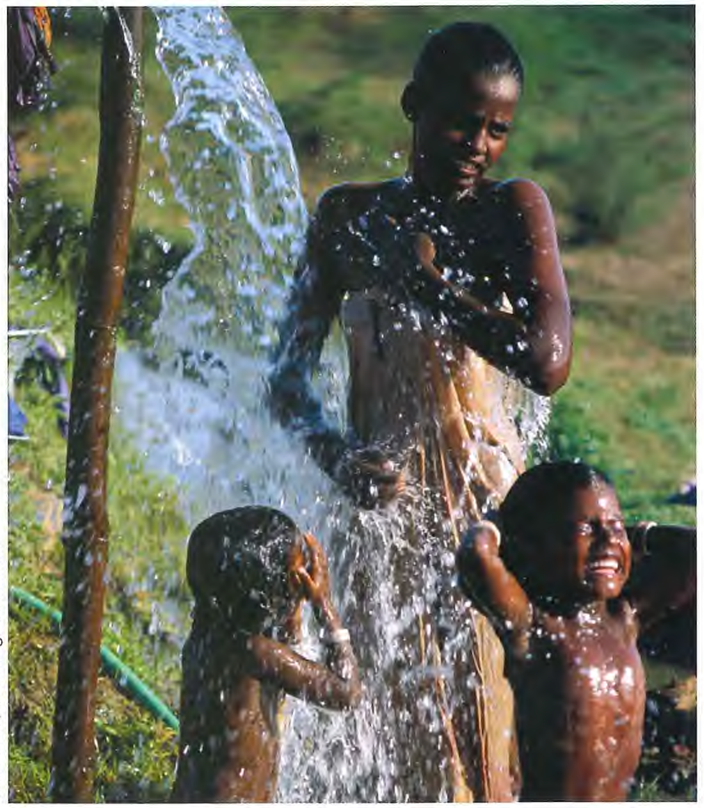
The Importance of Water

LEARNING OBJECTIVES

1. **Describe** the structure of a water molecule and explain how hydrogen bonds form between adjacent water molecules.
2. **List** the unique properties of water.
3. **Explain** how processes of the hydrologic cycle allow water to circulate through the abiotic environment.

Life on planet Earth would be impossible without water. All life forms, from unicellular bacteria to multicellular plants and animals, contain water. Humans are composed of approximately 70 percent water by body weight. We depend on water for our survival as well as for our convenience: We drink it, cook with it, wash with it (**Figure 10.1**), travel on it, and use an enormous amount of it for agriculture, manufacturing, mining, energy production, and waste disposal.

Young brick workers in India bathe with water from an irrigation pipe • Figure 10.1



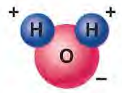
Jodi Cobb/NG Image Collection

Although Earth has plenty of water, about 97 percent of it is salty and not consumable by most terrestrial organisms (see graph in the chapter opener). Fresh water is distributed unevenly, resulting in serious regional water supply problems and conflicts. Water experts predict that by 2025, more than one-third of the human population will live in areas where there isn't enough fresh water for drinking and irrigation.

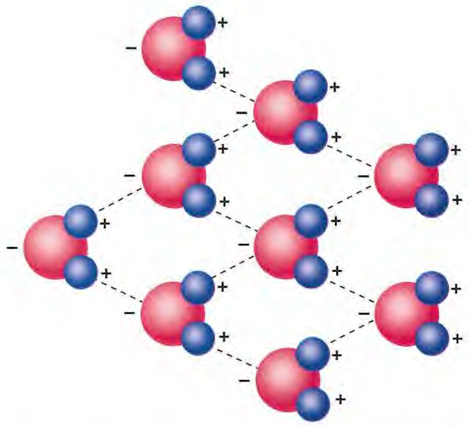
Properties of Water

Water is composed of molecules of H_2O, each consisting of two atoms of hydrogen and one atom of oxygen. Water molecules are **polar**—that is, one end of the molecule has a positive electrical charge, and the other end has a negative charge (**Figure 10.2**). The negative (oxygen) end of one water molecule is attracted to the positive (hydrogen) end of another water molecule, forming a **hydrogen bond** between the two molecules. Hydrogen bonds are the basis for many of water's physical properties, including its high melting/freezing point (0°C, 32°F) and high boiling point (100°C, 212°F). Because most of Earth has a temperature between 0°C and 100°C, most water exists in the liquid form organisms need.

Chemical properties of water • Figure 10.2



a. Each water molecule consists of two hydrogen atoms and one oxygen atom. Water molecules are polar, with positively and negatively charged areas.



b. The polarity causes hydrogen bonds (represented by dashed lines) to form between the positive areas of one water molecule and the negative areas of others. Each water molecule forms up to four hydrogen bonds with other water molecules.

Water absorbs a great deal of solar heat without substantially increasing in temperature. This high heat capacity allows the ocean to have a moderating influence on climate, particularly along coastal areas; the ocean does not experience the wide temperature fluctuations common on land.

Water is a *solvent*, meaning that it can dissolve many materials. In nature, water is never completely pure because it contains dissolved gases from the atmosphere and dissolved mineral salts from the land. Water's abilities as a solvent have a major drawback: Many of the substances that dissolve and are transported in water cause water pollution.

The Hydrologic Cycle and Our Supply of Fresh Water

In the **hydrologic cycle**, water continuously circulates through the environment, from the ocean to the atmosphere to the land and back to the ocean (see **Figure 10.3**; also see Figure 5.10 for a more thorough discussion of all components of the hydrologic cycle). The result is a balance of the water resources in the ocean, on the land, and in the atmosphere. The hydrologic cycle provides a continual renewal of the supply of fresh water on land, which is essential to terrestrial organisms.

Surface water is water found in streams, rivers, lakes, ponds, reservoirs, and **wetlands** (areas of land covered with water for at least part of the year). The **runoff** of precipitation from the land replenishes surface waters and is considered a renewable, although finite, resource. A **drainage basin**, or **watershed**, is the area of land drained by a single river or stream. Watersheds range in size from less than 1 km^2 for a small stream to a huge portion of the continent for a major river system such as the Mississippi River.

> **surface water** Precipitation that remains on the surface of the land and does not seep down through the soil.
>
> **runoff** The movement of fresh water from precipitation and snowmelt to rivers, lakes, wetlands, and the ocean.

