The Extreme Earth

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Foreword by
Geoffrey H. Nash, Geologist

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This book is dedicated to the world's libraries, repositories of great knowledge and enlightenment. Also to the librarians, who both guard that knowledge and dispense it with remarkable expertise and good cheer. And to my mother, Helen Anderson Burnham, a librarian of the highest caliber, who brought the joy of good books, not only to her children, but also to thousands of appreciative patrons.

RIVERS

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Contents

Foreword

Rivers are powerful forces of nature. Most move night and day, season after season, with relentless motion toward the ocean. Mountain tributaries rush over boulders and wear down mountains. Away from the steep slopes, rivers meander slowly downhill before dropping their accumulated sediment in the ocean. In spring, some become raging torrents; in winter, some freeze solid. Some seem to wander aimlessly; others flow with great dispatch toward the ocean. Constantly moving and changing, they are endlessly fascinating.

Rivers provide drinking water for innumerable cities, haul commodities to market, and offer ever-changing vistas. But they are destructive as well as nourishing. Despite efforts to control their flow, rivers are dangerous when their channels are full, and their tendency to flood has wreaked havoc on low-lying areas. Our dependency on such fickle forces of nature alternately draws us to them and at times punishes us for living too close to their fertile plains and beautiful shores.

Rivers by Laurie Burnham immerses the reader in the development of 10 rivers of the world that are unmatched in length; many are also unmatched in their influence on human history. In the first chapter, readers are introduced to Africa's Nile River, whose waters helped create the cradle of civilization. To water their crops, the early Egyptians built sophisticated irrigation systems, which laid the groundwork for their civilization. The next chapter describes the Amazon River in South America with its phenomenal biodiversity. Other chapters highlight China's Yangtze River, which has been a powerful force throughout Chinese history, but today is tainted by rampant industrialization, and the Mississippi River, an icon of American expansion and the setting for Mark Twain's most famous stories.

From time immemorial, rivers have provided human beings with food and water, the basics of life. They have also been co-opted as sewers to carry away human waste and pollution. Not surprisingly, so much riverborne waste is degrading our drinking water and also our oceans. An extensive dead zone now exists offshore from the Mississippi delta, where little life is evident in the oxygen-starved ocean waters. Rivers are dammed to produce hydroelectric power for industrial development and are diverted for use by farmers and factories. Rivers are also incubators for fish species, such as salmon, which begin and end their life cycle at spawning grounds far upstream. Some, such as Asia's Amur River, form handy political boundaries between countries, even though sharing a river can make managing the river more difficult. Some rivers are so overexploited that little of their annual flow ever reaches the ocean.

Readers of this book will be exposed to the vocabulary of geologists, geographers, and engineers and come to understand terms such as *delta, braided stream,* and *sandbar.* Laurie Burnham's book takes readers on a global journey to the world's major rivers and explains why they sustain life on Earth. Only 3.5 percent of our planet's water is freshwater, and of all the water on the Earth, only 0.006 percent is in rivers. No matter where one lives in the world, it is easy to see how freshwater will become significantly more valuable as it becomes scarcer. An appreciation of the origins and function of rivers will hopefully lead to the desire to protect these natural wonders for the future.

—Geoffrey H. Nash, geologist

Preface

From outer space, Earth resembles a fragile blue marble, as revealed in the famous photograph taken by the *Apollo 17* astronauts in December 1972. Eugene Cernan, Ronald Evans, and Jack Schmitt were some 28,000 miles (45,061 km) away when one of them snapped the famous picture that provided the first clear image of the planet from space.

Zoom in closer and the view is quite different. Far beneath the vast seas that give the blue marble its rich hue are soaring mountains and deep ridges. On land, more mountains and canyons come into view, rugged terrain initiated by movement beneath the Earth's crust and then sculpted by wind and water. Arid deserts and hollow caves are here too, existing in counterpoint to coursing rivers, sprawling lakes, and plummeting waterfalls.

The Extreme Earth is a set of eight books that presents the geology of these landforms, with clear explanations of their origins, histories, and structures. Similarities exist, of course, among the many mountains of the world, just as they exist among individual rivers, caves, deserts, canyons, waterfalls, lakes, ocean ridges, and trenches. Some qualify as the biggest, highest, deepest, longest, widest, oldest, or most unusual, and these are the examples singled out in this set. Each book introduces 10 superlative examples, one by one, of the individual landforms and reveals why these landforms are never static but always changing. Some of them are internationally known, located in populated areas. Others are in more remote locations and known primarily to people in the region. All of them are worthy of inclusion.

To some people, the ever-shifting contours of the Earth are just so much scenery. Others sit and ponder ocean ridges and undersea trenches, imagining mysteries that they can neither interact with nor examine in person. Some gaze at majestic canyons, rushing waterfalls, or placid lakes, appreciating the scenery from behind a railing, on a path, or aboard a boat. Still others climb mountains, float rivers, explore caves, and cross deserts, interacting directly with nature in a personal way.

Even people with a heightened interest in the scenic wonders of the world do not always understand the complexity of these landforms. The eight books in the Extreme Earth set provide basic information on how individual landforms came to exist and their place in the history of the planet. Here, too, is information on what makes each one unusual, what roles they play in the world today, and, in some cases, who discovered and named them. Each chapter in each volume also includes material on environmental challenges and reports on science in action, with details on field studies conducted at each site. All the books include photographs in color and black-and-white, line drawings, a glossary of scientific terms related to the text, and a listing of resources for more information.

When students who have read the eight books in the Extreme Earth set venture outdoors—whether close to home, on a family vacation, or to distant shores—they will know what they are looking at, how it got there, and what likely will happen next. They will know the stories of how lakes form, how wind and weather work together to etch mountain ranges, and how water carves canyons. These all are thrilling stories—stories that inhabitants of this planet have a responsibility to know.

The primary goal of the Extreme Earth set of books is to inform readers of all ages about the most interesting mountains, rivers, caves, deserts, canyons, waterfalls, lakes, ocean ridges, and trenches in the world. Even as these books serve to increase both understanding of the history of the planet and appreciation for all its landforms, ideally they also will encourage a sense of responsible stewardship for this magnificent blue marble.

Acknowledgments

A book is never the product of one person writing in isolation. Books happen because friends, colleagues, relatives, and publishers believe in their intellectual merit and willingly offer support, commentary, cajolement . . . and criticism.

Rivers would not have happened without such a broad network of people who believed the project had merit. Among the book's most ardent supporters were librarians, who found reams of arcane data for me, endlessly renewed my overdue books, and opened their doors—and online search engines—to my inquisitive needs. In particular, I would like to thank the research librarians at the Library of Congress, the University of Minnesota, the University of Maryland, Macalester College, and Dartmouth College. In addition, I thank the librarians of Thetford's Latham Library, Hanover's Howe Library, and the St. Paul Public Library.

I am also indebted to the publisher's staff for their never-failing support. I thank my editor, Frank Darmstadt, for his (almost) unrelenting patience, for his insightful queries, and for his wonderful attention to detail. He has proved an excellent taskmaster. I am most beholden to Diane K. French, photo researcher extraordinaire. Thanks to her keen eye and hard work, this volume is alive with evocative photographs.

Thanks, too, to my agent, Jeanne Hanson, who brought this project to my attention. Without her encouragement, I would not have written a word. I am deeply grateful.

A bevy of friends, including Holly Brewer, Susan Brison, Karen Bromelkamp, Ann Bumpas, Mary Hoather, Nancy Ninteman, Pi Smith, Melissa Stockdale, and Gayle Winegar, provided encouragement and assistance of various kinds throughout the writing process. Dana Boyle introduced me to pingos, and I owe their mention in this book to her. Tim Jones taught me about dredging. Ken Miyata introduced me to the Amazon. Erika Stenrick entertained me with tales of the Yangtze.

Most of all I am grateful to my family, Adam, Linnea, and Emma. They encouraged me. They helped me. They coddled me. They were beyond patient. They mean everything to me.

In addition, I am indebted to Geoffrey Nash, author of the book's foreword, who brought both geological wisdom and a keen eye to the manuscript, correcting errors, adding substance, and cajoling me to say more about such droll topics as woolly mammoths and pink dolphins. He was a wonderful surprise.

Introduction

[Rivers] are the natural highways of all nations, not only leveling the ground and removing obstacles from the path of the traveler, quenching his thirst, and bearing him on their bosoms, but conducting him through the most interesting scenery, the most populous portions of the globe, and where the animal and vegetable kingdoms attain their greatest perfection.

—Henry David Thoreau

Rivers flow across continents, form boundaries between nations, give rise to biological diversity, and allow for the growth of cities and commerce. Without rivers, life on Earth as we know it would not exist. They are the bloodlines of our planet, transporting water to the far reaches of the Earth and delivering moisture to lands that would wither without this essential life ingredient.

Rivers carve our landscapes, create breathtaking scenery, and maintain our planet's equilibrium by shunting water molecules that fall from the sky to the oceans in a never-ending continuum. They also tug at our heartstrings, beckoning us to picnic by their shores, swim in their waters, and paddle their currents. Explorers and geologists have long been drawn to rivers, pulled by a desire to traverse them from beginning to end and in so doing better understand our planet. Thanks to their efforts, much is now known about the world's waterways.

Why do rivers exert such emotional pull? Because—like mountains—they are there, beckoning adventurers onward, offering the thrill of discovery, the excitement of not knowing what lies around the next bend, the chance to be the first. The story of British missionary and explorer David Livingstone's seven-year (and ultimately unsuccessful) quest to find the headwaters of the Nile remains one of the great adventure tales of all time (see chapter 1).

Rivers, one of eight volumes in the Extreme Earth set, promises its readers an extraordinary armchair adventure. We will begin our tour of the Earth's legendary rivers in northern Africa and from there go to South

America, North America, and Asia. Here, in alphabetical order, are the rivers that are profiled in this book:

Amazon in South America
Amur in northern Russia
Congo in sub-Saharan Africa
Huang Ho (Hwang River, Haunghe) in China
Mackenzie in Canada
Mississippi in the United States
Nile in northern Africa
Ob' in Russia
Yangtze (Yangzi, Chang) in China
Yenisey in Siberia

Each of these 10 rivers boasts extraordinary power. Each one is extreme in its own way, bigger and better than countless other rivers that traverse the planet. And while there is no consensus on what constitutes greatness in a river, great rivers generally reflect some combination of length, volume, and speed, all of which are hard to measure. The 10 rivers in this volume appear repeatedly on top-10 lists compiled by credible and authoritative sources such as the American Geophysical Union, the U.S. Geological Survey, the National Geographic Society, and the Encyclopaedia Britannica.

The result is a collection of dazzling waterways. The giant Amazon passes through some of the richest ecosystems our world has ever known. The Nile—rife with mystery and intrigue—bisects the cradle of human civilization. The United States's mighty Mississippi, which was brought to life in the writings of Mark Twain, remains an industrial and cultural icon. Also included in this volume are the major waterways of China: the Yangtze, which has long been a critical means of transportation, is now an industrial superhighway. The Huang Ho is China's "sorrow" for its floods that have robbed millions of their lives. In sub-Saharan Africa, the giant horseshoe-shaped Congo runs both fast and slow but is always treacherous. The Mackenzie River flows through the pristine forests of northern Canada before emptying into the Arctic Ocean. Rounding out the list are the great rivers of Siberia: the Ob', the Amur, and the Yenisey that traverse subpolar forests and are frozen solid some six months a year.

I have felt the flowing waters of only two rivers on this list, yet those experiences are unforgettable. In Minnesota, I have forded the mouth of the Mississippi, a tiny trickle that is easily crossed in a couple of steps; I marveled that a body of water so seemingly insignificant could be the same river that reaches some 3,500 feet (1,067 m) in width by the time it roars through St. Louis. And in Ecuador, I have paddled a canoe down the muddy waters of an Amazonian tributary, alert for anacondas, poison darts, and submerged tree trunks, ever mindful that these waters course through and sustain vast tracts of rain forest teeming with biological riches.

These two rivers, along with eight more, are described in detail in this book, each in its own chapter. Information is provided about the geological, ecological, and cultural history of each waterway, as well as its appearance, length, volume, flow, drainage area, and economic significance. Recent studies, environmental threats, and other noteworthy news are also included. Come join me now to learn not only how each super river was formed but also why each is both unique and vital to our planet.

Origin of the Landform

Rivers

A river seems a magic thing. A magic, moving, living part of the very earth itself.

—Laura Gilpin, *The Rio Grande*, 1949

Rivers have adorned the Earth's surface for billions of years, ever changing and ever moving. They change course as continents drift apart and come together, as mountains rise and fall, as canyons and bends form. They move as if alive, with the power and unpredictable behavior of a living organism. They travel, carry, destroy, build up, swell, and shrink.

Rivers carve their way through majestic mountains, roil through gorges, meander through farmland, and spew great volumes into the ocean. No two are alike. Some pound and thunder downstream, churning through rapids and over waterfalls; others lap sleepily at their banks, rolling ever so gently downhill to the sea. Some do both. And some are so wide and long that they are visible from outer space, appearing to orbiting satellites as silvery ribbons crisscrossing the continents.

Rivers have shaped not only the Earth but also human history. They are cultural icons, responsible for the rise of many great civilizations. For thousands of years, they have served as critical avenues for commerce and migration. Those with powerful waters are dammed to provide hydroelectric power. Those that move slowly give rise to green and lush land, which in turn produces agricultural riches for human consumption. But rivers are not only benefactors of humanity; they can also be cruel masters. Throughout history, they have unpredictably jumped their banks and drowned civilizations within their reach.

HOW RIVERS FORM

For all their power, rivers have surprisingly modest origins. No matter how wide and forceful they are when they reach the sea, they inevitably start small, usually in mountainous regions. Many are so small, in fact, that their flow is barely discernible. Some begin as little more than puddles in areas where groundwater oozes from waterlogged soil. Others bubble meekly from underground springs that well up through the Earth's surface. Still others enter existence as falling rain. Gravity plays an especially critical role in these early stages, pulling the surface water—which may lack its own momentum—downhill and funneling it into channels of ever-increasing volume.

The birth and evolution of a river system takes place over thousands of years, so no one has directly observed the event. Hydrologists rely instead on numerous methods to reconstruct a river's history. They do fieldwork, mostly in remote mountainous areas. They also examine historical maps, study aerial photographs, use global positioning systems, and create laboratory simulations.

UNDERSTANDING HOW A CHANNEL IS CREATED

Carving out a *channel*, that is, the bed where a natural stream of water runs, is the first step in forming a river. To make such a channel requires momentum. In other words, water must flow across the land with enough force to not only erode the surface but also to transport the eroded particles elsewhere. Such momentum depends on two factors: sufficient water and sufficient slope.

Though seemingly inconsequential, rain plays a pivotal role in the birth of a river. *Field hydrologists* (specialists who study water in nature) know from observation that raindrops can strike muddy soil with enough force to create miniature gullies or indentations. If the land is either nonporous or too waterlogged to absorb the rain, water collects in these gullies, which are known technically as *rills*. With the help of a small incline and groundwater seepage, water flowing through the rills creates a current strong enough to carve a small channel. Rills themselves are not permanent features on the ground, but are formed anew when it rains. But the water from these rills may combine with seepage to form a small channel. Over time—particularly in areas prone to torrential rains—the continual movement of water further deepens and widens the channel. The process then becomes self-reinforcing: The more defined the channel, the more likely that surface water will be captured and the greater the force of erosion, which in turn further deepens the channel, and so on until the channel is permanent.

HOW RIVER SYSTEMS FORM

Few rivers begin and end as single channels. Particularly in mountainous regions, tiny streams form at numerous locations, then come together to form larger channels. As their water cascades downward, one trickle joins another and another, resulting in a steady increase in the volume of water heading toward sea. A flow that was barely perceptible uphill may soon become a brook large enough for small fish. Brooks combine to form streams, which in turn empty—along with countless other streams—into ever-larger rivers that eventually discharge their watery load into the ocean.

Virtually all rivers grow larger as they flow downhill, fed by runoff and smaller streams called *tributaries*. The upshot is a complex *river system*, which consists of all the tributary systems (and there can be hundreds, sometimes thousands of branches) that successively converge to form the main trunk of a river. Each stream in a river system has its own *drainage basin*, or watershed, the area from which it receives runoff and groundwater.

Sometimes the combining streams are markedly unequal in size, sometimes they are almost the same, but a river system's *main trunk* is always the channel that carries the greatest volume of water (see chapter 2, p. 32 for more on stream classification). Not surprisingly, the world's biggest trunks bear the names listed in this volume: the Nile, the Amazon, the Congo, the Mississippi, and so on.

MAPPING A WATERWAY

Mapping a river's main trunk becomes progressively harder the further upstream one travels, as each tributary and channel becomes smaller and less differentiated. Identifying the exact origin of a given river is often impossible. To begin with, one cannot precisely pinpoint the source of a body of water that begins as seepage or rainfall over a broad area. In addition, many rivers empty into and exit from lakes, blurring the line between where one stream begins and another ends. A typical lake receives input from many small streams but discharges into a single exit stream. The *source* of the Mackenzie River, for example, is Canada's Slave Lake, which in turn is fed by other rivers, including the Hay and Slave, both of which are considered tributaries of the Mackenzie. The Amazon discharges many miles into the Atlantic Ocean, a distance that varies seasonally. So where does the Mackenzie technically begin? Where does the Amazon end? The answers are somewhat arbitrary.

A RIVER'S KEY PARAMETERS

Determining greatness in a river is also somewhat arbitrary. Rivers are typically described by three parameters: length, volume, and the speed of their currents. But volume and speed shift dramatically by season, by climatic event, and by year. Accurate measurements of a river's length are almost impossible to obtain. No two sources agree on the exact mile-age from beginning to end of any river in this volume. To give you an idea of the problem, estimates of length of the Amazon range from 3,700 to 4,850 miles (5,955 to 7,805 km). Even sophisticated satellite images rarely provide accurate, i.e., consistent, measurements.

Why? One reason is that rivers are dynamic entities, forever changing and altering their course. A bend may become more exaggerated from one year to the next; a channel may grow deeper and straighter. A second reason is that many rivers begin subtly—sometimes as little more than bogs—and thus their origins are impossible to pinpoint.

A third reason is that no standard methodology for determining a river's length exists. Rivers have traditionally been measured by running map wheels over aerial photographs, but no rule dictates whether the wheel must be run along the outside or inside of a bend, or even follow the channel's midsection. Over thousands of miles, these variables become significant. In addition, computer-assisted measurements lack standards for counting pixel lengths and so cannot guarantee accuracy either.

A fourth reason is that rivers are rarely single channels. Virtually all of them have tributaries, raising questions about which branch is the primary one, that is, the one leading to the true source. One need only look at a map of the Amazon (see chapter 2, p. 25) to grasp the complexities involved. In some cases, a major tributary, such as the Missouri, which feeds into the Mississippi, is a formidable river in its own right. While most *cartographers* (mapmakers) include the Missouri in their length calculations, which puts the Mississippi at number four or five of the world's longest rivers, some choose to omit it, which drops the Mississippi to number 14. Thus few experts agree beyond the top two or three—those indisputable giants such as the Nile and the Amazon—just which rivers belong on the lists of the world's longest—or even greatest—rivers.

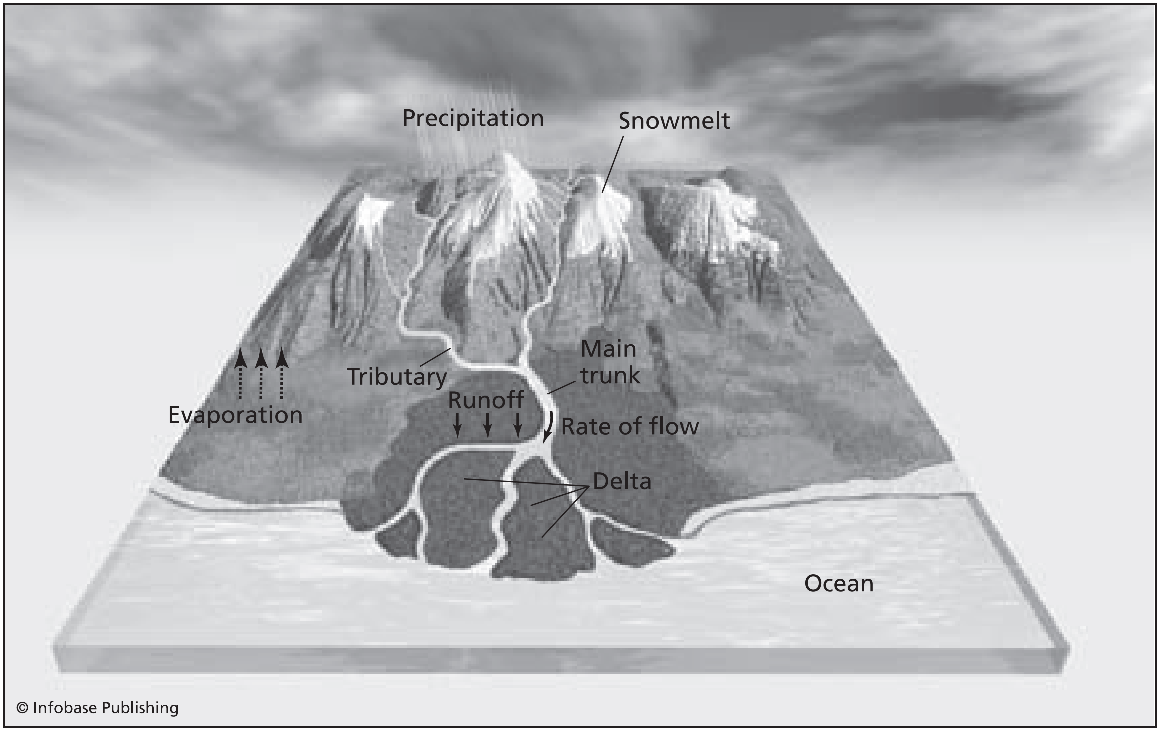
AS RIVERS AGE

Rivers do not age in a traditional chronological sense, but in a geological sense, as they move toward sea level. Young rivers are typically found in mountainous areas, where the slope is relatively steep and the narrow stream channels are filled with rocks and boulders. Here water rushes over rocks and forms waterfalls, especially in the spring when melting ice and snow add to the flow. Tumbling exuberantly downhill, these fast-flowing waters keep their channels clean, deepening and cleansing them through the force of erosion. Water moves powerfully in these youthful channels, whose edges are still rough and whose bottoms are rocky. Indeed, the upper Congo typifies such youth, with boiling rapids and waterfalls that resist navigation.

In its upper reaches, the White Nile, like most rivers, is young and restless, plunging down cataracts and through ravines. *(Tom Streithorst/AP)*

Mature rivers are those found at lower altitudes, where their downward slope may be barely perceptible. They are sleepy, quiet things. Their water moves slowly in channels that have filled with sediment over the course of millions of years. And without rushing water to sweep their bottoms clean and dig their channels deeper, they lazily spread out, expanding their banks rather than their bottoms. Both the Mississippi and the Yangtze exemplify the slow-moving, elder rivers of the world.

Most rivers are considered old by the time they reach the ocean. A river's age is especially evident at its mouth, where its broad delta reflects thousands of years of sediment buildup. Land around the mouth of such rivers tends to be flat and the water flow relatively calm, more meandering than rapid.



Rivers age as they move downstream, transforming from fast, tumultuous streams to slow, meandering waterways that deposit sediment as they move seaward. As the slope diminishes, flow rates and sediment loads decrease, whereas the volume of discharge generally increases.

TERRESTRIAL CIRCULATION

Water molecules are forever on the move, moving from land to sea to air in a continuous, one-way loop. The vast majority of those molecules are found in the world's oceans, where they mix with various dissolved salts (hence the term *salt water*). Only a tiny percentage of the Earth's water molecules exists as freshwater—the kind needed by human beings. In fact, only 3.5 percent of the Earth's water is freshwater, and most of that amount exists as ice. Of all the water on the Earth, only 0.006 percent is in rivers.

Yet without rivers, life on Earth would not exist as we know it. Apart from everything else, rivers are key players in our planet's never-ending water cycle. Most freshwater molecules enter the cycle as precipitation—either as rain or as snow that melts in the spring, which is why many northern rivers become raging torrents once winter loosens its grip. Some of those water molecules, of course, reenter the atmosphere via evaporation or percolate slowly through the soil to become groundwater, but the great majority cascade downstream in river channels to the sea. There they will disappear into the vastness of the ocean until they eventually evaporate into the atmosphere. Carried aloft, they will once again fall to the Earth as precipitation, forever on the move through our planet's water cycle.

Because rivers constantly drain to the sea, they are impermanent and permanent at the same time. Individual molecules move on, passing from mountaintop to ocean to the atmosphere and back to Earth, never staying put, while the river itself remains fixed, constantly fed by new water molecules that enter via tributaries or surface runoff. The end result is a self-replenishing loop that drives geological change and sustains life on the planet.

The emotion evoked by this wondrous circuit is exquisitely stated by the journalist and naturalist Hal Borland, who in 1964 at the age of 64 wrote, "Man is not an aquatic animal, but from the time we stand in youthful wonder beside a Spring brook till we sit in old age and watch the endless roll of the sea, we feel a strong kinship with the waters of this world." These words sing, even today.

1

The Nile

Africa

From the Mountains of the Moon . . . comes the Nile, the most beautiful and greatest of the rivers of all the earth.

—Scheadeddin, Arabian geographer of the 15th century

Measuring some 4,160 miles (6,695 km) long, the Nile River is by all accounts the world's longest river; to many, it is also the world's most beckoning. The river begins as a tiny trickle deep in the heart of Africa, in a cluster of snow-covered peaks near the equator that are so high and austere they are called the Mountains of the Moon.

As it flows downhill from its majestic beginnings in Burundi, the Nile broadens, becoming faster and more powerful. But the river cannot sustain its high speed and undergoes dramatic changes as it moves northward. Entering Sudan, where the topography suddenly flattens, the Nile slows drastically. Crossing into Egypt, the current once again accelerates, hurtling through rocky rapids. And then the river does something most remarkable—it passes through 750 miles (1,207 km) of extreme desert, where it receives no rain and no water from any *tributary*. Although its flow changes seasonally, it never dries up. In winter, the Nile is a modest river; in summer, torrents of water surge through its channels. Wending its way to the sea, the waterway even shifts direction, heading due south for several hundred miles in Egypt, for example, before once again resuming its northerly passage.

By the time the Nile reaches its destination in northeast Africa, its channel has widened considerably. Here the river spans almost five miles (8 km) in width, though it is still many times narrower than its rival rivers, including the Amazon and the Mississippi. All told, the Nile basin covers an area of about 1.1 million square miles (2.9 million km^2). Though its waters flow through nine African nations, including Sudan, the continent's largest, 84 percent of its water comes from one country: Ethiopia.

The world's longest river, the Nile, flows 4,160 miles (6,695 km) from its source in Burundi to its discharge in the Mediterranean Sea.

From its mythic origins in the Mountains of the Moon to its exit in the Mediterranean, the Nile has always been a uniquely beautiful river, as seen in the color insert on page C-1 (top). Much of the land through which it passes is pristine wilderness: mountainous ridges, impassable waterfalls, jungles teeming with orchids and monkeys, and swamps rife with hippopotamuses and crocodiles. Date palms line its shores. Some even say that sunsets on the Nile are the most magnificent in the world, their beauty reflecting both the lack of humidity and the dust arising from fine sediments deposited along the river's shores.

But the Nile is undoubtedly best known for its role in human history. It was along its shores some 3,000 years ago that Egypt's cradle of civilization was born. It was here that the great pyramids of Egypt were built under the watchful eye of ruling pharaohs. It was here amid water reeds that the baby Moses was stowed in his basket. And it was within sight of its banks that Alexander the Great, Julius Caesar, and Antony and Cleopatra came to power. That these ancient civilizations not only persisted but also thrived for thousands of years speaks to the life-giving power of the Nile. Bringing water—one of life's essential ingredients—to desert lands made human settlement possible. No wonder Egypt is often referred to as the "gift of the Nile." No other river so profoundly spells life or death for those in its environs. No other river so totally dictates a nation's economic and cultural variety or even its very existence. Without the Nile, Egypt would be nothing more than uninhabitable desert.

Unlike the Amazon River, with its endless branches and tributaries, the Nile river system is relatively simple. It has two main branches, the White Nile and the Blue Nile, which come together in the city of Khartoum in Sudan. Thereafter, the river is simply called the Nile.

WHITE NILE: FROM THE MOUNTAINS OF THE MOON TO THE SEA

At 2,285 miles (3,677 km), the White Nile (some call it the true Nile) is more than twice as long as the 1,080-mile (1,738-km) Blue Nile. Although its exact *source* is difficult to pinpoint, hydrologists generally agree that the White Nile begins inconspicuously as melting snow and springwater in the *highlands* of Rwanda and Burundi, not far from the equator. From there, the water flows down into central Africa's Great Rift Valley, where it finds its way into one of three lakes: Lake Victoria, Lake Edward, or Lake Albert.

Lake Victoria, which sits at the intersection of Uganda, Tanzania, and Kenya, is the largest—and best known—of the three. With a shoreline of some 2,100 miles (3,380 km), it is the second-widest freshwater body in the world. Lake Edward and Lake Albert are both smaller than Victoria, and they sit to the northwest, where they form a border between Uganda and the Congo.

The White Nile emerges as a recognizable river just north of Lake Albert. There water flowing from Lake Victoria (a distinct waterway called the Victoria Nile) joins the *discharge* from Lake Albert (sometimes called the Albert Nile) and begins to flow toward the Mediterranean in earnest.

From here, the White Nile flows into southern Sudan, where it abruptly transforms from a fast-flowing river into a barely moving quagmire. The swift currents, powered by water tumbling from Burundi's snow-capped mountains, suddenly reach land that is almost table-top flat, and they can no longer maintain their momentum. The river slows and spreads, becoming more swamp than river.

Known as the Sudd, this area of Sudan is a vast expanse (about 200 miles wide by 250 miles long [322 by 402 km]) of weed-choked, almost impenetrable marsh. This stretch is also a navigational nightmare. To travel either upstream or downstream means hacking a navigable channel through dense vegetation, a task generally undertaken with machetes. Those foolish enough to try must also endure swarms of mosquitoes and other biting flies. The British explorer Samuel Baker described the Sudd in his 1867 book *The Nile Tributaries of Abyssinia* as a "horrible region of everlasting swamp." This area remains barely passable to this day.

Moving north, the terrain gains slope, and the White Nile picks up steam in central Sudan. With its renewed momentum, the river once again has the power to carve a distinct channel for itself. From here to Khartoum, it continues with impressive deliberation. Now navigable, the river serves as a critical north-south transportation route along this stretch. In Khartoum, the White Nile joins its sister branch, the Blue Nile.

THE BLUE NILE

At half the length of the White Nile, the Blue Nile appears the more diminutive and thus the less significant of the Nile's two great branches. But nothing could be further from the truth. It is the Blue Nile that delivers life to Egypt, providing almost 60 percent of the water that feeds and fertilizes the country's fields.

Unlike the White Nile, which flows almost straight north from Burundi to Khartoum, the Blue Nile wends its way to Khartoum via a northwesterly route from the mountains of Ethiopia. Like its sister river, it has modest beginnings: The Blue Nile first emerges as a spring flowing from a small lake in the southwestern part of Ethiopia; not until the river reaches Lake Tana in the Ethiopian Highlands does it become a true waterway.

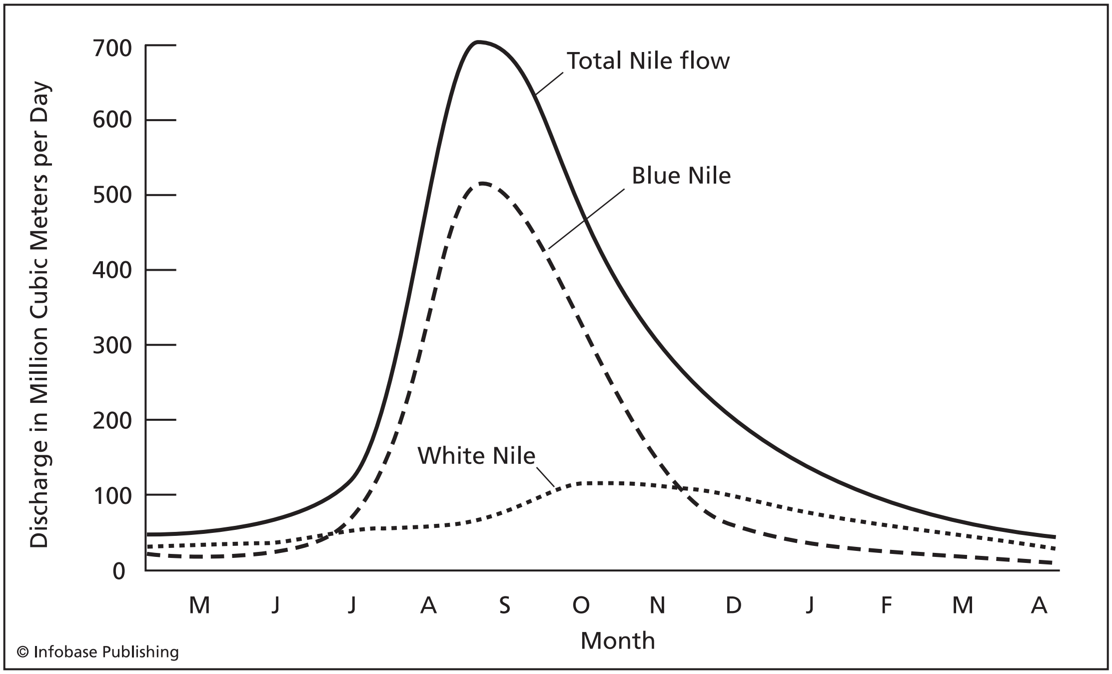
Shortly after leaving the lake, the Blue Nile does something surprising. Instead of heading north toward Khartoum, the river shoots in the opposite direction, flowing toward the southeast as if to the Indian Ocean.

Thus begins the river's great circuitous journey through Ethiopia and its passage through one of Africa's great natural wonders—a deep canyon called the Blue Nile Gorge. This geological feature is as deeply etched into the surface of the Earth as the Grand Canyon of the United States.

LIFE GIVER OF THE DESERT

Weather patterns in the Indian Ocean determine how much water cascades down the Blue Nile every summer. During the year's hottest months, winds along Africa's east coast shift direction. Instead of blowing from west to east as they do most of the year, in summer, they waft from east to west. When they shift, warm tropical air, which can hold copious amounts of moisture, moves inland from the ocean. As the drenched air rises over the Ethiopian Plateau, it cools, losing its capacity to hold water. The result is a deluge of torrential rainstorms called *monsoons*.

The pelting rains make their way to the Blue Nile, which becomes a raging waterway. As the water races downhill in a hurry to reach the sea, it claws at its rocky trench, pulling off nutrient-rich basalt and other minerals and carrying them downstream. In a cycle that persisted for thousands of years (until construction of the Aswān Dam), the swollen Blue Nile then roared north until it reached Egypt's low-lying river valleys. There it would overflow its banks, flooding the valley. Not only did the floods deliver much-needed moisture to thirsty lands, they also enriched them with pulverized basalt and other important minerals and so enhanced their fertility each year.



The White Nile may be the longest Nile tributary, but its flow, which is largely derived from snowmelt, is small relative to the Blue Nile and also mostly constant. By contrast, the Blue Nile delivers a sudden deluge each summer when it is fed by tropical monsoons.

About a mile deep, it is also some 250 miles (402 km) long, or more than half the length of the Blue Nile.

One need only look at a map to see the canyon's great curvature. From Lake Tana, the Blue Nile turns first south, then west, then north—a 270-degree turn—before straightening out and broadening as it reaches Khartoum. Like water rushing through a giant water tube, the Blue Nile churns along this circular gorge with impressive speed. Travel is always perilous; in some stretches, it is impossible.

The waters of this branch of the Nile are a murky, sediment-laden brown, which raises questions about the appropriateness of the river's name. Some people think the river should be recognized for its distinctive character and have suggested changing its name to Summer River. While such a name change after so much history is unlikely, *summer* is indeed an apt adjective. During the warmer months the Blue Nile comes into its own, swelling with torrential rains and surpassing the White Nile in discharge. (During the rest of the year, the White Nile dominates.)

In the past—before completion of the Aswān High Dam in 1970—the Nile would overflow its banks almost every summer, causing extensive flooding in Egypt's Nile River valley. Far from destructive, these floods enriched the land, dumping some 4 million tons of nutrient-rich sediment on the valley floor. But there were years when the floods drowned settlements and other years when they did not come at all. To eliminate such uncertainty and introduce control, Egypt decided to dam the Nile. Today the Blue Nile still carries enough water in summer to provide irrigation for the cotton lands and other agricultural crops of Sudan's Gezira region, but delivers little moisture directly to Egypt's agricultural sector.

FATHER NILE: CRADLE OF CIVILIZATION

Ancient Egyptians worshipped the Nile, thankful for its torrential flow in summer. Almost every year the river, swollen from rain, would escape its banks, bringing wealth in the form of rich silt to their fields and making abundant crops possible. The Greek poet Homer captured this sentiment when he said, "The Nile flows down from Heaven."

Totally dependent on the Nile's water, ancient Egyptians made the river a central part of their lives. But the Nile brought more than sustenance to these people: It brought intellectual challenges, which in turn set the stage for the emergence of one of the world's great civilizations. Managing the river required that knowledge be passed from person to person, and so communication systems were created. In addition, sophisticated irrigation systems were needed to take advantage of summer's sudden rush of high water. Such work required the coordination of thousands of workers, especially during flood season. The workers needed leaders and also laws, and so formal governments arose. At the same time, farmers

Ancient Egyptians built pyramids more than 3,000 years ago to honor their gods and kings. The granite blocks from which the massive monuments were built were floated from quarries in southern Egypt downstream to the Valley of the Kings.
(WH Chow/Shutterstock)

realized that irrigation systems would work best if they could predict—at least to some degree—when the floods were likely to rise and retreat each year. So they began taking careful note of seasonal changes and the movement of stars. These observations eventually gave rise to the study of astronomy and to the creation of calendars. Math and also written language similarly evolved when the Egyptians learned they could prevent property disputes by accurately measuring parcels of land and recording their official coordinates prior to flooding.

Ancient Egypt's treasured architecture also owes its existence to the Nile. The colossal pyramids and mighty temples to honor gods and kings could not have been built without the river. Performing the role of today's massive freighters and other construction vehicles, the Nile carried huge limestone and granite blocks in its powerful currents, pushing them downstream from southern Egypt to the Valley of the Kings. Hauled to land, these weather-resistant blocks were turned into monuments that evoke wonder to this day.

IN THE FIELD: FOSSIL HUNTING IN THE BLUE NILE GORGE

The Blue Nile Gorge exposes rock strata that are millions of years old, ranging in age from late Jurassic deposits that were laid down more than 150 million years ago to Tertiary sediments that are as young as 30 million years. Many of the Jurassic strata consist of fine-grained sandstone that was originally deposited as silt, perhaps the gift of a prehistoric flood. Such fine-grained sedimentary rocks are ideal for preserving fossils, and indeed some remarkable specimens have been discovered along the banks of the Blue Nile.

With financial support from the National Science Foundation, four paleontologists—Michael Goodwin and William Clemens of the University of California, Berkeley; Charles Schauff of Harvard; and C. B. Wood of Providence College—have made several research expeditions to Ethiopia's Blue Nile Gorge compiling a paleontological record of prehistoric species that roamed the African landscape and plied its waters long before humans or even most mammals appeared on Earth. Recently, they unearthed the teeth of Ethiopia's first-known dinosaur, a relative of *Tyrannosaurus rex*, no less. They have also identified new species of crocodilians, turtles, and fish, a fossil assemblage that suggests the ecological landscape of prehistoric Ethiopia was warmer and wetter than today.

ONE NILE

The White and Blue Niles meet in Khartoum, the capital of Sudan. A mere 200 miles (322 km) downstream, the Nile is joined by its last major tributary, the Atbara, which drains from the east and also pulls water from the Ethiopian Highlands. From then on, the Nile flows uninterrupted to the sea. For the next 1,700 miles (2,736 km), until it empties into the Mediterranean, the river meets no other tributaries and so goes un-replenished. Rarely even does the waterway see rain. Yet the Nile manages to pass through the Sahara, where the Sun, heat, and aridity are intense and where evaporation rates are extremely high, without drying up.

The Big Bend

In the heart of the Sahara, not far from its confluence with the Atbara, the Nile does something surprising. It suddenly turns toward the southwest, as if falling over on itself, and flows some 185 miles (298 km) in the wrong direction before once again heading north toward the sea. This diversion takes the Nile 540 miles (869 km) out of its way.

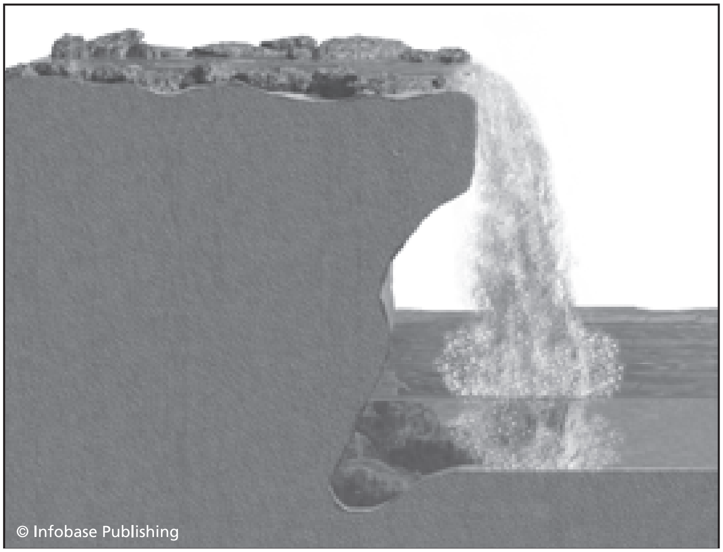
The unusual curvature reflects the region's geological history and tectonic uplift of its surface strata. Before reaching the area of the Big Bend, the river passes through layers of soft sandstone and limestone, which succumb to erosion relatively easily, creating a broad channel. But in the Sahara, the softer sedimentary rocks give way to granite and other hard igneous rocks, which resist erosion. The resulting channel is deep rather than broad. In this region, the Nile River is narrow, fast, and treacherous.

The same *uplift* activity that brought granite to the surface created six *cataracts*, or waterfalls. The cataracts, which are numbered consecutively from north to south, interrupt the Nile's flow, creating conditions that make passage extremely difficult. In ancient times, travelers up the Nile had to hire teams of men who would pull boats by rope over the falls. Even then, they could only reach Khartoum during the summer when the water was at its highest.

As the Nile moves further north into Egypt, it passes through towering sandstone cliffs that separate the green river valley from the surrounding desert. Here the river brings water—and therefore life—to one of the world's harshest deserts. One need only look at satellite images to understand the importance of the Nile to Northeast Africa. Such photos show a lush, water-fed Nile valley snaking through an otherwise barren and brown landscape. Without the Nile, Egypt's Nile River Valley would be as lifeless as its desert surroundings.

At a town called Qena, the Nile shifts toward the east and broadens into an area known as the Valley of the Kings, where the ancient pharaohs were entombed (see the color insert, p. C-1 [bottom]). At the foot of the valley, the Nile's slope diminishes and its floodplain expands, extending toward distant limestone cliffs. Agriculture thrives in this nutrient-rich

CATARACTS



Cataracts develop when a lower section of the river channel erodes more readily than the rock lying above it. When such erosion occurs, the channel develops what is called an irregular profile.

Known to most thrill seekers as rapids, river cataracts occur when flowing water suddenly drops from one level to another, sometimes vertically. A sandy bottom may give way to boulders and ledges that create major interruptions. Water, which once flowed steadily, becomes agitated as it tumbles and foams past the obstacles in its way.

Rivers typically smooth out such irregularities by the process of erosion. The *irregular profile,* which is characteristic of a cataract, develops when the substratum, or lower layer of rock in a streambed, is considerably harder than the rock lying above it. The softer layers erode more quickly, leaving behind ledges and other rocks that resist erosion. Uneven erosion is greatest in areas where folding of the rock layers has taken place, bringing different rock types to the surface and creating a jumble of boulders. In addition, the gradient in these areas tends to be steep. The outcome may be a streambed that has the feel of a horizontal waterfall, with water coursing over big chunks of granite.

Six cataracts have been identified along the Nile between Khartoum and the Aswān High Dam (there are more, but they are smaller and unnamed). All owe their existence to an irregular profile that was created by tectonic uplift millions of years ago. As the Nile made its way across the desert *plateau,* burrowing through from 300 to 1,000 feet (91 to 305 m) of *Nubian sandstone,* it came into contact six times with a layer of granite that had been thrust upward by geological unrest. This layer, which is much harder than the sandstone above it, remained intact even as the Nile eroded the surrounding sandstone. The result each time was the emergence of a cataract.

Aswān marks the first cataract, which once consisted of rocky rapids and small islands that rendered boat travel difficult. That cataract has now, of course, been obliterated by the dam, which sits above it. Similarly, the second cataract now lies deep under Lake Nasser. The third cataract (also known as the Mekade cataract) was once described by Winston Churchill as “a formidable barrier.” Here the river rushes through a narrow ravine, over and between rocks from 30 to 40 feet (9 to 12 m) high. These falls are said to be the only insurmountable obstacle to navigation of the Nile by large vessels. The fourth cataract lies in the Monassir Desert and consists of a great confusion of boulders. The fifth and sixth cataracts are in regions of swift and rough water but can be navigated year-round.

floodplain. Interestingly, nearly 90 percent of the cultivatable land in Upper Egypt lies on the river's west bank, which is also home to Cairo. Cairo sits at the end of the valley, just before the Nile fans into a grand delta.

ASWĀN DAM

In the 1960s, the Egyptian government, engineers, economists, and agriculturists decided to assess the costs and benefits associated with the Nile's annual floods. The river's cyclical depositions of mineral-rich sediments were vital to agricultural productivity, but the flooding itself was highly unpredictable. The exact arrival and indeed the height of any flood could not be accurately predicted. Some summers would give rise to disastrous floods; other summers would fail to produce any flooding at all. What's more, the floods only occurred once a year, which limited farmers to one planting.

