The Three Gorges Dam

When finished in 2009, the Three Gorges Dam on the Chang Jiang (Yangtze River) will be the largest dam in the world. Spanning 2.0 km (1.2 mi) and standing 185 m (607 ft) above normal river level, the dam will create a reservoir more than 644 km (400 mi) long. The dam is designed to control floods, ease navigation, and generate 18,200 megawatts of electricity to support industrialization and modernization in China's heartland.

The dam is flooding the scenic Three Gorges, one of China's most picturesque and historically significant areas. It already has displaced more than a million people, and will flood 1,300 cities and villages and more than 8,000 archeological and cultural sites. Water stored in the reservoir will make possible a long-discussed plan to build aqueducts to carry water from southern China to the dry plains around Beijing (fig. 10.1). Planners expect the dam to reduce annual floods that for centuries have caused misery and death for the 300 million people who live in the Yangtze River Valley.

Environmentalists criticize the dam because it will reduce fish stocks, eliminate important agricultural lands, and disrupt habitats and migration patterns of critically endangered species such as the Yangtze River dolphin and the Chinese sturgeon. Currently, about a trillion liters (roughly 260 billion gallons) of untreated sewage is dumped into the Yangtze and flushed out to sea every year. Critics claim the reservoir will become a stagnant cesspool, dangerous to both aquatic life and to the millions of people who depend on the river for their drinking water.

Tremendous volumes of sediment will accumulate as the silt-laden Yangtze River slows in the reservoir. To reduce sediment buildup, dam operators plan to let spring floods flow through silt gates at the bottom of the dam. They hope this flow will scour out the bottom of the reservoir. Critics doubt this will work.

Geologists worry about catastrophic dam failure because the dam is built over an active seismic fault. Engineers are confident the dam can withstand the maximum expected earthquake, but China has a poor record of dam safety. More than 3,200 Chinese dams have failed since 1949. Probably the worst series of dam failures in world history occurred in Henan Province in 1975, when heavy monsoon rains caused 62 large, modern dams to fall like a line of dominoes. Some 230,000 people died in the massive flooding that followed. Even if the dam is able to withstand earthquakes, giant waves spawned by upstream landslides could easily

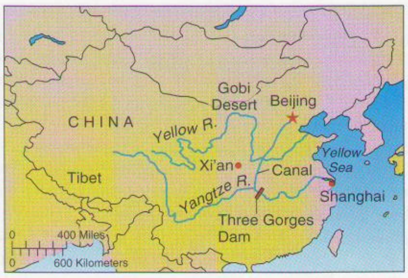

FIGURE 10.1 *Flowing more than 4,800 km (3,000 mi) from the high Tibetian Plateau, across the southern Gobi Desert, to the Yellow Sea, the Huang He, or Yellow River, is the major water source for much of the arid North China Plain. Currently, agricultural, industrial, and domestic water withdrawals drain the river dry for several months each year.*

cause a calamitous dam failure. In 1986, a landslide just a few miles upstream from the dam site dumped 15,000 m^3 of rock and soil into the river, creating an 80-m-high (260-ft) wave. If a similar wave hits the dam when the reservoir is full, some engineers predict a flood "of biblical proportions" that could kill millions of people downstream. The Chinese government has banned timber cutting and farming on steep upstream hillsides in an effort to control both landslides and sediment loads in the river.

Critics of this project claim that a series of smaller dams on tributary streams might have been much cheaper and less disruptive than the current project. Original estimates were that the Three Gorges Dam would cost $11 billion. By 2002, the costs for construction, relocation, and landscape stabilization had risen to $75 billion, and the project is not yet finished (see chapter 12).

This complex project illustrates the importance of water resources for modern societies. The United Nations warns that water supplies are likely to become one of the most pressing resource issues of the twenty-first century. By 2025, two-thirds of all humans could be living in countries where water supplies are inadequate. Our attempts to reengineer those shrinking resources are increasingly in conflict with natural systems. In this chapter, we'll look at where our fresh water comes from, what we do with it, and how we might protect its quality and extend its usefulness.

WATER RESOURCES

Water is a marvelous substance—flowing, swirling, seeping, constantly moving from sea to land and back again. It shapes the earth's surface and moderates our climate. Water is essential for life. It is the medium in which all living processes occur (see chapter 2). Water dissolves nutrients and distributes them to cells, regulates body temperature, supports structures, and removes waste products. About 60 percent of your body is water. You could survive for weeks without food, but only a few days without water. An American family of four consumes more than 1,000 m^3 (264,000 gal) of water per year. Families in other countries subsist on a tiny fraction of that amount.