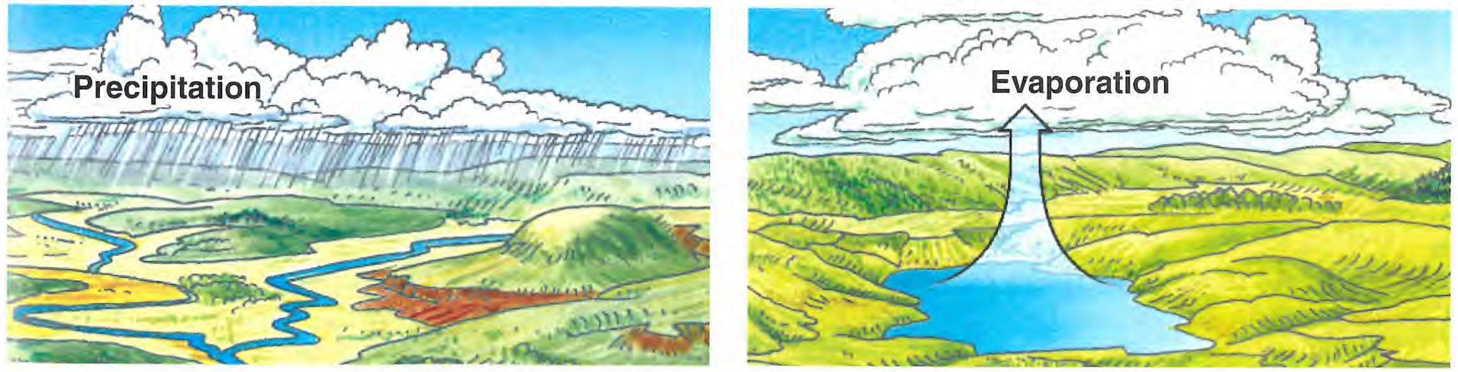
Earth contains underground formations that collect and store water. This water originates as rain or melting snow that slowly seeps into the soil. It works its way down through cracks and spaces in sand, gravel, or rock until an impenetrable layer stops it; there it accumulates as **groundwater**. Groundwater flows through permeable sediments or rocks slowly, typically covering distances of several millimeters to a few meters per day. This process of downward movement and accumulation is called *groundwater recharge*. Eventually groundwater is discharged into rivers, wetlands, springs, or the ocean. Thus, surface water

> **groundwater** The supply of fresh water under Earth's surface that is stored in underground aquifers.

Two important components of the hydrologic cycle • Figure 10.3

a. Liquid and solid precipitation continuously falls from the atmosphere to the land and ocean.

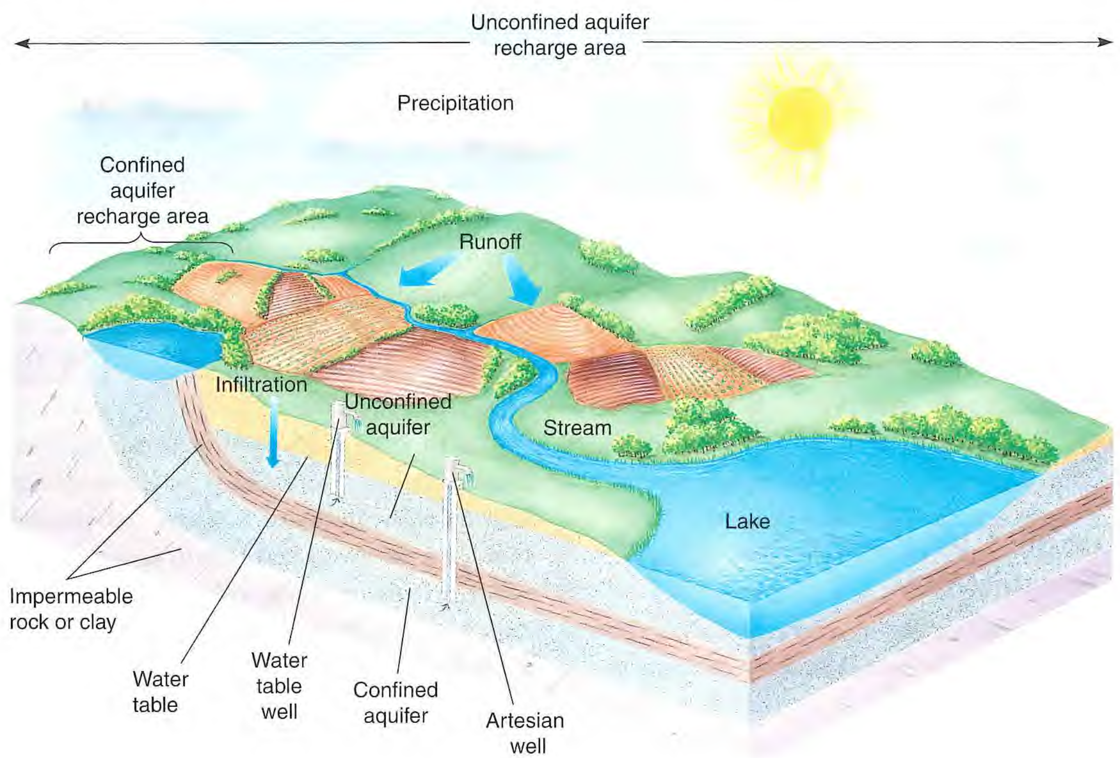
b. Evaporation continuously moves water vapor from the land and ocean into the atmosphere.



Adapted from Figure 2.8 on p. 28 in Stahler, A. and A. Strahler. *Physical Geography: Science and Systems of the Human Environment*. Hoboken, NJ: John Wiley & Sons, Inc. (2002).

Groundwater • Figure 10.4

Excess surface water seeps downward through soil and porous rock layers until it reaches impermeable rock or clay. An unconfined aquifer holds groundwater recharged by surface water directly above it. A confined aquifer stores groundwater between impermeable layers.



and groundwater are interrelated parts of the hydrologic cycle. **Aquifers** are underground reservoirs in which groundwater is stored (**Figure 10.4**).

Most groundwater is considered a nonrenewable resource because it has taken hundreds or even thousands of years to accumulate, and usually only a small portion of it is replaced each year by seepage of surface water.

CONCEPT CHECK STOP

1. **How** do hydrogen bonds form between adjacent water molecules?
2. **What** are two unique properties of water?
3. **How** do processes in the hydrologic cycle affect the accumulation of groundwater?

Water Resource Problems

LEARNING OBJECTIVES

1. **Relate** some of the problems caused by aquifer depletion, overdrawing of surface waters, and salinization of irrigated soil.
2. **Contrast** the water problems associated with the Ogallala Aquifer and the Colorado River Basin.
3. **Describe** the role of international cooperation in managing shared water resources.

Water resource problems fall into three categories: too much water, too little water, and poor-quality water. Flooding occurs when a river's discharge cannot be contained within its normal channel. Today's floods are more disastrous in terms of property loss than those of the past because humans often remove water-absorbing plant cover from the soil and construct buildings on floodplains. (A **floodplain** is the area bordering a river channel that has the potential to flood.) These activities increase the likelihood of both floods and flood damage.

When a natural area—that is, an area undisturbed by humans—is inundated with heavy precipitation, the plant-protected soil absorbs much of the excess water. What the soil cannot absorb runs off into the river, which may then spill over its banks onto the floodplain. Because rivers meander, the flow is slowed, and the swollen waters rarely cause significant damage to the surrounding area. (See Figure 6.13 for a diagram of a typical river, including its floodplain.)

