in the sphere of the infrastructure decrease the cost of direct production activity. Production costs increase with decreasing infrastructural costs until a minimum infrastructural value is attained which is indispensable for obtaining any output from the direct production activity.

The national objective is to increase production at the minimum total cost, i.e. including the expenditures both in direct production activity and in the infrastructure. The curve expressing the relation between direct production costs, investment and operation costs in the sphere of infrastructure, also including investment and operation costs for water development projects, is hyperbolic. It moves gradually away from the zero point in time, due to more developed and financially more and more demanding investments.

The way to technically more developed production may be twofold:

(a) with deficient infrastructural capacity, requiring higher direct production costs,

(b) with excess infrastructural capacity, permitting direct production costs to be maintained at a low level.

The development scenario with excess infrastructural capacity (A A_2 B B_2 C) - (Fig. 5.3) enables lower production costs, thus forming more favourable productions, attracting productive investments and dynamically increasing living standards.

The development scenario with deficient infrastructural capacity, which appears in countries with slowly developing economies (path A B_1 B C_1 C), leads to higher production costs, which are then difficult to reduce in the period of a sufficient infrastructure. It is therefore advantageous to develop water investments belonging partly, in some economic models, to the production sphere, five to ten years before the full development of the production sphere.

Second principle of water development strategy:

RESPECTING THE LIMITS OF THE NATURAL ENVIRONMENT IN THE STAGE OF ITS FULL, RATIONAL AND LASTING UTILIZATION FOR THE SAKE OF HUMAN SOCIETY.

The basic objective of water development as an integral part of social and economic development can be defined simply either as

- the maximization of the living standard for the population or in its second extreme, under completely different local or environmental conditions,
- the safeguarding of the survival of the population.

The second objective may appear as decisive, not only under the speficic conditions of underdeveloped populated countries or areas with extreme climatological conditions, but also in the conditions of some developed areas whose development has already exceeded the environmental limits, i.e. the potential of renewable natural resources. As mentioned before feedbacks exist, causing a deterioration in the environmental quality as a result of any over-utilization.

The resources potential of a certain area can be defined as its ability to satisfy permanently the needs of society, arising from its socio-economic development. In can be expressed by a multitude of physical, chemical, biological and aesthetic values and be simply represented by the number of inhabitants whose nourishment and economic development it is possible to permanently sustain by agricultural or other production. Overproduction in excess of this resources potential is therefore possible, but relevant feedback causes a temporal or permanent deterioration in the environmental quality.

Water potential, which forms an integral part of this resources potential, can be defined by the

- annual discharge of the surface water and by the table and quantity of the groundwater,
- annual rainfall and the discharge coefficients,
- minimum discharges and the flow duration curve
- water quality relevant to quantity records or to the depth below the surface.

Over-utilization of the water potential causes first the decline in the water quality, and the second decline of the environment.

During the development of water resources local resources available nearby are used first. The utilization of these local water resources is, in the next development stage, often replaced by mass water supply from substantial resources of generally lower quality. The inter-connection of these mass water supply networks gradually creates regional water supply systems. The possibilities of further extensive development are exhausted by long-distance water conveyance and by the creation of an inter-regional system.

Respecting the limits of the natural environment means a rational approach from the stage of a non-systematic utilization of water resources, depending on their availability and economic feasibility, to the ultimate development stage of the full, rational and lasting utilization of water resources without any important long-term impact on the natural equilibrium.

Third principle of water development strategy:

MAXIMIZATION OF THE REQUIRED OR POSITIVE EFFECTS OF THE PROJECT AND MINIMIZING ITS SIZE AND NEGATIVE IMPACT.

This principle is derived not only from the need of economic feasibility, but also from the previous principle of respecting the environmental limits. By decreasing the size of the project, its negative impact may also be reduced and reserves left for the diverse future needs of the society.

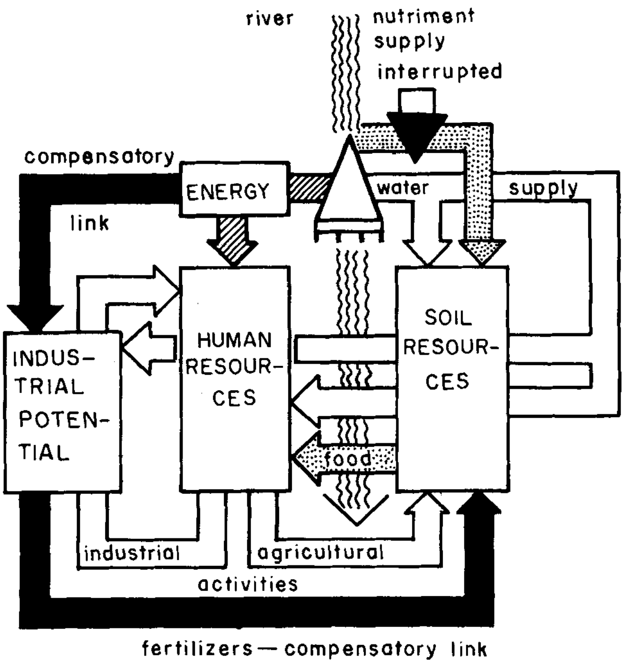


Fig. 5.4. An indispensable precondition for the efficiency of any water development measures is the maintenance of the uninterrupted structures of the system: interrupted structures have to be replaced by new ones, e.g. fertilizing effect of floods after completed flood control measures has to be compensated by artificial fertilizers, which is energy- and labour-intensive.