Where Does Our Water Come From?

The water we use cycles endlessly through the environment. The total amount of water on our planet is immense—more than 1,404 million km^3 (370 billion billion gal) (table 10.1). This water evaporates from moist surfaces, falls as rain or snow, passes through living organisms, and returns to the ocean in a process known as the hydrologic cycle (see fig. 2.18). Every year, about 500,000 km^3, or a layer 1.4 m thick, evaporates from the oceans. More than 90 percent of that moisture falls back on the ocean. The 47,000 km^3 carried onshore joins some 72,000 km^3 that evaporate from lakes, rivers, soil, and plants to become our annual, renewable freshwater supply. Plants play a major role in the hydrologic cycle, absorbing groundwater and pumping it into the atmosphere by transpiration (transport plus evaporation). In tropical forests, as much as 75 percent of annual precipitation is returned to the atmosphere by plants.

Solar energy drives the hydrologic cycle by evaporating surface water, which becomes rain and snow. Because water and sunlight are unevenly distributed around the globe, water resources are very uneven. At Iquique in the Chilean desert, for instance, no rain has fallen in recorded history. At the other end of the scale, 22 m (72 ft) of rain was recorded in a single year at Cherrapunji in India. Figure 10.2 shows broad patterns of precipitation around the world. Most of the world's rainiest regions are tropical, where heavy rainy seasons occur, or in coastal mountain regions. Most of the driest areas are in the high-pressure bands of deserts (see chapter 9). Deserts occur on every continent just outside the tropics (the Sahara, the Namib, the Gobi, the Sonoran, and many others). Rainfall is also slight at very high latitudes, another high-pressure region.

Mountains also influence moisture distribution. The windward sides of mountain ranges, including the Pacific Northwest and the flanks of the Himalayas, are typically wet and have large rivers; on the leeward sides of mountains, in areas known as the rain shadow, dry conditions dominate, and water can be very scarce. The windward side of Mount Waialeale on the island of Kauai, for example, is one of the wettest places on earth, with an annual rainfall near 12 m (460 in.). The leeward side, only a few kilometers away, has an average yearly rainfall of only 46 cm (18 in.).

TABLE 10.1 Units of Water Measurement

One cubic kilometer (km^3) equals 1 billion cubic meters (m^3), 1 trillion liters, or 264 billion gal.

One acre-foot is the amount of water required to cover an acre of ground 1 ft deep. This is equivalent to 325,851 gal, or 1.2 million liters, or 1,234 m^3, approximately the amount consumed annually by a family of four in the United States.

One cubic foot per second of river flow equals 28.3 liters per second, or 449 gal per minute.

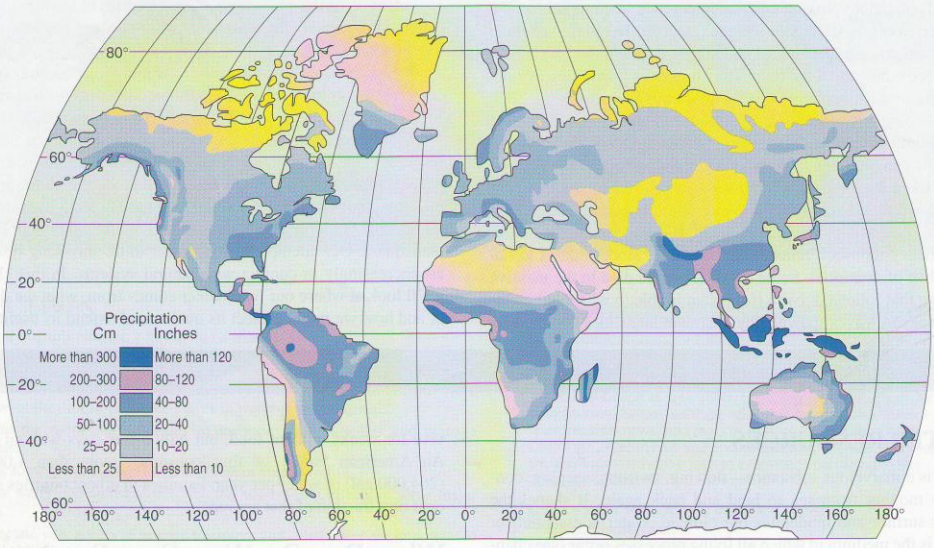

FIGURE 10.2 *Mean annual precipitation. Note wet areas that support tropical rainforests occur along the equator, while the major world deserts occur in zones of dry, descending air between 20 and 40 degrees North and South.*