When an area is developed for human use, construction projects replace much of this protective plant cover. Buildings and paved roads don't absorb water, so runoff, usually in the form of storm sewer runoff, is significantly greater in developed areas (**Figure 10.5**). People who build homes or businesses on the floodplain of a river will most likely experience flooding at some point (**Figure 10.6**).

Arid lands, or deserts, are fragile ecosystems in which plant growth is limited by lack of precipitation. **Semiarid lands** receive more precipitation than deserts but are subject to frequent and prolonged droughts.

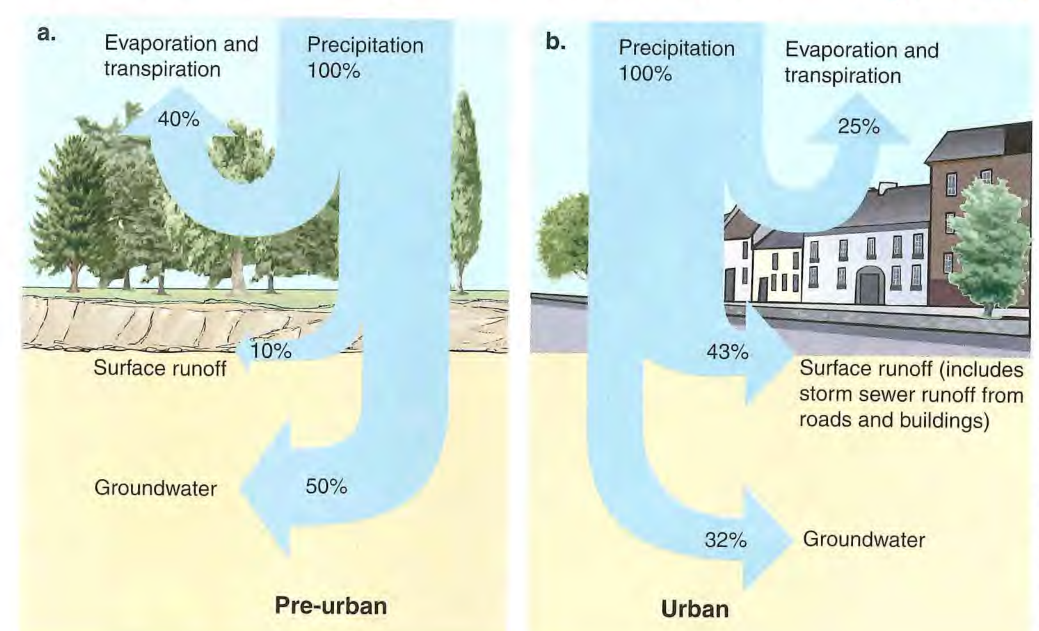
Farmers increase the agricultural productivity of arid and semiarid lands with irrigation. Irrigation of these

Flooding in Queensland, Australia • Figure 10.6

A neighborhood in Rockhampton, Queensland, in northeastern Australia, is inundated by the swollen Fitzroy River on January 4, 2011. The region has experienced severe seasonal flooding in recent years, suffering in 2011 at least 35 deaths and costing the nation as much as $30 billion.

© Janie Barrett/Pool/epa/Corbis

How development changes the natural flow of water • Figure 10.5



Control of Water Pollution from Urban Runoff. Paris: Organization for Economic Cooperation and Development (1986).

Shown is the fate of precipitation in Ontario, Canada, before **(a)** and after **(b)** urbanization. After Ontario was developed, surface runoff increased substantially, from 10 percent to 43 percent.

lands has become increasingly important worldwide in efforts to produce enough food for burgeoning populations (**Figure 10.7**). Since 1955, the amount of irrigated land has more than tripled; Asia has more agricultural land under irrigation than do other continents, primarily in China, India, and Pakistan. Water use for irrigation will probably continue to increase in the 21st century, but at a slower rate than in the last half of the 20th century.

Population growth in arid and semiarid regions intensifies water shortage. More people need food, so additional water resources are diverted for irrigation. Also, the immediate need for food prompts people to remove natural plant cover to grow crops on marginal lands subject to frequent drought, which in turn reduces water absorption into soils when rains do come.

Aquifer Depletion

Aquifer depletion from excessive removal of groundwater lowers the **water table**, the upper surface of the saturated zone of groundwater (see Figure 10.4). Prolonged aquifer depletion drains an aquifer dry, effectively eliminating it as a water resource. Even areas with high rainfall can experience aquifer depletion if humans remove more groundwater than can be recharged. In addition, aquifer depletion from porous sediments causes **subsidence**, or sinking, of the land above it. **Saltwater intrusion** occurs along coastal areas when groundwater is depleted faster than it recharges. Saltwater intrusion is also occurring in low-lying areas due to sea-level rise associated with global climate change. Well water in such areas eventually becomes too salty for human consumption or other freshwater uses.

aquifer depletion The removal of groundwater faster than it can be recharged by precipitation or melting snow.

saltwater intrusion The movement of seawater into a freshwater aquifer near the coast.

Agricultural use of water • Figure 10.7

These fields in Kansas use center-pivot irrigation, which minimizes evaporative water loss and gives fields a distinctive circular shape. Each circle is the result of a long irrigation pipe that extends along the radius from the circle's center to its edge and slowly rotates, spraying the crops. This satellite photo, taken in June, shows wheat fields (bright yellow), corn fields (dark green), and newly emerging sorghum (light green).

Courtesy NASA

The Ogallala Aquifer The High Plains cover 6 percent of U.S. land but produce more than 15 percent of the nation's wheat, corn, sorghum, and cotton and almost 40 percent of its livestock. This productivity requires approximately 30 percent of the irrigation water used in the United States. Farmers on the High Plains rely on water from the **Ogallala Aquifer**, the largest groundwater deposit in the world (**Figure 10.8**).

In some areas farmers are drawing water from the Ogallala Aquifer as much as 40 times faster than nature replaces it. This rapid depletion has lowered the water table more than 30 m (100 ft) in some places. Most hydrologists (scientists who study water supplies) predict that groundwater will eventually drop in all areas of the Ogallala to a level uneconomical to pump. Their goal is to postpone that day through water conservation, including the use of water-saving irrigation systems.

Ogallala Aquifer • Figure 10.8

This massive deposit of groundwater lies under eight states, with extensive portions in Texas, Kansas, and Nebraska. Water in the Ogallala Aquifer takes hundreds or even thousands of years to renew after it is withdrawn to grow crops and raise cattle.

NG Maps

Courtesy of the U.S. Geological Survey.

Overdrawing of Surface Waters

Removing too much fresh water from a river or lake can have disastrous consequences in local ecosystems. Growing human populations place demands on water sources that are not sustainable. In the arid American Southwest, it is not unusual for 70 percent or more of surface water to be removed.