Hoping to gain control over the unwieldy process, the Egyptians decided to build a dam at the sight of the first cataract, 600 miles (966 km) upstream from Cairo. The idea was to block the river, thus creating a reservoir that would allow engineers to store water during the rainy season and release it during times of drought. Such a strategy would make year-round cultivation possible and reduce—if not eliminate—drought-induced famine. The dam, completed in 1970, is called the Aswān High Dam. Enormous in size, the artificial lake that formed when the dam was built is the world's third-largest reservoir and stretches for 200 miles (322 km) upriver. To Egyptians the reservoir is known as Lake Nasser; to Sudanese it is Lake Nubia.

Although large numbers of people—some 90,000—were displaced when Lake Nasser was created, in many ways, the project has been a great success. Lake Nasser provides reliable water for irrigation and has significantly improved crop yields by allowing farmers to grow two or three crops a year instead of one. In addition, water flowing through the dam's turbines provides large amounts of hydroelectric power, enough to meet most of Egypt's energy needs, no trivial matter for a country with a rapidly growing population (see chapter 6, p. 92).

Yet the Aswān High Dam has also fallen short of expectations and given rise to unforeseen problems. To begin with, Lake Nasser traps 98 percent of the valuable sediment that washes downstream from the Ethiopian Highlands. Farmland that was once naturally enriched by mineral-laden floodwaters now has to be artificially fertilized, a process that is both expensive and fills the Nile with pollutant runoff. In addition, erosion in the coastal region has become a serious issue. Thousands of square yards of land are disappearing each year, no longer replaced as they once were by the yearly delivery of sediments.

Also, the huge surface area of Lake Nasser combined with its desert locale means much of the lake's water is lost each year to evaporation, greatly reducing the operation's efficiency. Finally, the increase in artificial irrigation has created some serious *salinity* problems. Few of the dissolved salts found in irrigation water are taken up by plants. Instead, most salt is left behind in the soil, where it concentrates over time, creating conditions that are detrimental to farming.

All these problems, however, pale in the face of population growth and the growing regional need for water. Currently, Cairo has one of the highest birth rates in the world. With each human being comes added stress on the region's water supply. The roughly 8 million who live in Cairo extract 90 percent of their water from the Nile. By 2050, the population is expected to double. Without a secure supply of fresh, clean water for its people and crops, water will undoubtedly spell success or disaster for the Nile valley in coming years. Water, many say, will become as valuable as oil is today.

CLASSIC DELTA

The Nile's *delta* began forming several million years ago, when the initial canyon carved into the sea began accumulating sediment both from the river and from the Mediterranean. As the sediments piled up, the process became self-reinforcing: A river made sluggish by sediments in turn deposits more sediments, and so the rate of silt deposition in the delta increased every year. Over the course of many thousands of years, the slowing river split into several branches that open into the Mediterranean. These branches account for delta's distinctive fanlike appearance. The two main branches, also known as *mouths,* are the Rosetta, or Rashid, to the west and the Damietta to the east.

The term *delta* hearkens back to about 480 B.C.E., when the Greek historian Herodotus visited the mouth of the Nile. Struck by its resemblance to the letter Δ, he inserted the descriptive term in his travel writings. The name caught on and has been widely appropriated to describe all fanlike deposits at the mouths of rivers. (See figure 21 in chapter 4, p. 68.)

Today the Nile Delta occupies an 8,500-square-mile (13,679-km^2) triangle between Cairo and the Mediterranean coast. Although the region accounts for only 3 percent of Egypt's land, it is home to 96 percent of that nation's population. Some 20 million people live in an area about the size of Maryland. Such population density would not be possible without the rich sediments that make the delta exceptionally fertile. Even today, with erosion becoming a serious problem, the delta has about twice the agricultural land found elsewhere along the Nile. The Nile's terminus is readily visible, in fact, on satellite images—appearing as a large, green fan, or like a gingko leaf at the end of its stem.

QUEST FOR THE HEADWATERS

The search for the source of the Nile remains one of the greatest adventure stories of the 19th century. The desire to know the origins of the ever-mysterious Nile can be traced back to ancient Egypt. No one knew why the river poured forth in excess each summer. Early Egyptian farmers knew only that once a year a deluge descended on them, and they were grateful for the silt-laden aftermath. But they nevertheless wondered whether their watery gift came from another world, from some other civilization, or from God himself. Even Julius Caesar purportedly exclaimed that the one thing he most wanted to know about the world was where the Nile began. Little is known about attempts to explore the Nile prior to the 17th century; virtually nothing survives in the historical record.

Thereafter, history indicates that the earliest adventurers ventured up the Blue Nile, most likely driven by a desire to better understand its mysterious floods. The Blue Nile gave up its secrets relatively easily. In the early 17th century, Padre Páez, a Spanish missionary traveling in the Ethiopian mountains, came upon Lake Tana and knew he was looking at the source of the Blue Nile. Clearly emotional, he wrote of his discovery on April 21, 1618: "I confess I feel fortunate and happy for seeing what Alexander the Great, Julius Caesar and the Kings Ciro and Cambesses desired to see in the past but never accomplished." But Páez was also a modest man. Although he is the first-known European to come across Lake Tana, he downplayed his discovery, knowing that Ethiopians must have traversed the same route long before him.

In 1768, some 150 years after Páez, a Scottish explorer by the name of James Bruce set forth from Cairo, determined to find the Nile's source. After two arduous years, he finally reached Lake Tana and knew he had found the beginning of the Blue Nile. For the rest of his life—perhaps because he did not know of Páez or simply thought he deserved credit for traversing the entire river—he claimed to have been the first to reach the source of the Blue Nile.

In the modern era, numerous adventurers have tried to travel the Blue Nile by boat from Lake Tana to the sea. None have had an easy time of it. In 1972, for example, a four-man British team successfully navigated several white-water rapids that others had found impossible. But they quit the river after only 12 days, having been repeatedly attacked by crocodiles and gun-wielding Shifta bandits. Even as recently as 1999, a National Geographic Society expedition ran into numerous hazards, including crocodiles, armed militia, and multiple rapids that had to be portaged. Fearing for their lives, they went no further than 500 miles (805 km) downstream.

Not until the 19th century did the world's attention turn to the White Nile, when a veritable race to discover its *headwaters* began. The first European, a French explorer by the name of M. Linant, set forth in 1827. He traveled several hundred miles past the junction of the White and the Blue Niles, but then reached the Sudd. Unable to navigate through the nightmarish swamp, he gave up. About 1840, two Egyptian naval officers (at the request of Egypt's ruler, Mohammed Ali) somehow hacked their way through the immense Sudd and came to within three degrees of the equator. But they, too, had to turn back.

Next came a wave of British explorers: Richard Francis Burton, John Hanning Speke, James Augustus Grant, Samuel and Florence Baker, and David Livingstone and Henry Morton Stanley. All headed upstream, determined—like their predecessors—to find the Nile's start. They captured the imagination of the Western world for much of the century, and their search became the Holy Grail for their generation; the "Great Prize."

In the 1860s, Samuel Baker headed up the Nile. While his hunt for the source was ultimately unsuccessful, he was the first European to reach Lake Albert and follow the Nile as far south as Uganda. Wanting to explore the great lakes rumored to be in central Africa, Richard Burton and John Speke went upstream in the 1850s. Mid-journey, Burton took ill, but Speke carried on, eventually reaching Lake Victoria in 1858. He declared himself the winner of the Great Prize, mistakenly believing the lake marked the source of the Nile. Only later was the Kagera River, which begins some 500 miles southwest of its entrance to the lake, identified as the source of the Victoria system.

Another 30 years would pass before the Great Prize was won. On May 25, 1888, the intrepid Henry Morton Stanley made his way to a plateau above Albert Lake. From there, he crossed the Semliki River, which he followed downstream to its entry into Lake Albert. Looking upstream, he saw a cluster of snow-capped mountains, which he guessed to be some 50 miles (81 km) to the southeast. Connecting the flowing water by his feet to snow melted by the Sun, he realized the source of the Nile must reside in the distant mountains. Stanley later wrote, "Little did we imagine it, but the results of our journey . . . established beyond a doubt that the snowy mountains are identical with what the ancients called the 'Mountains of the Moon.'"

Even so, it was not until 1937 that the Nile gave up her carefully guarded secret. Coming upon a small, bubbling spring in the mountains of Burundi, a little-known German explorer by the name of Burkhart

Waldecker realized he had found the southernmost source of the Nile. Today the spot is marked by a small pyramid on which sits a metal plaque inscribed with the words *Caput Nili*, or "source of the Nile."

IN THE FIELD: COMBATING SALINITY

The Nile valley, still one of the most productive agricultural areas in the world, has a major problem: too much salt. The Nile River has always transported large quantities of salts downstream, including such valuable fertilizers as potassium and potash. The salts, which readily dissolve in water, would flow into the valley's *alluvial plains* during flood times but wash away with the subsiding waters.

The salt cycle changed when the Aswān High Dam was constructed. Floods were relegated to the history books. In their place came year-round irrigation systems. Artificial irrigation increased agricultural productivity but created a salinization nightmare. Salt no longer washed away with receding floodwaters but was left behind when water sprayed from hoses evaporated from the soil. Over time, the salt deposits grew; in some places, the ground is now encrusted with salt. Toxic to plants in such concentrations, excess salinity is sometimes referred to as the "White Death." If remediation efforts are not taken, the buildup can progress until rich farmland is reduced to a barren, salty landscape.

With a rapidly growing population, Egypt must take any threat to its agricultural productivity seriously, and so the country follows salinization trends closely. For example, the Ministry of Public Works and Water Resources regularly monitors salinity levels as does the River Nile Research Institute.

A soil's salinity, measured as its level of soluble salt, can be quickly and simply determined in the field by measuring the electrical conductivity (EC) of the soil. Two metal probes are inserted into the soil, and an electric current is passed between them. A gauge measures the conductivity of the soil, that is, how readily the current flows between the probes. As the concentration of salt increases, the current also increases and is expressed as a higher EC reading.

A number of techniques are used to combat the buildup of salt. Apart from more efficient irrigation methods that require less water, the most common strategy is to install sophisticated subsurface drains. With proper drainage, excess water (and the dissolved salts it contains) can be pulled from the soil before it evaporates.

Other strategies include adding compounds that bind to the salt, rendering it less toxic; seeding a contaminated area with plants that not only tolerate but also absorb salt; and flushing the land with water, in essence mimicking the actions of flooding.

LOOKING TO THE FUTURE

The beautiful and historic Nile has brought life to otherwise inhospitable terrain for thousands of years, generously depositing nutrients that in turn enabled the great civilizations of northern Africa to thrive. Yet its future as a giver of life is far from secure. Along with its serpentine flow of watery riches have come the problems of the modern world. The Nile's verdant valleys have given rise to rapidly enlarging populations, which in turn have necessitated greater agricultural productivity and increased irrigation, fertilization, and pesticide use. Soils have turned salty and unproductive as a result of over-irrigation, and the Nile itself is now polluted from agricultural runoff. More concerning, however, are the political tensions that are arising in response to the growing scarcity of clean water. Who, after all, can claim ownership to the Nile? The river passes through nine countries on its way to the Mediterranean. Should Egypt, home to some 70 million people, have a right to more water than, say, the tiny nation of Burundi? The equitable distribution of water in northern Africa is seen by many as one of the great challenges of this century.

2

The Amazon

South America

The river flowed northward toward the equator, but wither it would go, whether it would turn one way or another, the length of its course, where it would come out . . . all these things were yet to be discovered.

—Theodore Roosevelt, *Down an Unknown River*

If ever a river were defined by extremes, surely it is the Amazon. Though its channel may be second in length to the Nile, by every other measure the Amazon is the world's greatest river. This grandiose waterway is defined by superlatives (widest, fastest, etc.), as is its *watershed*. The Amazon basin gives rise to biological riches found nowhere else on Earth. Interspersed among the river's vast *tributaries* sit rich deposits of minerals and oils. Indigenous peoples still live in the basin's upper reaches, unassimilated into the Western world. Many of the Amazon's tributaries flow through lush, impenetrable jungle. Over millions of years, abundant rainfall, consistent warmth, and an enormous *drainage basin* have created one of the most wondrous habitats on Earth.

Consider the superlatives to which the Amazon lays claim:

- The Amazon discharges more water into the ocean than any other river. Some 5 million cubic feet (142,000 m^3) of Amazon water enter the Atlantic every second. This is five times the rate of its closest competitor, the Congo, and 12 times that of the mighty Mississippi. Overall, the Amazon contributes almost one-fifth of all river water that empties into the oceans each year. Along with water, it dumps 3 million tons of sediment a day into the Atlantic.

- The Amazon draws water from more square miles of land than any other river, with a drainage basin that easily dwarfs all others. This one river pulls water from an area of 2.6 million square miles (6.8 million km^2), or more than one-third the continent

The Amazon River drains from a bigger area and has more miles of tributaries than any other river. From its source in the Peruvian Andes to its discharge in the Atlantic Ocean, the mighty river travels some 4,000 miles (6,437 km).

of South America. In fact, the Amazon's watershed dwarfs its nearest competitor, the Congo, by a factor of two.

- The Amazon gives rise to more branches than any other waterway—so many its tributaries have never been fully counted. Estimates exceed 1,000.
- This monstrous river system has more miles of tributaries than any other river in the world. Three of the Amazon's branches are longer than 1,850 miles (3,000 km) and major waterways in their own right. A full seven of its tributaries span more than 1,000 miles (1,600 km). Overall, its tributaries are so intricate and numerous that hydrologists cannot even agree whether the Amazon is a 12th- or 13th-*order stream*.
- The Amazon draws water from both hemispheres, a feat no other major river can claim.

- The river passes through the largest remaining tropical rain forest on Earth.

This great South American waterway is extraordinary in other ways. To begin with, its full length—from source to sea—has never been verified. While some accounts give the river a length of 3,900 miles (6,400 km), others say it could be 4,200 miles (6,759 km) long, which—if true—would make it slightly longer than the Nile.

The Amazon certainly carries more water than the Nile: 60 times as much, in fact. When it comes to width, the Amazon also emerges as the hands-down champion. Flowing through soft sediments on its way to the ocean, the channel becomes so broad in places that it resembles a great lake more than a river. For a full 250 miles (402 km) before reaching the Atlantic, the Amazon runs 50 miles (80 km) wide; at its mouth, it expands to some 200 miles (322 km). Unlike most rivers, which are either wide (and slow-moving) or deep (and fast-moving), the Amazon is both. Its depth reaches as much as 120 feet (37 m) in places, and overall, the channel is much deeper than the narrower and faster Mississippi.

Such a navigable channel makes the Amazon welcoming to large ships and freighters. Oceangoing vessels easily sail upstream as far as Iquitos, a town some 2,300 miles (2,700 km) from the coast. In this regard, the Amazon is also unparalleled; no other river in the world allows large (3,000-ton) seafaring boats to go so far upriver.

Also remarkable is that the Amazon remains reasonably unspoiled, a fact no doubt related to its enormity. Not only are its waters among the cleanest of the world's major rivers but its main stem remains undammed.

ORIGINS OF THE AMAZON

Hundreds of millions of years ago, when South America and Africa were one landmass, the Amazon emptied, not into the Atlantic as it does today, but into the Pacific. Over the next 100 million years, as a result of *continental drift*, the continents moved apart, and the river became smaller. But the waterway still flowed westward to the Pacific. Then, about 7 million years ago, a sudden burst of *tectonic activity* pushed the Andean mountains upward, preventing the river from reaching the sea. The *uplift* was akin to building a dam, and a large, inland lake formed east of the Andes. Eventually, the lake drained eastward, working its way over the course of many millennia through ancient rock known as the Brazilian and Guiana Shields. Eventually, the draining water carved a *channel* to the Atlantic, giving birth to what is today the Amazon River.

For all its eventual power and size, today's Amazon has surprisingly modest beginnings. The river forms high in the Peruvian Andes in the Ucayali valley, a mere 100 miles (161 km) from the Pacific Ocean, at an elevation of 18,673 feet. Not far from its *headwaters* and at an altitude of 9,850 feet (3,000 m) lies the Sacred valley of the Inca, the site of ancient Indian ruins. Machu Picchu sits only a few kilometers away, evidence that this upland area once supported farming and a sophisticated culture, both of which disappeared hundreds of years ago and are represented today only by artifacts.

Explorers have long known that streams descending from the snow-covered Andes feed the Amazon. The two largest branches of the nascent Amazon are the Ucayali, which descends from the headwaters, and the Marañón, which originates further north in the Andes. Each river flows north, though the Marañón takes a sharp turn to the east before meeting the Ucayali in northern Peru, about 50 miles south of Iquitos. Soon thereafter, they are joined by the Napo River, which descends from Ecuador. From that point on, the rivers form the main trunk of the Amazon.

The Amazon wends its way east, hugging the equator as it goes, never further than two degrees latitude from the Earth's middle. After dropping nearly 14,000 feet (4,267 m) in its first 600 miles (966 km), the river now flattens. From Iquitos to its point of discharge into the Atlantic—a distance of 2,300 miles (3,700 km)—the river descends a mere 300 feet (91 m), dropping less than one inch per mile on its ocean-bound journey. Without the momentum downhill provides, the water moves languidly, in no hurry to reach the sea. That the Amazon flows at all in this stretch is because the river is pushed by runoff from the Andes.

Moving slowly, the Amazon heads east, joined by tributaries that descend from Peru, Colombia, and Ecuador to the west; Venezuela and Guyana to the north; and Bolivia to the south. One such tributary is depicted in the color insert on page C-2 (top). Here the Rio Pastaza flows through eastern Ecuador, eroding sediments and carving a channel deep into the Andean foothills, a pattern repeated throughout the region. As a result of continued tectonic activity, the Andes are still rising, and their relative instability, manifested in earthquakes and volcanic activity, contributes to the erosion of their sediments, which are deposited throughout the Amazonian *floodplain*.

The Amazon unites with its best-known tributary, the Río Negro, at the bustling port city of Manaus, home to 1 million people. The channel broadens into a giant expanse of water called a *ria* just downstream from Manaus. Here the riverbanks stand several miles apart and separate still further during flood season. So broad is the channel, in fact, that early Portuguese explorers dubbed the river Rio Mar, or Ocean River.

Moving seaward, the Amazon continues to grow in girth and eventually divides in two, flowing around an enormous island called Marajó. The river's northern branch, though a major shipping route, becomes a maze of islands and channels. The southern branch, called the Pará River, provides a port for oncoming boats and gives rise to the city of Belem. With a population of 1.4 million, Belem is the largest city in eastern Brazil.

The Amazon passes through a large *estuary,* which stretches some 200 miles (322 km) across the coastal landscape before finally discharging into the ocean. The Atlantic, unlike the Mediterranean (site of the Nile's *delta*) is a high-energy coastal environment, and so the Amazon does not build a true delta (see the figure in chapter 4) but instead discharges into the roiling sea, which sweeps the river's sediments far from shore. Billowing sediment plumes (muddy swirls of silt-laden water) are visible some 150 miles (241 km) out to sea.

IN THE FIELD: MEASURING A RIVER'S RATE OF FLOW

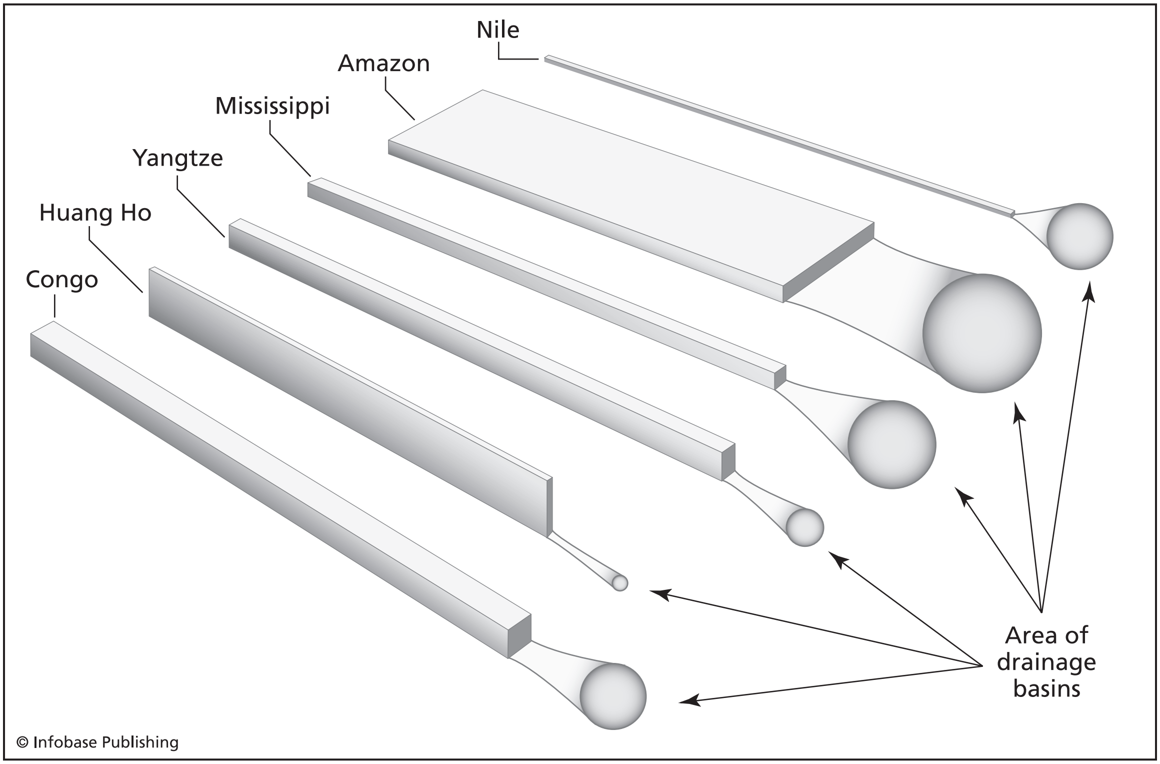
Determining a river's rate of flow, or *discharge,* is not an easy task. River volume changes seasonally and even by time of day. In addition, a river's speed can vary by both channel width and depth. Discharge rates thus differ from one point to another but predictably increase as one goes downstream. Consequently, most discharge measurements are taken near a river's mouth and are recorded as mean annual discharge.

The larger the river, the harder it is to accurately measure discharge, which is defined as the volume of water passing through a specific cross section of the river at a given point in time. To obtain a discharge value, *hydrologists* must measure the area of the cross section and multiply it by the average velocity of the river at that point.

Because a stream's velocity varies within the river channel (water runs faster mid-channel), hydrologists must take measurements at multiple points throughout a cross section and average them. They then multiply the average speed of flow by the area of the cross section. In the past, the process has been cumbersome, involving gauges called current meters and cross-sectional contour lines.

A scientific instrument called an acoustic doppler current profiler, or ADCP, has revolutionized the accuracy and ease with which the speed of flowing water is measured. Using this technique, French and Brazilian hydrologists recently clocked the Amazon's rate of discharge at 57 million gallons (214 million L) per second.

The ADCP works by emitting sound waves that (like all sound waves) not only deflect in the face of resistance but also slow down as they travel, creating what is known as the Doppler effect. The closer a sound wave is



Six of the world's longest rivers vary not only in length but also in width, depth, and basin area. The world's most powerful river, the Amazon, is slightly shorter than the Nile but deeper and much wider.

to one's ear, the higher its frequency, or pitch; the farther away, the lower its frequency.

Lowered into a river, an ADCP transmits high-frequency sound waves. As the sound waves travel, they bounce off sediments in the moving water and reflect back to the instrument. The speed with which a particle is moving away from the instrument can be determined using Doppler principles: Sound waves bounced back from a suspended particle will have a lower frequency if they are moving away from the instrument and a higher frequency if they are moving toward it. By measuring the frequency of the waves and the time it takes for them to bounce back, a profiler can quickly tabulate the speed of a current; the test can then be repeated at different depths.

Some ADCPs are anchored on the bottom of a river or ocean, others are mounted horizontally on submerged bridge pilings, and still others are mounted on boats. The measurements of the Amazon were made from boats that also had computers to receive the data and a global position-

FINDING THE SOURCE

Despite its status as one of the world's supreme rivers, much about the Amazon remains unknown. Still unresolved, for example, is the exact location of its headwaters, or *source.* By definition, a source is the farthest point of continuously flowing water that can be traced upstream from a river's *mouth.* Given the overall magnitude of the Amazon's watershed, with its thousands of tributaries, for many years finding the source has been akin to seeking a needle in a haystack. But recently, with the help of satellite imagery, an indisputable source has emerged. The Ucayali may not be the longest of the Amazon's tributaries, but when connected to the Amazon, the two form a continuous channel that runs some 4,200 miles (6,759 km) to the sea, the longest-running channel in the river system. The Ucayali itself has tributaries, but only one can claim to be the true headwaters of the Amazon. Determining which one is the longest has proved challenging.

In 2000, the National Geographic Society sponsored an expedition to map the exact location of the Amazon's headwaters. The society sent a 22-member international team of hydrologists, geologists, and *cartographers,* armed with a global positioning system (GPS), into the Ucayali valley of southern Peru. The team battled difficult terrain, high altitudes, strong winds, and freezing temperatures, making their way up five remote streams in the vicinity of a mountain called Nevado Mismi. Using their GPS, expedition members were elated to identify one stream that extended farther from the mouth of the Amazon than any other.

Unfortunately, the scientists' findings are technically flawed. While they accurately measured the length of the five mountain streams they traversed, they failed to standardize their findings by measuring the entire length of the Amazon using the same technique. The latter is certainly a daunting task, however, and so may be left to future generations.

ing system (GPS) so the ship's movements could be subtracted from the movement of the water.

GREAT BASIN

The Amazon is a river system of exceptional complexity, with a dense network of tributaries forming a pattern across South America reminiscent of blood vessels infiltrating human tissue. Because each tributary brings its own watershed to a system, a primary watershed grows in lockstep with its tributaries. Every time a tributary joins the main river, so does the tributary's watershed. As a river flows downward, therefore, the size of its watershed tends to grow in abrupt jumps. This cumulative affect accounts for the Amazon's enormous watershed, technically called a drainage basin.

The Amazon basin stays lush and damp year-round, fed by abundant rain. In Brazil, the Amazon receives an average annual precipitation of eight feet (2.4 m), though more rain falls from February to May (the rainy season) than from June to October (the dry season). Approximately 60 percent of the rain that falls enters the local atmosphere through transpiration (vapor loss from plants) and through direct evaporation. The other 40 percent comes from moisture-laden winds blowing inland from the Atlantic, in effect creating a mini–water cycle. Depending on the season, the Amazon's water levels may vary by as much as 30 feet (9 m).

The Amazon swells most notably in the summer. Melting snow pours from the Andes mountains, creating a surge of water that quickly moves downstream, raising water levels. These seasonal floods generally begin in late November or early December, when summer unfolds south of the equator. As the river overflows its banks, trunks of trees disappear and habitats that were once terrestrial are invaded by aquatic animals.

When the waters recede, so do the fish, frogs, turtles, and caimans. Tree trunks reemerge, their roots replenished with nutrients, their stained bark a testament to the high watermark. This cycle is essential to the health of the rain forest: The floods remove organic debris and deposit it downstream, where it decomposes into valuable nutrients. The high water, which tears at plants and trees, pulling all manner of vegetative material into its flow, also plays a big role in distributing and dispersing seeds.

Most of the Amazon basin is thickly carpeted with tropical rain forest, replete with vines on which monkeys swing, giant ferns, and trees that may tower 15 stories high. The canopy of trees is so dense that, from an airplane, their tops look like a never-ending field of broccoli. In terms of size and species diversity, the Amazon's forests have no equal on Earth. Though development is rapidly whittling away this priceless habitat, the sheer size of the basin buys time to plan for sustainable growth.

HOW THE AMAZON GOT ITS NAME

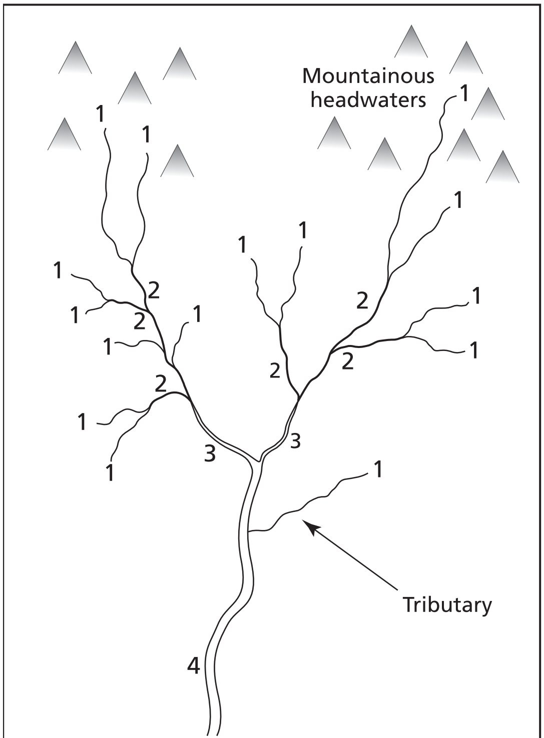
Although no one knows for sure how the Amazon was named, two plausible theories exist. One goes back to the days of Francisco Orellana, the Spanish conquistador who paddled down the Río Napo to the Atlantic. Along the way, he encountered bands of women warriors whom he called Amazons, after the fierce women in Greek mythology. It makes sense that Orellana would have found such women memorable and that after months of downstream paddling he would have wanted to name the river that led him to safety. What anthropologists now know—and Orellana did not—is that the warriors were almost certainly not women but men with exceptionally long hair.

The other theory attributes the river's name to the Indian term *Amassonia*, which means boat destroyer. Such a term aptly describes the

DETERMINING STREAM ORDER

In the 1940s, an American hydraulic engineer by the name of Robert Horton found he could categorize streams according to their branching hierarchy, that is, the relative geometry of their various tributaries. He devised a system whereby each river is assigned an order number based on its complexity. Streams that are simple, without tributaries, are called first-order streams. These first-order streams in turn feed second-order streams. When two second-order streams come together, a third-order stream is formed, and so on. The higher the number, the more complex the branching pattern.

One river can have many segments of each rank. As the stream order increases, so does the intricacy of the river system, with tributaries giving rise to more tributaries in a seemingly endless continuum. The Mississippi River is a 10th-order stream; the Amazon and the Congo, the two largest in the world, are recognized as either 12th- or 13th-order streams. The uncertainty as to which order they are reflects their overwhelming complexity.



Rivers are ranked according to stream order, that is, the number of branches that form the main trunk. Two first-order streams combine to form a second-order stream; two second-order streams form a third-order stream, and so on. The Amazon is thought to be a 12th- or 13th-order stream, but the river system is too complex to know for sure.

violent tidal waves that roar in from the Atlantic, wreaking havoc both on water and on land as they move upstream. It, too, seems a credible explanation.

FOUR MONSTROUS TRIBUTARIES

Each of the Amazon's major tributaries is distinct, characterized by its own geology and economic activity. Some originate in the high Andes, others in tropical lowlands. Some have muddy substrates, others have rocky bottoms. But each one is long enough to be a major river in its own right.

Each tributary assumes the color of whatever it transports, and so the Amazon system is a kaleidoscope of color: Its rivers are white, muddy, black, clear, and so on, with varying gradations. Even from the air, their colors are distinct, each river appearing as a colored ribbon on an endless green carpet. The Madeira, Ucayali, and Marañón Rivers, for example, are the color of café au lait, a hue created by mud pulled from the Andean foothills. Nearly 90 percent of the Amazon River's sediment load is carried by these three rivers.

Some tributaries are longer than others; some have bigger watersheds. Four of the Amazon's tributaries are major waterways, each considered a principal contributor to the Amazon system, both in terms of length and discharge. The four most important are the Rio Negro, Rio Madeira, Rio Tapajós, and the Rio Xingu. Each is presented in the order in which it joins the Amazon on its downward flow to the sea.

Rio Negro

The Río (Rio in Portuguese) Negro is the Amazon's northernmost tributary, originating on the Guiana Shield in southern Venezuela and eastern Colombia. From there, it makes a steady, southeasterly run toward the Amazon, connecting to it at the bustling city of Manaus, some 1,500 miles (2,500 km) from its source. All told, the Negro covers a distance of 2,300 miles (3,700 km) from its headwaters to its end point in the Atlantic Ocean.

Named by the Portuguese for the inky color of its water, the Negro is the world's largest *blackwater* river. Its color comes from abundant vegetation that falls into its waters. *Humic acids* and *tannins* leach from the vegetation in a process analogous to brewing tea. Oddly enough, the resulting water is dark in color, as if rich in nutrients, but so high in acid as to be almost sterile. The darkness of its waters creates a remarkable contrast at the river's juncture with the Amazon. There the Negro's black waters push into the light brown water of the Amazon, forming a bi-colored boundary that remains distinct for many kilometers.

On the basis of its annual discharge, the Río Negro is the sixth-largest river in the world. (To get a sense of proportion, consider the fact that the Negro empties four times as much water into the Amazon as does the Mississippi into the Gulf of Mexico.)

The Negro has another distinguishing feature. Along its length, the river gives rise to numerous *archipelagos*, smaller clusters of islands that arise midstream. Though inundated during flood season, they are richly forested and support surprisingly diverse—if transient—populations of both vertebrates and invertebrates. Two large archipelagos, with more than 1,000 islands between them, have arisen in the middle and lower sections of the river.

Because the Negro originates in an area of high rainfall, it is constantly replenished and always full of water. The river also benefits from its large drainage area, which spans nearly 270,300 square miles (700,000 km^2), an area larger than California. The Rio Madeira may have a drainage basin twice as large, but because of all the rain the Negro receives, the latter

EARLY EXPLORATION

Explorers have long sought adventure along the Amazon and its tributaries. As early as 1500, Spain repeatedly sent expeditions of men upriver in search of riches and a chance to claim bounty from the New World. One of these expeditions stands apart from the others, not only for its historical significance, but also for the sheer improbability of its success. It is the voyage of the Spanish conquistador Francisco Orellana in 1540.

In that year, Orellana joined a large Spanish regiment that set forth to explore the wilds of western Peru. Orellana had no intention of sailing down the Amazon . . . or any other river. But fate was unkind to him. While making their way through difficult terrain, Orellana and some other men fell behind. One can only imagine the Spaniards' despair when they realized they were lost in impenetrable jungle, with virtually no hope of rejoining their colleagues. Without food or much in the way of equipment, Orellana decided the group's only chance for survival was to sail downriver. He had no idea, of course, what river they were on, what they might encounter en route, or even where they would end up.

The men set their handmade canoes into what would later be known as the Río Napo, an Amazonian tributary, and prayed as the current sped them eastward, away from their fellow Spaniards. The trip was an unending nightmare: For many months, they not only battled warring people but also disease, hunger, and treacherous waters. They also suffered psychologically, unprepared for the magnitude of the journey and uncertain of the outcome. Who could imagine rivers of such enormous width and apparently endless length? But miraculously, Orellana and his comrades reached the Atlantic Ocean and became the first Europeans to tell an amazing—if horrific—tale about a river that could take a person from one side of the continent to the other. Some even say Orellana's reports of seeing female warriors along the way gave the river its name.

In 1637, reversing what Orellana had done almost 100 years earlier, the Portuguese adventurer Pedro Teixiera paddled up the Napo River; he was the first European to do so. On reaching the headwaters, he crossed the Andes into Quito, Ecuador. But it was not until 1743 that the first scientific expedition to the region was launched. In that year, French mathematician Charles-Marie de La Condamine sailed up the Amazon, returning to France with geological data and thousands of specimens of strange plants and animals for the Académie Royale des Sciences.

Over the centuries, innumerable scientists have explored the Amazon, collecting an abundance of biological, geological, and anthropological data. So compelling was the region that the naturalist John Muir went there in 1911 at the age of 73, traveling upriver all the way to Manaus. Even Teddy Roosevelt, ever the intrepid adventurer, sailed up the Amazon in 1914 while president of the United States. Today explorers still travel its many tributaries, wanting to experience this lush repository of life and see animals and plants that perhaps no one else has seen.

contributes almost as much water (14 percent versus the Madeira's 15 percent) to the Amazon's total flow. The Negro travels through ancient sandstone and granite, and so the sediments it deposits are mostly sandy. Not conducive to farming, these soils provide little incentive for settlers, and so for long stretches the river is sparsely populated.

In place of farming, many local people have turned to fishing. With interest in aquarium pets growing in the United States, a large fishing industry has arisen to meet the demand for ornamental fish. The river supports more than 100 species of small, brightly colored fish, including the popular tetra. By stringing nets across the channel, fisherman can capture hundreds of fish a day. The live fish are then flown from airports such as Manaus to pet stores in the United States, where a single fish may sell for hundreds of dollars.

Rio Madeira

The Rio Madeira is the longest of the Amazon's four main tributaries. It is also the second-longest tributary in the world (exceeded only by the Missouri River). The river flows more than 2,083 miles (3,352 km) from its source near the border of Brazil and Bolivia to its union with the Amazon. The combined rivers then surge another 600 miles (966 km) to the Atlantic. The Madeira's watershed is gigantic, covering approximately 20 percent of the entire Amazon basin, or 540,000 square miles (1.4 million km^2). In discharge alone, it is the fifth-largest river in the world.

Madeira means "river of wood" in Portuguese, a reference to the number of uprooted trees that commonly float in its waters. Hundreds of trees fall into the river at the end of the rainy season when the river suddenly recedes, dropping by as much as 20 feet (6 m) in a matter of weeks. When such drastic changes occur, the river's muddy banks give way. They fall into the water, taking hundreds of trees with them. The woody flotsam chokes smaller tributaries, making navigation difficult. Although the trees eventually make their way downriver, the journey may take 10 years or more.

The Madeira starts life high in the Andes as a small stream, less than 10 feet (3 m) wide. Fed by melting snow, its temperatures hover around 53°F (12°C), significantly lower than the Amazon's comparatively balmy 82°F (28°C). As the river descends from 13,000 feet (3,962 m), cascading down the Andean slopes, it passes through pristine cloud forests, bringing coolness to them. These forests are low enough—at altitudes of from 5,000 to 10,000 feet (1,524 to 3,048 m)—to support rich vegetation yet high enough to be chilly. The result is a damp, mist-shrouded landscape that teems with moisture-loving species such as frogs and orchids.

INDIGENOUS PEOPLES: THE YANOMAMO

Yanomamo children belong to a tribe of hunter-gatherers that has lived in the Amazon basin for thousands of years, largely untouched by the modern world. *(Lopez-Mills/AP)*

A tribe of indigenous people known as the Yanomamo, or Yanamami, occupies a remote jungle region of northern Brazil and southern Venezuela, not far from the northern waters of the Río Negro. Although the tribespeople were first contacted by Europeans in 1929 and have been studied by numerous anthropologists since, they remain one of the few culturally intact people in the world, far enough from civilization to have withstood its encroachment. They are relatively few in number—their population totals only about 20,000—though their territory spans some 70,000 square miles (181,300 km²).

The Yanomamo maintain a subsistence lifestyle, living mostly as hunters and gatherers and to a limited extent as gardeners. Still, over the past 20 years, their world has been threatened in multiple ways. Contact with the outside world, which was once rare, is now increasingly common. Pressure to develop the Amazon basin has opened the region; roads, farms, sawmills and natural gas wells now dot what was once unbroken wilderness. Nonindigenous peoples have introduced deadly diseases such as tuberculosis and measles to the tribe and encouraged outward migration. Recently, the discovery of gold in Yanomamo territory has attracted miners, who have brought alcoholism and violence to the area. Although the Brazilian National Park Service has made preserving the Yanomamo way of life a priority, development is proving to be a formidable enemy.

Such lovely beginnings give way for a while to rough, rocky waters. Along one 225-mile (360-km) stretch, or reach, the Madeira passes through 16 major *cataracts*. (See chapter 1, p. 17.) Some, such as the Teotonio rapids that occur just upstream from the town of Pôrto Velho, are bad enough to deter navigation. At lower altitudes, the Madeira transforms into an entirely different river. The tributary begins to meander, its raging cataracts giving way to peaceful *oxbow lakes*. Regular cave-ins of its banks in this region fill the river with a great deal of sediment, making the Madeira the muddiest of the big tributaries. By some estimates, this one river contributes about half the sediments carried by the Amazon to the Atlantic.

Rio Tapajós

The Rio Tapajós arises farther south than any other Amazon tributary, coming into existence in a mountainous region of the Brazilian state Mato

Grosso. The tributary joins the Amazon some 300 miles (483 km) after the Rio Madeira, just north of the city of Santarem, and only about 500 miles (805 km) from the Atlantic Ocean. Though still sizable, the Tapajós represents the fifth-largest tributary basin in the Amazon, covering an area of about 188,800 square miles (489,000 km^2). The river, which is both long (1,150 miles [1,851 km]) and relatively unobstructed, provides an important transportation link between central and northern Brazil.

The metamorphic rocks through which the Tapajós flows yield little sediment, and consequently, the Tapajós flows more clearly than any other of the Amazon's branch rivers. Unlike the Río Negro, which clashes with the Amazon on account of its blackness, the Tapajós stands apart by virtue of its clarity. Its crystalline waters move smoothly, interrupted only occasionally by pink dolphins breaking its surface.

Unfortunately, gold mining has spread to this area, contaminating the Tapajós. Clear waters are being muddied by mining slurry and polluted by mercury. Though the gold rush seems to have passed its peak, the Tapajós remains the most polluted of all the Amazon's tributaries.

Like the Río Negro, the Tapajós metamorphoses into a giant body of water at its junction with the Amazon. These *mouth lakes* occur when a smaller river suddenly spreads in the presence of a larger river. The resulting body of water is so wide it no longer resembles a flowing channel

PINK DOLPHINS

The boto (*Inia geoffrensis*) is one of four species of freshwater dolphins, a group that until recently included the baiji (see chapter 3, p. 54). Only the boto is pink, the intensity of its color reflecting its age: Young dolphins are gray but turn pink as they mature, with males turning a darker pink than females.

Also called Amazon river dolphins, these droll mammals come to the surface to breathe, splashing and vocalizing before disappearing underwater in search of prey. Many are playful, quick to rub alongside canoes or grab a fisherman's paddle. Able to turn their head in all directions, they inquisitively scan their surroundings, which adds to their appeal. The animal tends to be solitary, though mothers and their calves form a strong bond, staying together for more than a year before parting ways.

Widespread, they have adapted to a range of habitats and can be found not only in the Amazon's main channel but under waterfalls and in small tributaries and lakes throughout the river basin. They also have highly mobile flippers, which enable them to maneuver through dense vegetation in flooded areas. Averaging a little more than seven feet (2 m) long and weighing about 275 pounds (124 kg) as adults (males are slightly bigger than females), an individual may live for some 25 years.

According to South American folklore, the boto has a supernatural powers, and bad luck will haunt anyone foolish enough to kill one. Some legends say the animals turn at night into beautiful women who lure men to the river. Others say they are the watchful ghosts of people who once drowned in the Amazon River's turbulent waters.

but looks more like a colossal lake. The Tapajós mouth lake, for example, extends more than 12 miles (20 km) wide and 90 miles (150 km) long.

Geologists think the Amazon's mouth lakes, which they call *rias*, may have formed in one of two ways. Either they came into existence many eons ago when the rivers were steeper and faster than today and had more power to deepen and widen their channels, or they arose some 7 million years ago when the Amazon itself was a giant lake. As the Amazon drained eastward, large depressions in the land may have retained river water.

Rio Xingu

The last major tributary—the Rio Xingu—joins the Amazon about 1,200 miles (1,931 km) downstream at the Brazilian city of Santarem, or about 260 miles (420 km) upstream from the Atlantic. All told, the Xingu flows for about 1,550 miles (2,500 km; its basin is the fourth-largest in the Amazon).

The river begins south of the Amazon. Its headwaters arise in an area of scrubby upland savanna in Mato Grosso. As the channel descends from this ancient upland plateau, it passes through hard sandstone and granite and is interrupted along its length by both rapids and waterfalls.

The waterfalls along the Xingu are truly spectacular—the best the Amazon has to offer. Among the river's most famous are the breathtaking Serra do Cachimbo Falls. Such beauty, however, makes for difficult navigation. Altogether, the river flows through more than 400 miles (644 km) of rapids, including the **Volta Grande** rapids near Altamira. Like the Tapajós, the waters of the Xingu are clear.

The Xingu is a distinctly shallow river, with depths during the dry season of less than three feet (1 m), but it nevertheless pulls water from a significant portion of the Amazon basin. The river's watershed covers 194,500 square miles (504,000 km^2), an area roughly the size of Spain. Of the major tributaries, the Xingu contributes the smallest amount of water to the Amazon, only about 4 percent of the total discharge.

Like the Tapajós, the Xingu spreads into a giant mouth lake when it joins the Amazon. The Xingu connects with the Amazon so close to the Atlantic that oceanic tides, which roll upstream, have been detected at least 60 miles (100 km) inland.

SO WIDE A MOUTH

As it nears the Atlantic, the Amazon splits in two. One branch flows north around an island large enough to be a small country; the other branch flows to the south. The massive island, called Marajó, covers an area of 18,900 square miles (49,000 km^2) and is about twice the size of New Hampshire.

TIDAL BORES

Tidal bores that roar up the Amazon from the Atlantic have given rise to the extreme sport of river surfing. *(Paulo Santos/AP)*

In what is surely an interesting reversal, the Amazon, which feeds so much water and sediment to the Atlantic, periodically receives vast amounts of salt water in return. The water comes in the form of ocean-generated tidal waves called *bores* that roll violently upriver. They are known locally as *pororoca* or "big roar." Although most are no taller than six feet (1.8 m) and move at less than 10 miles (16 km) an hour, they still leave much destruction in their wake. And sometimes they reach truly frightening proportions, with heights as tall as 16 feet (5 m) and speeds of 45 miles (72 km) an hour. The more powerful ones are felt hundreds of miles upstream. Aptly named, the *pororoca* can be heard from several miles away. As the enraged water rushes upstream, it smacks against the river's banks like waves breaking against a sea wall; huge logs and other debris toss like matchsticks in its churning water.

Fewer than 100 rivers in the world are known to have obvious tidal bores, among them the Severn in England and the Ch'ien-t'ang (Qiantang) River in China. All have shallow mouths that both slow incoming waves and provide them with added momentum: As the ocean waves move toward land, they are slowed by bottom friction; the slowing helps build a wall of water that is then pushed forward by oncoming waves.