TABLE 10.2 Earth's Water Compartments

COMPARTMENT	VOLUME (1,000 KM³)	PERCENT OF TOTAL WATER	AVERAGE RESIDENCE TIME
Total	1,386,000	100	2,800 years
Oceans	1,338,000	96.5	3,000 to 30,000 years*
Ice and snow	24,364	1.76	1 to 100,000 years*
Saline groundwater	12,870	0.93	Days to thousands of years*
Fresh groundwater	10,530	0.76	Days to thousands of years*
Fresh lakes	91	0.007	1 to 500 years*
Saline lakes	85	0.006	1 to 1,000 years*
Soil moisture	16.5	0.001	2 weeks to 1 year*
Atmosphere	12.9	0.001	1 week
Marshes, wetlands	11.5	0.001	Months to years
Rivers, streams	2.12	0.0002	1 week to 1 month
Living organisms	1.12	0.0001	1 week

*Depends on depth and other factors
Source: UNEP, 2002.

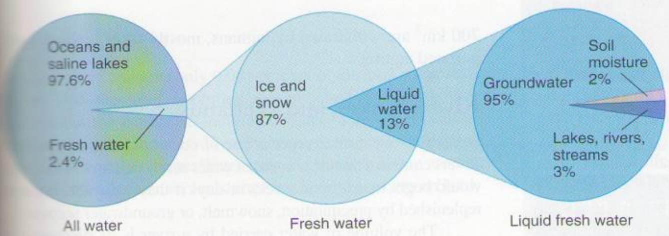

FIGURE 10.3 *The easily accessible water in lakes, rivers, and streams represents only 3 percent of all liquid fresh water, which is 13 percent of all fresh water, which is 2.4 percent of all water on the earth.*

MAJOR WATER COMPARTMENTS

The distribution of water often is described in terms of interacting compartments in which water resides, sometimes briefly and sometimes for eons (table 10.2). The length of time water typically stays in a compartment is its **residence time.** On average, a water molecule stays in the ocean for about 3,000 years, for example, before it evaporates and starts through the hydrologic cycle again. Nearly all the world's water is in the oceans (fig. 10.3). Oceans play a crucial role in moderating the earth's temperature, and over 90 percent of the world's living biomass is contained in the oceans. What we mainly need, though, is fresh water. Of the 2.4 percent that is fresh, most is locked up in glaciers or in groundwater. Amazingly, only about 0.1 percent of the world's water is in a form accessible to us and to other organisms that rely on fresh water (fig. 10.4).

Groundwater

Groundwater is one of our most important freshwater resources. Originating as precipitation that percolates into layers of soil and

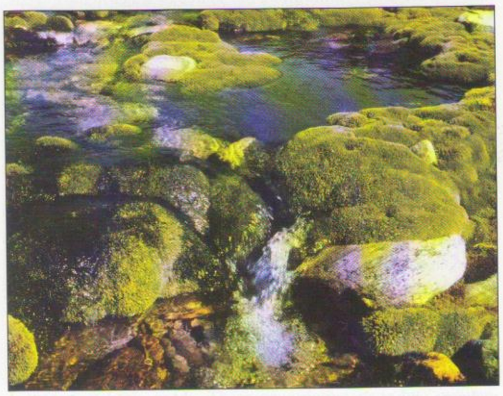

FIGURE 10.4 *Water is essential for life, yet only about 0.1 percent of the world's total supply is accessible fresh water.*

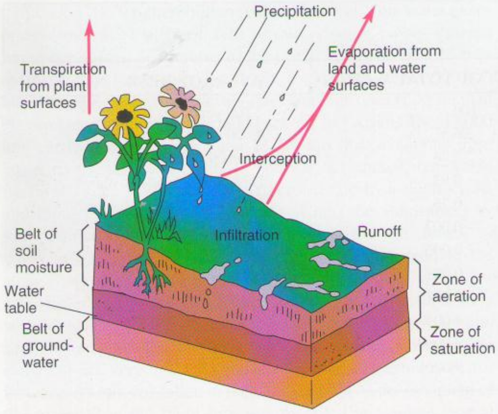

FIGURE 10.5 *Precipitation that does not evaporate or run off over the surface percolates through the soil in a process called infiltration. The upper layers of soil hold droplets of moisture between air-filled spaces. Lower layers, where all spaces are filled with water, make up the zone of saturation, or groundwater.*

rock, groundwater makes up the largest compartment of liquid, fresh water (fig. 10.5). The groundwater within 1 km of the surface is more than 100 times the volume of all the freshwater lakes, rivers, and reservoirs combined.