5.4 TACTICS OF WATER MANAGEMENT

Water requirements and water withdrawals usually exceed, or tend to exceed, the rational water requirements. In addition to this, effluents and excessive water consumption impair water quality, restricting its further utilization. The need to search for means of managing a water economy usually arises as a result of an actual or expected deterioration in water resources caused by the pollution of the area in question or of a whole country. An adequate utilization of water resources and a proper control of the use of water are impossible without an adequate utilization of all available means, which are basically:

(a)	legal	l
(b)	institutional (and organizational)	i
(c)	technical	t
(d)	economic	e
(e)	personal and moral	p

The legal, institutional, organizational, technical, economic and personal arrangements and criteria which are required to provide effective tools for the rational and integrated development, use and conservation of water resources at the national level are not very different from those required at the local level. Water withdrawals W, water consumption C and water pollution N are a function of the indispensable water requirements R_i and of the above variables:

$$W, C, N = f_{1-3} (l, i, t, e, p, R_i) \qquad (m^3.s^{-1}, BOD_5.m^{-3}) \quad (5.1)$$

From a social point of view, it is indispensable to safeguard first of all the relevant personal water requirements of any individuum as a basic precondition of his living standard. This basic quantity is to be offered to the individuum in the optimum quality and at a rate which does not substantially restrict his living standard. Water requirements and uses in industry, agriculture, energetics and transport are to be safeguarded under different economic conditions, because these bodies directly benefit from water utilization.

On the other hand, it is indispensable to use all the above tools for the protection of human society before unuseful wastage, misuse and depreciation of water resources and before overexcessive water withdrawals, demands and arrangements threaten or have a negative impact on the environment, thereby restricting the future development or negatively influencing the living standard or life-style of the society concerned.

A dominant economic characteristic of water utilities is the large investment in fixed capital, characterized by the capital-turnover ratio, i.e. gross annual revenues divided by total investment, ranging from 0.15 - 0.25 comparing with 0.3 to 0.5 for other utilities and 2.0 for manufacturing industries.

A negative relationship exists between water price and the water quantity demanded. An increase in price is associated with a reduction in the quantity demanded. Pricing policy, by affecting water requirements, is the effective tool which can, in relation to other tools, satisfy the varied goals of water management.

Domestic, industrial, agricultural and infrastructural water requirements are responsive to price changes. Concerning domestic water requirements, the change from flat rates to metered rates may result in a permanent decrease of some 30 to 40% in water use. A decrease exceeding 60% was recorded as a result of warm water supply metering and paying separately for each flat, being a result of altering basic uses, e.g. using stoppers, dishpans etc. instead of constant flow, repairing leaks in the domestic plumbing system etc.

When the ratio of water management costs to the total social property is relatively small, water development and management expenses can be fully covered either from private or from common funds. There is a great diversity in the degree of institutional integration in water management, but the growing costs of water development and management result in increasing state and international coordination and financial intervention, and in a general tendency to ensure that the users who directly benefit from such control cover the cost.

TABLE 5.2

Product	Unit	Definition	Symbol
1. Surface (raw, irrigation) water	m^3	Water withdrawn from a stream. (delivered to the user)	M_1
2. Groundwater	m^3	Water withdrawn from an aquifer.	M_2
3. Drinking water	m^3	Water corresponding to drinking water quality standards, delivered to the water user.	M_3
4. Process water	m^3	Treated water delivered to the water user for industrial use.	M_4
5. Waste water	m^3	Waste water taken away by the sewerage system to the stream or waste water treatment plant.	M_5
6. Treated waste water	m^3	Waste water treated in the waste water treatment plant.	M_6
7. Sludge	t	Utilisable waste from waste water treatment and purification plants incl. recovered material.	M_7
8. Hydropower	kWh	Energy (average continuous, peak, breakdown) generated by concentration of head and by storage, if required.	M_8

Classification of water management products.

This tendency results in the formation of river boards and water supply/disposal authorities as economic organizations safeguarding the required products, productive and unproductive services (Tab. 5.2, 5.3). Hence, the task of economic management tools is as follows:

(a) they partially or fully finance the main activities of water management organizations, which regulate water development activities,

(b) they regulate water withdrawals, water consumption and the quantity and quality of effluent,

(c) they regulate industrial and agricultural development, municipal and rural development, water power generation, inland navigation, water recreation, thus also influencing the living standard of the population, which is also directly affected by their impact on the domestic water requirements.

The determination of charges for water withdrawals, water consumption, in-stream water use, water pollution, effluent disposal, as well as variations and exemptions in these charges and rates, and using water for any of the mentioned purposes without charges, influences the social efficiency of water utilization. But the degree of such influence depends on local, and especially economic conditions. These charges and rates influence the water requirements of the population in connection with the living standard and style, i.e. the net income, standard of dwelling and social customs.

The influence of water rates on agricultural water requirements mainly depends on the cost-benefit ratio, on expenses for other arrangements needed for an increase in agricultural yield, on the market and credit possibilities, and on the inertia of traditional irrigation and other agricultural practices.

TABLE 5.3

Water management services	Unit	Definition	Symbol
Productive service:			
1. Flood control	km^2	Water resources management aimed at protection against floods and erosion.	N_1
2. Soil protection	km^2	Drainage and soil protection.	N_2
3. Navigation	tkm	Improvement of waterways, operation of locks and flow control.	N_3
4. Aquatic life management	$m^3.s^{-1}$	Water delivery and water resources management to increase especially fish production.	N_4
5. Pollution control	$m^3.s^{-1}$	Management of water resources to restrict water pollution.	N_5
6. Other productive services	$m^3.s^{-1}$	Management of water resources to enable production in other production sectors, e.g. water delivery for pump storage plants etc.	N_6
Unproductive services:			
7. Recreation and water sports	capita per season	Management of water courses to enable or improve recreation.	N_7
8. Hydrometeorological services		Collection and processing of hydrometeorological data.	N_8
9. Other unproductive services			

Categorization of water management services.

The impact of water rates on industrial water demands depends on the ratio of the water supply and effluent disposal cost to the total cost of production, on their influence on the development of the relevant industrial plant, on the water-saving technology available, on the inertia of traditional production practices, and, last but not least, on their influence on the net income of the relevant managers.

Practical water pricing systems generally represent combinations of the following water pricing possibilities:

(a) Free of charge, i.e. price of water included in general taxes,

(b) Specific water tax,

(c) Water rates

- per unit of water ($ per $l.s^{-1}$)
- per unit of product ($ per 1000 pc, per kWh)
- per unit of services (tkm)
- lump sum, without relation to the quantity of water supplied.

Rates can take the following forms

(a) uniform rates, dependent on the quantity supplied in the relevant categories of water users,

(b) rates with increase for increased quantities (supporting water saving)

(c) rates with reductions for increased quantities (supporting the development in the relevant category of water users)

(d) seasonal (depending on the balances of water resources and requirements and supporting water saving in the period of its deficiency).