Bores, like all ocean tides, are linked to the Moon's gravitational pull and tend to be highest when the Moon is new or full. The waves rise still higher when the weather is stormy and the winds blow inland. Adding to the height of the Amazon's bores are submerged sand dunes that act as moguls, sending the ocean waves upward in a great burst of energy.

Despite the fear they evoke, tidal bores have given rise to a new sport called river surfing. Thrill seekers watch for high tides, then climb onto surf boards, hoping to move upstream by wave power. In 2005, a Brazilian surfer, Serginho Laus, broke the world record for distance surfing when he rode the *pororoca* for six miles (10 km), more than a mile (2 km) longer than the previous record. The sport is flourishing; every year increasing numbers of riders defy death on the Amazon, willing to risk their lives for several minutes of upright glory.

Pouring into the ocean, the river lacks the patience to build a delta. Its sediments are moving too fast and entering waters too turbulent to permit their slow drift to the ocean floor. Instead, they churn forcefully seaward. During rainy season, the sediment—estimated at some 3 million tons (2.7 million metric tons) a year—imparts a visible brown color to the ocean as far as 150 miles (241 km) offshore. Overall, the Amazon's freshwater can be detected in the Atlantic for an estimated 1,000 square miles (1,609 km^2).

BIOLOGICAL TREASURE TROVE

Encompassing 3 million square miles (7.8 million km^2), the Amazon's verdant watershed represents a vast expanse of greenery the size of the continental United States. The colossal basin contains unsurpassed biological wealth, housing more species than any other habitat on Earth. While an acre of forest in North America might have six species of trees, the same area in the Amazon could have more than 300. To date, more than 10,000 species of ants and some 80,000 different plants have been found in the Amazon basin. One square mile may support 23,000 species. Many biologists think the numbers of species will grow much higher as the area continues to be explored; some experts predict as many as 30 million insect species roam this vast ecosystem.

Warmth and humidity have undoubtedly contributed to the area's astonishing biological richness, providing conditions, for example, that enable trees to grow some 15 stories tall. At such heights, each tree becomes something of an island, hosting a unique array of species, some of which exist there and nowhere else. Another factor driving diversity is the fact that life near the equator continues year-round, unimpeded by winter. A further factor is the river system itself. With its endlessly branching tributaries and streams, the Amazon has created millions of microhabitats, each one bounded by flowing water. Species living under such isolated conditions diverge from one another over time, evolving into new species. The end result is a biological richness that is both staggering and fragile.

LOOKING TO THE FUTURE

Though revered for its pristine beauty, the Amazon basin is also valued for its considerable economic wealth. Today this vast tract of unspoiled wilderness is succumbing to the forces of civilization and industrialization, and to the world's never-ending thirst for material goods. Ironically, the very tributaries that helped create the region's biological riches have also hastened its destruction, providing gateways to its resources.

A frontier mentality has taken over the basin in recent decades, with boom and bust towns appearing even in remote areas. Growing numbers of gold miners, mineral seekers, oil drillers, cattle farmers, and loggers are traversing the land, seeking its bounty. Drug traffickers, guerrilla troops, and squatters are also moving in, overwhelming what little law enforcement exists. A small glimpse of the damage wreaked by logging pristine rain forests can be seen in the color insert on page C-2 (bottom).

DANGERS LURKING BELOW

Danger lurks in the Amazon's muddy waters, much of it described in the journals of intrepid explorers and in the imaginations of filmmakers and novelists. Of the hundreds of species of snakes that inhabit the Amazon basin—many of them poisonous—the largest is the anaconda, which lives at the river's edge. Anacondas grow to almost 30 feet (9 m) and weigh several hundred pounds; the heaviest one weighed to date tipped the scales at 350 pounds (159 kg).

Like other members of the constrictor family, the anaconda kills by strangling its prey. Most often the snake is seen partially submerged, log-like near the river's edge, though at times it can be spotted lying along the bank. The snake strikes from its submerged position, grabbing its victim, which may be a deer or other animal that comes to drink from the river, between its jaws and pulling it underwater. The snake coils around its prey, suffocating the animal before swallowing it whole. Though the anaconda does attack large animals, including deer, tapirs, and pigs, attacks on humans are rare and mostly undocumented.

Piranha fish are common in the Amazon River system. Despite their ferocious teeth and bloodthirsty reputation, they are not known for attacking healthy animals or humans. *(AbleStock)*

Caimans, which are related to crocodiles, are also intimidating predators. They can grow to nine feet (3 m) long and weigh several hundred pounds. Like crocodiles along the Nile, they spend many hours sunning themselves on the riverbank, submerging only when they are hot or hungry. In muddy water, with just their eyes and nostrils visible, they are easily mistaken for floating logs.

This reptile species—despite its lethargic appearance—attacks with surprising speed. Homing in on a victim, it either leaps explosively forward, seizing its prey with a quick snap of its jaws, or whips its tail around with enough force to knock its victim senseless. The caiman then drags its catch underwater, holding tight to its victim's flesh while spinning like a top. In this way, the prey is quickly eviscerated. Four species of caimans live in Amazon; of these, only the black caiman is known to attack humans. Though such attacks are relatively rare, a person should avoid caiman-infested waters.

The piranha fish also appears frequently in Amazonian lore, renowned for its blood thirst and razorlike teeth. Campfire stories would have one believe that hoardes of fish, unprovoked, swarm over their hapless victims, ripping the flesh from their bones. Tales are told about people being thrown into piranha-riddled waters and reduced to skeletons in a feeding frenzy that lasts only seconds. Such horror-inspiring tales, however, have never been substantiated. Piranhas are carnivorous, but they prefer diseased or decaying flesh and so pose little threat to healthy animals. The fish do have terrifyingly sharp teeth that readily draw blood, but no person is ever known to have been killed or seriously injured by a piranha.

Highways are being built, hastening habitat destruction by encouraging millions of settlers to colonize an otherwise impenetrable rain forest. Two of them—the Belem-Brasilia Highway and the Trans-Amazonian Highway—stretch for thousands of miles. Large cities, many of them centers of industry and shipping, have sprung up along the Amazon's larger tributaries. Three of them—Belem, Manaus, and Iquitos—have populations in excess of 1 million.

Environmentalists decry the loss of the world's largest remaining tract of rain forest. They see its pillaging as not only irreversible but also shortsighted, providing short-term economic gain at great long-term cost. A wondrous habitat that has evolved over many millions of years may be extinguished in a matter of decades. Forests are being obliterated at an unprecedented pace, along with the countless species that contribute in immeasurable ways to the vital functioning of the planet.

Adding to the tragedy is that whatever gains are to be made are likely to be short-lived. Much of the destruction involves cutting and burning the forest to create farmland. But the Amazon is ill-suited for farming, and the pastures being created last only a few years. To understand why, one need only look at the soil.

Unlike the Nile's fertile valley, Amazonian soil has few nutrients and little organic matter. It is thin and sandy, unreplenished by leaf litter and other detritus. Whatever organic matter falls to the forest floor is rapidly broken down in the heat and humidity by bacteria and other microorganisms. The remaining nutrients are then taken up by fast-growing vegetation. The wealth of the Amazonian forest lies in its organisms, not in its soil. In the words of biologist Wade Davis, the rain forest is "a castle of immense biological sophistication built quite literally on a house of sand." Efforts to burn and clear the forest may create land suitable for grazing cattle, but after a few years, the shallow soil dries out and washes away.

The great challenge facing the Amazon River basin in the 21st century is balancing the need to provide resources for a growing world population against the need to preserve a habitat that indirectly and directly supports a great deal of life on Earth; however, once gone, it can never be replaced. Human choices over the next few decades will determine the fate of this remarkable region.

3

The Yangtze

Asia

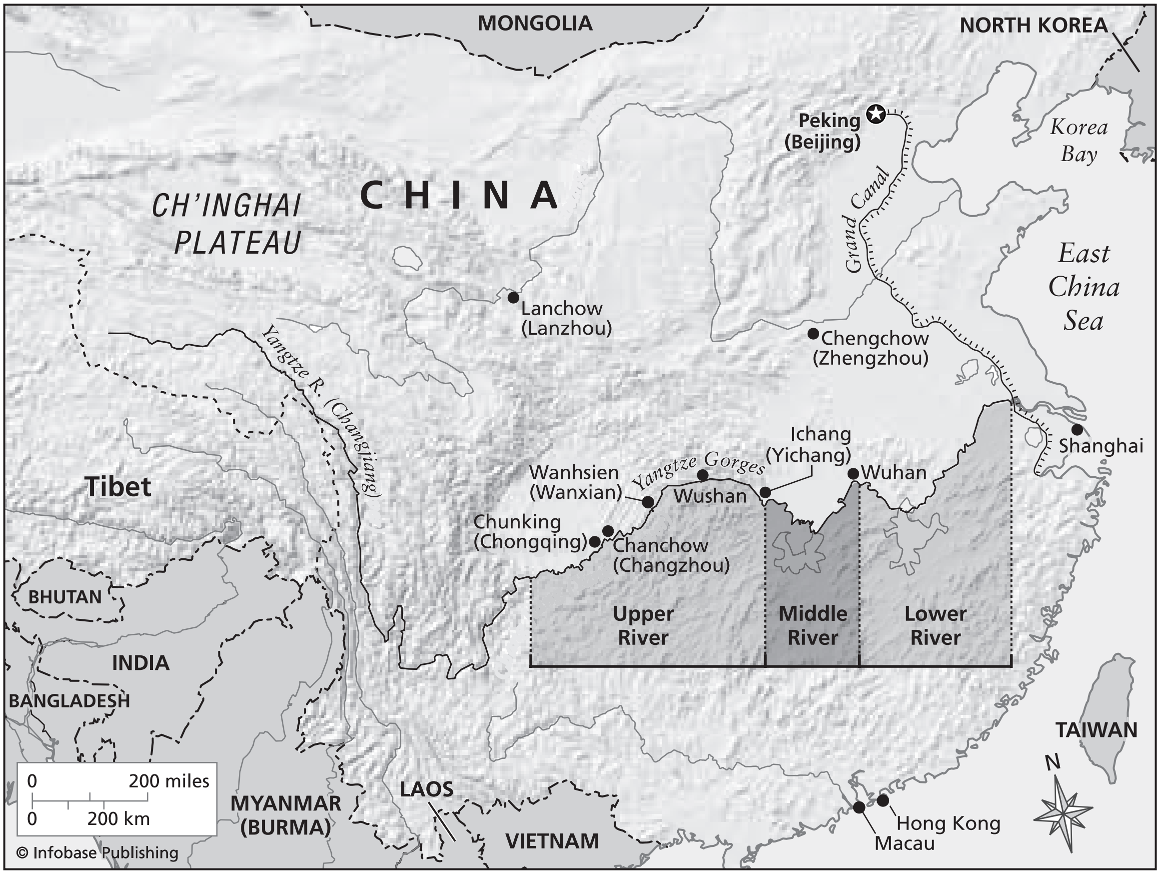
The river varies so wonderfully at different seasons that any description must be carefully understood only to apply to the day upon which it is written.

—Archibald Little, *Through the Yangtse Gorges* (1887)

Measuring some 3,915 miles (6,300 km) long, the Yangtze (also Yangtse, Yangzi, or Chang) claims third place among the world's longest rivers. This wondrous yet formidable river originates on the southeast edge of the great *steppes* of central Asia. Rising almost due north from Calcutta in the Tibetan highlands of western China, the Yangtze flows east for some 500 miles (805 km) and then makes a great dip toward the south before heading to the northeast. In its path to the East China Sea, the Yangtze never leaves China but crosses 10 of the country's provinces, including Szechwan (Sichuan). While not as richly branched as the Amazon, the Yangtze still receives input from at least 700 tributaries.

A tumultuous waterway, the Yangtze ranks second after the Amazon in terms of discharge. Fed by copious amounts of melting snow and also heavy rains, the river's flow is 10 times greater than China's Huang Ho (Hwang River, Huanghe; also known in English as the Yellow River). The Yangtze's watershed encompasses 698,265 square miles (1,808,500 km^2), or one-fifth of China's surface area. The silt load of the Yangtze averages 520 million tons per year, the fourth largest in the world. The Yangtze is also known to be one of the most dangerous rivers in the world; untold thousands have lost their lives in its treacherous waters or while working on its dams and bridges.

The river looms large in Chinese history, culture, and commerce; rice was first cultivated along its banks some 11,000 years ago. The Yangtze provides water not only for irrigation purposes but also for drinking and washing. Known to many Chinese as the Chang, or Long, River, the Yangtze serves as the country's main thoroughfare, connecting China's vast



The Yangtze River begins its journey in Tibet and reaches the East China Sea some 3,915 miles (6,300 km) later.

farmland to its industrial centers. Fishing boats, cruise ships, and freighters crowd the waterway from Shanghai to Chunking (Chongqing), a distance of 1,490 miles (2,399 km), and also ply the 1,114-mile- (1,795-km-) long Grand Canal to Peking (Beijing). The city of Shanghai, home to 11 million people, sits at the river's mouth. Altogether, some 400 million people populate the river's banks, and 80 percent of all river traffic in China takes place on the Yangtze.

Although pristine in its upper reaches, the Yangtze becomes progressively dirtier and more densely populated as it approaches the sea. In its lower regions, the river has become China's unfortunate sewer, carrying the human waste and industrial effluents of its many cities downstream. Indeed, one of the major challenges facing China this century is the need to abate pollution while continuing down the path of increasing industrialization.

ANCIENT ORIGINS

The Yangtze River first formed millions of years ago, a by-product of *continental drift*. Although the process itself took many millennia, the Ch'ing-hai (Qinghai) Plateau, from which the Yangtze descends, rose from the Earth's crust some 40 million years ago when the Indian subcontinent and Eurasia crashed into one another, forming a single landmass. The force of this collision in turn deformed the Earth's crust, pushing the Himalayas skyward and causing lifting of the plateau. At the same time, a vast inland sea formed in western China. As the sea began to drain east, its flowing waters etched out a drainage *channel*. This drainage channel became the Yangtze, which eventually worked its way to the East China Sea.

China's other great rivers, including the Huang Ho, formed at the same time, originating from the same massive *drainage basin*. Because the plateau tilts slightly to the east, China's major rivers flow from west to east, discharging their contents into the East China Sea. Smaller tributaries flow north and south but empty into eastward-flowing streams. In this way, all flowing water eventually moves east toward the sea.

FROM WESTERN CHINA TO THE EAST CHINA SEA

The source of the Yangtze is the Wu-lan-mu-lun River, which originates on the slopes of the southern Kunlun mountain range in China's western Ch'ing-hai Province near the border of the Tibet. From modest beginnings and a width measured in feet, the river grows rapidly as it loses elevation; by the time its flow reaches the ocean, the Yangtze spans some nine miles (15 km). The river changes so drastically, in fact, as it moves downward that the Chinese refer to it by four different names: the High Yangtze, the Upper Yangtze, the Middle Yangtze, and the Lower Yangtze.

High Yangtze

The high river holds a mythical place in Chinese culture, representing a location largely bypassed by the modern world. Here, on a barren landscape, water tumbles from mountain glaciers some 21,000 feet (6,100 m) high. Made from melting snow, small streams flow downward from several snowclad peaks. They come together on the plateau, where they give rise to the Yangtze. Thereafter the river continues its downward plunge, dropping hundreds of feet per mile. Heading first east and then south, the Yangtze moves quickly across the windswept Ch'ing-hai Plateau.

The landscape at this altitude is inhospitable to life, and so the region is sparsely populated. Winters on the alpine plain are bitter cold, and the growing season is short. Largely isolated from the rest of the world, the Tibetans who live here under Chinese rule eke out a living in much the same way as their ancestors did. They till the land with yaks and rely on human and animal power; electricity in the region is rare. The people call the river the Chin-sha-chiang (Jinshajiang), which means "Golden River," a name that refers to the small amount of fine gold sand carried by the current.

Upper Yangtze

After descending from the Ch'ing-hai Plateau and straightening its path eastward, the Yangtze forces its way through mountains called the Wuhan range. Called the Upper Yangtze, this formidable 500-mile (800-km) stretch of fast-flowing water passes between the cities of Chunking (Chongqing) and I-chang (Yichang).

Here—for millions of years—the Yangtze has churned through mountainous limestone-rich peaks, its powerful waters carving out three legendary gorges. Today enormous limestone cliffs—towering and forbidding and spectacular—line each side of the Yangtze's deep channel as seen in the color insert on page C-3 (top). Adding to the river's evocative beauty as it hurtles seaward is its curious zigzag path. At points, the river makes right-angle turns so abruptly that it appears to dead-end.

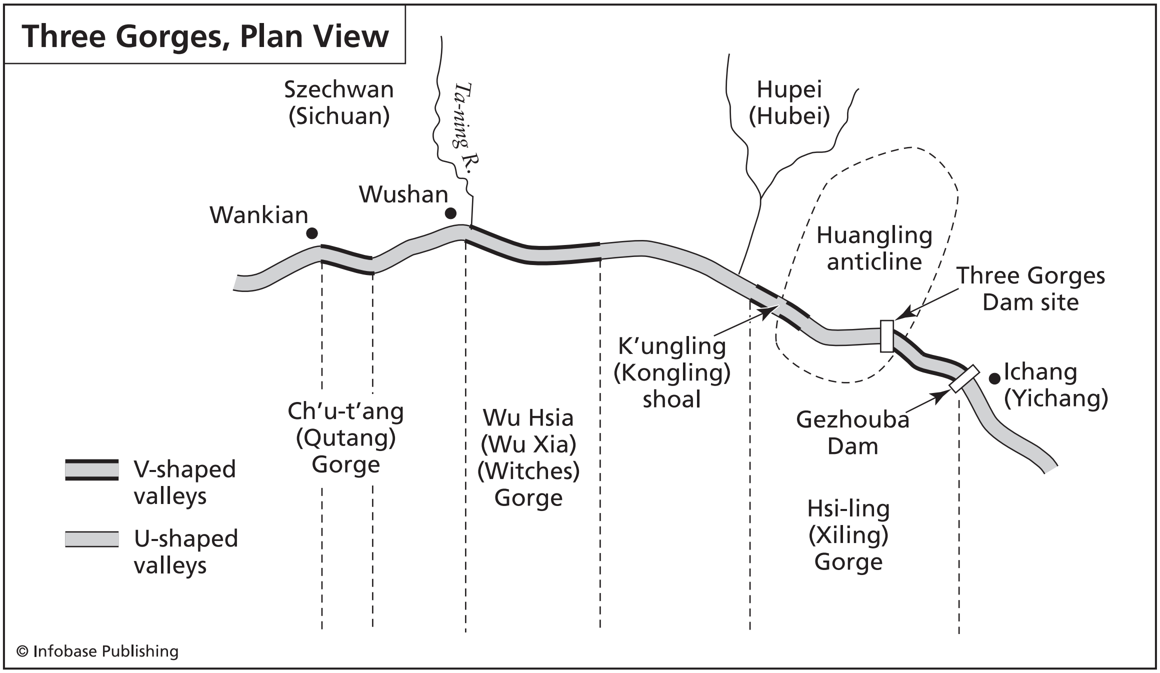
The three gorges lie at separate points along a horizontal 150-mile (241-km) stretch of the Yangtze but are collectively known as the Three Gorges. Each is uniquely perilous. They are—in the order in which they appear as one heads downstream—the Ch'u-tang (Qutang), the Wu Hsia (Wuxia), and the Hsi-ling (Xiling).

The first gorge, the Ch'u-tang, is the shortest; it is only about five miles (8 km) long but is the most dramatic. Approaching the gorge at high speed, fueled by melting snow and its steep fall from the Ch'ing-hai Plateau, the riv-

CULTURAL TRADITIONS

The Yangtze valley has long been recognized as a region of great geologic and historic complexity. Over thousands of years, many emperors and dynasties have arisen in the shadows of the Yangtze; ancient temples stand guard from vantages high above the waterway. Peasants today live in houses and villages that were built 3,000 years ago. According to local lore, the Yangtze's unique gorges were created by Yu, a Chinese folk hero. With help from a band of dragons, he created the great river channel, piling rocks to the sky where necessary, so the surrounding land could be drained and made habitable for the Chinese people. Similar tales and traditions have been handed down from generation to generation.

One tradition that persists is the naming of inanimate objects. Perhaps the custom has roots in illiteracy; historically, less than 10 percent of the population could read. Instead of maps, the Chinese relied on names. Every rock and cliff along the Yangtze has a name, many of them both lovely and apt. Two rocks that arise next to each other, for example, are called "Seated Woman and the Pouncing Lion"; another one is called "Fairy Princess." A third stone appears in silhouette over the gorge, looking very much like a rhinoceros facing west; the stone is duly named "Rhinoceros Looking at the Moon." One peak in the Wu Gorge goes by the name "Climbing Dragon"; another by the name "Flying Phoenix."



Three spectacular limestone gorges occur along a 150-mile (241-km) stretch of the Yangtze River, each one beautiful but deadly.

er suddenly turns south. There its channel narrows abruptly to only 350 feet (107 m) wide, the narrowest point on the river since its formation.

Faced with a sudden bottleneck, which was created by rapid uplift of the rock formation, the Yangtze churns and boils as it fights its way through the narrow opening. A steep incline adds to the water's velocity and turmoil. A torrential downpour or a burst of unexpectedly warm weather (creating more snowmelt) can cause the water to rise or fall by as much as 20 feet (6 m) in 24 hours or 70 to 80 feet (21 to 24 m) over the course of a season. The vertical cliffs along the ravines of the Yangtze are the most hazardous and tallest of all known rivers. Some reach nearly 4,000 feet (1,200 m) in height. The cliffs, though rounded at top, tower ominously above the water and are often shrouded in mist.

Just before reaching the second gorge, the Wu Hsia Gorge, also known as the Witches Gorge, the Yangtze widens, but not enough to slow the river's momentum. The Wu Hsia extends for 25 miles (40 km), a distance that must seem interminable to those trying to navigate its waters. The cliffs that line the gorge are both breathtaking and frightening: They rise perpendicularly, extending as much as 1,000 feet (305 m) into the air, and are so tall that little light enters the channel and the river water flows in perpetual shadow. The walls of solid rock rise to sharp peaks, which are reminiscent of witches' hats, hence the derivation of the canyon's name.

The river enters the third and final gorge some 25 miles (40 km) downstream, near the city of Hsin Tan (Xintan). Known as the Hsi-ling (Xiling), this gorge is the longest and traditionally the most feared of the Three Gorges. Although the gorge has been fundamentally changed by the Three Gorges Dam and also reengineered to be more navigable, not long ago boats entering this stretch of the Yangtze had to endure 30 miles (48 km) of unending terror: rapids and hidden boulders that would smash a boat to smithereens riddled this section of the waterways.

Today the area upstream of the dam has become a large reservoir; downstream the channel has been dynamited to remove and quiet the rapids. In addition, the channel has been dredged, making the riverbed deeper. Still the water gives rise to numerous whirlpools and eddies that require a boat captain's sharp attention.

THREE GORGES DAM

In 1995, China began construction on the world's largest hydroelectric dam, a $30 billion project considered necessary to meet the energy needs of China's growing factories and provide electricity to millions of its people. Spanning the Yangtze's Hsi-ling Gorge, the dam eventually will have 26 turbines that together generate as much power as 18 nuclear power plants (see "Hydroelectric Power" in chapter 6, p. 92).

Completed in the spring of 2006, though not yet generating hydroelectric power, the dam is a marvel of engineering and persistence. A massive undertaking, the dam was under construction for more than 10 years, and

TREACHEROUS TRAVEL

Historically, travel through the Yangtze's Three Gorges was considered one of the world's most hazardous journeys. Going upstream could only be accomplished with the aid of many men who would pull a boat upstream by means of ropes that would run from the boat to harnesses on their backs. Bent over, the laborers plodded in unison, straining their bodies against the surging Yangtze. The work was indescribably brutal; tales are told of men falling off the cliffs, of breaking bones, of being trampled when they stumbled.

Still greater danger lay in the downstream journey. The Yangtze flowed with such great velocity that boat captains had no time for reflection or for taking soundings to determine the presence of hidden rocks. Going downstream, in fact, was daring to the point of foolhardiness. Like an Olympics luge run, survival depended on the lightning reactions of a ship's pilot. Boats had to stay midstream, where currents raged the fastest, because if they moved to calmer (though still raging) waters nearer the channel's edge they risked being smashed against the rocks. By some estimates, one out of every five boats traveling downstream was damaged in some way; one of every 20 boats was completely destroyed and all lives lost.

tens of thousands of laborers have toiled to construct the concrete monolith. Even to look at it takes one's breath away: The dam rises 607 feet (185 m) from the riverbed and stretches one mile (1,600 m) across the gorge, dwarfing every other dam on Earth.

Despite the brilliance of its engineering, the dam has brought irrevocable changes to the Yangtze valley. Not only has the Yangtze been disrupted midstream and converted from a river to a 429-mile (690-km) serpentine lake, but 200 miles (322 km) of its beautiful canyons have been diminished, though not entirely obliterated. Because the dam blocks much of the Yangtze's discharge, about 671 square miles (1,080 km^2) of what was once dry land is now underwater. Some 1,400 villages have been lost, completely wiped out. An estimated 1.2 million people have been forced to find new homes.

In addition, preservationists decry the loss of China's cultural heritage and the number of ancient archaeological sites drowned by the dam's mammoth reservoir. Wildlife biologists are rightfully alarmed by the threat posed to the region's many species. In 2007, the Chinese river dolphin, which made its home in the Yangtze, was declared extinct. Other species may soon follow.

While it is too early to tabulate the ecological costs of the Three Gorges Dam, many biologists worry about the long-term effects of such a project. Small changes to the river's ecosystem are already noticeable and could signal greater problems in the future.

For example, invasive species, such as the Malayan jellyfish (*Sanderia malayensis*) have recently gained a foothold in the Yangtze. The animals arrive with the tide, which flows further upstream now that the Yangtze no longer sends so much water downstream. In just a few years, the jellyfish have become so abundant that in some places they blanket the estuary. Fisherman and others fear the jellyfish blooms could devastate China's fishing industry. Some 361 fish species have been identified in the Yangtze, 36 percent of all freshwater fish in China. Of these, 177 species are thought to be unique to the Yangtze; 25 of them are endangered.

In addition, ecologists are concerned that the dam and reservoir are fragmenting the local ecosystem on a scale that may spell disaster for many plants and animals. Such biological fragmentation means that species are divided into small populations that may not be self-sustaining. Dam-related activities, such as the construction of new cities and roads that are being built to accommodate the people who have lost their homes to the project, will further alter the ecological landscape—not only destroying habitat but also interfering with processes such as nutrient and water cycling.

Geologists and others say that the unprecedented scale of the project—the dam's height, the size of its reservoir, and the amount of sediment carried by the Yangtze—make it hard to predict all that might go wrong. The bigger the reservoir, the more power the dam generates, but a bigger reservoir means more sediment, which may choke waterways upstream of the dam. Some engineers fear, for example, that sediments will build up in Chunking, blocking the outlet of the Chia-ling (Jialing) River where it joins the Yangtze and thus closing the harbor. If such a buildup of sediment occurs, not only will commerce on the river suffer, but sediments once carried 621 miles (1,000 km) downstream to China's fertile farming areas will be trapped upstream.

FLOODING

Like most of the world's great rivers, the Yangtze periodically overflows its banks, drowning its surroundings under several feet of water. Some years, when heavy *glacial melt* from the mountains combines with unusually intense *monsoon* rains, the river climbs to as much as 49 feet (15 m) above its low-water level. The highwater mark in the Yangtze's narrow canyons and gorges can be more than 197 feet (60 m).

Floodwaters have surged through the Three Gorges Dam project with such intensity that at times the river has been closed to navigation. During peak flood times, the flow has reached rates as high as 1,624,475 cubic feet (46,000 m^2) per second. In 2003, China experienced a particularly bad spate of flooding, with seven floods in one season. Thousands of people were killed, either by drowning or by being buried in massive mudslides; millions were made homeless. So serious was the devastation that at one point officials spoke of blasting the upstream dikes to release water. They were faced with the choice of either flooding an area where half a million people lived or saving the cities and their tens of millions of inhabitants downstream. Fortunately, the river subsided before they had to make that choice.

Nor are they likely to be faced with such a choice in the future. With the Three Gorges Dam recently completed, many Chinese officials expect flooding in the Yangtze valley to be largely an event of the past. They also point to lessons learned over the years that will lessen the likelihood of flooding. For example, the Chinese now know they cannot continue to exploit their country's resources without regard for environmental costs. Deforestation, road building, and strip mining have created soil erosion (which in turn has added tons of silt to riverbeds, raising their water levels), and the filling in of lakes and rivers to create more farmland has closed an important escape valve for the Yangtze's overflow. China's government says they will avoid such projects in sensitive areas in the future, although the population's many needs, including food, may make such a promise difficult to keep.

Middle Yangtze

Leaving the last rocky canyon behind at Ichang, the Yangtze pours onto the broad plain of central China, spreading to more than a mile (2 km) wide on its way to Wuhan. This vast *alluvial plain* extends 590 miles (950 km) from here to the coast.

Now dammed, the Middle Yangtze retains its largely docile character, though its flow is diminished and it no longer has the ardor it once did. Before completion of the Three Gorges Dam, the Yangtze would abruptly change from a wild river to a serene one as it emerged from its last limestone canyon. Today the river exits the canyon region via the turbines of the Three Gorges Dam. Although its volume is reduced, the river still spreads out as it heads seaward. Here the channel widens to about a mile and becomes easily navigable. Many tributaries join the Yangtze at this point; among the largest are the Hsiang (Xiang) and Gan Rivers from the south and the Han from the north.

Entering a broad basin-shaped stretch of countryside, the Yangtze develops into what is known as a *braided stream*. Here, as a result of sudden slowing, the river's abundant sediments settle in a pattern that disrupts the main channel. Numerous small rivers separate from the main trunk, moving in different directions. Many of them do not rejoin the Yangtze directly but link up with its tributaries. Some meander for a considerable distance, rejoining the main river some 124 miles (200 km) downstream. The slope of the Yangtze in this region is barely perceptible; the river drops by only an inch and a half per mile from here to the ocean.

Lower Yangtze

As the river flows slowly east from Wuhan to Shanghai, it works its way through an alluvial plain, fertile land created by the process of sedimentation over the course of hundreds or thousands of years. Although the region boasts a few isolated hills, in general the land is level, at most 150 feet (46 m) above sea level.

The Yangtze increases its girth as it flows toward the sea, expanding finally into a great delta. At this point, the river discharges into the East China Sea at a rate of about 776,923 cubic feet (22,000 m^3) per second, or 166 cubic miles (690 km^3) of water each year. A heavy load of sediments is discharged at the same time, resulting in offshore sediment plumes that are visible from the air. More than 5 billion cubic feet (142 million m^3) of sediment flows down the Yangtze every year, enough to add a full mile to the delta every 70 years or so.

The Yangtze is categorized as a tidally dominated delta, which means that more sediment in the delta region is deposited by the incoming tide than by the river. The process is simple, if circuitous: Sediments dumped

BRAIDED STREAMS

A river becomes braided, that is, divided into a complex network of smaller channels, when sediments and other debris form island-like deposits that interfere with the water's flow. Braided rivers may follow varied and complicated patterns; often they appear as a network of dividing and reuniting channels. The Yangtze exemplifies a highly complex pattern of braiding; in the United States, the Platte River is an example of a long braided stream.

Braiding appears rather unpredictably and follows few rules. Some braided streams run for a short distance; others for many miles. They form in humid as well as arid environments and in both upland and lowland areas. But none can form without an abundance of sediment, which is typically mud, sand, or gravel. In addition, braided rivers are always wide and shallow, though the sediments that divide the channel may be submerged at times of high flow.

Braiding reflects a shift in a river's *equilibrium;* a localized imbalance of sediment transport may result in the uneven buildup of *alluvium,* or sediment dropped by a stream. Sometimes excess sand accumulates in parallel bars; in other places, islands of gravel may collect mid-channel; in northern rivers, boulders left by retreating glaciers may force the river to find alternate channels. Over time, crisscrossing may occur between channels, giving the river a characteristic braided appearance when seen from the air, hence the name. Braided rivers are constantly evolving; they are particularly unstable forms, even in the short term.

Braided streams arise when huge quantities of sediment or rocky debris, often left by retreating glaciers, fill a river channel. Braided rivers tend to form at lower altitudes, where the river is wide and shallow.

GRAND CANAL

Rivaling China's Great Wall as a masterpiece of engineering and a tribute to human endurance is China's Grand Canal. Totally humanmade, the canal is the world's longest. From its beginnings at the southern city of Hangchow (Hangzhou) to its termination in Peking (Beijing), the canal measures 1,114 miles (1,795 km) long. Constructed from the sixth to the eighth centuries, the canal was built to carry rice and other crops from the fertile farmlands along the Yangtze to China's northern cities. Much of the canal is lined with stones, and its width ranges from 100 to 200 feet (30 to 61 m), wide enough to accommodate cargo ships. According to historical records, about 6 million men built the canal; half of them died doing so.

Despite the human toll, the canal has played a vital role in China's history. Even today it serves as the nation's major north-south route, critical not only to commerce but also to national unity.

into the ocean by the river, which moves too fast to allow them to settle, are washed back toward land with the tides. Like other tide-dominated deltas, the pattern of deposition results in a bell-shaped delta that builds outward at an estimated rate of about 1.2 miles (2 km) per century.

The region also has many *sandbars* and *tidal flats,* which are typical of deltas shaped by tidal forces. The sandbars in turn help create sandy channels that fill with water. Today the entire Yangtze delta is overlaid with a watery network: Channels formed by *fluvial* action connect to humanmade canals that provide drainage, irrigation, and transportation. Known as Chiang-nan, or "South of the River," this low-lying alluvial plain has so many waterways that almost every town is connected by water to its neighbors.

Some subsidence of the delta occurs simultaneously with deposition; this slows the rate of deposition. To prevent the loss of sediments, engineers have constructed reclamation dikes with *sluice gates* that allow the tide to come in but are then closed to permit the settling out of most silt and clay-sized particles. Such human intervention accounts for much of China's coastline around the mouth of the Yangtze, especially to the north. The sediment-rich land captured by this process is now under extensive cultivation; seawalls protect it from further erosion.

The last 500 miles (805 km) of the Yangtze have historically supported vast tracts of agriculture; the banks of the slow-flowing river have been the country's epicenter of rice cultivation for thousands of years. Although agriculture remains the dominant industry, in recent years this region has witnessed an unprecedented industrial explosion. While good for the economy, such rapid industrialization has been hard on the environment. New factories are built without regard for their environmental impact, and many discharge their effluents directly into the Yangtze.

The once magnificent waterway is now muddy and polluted. The Yangtze not only meanders past factories but also by the homes of millions of people. The greater city of Chunking, also called Yu, supports some 31 million people. Farther south—on the west bank of the

Huang-p'u (Huangpu) River, which is the Yangtze's last tributary—lies Shanghai, China's most populated city. A coastal city and major port, Shanghai has seen explosive growth in recent years. Not far into the 21st century, the city's population exceeds more than 11 million. Without question, the Lower Yangtze is China's economic and cultural center; hungry for power, its status will increasingly depend on electricity generated by the Three Gorges Dam.

IN THE FIELD: ANCIENT CULTIVATOR OF RICE

In 1997, a team of Japanese and Chinese archaeologists found evidence that the world's earliest rice cultivation took place along the Middle Yangtze. Applying radioactive carbon dating to fossilized rice grains and other plant remains from more than 100 sites along the Yangtze, the archaeologists found that the oldest samples came from the banks of the Yangtze in central China. Whereas the rice grains from these sites were about 11,500 years old, samples taken from sites both farther upstream and downstream were younger, ranging in age from 4,000 to 10,000 years old. Syuichi Toyama, an environmental archaeologist at Japan's Kogakukan University, says the pattern shows that rice cultivation must have originated in the Middle Yangtze and spread outward from there.

FACING THE FUTURE

The Yangtze has paid a steep price for becoming China's commercial and industrial mainline. For thousands of years, the Chinese have lived and

BAIJI

For millions of years, the Yangtze has been home to the baiji, *Lipotes vexillifer*, one of only four species of freshwater dolphins (see "Pink Dolphins," Chapter 2, page 37) in the world. Sadly, after several decades of dwindling numbers, the animal no longer exists. In the 1980s, at least 400 baiji were living in the Yangtze; yet by 1997, the population had dropped to 13. In 2006, despite extensive searching, none could be found.

For nearly six weeks, more than 30 scientists looked for baiji along a 1,000-mile (1,609.3-km) stretch of the Yangtze. Armed with sophisticated surveillance techniques, including high-tech binoculars and underwater microphones, they scoured the river yet failed to find a single animal. According to August Pfluger, a Swiss scientist involved in the search, "We have to accept the fact that the baiji is functionally extinct. We lost the race."

By all accounts, human development is to blame. In recent years, many baiji have died in collisions with ships or after becoming entangled in fishing nets. Others were injured by channel dredging or caught illegally. At the same time, the animals' habitat was severely compromised. Water levels dropped; the fish that composed the baiji's diet became scarce; and pollution levels reached unprecedented levels. In addition, the Three Gorges Dam altered the Yangtze's flow for at least 120 miles (200 km) downstream, eliminating the source of eddies that were home to the dolphins.

New cities, such as the one depicted here, are being built along the Yangtze to accommodate China's rampant industrialization. *(Taolmor/Shutterstock)*

farmed the river, adding more people each year to the cities that grow steadily along its banks. What was once a meandering river valley dotted with rice paddies, forests, and cliffs is now a landscape largely denuded of vegetation and biological riches. Unlike the Amazon, which remains relatively unspoiled, the Yangtze has witnessed astonishing rates of development, much of the growth unregulated.

The river's banks are now home to countless factories, the region's air and waterways are heavy with pollutants, and wildlife is scarce. According to China's state media, the river is "cancerous" with pollution, and by 2010, 70 percent of its water may be unusable. One can travel upstream for 1,000 miles (1,609 km) and barely see a bird or a tree. In the 1980s, the river supported 126 animal species; by 2002, the number had dropped to 52. Yet more development is likely, fueled by the vast supply of electricity now being generated by the Three Gorges Dam and by the desire of many Chinese to achieve a higher standard of living. Whether China can create a balance between continued development along the Yangtze and environmental protection remains to be seen. Certainly, meeting the needs and desires of 1.3 billion people creates great challenges in a country that is experiencing unprecedented change at an unprecedented rate.

4

The Mississippi

North America

> *The Mississippi is . . . everything. It is the Hudson, the Delaware, the Potomac, and all the navigable rivers of the Atlantic States formed into one stream.*
>
> —James Madison [1803, at the time of the Louisiana Purchase]

From the origins of the Missouri River high in the Rocky Mountains to the Gulf of Mexico, that is, from beginning to end, the Mississippi-Missouri system measures about 3,900 miles (6,270 km) long, a length just shy of that of the Nile.

Three great tributaries give rise to the system. They are—in order of length—the Missouri, the Upper Mississippi, and the Ohio Rivers. These and other waterways coalesce to form a drainage system that draws water from a broad swath of the United States. The system, which covers almost half (41 percent) of the continental United States—or some 3.27 million square miles (8.5 million km^2)—extends as far north as southern Canada, as far west as the Rockies, and as far east as the Allegheny Mountains. All or parts of 31 states and two Canadian provinces fall within the outlines of this *watershed*. Only the watersheds of the Amazon and the Congo are larger.

Despite its continental spread, the Mississippi carries less water than its global rivals, ranking ninth in the world in *discharge*. At its *mouth*, the Mississippi averages a discharge rate of about 620,000 cubic feet (17,500 m^3) a second, although this rate may increase fivefold during flood season. Runoff peaks with snowmelt in April and is lowest in September, apparently because of high rates of evapotranspiration during the summer months. (See "Measuring a River's Rate of Flow" in chapter 2.)

When one thinks of the Mississippi, one thinks of a single river. Together the Upper and Lower Mississippi form a waterway of great hydrological, cultural, and economic significance. Indeed, the north-south channel—as it runs from Minnesota to Louisiana—looms large in the American psyche. A cultural and geographical icon, this singular waterway bears many names: "Big Muddy," "Mighty Mississippi," "Ol' Man River," or simply "the Mississippi." In many ways, the river defines America, neatly bisecting the country in two, differentiating between east and west, and at one time separating the civilized world from the wild frontier. Exalted by more writers than any other American stream, the Mississippi has been immortalized by such literary giants as Mark Twain and Edna Ferber. To many Americans, mention of its name evokes images of Tom Sawyer and Huck Finn, and of Paul Robeson in *Showboat.* To others, the Mississippi is simply the nation's premier north-south navigation route providing transportation for endless barges, as seen in the color insert on page C-3 (bottom).

From its headwaters in northern Minnesota to its discharge into the Gulf of Mexico at New Orleans, the Mississippi heads almost due south, appearing on maps as a clear—if at times wobbly—line down the middle of the United States. As its waters chug southward, the Mississippi forms the borders of eight states: Wisconsin, Iowa, Illinois, Missouri, Kentucky, Arkansas, Tennessee, and Mississippi. At one end, the river runs through the middle of Minnesota; at the other, the Mississippi passes through the center of Louisiana. Along the way, the Mississippi gains myriad branches, the largest of which are the Missouri, which joins the Mississippi in St. Louis, and the Ohio, which joins the river in Cairo, Illinois. By the time the river reaches the Gulf, the waterway has grown to a 10th-order stream.

Unlike the Amazon, which runs from west to east along the equator, the Mississippi flows north to south through temperate latitudes and so experiences dramatic climatic shifts. In the far north, the Mississippi succumbs to ice cover for several months each year, its waters cooled by air temperatures that may drop to -20°F or -30°F (-29°C or -34°C). In summer, the same stretch may be warmed by ambient temperatures as high as 95°F (35°C). By contrast, the southern end of the river experiences few temperature fluctuations; the channel passes through a subtropical landscape, where the weather remains warm and humid year-round.

RIVER IN THREE PARTS

Some 50 or 60 million years ago, the stage was set for the formation of this great river. Tectonic activity thrust the Rocky Mountains upward, creating a *continental divide.* Waters that flowed westward from the Great Plains area were now blocked by emerging mountains. Unable to flow uphill, they flowed downward to the south. On its western edge, the Missouri-Mississippi watershed follows the continental divide; waters flowing down the east slope of the Rockies drain into one of its many tributaries and eventually into the Gulf of Mexico.

The Mississippi is divided into three parts: the *headwaters,* which begin as a small stream flowing from Lake Itasca in northern Minnesota and flow south for 400 miles (644 km) to St. Anthony Falls in Minneapolis; the Upper Mississippi, which runs from Minneapolis to St. Louis, where the river meets the Missouri; and the Lower Mississippi, which flows from its junction with the Ohio River in Cairo, Illinois, to the Gulf of Mexico. The length of this continuous channel, that is, from Itasca south to the Gulf, including all the river's meandering turns, is about 2,320 miles (3,733 km).

Headwaters

The Mississippi enters the world as a first-order stream—a single channel flowing through the rocky outcrops and spruce swamps of northern Minnesota. The river takes shape when it pours over the edge of Lake Itasca at an elevation of 1,275 feet (450 m) above sea level. On leaving the lake, the Mississippi moves due north for several miles, through an area that was once touched by the leading edge of a glacier. Left behind when the glacier retreated was an unkempt bed of ancient igneous and metamorphic rocks. Today this rough and hilly terrain, also known as "knob and kettle" topography, remains pockmarked with coarse gravel and boulders. The knobs are piles of glacial debris; the kettles are concave depressions, often filled with water, that were once ice pockets under glacial debris.

Before turning south, the river heads east for a few miles, then churns toward Minneapolis. On its way, the 20- to 30-foot- (6- to 9-m-) wide stream passes through an austere but beautiful landscape dominated by bogs, *boreal forest*, and glacial lakes. In Minneapolis, the river flows over exposed *bedrock*, creating the only significant waterfall on the Mississippi. Known as St. Anthony Falls, the geological formation has lost its natural beauty and is now reinforced with concrete and power-generating turbines.

Upper Mississippi

Once past St. Anthony Falls, the Mississippi widens, making an S-shape turn around the Twin Cities of Minneapolis and Saint Paul before heading toward the Gulf. Straightening out, the river picks up speed, carving a wide channel through limestone cliffs and forming the border between Minnesota and Wisconsin. Steep bluffs rise above both banks.

Some 47 miles (75 km) downstream from Saint Paul, the river expands dramatically, forming a *mouth lake* like those along the Amazon River. Here the Mississippi widens its banks to 2.5 miles (4 km) for a distance of 22 miles (35 km). This stretch, called Lake Pepin, freezes in winter, with ice that is 24 inches (61 cm) thick in some places. Ice-fishing shacks dot the lake's surface until March, when the ice disappears and barge traffic begins anew.

As the Mississippi moves toward Missouri, the limestone bluffs that line its channel give way to farmland. Ten miles north of St. Louis, the mighty Mississippi meets the Missouri, which has descended some 2,315

The Mississippi and Missouri Rivers constitute the fourth-longest river system in the world. From the tip of the Missouri to the Gulf of Mexico, this river measures 3,900 miles (6,270 km).

miles (3,726 km) from the mountains of Montana. The river again widens and continues south though the Ozark Mountains to Cairo, Illinois, where it joins with the Ohio River. At this point, the Mississippi becomes not only a 10th-order stream but also the largest river in North America.

GREAT FLOOD OF 1993

The Mississippi, like all snow-fed rivers, swells in the spring and summer when snowmelt and rain pour into its waterway. Flooding often occurs along the northern tributaries, but levees typically keep the river in check elsewhere. Nonetheless, the Mississippi occasionally overflows its banks, sometimes with disastrous results. One such disaster took place in 1993. After a spring of unrelenting rain, the Mississippi gave rise to the worst flood in 150 years.

In late June 1993, the river jumped its banks in Minnesota. What was worse, the watery disaster moved downstream as the summer unfolded. By early July, parts of nine states were under water; by the end of July, the flood had reached catastrophic proportions. Within weeks, 1,100 of 1,576 levees had failed. As depicted in the color insert on page C-4 (top), entire towns were under water. Fifty people died. Floodwaters spread across 23 million acres (9 million ha), affecting low-lying areas from Minnesota south to Cairo. The raging Mississippi was closed to shipping for two months. Train tracks and bridges were also washed away by the torrential power of North America's greatest river.