Plants get moisture from a relatively shallow layer of soil containing both air and water, known as the *zone of aeration.* Depending on rainfall amount, soil type, and surface topography, the zone of aeration may be a few centimeters or many meters deep. Lower soil layers, where all soil pores are filled with water, make up the *zone of saturation,* the source of water in most wells; the top of this zone is the **water table.**

Geologic layers that contain water are known as **aquifers.** Aquifers may consist of porous layers of sand or gravel, or of cracked or porous rock. Below an aquifer, relatively impermeable layers of rock or clay keep water from seeping out at the bottom. Instead water seeps more or less horizontally through the porous layer. Depending on geology, it can take anywhere from a few hours to several years for water to move a few hundred meters through an aquifer. If impermeable layers lie above an aquifer, pressure can develop within the water-bearing layer. A well or conduit puncturing the aquifer flows freely at the surface and is called an *artesian well* or spring.

Areas where surface water filters into an aquifer are **recharge zones** (fig. 10.6). Most aquifers recharge extremely slowly, and road and house construction or water use at the surface can further slow recharge rates. Contaminants can also enter aquifers through recharge zones. Urban or agricultural runoff in recharge zones is often a serious problem. About 2 billion people—approximately one-third of the world's population—depend on groundwater for drinking and other uses. Every year

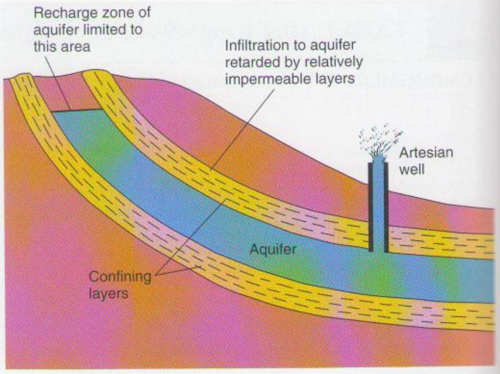

FIGURE 10.6 *An aquifer is a porous, water-bearing layer of sand, gravel, or rock. This aquifer is confined between layers of rock or clay and bent by geological forces, creating hydrostatic pressure. A break in the overlying layer creates an artesian well or spring.*

700 km^3 are withdrawn by humans, mostly from shallow, easily polluted aquifers.

Rivers, Lakes, and Wetlands

Fresh, flowing surface water is one of our most precious resources. Rivers contain a minute amount of water at any one time. Most rivers would begin to dry up in weeks or days if they were not constantly replenished by precipitation, snowmelt, or groundwater seepage.

The volume of water carried by a river is its **discharge,** or the amount of water that passes a fixed point in a given amount of time. This is usually expressed as liters or cubic feet of water per second. The 16 largest rivers in the world carry nearly half of all surface runoff on the earth, and a large fraction of that occurs in a single river, the Amazon, which carries ten times as much water as the Mississippi (table 10.3).

Lakes contain nearly 100 times as much water as all rivers and streams combined, but much of this water is in a few of the world's largest lakes. Lake Baikal in Siberia, the Great Lakes of North America, the Great Rift Lakes of Africa, and a few other lakes contain vast amounts of water, not all of it fresh. Worldwide, lakes are almost as important as rivers in terms of water supplies, food, transportation, and settlement.

Wetlands—bogs, swamps, wet meadows, and marshes—play a vital and often unappreciated role in the hydrological cycle. Their lush plant growth stabilizes soil and holds back surface runoff, allowing time for infiltration into aquifers and producing even, year-long stream flow. In the United States, about 20 percent of the 1 billion ha of land area was once wetland. When wetlands are disturbed, their natural water-absorbing capacity is reduced and surface waters run off quickly, resulting in floods and erosion during the rainy season and low stream flow the rest of the year.