When surface waters are overdrawn, wetlands dry up. **Estuaries**, where rivers empty into seawater, become saltier when surface waters are overdrawn, which reduces their productivity. Wetlands and estuaries, which serve as breeding grounds for many species of birds and other animals, also play a vital role in the hydrologic cycle. When these resources are depleted, the ensuing water shortages and reduced productivity have economic as well as ecological ramifications.

The increased use of U.S. surface water for agriculture, industry, and personal consumption since the 1960s has caused many water supply and quality problems. Some regions that have grown in population during this period—for example, California, Nevada, Arizona, Georgia (metropolitan Atlanta), and Florida—have placed correspondingly greater burdens on their water supplies. If water consumption in these and other areas continues to increase, regional problems with availability of surface waters will become more serious, even in places that have never experienced water shortages.

Nowhere in the country are water problems as severe as they are in the West and Southwest. Much of this large region is arid or semiarid, receiving less than 50 cm (20 in) of precipitation annually. With the rapid expansion of the population there during the past 25 years, municipal, commercial, and industrial uses now compete heavily with irrigation for available water. Much of the water used in the West and Southwest originates as snow in the Rocky Mountains and the Sierra Nevada; climate change appears to be causing reduced snowfall—and thus making less total water available for a growing population.

The Colorado River Basin One of the most serious water supply problems in the United States is in the Colorado River Basin. The river's headwaters are formed from snowmelt in Colorado, Utah, and Wyoming, and major tributaries—collectively called the upper Colorado—extend throughout these states. The lower Colorado River runs through part of Arizona and then along the border between Arizona and both Nevada and California before crossing into Mexico and emptying into the Gulf of California.

The Colorado River system provides water for more than 30 million people, including those in the cities of Denver, Las Vegas, Albuquerque, Phoenix, Los Angeles, and San Diego, with plans in Utah to divert Colorado River water to Salt Lake City. It irrigates 1.4 million hectares (3.5 million acres) of fruit, vegetable, and field crops worth $1.5 billion per year. The Colorado River has 49 dams, 11 of which produce electricity by hydropower. The river produces $1.25 billion per year in revenues from the recreation industry.

An international agreement with Mexico, along with federal and state laws, severely restricts the use of the Colorado's waters. The most important of all the treaties regulating use of Colorado River water is the 1922 **Colorado River Compact**, which stipulates an annual allotment of 7.5 million acre-feet of water to the lower Colorado (California, Nevada, Arizona, and New Mexico) and the remainder to the upper Colorado (Colorado, Utah, and Wyoming). Each acre-foot equals 326,000 gal (1.2 million liters), enough for about eight people for 1 year. However, the Colorado River Compact overestimated the average annual flow of the Colorado River, and it locked that estimate into the multistate agreement. Mexico also receives a share of the Colorado, as stipulated by a 1944 treaty.

Population growth in the upper Colorado region exacerbates the heavy demand already placed on the river by states through which the lower Colorado flows, particularly California. Consequently, the Colorado River water is often completely consumed before it can reach the Pacific Ocean in Mexico, causing serious problems for the ecosystem and inhabitants of the Colorado River delta (**Figure 10.9**). To compound the problem, as more and more water is used, the lower Colorado becomes increasingly salty—in some places saltier than the ocean—as it flows toward Mexico.

In 2003 California agreed to limit its water withdrawals from the Colorado River to quantities specified in the Colorado River Compact. Also, some California farmers agreed to sell some water they would normally use for irrigation and use the money earned to update their irrigation systems so that they would make more efficient use of their water.

Salinization of Irrigated Soil

Although irrigation improves the agricultural productivity of arid and semiarid lands, it often causes salt to accumulate in the soil, a phenomenon called **salinization**. Irrigation water contains small amounts of dissolved salts. Normally, through precipitation runoff, rivers carry away salt. Irrigation water, however, normally soaks into the soil and does not run off into rivers. The continued application of such water, season after season, year after year, leads to the gradual accumulation of salt in the soil. Given enough time, the salt concentration can rise to such a high level that plants are poisoned or their roots become dehydrated. Thus, salt hurts soil productivity and, in extreme cases, renders soil unfit for crop production.

> **salinization** The gradual accumulation of salt in soil, often as a result of improper irrigation methods.

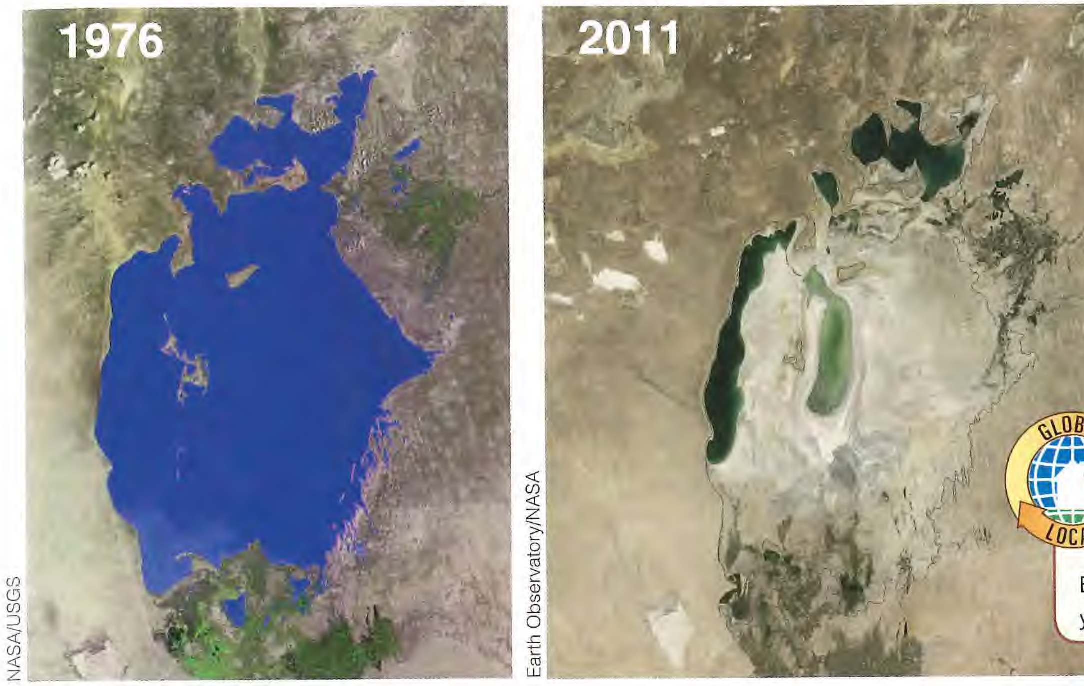
Colorado River Delta at the Gulf of California • Figure 10.9

As a result of diversion for irrigation and other uses in the United States, the Colorado River often dries up before reaching the Gulf of California in Mexico.