The river eventually subsided. Broken levees were repaired, and normalcy returned to the Missouri-Mississippi valley. But the area's increasing reliance on levees has subsequently sparked a lively debate. Levees essentially squeeze a river, causing it to run faster and deeper, which makes

A HYDROLOGICAL MISNOMER

Few people realize the Upper Mississippi is technically only a *tributary* (the Lower Mississippi forms the true main trunk) and is also much shorter than the Missouri. Remove the Missouri River from the system, in fact, and the Mississippi loses its place among the world's longest rivers. But such confusion is hardly surprising. Not only has the river's source been pinpointed in northern Minnesota, but its north-south *channel* is recognized as one of America's primary shipping routes, traversed by thousands of barges every year.

The reason for the misnomer is largely historical: Europeans discovered the northern reaches of the Mississippi long before they wandered its western branches. La Salle and others who sailed downstream from Minnesota to the Gulf of Mexico assumed this south-flowing channel to be the river's main trunk and had little reason to doubt otherwise. In St. Louis, where the Mississippi and Missouri meet, the Mississippi is the broader of the two rivers. Certainly no one is advocating a name change now, but by definition, the Missouri should be the Mississippi, and the headwaters traced northwest to Montana.

Winding slowly downstream, the Mississippi River deposits sand, called point bars, along its curves. Sand will accumulate where the flow is slowest and erode from those areas where the flow is fastest. *(The author)*

the river more prone to flooding. If and when the levees do break, the results can be catastrophic. The river does not just overflow its banks—it pours down the sides of the levee, its velocity increased by the force of gravity. The downward flow may also wash away the levee, causing further flooding.

Development adds further stress to the waterway. Deforestation and industrial development mean more runoff, which increases the river's overall volume. When the average height of the river increases, existing levees become obsolete, so each year new ones are made that are even taller than the others. But the alternative—removing the levees and allowing floodwaters to spread slowly over an area—is not attractive either. To do so would put millions of homes at risk and also jeopardize the Mississippi's core shipping channel.

IN THE FIELD: FLOOD FORECASTING

Any river is susceptible to flooding if too much water pours into its channel. In 1889, long before the Mississippi was constrained by levees, the U.S. Geological Survey—recognizing the economic and social costs of such flooding—initiated a monitoring system. Called the National Streamflow Information Program, the system now has some 7,400 stream gauges placed in rivers around the United States that are connected via telephone lines to government computers. Minnesota alone has 97 stream-gauge stations to monitor the Mississippi and various tributaries within the state's borders.

SERVING HUMANKIND

The banks of the Mississippi have sustained human populations for at least 10,000 years, a history told by Indian artifacts unearthed from countless archaeological sites and burial mounds. The river's name in fact comes from the Ojibwa words *misi ziibi*, which mean "great river."

Almost 500 years ago, the first European explorers came upon the Mississippi. The earliest was the Spaniard Hernando de Soto, who reached the river's mouth in 1541, astonished no doubt by its colossal width. A century later, three French trappers and explorers—the team of Jacques Marquette and Louis Jolliet, and later René-Robert Cavelier, sieur de La Salle—came south from Canada and traveled the Mississippi's upper reaches. In 1679, La Salle returned to the river and spent four years traveling its entire length. When he reached the Gulf of Mexico in 1682, he claimed the entire Mississippi and its environs for France. To honor his country's ruler, King Louis XIV, he named its southern reaches Louisiana.

For the next 100 years, the French retained supremacy of the region. By the 1760s, however, large numbers of English were moving westward from the east, and the Spanish were moving north and east from the southwest. Under pressure, France ceded the area to Spain in 1762. Less than 40 years later, Napoléon Bonaparte reclaimed the territory for France. Shortly thereafter—in 1803—France sold the entire drainage basin to the United States for $20 million, in a bargain real estate deal that is famously known as the Louisiana Purchase.

In 1811, the first steamboat sailed down the Mississippi, opening a new chapter in American history. With steamboats came the ability to move heavy loads over large distances, and so the Mississippi quickly became the country's major channel of communication and commerce. By 1856, the equivalent of $80 million of raw goods, including grains and ores, were passing through the port of New Orleans each year, destined for overseas markets. To this day, the Mississippi remains a key transport route for grain and other agricultural riches from America's heartland that are desired by countries around the world.

The gauges play a prominent role in flood forecasting by measuring the level and flow of water in a stream. Typically, a gauge sits belowground in a vertical standpipe or in a wooden structure by the riverbank. A horizontal pipe runs from the standpipe to the river channel; as the water level rises and falls, a pressure-sensitive electronic transducer within the pipe records the change in water elevation. A separate instrument in the river itself measures stream velocity.

Data collected from gauges throughout a watershed provide critical information about water levels in the entire river system. These measurements are combined with meteorological and historical data and used to formulate a flood forecast.

If hydrologists determine there is potential for flooding within a given watershed, they issue warnings to vulnerable municipalities. If the situation looks extreme, they may issue evacuation orders, giving people time to move to higher ground.

MISSOURI RIVER

The Missouri River runs 2,540 miles (4,088 km) from its source at the headwaters of the Red Rock River in the Rocky Mountains to its *confluence* with the Mississippi. Though not as well known as the Mississippi, the Missouri flows farther than any other river in the United States. As it descends to the Mississippi, the waterway gives rise to an impressive watershed. With a rich network of tributaries, the Missouri creates the second-largest drainage basin in the United States. All told, the Missouri adds 514,215 square miles (1,331,810 km^2) to the total area drained by the Mississippi.

But for all its length, the Missouri disappoints when it comes to volume. Relatively little rain falls in its basin area, much of which is prairie. In terms of discharge, the Missouri ranks sixth among American rivers and increases the flow of the Upper Mississippi by only one-third.

Like the Mississippi, the Missouri carries a large *sediment load;* like the Lower Mississippi, it is sometimes called the "Big Muddy." Most of the suspended sediments in the Missouri come either from the riverbed itself or from its unstable banks. Turbulent waters tearing at the river bottom pull silt and sand into the river, and fast-moving currents wash clay, silt, and sand from the river's banks. The sediments collect in reservoirs, which then have to be dredged. (See "Sediment Load" in chapter 5.)

In contrast to the Mississippi, which has long been an American icon and major transportation route, the Missouri has languished in relative obscurity. The first explorers to follow the river upstream—the famed Meriwether Lewis and William Clark—did not reach the river until 1804. Infrequently used by American settlers heading west, little was done to develop the river as a commercial waterway or even as a source of irrigation.

The river basin remains sparsely populated today, flowing as it does through the plains states of Montana, North and South Dakota, Nebraska, Iowa, and Kansas.

OHIO RIVER

Of the Mississippi's three great tributaries, the Ohio River has the shortest channel. At 981 miles (1,579 km), the waterway is only half the length of the Mississippi, yet it contributes more water than any other branch in the river system. In terms of volume, the Ohio is the third-largest river in the United States. This one river, which is fed by abundant rainfall along its entire length, accounts for more than 40 percent of the total discharge of the Mississippi.

The Ohio's drainage basin, which is not especially large, spreads across 203,900 square miles (528,100 km^2). The river's various branches touch major portions of eight states and minor portions of another six states, from New York to Georgia and Alabama. The basin generally slopes from east to west, fed by thousands of streams from the Blue Ridge and Appalachian Plateaus of the Appalachian Highlands.

As the river moves down from the Appalachian Mountains, it courses toward the northwest, flowing out of Pennsylvania before turning toward the southwest and its eventual junction with the Mississippi. Throughout its length, the Ohio remains relatively narrow, averaging only half a mile in width near Pittsburgh and never growing much beyond a mile wide.

The river's trajectory—from Pittsburgh to Louisville and Cincinnati and then Cairo—traces almost perfectly the line of advance of ancient glaciers. By blocking the flow of water, the ancient ice sheets forced streams to flow where the glaciers were melting. Although the river now passes through largely urban and agricultural landscapes, historically the Ohio flowed through heavily forested terrain. Early French explorers called it La Belle Rivière, or "The Beautiful River." The Iroquois called it the Ohio, which has the same meaning.

Lower Mississippi

From its confluence with the Ohio River, the Mississippi winds its way to the Gulf, first passing through the Ozark highlands of Missouri and Arkansas. There the uplifted *plateau* of limestone, sandstone, and shale has been deformed by folds and faults. Ridges and valleys running east to west extend from Arkansas into Oklahoma, and numerous caves dot the region.

Filled with discharge from the Ohio, the Mississippi now contains about 80 percent of its final flow and swells to enormous width. By the time the waterway reaches Louisiana, it stretches as much as a mile and a half (2.4 km) across.

The river soon opens onto the Coastal Plain, a large, flat expanse of terrain thick with *alluvial* deposits. Here, bloated by sediment, the Mississippi becomes lethargic. Moving slowly, without much forward momentum, the river wanders. Forming great loops and hairpin turns, it appears in aerial view like a crumpled ribbon tossed on the ground. All the world's great *meandering* rivers—of which the Lower Mississippi is one—are similar in appearance; powered by centrifugal force, they are constantly changing shape, forever striving for an equilibrium they will never have.

The rich Mississippi floodplain extends almost all the way from Cairo to New Orleans. Once regularly nourished by periodic flooding, which now rarely occurs because the river channel is so tightly engineered, the low-lying plain is disappearing at a precipitous rate. But the plain still measures 125 miles (200 km) across at its widest point and embraces some 30,000 square miles (78,000 km^2) of silt-rich farmland. Warm temperatures and abundant rainfall, combined with fertile soil, have created prime agricultural conditions. Today nearly 80 percent of the coastal plain remains in agricultural production.

At Baton Rouge, which is as far upstream as oceangoing ships can travel (thereafter all shipping is by river barge), the river turns in a southeasterly direction as it crosses the deltaic plain toward New Orleans. The river then flows through the swamps and *bayous* of southern Louisiana before finally discharging into the Gulf of Mexico.

MISSISSIPPI DELTA

After leaving New Orleans, the Mississippi continues on its southeast course, flowing through a swampy region known locally as the Mississippi Embayment. This area, also known as the Delta, is rich in alluvial deposits that have been accumulating for many thousands of years.

The 100-mile- (161-km-) long delta projects, fingerlike, into the ocean. Because it has several lobes that extend outward in the manner of claws or talons, this type of formation is called a bird's-foot delta. Deltas assume this shape when a river discharges into a fairly docile sea; sediments settle out slowly, close to land, and over time lobes form, extending outward like talons, as is so clearly visible in the color insert on page C-4 (bottom). Over thousands of years, as the Mississippi's channel has become deeper and swifter and the delta longer, the suspended sediments are carried as far out to sea as the edge of the continental shelf.

Today, the bird's foot is no longer accumulating silt, and eventually, the Mississippi's distinctive delta will disappear. The once free-flowing river is now constrained, its channel created by levees that steer its discharge (and sediments) far offshore, past the continental shelf. Better to lose sediments to the deep waters of the Gulf, so the reasoning goes, than to risk clogging a major shipping route. In addition, the Lower Mississippi has seen a marked decrease in sediment load over the past 50 years, the result of dredging and the trapping of sediment in dam reservoirs. The net result is a subsiding delta and a gradually sinking Louisiana, which sees some 50 square miles (130 km^2) permanently submerged each year. The estimated 120 million tons of sediment that are lost annually are no longer available for the natural rebuilding processes of waves and currents. Normally, the sediment would be redistributed by oceanic action, reversing the land loss of Louisiana's marshes and frail barrier islands.

Engineering has also forced the Mississippi to flow through New Orleans on its way to the Gulf, rather than take a shorter route due south. Left alone, the Mississippi would jump from its present channel to that of the Atchafalaya, a small river that runs down the western side of the delta and reaches the Gulf in 140 miles (225 km). Instead, the river has been forced between massive levees into a channel called the Mississippi River Gulf Outlet, which directs the Mississippi farther east—and 160 miles (257 km) out of its way—to the port of New Orleans.

MEANDERING CHANNEL

Below its confluence with the Ohio, the Mississippi embarks on a wildly meandering course. In fact at one time—before the channel was reconfigured by the U.S. Army Corps of Engineers—the river wandered so much that it flowed east to west more than it flowed south. In some places, a boat might travel from 12 to 18 miles (20 to 30 km) back and forth in order to gain a mere two miles (3 km) southward. Mark Twain addresses the frustrations of such meanders in *Life on the Mississippi*, noting that "in some places, if you were to get ashore at one extremity of the horse-shoe and walk across the neck . . . you could sit down and rest a couple of hours while your steamer was coming around the long elbow. . . ."

Two factors play a determining role in the formation of river meanders: a reduction in flow velocity, as when a river suddenly reaches flat terrain, and the deflection of flow from the channel's central axis, as when an obstacle such as an island or snag suddenly appears midstream. Once a river is diverted in this way, it undergoes a series of pendulum movements. As the water begins sweeping sidewise, centrifugal forces kick in, forcing the water outward and exacerbating erosion of the river banks. Such lateral forces in turn cause the river to meander outwards in an ever-widening curve. Deep pools occur along the outside margins of bends, with extensive sandbars on the inside of curves.

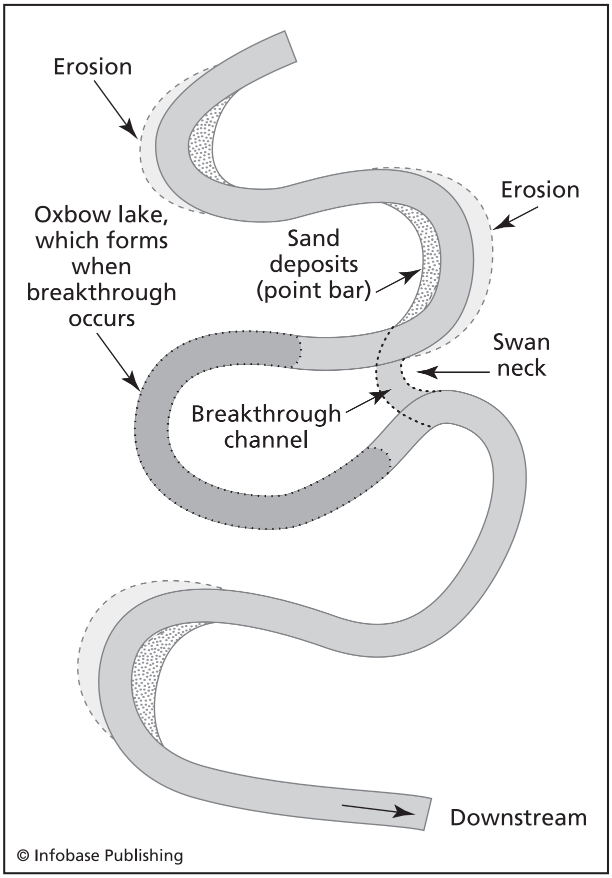
Meandering rivers become self-sustaining; they are always shifting and dynamic, never stable. As the meanders lengthen, they curve back around, forming great loops. Eventually, the meander comes almost full circle, so that its adjacent sides lie close together, a formation known as a swan's neck. When the river runs high, water flows across the neck, where it has free reign, and a deep channel is carved relatively quickly by the force of erosion. The new channel is now the river's principal channel, and the river—minus a meander of several miles—is suddenly shorter, which is one reason why the Mississippi seems to vary so much in length. The isolated meander, now cut off from the river flow, becomes a stagnant body of water called an oxbow lake. Eventually the oxbow disappears, losing its water to evaporation and its channel to sedimentation. Over time the river meanders again, once more driven by centrifugal force. Sometimes new meanders wander across old ones, recapturing abandoned channels and creating a pockmarked landscape.

Today the Atchafalaya represents the largest river swamp in America, with cypress forests, abundant alligators, and a rich array of insect and bird life. Some hydrologists think the Mississippi will eventually claim its rightful route, that no human intervention can withstand the power of this mighty river. Should the Mississippi's flow switch to the Atchafalaya, however, the human consequences could be considerable. New Orleans would lose its abundant supply of freshwater, and its status as a major seaport would likely be compromised.

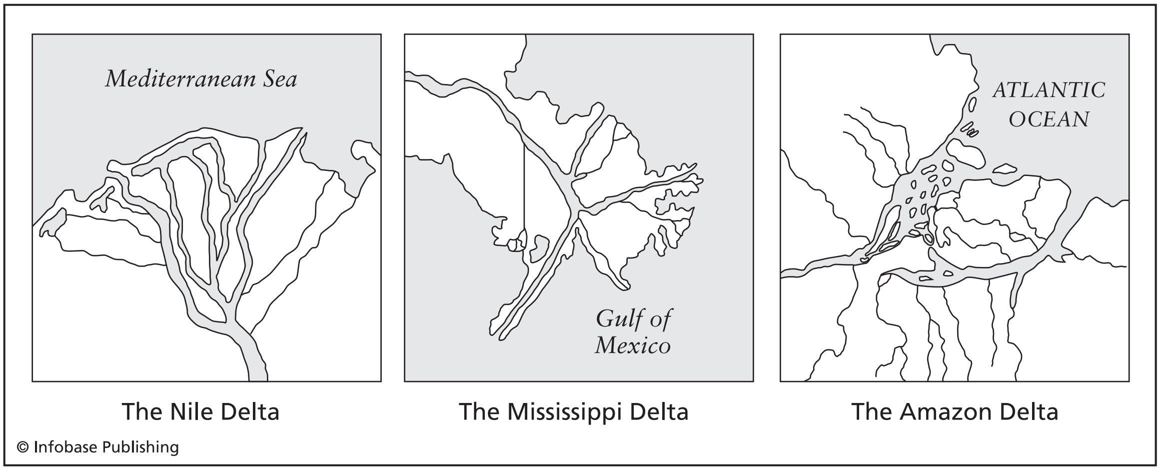
HIGHLY REGULATED WATERWAY

At the beginning of the 19th century, the Mississippi was a natural river, flowing and meandering freely across the continent. Today the Mississippi is one of the most regulated and engineered rivers in the world. Some 29

One can see abandoned stretches of meandering loops along the Lower Mississippi on both sides of the main channel. From the air, the loops appear as a tangle of horseshoe- or crescent-shaped remnants, some filled with water, others overgrown with vegetation. Although the Mississippi retains its meandering channel form, today the river's many levees prevent it from wandering much beyond its present channel.



Meandering rivers are constantly changing. The more the water curves, the greater its centrifugal force, which in turn creates a balance of erosion and deposition, moving the channel sideways. Over time, the meanders exaggerate and come close to one another, forming what looks like a swan neck. When the neck narrows to nothing, the river creates a shortcut, leaving behind the severed section, which is called an oxbow lake.



Deltas form when the amount of sediment carried by a river is greater than what the sea can disperse. Waves and tidal currents influence the shape and size of a delta, as does the pattern of channels at a river's mouth. The Nile (a) forms a classic triangular delta; the Mississippi, a bird's foot delta (b); and the Amazon, which spews its sediments far into the rough Atlantic Ocean (c), has many channels near its mouth but no real delta.

locks cross its channel from Minnesota to Illinois; from Cairo south, the river is virtually imprisoned by countless miles of levees.

These feats of engineering go back to the era of the steamboat, when the U.S. government realized how important the Mississippi was to the American economy. As early as 1824, the U.S. War Department began grooming and taming the river by removing snags and other debris. By 1829, the Army Corps of Engineers had moved in as caretakers of the river, a role they maintain today. For almost 200 years, engineers have dredged and straightened the Mississippi and built levees and locks to ensure that it remains navigable for oceangoing freighters and to reduce the likelihood of devastating floods.

In 1940, recognizing the Mississippi's importance to the nation, the U.S. Congress passed the Rivers and Harbors Act. Among other mandates, the act stipulates that the Mississippi channel must always be at least nine feet (3 m) deep and 400 feet (122 m) wide, big enough to accommodate multiple barge tows. To meet those requirements, the river is regularly dredged from Minnesota to the Gulf. All told, some 1 to 3 billion cubic feet (32 to 81 million m^2) are removed each year from 1,790 miles (2,880 km) of river. Another 2.1 billion cubic feet (60 million m^2) are removed from the Mississippi south of Baton Rouge to keep open a 39-foot- (12-m-) deep channel, one big enough to accommodate ocean freighters. Most tows plying the river consist of a dozen or more 195-foot (59-m) barges strung together, side by side, pushed by towboats or pulled by tugboats.

When levees break, as they did here in the great Mississippi flood of 1993, the results can be catastrophic: Water flows down the sides of the levee and sweeps across a landscape with tremendous velocity. *(J. R. Finley/AP)*

Levees line much of the Lower Mississippi. Some are naturally formed earthen embankments; many, however, are reinforced with concrete. The first levees were built in the early 1800s to protect New Orleans from ocean storms; by 1844, levees could be found all the way from New Orleans to the mouth of the Arkansas River. Today nearly 1,900 miles (3,050 km) of levees 30 feet (9.25 m) high line the lower Mississippi; another 650 miles (1,050 km) of levees are found along the river's many tributaries. In addition, some 29 dams block the river between Minneapolis and St. Louis.

The Mississippi River is so engineered that even its headwaters have been moved and reconstructed. At one time, the river flowed through an inaccessible swamp and thus was off-limits to tourists. In 1933, the U.S. Parks Service decided to make the headwaters visitor-friendly. With the help of the Civilian Conservation Corps, a new channel was dug, swampland was filled in, and a fake waterfall was created to increase the river's velocity. As so aptly expressed by an American writer, "from end to end

BIG MUDDY

The faster the Mississippi flows, the more sediment it carries in suspension. The river's velocity fluctuates seasonally and obviously increases when its volume increases, such as during periods of heavy rainfall. Midstream velocity measurements in the Lower Mississippi vary from three to eight feet (.9 to 2.4 m) per second during periods of low and moderate flow but increase to 16 feet (5 m) per second during high flow. The volume of water moving downstream averages about 578,000 cubic feet (16,000 m^2) per second by the time the river reaches Vicksburg.

Both the Missouri and Mississippi are sometimes called the "Big Muddy," an appropriate appellation for two waterways that carry such copious amounts of sediment. Still—when it comes to sediment load—both pale in comparison with the Yangtze and the Amazon.

The *sediment discharge rate* is the rate at which sediment flows past a particular point (usually a river's mouth). The Yangtze, which transports 500 million tons (454 metric tons) of sediment per year, is the muddiest river in the world. By comparison, the Amazon carries 498 million tons (452 metric tons) and the Mississippi 312 million tons (283 metric tons) of sediments each year.

and all through its middle, the Mississippi River bears the scars and shackles of our attempts to harness its power, beautify its appearance and control its might."

IN THE FIELD: SWIMMING THE MISSISSIPPI

For many years, swimmers have been drawn to the Mississippi, mostly for recreational swimming along the shores of Lake Pepin and other broad stretches. In 1997, Nick Irons, a 25-year-old from Maryland, was the first person to swim from Lake Itasca to Baton Rouge, a distance of 2,345 miles (3,774 km). His record was broken in 2002 by a 47-year-old Slovenian swimmer, Martin Strel, who swam downstream for 66 consecutive days. Accompanied by a support crew in kayaks, he swam from 10 to 12 hours a day, averaging 30 miles (48 km) daily. Along the way, he battled snags, rough and polluted waters, and barges. He almost drowned when swept into a whirlpool in Mississippi. When asked why he would risk his life for such a venture, Strel said he hoped the publicity around his swim would promote "peace, friendship and clean waters."

LOUISIANA WETLANDS

Wetlands are critical to a healthy ecosystem. They support a breathtaking diversity of plants and animals, help process nutrients, maintain an ecological equilibrium, and filter out pollutants. The impact of Hurricane Katrina on the Gulf coast in 2005 was devastating, not only to New Orleans and countless other towns but also to the Mississippi Delta and its adjacent wetlands. According to a panel convened by the National Academy of Sciences (NAS) after Hurricane Katrina, "The challenge of protecting and restoring this wetland system is unprecedented."

In issuing a call for action, the scientists on the panel stressed the urgency of the situation. In the last decade—even before Katrina—more than 232 square miles (600 km^2) of wetlands have disappeared, forever swept out to sea. Over the past 50 years, some 1,544 square miles (4,000 km^2) have been lost. Such massive deterioration—should it continue unabated—would surely spell disaster for the coast and possibly mean the end of New Orleans as well.

Today some 120 restoration projects are under way, including efforts to eradicate the nutria, a large semiaquatic rodent, and reclaim some badly eroded marshy areas. But these are relatively small projects that do little to restore hundreds of miles of devastated coastline. Instead, the NAS is recommending more ambitious initiatives. One idea is to redirect the Mississippi River westward and abandon the bird's foot delta altogether. Such a move would allow sediments to accumulate closer to shore rather than so far into the Gulf. Another idea is to divert some water from the Mississippi at a point about 62 miles (100 km) upstream from New Orleans and direct it specifically to empty spaces along the coast.

Wetlands restoration is considered essential for several reasons. Wetlands not only provide a key buffer to coastal communities, protecting them from storm surges, but also support an amazing array of life. If Louisiana's marshes disappear, so, too, will its coastal fishing industry. Oil and gas infrastructures in the region are threatened as well. If the coast continues to sink, New Orleans and nearby communities will find themselves increasingly at the mercy of encroaching tides and may have to retreat from the coast altogether.

FUTURE CHALLENGES

Compared with the Yangtze, the Mississippi remains relatively clean and unspoiled. Only 5 percent of its drainage basin has been urbanized; only a handful of cities with populations larger than 500,000 line its banks. And although 70 percent of the fertile Mississippi valley is cultivated, 25 percent of the land remains forested. The coastal zone of Louisiana, one of the world's largest estuaries, is especially biologically rich and accounts for an astonishing 25 percent of the nation's wetlands.

Still, the ecological integrity of the Mississippi's coastal plain is threatened in several ways. Engineering projects to improve navigation as well as storm damage (particularly in the wake of Hurricane Katrina) have resulted in the serious loss of wetland habitat. In addition, rising levels of industrial, urban, and agricultural activity have introduced chemical and other pollutants that threaten the area's wildlife and water quality. Finally, numerous nonnative species, among them the nutria, a beaver-size rodent introduced for its fur, are running amok, threatening to destroy Louisiana's fragile coastal ecosystem.

5

Huang Ho

Asia

These immense expanses, grey and flat . . .
and these completely bare and rocky mountains, provide
no moral hand-hold. One feels lost in such
demarcated country.

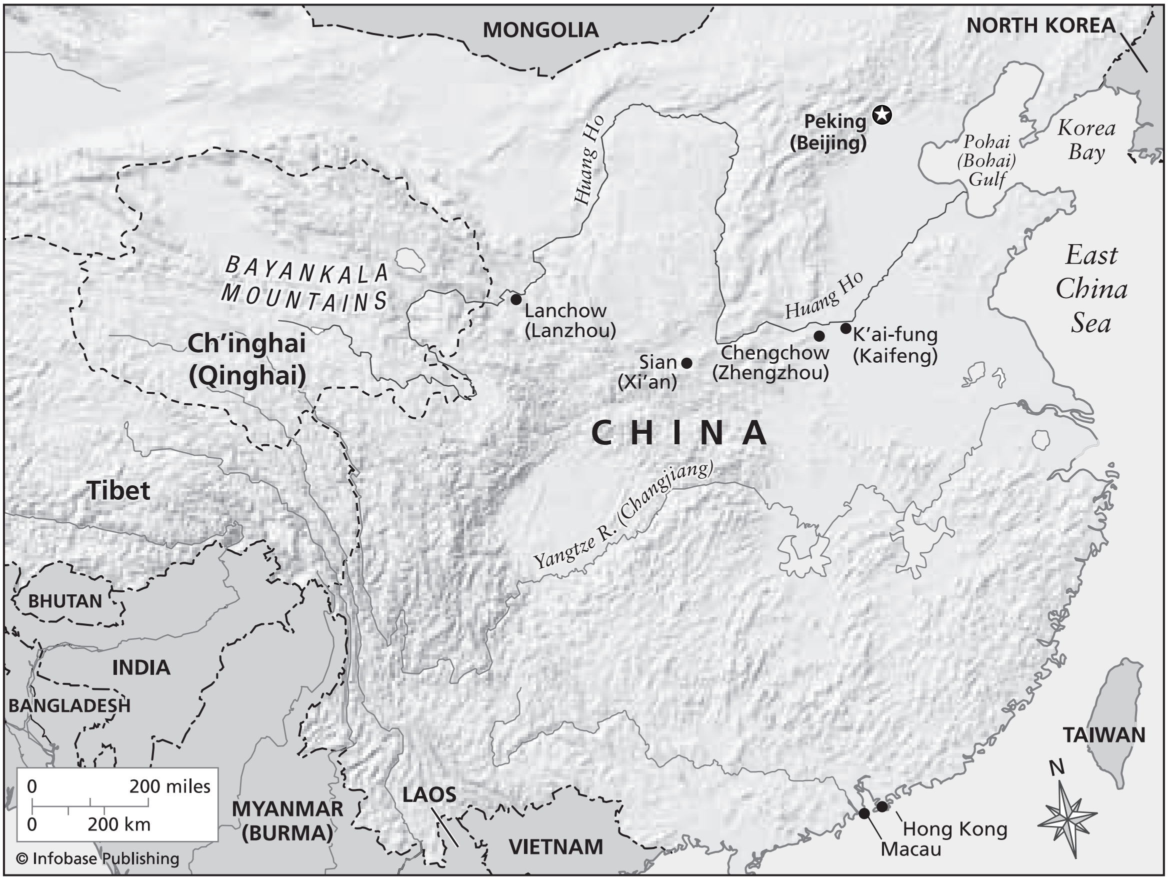
—Pierre Teilhard de Chardin,
a French paleontologist and explorer
to the Yellow River, 1923

Neither visually spectacular nor navigable, the Huang Ho (Hwang Ho, Huanghe), also known as the Yellow River, nevertheless deserves its place as China's second-longest waterway and as the fifth-longest river in the world. Slightly shorter than its southern neighbor, the Yangtze, the Huang Ho runs 3,395 miles (5,464 km) from the Tibetan Plateau to the Yellow (or East China) Sea.

Notoriously restless and dangerous, the Huang Ho has caused untold death and destruction for the past 3,000 years. Numerous nicknames reflect the river's ferocity and capriciousness, including "River of Tears," "China's Sorrow," and the "Scourge of the Sons of Han." Yet for all its destructive power, the Huang Ho is not a large river. In fact, in terms of average discharge—18,205 cubic feet (1,365 m^3) per second—the waterway ranks as a mere dribble compared with the torrential discharge of both the Amazon and Mississippi Rivers.

Even its official name, Huang Ho, carries a benign meaning. The river is so laden with silt that it has a hue, which—if not precisely yellow—at least resembles milk-laced coffee. When the river carries enough water to reach the Po Hai (Bohai) Gulf (formerly known as the Gulf of Chihli), it creates a plume that persists for many miles offshore and so in turn gives the ocean its more familiar name, the Yellow Sea.

Whereas the Yangtze has given rise to China's great industrial corridor, the Huang Ho has given rise to the nation's agricultural riches. Along its



The Huang Ho, or Yellow River, flows from Tibetan highlands—not far from the headwaters of the Yangtze—on a long and circuitous route of 3,500 miles (5,633 km) to the Bo Hai Gulf.

banks can be found the country's earliest granaries and irrigation works. Even as the river robbed many peasants of their lives, it sustained many more, allowing people to cultivate crops and practice subsistence agriculture. In the words of one Chinese writer, "If the river is a destroyer, it is also more charitable than any human benefactor, providing water to lands otherwise too parched to support human life." For thousands of years, China has depended on the grain surpluses of the Huang Ho's rich agricultural plain to feed its people. And even though more people live along the Yangtze today than along the Huang Ho, it is the Huang Ho that intersects several times with the Great Wall of China and gave rise to China's great civilizations.

And yet—as if to belie its importance—the Huang Ho offers little to the Chinese people in terms of navigation. The river's currents are too swift in places, its *channel* too broad and shallow elsewhere to make long-distance passage possible. Boats traverse certain inland stretches and also manage to sail some 25 miles upstream from the Bo Hai Gulf, but otherwise, the river is largely untouched by human travelers. Such poor navigability, combined with a temperamental nature, has not made the river welcoming to human settlers. Throughout thousands of years of history, only two large cities have been built along its banks: Lanzhou and Kaifeng.

Like the Yangtze, the Huang Ho originates in the barren highlands of Tibet and flows entirely within China's borders. Both rivers formed around 40 million years ago when the Tibetan Plateau was forced upward by shifting continents, creating a gradient that propelled their waters toward the Pacific. Today the Huang Ho follows an imprecise easterly path, twisting and weaving its way across China's vast terrain. As the river heads seaward, it sweeps over *plateaus*, moves through limestone gorges, and crosses great *alluvial plains*. As it wends its way to the ocean, the Huang Ho flows through three distinct geological regions called the Upper, Middle, and Lower Reaches.

INDIRECT ROUTE TO THE SEA

The Huang Ho, clear-flowing and cold when it begins its journey, slows precipitously as it descends from Tibet. By the time the Huang Ho approaches China's eastern seaboard, it has become a great muddy streak, its waters sludge-like. Even so, the river chugs resolutely forward, powerful enough to take a great detour on its journey to the Pacific and to overflow its banks with catastrophic effect.

Upper Reaches

The Huang Ho begins not far from the source of the Yangtze in the Highlands of Ch'ing-hai (Qinghai) Province. If one looks at a map, China's two great rivers appear to be almost mirror images, each following a lateral course to the east, and each with a large north-south detour. Separating the sister rivers are the Bayankala Mountains, which thrust skyward, forming a great dividing wall between the two river basins. Snowcapped and majestic, the tallest peaks in the range stand almost 18,000 feet (5,486 m) high.

China's second-longest river emerges in a marshy region at the foot of the Bayankala Mountains at a latitude that is roughly the same as that of Virginia and Kansas in the United States. Seepage from the swamp coalesces to form a stream that links two mountainous lakes, the Cha-ling (Zhaling) and the O-ling (Oling). As the newly formed river heads downhill from Lake O-ling, it moves across the windswept Tibetan Plateau at an elevation of 14,000 feet (4,267 m) above sea level. Few people populate this austere landscape, which is covered in snow and ice during the winter months. Sometimes *ice jams* form on the river, creating dangerous flood conditions, especially in early spring when snowmelt cascades down from the mountains (see chapter 10). Because of the danger the ice poses, the Chinese drop aerial bombs or launch artillery shells to break up the jams.

The Huang Ho twists and turns as it moves east for several hundred kilometers. It then makes a sudden hairpin turn and heads back in a westerly direction, skirting the southern slopes of the A'nyêmqên Mountains on its way. Swinging first to the north and then to the northeast, the Huang Ho passes through Lanchow (Lanzhou), an ancient city of 1.5 million people on the edge of the Ordos Desert. The Chinese who live in this region grow a great deal of wheat and other grains as evidenced by the tidy farms visible in the color insert on page C-5 (top). Such farms flourish with the help of gravity-fed irrigation systems that draw water from the Huang Ho. For thousands of years, this region's agricultural bounty has fed all of China.

Not far from Lanzhou, the river leaves the Tibetan Plateau, which marks the end of its upper reaches. By this point, the river has traveled some 725 miles (1,167 km) from its source, a tribute to hydrological persistence. Carving out its downhill channel has not been easy; for most of its passage, the Huang Ho has had to force its way through deep sedimentary rock and a challenging topography. Today the river flows through deep valleys, surrounded by highlands that rise 1,500 feet (457 m) above its waters. The harsh terrain remains pristine, a result of its inaccessibility.

Middle Reaches

After descending the Tibetan Plateau, the Huang Ho moves to the north, making a grand 1,800-mile (2,897-km) detour around the Ordos Desert, which runs along the eastern edge of the Gobi Desert. The river's wayward path creates the shape of a great arch, with its western end anchored by the city of Lanchow and its eastern end by its junction with the Wei River. In making the arch, the Huang Ho flows first 550 miles (885 km) to the north, then east for 500 miles (805 km), and then turns sharply to the south for 445 miles (716 km). As the river flows south, it establishes the border between Shensi (Shaanxi) and Shansi (Shanxi) Provinces.

Joined by the Wei, the Huang Ho makes a sudden and spectacular turn to the east, as if pushed by the forceful waters of its newly coupled tributary. Flowing almost due east, the river sweeps through the Tungkwan Gorges, which form the historic gateway from the Wei-Ho valley to China's lowlands. The gorge, which can be seen in the color insert on page C-5 (bottom), are intimidating, though not nearly as spectacular or as tall as the Three Gorges of the Yangtze. In the Chinese tradition, they have descriptive, colorful names, for example, the Yehu, or Wild Wolf Gorge, and the Longyang, or Dragon-and-Goat Gorge.

On its journey, the Huang Ho passes first through the Great Wall of China and then literally cuts through the Loess Plateau, a remarkable geological formation named for the German word *loess,* which means "loose." Made from deposits of powdery silt hundreds of meters deep, the plateau extends eastward at an elevation of from 3,000 to 7,000 feet (914 to 2,134 m) and looks more like the surface of an alien planet than something created on Earth.

The loess forms layers that are generally from 160 to 200 feet (49 to 61 m) thick but in some places grow to a depth of 500 feet (152 m). Blown about and deposited by wind, loess is as fine as dust, with a minute grain size from 0.06 to 0.02 mm. Easily eroded, the loess has been carved by wind into oddly shaped peaks reminiscent of a lunar landscape. Running through the peaks and across the plateau are the waters of the Huang Ho, which has carved a deep channel through the soft sediments.

It is here that the river earns its name. The unconsolidated loess deposits are porous, which allows the particles to be readily taken up and carried by water. Almost as easily washed away as flour, huge quantities of loess are swept downstream by the Huang Ho's strong currents, bestowing on the water a tint that is more chocolate than yellow. After a heavy downpour, so much loess is washed into the Huang that the river is said to resemble pea soup. In fact, a person can dip a glass jar into the river and—after allowing the silt to settle—find that as much as 36 percent of the river's total volume is attributed to loess.

Lower Reaches

The Huang Ho enters its final stretch at the city of Kai-fung (Kaifeng). Considered the base of the river's great *alluvial fan,* this region sits only about 425 feet (129 m) above sea level. From here, the Huang Ho unwinds in an easterly direction. This great featureless landscape was a shallow sea until 25 million years ago when the Huang Ho—its momentum suddenly slowed by the flat terrain—began filling it with sediments.

Today the Huang Ho still drops about 40 percent of its sediments on the North China Plain. When the river hits the almost flat terrain, it virtually stops in its tracks and lets go of its heavy load. From here until it reaches the sea—a stretch of 435 miles (700 km)—the river falls on average a mere three inches a mile (47 mm per km). No longer buoyed by turbulence, tons of loess that have been transported all the way from northwestern China filter slowly onto the alluvial plain.

When the river flows freely during the summer months, silt settles along the river's bottom and spills over the banks when the river does. In this way, with every flood the Huang Ho continues to build the very plain through which it flows. Over time, the river has created a cone-shaped embankment and now flows too high above ground as it passes through the alluvial fan to be joined by any tributaries. As silt flows outward from on high, most is deposited near the embarkment. Consequently, the alluvial fan's margins tend to be flat and so give rise to extensive marshes and floodplains.

The delivery of so much fine silt has created highly fertile land; not surprisingly, the plain has been densely populated for many millennia. Today more than 100 million people occupy the banks of the lower Huang, despite the river's mercurial nature.

Overall, the *delta* extends across an area of about 9,653 square miles (25,000 km^2), about 50 miles (80 km) from the river's *mouth*. Historically, it has been one of the most actively growing deltas in the world, growing outward by as much as 15 miles (24 km) in less than five years. Over thousands of years, the delta has overtaken islands in the Po Hai Gulf and incorporated them into the Great Plain of China. The hilly countryside known as Shantung, for example, was once an island in the East China Sea.

Today the river is so heavily engineered and oversubscribed that its flow to the coast is much reduced; many times a year, little or no water reaches the *gulf*. In some months, the riverbed becomes so dry that vehicles can drive across it. In 1997, for example, the river failed to reach the sea for

SEDIMENT LOAD

The amount of sediment carried by any one river is determined by several factors. To begin with, the faster and more turbulent a river, the more sediment it carries because fewer particles settle out in churning waters. In addition, the larger the volume of water, the greater the absolute amount of sediment it can carry. The type of terrain surrounding a stream also strongly affects its particulate content. Rivers that flow through hard strata such as granite erode very little and generally run clear. By contrast, rivers that flow through loose, unconsolidated sediments tend to easily erode their surroundings and are visibly muddy. As a general rule, unconsolidated terrain is more common in tropical environments, where abundant rain and warmth causes rapid weathering of exposed rock. The waters of both the Huang and the Mississippi therefore are relatively clear in their upper reaches but carry great quantities of loess in their middle and lower sections.

Weather patterns have a profound impact on sediment load. Torrential rain—especially in deforested areas—can send streams of mud cascading into a river. In addition, population and development pressures have accelerated the denuding of China's landscapes and so increased rates of runoff. Finally, a river's tributaries can be contributing factors, either because they carry a lot of silt themselves or are particularly numerous. Silt certainly pours into the Huang Ho from its tributaries, notably the Fen and Wei Rivers, further increasing its sediment load.

By the time the Huang Ho turns east onto the North China Plain, it carries an unrivaled 57 pounds of silt per cubic yard (34 kg of silt per m^3), roughly 30 times the sediment load of the Nile River and far more than any other river in the world, including the Mississippi. Flood waters are almost sludge-like, carrying as much as 1,200 pounds (544 kg) of silt per cubic yard of water, or 70 percent by volume. All told, the river carries about 1.52 billion tons (1.4 billion metric tons) of silt per year.

Relatively little of that sediment ever reaches the sea, except during flood season, when a visible chocolate plume appears off the coast. Instead most silt settles out in the river's lower basin. Over the past 10 years, however, the sediment load reaching the Bo Hai Gulf has dropped precipitously, to less than 1 percent of the annual sediment loads of the 1950s. The drastic reduction reflects an increase in dams, which trap sediments upstream, and irrigation works that divert the river for agricultural purposes.

a record 226 days, its channel dry as far as 435 miles (700 km) upstream. With the flow of water so radically diminished, pollutants are accumulating in the delta's ecologically sensitive estuaries, and much wildlife has disappeared. Although some measurements suggest the delta is still advancing, at best its annual growth rate seems to be 328 feet (100 m) a year.

CHANGING COURSE

Among all the major rivers of the world, the Huang Ho has changed the course of its lower channel more dramatically than any other. The waterway's wild vacillations can be blamed on its sediment load, which elevates the river channel, and on its sudden flow surges, which cause the river to jump its banks. Pouring down over the alluvial plain, the Huang Ho becomes disoriented, unable to return to its original course when the flood recedes. Instead, the river must find a new way to the ocean.

In the 2,500 years for which reliable historical documentation exists, the channel has relocated itself at least 10 times, perhaps as many as 26. Sometimes the river has flowed north of the Shantung (Shandong) Peninsula; at other times to the south. At different times throughout history, the Huang Ho has discharged into the ocean at points as far apart as 500 miles (805 km).

At the present day, the Huang Ho follows a northerly course but would likely relocate to the south if not constrained by a massive series of *dikes*. In 1887, the river did break out and shifted its course some 435 miles (700 km) to the south, linking up for a time with the Yangtze. Engineers managed to repair the dike and forced the river back into the northerly channel through which it flows today.

Remnants of deserted river channels are still visible in the alluvial fan, appearing as swamp-filled areas that give the surrounding landscape a distinctive character.

RIVER OF TEARS

The Huang may carry a relatively small volume of water, but it is unquestionably the most deadly river in the world. Two reasons explain the waterway's destructive power. One, the river's unprecedented silt burden—more than any other major river—generates conditions that create and exacerbate flooding. And two, the waterway experiences more drastic changes in flow than any river of its length, transforming from a mere trickle that evaporates before it reaches the sea to a massive raging torrent during flood season.

The potential for flooding unfolds every summer, when *snowmelt* from the Bayankala Mountains combines with *monsoon* rains that fall from June through August. During those three months, the Huang Ho basin receives from 50 to 60 percent of its annual rainfall.

The engorged river, its girth further widened by the contributions of its tributaries, rushes downstream, pulling copious quantities of silt and sand from its side walls. The turgid, mud-filled waters surge seaward until they reach the North China Plain, where they suddenly slow to a crawl, impeded by the flat terrain. Over the next 500 miles (805 km), the Huang Ho only drops 312 feet (95 m). As the river slows, its sediments settle out, drifting to the bottom before reaching the ocean. So slowly does the river move across its alluvial plain, in fact, that it loses from 40 to 50 percent of its silt burden before discharging into the Po Hai Gulf.

When water levels are high, the Huang Ho deposits sediments not only along its bottom but also atop its banks, a buildup that has caused the riverbed to rise above the surrounding plain. Dikes built along the river further confine the silt, which forces the water level still higher. With enough rain and silt, the river will rise above its channel, overflow its banks, and cascade downward, pummeling the land below.

Near the city of Kai-fung, the riverbed sits so far above the surrounding land that even at low water levels, the river flows 15 feet (4.6 m) above the countryside. High-water levels may be as high as 35 feet (11 m) above the surrounding flat plains. One can easily see how the momentum of water spilling from such heights can quickly turn into a sudden and disastrous flood.

Virtually every century has born witness to at least one catastrophic Huang Ho flood. In recent history, major disasters include the flood of 1887, which covered thousands of square miles, completely burying many villages under massive silt flows. Approximately 1 million people died. Two years later—in 1889—a second flood destroyed 1,500 villages and all their occupants.

The worst flood disaster in world history occurred in August of 1931, when the river overflowed, drowning an estimated 3.7 million people. Some 34,000 square miles (88,000 km^2) of land were completely buried underwater; another 8,000 square miles (21,000 km^2) were partially flooded.

Other notable floods occurred in 1921, when hundreds of villages were wiped out near the mouth of the Huang Ho, and in 1933, when more than 3,000 villages were submerged. An especially tragic flood took place in 1938 during the Second Sino-Japanese War when a Chinese official decided to blow up a *levee* to stop an advance of Japanese soldiers. He succeeded in stopping the soldiers, but the resulting flood killed 900,000 Chinese civilians.

In the 20th century alone, some 6 million people are thought to have lost their lives to the Huang Ho. Fishermen, boatmen, farmers, and others whose livelihoods depended on the river may have survived, but they lost their livelihoods.