Water rate per unit can be

(a) uniform for all water users,

(b) differentiated (dependent on the state social and development policy: basic quantity free of charge, lower prices for preferred water users, e.g. for agriculture, higher for high-income producers etc.)

(c) dependent on water quality (surface water, groundwater, treated water etc., class Ia, Ib, II, III, IV),

(d) dependent on the quality of the product (in energetics for kWh basic, peak, breakdown etc.)

(e) dependent on water consumption (in industry and energetics).

In the case of water rates per unit of water consumption, these can be

(a) uniform,

(b) categorised on the basis of the consumption ratio,

(c) with an increase for increased water consumption and a decrease for decreased consumption),

(d) seasonal (increased during unfavourable balance of water resources and needs).

Rates per unit of effluent can be

(a) uniform,

(b) with linear or exponential progressive increase for increased pollution,

(c) categorized according to the category of polluter (agriculture, industry, municipality),

(d) categorized on the basis of the water quantity and quality in the recipient, class Ia, Ib, II, III, IV,

(e) categorized on the basis of the effluent quantity and quality.

Legal tools can achieve similar stimulating functions to those of economic tools namely through:

(a) official duties (for utilization permissions, discharge permits, rulings etc.) P_1

(b) sanction rates, assessments P_2

(c) fines (e.g. for utilization of water in violation of valid regulations) P_3

(d) recompenses etc. P_4

Expenses connected with water development and management include

(a) management and control costs O_1

(b) operational costs for water withdrawal, distribution, purification, waste water disposal etc. O_2

(c) maintenance and reproduction costs of water development projects (depreciation costs etc.) O_3

(d) investment costs O_4

The balance of relevant benefits and expenses can be expressed by a simple equation

$$S + \sum_{k=1}^{4} O_k = \sum_{k=1}^{8} M_k + \sum_{k=1}^{6} N_k + \sum_{k=1}^{4} P_k + \sum_{k=1}^{n} G_k \qquad (5.5)$$

S - surplus required (if necessary)

G_k - grants from other sectors and bodies

O_k - expenses

N_k - accumulated charges for products connected with the water use

N_k - accumulated charges for services connected with the water use

P_k - duties, fines, recompenses etc. (if incorporated in economic tools).

The economic basis for water resources development and management has to be established by including or excluding the above mentioned components in the equation. Hence, this inclusion or exclusion and the level of the relevant charges not only decide on the creation of financial reserves, on a timely acquisition of the necessary means for operation, maintenance, investment, administrative and other costs, but also on the utilization of water resources in a socially desirable manner, on the coordination of the development rate, and, last but not least, on the development of living standards.

Bearing this in mind, water rates should be determined on the basis of the following factors:

(a) reimbursement of expenses for:

- operation,
- reproduction and modernization,
- administration,
- investment for further development,

TABLE 5.4

Factor	Basic aims in water supply	Basic aims in waste water disposal
	Reimbursement or partial reimbursement of expenses for:	
1. Financial balance	a) management and control b) operation and maintenance of water supply networks and facilities c) their modernization d) new water supply projects	a) management and control b) operation and maintenance of sewerage systems c) their modernization d) new waste water disposal projects
2. Factors of time	a) seasonal limitations of availability b) seasonal and daily limitation of requirements c) long term limitation of water needs due to limited resources	a) restriction of environmental pollution b) seasonal and daily control of waste water disposal c) limitation of lasting pollution due to resources potential
3. Factors of consumption and concentration	a) limitation of actual water consumption b) limitation of water consumption in the long term	a) limitation of concentration of toxic and other substances in waste waters b) restriction of change in ecosystems
4. Factors of quality	decrease in water requirements in the production sphere	a) decrease in water pollution b) material recovery
5. Policy	Effect of water and waste water disposal pricing on general economic development and on the living standard of population, especially on low-income groups. Effect of penalties and subsidies on water use from environmentally, regionally and socially desirable viewpoint.	

Categorization of the basic factors of water and waste water disposal pricing policy.

(b) passivity of the balance of water resources and needs,

(c) limitation of water consumption,

(d) restriction of water resources pollution,

(e) overall development goals.

The influence of economic tools on water withdrawals W, water consumption C and water pollution N ($BOD_5.m^{-3}$) can be expressed by a simplified equation 5.1 in this way

$$W , C , N = f_{1-3}(M_k) . R \qquad (m^3.s^{-1}, BOD_5.m^{-3}) \quad (5.6)$$

An increase in water rates results in a decrease in water withdrawals, in a decrease in effluent quantity and in a decrease in water consumption.

$$^1M_{1-4} > {}^2M_{1-4} \longrightarrow W_1 < W_2 \longrightarrow C_1 < C_2 \qquad \text{(see Tab. 5.2)} \qquad (5.7)$$

An exponential increase in rates for water pollution results in a drastic decrease in water pollution

$$^1M_{5-6} \gg {}^2M_{5-6} \longrightarrow N_1 \ll N_2 \qquad \text{(see Tab. 5.2)} \qquad (5.8)$$

The attributes of efficiency are associated with competitive prices. Therefore, the rates should be varied with the required changes in demand, consumption, water pollution and cost conditions. Water consumption can be influenced, i.e. decreased, by the introduction of special rates or by associating water rates with the value of the water consumption ratio

$$^1M_c > {}^2M_c > 0 \qquad C_1 < C_2 < C_3 \qquad (5.9)$$

Applying the forces of supply and demand, water withdrawals W can be expressed, according to Hanke and Davis (1971), as a reversed and exponential function of price

$$W = \frac{K}{M^e} \qquad (5.10)$$

M - unit rate

e - price elasticity of water withdrawals

K - constant, expressing the combined effect of other tools

K = f (l,i,t,e,p), and can be simply derived from indispensable water requirements R_i

$$K = k_i . R_i \quad \text{(see paragraph 3.2)} \qquad (5.11)$$

If price is to be changed from ^1M to ^2M, the expected water withdrawal W_2 can be estimated by taking the log transform

$$\text{Log } W_1 = \text{Log } K - e \log {}^1M$$
$$\text{Log } W_2 = \text{Log } K - e \log {}^2M \qquad (5.12)$$

as well as by subtracting and rearranging to find the water withdrawal W_2 from the known values of the other variables:

$$\text{Log } W_2 = e \,.\, (\log {}^1M - \log {}^2M) + \log W_1$$

In the water resources utilization sector of the economy prices are generally not determined by objective factors of supply and demand, but set by the pricing policies of utility managers. They remain constant from the season of peak availability to the season of peak demand. Available resources are used inefficiently and inequities are imposed on the utility's consumers.