© Pete Mcbride/National Geographic Society/Corbis

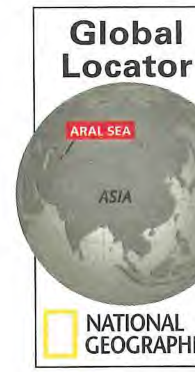
Aral Sea • Figure 10.10

The satellite images show the Aral Sea in 1976 and 2011. As water was diverted for irrigation, the sea level subsided.



NASA/USGS

Earth Observatory/NASA



NG Maps

GLOBAL LOCAL: How do water resource conflicts associated with the Aral Sea compare to those involving the Colorado River Basin? to water resource issues in your state or region?

Global Water Issues

As the world's population continues to increase, global water problems are becoming more serious. Earth's people and its water resources are often not concentrated in the same places. In India, where approximately 20 percent of the world's population has access to 4 percent of the world's fresh water, approximately 8000 villages have no local water supply. Water supplies are precarious in much of China, due to population pressures. In many parts of the country, water table levels are dropping; one-third of the wells in Beijing have gone dry. Much of the water in the Yellow River, one of China's main water basins, is diverted for irrigation, depriving downstream areas of water. Mexico is facing an unprecedented drought. The main aquifer supplying Mexico City is dropping rapidly, and the water table is falling fast in Guanajuato, an agricultural state. As of 2012, an estimated 2 million Mexicans lacked access to water.

As the needs of the growing human population deplete freshwater supplies, less water will be available for crops. Local famines often arise from water shortages. In early 2012, a looming drought in West Africa had already cut grain supplies by half in Chad and Mauritania, raising food prices and stimulating efforts to develop long-range approaches to drought relief.

Sharing Water Resources Among Countries In the 1950s, the then Soviet Union began diverting water that feeds into the Aral Sea to irrigate nearby desert areas. Over five decades, the Aral Sea all but disappeared (**Figure 10.10**); its total volume dropped 80 percent, and much of its biological diversity vanished. Millions of people living in the Aral Sea's watershed have developed serious health problems, probably due in part to storms lifting into the air toxic salts from the receding shoreline.

Following the breakup of the Soviet Union in 1991, responsibility for saving the Aral Sea shifted to the five Asian countries that share the Aral basin—Uzbekistan, Kazakstan, Kyrgyzstan, Turkmenistan, and Tajikistan. These nations' cooperative restoration efforts were backed by the World Bank and the U.N. Environment Program. At this time, recovery of the Aral Sea is mixed. Due in part to dam construction, the Northern Aral Sea experienced more than a 30 percent increase in surface area between 2003 and 2010 (though water levels dwindled somewhat in 2011), and salinity levels have been cut in half. The Southern Aral Sea, however, has shown little improvement over the past 20 years; water flow there is restricted by the dam. Like the Aral Sea, many of Earth's other watersheds cross political boundaries and face management issues associated with their shared use; water availability varies greatly worldwide (**Figure 10.11**).

The World's 10 Largest Watersheds

Watershed	Region	Area of watershed (thousand km²)
Amazon	South America	6145
Congo	Africa	3731
Nile	Africa	3255
Mississippi	North America	3202
Ob	Asia	2972
Paraná	South America	2583
Yenisey	Asia	2554
Lena	Asia	2307
Niger	Africa	2262
Yangtze	Asia	1722

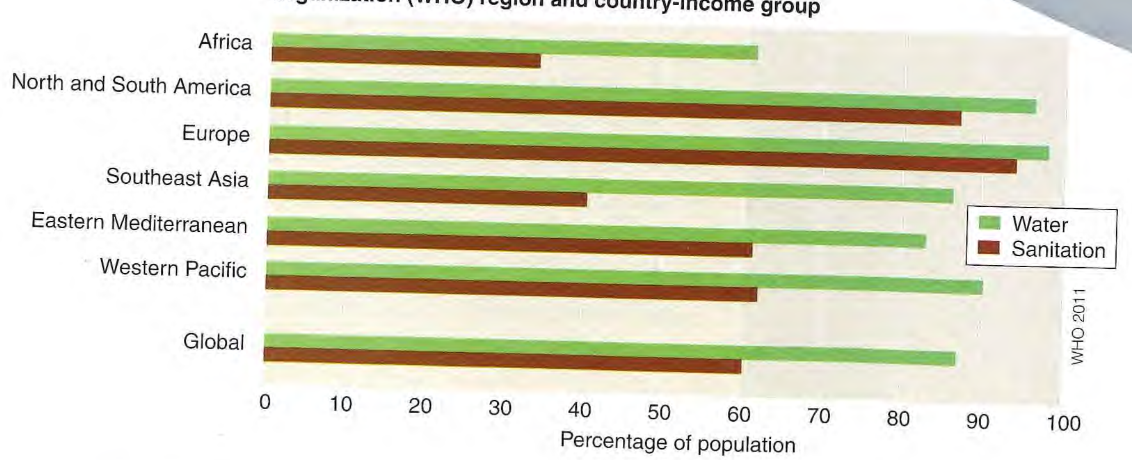
Source: Water Resources of the World, World Resources Institute (2010).

PRIMARY WATERSHEDS AND CRITICAL AREAS
Earth's bodies of fresh water can cover enormous areas and cross many political boundaries. Watersheds are Earth's rain barrels. They collect precipitation and filter it as they channel it to streams, rivers, lakes, and aquifers. Many watersheds are stressed by human activities.

Interpreting Data
Which continent appears to have the best access to fresh water? the poorest access?

ACCESS TO CLEAN FRESH WATER
Access to clean fresh water is critical for human health. Yet in many regions, potable water is becoming scarce because of heavy demands and pollution. Especially worrisome is the poisoning of aquifers—a primary source of water for nearly one-third of the world—by sewage, pesticides, and heavy metals.

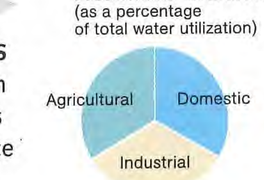
Percentage of population using improved drinking-water sources and sanitation facilities in 2008 by World Health Organization (WHO) region and country-income group



WATER
It's as vital to life as air. Yet fresh water is one of the rarest resources on Earth. Only 2.5 percent of Earth's water is fresh, and of that, the usable portion for humans is less that 1 percent of all fresh water, or 0.01 percent of all water on Earth. Water is constantly recycling through Earth's hydrologic cycle. But population growth and pollution are combining to make less and less available per person per year, while global climate change adds new uncertainty. Availability of fresh water varies tremendously around the world, inevitably triggering conflicts over water resources.

GLOBAL IRRIGATED AREAS AND WATER WITHDRAWALS
Since 1970 global water withdrawals have correlated with the rise in irrigated area. Some 70 percent of withdrawals are for agriculture, mostly for irrigation that helps produce 40 percent of the world's food.

Freshwater Withdrawal
(as a percentage of total water utilization)



Rhine River Basin • Figure 10.12

The Rhine River drains five European countries. (The green area represents the drainage basin.) Water management of such a river requires international cooperation.