MANDATE OF HEAVEN

For thousands of years, the Huang Ho has overflowed its banks, sometimes with cataclysmic consequences. In 2079 B.C.E., for example, virtually all human life in the Huang Ho valley was obliterated when the river suddenly surged across the land. Although the historical records are sketchy, the death toll from that ancient flood is thought to be in the millions.

The only way the ancient Chinese could make sense of these seemingly capricious events was to blame the floods on heaven's displeasure. They believed that floods were a signal from God, indicating their leader had fallen from heavenly favor. The converse was true also. For example, when the great emperor Yu successfully thwarted a disastrous flood in 2200 B.C.E., the people thought heaven must be rewarding his goodness. Thus was born the notion of a mandate from heaven. If a ruler began to behave badly—or so the thinking went—heaven would show its displeasure by inciting droughts, floods, or earthquakes. The upshot was that a flood of any magnitude could tarnish, if not undo, an imperial leader. Thereafter, Chinese peasants looked for signs from heaven to assess the virtue of their leaders.

Eventually, the mandate from heaven fell out of vogue, but a leader's political future—even today—rests on his or her ability to respond quickly to a Huang Ho disaster. A leader who fails to act appropriately faces social turmoil, mass migration, and political unrest. Hundreds of years ago, leaders learned they had to grapple with floods or face revolt by their citizens. As a result, through much of China's early history, rulers sought to protect their land and people from the mercurial Huang Ho by building dikes and diversion channels. Confucian engineers created large-scale hydraulic projects involving an extensive network of locks, spillways, and drainage canals to keep the river in check. Though such projects have been beneficial, the Huang—like most rivers—has proven more powerful than any human efforts to contain it.

SILK ROAD

The first imperial dynasties of China were established in the middle reaches of the Huang, mostly near the river's intersection with the Wei tributary in southern Shensi Province. Here the ancient city of Chang'an (now the city of Xi'an) was built, home to China's most powerful dynasties, including the Han, which lasted from 206 B.C.E. to 220 C.E., and the Tang, which lasted from 618 t o 907 C.E.

It was during the reign of the Han that the Wei River valley gave rise to one of the oldest and most important trade routes in human history. Called the Silk Road, this great transcontinental thoroughfare ran 4,000 miles (6,437 km) between the ancient city of Chang'an and the eastern Mediterranean, with many byways and secondary routes, including a road to India. Caravans carrying silk, jade, bronze dishes, and ceramics headed east; in return, precious metals and food came to China. The Great Wall of China was built (in part) to prevent bandits from attacking caravans as they approached Chang'an.

By the time of the Tang dynasty, Chang'an, which means "Perpetual or Everlasting Peace" was the cultural capital of East Asia and the largest city

LEVEE REPAIR

Repairing levees, or dikes, in the aftermath of a major flood can be a staggering endeavor. In 1852, for example, when the Huang Ho broke from its present channel near Kai-fung, some 60,000 workers spent 25 years rebuilding a 400-mile (641-km) stretch of wall 72 feet (22 m) high and 72 feet wide. Some effective repair techniques, which have been practiced in China for centuries, are still in use today. Though laborious, they rely on the river's unique self-healing properties made possible by its extraordinary sediment load. When a dike is breached, workers heap up sand and stone to rebuild the walls. They then construct wedges made from lattices of sticks and branches, which they set over gaping holes and anchor in place. Silt flowing downstream soon fills the lattice, effectively sealing it.

in the world. (By contrast, the modern city Xi'an is one-seventh the size of its ancestral city.) Agriculture flourished in the region—as it still does today—benefiting from gravity-fed irrigation systems. With trade flourishing, the emperor of the Ta'ng dynasty became very wealthy. Wishing to live in luxury, he had beautiful—some would say ostentatious—palaces and parks built in Chang'an, the remnants of which can still be seen today.

LOOKING TO THE FUTURE

Like a double-edged sword, the Huang Ho's countless floods have enriched and renewed China's soil but also brought widespread suffering and social turmoil. In an attempt to tame and control the river, engineers have encased one-third of the Huang Ho in a series of dikes that become ever taller with every fresh onslaught of sediments.

Two giant hydroelectric dams now bridge the Huang Ho, both of them intended to help with flood control and also power generation. One has been constructed at the Liu-chia (Liujia) Gorge, the other at the San-men (Sanmen) Gorge just above Chengchow (Zhengzhou). Both have reservoirs that trap sediment, preventing it from moving downstream, and so play a role in flood prevention. Both have also caused habitat destruction and led to increased pollution by helping promote economic development in the area. Overall, the dams have led to diminished water quality.

A bigger problem facing China, however, is a lack of water. Northern China faces a serious water shortage in part because so much of the Huang Ho has been diverted for agricultural and industrial use. Fearing that agricultural yields on the North China Plain might be threatened if water supplies are insufficient for irrigation, China has embarked on a gigantic water diversion project, called the North-South Water Transfer Scheme, to "balance the nation's water supply."

In the manner of China's other colossal engineering projects (such as the Great Wall, the Grand Canal, and the Three Gorges Dam), the diversion project involves building three canals across the eastern, middle, and

Trucks fill in the San-men Gorge on the Huang Ho as they begin to build China's second largest dam, the Xiaolangdi. *(Zhu/AP)*

western parts of China to divert water from the Yangtze to the Huang Ho, as well as to the Huai and the Hai Rivers.

Once it is completed, the project will divert anywhere from 1.3 trillion cubic feet (38 billion m^3) to 1.7 trillion cubic feet (48 billion m^3) of water to key agricultural areas as well as to the major cities of Beijing and Chengzhou. Construction began in 2002, and work on the first two routes, that is, the eastern and middle diversions, will take five to 10 years to complete. The western route, which will not be completed until 2050, presents the greatest challenges. Engineers intend to link the Yangtze to the headwaters of the Huang Ho by carving a path through the Bayankala Mountains. Necessitating the construction of many canals, pumping stations, reservoirs, and dams, the behemoth engineering project is estimated to cost some $62.5 billion (500 billion yuan) and take 50 years to complete.

Clearly, the demand for freshwater in China will only grow in the coming years, with both the nation's economy and population on an upward trend. Large-scale solutions in the manner of the south-north water diversion project suggest a degree of desperation. Whether or not the project will live up to expectations and deliver hydrological benefits that outweigh its capital and environmental costs remains to be seen.

6

The Yenisey

Asia

In winter the polar nights draw a curtain across the sky, the sun disappears altogether, the temperature sinks to minus sixty, and the snow and winds (strangle the river).

—Andrew Meier, *The Black Earth*

The Yenisey—one of the great arctic rivers of the world—begins life in Mongolia's lofty mountains, not far from the Chinese border. The river grows in girth as it descends the mountains, fed by snowmelt and abundant rain. Cascading downstream, the Yenisey's icy waters flow across the Siberian Plateau: through magnificent boreal forests, frozen tracts of *tundra*, and relatively untouched wilderness as shown in the color insert on page C-6 (top). Only a handful of cities have sprung up along the banks of this remote waterway; the entire river basin, which encompasses 986,291 square miles (2,554,482 km^2), is sparsely populated with on average only two persons per square kilometer.

Joined by its major tributary, the Angara, the Yenisey represents the sixth-longest river in the world. From its ultimate source at the base of the Altay Mountains to its outlet in the Kara Sea, the Yenisey flows for a distance of about 3,450 miles (5,552 km). At this length, the Yenisey is slightly shorter than the Mississippi but 50 percent more plentiful, with an average annual discharge of 692,272 square feet per second (19,600 m^3/s). In both length and volume, the Yenisey River system exceeds all others in Russia.

For part of the year, the middle stretches of the Yenisey are navigable, but the river's value as a commercial route is limited by the harsh climate of northern Siberia. For six of 12 months, beginning in October, thick ice covers the northern reaches of the Yenisey. Even in populous areas, the ice-shrouded river is more navigable by car and truck than it is by boat. Still, with its wealth of natural resources, including oil, the Yenisey-

Angara region is booming, connected to the rest of the world year-round by airplane, if not by land or sea.

FROM MONGOLIA TO THE ARCTIC

The Yenisey proper comes into being as a small stream that descends from the southern flank of the East Sayan Mountains of central Mongolia. Known as the Great Yenisey, or Bolshoy, the river moves eastward and enters Siberia near the Chinese border town Kyakhta. After flowing downhill for 1,200 miles (1,931 km), the Great Yenisey meets a second but shorter river called the Little Yenisey, or Maly. They join together at the city of Kyzyl in Russia's western Tuva republic, henceforth forming the main trunk of the Yenisey River. (Note: The Great Yenisey, which is the longer of the two branches, is generally considered the Yenisey's source. But the true source of the Yenisey-Angara lies farther to the south, at the *headwaters* of the Selenga River.)

From Kyzyl, the Yenisey winds toward the west, entering the rocky Tuva Basin. Relatively shallow and only a hundred or so yards wide, the river is interrupted by gravelly *shoals* and assumes the form of a *braided channel*. The waterway then turns north for 840 miles (1,352 km) to its meeting with the longer and more powerful Angara River near the Siberian town of Strelka. Thereafter, the two rivers continue north for another 1,328 miles (2,137 km) until they reach the edge of the icy Arctic and discharge their contents into an *embayment* called the Yenisey Gulf.

ANGARA RIVER

The Yenisey River system owes its great stature not to the relatively modest Yenisey but to both its major tributary, the Angara, which flows from Lake Baikal near the foot of the Central Siberian Plateau, and to its most distant tributary, the Selenga River, which flows 920 miles (1,480 km) across northern Mongolia into Lake Baikal. As the source of most freshwater that enters Baikal, the Selenga ultimately feeds into the Angara and so could be considered the true source of the Yenisey. Adding the Selenga increases the Yenisey's length to 3,450 miles (5,552 km) and the size of its river *basin* to 996,000 square miles (2,580,000 km^2,) which catapults the Yenisey to sixth place on the world list.

Two rivers bear the name Angara, although they connect with one another only indirectly. One of them, the Upper Angara, begins 200 miles (322 km) northeast of Lake Baikal and enters the lake at its western tip. The second one, the Angara proper, exits from the southeastern end of Lake Baikal, along with the waters of the Selenga.

Pouring forth from Lake Baikal, the newborn Angara River moves 45 miles (72 km) downstream to Siberia's capital city, Irkutsk. The Angara continues northward to Bratsk, where its turbulent and fast waters

The Yenisey, when combined with its major tributary, the Angara, measures 3,450 miles (5,552 km) from its source in Mongolia to its discharge in the Arctic Ocean.

LAKE BAIKAL

In satellite imagery, Lake Baikal appears as a small gash—some might say a dried string bean—lying slightly askew on the Central Siberian Plain. Although the lake is unquestionably large—395 miles (636 km) long and roughly 30 miles (48 km) wide—Baikal is visibly smaller than other large lakes, including the better-known Lakes Superior and Victoria. But appearances can be deceptive. In truth, Lake Baikal is the world's deepest lake, with a bottom that lies a mile below the surface, and thus is also the largest lake by volume, with more water than any other body of freshwater in the world. This remote Siberian lake contains one-fifth of all freshwater on the Earth's surface, a mammoth natural reservoir that contains an almost 5,500 cubic miles (23,000 km^3) of water.

More than 330 rivers and streams, including the Upper Angara, feed Lake Baikal. The largest among them is the Selenga. Because these rivers flow across the erosion-resistant Angara Shield, they carry little sediment. As a result, their waters and those of Lake Baikal run crystal clear. In contrast to the large number of incoming streams, only one river flows from the lake: the Angara, which in turn feeds into the Yenisey.

Lake Baikal is also one of the world's oldest lakes, having been created 25 million years ago by tectonic *rifling* activity, the pulling apart of two crustal plates. As a result of its age and isolation, the lake supports a unique assemblage of plants and animals, including the Baikal seal, a freshwater relative of oceanfaring seals. The lake's surface freezes for five or six months every winter; in summer, its waters remain icy, never exceeding 54°F (12°C) except in shallow coves, where the temperature may reach 68°F (20°C) on a sunny day.

Although development and industrial runoff have polluted some parts of Lake Baikal, the lake remains relatively unspoiled, a fact that reflects both its size and location. In recent years, under pressure from environmentalists, the Russian government—not generally known for its pro-preservation stance—has made a concerted effort to protect the lake. In 1996, for example, Russia allowed the United Nations Educational, Scientific and Cultural Organization (UNESCO) to declare Lake Baikal a World Heritage Site. Ten years later, in 2006, Vladimir Putin, head of the Russian Federation, stopped construction of a transcontinental gas pipeline that would have run close to the shores of Lake Baikal, threatening the region's ecological integrity.

are diverted through the gates of a large hydroelectric dam. Not long thereafter, the river curves sharply to the west, flowing through a deeply eroded channel whose banks reach from 60 to 100 feet (18 to 30 m) above the waterline. Some 1,188 miles (1,912 km) after leaving Lake Baikal, the Angara reaches the port town of Strelka and its confluence with the Yenisey.

Like strangers who have nothing in common, the Angara and Yenisey barely commingle when they finally meet. The Angara is not only broader than the Yenisey, but it flows with the quiet force of a river that is steadily fed by a large lake. By contrast, the Yenisey has all the impatience and turbulence of a waterway that is periodically engorged by sudden downpours and massive snowmelt. In summer, when the Yenisey reaches its peak flow, the two rivers will flow as far as nine miles (14 km) downstream before mixing.

From the port town of Strelka in central Siberia, the Yenisey takes a decisive turn north, literally hugging the western boundary of the Central Siberian Plateau as it flows. Along the east bank of the river stand the precipitous slopes of the *plateau;* along the west bank are forests and low-lying marshes. The river is also wider at this point, fed by the waters of thousands of small streams and other tributaries. Traversing the eastern side of the Central Siberian Plateau and almost parallel to the Yenisey is the Lena, another one of Russia's great northern waterways.

ONE RIVER TO THE ARCTIC

The middle region of the Yenisey is navigable and plied with barges that transport both raw and processed material either to the Kara Sea in the summer or to Irkutsk for transfer to the Trans-Siberian Railroad.

Not far downstream from Strelka sits the town of Yeniseysk, which was founded in 1618 as a major river port and fur-trading center. Once a bustling city, the town lost population and prestige when the Trans-Siberian Railroad was built further south at Irkutsk, robbing Yeniseysk of much commerce. Today Yeniseysk has a population of 20,000.

As the river wends north, it passes through deeply forested *taiga* and then desolate, unoccupied tundra. Periodically, the Yenisey churns through a steep-sided gorge. Several hundred miles beyond the Arctic Circle at the city of Dudinka, the river makes a sharp turn to the west. Several islands, some of them 10 or 12 miles (16 or 19 km) long, arise midstream, turning this portion of the Yenisey into a braided stream.

Closer to the ocean, near the city of Ust'-Port, the river enters an island-filled *estuary.* The land here has almost no slope, so the relatively few sediments carried by the Yenisey settle to the channel's bottom, filling in the embayment. Over tens of thousands of years, the estuary has grown

IRKUTSK

The first city to greet the Angara on its travels north from Lake Baikal is Irkutsk, Siberia's capital and a bustling trade center with a population of 600,000 people. First established in the late 17th century as a fur outpost, Irkutsk grew as a port and place of trade but then transformed into a major transportation and cultural center after the Trans-Siberian Railroad came through the city in 1898. About that time, a well-known Russian intellectual, N. Shelgunov, wrote that "Irkutsk is the only Siberian city which has the city character. . . . As England created London, France—Paris, Siberia created Irkutsk." Today, though it still retains some historic character, Irkutsk is a thriving, modern trade and cultural center that draws visitors from around the world.

outward, and vestiges of old islands, now incorporated into the *delta,* are visible from the air.

Just north of Ust'-Port, the Yenisey splits into several channels and fans out across the delta, with one bank of the river sitting about 47 miles (76 km) from the other. When the river is not icebound, as it is at least six months of the year, water flows across the delta, discharging into a long, narrow bay of the Kara Sea called the Yenisey Gulf. The Kara Sea itself is covered with ice most of the year, though some melting occurs during the summer months when average air temperatures climb above freezing. Even then, the climate is undeniably harsh. During the winter, frequent blizzards sweep over the Yenisey Gulf; in summer, snow squalls and fog shroud the coast.

ICE BREAKUP

For six months a year, the Yenisey freezes, transforming from a fast-flowing stream to a river encased in a thick sheet of ice. Because the river runs from north to south, an interesting phenomenon occurs every spring. The Yenisey thaws upstream before it does downstream, and so its upstream waters begin to flow when its lower reaches—those closest to the Arctic Circle—are still blocked by ice. As with a blocked drain of any kind, the water backs up, seeking an outlet anywhere it can find one. (See "Ice Breakup" in chapter 10.)

Hindered at one end by a frozen ocean, the turbulent spring waters pour over the river's banks, flooding the surrounding valley. The river surges with so much intensity that logs, ice chunks, and other debris are sent crashing into the surrounding forest, ripping deep gashes in the trunks of trees. The height of those gashes provides a visible record of each season's high-water mark. Such flooding would likely be devastating in a more populated region, but as the Yenisey flows closer to the Arctic Circle, settlements become rarer and so the river—despite its fury—has little impact on Siberia's human inhabitants.

SIBERIAN BASIN

The Yenisey-Angara network spreads across most of the Central Siberian Plateau, a stable and ancient rock platform also known as the Angara Shield. The metamorphic rocks that make up the plateau are some of the oldest on Earth. Precambrian in age, they are at least 1 billion years old, and maybe older. In some places, the older crystalline rocks are exposed, but mostly they are covered by more recent deposits of sedimentary rock.

With its rich network of tributaries, the Yenisey-Angara is reminiscent of the Amazon, though on a smaller scale. Fanning out across the Central Siberian Plateau are some 20,000 tributaries and small streams, all of which drain to the west and eventually into the Yenisey. Together they account for an astounding 550,000 miles (885,000 km) of flowing water.

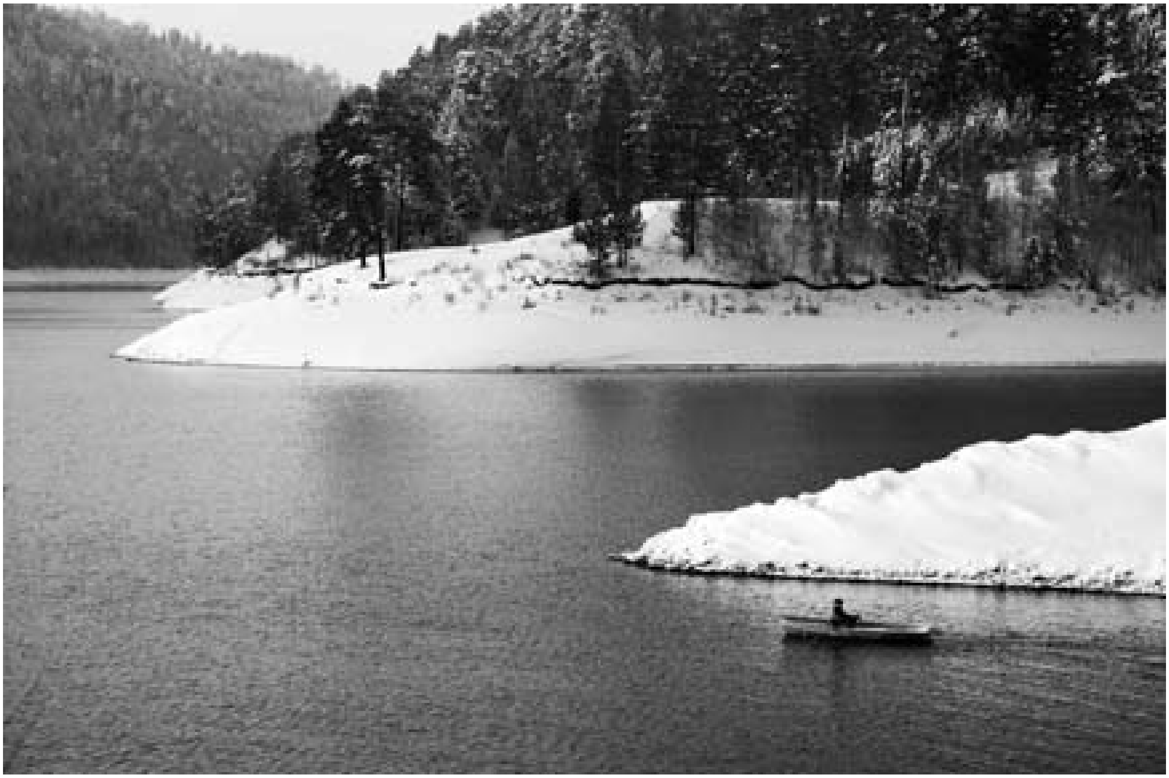
Though their climates differ markedly, the Yenisey and Amazon basins share another commonality. Both are thickly carpeted with green, their rivers barely visible from the air. At least 50 percent of the Yenisey basin is covered with subarctic coniferous forest, called taiga, made mostly of spruce, fir, and cedar stands. Further north, the vegetation diminishes, and the forests give way to *permafrost* and tundra. Here the landscape is too cold and windswept to support anything taller than moss and low-lying shrubs, but it also stretches for miles, unmarred by human activity.

Cold temperatures prevail year-round in the Yenisey basin but are lowest in the far north, that is, above the Arctic Circle. There temperatures generally stay below freezing for nine or 10 months a year, whereas farther south—for example, around Irkutsk—they remain below freezing for only seven to eight months. Freezing begins on northern sections of the river in early October and takes over the entire river by mid-November. (See "Turning to Ice" in chapter 10.) Thawing takes place in reverse, with the upper reaches beginning to melt toward the end of April and the lower reaches not undergoing much melting until May to mid-June. Average temperatures in the basin range from an average of 35°F (1.6°C) in June, with highs reaching

ICE BATTLE ON THE "YEN-E-SAY"

The 19th-century English writer Henry Seebohm provides a hair-raising account of being trapped on the Yenisey when the ice began to break in spring, attesting in vivid terms to the power of an ice-laden river and the fragility of a wooden ship.

> Half a mile ahead of us, as we looked down the river, was the edge of the Yen-e-say ice. The river was rising again; but before the stern was afloat, we discovered, to our dismay, that another large field of ice had broken up; and the Koo-ray-i-ka [a tributary] was soon full of ice again. In the course of the night the whole of the ice on the Yen-e-say, as far as we could see, broke up with a tremendous crash, and a dense mass of ice-floes, pack-ice, and icebergs backed up the Koo-ray-i-ka, and with irresistible force drove the Koo-ray-i-ka ice before it. When it reached the ship, we had but one alternative, to slip the anchor and let her drive with the ice. For about a mile we had an exciting ride, pitching and rolling as the floes of ice squeezed the ship, and tried to lift her bodily out of the water, or crawl up her sides like a snake. The rudder was soon broken to pieces, and finally carried away. Some of the sailors jumped on to the ice and scrambled ashore, whilst others began to throw overboard their goods and chattels. Away we went up the Koo-ray-i-ka, the ice rolling and tumbling and squeezing along side, huge lumps climbing one on the top of another, until we were finally jammed in a slight bay, along with a lot of pack-ice. The ship went through the terrible ordeal bravely. In the evening the ship was lying amidst huge hummocks of ice, almost high and dry. We calculated that about 50,000 acres of ice passed the ship up stream during these two days; and we afterwards learned that most of this ice got away some miles up the Koo-ray-i-ka, where the banks are low, and was lost in the forest.



Pristine and lovely, the Yenisey curves through boreal forest on its trajectory north. Although snow has fallen by early October, the river itself is not yet frozen and can still be navigated by rowboat. *(Ilya Naymushin/Reuters)*

into the 50s°F (10s°C), to –18°F to –4°F (–28°C to –20°C) in January, with average lows of –51°F (–46°C).

About half of the Yenisey's water comes from snow, a little more than one-third from rainwater, and the remainder from *groundwater* that bubbles up to the surface. Flow follows a seasonal pattern, with flooding precipitated in the spring by *ice jams* and the influx of *meltwater* from the south. Once the ice dissipates, water levels drop rapidly but are soon replenished by summer and fall rains. In winter, the Yenisey's flow is again reduced, but water levels remain high because of ice buildup downstream. The ice acts like a dam, effectively (if temporarily) turning the Yenisey's upper reaches into a *reservoir.*

Overall, the Yenisey produces greater discharge than any other river in Russia, sending about 150 cubic miles (620 km^3) of water to the ocean each year. Although the river carries almost no sediment when compared with such giants as the Huang and the Mississippi, it still manages to deposit about 10.5 million tons (9.5 million metric tons) of silt in the Kara Sea each year.

FLOWING THROUGH TUNDRA

As the Yenisey heads north to its outlet in the Arctic Ocean, it passes through tundra, an ecosystem often described as a stark and almost lifeless landscape. The word *tundra* comes from the Finnish word *tunturia*, which means a barren or treeless land. Found at high latitudes, between 55° and 70° north, tundra encircles the North Pole. For several weeks each year, the region is plunged into total darkness, and temperatures will drop to –70°F (–57°C). Even in summer, the temperatures rarely climb above 54°F (12°C), and the soil, which is mostly permafrost, remains perpetually frozen below the thin surface layer. The little soil that does thaw in the summer is insufficient to support vegetation with deep roots, and so trees are noticeably absent above the Arctic Circle. Virtually the only plants that survive on the tundra are lichens, mosses, grasses, and a few wildflowers that burst into life during the short summer.

In the summer, when temperatures rise above freezing, the top layer of soil thaws. Unable to percolate through permafrost, the snowmelt creates lakes, bogs, and streams, which in turn create conditions conducive to life, much of it in the form of short-lived biting flies, though some birds and mammals also make the tundra their home.

IN THE FIELD: PERMAFROST MONITORING

In 1999, the World Meteorological Association established a multinational initiative called the Global Terrestrial Network for Permafrost to monitor temperature fluctuations in the environmentally sensitive arctic. Any long-term, discernible change in permafrost temperatures would provide important evidence that Earth's climate is changing.

BURIED IN PERMAFROST

As recently as 10,000 years ago, herds of woolly mammoths (*Mammuthus primigenius*), an extinct species related to the modern elephant, roamed the frozen tundra and river valleys of northern Siberia. The ability of these animals to endure the extreme cold of the last Ice Age was facilitated by thick layers of body fat and dense fur. No one knows for certain why the species disappeared from the planet. Some scientists think the mammoths were felled by infectious disease, others think climate change, which caused vegetative shifts, decimated their food supply and led to mass starvation.

Today thousands—if not millions—of these extinct animals lie deep within Siberia's frozen peat bogs along the banks of the Yenisey and Ob' Rivers. Based on the age and condition of these specimens, paleontologists surmise that many died when they were swept away by spring floods; others may have fallen through thin ice and drowned.

Excavation of these ancient mammals has been hindered by the harsh arctic climate and the logistical nightmare of digging a giant skeleton from remote terrain. So far, about 100 specimens have been unearthed, including more than 20 complete skeletons. Pulled from the deep freeze, some of the mammoths are remarkably well preserved, with fur, internal organs, and stomach contents still intact.

Teams of Russian scientists from various institutions, including Moscow State University, Mel'nikov Permafrost Institute, Institute of Environmental Geoscience, and Russian Academy of Sciences, are participating in data collection, monitoring, and analysis. To date, more than 50 *boreholes* have been drilled in a north-south transact in Siberia. The methodology is relatively simple: Each borehole descends from 33 feet (10 m) to 82 feet (25 m) below the surface of the Earth. After the holes

TURNING RIVER POWER INTO ELECTRICITY

Human beings have long exploited the power of flowing water, from the earliest flour and grist mills to today's mammoth hydroelectric plants. With interest in nonpolluting power sources growing, hydroelectric power is emerging as a serious alternative to carbon-based fuels. To many hydrological engineers, converting the *kinetic energy* of a fast-moving river into electricity makes great sense. Not only is hydroelectricity renewable, that is, unlimited in supply, but it is considered to be nonpolluting; hydroelectric plants do not emit carbon dioxide or nitrous oxides.

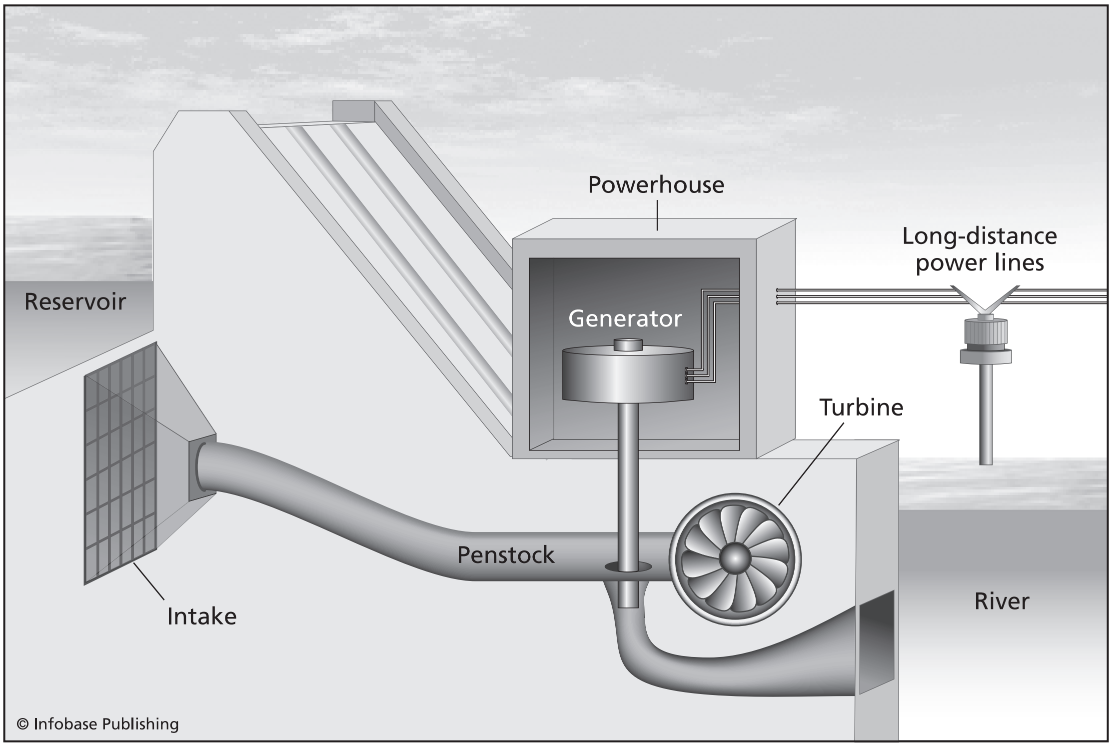
Hydropower plants are based on a simple concept: Water flowing downstream has enough kinetic energy to turn a turbine, which then turns a generator, producing electricity on demand. More turbines and bigger turbines mean more electricity generated. Dams consist of two parts: the dam itself, though which water flows, and the reservoir or lake that forms upstream. The reservoir is vital to energy generation because it raises the river level, giving the water greater kinetic energy as it rushes downward through the dam. The higher the height, the more force that is generated, a term referred to as a dam's *hydraulic head.*

The steps involved in converting the river's kinetic energy to electricity are as follows:

- Water enters the dam through a gate or *sluice* (which can be opened or closed depending on need).
- This so-called intake water rushes down a chute called a *penstock,* at the bottom of which sits a *turbine.* As the water strikes the blades on the turbine, it causes them to spin.
- When the blades spin, they turn a shaft on the turbine, which connects to a *generator.*
- Inside the generator, the shaft rotates a series of magnets, causing them to spin past copper coils. Following the principles of electromagnetism, the magnets start the flow of electrons, producing a form of electricity called alternating current.
- The alternating current then passes through a *transformer,* which converts it to high-voltage current for transmission over power lines. Before reaching end users, the high-voltage current is then converted back, i.e., weakened, to alternating current so that it can be safely used.
- Meanwhile, once past the turbines, the water moves through outflow channels back into the river, where it continues on its way downstream.

Today hydroelectricity accounts for only 10 to 20 percent of electricity in the world, even in countries that have abundant rivers. Although that percentage is expected to grow, hydroelectric dams have certain drawbacks. Harnessing hydropower for human use necessitates the construction of massive are drilled, temperature and humidity sensors, which are attached at set intervals along a length of cable, are lowered inside protective tubes lining each hole. For example, a 13-foot (4-m) cable has 15 sensors at .82-foot (0.25-m) intervals; a 66-foot (20-m) cable has 30 sensors at 3.3-foot (1-m) intervals. The probes record daily and monthly temperature readings at various depths. Over time, these sensors have produced an enormous amount of data.

dams and reservoirs that alter the natural flow of a river and destroy ecosystems. Such construction projects are complicated engineering feats (requiring decades of planning and construction.) Dams are also hugely expensive to build, as evidenced by the costs of the Three Gorges Dam on the Yangtze River. Finally, because hydroelectric plants are often built on remote rivers, hundreds if not thousands of miles of power lines must be strung across rough topography to get the electricity to the cities and factories where it is most needed.



Hydroelectric dams convert the kinetic energy of flowing water to electricity through a series of steps from intake to outflow.

DIVERTING RIVER WATER

In the 1960s, the now-disbanded Soviet Union embarked on a massive water-transfer scheme that would take water from a cluster of Siberian rivers, including the Yenisey, and divert it to the parched lands of central Asia. The idea was to construct a *canal* from the Yenisey to the Ob' to the Irtysh and finally to the Caspian Sea, which was shrinking. The plan was to build a waterway from 984 to 1,640 feet (300 to 500 m) wide and from 39 to 49 feet (12 to 15 m) deep. So grandiose was the scheme that Igor Gerardi, the project's chief engineer, proclaimed, ". . . a single generation will not be able to carry it out. We shall begin the construction and future generations will complete it."

Although former Soviet Union president Mikhail Gorbachev canceled the project in 1986, fearful of its financial and ecological costs, the increased scarcity of water may revive interest in a Siberian river diversion. (See also "Siphoning Water" in chapter 10.) With the Soviet Union no longer in existence, any such endeavor will necessitate international agreement and so may be difficult to execute. In addition, Siberia, which is experiencing economic growth, may be reluctant to part with its water, ultimately one of the planet's most valuable resources.

Radio transmitters store and then transmit temperature measurements to research computers. Large-capacity batteries (which can function in the darkness and deep cold of winter) are connected to a 50-watt solar panel. Together they supply energy to run the instruments. Although the data are still preliminary, temperatures in the upper layers of permafrost are swinging upward, providing powerful evidence—when combined with other data from the Arctic such as glacial melting—that the Earth is indeed warming.

SOURCE OF HYDROPOWER

Central Siberia is not only a land rich in rivers but also a land rife with natural resources. Timber abounds, as do various ores and precious metals, including iron, gold, and aluminum. In the hardship years following World War II, Russia realized that by bringing electricity to the region, it could harvest and process those resources on a large scale. The time and place were perfect for hydropower. Taking advantage of the Angara's turbulent upper reaches, Russia began building its first hydroelectric dams in southern Siberia in the 1950s.

The first dam was built near Irkutsk in 1956. A second and much larger dam, near the city of Bratsk, was completed eight years later. The Bratsk dam, which stands 410 feet (125 m) tall and extends 14,488 feet (4,417 m) wide, has an electric power capacity of 4,500 megawatts. Building the dam was a great engineering challenge: Both the dam and a support infrastructure had to be created in a remote outpost on the sparsely populated Siberian *steppe,* which meant construction materials had to be transported over great distances. But more than an engineering challenge, the project was a test of human endurance. For several years, thousands of men labored under brutal conditions. Not only was the work hard, but in the dark of winter, temperatures in this corner of Siberia drop as low as –72°F (–58°C) and stay below zero for at least half the year. That the dam was completed at all says a great deal about human perseverance.

Today four dams span the Angara, including ones at Ust'-Ilimsk and Boguchany, both of which are downstream from Bratsk. All four are important generators of hydroelectricity, which runs the region's many paper mills, and have helped fuel industrial development more broadly. But the largest power-generating dam in Russia sits on the main stem of the Yenisey about 323 miles (520 km) south of Krasnoyarsk. Known as the Sayano-Shushenskaya Hydroelectric Station, the behemoth structure stands 800 feet high and more than half a mile wide. About 75 percent of its electricity output goes to a nearby aluminum refinery.

Not only does the Yenisey-Angara have greater hydroelectric potential than any other river system in Russia, but it is among the most heavily dammed of the world's river systems. The six dams operating today have a combined total generating capacity exceeding 25 million kilowatts. Additional dams have been proposed, but the environmental consequences of completely taming the Angara may—at least temporarily—thwart their construction.

LOOKING TO THE FUTURE

At the start of the 21st century, the Yenisey-Angara River basin, though still relatively pristine, as shown in the color insert on page C-6 (bottom), has experienced a growth of industrial activity. In addition to its natural beauty, the area has a rich endowment of resources that has caught the interest of developers. A massive new oil refinery has recently become operational south of Irkutsk, and several others are under construction in eastern and central Siberia. Gold, nickel, and aluminum mining operations are expanding. Rates of deforestation are at an all-time high.

All industrial activities leave their mark on the environment, but such disturbances are particularly damaging to the ecologically fragile tundra. Increased vehicular activity tears apart the thin soil and—with rates of biological decay greatly slowed by the cold temperatures—even footprints and tire tracks remain visible for years after they are made. Emissions from mines and oil-drilling operations have polluted the region's once pristine lakes and rivers. Tailings from nickel and copper mines near the Yenisey delta have contaminated the river's lower reaches and killed fragile arctic plants; radioactive tritium has been found in a tributary at a level 10 times above normal. In other places, logging has led to massive tree jams, the result of logs breaking loose from their floating platoons and either clogging the delta or washing up like refuse on riverbanks.

But the direst threat to this precarious northern landscape is the least visible one. Total river inflow to the Arctic Ocean from Siberia has increased by 7 percent since measurements were begun in the 1930s. The increase can be attributed to greater snowmelt, which in turn reflects escalating average annual temperatures. The effects of global warming, it seems, are not only sending more freshwater into the Arctic Ocean but also causing a reduction in permafrost and therefore threatening the integrity of this delicate ecosystem. The long-term ecological consequences of such warming trends remain unknown, though the coastal area may well see flooding in years to come and a significant reduction in permafrost, which could profoundly affect the area's vegetation. What does seem certain is that the Yenisey will continue to flow forcefully to the sea and grow in volume.

7

The Ob'

Asia

In winter small craft lay captive in the frozen river, while propeller-driven ski sledges roar across the ice delivering mail and occasional passengers to remote villages.

—Robert Jordan (1976)

To follow the Ob' from its headwaters in the mountains of northern Mongolia and then northward across western Siberia means a journey through magnificent *boreal forests,* vast marshy expanses, tracts of *tundra,* and relatively untouched wilderness. For much of its length, the Ob' runs clear, as seen in the color insert on page C-7 (top), its crystalline waters reflecting the color of the sky, which in summer ranges from azure blue to gunmetal gray. Wending its way north, the Ob' meets its great *tributary,* the Irtysh, in Khanty-Mansiysk and from there flows another 700 miles (1,126 km) to the Arctic Ocean.

Together, the Ob' and the Irtysh form the seventh-longest river system in the world and one of Russia's grandest waterways. Flowing diagonally across western Siberia to the Arctic Ocean, the Ob'-Irtysh travels 3,400 miles (5,600 km) from its most distant reach, that is, from the source of the Irtysh, to its final point of discharge.

The Ob' has the largest *watershed* of all arctic rivers. The river draws water from an area spanning some 1.3 million square miles (3.37 million km^2) of western Siberia, a parcel of land close in size to the Mississippi-Missouri basin. Latitudinally, the area stretches from 52°N to 68°N, and longitudinally from 61° to 94°. This *catchment area* abounds in waterways: More than 1,900 rivers drain into the Ob'. Put end to end, they would have a combined distance of 112,000 miles (180,000 km). In addition, some 450,000 lakes—most of them little more than half a mile (1 km) across—dot the landscape. But the *basin* has an odd asymmetry, with two-thirds (67 percent) of the watershed lying to the left of the Ob', along its western bank, and only one-third along its eastern shores.

Given its large size, the river's watershed covers several vegetation zones: *steppe* in the south, *taiga* in the central region, and tundra in the north. The region also abounds in energy resources. More than 78 percent of Russia's oil and 84 percent of its natural gas lie beneath the Ob' basin.

Although the output of the Ob' varies seasonally—with no water moving to the sea during winter—in spring the river's waters flow freely. Recent measurements suggest that the average annual *discharge* of the Ob' reaches 444,965 cubic feet per second (12,600 m^3/s), a number that is expected to increase as the rate of glacial melt accelerates in response to global warming. On average, the Ob' pours about 95 cubic miles (402 km^3) of water into the bay each year. One indication of the river's muscular flow is its immense hydroelectric potential, which is estimated at about 250 billion kilowatts. One major hydroelectric plant spans the river at Novosibirsk; two others have been built in the mountainous headwaters of the Irtysh.

Like all rivers that traverse northern Siberia, the Ob' River's ice cover melts during the summer months, when its northern banks are bathed in sunlight nearly 24 hours a day. During the winter months, the river transforms along with the surrounding landscape. The "Land of the Midnight Sun" becomes the "Land of Continuous Darkness," and the river enters a state of suspended animation, shrouded in ice and largely robbed of light.

The temperature extremes along the Ob' are among the most dramatic on Earth. In winter, ambient air temperatures may plummet to nearly –60°F (–51°C); in summer, they may soar to 100°F (38°C). Even with the help of icebreakers, the river is navigable only about 150 days a year in its lower reaches and 190 days a year upstream. Despite its harsh climate and geographic isolation, the river has long beckoned people to its shores. Indigenous tribes have herded reindeer and fished its waters for centuries. These early inhabitants of western Siberia referred to the Ob' as Babuska, or "Grandmother," in honor of their esteemed elders. Like the grandmothers among them, the Ob' was not only strong and slow but also provided sustenance in the manner of food, water, and transportation.

Today the settlements that line the river's banks are largely those of European Russians. In the last 100 years, large numbers of outsiders have made western Siberia their home, drawn by the region's natural wealth, which includes oil, gas, coal, precious metals, old-growth forests, and plentiful water. Their activities have taken a toll on the once pristine waters of the Ob'. Today the mouth of the Ob', home to major oil and coal reserves, is contaminated with heavy metals and other industrial waste. By most accounts, the Ob' is the most polluted river in Siberia.

WATERWAY TO THE ARCTIC

The Ob' River's main trunk, without the Irtysh, runs for 2,300 miles (3,700 km) and is divided into three distinct parts: Upper, Middle, and Lower. The confluence of the Irtysh and the Ob' marks the beginning of the river's lower stretch. From this point to the sea, the river flows about 700 miles (1,126 km) through desolate terrain and permafrost.

Upper Ob'

From its source, the Ob' runs 2,300 miles (3,700 km) to the sea and—like the Mississippi—is shorter than its major tributary, the Irtysh. Like the Mississippi, the Ob' has historically been considered the dominant river and retains its supremacy to the present day. Both the Ob' and the Irtysh originate in the Altay Mountains of southwestern Siberia, but the waters of the Ob' begin further east, just north of the Mongolian border. The word *oba,* which means "both" in Russian, refers to the river's forked beginning. Two streams tumble down from the Altai Mountains: the Biya, which flows from Lake Teletskoye, a deep sliver of water 50 miles (80 km) long and two miles (3.2 km) wide, and the rock-strewn Katun', which arises from the glaciers of Mount Belukha. The Biya and Katun' meet southwest of the city of Biysk and are henceforth known as the Ob'.

From Biysk, the Ob' continues to flow northward, moving across the Siberian lowlands at a visible pace, propelled by a noticeable downhill slope. In this region, the river's channel is *braided:* Its waters move through a relatively shallow bed studded with sandy *shoals* that break the stream into multiple channels. As is the case for many braided streams, the braiding is most visible at the point where the river leaves the mountains and begins flowing across relatively flat plains. (See "Braided Streams" in chapter 3.) For several hundred miles, the Ob' drops an average of one foot per mile (20 cm/km). By the time the waterway approaches Siberia's largest city, Novosibirsk, it has transformed into a tranquil and wide river in no apparent hurry to reach the sea.

Rich in sediments, the low-lying floodplain surrounding Novosibirsk is known as Siberia's breadbasket. One of its most prolific crops is spring wheat, which is harvested and shipped west to Moscow and to Europe.

At a point some 186 miles (300 km) north of Novosibirsk, the Upper Ob' ends. Here the Tom River, which flows through the city of Tomsk, joins the Ob' from the east.

Middle Ob'

The midsection of the Ob' River stretches from the *confluence* of the Tom River to the arrival of the Irtysh River. From this point, the river angles

The Ob' River and its tributary, the Irtysh, arise in the Altay Mountains of northern Mongolia, moving 3,400 miles (5,472 km) north through the Arctic Circle to the Gulf of Ob'.

Novosibirsk, which sits on the Ob' River's east bank, is Siberia's largest city and a major industrial and transportation hub despite the harsh climate. *(Misha Japaridze/AP)*

in a northwest direction across Siberia, becoming noticeably deeper and wider as it makes its way through barren lowlands, joined on its journey by successive tributaries. Passing through taiga, this middle stretch of the great Ob' moves slowly, hindered by the flat landscape. Here, too, the river flows around numerous sandy shoals, forming a complex network of channels and becoming again a braided stream. With no canyons, cliffs, or other barriers to the river in this region, the Ob' regularly inundates the surrounding *floodplain*, which broadens to as much as 12 to 18 miles (19 to 29 km). Floods drench the landscape every year, spreading 50 miles (80 km) beyond the river channel.

Along this stretch of the Ob', the taiga forests give way to swampland, and waterlogged soils sit atop permafrost. In summer, when the ice melts, the swamps become major breeding grounds for mosquitoes and other biting flies, which can render life in the region unbearable.

NOVOSIBIRSK

Novosibirsk, which owes its existence not only to the Ob' River but to the Trans-Siberian Railway, has developed in recent years into Russia's grandest industrial city. With a population of about 1.5 million, Novosibirsk is the nation's third-largest city after Moscow and Saint Petersburg. By American standards, Novosibirsk is a dirty city: Its numerous steel mills and factories spew largely unfiltered waste into the surrounding air and water.