The season of peak water demands frequently occurs in the period of low water availability. Water withdrawals in the season of peak water demand or in the period of low water availability are economically different from those in other periods: This water is high-cost water, because additional capacity must be provided if requirements exceed the original capacity. By not varying water rates to reflect these cost differences, investments are larger than economically justified.

The elasticity of water requirements and their sensitivity to changes in water rates vary according to the different categories of water users. But in any case the seasonal regulation of water rates decreases the difference between the maximum and minimum values of total withdrawals

$$W_{max} - W_{min} > W^+_{max} - W^+_{min} \qquad (5.14)$$

provided that W^+ and W correspond to seasonal and constant prices respectively which reimburse the same total amount.

The application of seasonal water rates for a hypothetical utility can be illustrated by two curves:

m_{min} - curve representing off-peak water requirements (for the period of an effective balance of water resources and needs)

m_{max} - curve representing peak water requirements (for the period of a passive balance of water resources and needs) (Fig. 5.5).

The constant average cost pricing line is horizontal and implies that capacity stands at some constant ratio to peak water requirements. The average variable costs are assumed to be constant and equal to marginal costs. The in-

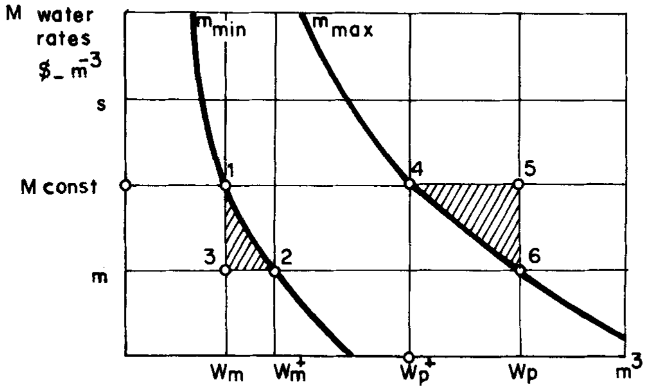


Fig. 5.5. The effect of an increase in water prices in the season of increased water requirements and drop in water availability and its off-seasonal decrease, safeguarding the same profit but increased efficiency in water use according to Hanke and Davis (1971).

cremental costs of expansion are depicted by a proxy, average variable costs plus recorded capacity costs distributed over six months.

Constant average prices result in inefficiencies during the period of peak water requirements, demanding the needlessly excessive capacity W_p. The use of water in the period of excess availability is needlessly limited, leading to withdrawals W_m.

Seasonal prices produce higher off-peak requirements W_m^+ and lower water requirements W_p^+ during the period of lack of water. Water use in the off-peak season should be allowed until the relevant incremental costs are equated to incremental value. By allowing this expansion in off-peak use there would be an efficiency gain, represented by the triangle 123 (Fig. 5.5). In the case of maximum withdrawals during constant prices W_p, the loss generated by the needlessly excessive capacity pricing rule is postulated for future years, significant reductions in water requirements can be expected, resulting in investment savings.

To relieve the problem of peak requirements occurring in the period of low water availability and safeguard a dynamic water development

(a) the water rates should refer to the actual cost structure and actual cost of resources used or saved by consumer decisions,

(b) the water rates should reflect operating costs with no, or only a partial contribution to capacity costs, if the capacity of the available resources is not adequately utilized (i.e. in the period of a highly active balance of water resources and needs),

(c) the period of an equilibrium of water resources and needs, or if requirements exceed capacity at the relevant price, the price should reflect both operation and capacity costs and should be adjusted upward to restrain water withdrawals to the capacity level, and seasonal rates should be determined to restrict the fluctuation of water withdrawals during peak and off-peak periods of demand.

A similar policy should be accepted to decrease water pollution by industry.

5.5 NON-CONVENTIONAL TECHNIQUES OF WATER USAGE

The programme in keeping with the final phase of water development, when all surface and groundwater resources are fully utilized in the conventional way, includes

- the general extension of water-saving technologies, including non-conventional water utilization and
- using non-conventional water resources or non-conventional techniques of water supply, i.e.

(a) long-distance water conveyance and long-distance transportation of water,

(b) conjunctive utilization of surface and groundwater resources,

(c) groundwater mining and artificial recharge,

(d) watershed management aimed at modifying the quantity and timing of water production,

(e) changes of total runoff, namely changes of evaporation or evapotranspiration rate, changes of snow and ice melting,

(f) weather modification,

(g) desalination, renovation of waste water, treatment of other low-quality water.

5.5.1 Long-Distance Water Conveyance and Long-Distance Transportation of Water

The problem of the long-distance conveyance and transportation of water is basically economic. During the conventional water supply the costs for water withdrawals and treatment prevail:

$$M_w + M_t \ll M_c \cdot L$$

M_w - specific cost for withdrawal of 1 m^3 of water (\$ per m^3)

M_t - specific cost for treatment of 1 m^3 of water (\$ per m^3)

M_c - specific conveyance cost for transport of 1 m^3 of water (\$.m^{-4})

The total specific cost M_o is, therefore,

$$M_o = M_w + M_t + M_c \cdot L \qquad (\$ \text{ per } m^3) \qquad (5.16)$$

and $M_o = (r_{tc} + 1) \cdot M_c \cdot L$ (5.17)

$$r_{tc} = \frac{M_w + M_t}{M_c \cdot L}$$

L - conveyance distance (length of the headrace or pipeline) (m)

r_{tc} - ratio of water supply and transport costs

Water losses during water conveyance depend first on the construction of the conveyance structures and second on their length. Leaving the losses which occur during water withdrawal and treatment aside, the water quantity supplied can be simply expressed on the basis of the quantity withdrawn as

$$D = (1 - c_w \cdot L) \cdot W \qquad (5.18)$$

D - water delivery - quantity of water supplied $(m^3.s^{-1})$

W - water withdrawal $(m^3.s^{-1})$

c_w - coefficient of specific water conveyance losses (m^{-1})