NG Maps

Three-fourths of the world's 200 or so major watersheds are shared between at least two nations. International cooperation is required to manage rivers that cross international borders. The heavily populated drainage basin for the Rhine River in Europe spans five countries—Switzerland, Germany, France, Luxembourg, and the Netherlands (**Figure 10.12**). All five nations recognize that international cooperation is essential to conserve and protect the supply and quality of the Rhine River. Together they formed the International Commission for Protection of the Rhine, which in 1987 initiated a 15-year Rhine Action Programme. Their efforts have paid off: The main sources of pollution have been eliminated, and water in the Rhine River today is almost as pure as drinking water; long-absent fishes have returned; and projects are under way to restore riverbanks, control flooding, and clean up remaining pollutants.

CONCEPT CHECK STOP

1. **What** problems are associated with overdrawing surface water? with aquifer depletion?
2. **What** issues surround water problems of the Ogallala Aquifer? the Colorado River Basin?
3. **How** does international cooperation affect shared water resources?

Water Management

LEARNING OBJECTIVES

1. **Define** *sustainable water use.*
2. **Contrast** the benefits and drawbacks of dams and reservoirs.
3. **Give** examples of water conservation in agriculture, industry, and individual homes and buildings.

The main goal of water management is to provide a sustainable supply of high-quality water. **Sustainable water use** means careful human use of water resources so that water is available for future generations and for existing nonhuman needs.

sustainable water use The wise use of water resources, without harming the essential functioning of the hydrologic cycle or the ecosystems on which present and future humans depend.

Water supplies are obtained by building dams, diverting water, or removing salt from seawater or salty groundwater, through a process called *desalinization.* Conservation, which includes reusing water, recycling water, and improving water-use efficiency, augments water supplies and is an important aspect of sustainable water use. Economic policies are also important in managing water sustainably: When water is inexpensive, it tends to be wasted. Raising the price of water to reflect the actual cost generally promotes its more efficient use.

Dams and Reservoirs: Managing the Columbia River

Dams generate electricity and ensure a year-round supply of water in areas with seasonal precipitation or snowmelt, often for populations that have outgrown other water sources, but many people think their costs outweigh their benefits. In recent years scientists have come to understand how dams alter river ecosystems. Heavy sediment deposition can occur in the reservoir behind a dam, and the water that passes over a dam does not have its normal sediment load. As a result, the river floor downstream of a dam is scoured, producing a deep-cut channel that is a poor habitat for aquatic organisms.

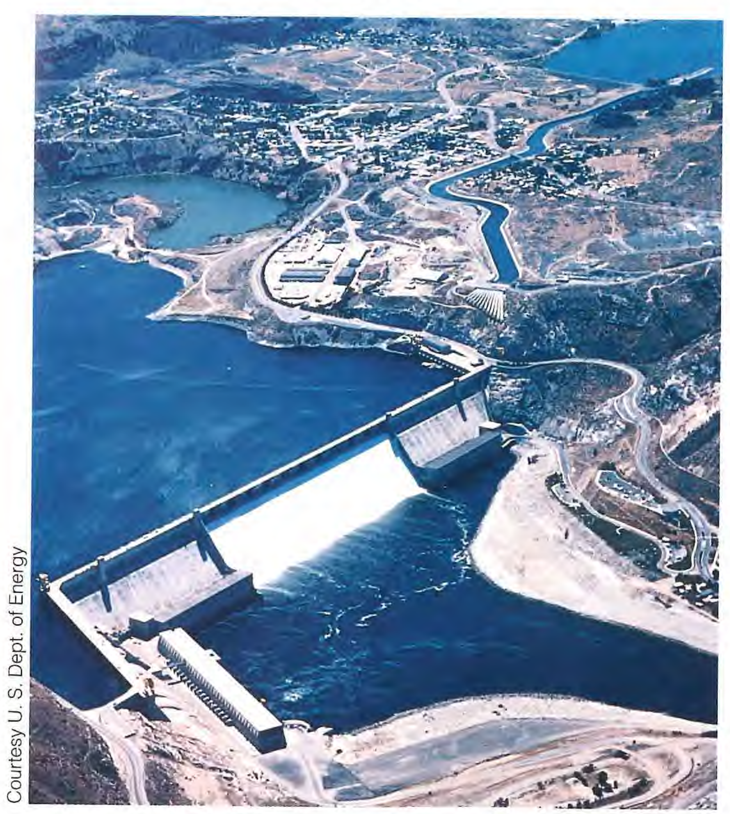
The Columbia River, the fourth-largest river in North America, illustrates the impact of dams on natural fish communities. There are more than 100 dams in the Columbia River system, 19 of which are major generators of hydroelectric power (**Figure 10.13**). The Columbia River system supplies municipal and industrial water to several major urban areas in the northwestern United States and irrigation water for more than 1.2 million hectares (3 million acres) of agricultural land.

As is often the case in natural resource management, one particular use of the Columbia River system may have a negative impact on other uses. The dams that generate electricity and control floods have adversely affected fish populations. The salmon population in the Columbia River system is only a fraction of what it was before the watershed was developed. The many dams that impede salmon migrations are widely considered the most significant factor in salmon decline. Projects to rebuild salmon populations have not proved particularly successful.

To protect remaining natural salmon habitats, several streams in the Columbia River system are off-limits for dam development. Many dams have fish ladders to allow some of the adult salmon to bypass the dams and continue their upstream migration (**Figure 10.14**). Underwater

Grand Coulee Dam on the Columbia River • Figure 10.13

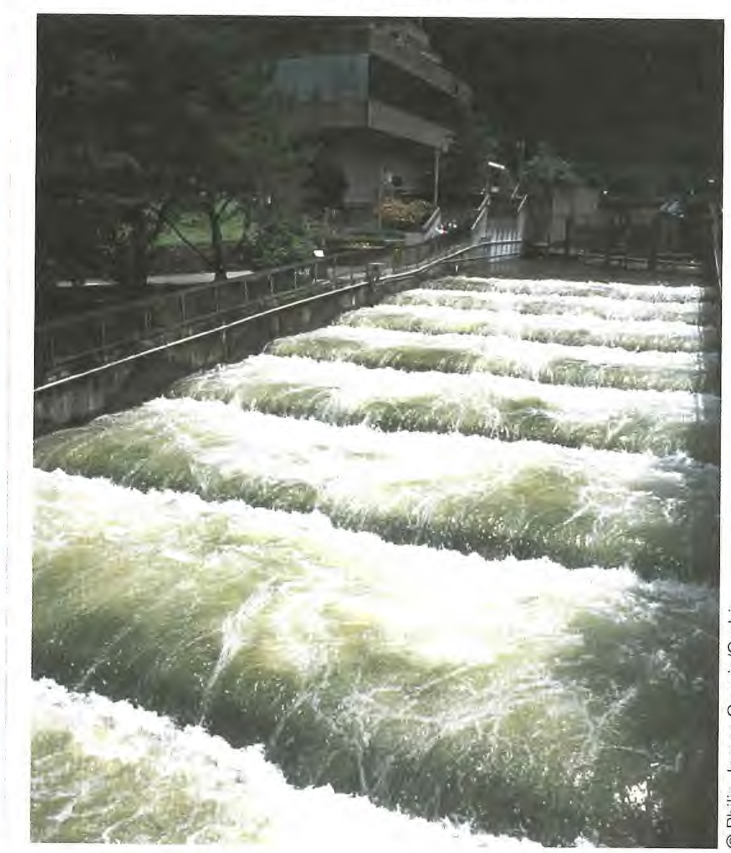
Shown are the dam and part of its reservoir, Lake Roosevelt. Dams provide electricity generation, flood control, and water recreation opportunities, but they disrupt or destroy natural river habitats and are expensive to build.