Over the past century, the city has emerged as a vital transportation hub. Much commerce takes place in this region, with raw materials going from river to rail and back again. Wheat and other grains from the south, furs from the north, and lumber from the surrounding taiga are shipped to the west, mostly by the Trans-Siberian Railroad. To meet the industrial demand for electricity, a huge hydroelectric dam was built across the Ob' just south of Novosibirsk in 1956. The reservoir, which is known as the Ob' Sea, is large enough to be visible on a satellite photograph. No other dams block the flow of the Ob'.

Over thousands of years, large *peat* deposits have formed on this saturated, marshy ground. Over an area that spans 386,102 square miles (1 million km^2), some 90,000 to 100,000 million tons of peat, or partially decomposed vegetation characteristic of wetlands, have accumulated. With such large concentrations of peat, the area acts as a giant sponge, retaining an estimated 240 cubic miles (1,000 km^3) of water, an amount equal to the Ob' River's total discharge in two years. In spring, when the upper layers of peat thaw, the area becomes a soggy, impassable tract, and roads that can be traversed in winter are no longer navigable. All told, the Ob' flows through some 1,243 miles (2,000 km) of these western Siberian wetlands.

TRANS-SIBERIAN RAILROAD

Beginning in the mid-1800s, Siberia's fur traders and mineral seekers pressed the Russian government for a railroad that would connect them to Moscow, Saint Petersburg, and the expanding cities of eastern and western Europe. As one of them pleaded in 1875 in a letter addressed to the Russian czar, "Only us, Thy children, O Emperor, are far from Thee, if not in heart, then in space. We suffer great hardship from this. Grant us the railroad, bring us close to thee."

Construction of the Trans-Siberian Railroad began east of the Urals in 1892. Like many of the world's great engineering projects, this one depended heavily on the sweat and blood of human laborers. Thousands of Russians, wielding little more than spades and wheelbarrows, hacked the rail bed through vast tracts of wilderness. These hardworking men cleared dense coniferous forest. They laid tracks across mosquito-filled swamps. They carved rocky passages through mountainous lands. They also had to grapple with *permafrost*, soil that remains perpetually frozen.

Chipping away at the frozen ground was akin to carving granite; in addition, the surface soil overlying the permafrost would melt during the summer, creating an unstable substratum that threatened the integrity of the train tracks.

After seven years, track for the Trans-Siberian Railroad extended all the way to Lake Baikal. With the track's completion, Siberia was suddenly accessible to the rest of the world. Hoards of settlers and other fortune seekers sought new lives in the region. By 1914, more than 4 million people had immigrated to Siberia from European Russia, doubling the population east of the Ural Mountains. During the Communist era, few people willingly moved to Siberia, but with the breakup of the Soviet Union in 1991, migration into the area has increased exponentially, with millions of people drawn to jobs in mining and natural gas extraction.

The railroad serves as a crucial transportation route from Moscow to points in eastern Asia. Six large bridges provide vital links in the chain, enabling the railroad to cross Siberia's largest rivers. The bridges include one at Omsk, which spans the Irtysh, and one at Novosibirsk, which crosses the Ob'. A third crosses the Yenisey at Krasnoyarsk, and a fourth crosses the Amur at Khabarovsk.

Today the Trans-Siberian Railway extends 5,800 miles (9,334 km) and is the largest railroad in the world. A trip from one end to the other takes seven days and seven nights. Satellite images taken at night show the impact of the railroad on development. Most of Siberia appears as a dark expanse, except for a horizontal path of lights. These bright spots—representing the lights of cities—illuminate the path of the railroad across the continent.

Lower Ob'

The Irtysh joins the lower Ob' at Khanty-Mansiysk, and thereafter—until they discharge into the Kara Sea—the two rivers run as one. At their point of confluence, the conjoined rivers span no more than two miles (3.2 km) across; by the time the river reaches the sea, however, its banks have spread by at least 25 miles (40 km). The largest settlement on the Lower Ob' is Salekhard.

The river discharges into a large inlet of the Kara Sea called the Gulf of Ob' or the Ob' Bay. Looking like a long, slender fissure in the Earth's crust, the gulf extends some 600 miles (1,000 km) almost due north. Compared to its length, the gulf is noticeably narrow, varying from 30 to 50 miles (50 to 80 km) in width. Water flows from the bay north to the Kara Sea, which in turn mixes its waters with those of the Arctic Ocean. The Kara Sea, which is a marginal shelf sea, undergoes major fluctuations in *salinity*. During the summer, the enormous freshwater discharges of the Ob' and Yenisey Rivers temporarily dilute the sea's salt water.

The eastern side of the Gulf of Ob’ is rocky and steep; the western side is low-lying and marshy. But massive gas reserves that may be among the largest in the world lie beneath the surface just to the east of Ob’ Bay. These deposits, which are shipped to Europe via pipelines and rail, have brought a flurry of economic activity to the area, even though the area is not especially conducive to human habitation.

The gulf itself deters the growth of commercial shipping. Not only is it too shallow for oceangoing freighters, with an average depth no greater than 39 feet (12 m), but the waterway is also icebound from October to July. During the seemingly endless winters, a layer of ice at least 6.6 feet (2 m) thick forms across the surface and may reach 45 feet (14 m) in places where icy ridges form. Many people travel short distances in winter by snowmobile or by reindeer-pulled sledges. Those who travel in and out of the region rely mostly on air transport.

THE IRTYSH

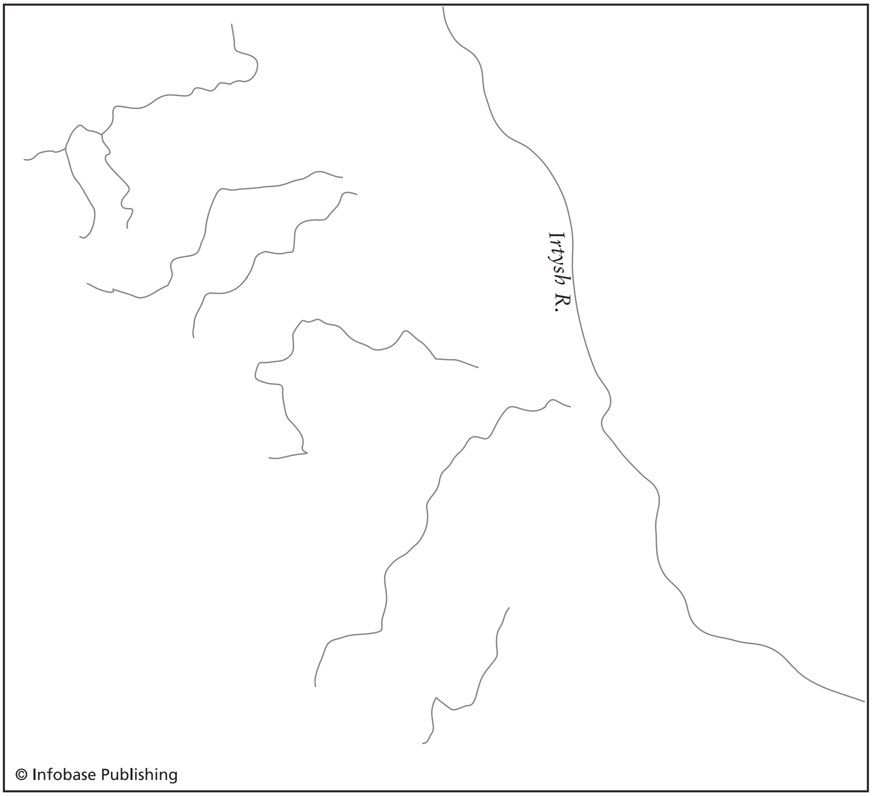
A great winding river, the Irtysh runs 2,640 miles (4,248 km) from beginning to end. The *headwaters* of the Irtysh, which arise farther south than those of the Ob’, form from glacial melt that cascades down the southwestern flank of the Altay Mountains in Sinkiang (Xinjiang), China. From here, the

WHEN FRESHWATER MEETS SALT WATER

Two major rivers empty into the Kara Sea: the Ob’ and the Yenisey. Both dump enormous amounts of freshwater into the Kara Sea, which then exchanges its waters with those of the saline Arctic Ocean. The Ob’ and the Yenisey alone account for an astounding 30 percent of the total annual freshwater discharge into the Arctic Ocean.

In a pattern typical of boreal rivers, which freeze at least six months a year, the Ob’ and Yenisey Rivers discharge most of their total volume into the Kara Sea during just three months, that is, from May to June. (In contrast, the Mississippi discharges 41 percent of its water during its peak three months.)

For the remaining nine months a year, the Kara Sea is covered in ice and receives little or no freshwater from the Ob’. Peak discharge takes place in June, when 80 percent of the annual discharge pours into the sea. The massive inundation of freshwater creates an interesting phenomenon called a bi-layered *pycnocline:* The warmer freshwater—having mixed with salt water in the Gulf of Ob’—tends to be *brackish* by the time it reaches the Kara Sea. Even so, it is lighter than salt water and floats on top of the cold ocean waters. This physical structuring of the water column determines the distribution of many aquatic organisms, which depend on the nutrient-filled waters of the Ob’. The freshwater is rich in organic carbon leached from peat deposits, a stark contrast to the *oligotrophic* arctic marine environment, which has few nutrients and therefore supports limited life. Many free-swimming planktonic organisms distribute themselves according to the physical structuring of the water column, which isolates the biological communities in the upper horizontal layer, where the water is warm, nutrient-laden, and low in salt.



Several Irtysh tributaries have dried up and separated from the river’s main channel, in a process called fragmentation. On a map, the severed tributaries (most still filled with water) look like ribs separated from a backbone.

frigid mountain stream courses westward through granite and limestone *outcrops*. On its way, the river passes from Mongolia to Kazakhstan before turning northward across the Russian border toward Khanty-Mansiysk.

In its mid-region, below the city of Omsk, the Irtysh flows through the *lowlands* of the East Siberian Plain. Like the western lowlands, the region contains numerous peat swamps and is pockmocked with lakes and hills. As the river flows farther west, it passes through land that becomes yet swampier, a great sodden expanse that is largely impassable in summer. This vast landscape is so wet that only 20 percent is considered dry land. Few trees grow here; instead, reeds and other marshy grasses are the dominant vegetation.

But the Irtysh watershed is distinct for another reason. Over many millennia, the catchment area has undergone a process called *fragmentation:* Many tributaries that were once part of the river system dried up and became separated from the main trunk. Sediments carried by the Irtysh blocked their desiccated channels, and over time—even during periods of deluge—the water in them ceased to reach the primary river channel. Today these tributaries appear in aerial photographs as empty channels; at least one hydrologist says they resemble ribs that have broken away from the spine.

SPRINGTIME DELUGE

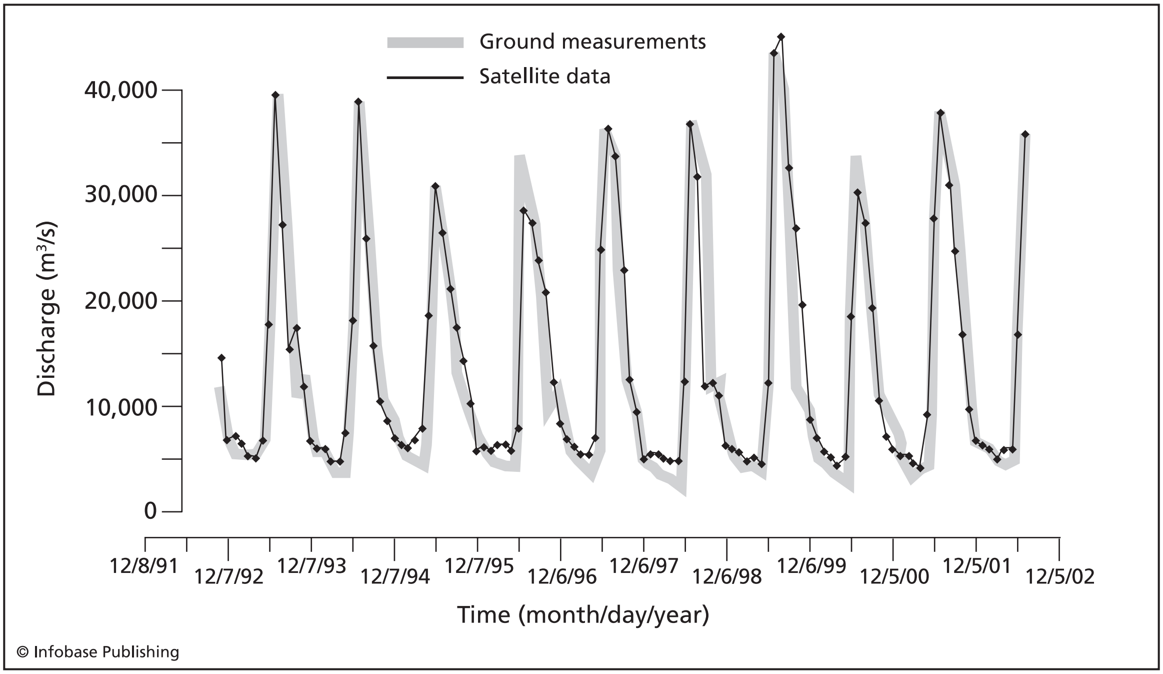
Flooding on the Upper Ob' occurs in two phases in early spring. The first bout of flooding begins when the snow around Biysk and other lowland areas in the south melts; the second round of flooding takes place when temperatures in the Altay Mountains finally rise. The tumultuous waters churn downstream, overflowing the Ob' River's banks, but encounter a roadblock when they reach the Middle Ob'. The river channel this far north remains blocked by ice for several more weeks. Such bottlenecking causes the free-flowing floodwaters to spread across the vast lowland plain, where they are absorbed by large quantities of sponge-like peat. By July, the channel is free from ice all the way to the gulf. As the Ob' flows northward toward the gulf, an interesting phenomenon takes place: The peat deposits through which the river passes act as filters, removing sediments from its water. By the time the Ob' discharges into the Arctic Ocean, it carries relatively little particulate matter.

By contrast, the Middle Ob' sees its water levels rise in mid-April and remain elevated through October. On the Lower Ob', flooding may last for four months. By the end of November, the entire river is frozen; the upper regions stay icebound for at least 150 days; the lower regions, which are closer to the Arctic Circle, remain frozen 50 percent longer, or more than 220 days each year.

Thawing of the ice takes longer than the freezing. The ice begins to melt in the Upper Ob' at the end of April; in the Lower Ob', the ice melts closer to the end of May. As a result of the uneven melting, *ice jams* are a frequent occurrence, marked by much groaning and cracking as the gargantuan ice chunks fight one another in the channel (see "Ice Breakup" in chapter 6). The melt ice creates a sudden influx of water that causes the river to rise dramatically. At Novosibirsk, for example, the river may rise as much as 25 feet (8 m) during peak flow. Farther upstream, the increase may be as great as 43 feet (13 m).

IN THE FIELD: SNOW DEPTH AS A PREDICTOR OF FLOODING

The amount of freshwater discharged by the Ob' River each year is heavily influenced by two factors. One is the extent and depth of winter snow in the river basin. The other is the amount of snow that melts each sum-



Measurements of the Ob' River's annual flow at Salekhard show a dramatic increase in summer and a dramatic drop in winter when the river is frozen. Data obtained from ground measurements are virtually identical to those taken by satellite.

mer, which is linked to snow density as well as ambient air temperatures. Recognizing that the snow-*runoff* relationship has important implications for flood prediction, a team of hydrologists from the Center for Spatial Studies of the Biosphere in Toulouse, France, is collecting data on snowpack depth in the Ob' basin utilizing a method known as passive microwave remote sensing (PMRS).

Measurements of microwave radiation emitted by the snow are taken with a special sensor on board a meteorological satellite. The sensor measures the scattering of *microwaves* from the snow at two distinct frequencies, which provides data on both the ground temperature and the density of the snow. Preliminary results show that brightness correlates inversely with depth: As levels of reflectivity increase, snow depth decreases. The timing of snowmelt is then predicted by comparing the differences between the two channels using a special computer model based on the *spectral gradient*.

One year, for example, the scientists accurately predicted that peak runoff would occur on the Ob' in early June, with flooding especially likely that year because snow depth throughout the watershed was above

PLANATION

As rivers age, they tend to make and enlarge their floodplain, a process once called *planation.* Over time, a floodplain grows both *headward* (toward the river's source) and sideways, becoming ever wider as the river's silt deposits spread laterally. When two or more rivers run parallel to one another, their lateral spreading floodplains eventually overlap, giving rise to a distinctly flat terrain sometimes known as a *panplain.* The great low plains that define the lower and middle courses of the Ob'-Irtysh are excellent examples of advanced panplains.

When the rivers descend from high mountains, as the Ob' and Irtysh do, the upstream regions retain their distinct character; only the downstream segments have overlapping floodplains.

average. Overall, the modeling has proven to be fairly accurate, but certain variables render it less than perfect. The physical characteristics of snow, for example, vary. Some snowflakes, or grains, are more compact than others; the more compact the grains, the denser the snowpack. Not only does grain size vary with each snowfall, but the grains also transform over time, becoming more compact under the pressure of successive snowfalls.

In addition to providing data that are critical to flood forecasting, PMRS offers an unparalleled method for monitoring global climate change, which is most dramatic in arctic regions. Not only are diminished depths of snowpack and progressively earlier melt dates early warning signs for climate change, but they also provide important data on potential feedback mechanisms that are likely to accelerate climate change. With less snow cover, for example, surface reflectivity decreases, which in turn can raise air temperatures and cause vegetative changes in the region.

IN THE FIELD: SATELLITE MONITORING

In situ measurements of discharge (see chapter 2, "In the Field: Measuring a River's Rate of Flow") are standard for easily reached and free-flowing rivers such as the Amazon and Mississippi. For remote arctic rivers that are icebound much of the year, such measurements are hard to obtain and therefore scarce. Fortunately, 21st-century technologies in the form of satellite-based measurements offer a viable alternative to ground stations.

A team of Russian and French hydrologists outfitted satellites with radar and also with *altimeters,* which make vertical measurements based on the time it takes for the radar to bounce from the Ob' River's reflective surface back to the satellite. Circling the Earth on an orbital cycle of 10 days, the satellite measures flow rates and depth levels, a frequency that is sufficient for climatological and ecological monitoring of the Ob'.

To compare the accuracy of satellite-based altimeter readings with in situ measurements, the team also looked at ground-based water level and discharge data from Salekhard, the last observation point before the Ob' enters the Ob' Bay. Although some error was introduced when the satellite's radar, responding to surface reflectivity, locked onto the river's water too long or—confused by the mountainous topography—refused to lock on at all, for the most part the satellite readings were accurate. The data correlated successfully with field measurements, producing an average error of only 8 percent. The team concluded that for hydrological studies of seasonally ice-covered arctic rivers, with their enormous logistical challenges, satellites provide a viable alternative to in situ data collection.

INDIGENOUS PEOPLES OF THE OB'-IRTYSH

For many centuries, small bands of nomadic reindeer herders occupied northern Siberia, moving across the moss- and lichen-covered tundra as the seasons changed. These people survived winter in sod-covered log cabins; in summer, they traveled with their reindeer herds, living in birch-bark *chums*, or tents, which they pulled to each new grazing site.

In the 1930s, these northern nomads fell prey to the communist fervor that swept what was then the Soviet Union and is now Russia. Soviet authorities decreed that all citizens, including indigenous tribes, must work for the common good (as defined by the state). As part of the new regime, Siberia's nomads were forced onto collective farms and away from reindeer herding.

Four distinct tribes still dwell along the banks of the Ob' River today: the Mansi, the Khanty, the Selkup, and the Ket peoples, although their numbers are dwindling. Most are sedentary and live in small towns, where they depend on agricultural rather than nomadic herding for their livelihood. Even so, a few hundred have resisted the sedentary lifestyle and today eke out a living as seminomadic reindeer herders. The Kanty, which is the largest ethnic group, numbers around 22,000 people. The Mansi tribe has about 8,000 people, the Selkup 3,000, and the Ket only 1,000. Overall, even with the rate of migration to the region increasing, the population density of northern Siberia remains among the lowest in the world.

FUTURE SHIFTS

The Ob', like all northern rivers, could be profoundly affected by global climate change. Recent data provided by the National Aeronautics and Space Administration shows that the Arctic's perennial sea ice, which normally lasts year-round, is melting at a potentially catastrophic rate.

THREATS FROM NUCLEAR CONTAMINATION

Like most of the world's rivers, the Ob' suffers from contamination, though its levels of human-derived pollutants fall far below those of, say, the Yangtze. But unlike these other rivers, the Ob' faces serious threats from radioactive waste. Over the years, various weapons-grade plutonium production and reprocessing plants have discharged their waste into the Ob'-Irtysh. Some of that waste is filtered out during the river's journey through the great Siberian marsh, and some is released to the Arctic Ocean, so present levels in the river—though detectable—are low. But an estimated 3 billion curies of nuclear waste remain buried in the Ob'-Irtysh watershed, which raises the specter of future releases into the river.

In addition, plutonium—deposited as global fallout from nuclear weapons testing—has been found in Ob' *estuary* sediments. At the same time, concentrations of plutonium associated with underwater weapons testing, radioactive-waste dumping, and terrestrial runoff into the Ob' River have been detected in the Kara Sea.

Of greatest concern, however, are containers of radioactive waste that were dumped in the Kara Sea during the Soviet era. When this fact was first reported in 1991, investigators told a startled world that 2.7 million curies of radioactive substances in the form of liquid waste, barrels of waste, and scrapped nuclear reactors had just been tossed into the sea. Six of the jettisoned warship reactors are thought to still contain nuclear fuel. If these containers and reactors ever corrode or develop leaks, the release of radioactivity will be significant.

Between 2004 and 2005, 14 percent of the region's perennial ice cover—an area the size of Texas—simply melted into the ocean. In what could become a runaway effect, the melting ice will likely raise ocean temperatures, which in turn may hasten further ice loss. The impact of rising sea levels and warmer temperatures on the world's arctic rivers, including the Ob', remains uncertain. Many hydrologists fear, however, that severe climatic changes will radically transform the ecology, if not the hydrology, of the entire river basin.

8

The Congo River

Africa

A mighty big river . . . resembling an immense snake uncoiled, with its head in the sea, its body at rest curving afar over a vast country, and its tail lost in the depths of the land.

—Joseph Conrad, *Heart of Darkness*

The Congo River, known for many years as the Zaire, makes a great horseshoe sweep across equatorial Africa. Churning first north, then west, and finally south, this tributary-rich river helps define the continent. Its waters feed lush jungles, connect far-flung villages, and provide a highway to the heart of Africa. From the air, as seen in the color insert on page C-7 (bottom) the river appears to meander through endless greenery, with densely parked trees stretching as far as the eye can see. On its journey to the Atlantic, the Congo crosses the equator, not once, but twice. Wending its way seaward, the mud-colored river passes almost entirely through one country: the Democratic Republic of the Congo, often referred to simply as Congo, as if synonymous with the river that arcs across its landscape.

At 2,900 miles (4,700 km), the Congo ranks ninth among the world's longest rivers. But a diminutive river it is not: No other river except the Amazon pours as much water into the ocean each year. And no other river except the Amazon has so large a *watershed*. Though the Congo *discharges* into the Atlantic on Africa's east coast, its far-flung tributaries almost overlap with those of Africa's other grandiose rivers, specifically the Niger to the north and the Nile to the east.

The Congo also claims fame as Africa's longest navigable waterway (exceeded on the continent only by the Nile). With its abundant network of tributaries, the river system represents an 8,700-mile (14,000-km) transport route within Congo, reaching into almost every corner of the country. In addition, its tributaries draw from both sides of the equator, spanning a north-south distance of 1,400 miles (2,253 km) and about 1,200 miles (1,931 km) from Africa's west coast to its eastern half. All told, the river's *drainage basin* spans 1.34 million square miles (3.6 km^2).

Yet for all its potential as a major trade route, the river is stymied by an unusual geology. Unlike most rivers that are navigable near their mouths, the Congo is virtually impassable in its lower reaches. A series of ferocious *cataracts* line the river channel from the seaport of Matadi at the head of the Congo estuary to Malebo Pool, some 100 miles (160 km) inland, thwarting all attempts to travel upstream from the coast.

To gain access to the interior of Congo and bypass the rapids on the lower Congo River, the Congo-Ocean Railway was constructed between Pointe-Noire on the coast and the inland city of Brazzaville. Although the railroad, which was completed in 1934, covers only 317 miles (510 km), it represents an engineering triumph. Built atop rough terrain, the railroad needed 172 bridges and 12 tunnels to reach its destination. Construction exacted a heavy toll: Working under conditions of high heat and humidity, at least 17,000 men died building the railroad. After operating for many years in poor condition the railway has recently been restored, but is still hampered by maintenance problems and the occasional attack by insurgents.

SERPENTINE FLOW TO THE ATLANTIC

The Congo flows through central Africa, forming a great serpent-shaped channel to the sea. Although the river passes predominantly through Congo, it also touches on parts of Republic of Congo, Central African Republic, eastern Zambia, northern Angola, Cameroon, and Tanzania. Divided into three parts, the Congo is most navigable in its midsection, which serves as Congo's main transport artery. Much of the river passes through impregnable jungle, a vast tract of largely untapped wealth, embodying for many the very heart of Africa.

Upper Congo

The Congo begins in the mountains of northeastern Zambia several hundred miles south of Lake Tanganyika and only 430 miles (692 km) from the Indian Ocean. Here, at a modest elevation of 5,760 feet (1,760 m) above sea level, the *headwaters* of its longest *tributary* begin their 2,900-mile (4,667-km) march to the ocean. At this point, the Congo is called the Chambeshi River.

As the Chambeshi moves almost due north through Congo, it joins with the Lualaba River, which in turn receives the waters of two other tributaries: the Luvua and the Lukuga. Continuing northward, the cojoined streams widen, becoming the Congo River proper.

The Congo River makes a grand horseshoe sweep across west-central Africa, passing largely through the Democratic Republic of the Congo on its 2,900-mile (4,700-km) journey to the Atlantic Ocean.

The river first passes through upland *savannas*, then narrows several times. Long stretches are interrupted by rapids and gorges with sinister names like Portes d'Enfer (French for "Gates of Hell"). Waterfalls occur with a frequency that makes navigation difficult, especially on the Lualaba, though smaller boats are able to portage around the rocky outcrops. A cluster of seven cataracts known as the Boyoma Falls (formerly Stanley Falls) occurs over one 62-mile (100-km) stretch just upstream from Kisangani (formerly Stanleyville), but these, too, can be circumnavigated. From the headwaters of the Chambeshi to its terminus in Kisangani, the Upper Congo flows some 1,300 miles (2,092 km).

Middle Congo

This stretch of the river, which extends for 1,077 miles (1,733 km) from Kisangani to just east of Kinshasa (formerly Léopoldville), is highly navigable. Boats readily move up and down this middle section, undeterred by physical obstacles. In sharp contrast to the angry river it will later become, the Congo flows calmly here, a largely placid stream marred only by the occasional tree snag or *sandbar*.

Just above Kisangani, the river expands. It passes through an *alluvial plain*, dividing into several channels and becoming a *braided stream*. (See "Braided Streams," in chapter 3.) With its multiple channels, the river grows to a girth of 3.5 miles (5.6 km). Just downstream from the city of Yangambi, the Congo is joined by its southern tributary, the Lomami River, and expands again, this time to a width of from five to seven miles (8 to 11 km). As the Congo curves toward the southwest, its waters pass through dense tropical forest, shrouded in sweltering humidity.

The Congo's midsection ends with an abrupt narrowing of the river channel. Here, in a section called the Couloir (which means "corridor" in French), the river constricts suddenly, and its once expansive banks narrow from seven miles to little more than half-a-mile wide. The raging river gains speed as it forces its way through this rocky bottleneck. In its rush seaward, its powerful currents cut a deep path through the surrounding sandstone *plateau*.

Once past the tiny chute, the Congo is joined by three *blackwater* (or high organic content) tributaries: the Ubangi and the Sangha from the north and the Kwango from the south. Powered by the massive influx of new water, the river surges onward, its rate of flow substantially increased. No longer constrained, the river spreads its channel wide.

And wide the river becomes. With its banks pushed apart and its slope greatly decreased, the river expands to form a vast lake called Malebo Pool (formerly called Stanley Pool), which measures about 17 miles (35 km) long by 15 miles (23 km) wide and has a sizable island, called Bamu Island, at its western end. Malebo Pool marks the beginning of the navigable portion of the Congo.

The lakelike river spreads across some 320 square miles (830 km^2) of west-central Africa, forming a border between the two African nations whose names sound almost interchangeable: Democratic Republic of the Congo and Republic of the Congo. The capitals of these two countries perch on opposite sides of the river. Kinshasa, now capital of Congo, sits on the left bank; Brazzaville, now capital of Republic of the Congo, lies on the right. Both cities have emerged as important ports and gateways to the continent's interior, and the two are connected by ferry. From these cities, the river easily transports travelers 1,077 miles (1,733 km) upstream, as far as the city of Kisangani.

Lower Congo

Just a few miles downstream from Kinshasa, the Congo, fed again by the discharged waters of several tributaries, heads precipitously downhill, its waters churned by a series of wild rapids and terrible cataracts. Rough water defines the lower Congo, although fairly calm water can be found interspersed between its cataract-riddled stretches.

Along this section, the Congo's plunging waters have eroded a deep channel, cutting some 131 to 295 feet (40 m to 90 m) into the riverbed. Softer sedimentary rock alternates with harder igneous rocks, such as granite, causing the uneven erosion typical of cataracts. On one 350-mile (563-km) stretch between Kinshasa and Matadi, for example, the river descends 853 feet (260 m), pouring over 32 cataracts on its tumultuous

NAVIGATING THE CONGO

Kisangani, perched on the river's edge in central Congo, was once a major transport hub; today its waterfront lurches with intermittent activity. Congo, one of the poorest countries in the world, has few resources with which to maintain its transportation infrastructure. Mired in bankruptcy, the national transportation company of Congo runs only the occasional boat up- and downriver. Dredging—necessary to maintaining an open channel—has ceased in recent years. As a result, only flat-bottomed boats such as barges traverse the river.

Even along the Congo's midsection, which offers boaters 1,000 miles (1,600 km) of relatively calm water, travel is arduous. To trek upstream means spending from two to six weeks floating on a decrepit, steamy, and overcrowded barge with virtually no amenities. The travel writer Simon Winchester describes the dreadfulness of such a journey:

> My trip . . . seemed an impossible feat: this cramped floating crate had to chug up 1,100 miles of jungle river. If I got sick, anyone got sick, if we broke down, there was nothing to be done about it but hope that Providence, so clearly unmoved by the tableau of mass suffering in Congo, might decide to make a gesture of divine benevolence towards us. Many merchants, I was to learn, had had friends die on the river, from cholera or malaria or other nameless fevers—a fate I hoped to avoid . . . The commencement of every voyage up the Congo was thus attended by fervent prayers for Godspeed, for whispered supplications to fetishes, by wailing farewells from relatives on shore. Our voyage was no exception. No one was certain who would arrive alive in Kisangani.

Yet, for most Congolese, the Congo represents their only mode of travel. Imagine life in a country the size of Western Europe with a population of 60 million and only 300 miles (483 km) of paved roads. No wonder people wait days for a barge to arrive and then pack themselves on board, where there is barely room to sit down.

trajectory. (See “Cataracts” in chapter 1.) The Congo’s tallest waterfall, Inga Falls (formerly known as Livingstone Falls), which reaches a height of 131 feet (40 m), lies along a particularly steep downhill stretch. Here the river drops 328 feet (100 m) in 17 miles (27 km).

Because of its steep topography, the Congo makes an especially dramatic—some might even say savage—departure from the continent. Not far from its mouth, the river—propelled forcefully by its upstream cataracts—thunders downhill through a narrow gorge, its channel tapering to only 738 feet (225 m) at one point, a sharp contrast from its upstream width of 7.5 miles (12 km).

This stretch of boiling, impassable water has a foreboding and apt name: Cauldron of Hell. Here the river continues to chug downhill. Unlike most other riverbeds, which become low-lying as they approach the sea, the Congo tumbles down a steep gradient, gaining enough momentum to etch a channel that passes across its *estuary* and into the ocean.

Estuary

The Congo’s estuary begins at the city of Matadi and stretches downstream for 83 miles (134 km) to the Atlantic Ocean, forming on its way the border between Congo and Angola. As it unfolds, the estuary grows in width, expanding from less than half a mile at its start to several miles wide at the edge of the Atlantic, where it is obstructed by several islands and forms several channels.

The river discharges into the Atlantic Ocean at Banana, a port city in Congo. Propelled by the precipitous slope in its lower reaches, the Congo’s waters continue to flow forcefully out to sea, coming together

HYDROELECTRIC POTENTIAL

With its torrential waters and steep inclines, the Congo River represents enormous hydroelectric potential. All told, the Congo basin is thought to hold one-sixth of the world’s known hydroelectric resources. Yet little of the river system’s potential has yet been harnessed. (See “Hydroelectric Power,” chapter 6.)

During the colonial era, a large hydroelectric facility was constructed at Inga Falls, formerly known as Livingstone Falls, just upriver from Matadi and about 93 miles (150 km) east of the river’s mouth. The site has a potential power output of some 40,000 megawatts—enough to meet the electrical needs of all sub-Saharan Africa for decades—but the current generators are in disrepair, and massive new generators are needed. The plant now generates less than 2,000 megawatts a year, only a tiny percentage of its annual capacity. Studies on the feasibility of rehabilitating and augmenting the existing hydroelectric stations are underway, but it may be many years—if ever—before the plants operate at full capacity. In addition to new generators, new transmission lines several thousand miles long will be needed to bring the electricity to the places where it is most needed.

beyond the mouth to cut a deep furrow or underwater canyon over the continental shelf. So great is the flow that discharge extends offshore for about 125 miles (201 km), forming a large deposit of sediments known as the Congo Fan.

FINDING THE SOURCE

In 1482, while sailing along the west coast of Africa, the Portuguese adventurer Diego Cão came upon the *mouth* of the Congo. Intrigued by the river's apparent size as suggested by large clusters of vegetative debris and the immense quantity of freshwater pouring into the ocean, he returned three years later, intent on following the waterway inland. Cão forced his way as far upstream as the Cauldron of Hell but there—blocked by the river's brutality—he was forced to retreat.

Other explorers followed Cão, but for centuries the Congo River remained an impenetrable, roiling body of water that easily squashed the efforts of outsiders to unveil its secrets. For four centuries, the heart of Africa remained the heart of darkness, deeply mysterious to the outside world. Not until exploration became vogue in Victorian-era Britain did European adventurers try again in earnest to map the Congo. Dr. David Livingstone, the famed British explorer, reached the Upper Congo in 1873, but he mistakenly thought he had found the headwaters of the Nile. He died in the African wilderness never knowing of his geographical blunder. In 1876, Sir Henry Morton Stanley launched the famous expedition that was eventually to take him almost from the headwaters of the Congo to the Atlantic.

In what was a remarkable display of both courage and daredevilry, Stanley began his horrific downstream adventure at Lake Taganyika. Intent on finding his way to the ocean, he plunged down the Lukuga River with no idea in what direction he was headed or indeed in what ocean he might find himself. At one point, he surmised he was on the Nile; at another point, he thought he was traveling down the Niger. Finally, after almost a year of nail-biting drama—during which 40 members of his team died—Stanley reached the Atlantic. Though triumphant to have met his goal, the explorer summed up his journey by saying, "We have a horror of the river now . . . the hateful, murderous river. . . ."

GEOLOGICAL REVERSAL

Africa was born some 150 million years ago, when the continent broke from the Eurasian landmass known as Gondwana. A time-traveler from the present would be hard-pressed to recognize the newly formed continent: Only its southern tip was above water. Most of Africa remained submerged until the end of the Cretaceous period some 65 million years ago. Thereafter, the continent underwent a series of tectonic rumblings that caused uplifting to the east. The land was pushed upward, creating the depression known today as the Congo River *basin* and also the river itself.

For several million years, the Congo emptied into a landlocked basin. Waters flowed westward into the basin's central depression or *cuvette*, but from there had no way of reaching the ocean. Evidence for a landlocked Congo can be found in the sediments surrounding Malebo Pool. Patterns of erosion show that the Congo's current moved in only one direction: toward the basin, not away from it. Eventually, water would have overflowed the basin and drained into tributaries, forcing them seaward in a process called *headward erosion*. Such changes of course did not happen quickly. Geologists estimate that the Congo River reached the Atlantic Ocean only as recently as 5 to 10 million years ago.

A team of geologists from the University of Cape Town in South Africa now believes that when the Congo first formed, the river flowed from west to east, in the opposite direction to what it does today. Instead of surging to the Atlantic Ocean, it ran to the Indian Ocean. Flow reversals of major rivers are rare but not unknown.

They base their hypothesis on several pieces of carefully constructed evidence. To begin with, they examined the age of the sediments in today's Congo Fan, near the river's mouth in the Atlantic Ocean. They found the sediments there to be only about 2 million years old, far younger than the river itself. They then turned to the fossil record. Here, too, they found few marine fossils of the right age along the west coast of Africa. But they did find abundant Cretaceous fossils representing species that could only have lived in a large, nutrient-rich estuary on the east coast.

Next, they constructed models of the paleo-Congo that showed how the early river would most likely have followed today's Lualaba River and drained east across the East African Rift valley into the Indian Ocean. The ancient waterway would have ended its journey at the Rufiji *delta* in Tanzania.

Finally, in examining sediments at the Rafiji site, they concluded that the delta there is simply too big to have been created by the diminutive Rafiji River, which is only 373 miles (600 km) long. Only an older and much bigger river—such as the Congo—could have brought so much sediment to the sea.

Based on this evidence, the South African hydrologists propose that today's Congo formed some 35 million years ago during a second wave of geological *uplift* in East Africa. As the East African Highlands pushed upward, the Chambeshi would have tipped westward, reversing its flow much like a teeter-totter shifts direction. This flow reversal would have launched a domino effect, causing the main trunk of the paleo-Congo to reverse direction. In this way, a small stream to the west became the main trunk of today's Congo, and the Lualaba was relegated to a mere tributary.

BIOLOGICALLY RICH BASIN

Verdant and teeming with life, the Congo basin appears from an airplane window to be a never-ending emerald carpet. On closer view, the same landscape appears to be an oppressive, claustrophobic tangle of vegetation. Either way, the Congo watershed is enormous. According to the United Nations Food and Agriculture Organization, the entire watershed covers some 520 million hectares, with close to 40 percent of the land covered in primordial forest.

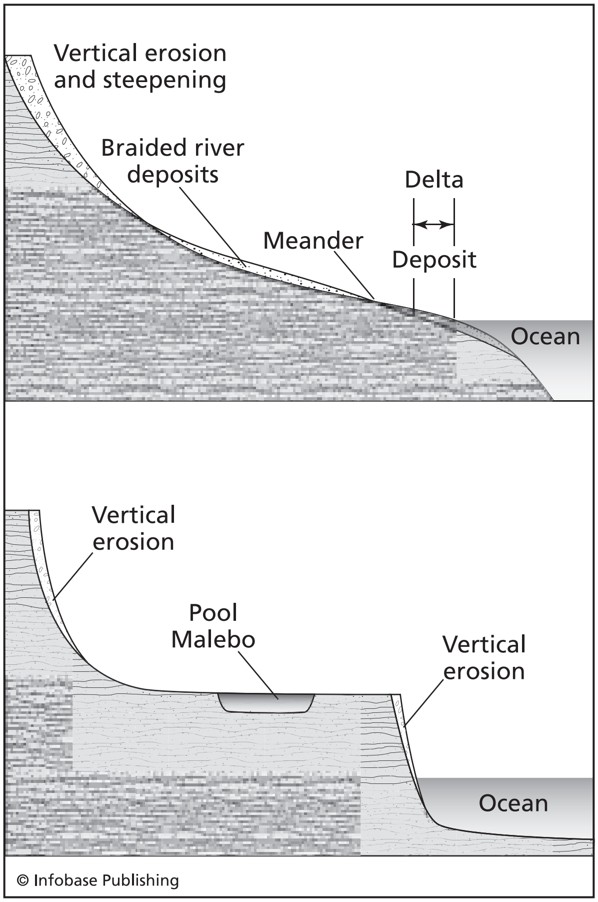
The Congo basin may be relatively young, but the bottom layers of the cuvette (from the French term for "basin") are themselves ancient. Alluvial deposits several million years old rest on thick sediments of continental origin, consisting principally of sands and sandstones. Boreholes reveal that these sediments have been accumulating in the basin for at least 570 million years (since the Precambrian Era) but were uplifted, as was the cuvette itself, during the Cretaceous Era around 65 million years ago, when the present Congo basin was formed. Since then, the center of the cuvette has settled downward while its outer edges have undergone uplift, creating its saucerlike shape.

A dense evergreen forest spreads across this central depression, which is bordered by vast subtropical grasslands called savanna. The entire basin teems with life. Crocodiles line the Congo's banks and float near shore but avoid the swift currents of mid-river. Hippopotamuses also wallow in the river's cool waters. Although no one knows for certain how many species exist in the Congo basin, so far scientists have identified some 400 species of mammals—including elephants, gorillas, and chimpanzees—1,000 species of birds, and 300 species of reptiles—

PARALLEL DRAINAGE

While some of the Congo's tributaries follow a classic *centripetal drainage* pattern, flowing downward into the central depression from slopes that range in elevation from 900 to 1,500 feet (274 to 257 m), most do not. Instead, many of the river's tributaries assume a *parallel drainage* pattern. As the southern tributaries flow north, they connect with westward-flowing streams that then move toward the Congo without converging. A similar pattern exists for the Congo's northern tributaries, which flow first south and then also west along parallel trajectories. In contrast, the tributaries of a centripetal river flow toward a central point following a standard branching pattern.

CHANNEL MORPHOLOGY



Most rivers exist in a state of equilibrium, with gradient profiles that curve steadily downward (top). In contrast, the Congo has yet to achieve equilibrium. The river has an unbalanced profile marked by a flat midsection and steep incline near its mouth (bottom).

River channels vary in their *morphology*, that is, in their form or physical shape. Several factors, called *flow characteristics*, account for a channel's morphology: Among them are the geology of the riverbed itself, which determines how much friction a stream encounters, the slope of the land, the river's *sediment load*, and the amount of water moving downstream.

Under stable climatic and watershed conditions, a balance generally exists between a river's flow characteristics and its channel form. Erosion is greatest where the gradient is steepest, with sedimentation increasing as the gradient lessens and vice versa. As the slope flattens, so do the river's erosive patterns.

Eventually, a balance between erosion and sedimentation emerges. When a river channel assumes this type of stability, it is said to be in a state of *equilibrium*. Rivers may adjust their size, shape, and pattern in response to varying flows and sediment load, but they almost always fluctuate about a mean condition, known as the equilibrium form, which is also sometimes referred to as a state of quasi-equilibrium. For most rivers, achieving equilibrium means their erosive powers match their sedimentation rate.

All rivers have a *gradient profile:* Most make a steep descent from a relatively high altitude and become progressively less steep until they almost level out in their lower reaches. When erosion in the upper reaches matches sedimentation in the lower reaches, a river is said to have a *balanced profile*.

The Congo shows a complete reversal of the typical gradient profile. The river flows across a broad *plain* in its middle reaches, where it deposits tons of silt before dropping down a steep incline to the ocean. The river's geological past—with its discharge into an inland basin—explains this anomaly. Though the process may take tens of millions of years, eventually the Congo will reach a state of quasi-equilibrium.

including many venomous types of snakes. Roughly 700 species of fish have been identified in the Congo, about one-third as many species as the Amazon, but twice the fish diversity of the Mississippi.

IN THE FIELD: SNAKE HUNTER

Kate Jackson, a young Canadian herpetologist, has made the study of poisonous snakes of Congo her specialty. In a recent field trip to remote northern Congo, she collected 130 specimens of rare snakes, lizards, and frogs, some of which were entirely new to science.

Accompanied only by a cook and guide, she ventured by foot into remote jungles in the Congo basin looking for snakes, sometimes at night with the aid of a headlamp. To catch water snakes, she strung fishnets across streams; to catch land snakes, she set plastic buckets called pitfall traps in the ground. Drawn by bait, snakes would fall into the trap and not be able to escape. Jackson killed the snakes she found and then photographed them before preserving them in formalin. After returning to the United States, she sent her specimens to the herpetology department at the Smithsonian Institution, where they have been cataloged, identified, and made available for study. Among her finds were two deadly cobras, each more than six feet (1.8 m) long.

Jackson is also working with the Congolese National Laboratory of Public Health to reduce deaths from snakebite, a significant problem in the heavily forested Congo, where many people go barefoot. Highly venomous snakes that dwell in the Congo basin include horned vipers, cobras, and black and green mambas. Even the rivers have water cobras. Not surprisingly, the Congolese are deathly afraid of snakebite.

CONSTANT FLOW

Vast as it is in size, the Congo's basin is a far distant second to that of its cousin river, the Amazon, and about half the latter's size. The *flow rate* of the Congo is also much less than that of the Amazon. Whereas the Amazon's rate of flow at its mouth exceeds 6.18 million cubic feet (174,998 m^3) per second, the Congo discharges at a diminished rate of only 1.45 million cubic feet (41,000 m^3) per second. Unlike the Amazon, the Congo is almost entirely rain-fed and receives no significant snowmelt from the mountains.