The total expenses of water supply can be similarly derived as

$$D \cdot M_o = W \cdot (M_w + M_t) + D \cdot M_c \cdot L$$

$$(1 - c_w \cdot L) \cdot M_o = M_w + M_t + (1 - c_w \cdot L) \cdot M_c \cdot L$$

$$(1 - c_w \cdot L) \cdot (M_o - M_c \cdot L) = M_w + M_t$$

This equation can be simplified to

$$M_o = M_c \cdot L \cdot \left[1 + \frac{r_{tc}}{1 - c_w . L} \right] \qquad (\$ \text{ per } m^3) \qquad (5.19)$$

Comparing two water conveyance projects of the same capacity (M_{c1} M_{c2} , c_{w1} c_{w2}), a limiting distance exists which has the same total conveyance cost in both cases:

$$(1 - c_{w1} \cdot L_m) \cdot W_1 = (1 - c_{w2} \cdot L_m) \cdot W_2 \qquad \text{(see eq. 5.18)}$$

$$W_1 \cdot M_{c1} = W_2 \cdot M_{c2}$$

$$L_m = \frac{M_{c1} - M_{c2}}{c_{w2} \cdot M_{c1} - c_{w1} \cdot M_{c2}} \qquad (m) \qquad (5.20)$$

L_m - marginal transport distance, requiring the same costs in both alternatives, i.e. one alternative is more feasible for longer conveyance distances and the other (with higher conveyance losses) for shorter ones.

The above equation is valid only for comparing projects which have the same costs for water withdrawal and treatment. It goes without saying that this limiting transport distance depends on the discharges diverted, their quality and purpose of their utilization.

The same equation can be applied for the option of transporting water from surplus areas to water-short areas by using cistern wagons, tankers or towing mammoth containers or blocks of icebergs. The realistic distance from the source to the receiver has to be in the order of below 2500 km, and the maximum size of the container approaches some 1.5 million m^3.

5.5.2 Conjunctive Use of Surface and Groundwater Resources

The volume in groundwater resources exceeds by more than a thousand times the volume of fresh water in all water courses. Half of this amount is available at a depth below 1000 m, but its quality is not sufficiently known and the rate of its natural replenishment is extremely low (see Tab. 1.1).

The over-excessive extraction of water from groundwater resources has the same character as mining minerals and causes similar environmental effects: settlement of the Earth's surface, ecological damages, diminution of discharges in rivers and streams, difficulties with both surface and groundwater quality etc.

Pumping from deep aquifers is energy-demanding. Owing to the high fluctuation of water tables, which is due to changing lifts, pumps often work under conditions of low pumping efficiency. The temperature of water from deep aquifers is often higher and depends not only on the depth but also on the geological age of the strata, - younger geological formations contain water of higher temperature.

Nevertheless, aquifers can be successfully used in conjuction with surface water resources, especially in the period of peak demands and in dry periods. Thick, interstitial aquifers in natural dry conditions, or only filled up with water to a minor extent, can be used as underground reservoirs to store large quantities of water of acceptable quality for the period of peak requirements.

Artificial infiltration can increase the quantity of water in groundwater resources by the help of infiltration basins, channels and artificial channels, infiltration galleries and wells, working in the period of excess water in surface resources. An overpumping of these groundwater resources in the period of drought may contribute considerably to balance water availability and needs even in the period of peak demand (see paragraph 5.5.3).

The conjunctive use of surface and groundwater resources means a coordinated utilization of available water discharges as well as reservoirs and compensation for a lack of water in two or more successive dry years by groundwater for seasonal, annual and carry-over storage.

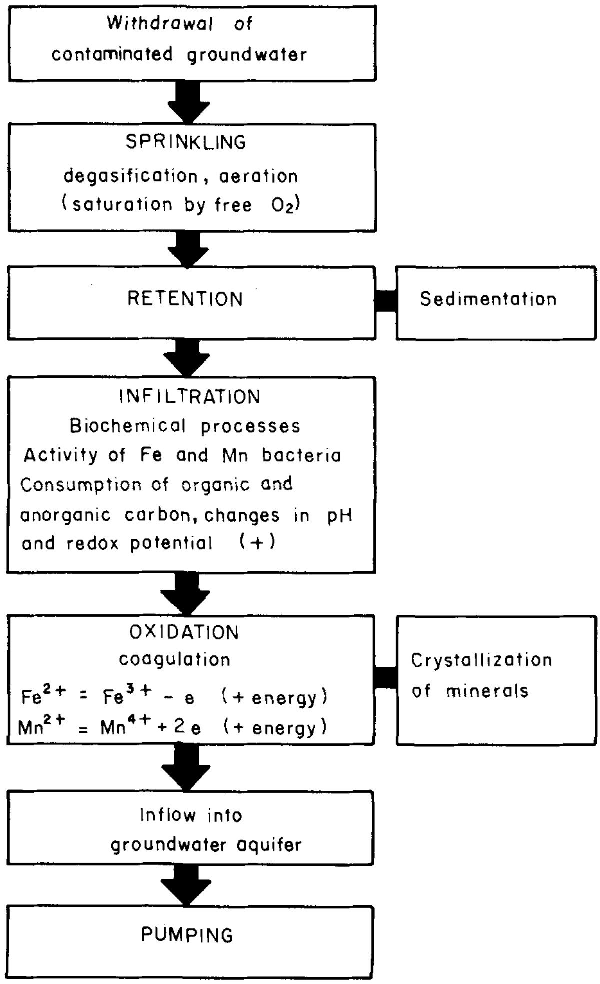


Fig. 5.6. Flow chart diagram representing the basic processes of the utilization of geological strata to change water quality, explored by Hatva and Reijonen (1972).