Courtesy U. S. Dept. of Energy

Fish ladder • Figure 10.14

This ladder is located at the Bonneville Dam on the Oregon side of the Columbia River. Fish ladders help migratory fishes to bypass dams in their migration upstream. Despite the installation of fish ladders, the salmon population remains low.



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screens and passages are being installed to steer young salmon (smolts) away from turbine blades, and at some sites the smolts are transported around dams.

Water Conservation

Today there is more competition than ever before among water users with different priorities (see pie charts on map in Figure 10.11), and water conservation measures are necessary to guarantee sufficient water supplies.

Reducing Agricultural Water Waste Irrigation generally makes inefficient use of water. Traditional irrigation methods involve flooding the land or diverting water to fields through open channels. Plants absorb only about 40 percent of the water that flood irrigation supplies to the soil; the rest of the water usually evaporates into the atmosphere, seeps into the ground, or leaves the fields as runoff transporting sediment.

One of the most important innovations in agricultural water conservation is **microirrigation**, also called **drip** or **trickle irrigation**, in which pipes with tiny holes bored in them convey water directly to individual plants (**Figure 10.15a**). Microirrigation substantially reduces the water needed to irrigate crops—usually by 40 percent to 60 percent compared to traditional irrigation—and also reduces the amount of salt that irrigation water leaves in the soil.

> **microirrigation**
> A type of irrigation that conserves water by piping it to crops through sealed systems.

Other measures that can save irrigation water include using lasers to level fields, and employing computer-controlled technology to place hoses and time water release, all of which allow more even water distribution, and making greater use of recycled wastewater. A drawback of such techniques is their cost, which makes them unaffordable for most farmers in highly developed countries, let alone subsistence farmers in developing nations.

Reducing Water Waste in Industry Electric power generators and many industrial processes require water. In the United States, five major industries—chemical products, paper and pulp, petroleum and coal, primary metals, and food processing—consume almost 90 percent of industrial water.

Stricter pollution-control laws provide some incentive for industries to conserve water. Industries usually recapture, purify, and reuse water to reduce their water use and their water treatment costs.

The potential for industries to conserve water is enormous. In 2010, for example, Jackson Family Wines in California began implementing a water recycling system estimated to eventually save the winery up to 6 million gallons of water annually and to greatly reduce their energy usage. In northeast China, a methanol plant reduces its overall water consumption by trading investments in local irrigation and water conservation projects for agricultural water-use quotas (**Figure 10.15b**).

International companies also have to consider water issues where they locate plants. Ford Motor Company reduced its global water use by 62 percent between 2000 and 2010. During the same period, its plant in Mexico's Sonoran Desert doubled production while cutting water consumption by 40 percent. The company has also installed complex water treatment systems that allow for reuse of 65 percent of its wastewater at plants in India and China—countries facing great water demands.

Reducing Municipal Water Waste Like industries, regions and cities—and the households within them—recycle or reuse water to reduce consumption (**Figure 10.15c**). For example, homes and other buildings can be modified to collect and store gray water. *Gray water* is water that has already been used in sinks, showers, washing machines, and dishwashers. Gray water is recycled to flush toilets, wash cars, or sprinkle lawns. In contrast to water *recycling*, wastewater *reuse* occurs when water is collected and treated before being redistributed. The reclaimed water is generally used for irrigation.

Cities also decrease water consumption by providing consumer education, requiring water-saving household fixtures, developing economic incentives to save water, and repairing leaky water supply systems. Also, increasing the price of water to approach its true cost promotes water conservation.

The average person in the United States uses 295 L (78 gal) of water per day at home on indoor uses. As a water user, you have a responsibility to use water carefully and wisely. The cumulative effect of many people practicing personal water conservation measures has a significant impact on overall water consumption.

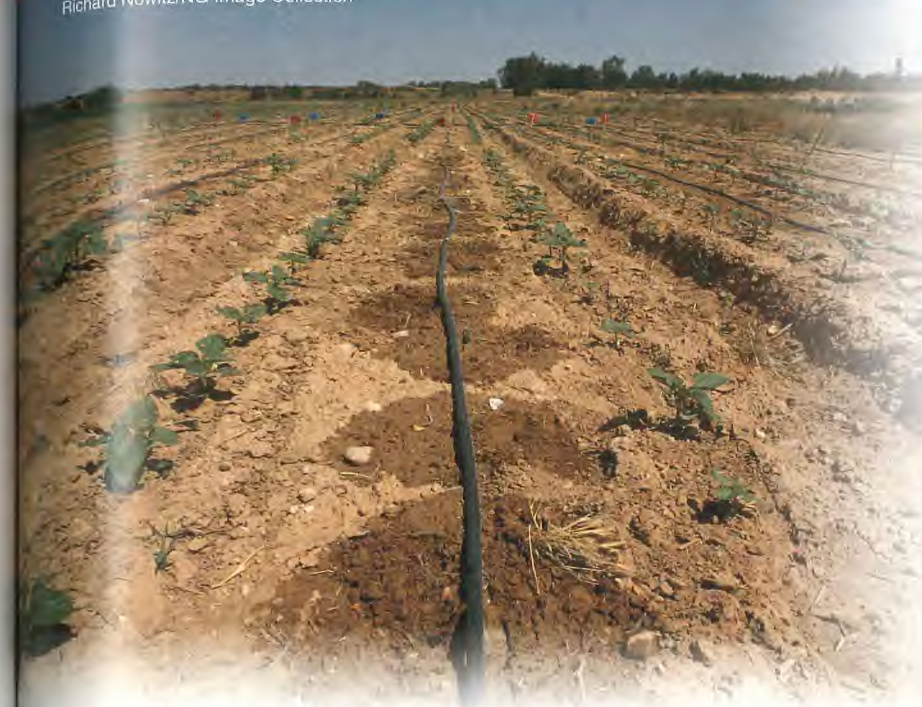
CONCEPT CHECK STOP

1. **What** is *sustainable water use*?
2. **What** are the benefits of dams on the Columbia River? the drawbacks?
3. **How** can individuals conserve and manage water resources?