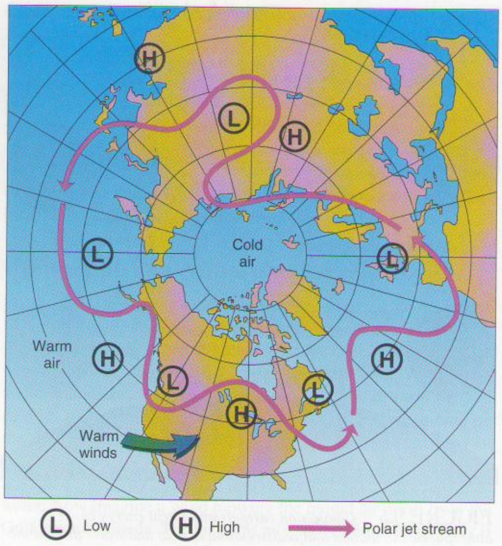

FIGURE 9.6 *The polar-front jet stream circles the pole, isolating arctic air from lower-latitude air. Also called the arctic circumpolar vortex, this large, circulating mass of cold air sends "fingers," or lobes, across North America and Eurasia, spreading storms in their path. If the vortex becomes stalled, weather patterns stabilize, causing droughts in some areas and excess rain elsewhere.*

important to us because they greatly affect weather patterns. Sometimes jet streams dip down near the top of the world's highest mountains, exposing mountain climbers to violent, brutally cold winds.

Ocean Currents

Warm and cold ocean currents strongly influence climate conditions on land. Surface ocean currents result from wind pushing on the ocean surface. As surface water moves, deep water wells up to replace it, creating deeper ocean currents. Differences in water density—depending on the temperature and saltiness of the water—also drive ocean circulation. Huge cycling currents called gyres carry water north and south, redistributing heat from low latitudes to high latitudes (see appendix 4, p. 376, global climate map). The Alaska current, flowing from Alaska southward to California, keeps San Francisco cool and foggy during the summer. The Gulf Stream, one of the best known currents, carries warm Caribbean water north past Canada's maritime provinces to northern Europe. This current is immense, some 800 times the volume of the Amazon, the world's largest river. The heat transported from the Gulf keeps Europe much warmer than it should be for its latitude. As the warm Gulf Stream passes Scandinavia and swirls around Iceland, the water cools and evaporates, becomes dense and salty, and plunges downward, creating a strong, deep, southward current.

Ocean circulation patterns were long thought to be unchanging, but now oceanographers believe that currents can shift abruptly. For example, melting ice at the North Pole could create a flood of cold, fresh water, disrupting the Gulf Stream and causing rapid, drastic cooling in Europe. This shift may have happened in geologic history, and many climatologists fear it could occur again if global warming melts arctic ice again.

Seasonal Winds and Monsoons

While figure 9.3 shows regular global wind patterns, large parts of the world, especially the tropics, receive seasonal winds and rainy seasons that are essential for sustaining both ecosystems and human life. Sometimes these seasonal rains are extreme, causing disastrous flooding. (See the related story "Floods in Mozambique" at www.mhhe.com/apps.)

Sometimes the rains fail, causing crop failures and famine. The most regular seasonal winds and rains are known as **monsoons.** In India and Bangladesh, monsoon rains come when seasonal winds blow hot, humid air from the Indian Ocean (fig. 9.7). Strong convection currents lift this air, causing heavy rain across the subcontinent. When the rising air reaches the Himalayas, it rises even further, creating some of the heaviest rainfall in the world. During the 5-month rainy season of 1970, a weather station in the foothills of the Himalayas recorded 25 m (82 ft) of rain!

Tropical and subtropical regions around the world have seasonal rainy and dry seasons (see the discussion of tropical biomes

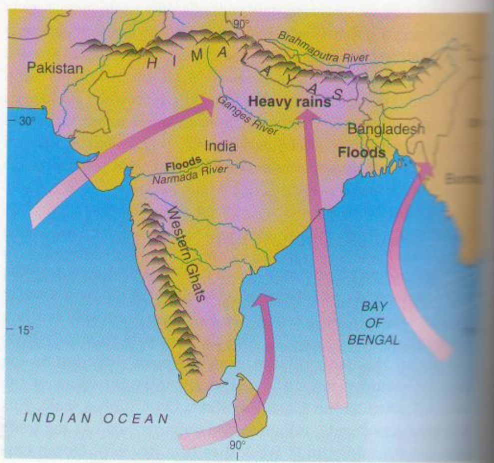

FIGURE 9.7 *Summer monsoon air flows over the Indian subcontinent. Warming air rises over the plains of central India in summer, creating a low-pressure cell that draws in warm, wet, oceanic air. As this moist air rises over the Western Ghats or the Himalayas, it cools, and heavy rains result. These monsoon rains flood the great rivers, bringing water for agriculture, but also causing much suffering*

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