The drop of the groundwater table provokes a more efficient natural recharge, also from non-utilized strata which do not normally contribute to the groundwater reserve of the aquifer in question. The volume of water extracted from groundwater resources in a dry year may, under favourable geomorphological and topographical conditions, even exceed the average annual recharge, provided the surface reservoirs safeguard the recharge during wet years.

The conjunctive use of surface and groundwater resources also forms conditions for water storage in locations where construction of a surface reservoir is not feasible, offering possibilities for economizing on the size of reservoirs and their use for carry-over storage. It restricts the space requirements for water development projects, thus enabling better utilization of the land surface.

In this way the availability for operational runoff regulation is utilized in an integrated and environmentally feasible manner, restricting the evaporation losses and also improving the water quality: artificial recharge offers favourable conditions for water treatment (Fig. 5.6).

Among the other advantages of the conjunctive use of surface and groundwater resources, the construction in stages should be mentioned: this enables the step-by-step connection of the new resources to the existing system of mass water supply for population, industry and agriculture. The conjunctive use of surface and groundwater resources economizes on the construction of the distribution and drainage network for irrigation: the groundwater table can be regulated by means of relevant recharge and supply wells, and the lining of distribution canals can be restricted, because the percolation losses recharge the groundwater reserve. A more flexible irrigation regime facilitates their operation, making it possible to pump outside the period of peak energy demand.

The main obstacles to a desirable development of the conjunctive use of surface and groundwater resources include:

(a) gaps in the investigation of deep aquifers,

(b) technical problems of waterlogging and clogging during infiltration,

(c) higher operational costs due to higher consumption of energy during extraction of groundwater from deep aquifers,

(d) institutional gaps and diversity in investigation of surface water and groundwater (see paragraph 3.1),

(e) the lack of common understanding between the relevant surface and groundwater specialists as well as tradition.

5.5.3 Groundwater Mining and Artificial Recharge

Under special economic and environmental conditions groundwater can be extracted as an exhaustible recource of fixed supply on a mining-yield basis. Mining yield is a total volume of non-renewable water in an aquifer, analogous to a mineral deposit (see paragraph 3.2). Five types of overdraft have to be recognized according to Snyder (1955):

(a) Development overdraft, a necessary first stage in groundwater development in that withdrawals cause a lowering of the water table in areas of natural recharge and discharge. This permits full utilization of the interaction between the components of the hydrologic cycle.

(b,c) Seasonal (annual) or cyclical (periodic) overdraft, both characterized by a zero net change in water levels over a specified interval of time. Seasonal overdraft occurs when water levels at the beginning of the pumping season remain the same from year to year, but are in a continual state of decline during pumping seasons. Cyclical overdraft exists when water levels decline over two or more seasons, but eventually return to their original level. These types of overdraft are relatively unimportant and depend a great deal on the seasonal or annual demand for water.

(d) Long-run overdraft is perennial pumping in excess of natural replenishment, which may lead, ultimately, to depletion.

(e) Critical overdraft occurs when pumping leads to some undesirable physical result, restoration from which is technologically or economically impossible.

If environmental restrictions (see paragraph 5.5.2) are not taken into account then long-run overdraft is profitable as long as annual net revenue from water mining exceeds the capitalized annual loss in value of recharge. Assuming that natural replenishment is constant and independent of the stage of storage development, Domenico and others (1968) determined the optimal-mining yield as

$$V_{my} = \frac{M_w}{M_p . S} - \frac{G_r}{r} \qquad (m^3) \qquad (5.21)$$

M_w - net unit value of water at the beginning of pumping ($\$.m^{-3}$)

M_p - marginal cost of pumping ($\$.m^{-4}$)

r - rate of interest

G_r - natural recharge (m^3)

$S = \frac{dh}{dV}$ - water level decline per unit of storage withdrawal ($m.m^{-3}$)

As a marginal cost of pumping becomes high, or the interest rate becomes small, the mineable volume is low, which indicates that a sustained yeild policy is desirable. Equilibrium storage is achieved when the rate of extraction is equal to natural (or natural and artificial) replenishment. The optimal water use policy then specifies use rates below natural recharge when storage is below its equilirbium value, the tendency being to move toward equilibrium storage.

Artificial recharge of groundwater may be defined as the planned activity of man to augment the natural infiltration of precipitation, surface and other water into underground formations with the objective to

(a) reduce overdraft and replenish depleted aquifer,

(b) store water for periods of lack of surface water or for periods of substantial drop in water quality of other resources.

(c) transport water to the locality of use,

(d) maintain the requested groundwater level (equilibrium storage),

(e) prevent intrusion of low quality water,

(f) improve the water quality by infiltration, and, under special circumstances,

(g) dispose unwanted water, industrial and mining wastes as well as toxic substances.

Methods of artificial recharge may be classified according to Huisman and Olsthoorn (1982) in two groups:

(a) indirect methods (induced recharge) in which increased replenishment is obtained by locating the means for groundwater abstraction as close as practicable to areas of natural discharge or effluents.

(b) direct methods, in which water from surface sources is conveyed to suitable aquifers where it is made to percolate into a body of groundwater.

Direct methods of artificial recharge are to be practised mainly when:

(a) sealing of a river bed seriously reduces the capacity of natural infiltration,

(b) the river bed is not in direct contact with the suitable aquifer,

(c) the supply area is far away from a suitable location of induced recharge,

(d) the surface water requires treatment or storage, which can be avoided by aquifer recharge.

The choice of the appropriate method of direct artificial recharge is governed mainly by topographic, geologic and economic conditions:

(a) when the aquifer extends to the ground surface, shallow ponds formed by a network of dikes and levees, further ditches and furrows, adapted to irregular terrain, modified dry stream beds or relatively flat land may be flooded to increase the area over which infiltration occurs and extend its duration,

(b) when the aquifer is situated at moderate depth, it can be replenished through shafts, pits and basins, e.g. through abandoned gravel pits,

(c) when confined and unconfined aquifers are situated at some depth below the ground surface and are topped by a semi-pervious or impervious layer, they can be replenished through wells and galleries.

5.5.4 Watershed Management

Watershed management is the planned use of land to conserve natural resources and produce renewable ones by an appropriate form of land and resources use and non-use, by modifications to the vegetative canopy and other measures to change surface runoff into groundwater runoff.