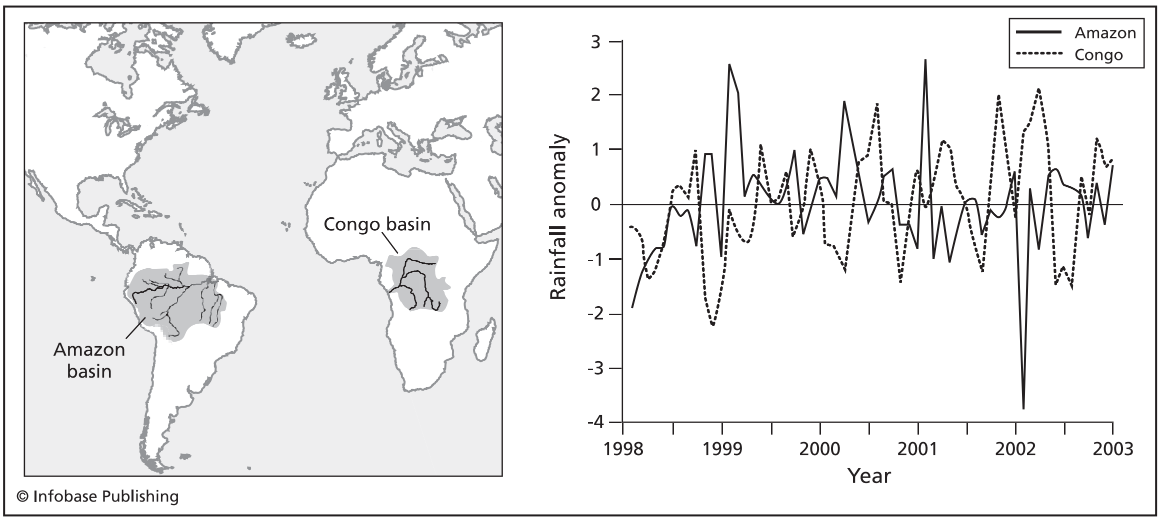
In contrast to the Amazon and indeed most major rivers, which see drastic shifts in water level depending on the season, the Congo moves predictably downstream day in and day out. Particularly heavy downpours may raise the river level slightly, just as an extended drought may lower the river, but these are relatively insignificant occurrences. Even if flooding affects one or more tributaries, by the time the river's waters join together, the difference is barely noticeable. Overall, the Congo's main stem does not dry up, and it does not flood. What accounts for the uniformity of its flow?

The answer has to do both with equatorial climate and with the geographical expanse of the Congo basin. Because the river drains from such a broad area, its tributaries span both sides of the equator. This hydrological idiosyncrasy creates a climatologic split among the tributaries: Winter affects rivers north of the equator when summer comes to those south of it and vice versa. Consequently, torrential downpours that drench one side of the equator are balanced by the onset of dry season on the other. The Congo's height varies by at most 13 feet (4 m), a far cry from the Amazon, which may see its waters rise by as much as 43 feet (13 m) in the summer.

Malebo Pool is at its lowest level in July, after drought in the southern end of the basin has persisted for several months and the floodwaters from the north have yet to arrive. Overall, however, the Congo basin is so vast that no one climatic event is likely to have a major impact on the river's height or rate of flow.

IN THE FIELD: SEESAW RELATIONSHIP

The Congo and the Amazon Rivers (and their respective watersheds) have long been known to be great repositories of biological wealth and major players in the global water cycle. They are also key contributors



The Congo and Amazon Rivers, both of which discharge into the Atlantic Ocean, participate in a climatic tug-of-war. Rainfall data indicate that when one basin is dry, the other is wet, and vice versa.

TORTURED HISTORY

For almost 150 years, Congo has lived through sequential miseries, from brutal colonial overseers to corrupt and inept officials. The country has yet to recover from the reign of Belgium's King Leopold, who in 1884 declared himself King Sovereign of the Congo, after bribing hundreds of tribal leaders for their land. He ruled the country until 1908, when an international outcry over his mercenary exploitation forced him to step down.

At that time, many people were optimistic about the country's future. Shortly after Leopold's departure, the British author J. Howard Reed wrote that "the work of the explorer, the trader and the missionary is already beginning to bear fruit. In their wake will follow civilization, commerce and Christianity. Cities—centers of industry and light—will be founded, and in due time the peoples of the 'Heart of Africa' will take their place in the progress of the world."

Such hopeful sentiments have yet to come true. In 1960, the Belgians abruptly gave the country back to the Congolese, ushering in a new era of political instability and civil unrest. Soon after, Mobutu Sese Seko assumed the presidency. A corrupt, brutal dictator, he quickly plundered the country of its wealth, plummeting Congo once again into dark, barbarous times. Although his regime was toppled in 1997, the country remains mired in bloodshed and turmoil. As John Donnelly, a *Boston Globe* reporter, aptly put it, "Few places have experienced such nonstop hell."

to the Earth's climate (they exchange vast amounts of gases and water vapor with the atmosphere). Now it appears that the two rivers participate in a climatic tug-of-war: When the Congo basin is dry, the Amazon basin is wet, and vice versa.

With the help of the Tropical Rainfall Measuring Mission, a research satellite first launched in 1997, scientists at the Massachusetts Institute of Technology have compiled extensive data on rainfall and river flow in the Southern Hemisphere. Their research has revealed an interesting link between the world's two largest equatorial rivers. It seems that floods in the Amazon basin tend to coincide with droughts in the Congo and vice versa, with most activity taking place during the Southern Hemisphere summer.

In the past, measurements of rainfall have been made using raingauge networks set at various locations, but sampling such vast and densely forested regions as the Amazon and Congo posed huge logistical nightmares and so few data were obtained. With satellite tracking, accurate estimates of rainfall distribution over tropical regions are now commonplace.

Aside from being inherently interesting, the link in precipitation patterns between the Amazon and the Congo has implications for global climate. Both rivers are the primary contributors of water to the Atlantic Ocean, capable of influencing salinity levels, evaporation rates, and oce-

Children wander the banks of the Congo River near Kisangani, where the rapids make for good fishing, a vital activity in the region. *(AFP/Getty)*

anic currents. Although the Amazon pours almost three times as much water each year into the ocean—about 1,511 cubic miles (6,300 km^3) a year—as does the Congo, which discharges 300 cubic miles (1,250 km^3) annually, the combined total is almost 2,000 cubic miles (8,336 km^3), an undeniably large amount.

FUTURE OF THE CONGO

The Congo River is widely viewed as holding the key to Congo's economic future and indeed to that of the entire African interior. Within the river's vast basin lies a cornucopia of natural resources, from exotic woods to gold, diamonds, and copper. Only when these and other goods can be reliably shipped up and down the river will this country, as well as its neighbors, have a shot at prosperity.

One proposal calls for building a railroad bridge from Kinshasa to Brazzaville so that at least Congo can benefit from the Republic of the Congo's railway connection to the coast. But the Congolese oppose

DEADLY VIRUS

The Ebola virus, which first emerged in Congo in 1976, is named for the Ebola River, one of the Congo's main tributaries. Among the most deadly of all known viruses, Ebola kills from 50 to 90 percent of its victims, inducing high fever accompanied by internal bleeding. Because the virus also interferes with a person's immune system, causing it to shut down, death can occur relatively quickly. The disease, which is transmitted from human to human, exists only in Africa but—if conditions were right—could easily spread worldwide.

the move, not wanting to depend economically on the Republic of the Congo's port city of Pointe-Noire, which is connected by rail to Brazzaville. Instead, the Congolese are asking the international community for funds to build a harbor at Banana and pay for regular dredging of the Congo as far upstream as Matadi, so that seagoing vessels can deliver goods directly to Congo. Meanwhile, civil unrest and guerrilla violence continue to undermine progress.

At the same time, the river has benefited from the lack of development. Its waters remain largely untainted, free from chemical pollution and industrial effluents, in stark contrast to such intensely polluted waterways as the Yangtze and lower Amur. But population growth, should it continue at its current rate, will likely put severe pressure on the river. Some 100 million people live in the basin (half of them in Congo), and most depend heavily on the forested basin for both food and energy. Yet a high birth rate means a rapidly increasing population, which will put great stress on the Congo's fragile ecosystem. Not only will more forest be cut for fuel and for housing, which will mean more erosion and more sediments washing into the river, but many of the river's fish may be overfished to the point of extinction.

Illegal logging, the poaching of endangered species, and the emergence of such potentially devastating diseases as the Ebola virus also represent dire threats to the region's ecological integrity. Rates of deforestation are accelerating, attributable in part to the growing population's need for firewood and farmland and in part to the world demand for tropical hardwoods. According to the U.N. Food and Agriculture Organization, some 2.3 million acres (934,000 ha) of pristine forest are cut each year. Over a 10-year period (from 1990 to 2000) some 20 million acres (8.3 million ha) of forest were lost in the Congo basin. Whether the sub-Saharan Africa will find a more sustainable path to development remains to be seen.

9

The Amur River

Asia

Surely there isn't anyone who could contemplate the majestic Amur River with indifference.

—V. Kuranov, 1980

Known in Chinese as the Black Dragon River, the Amur proper flows in a great S bend for 1,790 miles (2,881 km) to its *discharge* in the Strait of Tatar, which connects the Sea of Japan with the Sea of Okhotsk. If its longest *tributary*, the Shilka River, is added, the Amur River system extends for 2,744 miles (4,416 km), well deserving of its place on the list of the world's 10 longest rivers.

The *headwaters* of the Amur arise in the Mongolia and from there generally flow in a southeasterly direction to the Russian city of Khabarovsk. For most of this distance, the river forms the border between China and Russia and is closely shadowed by the Trans-Siberian Railroad. About 200 miles (322 km) from the Pacific coast, at the city of Kabarovsk, the Amur curves abruptly to the north and heads for the Strait of Tatar, where it discharges into the sea.

The Amur and its tributaries drain a sizable area. The river system's *basin* covers some 716,606 square miles (1,856,000 km^2). Russian geographers refer to the region bounded by the Amur River to the south, the Pacific Ocean to the east, and the Stanovoy Mountains to the west as the "Far East." This region is so vast that it encompasses five time zones. Winding its way across Asia—from the mountains of northeastern China to the Sea of Okhotsk—the Amur passes through a succession of rich ecosystems that range from *tundra* and *taiga* to *deciduous forest* and rich grasslands. Along its banks and in its waters live numerous unique species, including the endangered Siberian crane and a human-size fish called a *taimen*.

Over many centuries, the Amur has served as a cultural highway, providing transportation for people and goods moving back and forth from coastal regions to the rich forests and farmland of the interior. Virtually the entire river is navigable (except in winter when it freezes as shown in the color insert on page C-8 [top]), and even today the Amur remains the largest undammed river in the world. With rich soil filling its *floodplains,* settlers have been drawn to the Amur valley, particularly in its middle and lower reaches, for thousands of years. As long ago as the 17th century, this region was densely populated, and it remains so today.

Forming a 1,000-mile (1,609-km) border between Russia and China, the Amur has played an important role in Chinese-Russian relations, with tensions periodically erupting over such issues as pollution, irrigation rights, and hydroelectric development. Simon Winchester captured the tension in the February 2000 issue of *National Geographic:* "The Amur, or Black Dragon, is in short—and for perhaps not the very best of political reasons—a river whose time has come. A river to be watched, and watched with care." At the same time, however, the river has forced the two countries to work toward political and economic cooperation in the region, and limited strides are being made in that direction.

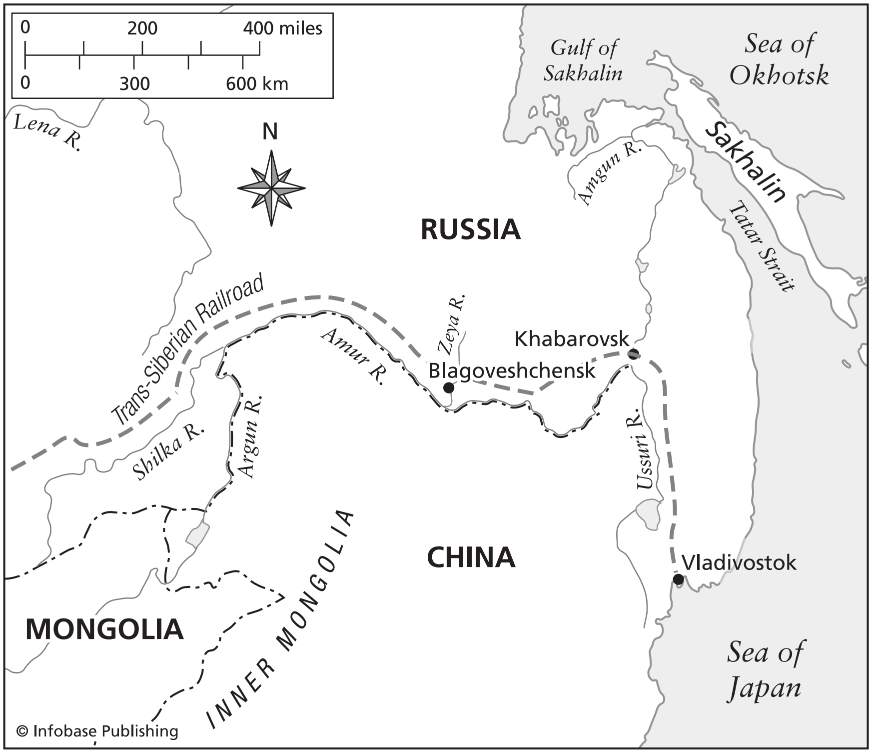
DRAGON-SHAPED WATERWAY

The curvaceous path of the Amur as it winds through eastern Asia resembles the outline of a fiery dragon, hence the origin of its Chinese name, Heilong Jiang. And like a dragon with a head, body, and tail, the Amur can be divided into three parts based on the structure of its valley, *bed,* and flow characteristics. But as is true for most tributary-rich rivers, the ultimate origins of the Amur are difficult to discern. The river's major tributaries descend from steep mountain ranges, where they in turn are fed by increasingly smaller tributaries.

Upper Amur

Two major tributaries come together to form the Amur: the Shilka, which descends from Siberia, and the Argun, which arises in Inner Mongolia. The Argun is the longer of the two tributaries, though its ultimate source—which has been traced to a mountainous region in southeastern Siberia—has yet to be pinpointed. From the junction of the Shilka and Argun Rivers, the Upper Amur curves southward out of the mountainous taiga and the *permafrost* into a region of deciduous forest. This stretch of the river, which ends in the city of Blagoveshchensk, runs a total of 549 miles (883 km).

Cascading downward, the Amur is a stormy and unruly river. Capped with froth and propelled by a steep incline, it cuts its way through the lichen-covered rocks of the Khingan Mountains. On emerging from the mountains through a valley surrounded by thick larch woods, the Amur continues its wild trajectory but is slowed by the flatter topography. Terraces along the riverbed tell of a long history, with the river carving its path seaward over a period of several million years. Farther downstream, the river cuts through



The curvaceous Amur River forms a long border between Russia and China before turning north into Russia and discharging into the Tatar Strait. From its farthest tributary to the sea, the river runs 2,744 miles (4,416 km).

unusual *shale* deposits that spontaneously ignite, bursting into flames. Such spontaneous combustion occurs in summer when the rocks absorb heat and undergo a sharp rise in temperature. Any air that leaks through cracks in the rock provides oxygen, allowing the rocks to ignite; naturally occurring crude oil present in the shale fuels the fire.

Passing through grassy *steppe*, the Amur becomes a classic example of a *braided stream*, forming several channels that intermittently flow separately and then coalesce. The landscape here is harsh, with few inhabitants, and winters are both long and cold. With January temperatures averaging –27°F (-33°C), exhaled breath turns immediately to ice, the crystals of which explode with a light snap.

Groundwater occasionally bubbles through cracks in the Earth's surface during winter. Although liquid when it arrives, the water instantly freezes and—in a process analogous to the creation of icicles—forms a large protruding cone of ice. These frozen cones may persist into July, looking like witches' hats amid the grass.

Middle Amur

The midsection of the Amur extends for 606 miles (975 km) and begins near Blagoveshchensk. Blagoveshchensk, which straddles the border between Russia and China, is the principal city of the Amur region. Here the Amur receives its major tributary, the Zeya River, which enters from the northwest. The Amur, though still relatively narrow, expands in breadth at this point, with the average distance between its banks stretching to almost one mile (1.5 km).

From Blagoveshchensk, the Amur flows through a narrow pass in the Malyy Khingan Mountains. As it churns through this rocky bottleneck, the river turns deep and treacherous. Like water from a high-pressure hose, its waters shoot from the pass into the valley, where the Amur is joined by yet another tributary, the Bureya, which descends from the north. By the time the river reaches the city of Khabarovsk, its width has broadened to two miles (3 km), and the river enters its lower reaches.

To the north of the Amur, in the valleys of its left tributaries, the Zeya and Bureya, extends a large fertile *plain* characterized by its black soil, which is rich in organic matter. With its mild summers and adequate rainfall, this region contrasts starkly with the harsh conditions found elsewhere in Siberia. The *floodplain*'s rich soil yields good crops of wheat and other grains, as well as fruits and watermelons that grow well in the warm climate.

The city of Svobodny, which sits on the right bank of the Zeya River, has become a bustling regional center. Goods brought to Svobodny via the Trans-Siberian Railroad are transferred to river vessels here and vice versa. With its agricultural wealth and easy access to transportation, the region is more densely populated than any other stretch along the Amur.

Lower Amur

At the city of Khabarovsk, the Amur is joined on its right bank by its tributary, the Ussuri River, which flows north from China. From here the lower Amur flows for 600 miles (966 km) to its *estuary*. Although heavily traveled by all manner of boats and freighters, the river is by no means tame on its final run to the sea. A former boat captain who steered boats from Khabarovsk to the Okhotsk for many years describes the lower Amur as "a most difficult, dangerous river; a stormy and uneasy stream, feared and loathed by most of us."

As it heads seaward, the Amur encounters a changing landscape. The river turns northward and runs parallel to the coast, at a distance of only 200 miles (322 km) from the Sea of Japan. Here ocean breezes warm the land, which is more temperate than boreal. C*oniferous forests* give way to deciduous ones, with firs and spruces replaced by oak, maple, and ash. Bears and tigers roam the trees and tall grasses. In summer, *monsoon* winds bring balmy temperatures along with torrential rains that drench the river with warm water. Even here, however, winter refuses to relinquish its icy grip. In November, cold descends on the area, causing temperatures to plummet as low as –58°F (–50°C) by January.

In this region, the river's valley is flat and muddy, with many islands and *sandbars* interspersed amid marshland. When the river floods, as it tends to do in the spring, the region transforms into an enormous lake. Approaching the sea, the Amur passes once more through mountainous terrain and then onto a low plain, where it is joined by its last tributary, the Amgun River. Boosted by water from the Amgun, the Amur chugs with dispatch to the sea. At its mouth, the Amur forms a sizable estuary that is 30 miles (48 km) long and 10 miles (16 km) wide.

Flowing about 30 miles (50 km) across its estuary, the Amur discharges into the Tatar Strait opposite the large island of Sakhalin in the Okhotsk Sea. The Tatar Strait is a narrow passage in the northwest Pacific Ocean that connects the Sea of Japan to the south with the Okhotsk Sea to the north. Looking much like a winebottle on its side, the *strait* is long: 393 miles (632 km) and also narrow. Although its southern end reaches a maximum width of 200 miles (322 km), the strait narrows drastically at its northern end, forming a neck that is only 4.6 miles (7 km) wide.

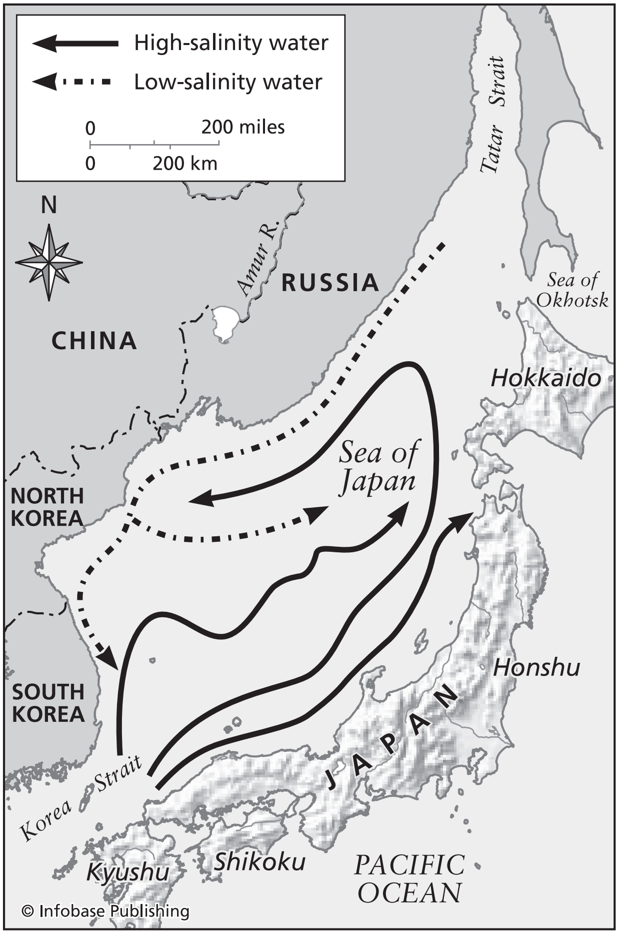
The river's mean annual *discharge* at its *mouth* is about 385,000 cubic feet (10,900 m^3) per second. The rate of flow varies tremendously depending on the season, with measurements as low as 5,300 cubic feet (150 m^3) per second in winter to 1,400,000 cubic feet (40,000 m^3) per second at the height of flooding. Water levels are affected both by spring and fall flooding, which raises the river by as much as 33 to 36 feet (10 to 11 m) in the upper and middle reaches and about 10 feet (3 m) near the estuary. Monsoon rains are the primary contributor to flooding, with prolific downpours that generally raise river levels occurring from May to October. Floodwaters subside sometime after September, and the river reaches its lowest levels in March or April. A small spike in discharge is seen in the early spring, when snowmelt enters the river, but not nearly to the degree caused by monsoon rains.

IN THE FIELD: DECIPHERING ANCIENT ENVIRONMENTS

Unlike the Ob' basin, which has extensive *peat* bogs, the Amur basin has accumulated little peat. Apart from the ecological impact such moisture-rich deposits provide, peat enables scientists to identify ancient plant pollens that are preserved throughout the peat and, on this basis, reconstruct past environments. The study of pollen in this way is known as *palynology*.

Until recently, without an extensive palynological record, not much was known about the paleoclimate of the Amur basin. Then, in 2004, a team of

IMPACT ON OCEANIC CIRCULATION



The Amur influences circulation in the Sea of Japan. Freshwater from the river sweeps into the Tatar Strait, where it mixes with the saltier waters of the Okhotsk Sea and then flows south (dashed lines.) At the same time, salt water from the Sea of Japan flows north (solid line), creating a counterclockwise current.

Like all rivers, the Amur discharges freshwater into a saline ocean environment. Hydrologists from Kyūshū University in Japan have studied the impact of the Amur deluge on circulation in the Japan Sea, or on what they call the Japan/East Sea Intermediate Water and the Japan Sea Proper Water. Unlike rivers that discharge directly into the ocean, the Amur first sends its freshwater into the low salinity waters of the Tatar Strait, where it becomes part of a grand circulatory pattern involving the Japan Sea to the south and the Sea of Okhotsk to the north.

Fresh waters from the Amur and saline waters from the Okhotsk Sea mix in the strait. The waters of the Amur move south at an average rate of 38,846 cubic feet (1,100 m^3) per second, while the salty waters of the Okhotsk flow south along the western edge of the strait at a rate of 52,972 cubic feet (1,500 m^3) per second. At the same time, the saltier waters of the Japan Sea move north along the eastern edge of the strait at an average rate of 31,783 cubic feet (900 m^3) per second.

The fresh waters of the Amur and the Okhotsk Sea undergo strong tidal mixing when the waters of the Okhotsk surge through the northern end of the Tatar Strait. The combined waters, which are dominated by the Amur's discharge, then move with the coastal current down the Russian coast, dramatically reducing levels of salinity along its path. In addition, waters from the Tatar Strait, which are lighter than salt water, generally stay near the surface, preventing deep convection at the northern end of the Sea of Japan.

scientists from the Russian Academy of Sciences reported finding a small peat bog in the lower Amur basin near the mouth of the Gur River, which joins the Amur's left bank just west of Khaboravosk. The team dug a pit 11 feet, or 134 inches (340 cm), deep and extracted 70 samples for pollen analysis at set intervals along the pit wall; they also removed 13 samples for dating. Pollen grains were extracted from the peat, identified under a microscope, and counted. The age of the sediments at various vertical intervals was then determined using carbon-14 dating techniques. For the first time, an accurate portrait of environmental changes in the region over the past 13,000 years was available.

The scientists identified several key paleoclimatic shifts that correlated with known global cooling and warming episodes. They determined that during the most recent glacial time period, around 12,000 years ago, the main vegetation in the vicinity of the Gursky peat bog was birch-alder forest, with some conifers. Then 2,400 years later—around 9,600 years ago—a marked warming occurred. For the next several thousand years, elm trees dominated the landscape; birch was the second most populous species. The Earth then cooled, and vegetation in the lower Amur basin once again shifted, this time seeing a sharp increase in Korean pine and the transition to a mixed coniferous-deciduous forest.

MAJOR TRANSPORTATION ROUTE

Unlike many rivers, the Amur is navigable along its entire length. Freighters and steamships, many of them operated by the Amur Shipping Company, ply its waters nine months a year. During the summer months the crowded river resembles an interstate highway. In winter, when the river freezes to a depth of six feet (1.8 m), the river is still busy. Trucks drive on its surface, turning the waterway into an ice road. (See “Navigating Frozen Rivers” in chapter 10.)

With economic ties between China and Russia increasing, traffic on the Amur now moves sideways as well, with boats regularly crossing the river channel. Despite its great length, the Amur is only bridged twice in its nearly 2,800 miles. Instead, ferries move back and forth between China and Russia in a frequent exchange of goods and people. In winter, people walk across the river; crossings by bus are also popular.

In addition, the river’s verdant shores attract thousands of summer residents who come to *dachas*, or summer cottages, they have constructed there. Many launch pleasure boats from the shore.

UNUSUAL ECOSYSTEM

The Amur River flows through a richly diverse ecosystem. In terms of biological diversity, its *watershed* ranks second highest among rivers in the Northern Hemisphere, topped only by the Mississippi. A rare blending of plants and animals occurs here, with northern species intermingling with southern ones. Northern pines grow amid liana vines, for example, and elk roam the same lands as the Mongolian tiger and Amur leopard.

The river itself is inhabited by more than 100 species of fish, including salmon, sturgeon, and carp. Fishing is an important source of sustenance for the many people who live along the river’s lower stretches.

INDIGENOUS PEOPLES OF THE AMUR

At least seven distinct groups inhabit the Amur region of the Far East, representing a mixture of Russian and Chinese lineages. During the 17th century, the Chinese wielded sovereignty over the entire Amur basin, but when Russian fur traders became the predominant settlers north of the river, the Chinese ceded these lands, as well as those east of the Ussuri River, to Russia in 1858 and 1860. Blagoveshchensk was founded and named the first capital of the Russian Far East.

Several indigenous tribes still dwell along the Amur River in Russia's Far East. The river has loomed large in the cultures of these groups. Even today many of them rely on the Amur for food and income. These groups include the largest group, the Nanai, who live near Khabarovsk and number just under 11,000, according to Russia's 2002 census. Other minority peoples include the Evenki, with 4,500 people; the Ulchi with 2,700; and the Nivchi with about 2,500.

Throughout much of their history, the various groups have interacted with one another, exchanging ideas and materials over the centuries. And though they still share similar economies, cultures, and beliefs, the tribes have retained distinct identities and languages. Many of the Nanai, have developed a culture that depends heavily on fish. Their ancestors once made clothes from fish skins; today the Nanai still make their shoes from fish and produce glue from fish skulls. The Evenki continue to breed reindeer, although they have given up their nomadic lifestyle for sedentary village life.

In 2005, the livelihoods of these indigenous groups were severely jeopardized by a Chinese chemical plant explosion that released 100 tons of highly toxic benzene into an Amur tributary. The Khabarovsk government declared that all trading in fish would be banned for at least a year. Repeated incidents of this type—should they occur—will likely destroy the cultures of these river-dependent tribes.

IN THE FIELD: EVIDENCE FOR ANCIENT AMUR VALLEY CIVILIZATIONS

In the early 1960s, East Asia was discovered to have the oldest known pottery in the world, when shards dating back to the end of the Pleistocene Era, some 12,000 to 14,000 years ago, turned up at sites in Japan, southern China, and the Russian Far East. Recently, archaeologists from the Russian Academy of Sciences, the University of Arizona, and Seoul National University have unearthed pottery remains from archaeological sites in the Amur River basin. Using carbon-dating techniques, they determined that the ancient pottery found there was made 13,000 years ago. These results suggest that Neolithic communities were more widespread and older than archaeologists previously believed.

At the same time, a second team of Sino-Russian archaeologists studying settlements along the Amur found evidence that humans migrating from Asia to America may have traveled through the Amur valley on their way north. The team unearthed Neolithic relics from a site near the city of Khabarovsk dating back some 1,900 to 9,000 years ago. The cache was surprisingly sophisticated and included more than 300 stoneware and earthenware pieces as well as hunting and fishing tools. The fact that such ancient people were fairly advanced at about the same time the Bering land link formed between Asia and North America led the archaeologists to conclude that some of these people may have been among the first to cross the Bering Strait.

GROWING PROBLEM OF POLLUTION

Vast quantities of pollution wash into the river from northern China. On an economic fast track, this region has seen a rapid proliferation of factories. In addition, China's Daqing oil field, which is the world's fourth-largest oil field, lies only a few hundred kilometers from the river.

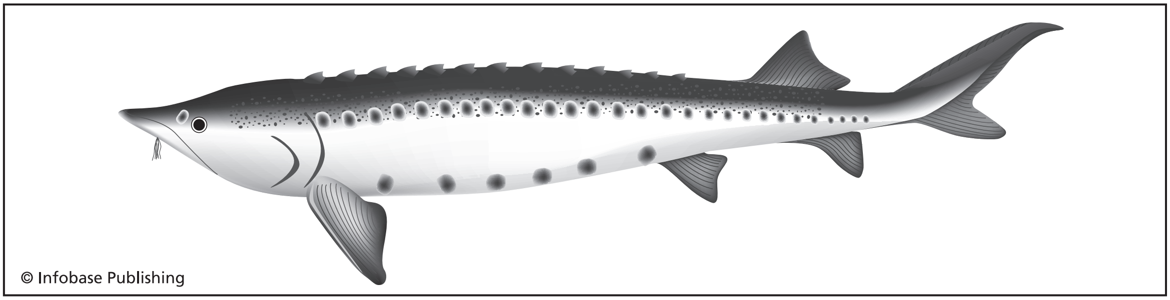
The Ussari tributary, which flows north from China into the Amur, brings with it an abundance of filth that has transformed the lower reaches of the formerly pristine Amur into a dirty river. In the words of journalist and best-selling author Simon Winchester, "The Amur is a river that begins mighty pretty, but one that becomes pretty mighty and ends downright ugly."

In 2004, a coalition of Russian and Chinese scientists, recognizing the seriousness of the situation, announced that the Amur River will turn dead in 20 years if urgent measures to stop contamination and start restoration work are not introduced soon. Unfortunately, the group has no

THE BAIKAL-AMUR RAIL LINE

In the 1930s, the Soviet government introduced a plan for the economic development of eastern Siberia. The plan included extending the Trans-Siberian Railroad from Lake Baikal to the Amur River. Work began on the eastern end at Lomsomolsk-on-the-Amur, and track was laid to Sovetskaya Gavan', a port on the coast of the Tatar Straits. Construction was interrupted by the assault of Hitler's armies on the Soviet Union but resumed in 1943 after the German army was defeated. More than 90,000 men went to work building the railroad. The intensity of the construction effort is described in this passage on the history of the Trans-Siberian express:

> Night and day, the work went on uninterrupted through frosts reaching –50° and through summer heat reaching 30° Celsius. It is hard to adequately describe the difficulties encountered on the Far Eastern section of the Baikal-Amur Line. People cut passages through chains of mountains with sledgehammers and pick hammers; they erected bridges standing in icy water; they laid down the railroad bed after felling innumerable trees with ordinary handsaws. Thus were 275 kilometers of the rail line completed.



Kaluga, a species of fish unique to the Amur, reach gigantic size. Adults measure 18 feet (5.6 m) long and may live for 80 years.

regulatory authority . . . and so dumping of toxic wastes into the river system continues unabated.

STORY OF STURGEON

The Amur River is home to more than 120 species of fish. Among them are four species belonging to the Acipenseridae, or sturgeon, family, two of which are found only in the Amur: the kaluga (*Huso dauricus*) and the Amur sturgeon (*Acipenser schrenckii*). The kaluga is a monstrous fish, the largest in the Amur, reaching more than 18 feet (5.6 m) in length and weighing a whopping 2,205 pounds (1,000 kg). Left alone, it can live for 80 years. Tribal fishermen are said to have baited their hooks with dead dogs to catch the giants.

The smaller sturgeon, by contrast, achieves a maximum length of about 10 feet (3 m) and a weight of 420 pounds (190 kg). No sturgeon is known to have lived more than 60 years. Both the kaluga and the sturgeon inhabit the Amur basin from the estuary to its upper reaches, living not only in the Amur proper but in several large tributaries.

Rampant overfishing severely threatens both species. Widely prized for both their meat and their roe, or caviar, the two fishes have been the focus of commercial fishing for more than 100 years. In 1891, 656 tons (595 metric tons) of kaluga and 670 tons (607 metric tons) of sturgeon were caught in the Amur River, an amount equal to almost half of the total fish haul from the river that year. But such high harvests could not be sustained for long.

By 1909, the numbers had plummeted. The catch of kaluga had fallen by more than two-thirds and the sturgeon by four-fifths. By 1948, the catch of kaluga was one-tenth the 1891 level and the sturgeon a mere hundredth of its former level. In 1958, the then-Soviet authorities banned fishing of both species. The ban remains in effect, and both species are on the International Union of Conservation of Nature and Natural Resources' (IUCN) so-called red list of threatened species.

Since the fall of the Soviet Union in 1991 and the decline of totalitarianism, poaching in the Amur River has increased to horrific levels. Fishermen no longer catch fish just to feed their families but also to sell on the open market. Moreover, on the lower Amur, organized groups have joined individual fishermen in sophisticated and extensive illegal fishing activities.

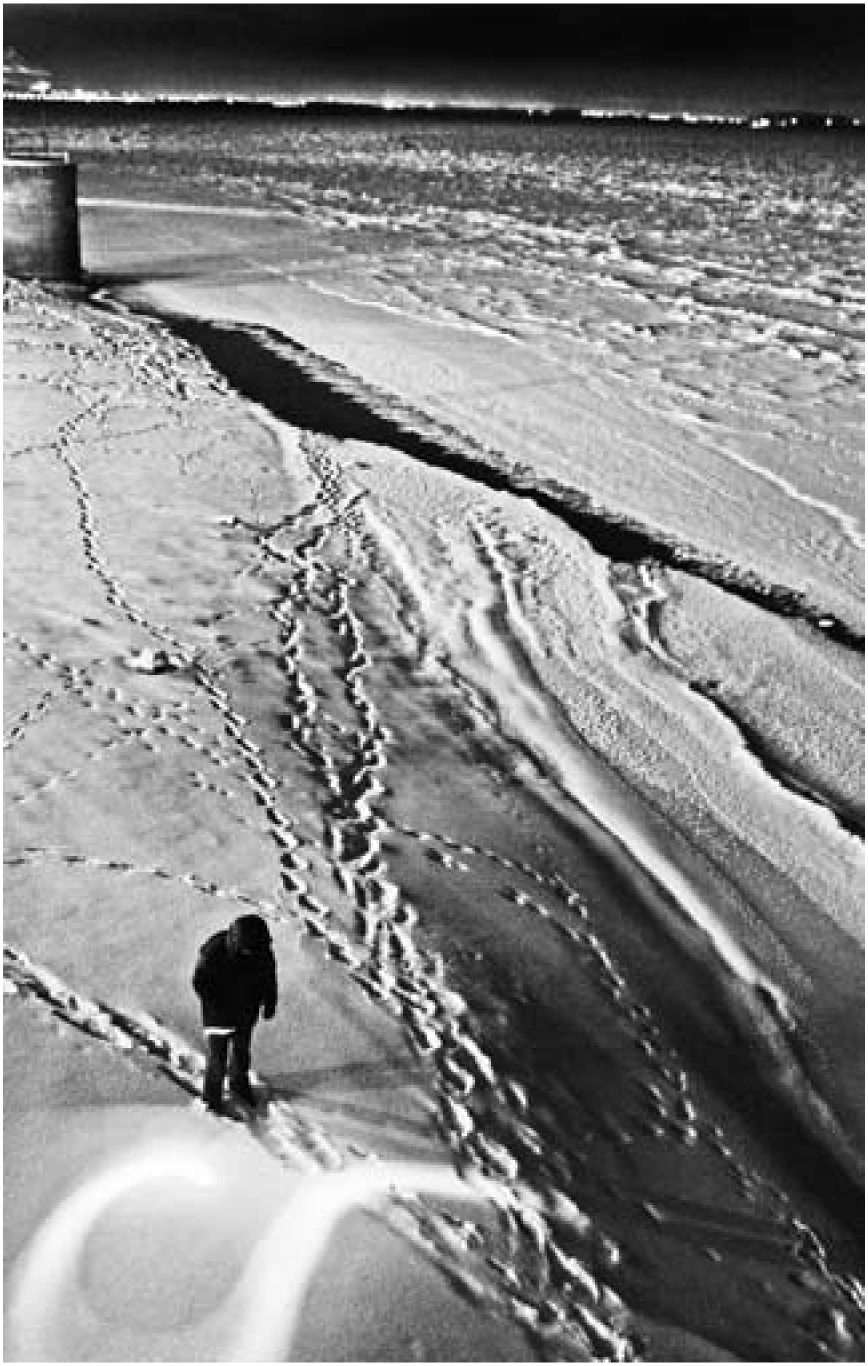
One government bureau, the Amur Fish Authority (AFA), is attempting to battle the poachers, but its efforts at law enforcement are largely ineffectual. In 2003, for example, the AFA brought more than 1,000 criminal charges against poachers but followed up on only 26 of them. Sadly, in a world where a single fish can bring more than $1,000, bribery rules.

Exacerbating the problem is the fact that no agreement exists between the Russians and Chinese concerning fishing in the Amur, so international competition enters the picture. To gain a competitive edge over the Chinese, the Russians try to snag as many migratory fish as they can from the lower Amur (which flows only through Russia) before the fish reach China's border. At the same time, the Chinese are contaminating the lower river at a fantastic rate, dumping into its waters heavy metals, oil products, phenols, and other industrial waste. Sometimes the level of toxins is so high, the fish are inedible for months at a time. Biologists fear that if the situation continues the kaluga and sturgeon populations—at least in the river's estuary and lower regions—will soon be decimated, bringing to an end two dazzling species whose origins can be traced back millions of years.

CHALLENGES AHEAD

Large areas of *wetlands* south of the Amur River in China have been seriously threatened in recent years. The marshes have been fragmented and drained, converted to farmland and other uses in response to the rapacious human demand for land and resources. One area of marshland, for example, which covered 49 percent of the plain in the 1950s, today occupies only 13 percent of that territory. Recognizing the potential environmental consequences of such catastrophic loss (which include flooding and species loss), the Chinese government has recently banned agricultural development on the San-chiang (Sanjiang) Plain.

Even so, development encroaches on numerous fronts. A proposed series of dams in the Amur River basin, for example, will likely result in many acres of wetlands lost to reservoirs. In addition, irrigation dams deprive surrounding wetlands of much needed water. Fertilizer runoff and pesticide application further degrade the region's wetlands, and little, if any attempt, has been made to regulate their use. Finally, the intensity of fishing in the Amur tributaries has had a negative impact not only on local populations of fish but also on the cranes, storks, geese, and other waterbirds that feed on those fish.



A man walks along the edge of the frozen Amur River in Khabarovsk, looking for signs of a toxic slick moving downstream from China. River pollution has increased tensions between Russia and China. *(Sergei Grits/AP)*

The Amur leopard, which roams the Amur valley, is a critically endangered species. Less than 30 adults survive on the river's Russian side; in China, they are already extinct. *(AbleStock)*

Thus the Amur, pristine in its upper reaches, despoiled in its lower ones, joins other rivers, such as the Yangtze, that have suffered from rampant economic development and human population growth. Whether the Amur suffers the same fate as the Yangtze—too polluted to support much biological life—remains to be seen. Flowing as it does between two countries, each of which is undergoing unprecedented industrial expansion, surely clouds the future.

10

The Mackenzie River

North America

At length, however, the agitation of the water was so great, that a wave striking on the bow of the canoe broke the line, and filled us with inexpressible dismay, as it appeared impossible that the vessel could escape from being dashed to pieces, and those who were in her from perishing.

—Alexander Mackenzie, 1801

The Mackenzie, North America's grand river to the Arctic, is exceeded in length on the continent only by the Mississippi-Missouri system. Known in Inuit as Deh Cho, or "Big River," the Mackenzie cuts a diagonal across Canada's Northwest Territories. From its headwaters to the edge of the Arctic Ocean, the river flows some 2,635 miles (4,241 km). With an average *discharge* of 264,860 cubic feet per second (7,000 m^3/s), the Mackenzie has a relatively low flow, but the river still delivers more freshwater to the Arctic Ocean than any other North American waterway and ranks fourth largest after the Ob', Yenisey, and Lena Rivers of Siberia.

During the summer, the river's powerful waters churn seaward, passing through lake-strewn northern Canada and transporting both goods and people up- and downstream. During the winter, the Mackenzie is stilled by ice that shutters its channel from November to June. When spring comes, the ice-clogged waterway pours forth with great exuberance: The river overflows its banks and drenches the already sodden land enveloping it.

The climate in the Mackenzie valley matches that of northern Siberia: In winter, perpetual darkness combines with temperatures well below 0°F (–17°C). In summer, biting flies engulf the land. Yet with such bleakness comes an unusual beauty. Few people inhabit this austere place, as shown in the color insert on page C-8 (bottom), so the Mackenzie basin remains sparsely populated—one of the few truly unspoiled places in the world.

FROM BRITISH COLUMBIA TO THE BEAUFORT SEA

The Mackenzie River begins its journey in British Columbia. There, on a ridge west of the Rockies at an elevation of about 7,000 feet (2,135 m), *rivulets* coalesce and cascade downward, widening as they go. Each time this great waterway enters and exits a lake, as it does several times, like a strand of thread moving through one pearl to the next, its name changes. For its first 280 miles (450 km), the river is known as the Finlay, until it discharges into Williston Lake in the southwestern corner of the Yukon Territory.

The water that flows from the lake's east side is called the Peace River. Following a slanted path to the northeast, the stream empties into the great Lake Athabasca in northern Alberta. A second Mackenzie *tributary,* the north-flowing Hay River, also flows into Lake Athabasca. Slave River leaves from Athabasca's opposite shore and heads almost due north to Great Slave Lake, where it becomes the Mackenzie proper.

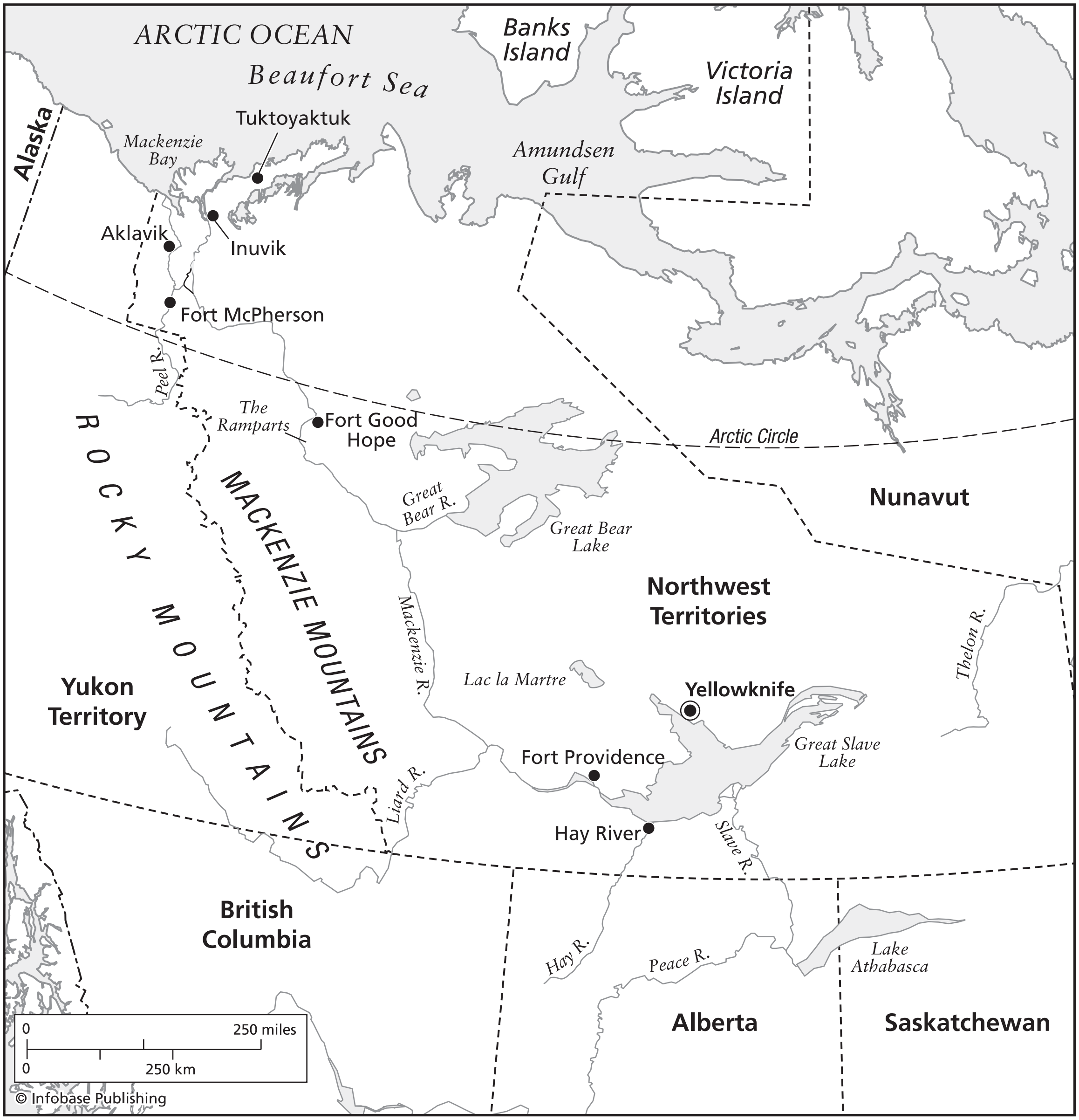
From Great Slave Lake, the Mackenzie begins its 1,025-mile (1,650-km) run to the coast. Along the way, the river divides into an upper section that runs parallel to Canada's snowclad Rocky Mountains and a lower section that passes through lowland *tundra* en route to the Beaufort Sea, an arm of the Arctic Ocean. Throughout much of its length, the Mackenzie remains steadily at one to two miles (1.6 to 3.2 km) wide, though its width increases to three to four miles (4.8 to 6.4 km) in areas where several islands arise within its channel.