Vegetation extracts water from the soil and transpires it into atmosphere, thus reducing the total runoff. Land management practices designed to affect the volume and timing of the surface and groundwater runoff involve modifications to the vegetative canopy.

Timber harvesting methods which reduce evapotranspiration rates and increase snowmelt include block and strip cutting as well as thinning. Heavy vegetation, phreatophytes, with a deep and extensive root system, also extracts water from deeper strata which are normally affected by evapotranspiration. Clear-cut watersheds yield an increase of 20%, even recharging 450 mm in humid areas. A reduction in phreatophytes results in a 5 - 15% increase: the replacement of old forests by young ones increases water yields, as does the conversion of pine forests into hardwood forests too, due to the greater interception losses and the longer period of intensive transpiration of evergreens.

The conversion of brush or chaparral into grass, and forests into forbs and shrubs generally increases the flow from the watershed. But the water yield may drop below the original value, when e.g. the grassland is lush from sufficient water supply and efficient fertilization.

Water yields which are obtained by vegetation conversion and/or removal and fall back to the original, pre-treatment levels with regrowth or as the natural cover becomes re-established. The yield increment corresponds to the difference in water requirements off the original and converted vegetative canopy. The change affects the natural ecosystems, with a possibly negative impact on wild-life and habitat. Management activities may involve problems with erosion, peak flows and water quality. Water yield increases are economically feasible if combined with other forest management objectives, especially timber production.

Runoff phenomena are the integrated result of overall watershed behaviour. The lack of understanding of the causal mechanisms limits the degree to which data obtained from pilot studies can be extrapolated for complex watersheds in order to forecast integrated hydrological responses on watersheds under different geomorphological and climatological conditions.

The type of vegetation can to a certain degree also affect the amount of water transpired. But evapotranspiration depends more on the climate: its rate is extremely high wherever heavy and dense vegetation, energy and moisture input occur together.

The suppression of evaporation is, therefore, of key importance in tropical areas, especially in arid and semi-arid areas. Measures to decrease the evaporation include in particular:

(a) surface-area reduction (removal of phreatophytes, groundwater storage, reservoirs with minimum ratio of area to storage, narrowing and straightening of channels etc.)

(b) reduction in moisture gradient (e.g. by limitation of air circulation by windbreaks)

(c) reduction in energy input (e.g. by protecting the surface by mechanical covers - roofs, floating rafts, screens or granulated material reflecting solar energy)

(d) evaporative suppressants (layers of porous material, dust mulch, quickly drying cultivated surface soil layer, pebble and paper mulch, chemical alteration of the soil surface e.g. by polyelectrolytes, thin impervious layers which form resistance in the evaporation process).

One of the basic tools available for the suppression of both evapotranspiration and evaporation are films of monomolecular thickness, e.g. the longer carbochain alcohol mixtures, straight-chain fatty alkanols incl. hexadecanol, octadeconal, ethylene oxide, dosoconol, ethylated ethers etc. All these chemicals have to be non-toxic, having no detrimental effects on man, fish, fowl and wildlife. They must form a thin continuous impervious layer, penetrable by raindrops and closing again after being broken, pervious to oxygen and carbon dioxide.

It is generally cheaper to use powdered monolayers for this purpose than liquid forms such as hot solutions and emulsions. The effects of monolayers on food chains in open lakes have been found to be negligible, with some beneficial interference with insect occurrence. The physical and chemical changes in water quality, such as a slight increase in water temperature and dissolved oxygen, have been found to be minor and not adverse. Any increase in bacteriological populations can be easily controlled by addition of normal bactericides.

The degree of the reduction in evaporation and evapotranspiration varies with the thickness of the applied film and with the kind of surface or plant. It also depends on the deterioration effect of winds, which occurs on free water surfaces after winds with a speed in excess of 8 km per hour. According to Haeussner (1972) reduction rates of 8 - 14% are reported for reservoir surfaces, and higher rates for smaller reservoirs. Reduction rates of up to 40% and 20% are reported for bare soils and citrus trees respectively. Due to the degradation, the maximum effect on reservoir surfaces within the first day decreases to a value of some 15% of the initial one within about ten days.

The quantity and timing of water production from glaciers, ice and snow can be achieved by a change in the albedo. A thin layer (1 mm) of light ashes, coal dust, foundry sand etc. can be used for this purpose, resulting in a reduction in the albedo from 0.6 to 0.1 and an increased rate of melting, depending on the solar energy input. Under favourable conditions the yield from glaciers can be doubled. According to Meir (1964) the mentioned change in the albedo results in an increment of 2.4 m^3 of water from 1 m^2 of glacier surface.

The disadvantages of this practice of runoff augmentation include the following negative environmental effects

(a) temporary deterioration in the scenary, which is otherwise attractive from the recreational point of view,

(b) water pollution by fine suspended matter, which is nevertheless not important from the water use point of view.

Depending on the balance of the hydrologic cycle, water which has been artificially withdrawn in this way can be recharged naturally. If not, the following practices for decreasing the rate of the melting process and the artificial recharge of water in glaciers have proven feasible:

(a) insulatory cover of the glacier surface, e.g. sawdust,

(b) snow breaks,

(c) weather modification, i.e. cloud seeding in winter.

5.5.5 Weather Modification

Water from the atmosphere can be extracted by various techniques of vapour condensation. These practices concern both the lower and upper layers of the atmosphere.

The moisture of the low atmosphere layers can be artificially condensed, the natural interception and fog drip increased and an accumulation of the resulting flow achieved by various technical measures and cultivation practices, such as by tree or other wood plantations in locations with favourable conditions for vapour condensation, by vegetative measures on and arrangement of the land surface, the installation of impervious sheets, the installation of constructions with plastic fibres, acting as water condensers and collectors, by applying various chemicals and by electrical means. The feasibility of such measures and arrangements depends on local conditions. Satisfactory quantities of water can be gained especially in areas with a high air humidity, being frequently in clouds, or where ground fogs are frequent - in mountains, maritime and submountain areas.