Upper Mackenzie

Arising at the relatively low elevation of 512 feet (156 m) above sea level, the Mackenzie drains from the southwestern end of Great Slave Lake. The river moves resolutely across swampland at the lake's edge, spreading wide at its point of discharge. The six-mile- (10-km-) wide channel might be mistaken for a lake inlet except for its steady current and the large island that fills its midsection. Only a few miles downstream, the upper Mackenzie narrows, becoming less than half-a-mile wide near Fort Providence.

The sudden narrowing of the river at Fort Providence creates an ideal crossing point, a channel that is easily breached by ferry in summer and by ice road in winter. Just west of Fort Providence, the river expands yet again, becoming lakelike, before narrowing once more to about a mile wide. Boulders left by retreating glaciers dot the riverbed along this stretch, creating rapids that are navigable only by small boats and flat-bottomed barges.

By the time the Mackenzie reaches Fort Simpson, some 200 miles (322 km) downstream from Great Slave Lake, the river sits only 400 feet (122 m) above sea level. The channel, which flows between steep



The Mackenzie River forms a great slash across northern Canada, traveling some 2,635 miles (4,241 km) from its origins in British Columbia to its ending at the Beaufort Sea.

banks, stays a mile wide for many miles. At Fort Simpson, the Mackenzie is joined by the Liard River, which enters from the southwest. Unlike the crystalline-clear Mackenzie, the Liard carries a high silt load, and so the confluence of the two rivers is a study in contrasts. The muddy waters of the Liard make a dramatic entrance, churning alongside the clear currents of the Mackenzie. So much friction is created by the roiling waters that the rivers remain visibly distinct for almost 300 miles (483 km) before finally intermingling.

Some 100 miles (161 km) beyond Fort Simpson—after a steady westward flow from Great Slave Lake—the Mackenzie turns abruptly to the north. To the left of the river lie the Mackenzie Mountains, foothills to the Rockies, which rise steeply to the west, reaching altitudes of 5,000 to 6,000 feet (1,524 to 1,829 m). Sedimentary rocks from the Cretaceous period some 65 to 100 million years ago form the region's underlying bedrock, over which retreating glaciers have left a thick mixture of sand, clay, and gravel. The Canadian Shield, a vast horseshoe-shaped area of exposed bedrock from the Precambrian Era, lies to the east. As it passes through mostly flat terrain, the Mackenzie chugs steadily and powerfully northward; few obstacles interfere with its flow along this stretch.

Lower Mackenzie

Fort Norman marks the beginning of the river's lower course and its confluence with the Great Bear River, its next-to-last tributary. (A few small

GREAT SLAVE LAKE

Great Slave Lake is the world's 10th-largest freshwater lake, with waters that spread across some 10,980 square miles (28,450 km^2). At the same time, Great Slave fills a deep hole—2,020 feet (615 m)—in the Earth's surface and so earns sixth place on the list of world's deepest lakes. Dimensionally, the lake measures about 298 miles (480 km) long and 62 miles (100 km) wide. Like many lakes strewn across North America, Great Slave Lake is an *ice-scour* lake. The lake was ground from the *bedrock* that forms the *Canadian Shield* during the last Ice Age by a moving ice sheet, or *glacier.* As the boulder-rich sheet moved across the continent, it scoured the rock below, gouging holes in the shield.

Despite its size, the lake freezes easily and remains at least partially frozen for a full eight months a year. During winter, the lake's surface transforms to a thick covering of ice, which grows to a depth of five or six feet (1.5 to 1.8 m) by March—thick enough to support the parade of semi-trailer trucks that routinely cross it in winter.

The lake is named for a group of indigenous, or First Nation, people called the Slavey band, who built their first dwellings along its shores thousands of years ago. They are the ancestors of today's Dene people, who continue to live in the region, many of them earning a living as trappers. The Dene also fish in Great Slave Lake and nearby bodies of freshwater, where the fish populations are plentiful but grow too slowly in the cold climate for commercial harvesting. Caribou, which roam widely across northern Canada, also loom large in the culture of these people, as they do in the lives of the Inuit and other First Nation people who continue to hunt the animals for food and fur.

The city of Yellowknife sits on the lake's northern side, where it serves as the capital of Canada's Northwest Territories. With a population of 20,000, Yellowknife is the only city in the Mackenzie valley and thus the region's primary commercial and transportation center.

rivers descend from the Mackenzie Mountains to the west but contribute little volume to the main river).

The Great Bear River is short: It runs a mere 77 miles (128 km) east from Great Bear Lake to its junction with the Mackenzie. The lake from which the river drains—Great Bear Lake—is not only Canada's largest lake but also the eighth largest in the world. Although Great Bear is not as deep as Great Slave Lake, it has a slightly bigger surface area and a markedly longer coastline with several long, fjord-like indentations. Great Bear, being farther to the north, is also far less populated than Great Slave Lake.

In contrast to the muddy Liard tributary, the Great Bear River fills the Mackenzie with clear, icy water that remains distinct from the murkier flow of the main river for almost 50 miles (80 km). With its girth increased by the large influx of water, the Mackenzie broadens to about four miles (6 km). The river also begins to slow along this stretch, its momentum slackened by a drop in elevation to about 175 feet (53 m) above sea level.

The *boreal forest* changes to tundra as the river continues its northward trajectory. Tall pines are replaced by lichen-covered rocks and straggly vegetation. Sparse trees, bent and haglike, struggle for life. The river passes through a second set of *cataracts* called the Sans Sault Rapids, where the riverbed plunges 20 feet (6 m) within a few miles, enough to add some excitement—but trifling relative to the Congo's cataracts and by no means rough enough to impede boat travel.

Not long after—just before reaching Fort Good Hope—the channel changes dramatically. Perpendicular limestone cliffs rise some 200 feet (650 m) to the sky, clutching the river in a rocky embrace. Called the Ramparts, the cliffs squeeze the channel through a five-mile (8-km) narrowing. The sudden constriction pushes the river seaward, accelerating its rate of flow and deepening its channel. Newly energized, the Mackenzie passes determinedly through boreal forest on its northward trek across a landscape interrupted by countless bogs and small lakes.

When the Mackenzie crosses the Arctic Circle, the river again loses momentum. The river's banks spread, creating a channel that spans from two to three miles (3 to 5 km) in width. Islands—mementos of retreating glaciers—dot the channel along with shifting *sandbars*.

Estuary

The Mackenzie *estuary* begins in earnest about 120 miles (193 km) before the Beaufort coastline, forming a classic *delta* shape that occupies 50 miles (80 km) of shoreline and more than 4,700 square miles (12,173 km^2) of northern Canada. Boreal forest has largely given way to tundra, although the land is not totally without trees. Stunted black spruce grab

Mature, ice-filled mounds called pingos rise from permafrost in the Mackenzie delta. This one stands more than 165 feet (50 m) tall and 1,000 feet (300 m) in diameter. *(AbleStock)*

the thin soil. Not much by loggers' standards, they are still big enough for building small homes and for fueling wood-burning stoves.

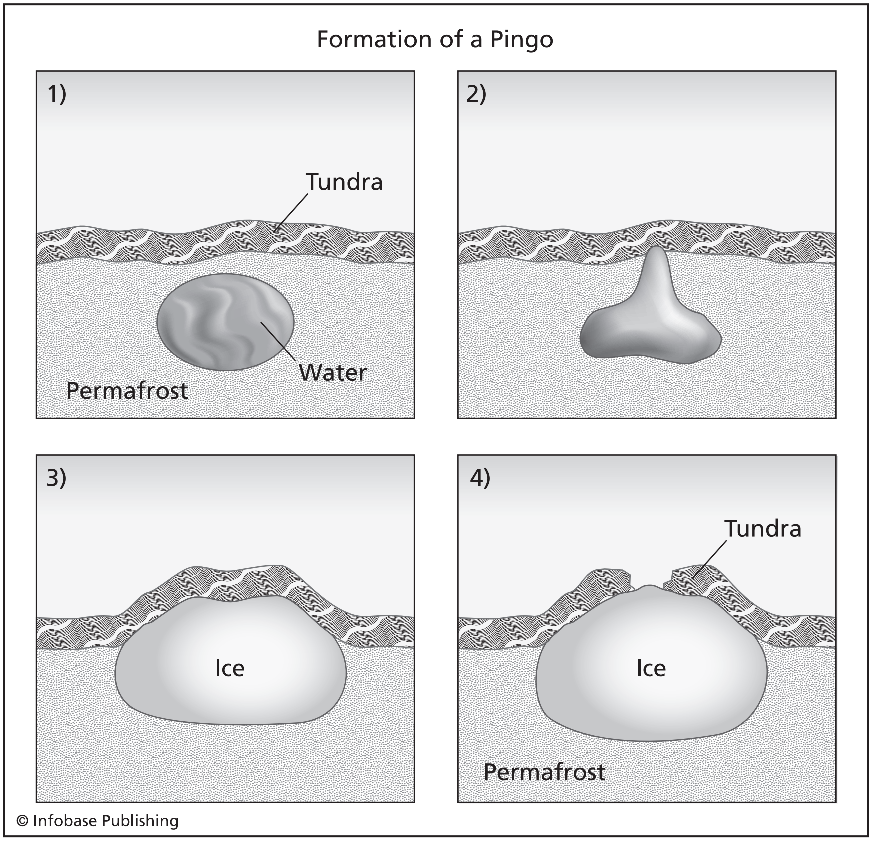
Distinctive mounds called *pingos* rise from the Mackenzie estuary. These mounds, sometimes called ice volcanoes, are conical hills that form when pressure pushes water up through the permafrost. The water freezes, creating an ice core that grows both upward and sideways. Some pingos are enormous, reaching 165 feet (50 m) tall and 100 feet (300 m) in diameter. They are also ancient, the biggest ones exceeding 1,000 years old. More than 1,400 of these distinctive mounds—the greatest concentration in the world—protrude from wetlands near Tuktoyaktuk.

Near the Beaufort Sea, the Mackenzie branches several times, forming a web of interconnected channels, lakes, and bogs. Here the river is joined by its last major tributary, the Peel River, which enters from the southwest. Closing in on the sea, the river splits into three distinct channels, all of which are navigable. The East Channel skirts the village of Inuvik on the delta's eastern edge; Peel Channel flows past the Inuit community called Aklavik to the west; and the Middle Channel, which carries the greatest amount of discharge, heads straight for the Beaufort Sea and the town of Tuktoyaktuk.

Rife with marshes, the Mackenzie delta provides a welcoming summer habitat for migrating birds, including snow geese and tundra swans. Other waterfowl, including geese and loons, come to the region's wetlands to breed. Caribou and moose graze in the area. Grizzly and black bears wander along the lower river. In addition, beluga whales, which prowl the Arctic Ocean, enter the Mackenzie estuary each spring to calve.

TREE-FILLED BASIN

The Mackenzie drainage basin, which is by far Canada's largest, spans some 697,000 square miles (1,805,200 km^2) and covers not only most of the Northwest Territories but also sizable tracts of British Columbia, Alberta, and Saskatchewan. All told, the basin extends from central Alberta in the south to the Beaufort Sea in the north, and from the Rocky



Pingos form slowly over many years. They begin when water drains into the permafrost. (1) The permafrost contracts in summer, pushing the water upward but not through the tundra's root mat. (2) Water continues to flow, turning to ice as it rises and forming a large mound. (3) Eventually, the pingo becomes so big that it breaks the surface. (4) The newly exposed ice melts in summer. Large pingos may be as much as 1,000 years old.

ARCTIC VILLAGES

The Inuit people have occupied the Mackenzie River basin for at least 10,000 years, subsisting almost entirely on the region's natural resources throughout their history. Even today the Inuit have a strong connection to the environment, relying heavily on trapping, fishing, and hunting caribou for their livelihood. Although Inuit villages exist all along the Mackenzie River, only three are situated as far north as the Mackenzie delta.

For many hundreds of years, Aklavik was the northernmost settlement and the only village in the delta. But the town frequently flooded each spring, so in 1955, the Canadian government built a new town, Inuvik, on higher ground to the east. A few hundred residents resisted the move and today remain in Aklavik, living in houses built on tall pilings. They evacuate when the river floods, accepting the inconvenience in exchange for their more traditional lifestyle. In 2006, however, the town was besieged by the worst flood in decades, a disaster most likely linked to global warming, which may devastate arctic regions. Meanwhile, nearby Inuvik has developed into a major transportation hub, with an airport and boat docks that can accommodate cruise ships traveling the length of the Mackenzie. Several thousand Inuit now live there.

A third village, Tuktoyaktuk, sits at the far end of the delta, at the head of the middle channel, where a notch in the coastline creates a natural harbor. The village functions as a switching yard for barges carrying goods to Inuit communities in the high Arctic. Like the Mississippi, the river channel is shallow, so freight must be transported on flat-bottomed barges that are pushed up- and downriver by towboat.

At Tuktoyaktuk, barges are uncoupled from river tugboats and attached to bigger ocean tugs that pull the heavy loads across the Beaufort Sea to Canada's many northern islands. The harbor has a short season, however, only staying open from July until the end of September. During the long winter, airplanes take the place of barges, delivering essential goods to outlying communities.

and Mackenzie mountain ranges in the west to the Canadian Shield, a massive, mostly flat area of the continent to the east.

As one goes from south to north, the vegetation shifts from prairies to boreal forest to tundra. Traveling east to west, flatland dotted with lakes and wetlands extends for hundreds of miles before giving rise to towering mountains that reach heights of 10,000 feet (3,048 m), demarcating the basin's western edge. So many trees pack the Mackenzie valley that each summer 30 or 40 lightning-started forest fires burn at one time, smoldering until they are extinguished by either rain—or more likely—the first snows of fall.

Scattered through the basin are mementos of the previous Ice Age. Among them are three of the world's largest freshwater lakes: Great Bear Lake (the world's eighth largest), Great Slave Lake (the world's 10th largest), and the slightly smaller Lake Athabasca. Beneath the basin's upper layers of soil lie many feet of *permafrost,* which extends as far south as Great Slave Lake but gets thinner at lower latitudes.

This mammoth basin pulls water from almost one-fifth of Canada. Yet unlike the great Amazon and Congo basins, which are drained by thousands of tributaries snaking into virtually every nook and corner, the Mackenzie watershed has a relative paucity of tributaries. Only seven notable rivers discharge into the Mackenzie: the Finlay, Peace, Slave, Hay, Liard, Great Bear, and Peel Rivers. Many of these waterways, especially the Great Bear River, are short, compared with, say, the branches of the Mississippi or Yenisey.

The directional flow of the Mackenzie tributaries reflects the region's glacial past. Near the end of the most recent Ice Age, some 11,000 years ago, meltwater from retreating glaciers streamed across northern Canada. But without valleys or other channels to direct its flow, the water poured across the Earth's surface in a seemingly haphazard way. In some cases—after miles of parallel flow—neighboring streams abruptly parted ways and headed for different drainage basins. The rivers that drain from Lake Wollaston in northern Saskatchewan exemplify this seemingly random pattern, exiting the lake in two different directions. One drainage (the Fond du Lac) heads to Lake Athabasca and from there into the Mackenzie; the other (the Cochrane) empties into the Churchill River system, which then heads northeast to Newfoundland.

The volume of water draining into the Mackenzie basin follows a similarly uneven pattern, with the mountainous subbasins of the west (including those drained by the Liard and Peace Rivers) contributing about 60 percent of the Mackenzie's flow. The subbasins of the interior plains, by contrast, although covering a much larger area, contribute to only about 40 percent of the river's flow.

Water flow in the basin is largely driven in spring by snowmelt (precipitation other than snow is relatively insignificant this far north), and so the Mackenzie is called a *nival* stream. Snow melts throughout the basin and then enters the river system, where it accelerates the thawing of river

TRADING POSTS

In the 18th and 19th centuries, plentiful populations of fur-bearing animals attracted thousands of traders to Canada's vast Northwest Territories. Among the species hunted were muskrat, beaver, lynx, and fox, as well as an occasional polar bear. Forts, which functioned largely as trading posts but also as territorial markers, sprang up along the Mackenzie River.

The first trading post was built on the shores of the Mackenzie in 1796. Over the next 80 years, many more were founded, the majority of them at the *confluence* of tributaries. Some, such as Fort Good Hope and Fort Providence, were given names that expressed optimism in a forlorn land; others, such as Fort Simpson and Fort McPherson, were named in honor of brave men and commanders. The Dene and Inuit peoples brought furs to the posts, where they received tobacco, rifles, and clothing in exchange. Such activities stoked the fortunes of two British companies—the Hudson's Bay Company—and the North West Company—and over time gave the forts a permanence that has kept them in business to the present day.

and lake ice. During this time, water levels rise to their greatest height, with many lakes and rivers overflowing their banks.

UNEXPECTED DISCOVERY

In the late 18th century, at the height of the fur trade in northern Canada, the North West Company desperately needed a shipping route across the Rocky Mountains to the Pacific. The commander of a remote trading post on Lake Athabasca was certain the river he could see draining westward must flow to the Pacific Ocean. Unable (or unwilling) to go himself, he ordered Alexander Mackenzie, a Scottish fur trader and company employee, to head downstream in quest of the Pacific.

On a humid morning in early June 1789, Mackenzie, along with a team of 11 others, dutifully set canoes into the river, swatting swarms of black flies as they climbed aboard. Paddling feverishly downstream to escape the biting insects, they soon reached Great Slave Lake, jubilant to find a drainage river again heading to the west. Convinced they would see the continent's edge in a matter of weeks, they paddled on with great enthusiasm.

A few days later, the explorers' heady spirits dissipated. Without much warning, the river turned and—instead of heading west—began to flow northward. Mile after mile, this unknown waterway resisted curving back toward the Pacific. Each time the river made even the slightest bend westward, the crew's hopes soared, only to be dashed when the river resumed its northerly flow. Soon a chain of seemingly unending mountains appeared along the left bank. Mackenzie pulled his expedition ashore, setting up camp long enough to climb one of the peaks. Hoping to see a distant pass or opening to the west, he saw only endless mountain chains and a river that flowed doggedly north.

The crew persevered downstream, not yet conceding defeat. As they pressed on, they found the days getting inexplicably longer; one day the Sun never set. With a sinking heart, Mackenzie knew their journey downstream had taken them north of the Arctic Circle. A few days later, the group experienced one last insult: A sudden onrush of salty water swept over their camp, soaking them and their belongings. Swamped by high tide, they knew they had reached the ocean. But the icy waves lapping the shore on which they stood were not those of the Pacific but of the Arctic Ocean.

With July drawing to a close and summer growing short, the weary travelers resolutely retraced their path southward, paddling this time against the current. Many weeks later, they reached Lake Athabasca . . . alive though defeated. A frustrated Mackenzie named the waterway Disappointment River. The trip was not in vain, however. Mackenzie kept a journal of his travels and managed to create a detailed chart of the river's path to the Arctic. Years later, the river was named after Alexander Mackenzie, who was knighted by the king of England for his discovery. The mountain range that parallels the river in its upper section also bears his name, as do several other geographic features in the Northwest Territories.

TURNING TO ICE

Like all rivers that flow through high latitudes, the Mackenzie freezes every year. The process, aptly named *freeze up* begins in the fall, when ambient air temperatures plummet. The faster the current, the slower the freezing, and so—like its cousin rivers in Siberia—the Mackenzie freezes slowly. Freeze up, which culminates in the formation of intact surface ice, begins in the river's lower portions and moves progressively upstream. The freezing process from one end of the Mackenzie to the other may take as long as 60 days and occurs in successive stages.

At first, the river simply cools, its temperature forced downward by ambient air temperatures that are now below 32°F (0°C). For a couple of weeks, the turbulent waters resist freezing, and the river flows in a supercooled condition. But eventually the north-flowing waters succumb to winter's grip. Crystals of ice form, sticking to anything they touch. They cling to rocks, to riverbanks, and to each other, creating rafts of floating slush. When the slushy clumps brush into one another they, too, stick together, forming still larger chunks called *ice pans*. The ice pans collide, polishing each other's edges until they look like floating pie pans (hence their name). Day after day, the river channel continues to cool as the surrounding air temperatures drop. If the river bottom becomes cold enough, a thin layer of ice called *anchor ice* forms over it.

Meanwhile, ice accumulates along the riverbanks, growing outward and narrowing the channel. Ice pans become more numerous and enlarge. They stick to one another, glued by viscous water that soon turns to ice. In what becomes an accelerating process, the pans become ensnared in ice forming along the shore, creating large sheets that grow toward mid-channel. Soon the entire channel is covered in ice. Ice continues to build on the underside of the surface layer, and snow settles above it. Freeze up finally occurs when the surface ice forms a continuous sheet across the channel's entire cross section.

The freeze-up date for a river depends in part on local temperatures but also on the streams that feed into it. A river whose main tributaries drain from warmer latitudes in the south is likely to freeze later than a river whose waters come from the north. On this basis, the Mackenzie, which begins at Great Slave Lake in the south, might be expected to freeze later in the year than it does. But the river's warmer waters are dwarfed by icy waters descending from high mountains to the west, and so the waterway begins to freeze in earnest by October and remains icebound for eight months each year.

ICE BREAKUP

In the spring, ice breakup occurs in two ways: The ice melts in place, dissipating into the current, and it also undergoes mechanical breakup, which is often a violent affair (see "Ice Breakup," in chapter 6). Under the warming sun, the top layer of ice thins; at the same time, melting snow and ice pour into the river channel. The current becomes increasingly powerful; pressure created by its swelling waters pushes against the surface, forcing the ice upward and causing it to crack into great chunks. As soon as ice along the shore melts, the large surface sheets have room to shift position and head downstream. Meanwhile, the current, fueled by continuous meltwater, continues to juggle the floating ice chunks, breaking them into pieces called *floes*.

The ice floes move downstream with all the grace of bumper cars. They get stuck around bends, they go aground, and they become snared by fallen logs and other debris. Most notably, they crash into one another, forming massive pileups. The annual ice jam on the Liard River, just before it joins the Mackenzie, may be 12.5 miles (20 km) long and as much as 26 feet (8 m) thick. The noise of floes piling into each other at speeds of 12.5 miles per hour (20 km/hr) is deafening.

Flooding is exacerbated by *ice jams* that clog the river channel, effectively stopping its downstream flow. The economic and social damage caused by these jams and their related floods is enormous, with annual damages averaging $60 million in the Mackenzie valley alone. Some damage is caused by water, which floods low-lying buildings, but most

NAVIGATING FROZEN RIVERS

Rivers that are ice-filled for many months create transportation challenges. Arctic communities have two ways of dealing with their icy waterways. One is to utilize the frozen surface of a river just as one would a paved road. The other is to deploy icebreakers to keep the river channels open for boat traffic. Icebreakers are used extensively in Russia, but they are costly to operate, particularly over a lengthy winter season.

Ice roads are commonplace in northern Canada. From 10 percent to 15 percent of the total volume of goods transported throughout the Mackenzie River valley are carried on ice roads. In winter, cars and trucks drive on the river from Fort Simpson all the way to Fort Good Hope on the edge of the Arctic Circle. Plows regularly clear the ice roads, keeping them free of snow until spring when the ice becomes too thin to traverse safely. Travel is restricted from that point until the waterway becomes entirely ice-free. During open-water season, most goods travel by barge.

is caused by the boulderlike ice chunks that fly about with the force of a wreaking ball, destroying bridges, dams, and low-lying buildings. Such trauma takes a toll on the river channel itself, causing it to shift its course every year, and so the Mackenzie must be carefully re-navigated each spring. Because ice jamming often takes place without much warning, accurate forecasting has become a research priority in the region.

Many variables influence the timing of ice breakup. The number of *melting-degree days* in the month preceding breakup has long been known to influence the disappearance of ice from a river. In addition, the depth of snow, which can act as insulation and delay melting of the river, must be considered, as well as fall and winter temperatures. Other climatic variables include the number of cloudy versus cloudless days, depth of snowcover throughout the entire basin, number of ice-free tributaries that feed into the system, and the thickness and strength of the ice layer itself. In addition, a river channel's slope, shape, and size influences the formation and breakup of ice so that conditions within a river system—and even along one channel—can vary, resulting in very different breakup patterns within a single basin.

The Mackenzie proper loses its ice later in the season than its tributaries, usually at the end of May or early June. After nine months under ice, there is much anticipation surrounding the river's transformation to liquid. People often bet on the precise time of breakup, which can mean anything from the first cracks in ice cover to the final disappearance of ice. At Lang Trading Post in the Mackenzie delta, breakup is defined (for the purposes of betting) as the time when driftwood from the nearby Peel River first floats past the trading post.

IN THE FIELD: FLOOD FORECASTING

Because the flooding associated with ice dams can devastate communities in the Mackenzie basin, scientists have tried for years to understand the behavior of this northern river system. Yet ice breakup is still a poorly understood process, complicated by the difficulty of conducting basic hydrologic research in remote regions.

Historically, scientists have taken temperature and flow measurements from one or more ground-based stations throughout the Mackenzie River system, but these have produced limited data. Not only are such stations difficult to access with any frequency, especially in winter, but data collection has also been stymied by the reality of ice breakup: Instruments set near the Mackenzie River and its tributaries are readily smashed by hurtling ice floes.

Modern satellite technology is now revolutionizing the monitoring of remote rivers. Researchers at the University of California, Los Angeles, for example, have recently initiated long-term monitoring of climatic conditions in the Mackenzie valley utilizing satellite data obtained by NASA's Earth Observing System. Two technologies, the Moderate Resolution Imaging Spectroradiometer (MODIS) and the Advanced Very High Resolution Radiometer (AVHRR), have already provided—and continue to provide—a wealth of information.

The satellite-based instruments sweep the planet every one to two days, providing a detailed glimpse of the Earth's surface. MODIS creates detailed images of northern Canada that not only provide visual data on the extent of snow cover but temperature and reflectivity readings as well. In contrast, the AVHRR is a radiation-detection imager that remotely measures cloud cover as well as the surface temperatures of land and water. Together, the satellite systems provide high *spatial* resolution that shows the presence or absence of ice within a channel. They also offer great *temporal* resolution by providing new photos every two days, which is a frequency that allows scientists to identify quickly changing conditions over the entire length of an ice-bound channel. Once melting begins, the images can be compared chronologically in order to track the rate at which segments of channel lose their ice cover and to create predictive models based on temperature readings and other correlating variables.

A second team of hydrologists, from the École de Technologie Supérieure in Montreal, hopes to improve the accuracy of flood forecasting by using remote-sensing techniques to measure soil emissivity, which is a measure of the energy emitted when a surface is directly viewed. Moisture in the soil reduces its emissivity, and so lower readings indicate a greater capacity to absorb floodwaters. By measuring the ratio of wet to dry soils, they hope to construct a model for predicting the basin's resilience to flooding. Other scientists are analyzing the impact of global warming on the region, trying to ascertain how rising temperatures might affect the frequency and severity of ice jams and floods. Their data are not yet conclusive but suggest that the volume of meltwater is increasing, which is likely to intensify flooding.

LOOKING TO THE FUTURE

Just 50 years ago, the Lower Mackenzie was closed off from the rest of the world eight months a year. No boats could ply its frozen river, and other forms of transportation were virtually nonexistent. Today roads, railways, and airplanes provide year-round access to the river's northern communities. In a region so rich in natural resources, such improved access has brought a burst of development.

Oil deposits have been tapped throughout the Mackenzie valley; their oil and gas reserves delivered by pipeline to refineries in the south. Mineral deposits, including gold and uranium ore, are mined in the basin and transported by rail to Edmonton, Alberta.

As it nears the Beaufort Sea, the Mackenzie River flows through marshes and bogs that routinely flood in the spring. *(AbleStock)*

SIPHONING WATER

In a world increasingly troubled by water scarcity, countries with abundant freshwater now realize their rivers represent a marketable commodity. Canada has more water flowing across its land that it could ever envision need for its own people. By contrast, the parched desert regions of the American Southwest, beset by steep rises in consumption, are facing water shortages.

In 1964, an engineering firm in California devised a plan to divert river water from Canada to these water-hungry communities. Called the North American Water and Power Alliance (NAWAPA), the plan would transfer great quantities of water from the Mackenzie River to parts of Nevada, Arizona, and southern California, effectively creating a human-made river system. Water would be sent via pipeline to the Rocky Mountains Trench, a giant natural cistern, and from there be funneled into parched communities, along with water from the Columbia, Missouri, and Colorado Rivers.

The sheer scale of the design, like similar water diversion projects in China and Russia (see "Diverting River Water" in Chapter 6) underscores the human species' dependence on freshwater. Although diverting millions of gallons of water over many thousands of miles and across borders would be enormously expensive, such an undertaking is not only theoretically possible but also potentially hugely profitable. For the moment, however, significant engineering and environmental problems, as well as economic and social issues, have stopped the project. Even so, some politicians think significant climate change, which on one hand may increase the flow of the Mackenzie and on the other exacerbate water shortages in the United States, will give new life to these grandiose engineering schemes.

Two hydroelectric dams span the Mackenzie River system, both of them on the Peace River, which is closest to populous Vancouver. Although the entire system has significant hydroelectric potential, the cost of transmission lines to carry the electricity to cities where it is needed is prohibitive. Built in the late 1960s, the transmission lines from the Peace Canyon and Bennett Dams to Vancouver run 600 miles (966 km).

In 2006, a development company announced plans to build a series of strip mines capable of producing up to 33 million tons (30 million metric tons) of coal, which will be converted to natural gas in gasification plants and shipped to southern markets via a gas pipeline.

In addition, an 1,120-mile (1,800-km) highway is now planned for the Mackenzie valley. The road will connect the town of Hay River on the shores of Great Slave Lake to the Arctic Ocean and include a bridge at Fort Providence, replacing the ice road and barge system currently in use.

With a new road connecting the populous south to the resource-rich north, population growth and economic development in the Mackenzie basin are inevitable. The degree to which these occur remains to be seen. For the time being, the Mackenzie River delta and most of the land abutting the oil-rich Beaufort Sea appear well protected. This land is almost entirely owned by native Inuit and to a lesser extent by the Dene tribe.

Development of the area, whether for oil or any other commodity, requires the consent of its owners, who are likely to resist easy money in exchange for environmental degradation. The First Nation peoples of Canada share a common and fundamental belief that the Earth is sacred and must be protected. If they uphold those values, the Mackenzie will surely top the list of unspoiled rivers far into the future, if not forever.

Dawn illuminates the ancient Egyptian city of Thebes, which sits on the west bank of the Nile River about 497 miles (800 km) upstream from the Mediterranean Sea. Limestone cliffs tower in the background, marking the transition from floodplain to desert. *(Mary Lane/Shutterstock)*

Carved from Nubian sandstone cliffs more than 3,000 years ago, four giant statues of the Egyptian king Ramses II overlook Lake Nasser above the Aswān Dam. The statues, which once sat on the banks of the Nile, had to be rescued from the rising waters of Lake Nasser and relocated to higher ground. *(David S. Boyer/National Geographic/Getty Images)*

The Pastaza River descends from the eastern foothills of the Andes, winding its way southeast through Ecuador to its confluence with the Amazon. *(The author)*

Deforestation, much of it for agricultural expansion, has decimated vast tracts of Amazonian rain forest. By some estimates, the Amazon basin may be losing some 12,000 square miles (31,000 km^2) a year, along with thousands of species. *(Samba Photo/Getty Images)*

The Upper Yangtze flows through a series of spectacular but treacherous limestone gorges. The river moves fast through this section, its currents squeezed by the vertical cliffs that rise as much as 1,000 feet (305 m), creating the world's deepest river canyon. *(Taolmor/Shutterstock)*

Tugboats pushing clusters of barges up- and downstream are a common sight on the Mississippi. Many are filled with grain from the nation's breadbasket or with iron ore from northern Minnesota. The river is a major shipping channel; more barges ply the Mississippi than any other river in the United States. *(Kevin Horan/Stone Collection/Getty Images)*

In 1993, the Mississippi River overflowed its banks, creating the worst flood in 150 years. Levees built to contain the river failed, causing floodwaters to spread across 23 million acres (9 million ha) of land from Minnesota to Illinois. Tens of thousands of people evacuated their homes, and 50 people lost their lives. *(Frank Oberle/Stone Collection/Getty Images)*

The Mississippi River delta projects clawlike into the ocean, a formation known as a bird's foot delta. The river water discharges in several directions, depositing sediments (shown in green) far out to sea. *(U.S. Geological Survey)*

The Huang Ho, also known as the Yellow River, carries more sediment than any other major river, hence its chocolate color. Here the river skirts the A'nyêmagên Mountains on its southeasterly path through Qinghai Province. The Chinese grow abundant wheat and other crops near the river but depend heavily on irrigation systems to do so. *(Robert Harding/World Imagery/Getty Images)*

In winter, the Huang Ho partially freezes. Here it passes through gorges in Shanxi Province. A remnant of China's Great Wall stands above the left bank. *(Robert Harding/World Imagery/Getty Images)*

The Yenisey River heads north to the Arctic Ocean, the setting Sun reflecting off its icy waters. *(Ilya Naymushin/Reuters)*

Sandbars line the Yenisey on its path through boreal forest. Summer visitors who like to boat and fish are drawn to the river's clean waters. *(Ilya Naymushin/Reuters)*

The Ob' passes through beautiful tracts of untouched wilderness, including deciduous forests in southern Siberia. *(Dean Conger/Corbis)*

The mud-colored Congo winds its way slowly through dense tropical jungle in equatorial Africa. *(Frans Lanting/ Minden Pictures)*

A toxic slick from China flowed down the Amur River to the Russian city of Khabarovsk in December 2000, increasing tensions between Russia and China. *(Sergei Grits/AP)*

The Mackenzie River forms a web of interconnected channels and bogs as it nears the Arctic Ocean. This stretch of river, shown here in summer, freezes nine months a year. *(AbleStock)*

Glossary

alluvial fan a fan-shaped deposit of sediments

alluvial plain a fertile low-lying area adjacent to a river formed by sediments deposited by flooding

alluvium sediments deposited by rivers

altimeter an instrument that measures the altitude of an object, such as a satellite, with respect to a fixed point such as sea level

anchor ice the thin layer of ice that forms on a river's bottom in winter

basin the area drained by a river and its tributaries; synonymous with drainage basin

bayou a marshy, sluggish body of water often found in an abandoned channel or near a delta

bed the bottom of a river channel

bedload particles transported by a river that are too heavy to be carried in suspension but instead roll and bounce along the bottom

bedrock general term for any layer of solid rock that exists below the Earth's surface

blackwater dark-colored water that is rich in tannins and other dissolved plant matter

bore a high, breaking wave of water that advances rapidly up an estuary; also called a tidal bore

boreal forest northern forests that consist primarily of needle-leaved evergreen trees, or conifers; also known as taiga

borehole a shaft sunk into the ground that may be dug or drilled to a certain depth

brackish a type of water that mixes with ocean water in low-lying coastal areas and thus has more salt content than freshwater

braided stream a river or stream that divides into several interlinking channels

breakup the point when ice on a river disappears, either by simply melting or by breaking into pieces, which are then carried downstream by the current

Canadian Shield an ancient (around 3.5-billion-year-old) block of metamorphic rock that underlies much of Canada

canal a human-made channel that transports water and/or boats from one point to another
cartographer a mapmaker
cataracts waterfalls that arise from an abrupt steepening of the river channel
catchment area drainage basin
centripetal drainage pattern a term describing tributaries that converge toward a central point
channel the central portion of a river that carries the main current
confluence the point at which rivers meet, thereafter forming a single flow of water moving downstream
coniferous forest a forest consisting primarily of evergreen trees with needle or scalelike leaves and seeds in the form of cones
continental divide a drainage divide that separates a continent, with streams on one side going in one direction, say east, and streams on the other going west
continental drift the fragmentation and movement of landmasses called continents throughout geological history
cuvette a French word meaning "basin"
dachas summer cottages in the Russian countryside
deciduous forest a forest dominated by trees, such as oaks, maples, and birches, that shed their leaves seasonally
delta the exposed and submerged plain formed by a river at its mouth
dike a bank usually made of earth constructed to control or confine water
discharge the volume of water flowing past a fixed point, calculated by multiplying the cross-sectional area of a river by the velocity of its current at specific point in time
divide elevated land that divides adjacent watersheds; also called a drainage divide
drainage basin a geographic area from which all water drains into one river; also known as a watershed or catchment area
equilibrium a state in the evolution of a river channel when the rate of erosion matches the rate of deposition
estuary the lower end of a river where freshwater currents interact freely with the sea and its tidal waters
floes chunks of floating ice
flood an overflow of river water that inundates land not normally submerged
floodplain a level surface adjacent to a river that is periodically flooded, accumulating with each flood a fresh influx of sediment
flow rate the volume of river water that passes through a defined cross section at a specific point in time
fluvial term meaning of, or belonging to, rivers
fragmentation a geological process whereby tributaries separate from the main trunk of a river and dry up

freeze up the point at which a defined length of a river is encased in surface ice
generator a machine that converts mechanical energy into electrical energy
glacial melt water that results from summer melting of the upper surface of a glacier
glacier a mass of land ice that moves slowly across a continent
groundwater water that saturates the ground, filling all available spaces from pores in the soil to large underground caverns
gulf an inlet, or extension, of the sea that is partly enclosed by land
headward erosion erosion caused by water flowing at the head of a valley that lengthens the valley in an upstream direction
headwaters the source and uppermost waters of a river
highlands elevated or mountainous lands
hydraulic head the strength of the force or pressure pushing on water
hydrologist an individual who specializes in the study of water
ice jams a pileup of large ice chunks, or floes, that block the river channel
ice pans chunks of ice formed by slushy clusters that stick to one another when a river begins to freeze
ice-scour lakes lakes carved from bedrock by retreating ice sheets
irregular profile a river channel that fails to maintain a steady downward slope on its journey to the sea
kinetic energy the energy associated with motion
levee a raised rim of earth along a river channel. Natural ones form when a river overflows its banks and deposits coarse sediment along its banks; artificial ones are built to prevent a river from flooding
lock a chamber with gates on both ends that connect two sections of a canal or other waterway; the chamber functions like an elevator, raising and lowering the water level in each section to enable boats to move up and down a steep incline
loess deposits of powdery silt
lowlands an expanse of land at low elevation, typically near the mouth of a river
main trunk the principal, or largest, stream of a given river system or drainage basin
meandering river a river channel with a winding or sinuous course typical of older, slower rivers
melting degree days days when ambient air temperature rises above freezing point
meltwater water derived from melting ice or snow, especially glacier ice
microwaves short-frequency electromagnetic waves
monsoon a large-scale wind system that reverses direction seasonally
mouth the place where one body of water discharges into another; most commonly where a river empties into the sea
mouth lake an enormous broadening of the river channel that sometimes occurs at the mouth of a tributary

nival river a stream that is fed primarily by snowmelt

Nubian sandstone sedimentary rock that forms a large desert plateau called the Nubian Desert along the eastern edge of the Nile valley

oligotrophic a well-oxygenated lake, one low in nutrients and relatively unpolluted

order stream a hierarchy of streams based on the number of tributaries flowing into a river system's main trunk

outcrop exposed rock at the surface of the Earth

oxbow lake a U-shaped, almost circular lake that was once a river meander but is now isolated from the river that created it

panplain distinctly flat terrain created by the overlapping floodplains of adjacent rivers

parallel drainage pattern a river's tributaries flow parallel to one another rather than converging to a central point in the watershed

peat the remains of partially decayed plants that have accumulated over thousands of years in cold water and formed vegetative layers many feet deep

penstock a conduit or pipe that controls the flow of water through the turbines of a hydroelectric plant

permafrost permanently frozen ground

plain a broad expanse of mostly treeless country

planation the expansion of a river's floodplain, a process associated with a slower rate of flow

plateau a broad, elevated expanse of land, sometimes called tableland

pycnocline a change in the density (salinity) of ocean water, usually related to depth

reservoir an artificial lake or storage basin that forms upstream from a dam, providing water for later use, including drinking, irrigation, and hydroelectric power

ria a long, narrow, coastal inlet

rifting a pulling apart or diverging of two tectonic plates

rift valley a trough that forms when the ground sinks between a pair of long, parallel faults in the Earth's crust, typically resulting in the formation of lakes

rills a miniature and impermanent gully that is formed by water from a single raindrop or from melting snow

riverbed the channel that contains a river

river system a system of connected river channels, each with its own drainage basin, that comes together to form one large drainage basin

rivulet a small stream or brook

runoff the amount of water leaving a watershed each year, measured theoretically as the amount of precipitation minus water lost to evapotranspiration

salinity the quantity of dissolved salts in water

salinization the accumulation of salt in soil as a result of evaporation

sandbar a bar or ridge of sand deposited near shore by currents that suddenly slow, as when a river begins to meander
savanna a tropical or subtropical grassland with scattered trees
sediment discharge rate the rate at which sediment flows past a particular point or cross section of a river
sediment load the amount of sediment transported by suspension in water, typically measured as the amount of sediment (by volume) that moves through a defined cross section of the river in a specific time interval
shale a fine-grained sedimentary rock
shoal an accumulation of sediment, either exposed or submerged, in a river channel
sluice a passage fitted with a vertical sliding gate that regulates the flow of water in a channel
snowmelt water resulting from the melting of snow
source the place where a river begins
spatial relating to or occupying space as opposed to time
spectral gradient the range of wavelengths, or frequencies, in electromagnetic radiation
steppe an expanse of arid grassland across central Asia
strait a narrow waterway connecting two larger bodies of water
taiga a forest of mostly coniferous trees that occurs in northern regions
temporal of or relating to time as distinguished from space
tidal flat coastal flatland that is alternately submerged or exposed as the tide rises and falls
transformer a device used to transfer electric energy from one type of circuit to another
tributary a river that flows into a larger river at a confluence
tundra an area of scraggly vegetation and thin soil that sits atop permafrost in arctic regions
turbine a machine outfitted with blades that is turned by a moving stream, transforming the kinetic energy of the fluid into mechanical energy
uplift a vertical elevation of the Earth's surface
watershed a nontechnical term for drainage basin
wetlands a type of poorly drained land that is submerged or saturated much or all of the time; examples include bogs, marshes, and swamps

Books

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Mackenzie, Alexander. *Journals of Alexander Mackenzie: Exploring across Canada in 1789 and 1793*. Reprint, Mechanicsburg, Pa.: Stackpole Books, 2001. A story of adventure down the Mackenzie written by the man who mapped the river's path to the Arctic.

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———. *Rivers of America*. New York: Harry N. Abrams, 2006. An astonishing collection of photographs and literary descriptions of America's waterways by someone who has devoted his life to rivers.

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Van Slyke, Lyman. *Yangtze: Nature, History and the River.* Reading, Mass.: Addison-Wesley, 1988. A travel book with a lot of history.

Ward, Andy D., and Stanley W. Trimble. *Environmental Hydrology*. Boca Raton, Fla.: Lewis Publishers, 2004. Offers up-to-date information on some river systems, including the Huang Ho.

Magazines

National Geographic
1145 17th Street NW
Washington, DC 20036-4688
http://www.nationalgeographic.com
The magazine routinely provides gripping firsthand accounts of the world's rivers, including all 10 included in this book, along with stunning photographs.

Outside Magazine
400 Market Street
Santa Fe, NM 87501
http://outside.away.com
The magazine runs numerous adventure pieces, with frequent stories about the world's rivers, with an eye to encouraging readers to explore the natural world.

Science
1200 New York Avenue NW
Washington, DC 20005
http://www.sciencemag.org
A publication of the American Association for the Advancement of Science, with both research articles and journalist-written pieces covering all matters of science and science news, including hydrology and freshwater.

Scientific American
415 Madison Avenue
New York, NY 10017
http://www.sciam.com
A popular science magazine devoted to excellence, with articles written by both scientists and staff writers at a level appropriate for a general audience.

Smithsonian
900 Jefferson Drive
Washington, DC 20560
http://www.smithsonianmagazine.com
A magazine devoted to history, nature, science, and the arts that is full of great writing and photography.

Web Sites

Amazon River
http://www.mbarron.net/Amazon
Some facts and information about one of the world's greatest rivers
http://www.extremescience.com/AmazonRiver.htm
A great overview of the river

Canadian Council for Geographic Education
http://www.rcgs.org/ccge/english/Resources/rivers/tr_rivers_mackenzieRiver.asp
A good source of information about the Mackenzie and its tributaries

Congo River
http://library.thinkquest.org/16645/the_land/congo_river.shtml
A good source of information about the Congo

Encyclopaedia Britannica
http://www.search.eb.com
A general reference tool with good maps and descriptions of all the world's rivers

Huang Ho River
http://www.geol.lsu.edu/WDD/ASIAN/Huanghe/Graphic%20files/graphics_list.htm
An encyclopedic site full of information about the Huang Ho River and its basin, with some wonderful satellite images

Indian Cultures from around the World
http://indian-cultures.com
An excellent site for finding out more about the indigenous peoples who live along the world's rivers

NASA's Visible Earth Catalog
http://www.visibleearth.nasa.gov/view
Includes satellite images of the Earth, including its major river systems

National Aeronautics and Space Administration (NASA) Satellite Imagery
http://disc.gsfc.nasa.gov
Another source of good satellite images

National Park Service
http://www.nps.gov/miss/features/factoids
Includes many facts about American rivers, including the Mississippi

Nile River
http://www.nileriver.com
Wealth of information about the Nile River

http://www.utdallas.edu/geosciences/remsens/Nile/image.html
A great overview of the Nile River from a geological and hydrological perspective

River Systems of the World
http://www.rev.net/~aloe/river
A comprehensive coverage of various rivers

Three Gorges Dam
http://www.chinadam.com
Includes up-to-date information about this major construction project and its impact on the Yangtze basin

U.S. Army Corps of Engineers
http://www.iwr.usace.army.mil/ndc
Has many facts and up-to-date information about channels, boats, dredging operations, and stream monitoring for American rivers

Water Resources of the United States
http://www.water.usgs.gov
A good source for information on American rivers

World Water Development Report
http://www.unesdoc.unesco.org
An overview of threats to the world's freshwater water

Yangtze River
http://cgee.hamline.edu/rivers/Resources/river_profiles/Yangtze.html
Profile of the river with some interesting facts

Yellow River
http://www.cis.umassd.edu/~gleung
A wealth of information on the history and hydrology of the Huang Ho, including maps and interesting facts

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