Artificial precipitation, augmenting natural rainfall within meteorological limits at a given place and time, requires a comprehensive understanding of the physics of rainfall occurrence. The problem of weather modification consists especially in:

(a) determining the need of this treatment and its justification,

(b) recognizing a suitable opportunity,

(c) method of delivering the required treatment,

(d) method of evaluating the result of this treatment,

(e) unpredictable impact on long-term changes of climate,

(f) compensating for economic benefits and losses in the areas affected, and for possible adverse impacts on the environment.

Rainfall and snowfall can be influenced by changes in the heat balance in the atmosphere. Its equilibrium can be affected e.g. by cool water pumped from deep sea layers.

A feasible technology for gaining more water from showers over agricultural areas in summer and increasing snowfall or rainfall in mountains is offered by cloud seeding. This technology consists in dispersing condensation nuclei - silver diiodide AgJ_2, ammonium nitrate NH_4NO_3, compounds of urea and their combinations, other hygroscopic materials, e.g. finely divided common salt NaCl, by burning propane and acetone solutions of silver diiodide or by the electric disintegration of the various compounds whose product this silver diiodide is.

Cloud seeding is practised from aircraft or directly from the ground surface, using upward air currents. The air mass movement cannot be determined with the required accuracy, unless limited by a land surface, e.g. by a mountain barrier.

But uncertainty still remains, in the case of both cold and warm cloud seeding, because the rainfall mechanism is extremely complicated (Fig. 1.8); it depends on air conditions including wind profiles, updraft velocity, on a good supply of supercooled liquid droplets and low concentrations of freezing nuclei, on the course of the coalescence growth process etc.

Summer cumulus producing moderate showers and shallow winter clouds, formed by the mountain-produced lifting of moist air, offer suitable seeding opportunities. The seeding of heavy summer rain clouds and deep winter clouds can even decrease precipitation in comparison with the normal rate.

Current techniques have little value in areas with very low rainfall occurrence and during dry periods in areas of medium precipitation. The best results are still achieved in regions where, and during seasons when natural rainfall is most likely.

The evaluation of the results of cloud seeding is based on probabilistic methods. Due to the great variations of precipitation over time and space, methods which compare the target area and control area data are more reliable but not sufficiently free of uncertainty.

The economic effects and losses caused by cloud seeding bring about serious problems of compensation or reimbursement. This treatment may not only cause excessive floods or hail events, but also avalanches in mountainous areas. It negatively affects other areas as well, where a substantial decrease in rainfall may occur. Cloud seeding which results in increased precipitation over continental areas with a precipitation deficiency and reduces precipitation over seas is the only case where this discrepancy does not appear.

The efficiency of cloud seeding, ranging from 8 - 15 percent of the expected values for annual rainfall (the limit of a possible increase by improved application being estimated at some 30%), may under favourable conditions be of crucial importance for saving the harvest in critical dry periods.

5.5.6 Desalination and Treatment of Low-Quality Waters

Water desalination and the treatment of low-quality waters may prove to be practicable solutions to the problem of water shortage in certain restricted areas. Salinity control measures which reduce the salinity of surface water discharges include:

(a) point source control, insulation of a localized area or removal of a source which contributes an extremely salt load to the system (insulation of salt plugs, diversion or desalination of salty springs, mine drainage, decreasing the table of salty groundwater, beneficial consumptive use of the salty water within the catchment, utilizing saline return flow from irrigation etc.),

(b) diffuse source control, i.e. control of salt concentration and disposal spread over large areas (collection and consumptive use, evaporation, desalting, measures of watershed management etc.),

(c) reduction of evaporation and evapotranspiration (especially in regions of groundwater recharge, improving irrigation efficiencies, by watershed management measures incl. phreatophyte removal etc.),

(d) desalination of the discharge.

Most natural waters are not sufficiently suitable for desalination, but pretreatment can sufficiently modify their quality for subsequent

- distillation processes,
- membrane processes, i.e. electrodialysis and reverse osmosis,
- chemical processes, especially by ion exchange,
- crystalization, especially freezing processes.

These techniques can be applied for the desalination of sea water, surface and groundwater as well as for the desalination of geothermal water resources. Desalting processes are still economically feasible only under special circumstances, being used almost exclusively for drinking or feed water supply. The basic problems involved in desalination are

(a) high energy input requirements,

(b) disposal of residual salts.

Similar problems are also encountered in techniques for treating low quality waters e.g. heavily polluted waste water for re-use, which are essentially concerned with the removal of nitrogenous compounds, phosphorus, heavy metals, other dissolved inorganic compounds, as well as with the inactivation of pathogens.

5.6 CONCLUSIONS

At present, at the dawn of a combined population and technological boom, it is indispensable not only to declare, but also to safeguard in a rational and planned manner the right of mankind and of each individual to live in sufficiency and beauty. It is, therefore, essential to accept population growth and the associated development of heterogeneous demands as the basic criterion for making decisions concerning the allocation of water and other natural resources.

The utilization of water and other natural resources is a precondition of economic growth. The dramatic pace of current economic development, however, is based on an over-utilization of these resources. While some natural resources (such as air, water and soil) are renewable, they may - and increasingly do - become gradually deteriorated as a result of the secondary effects of their development. An over-utilization and excessive deterioration of natural resources, results in additional and inordinate restrictions on future development. It is, therefore, absolutely necessary to manage the given development process within the framework of the biosphere, taking into account the numerous functional relationships as well as environmental constraints, and to make optimum use of all water and finite natural resources.

The recognition of this new responsibility for integrated development/biosphere management is a crucial first step to achieving sustainable economic growth. To move towards this policy, it is possible to choose optimum scenarios by means of modelling and optimization.

The very serious environmental constraints which could arise through the interaction of agricultural, industrial, urban and rural development on the one hand and the biosphere on the other hand may require such measures as:

- the revision of raw/waste material use/re-use and water/waste water utilization in industry,
- the revision of land use patterns and forestry/agricultural/irrigation practices etc.

A new and complex interdisciplinary theory has to be developed for the approach described above, penetrating into every activity of mankind. The present monograph attempts to formulate at least part of this theory, the theory of water development and management, from this point of view and so form the basis for a deeper understanding between civil engineers, economists, natural scientists and other specialists involved in the gradual change in current practices towards a rational and balanced utilization of the biospheric system in this particular field.

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