Environmental InSight

Water conservation • Figure 10.15

THE PLANNER

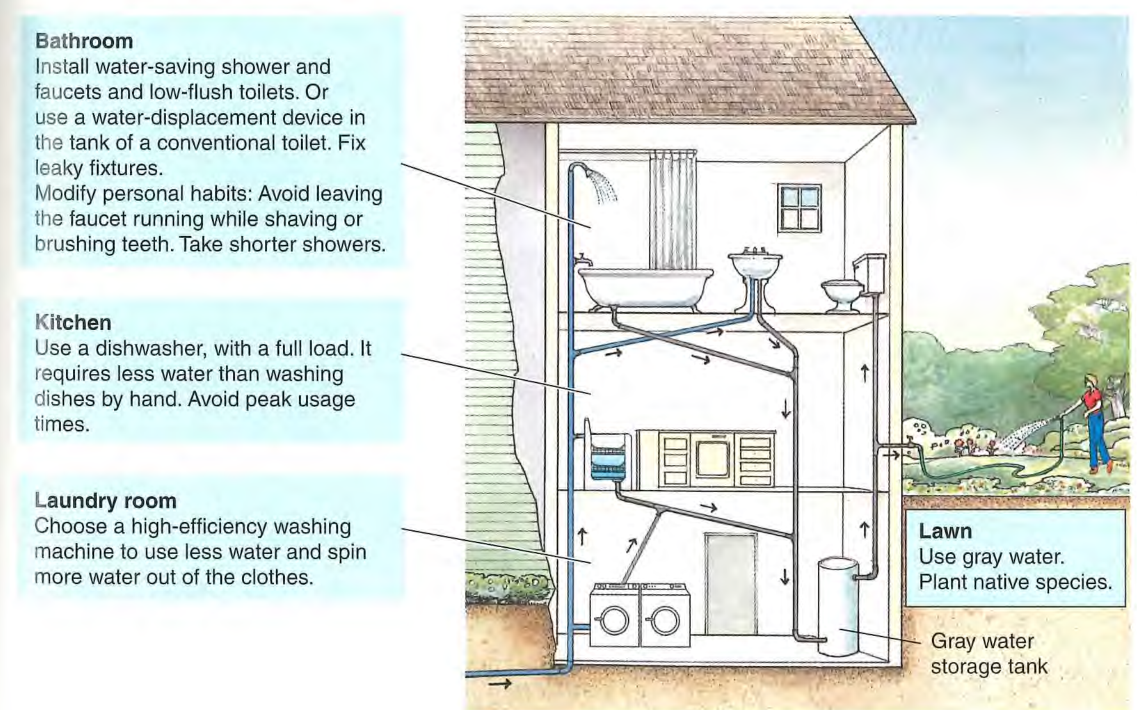


Richard Nowitz/NG Image Collection

a. **Microirrigation.** Close-up of a drip irrigation pipe system releasing water directly between young plants, eliminating much of the waste associated with traditional methods of irrigation. Photographed on an experimental farm in the Negev Desert, Israel.

© Peng Zhaozhi/Xinhua Press/Corbis

b. **Industrial Water Conservation.** A technician at a methanol plant in Lingwu, China, operates a pump involved in water recycling. The plant, part of Shenhua Ningxia Coal Industry Group, reduces its water consumption in part by trading water conservation technology, such as renovating old irrigation facilities, for agricultural water quotas in the region.



c. **Conserving Water at Home.** In your bathroom, kitchen, and laundry room, as well as on your lawn, you can take many steps to limit water use. Individual homes and buildings can be modified to collect and store "gray water"—water already used in sinks, showers, washing machines, and dishwashers—when clean water is not required: in flushing toilets, washing the car, and sprinkling the lawn, or, especially in the Southwest, irrigating golf courses. Permits to install gray water systems vary from state to state. Arizona and other states with severe water shortages are more flexible than other states about allowing gray water systems. Home owners can also conserve water used for landscaping by planting native species adapted to their local climate.

Water Pollution

LEARNING OBJECTIVES

1. **Define** water pollution.
2. **Discuss** how sewage is related to eutrophication, biochemical oxygen demand (BOD), and dissolved oxygen.
3. **Distinguish** between the two types of pollution sources and give examples of each.
4. **Describe** sources of groundwater pollution.

Water pollution is a global problem that varies in magnitude and type of pollutant from one region to another. In many locations, particularly in developing countries, the main water pollution issue is providing individuals with disease-free drinking water.

water pollution A physical, biological, or chemical change in water that adversely affects the health of humans and other organisms.

Types of Water Pollution

As discussed earlier in the chapter, water's chemical properties enable it to dissolve many substances, including pollutants. Water pollutants are divided into eight categories: sewage, disease-causing agents, sediment pollution, inorganic plant and algal nutrients, organic compounds, inorganic chemicals, radioactive substances, and thermal pollution. These eight types are not exclusive; for example, sewage can contain disease-causing agents, inorganic plant and algal nutrients, and organic compounds. Causes and examples of each type of water pollution are summarized in Table 10.1. Here we explore pollution threats associated with sewage.

Sewage The release of **sewage** into water causes several pollution problems. First, because sewage may carry disease-causing agents, water polluted with sewage poses a threat to public health (see Chapter 4). Sewage also generates two serious environmental problems: enrichment and oxygen demand. **Enrichment**, the fertilization of a body of water, is due to the presence of high levels of plant and algal nutrients such as nitrogen and phosphorus, both of which are sewage products. Microorganisms decompose sewage and other organic materials, but they require oxygen to do so. When an aquatic ecosystem contains high levels of sewage or other organic material, decomposing microorganisms use up most of the dissolved oxygen, leaving little available for fishes and other aquatic animals. At extremely low oxygen levels, these animals leave or die.

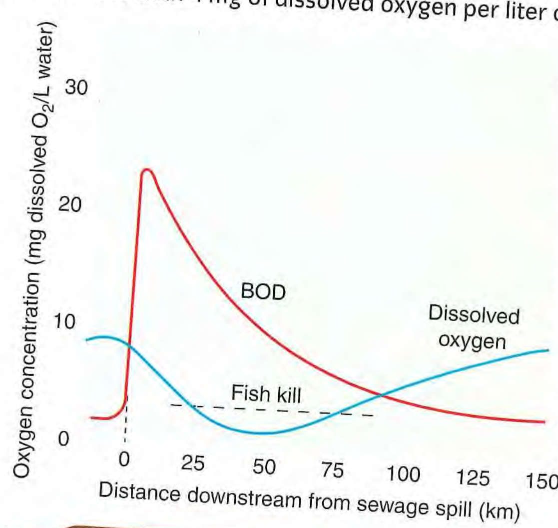
sewage Wastewater from drains or sewers (from toilets, washing machines, and showers); includes human wastes, soaps, and detergents.

biochemical oxygen demand (BOD) The amount of oxygen that microorganisms need to decompose biological wastes into carbon dioxide, water, and minerals.

Sewage and other organic wastes are measured in terms of their **biochemical oxygen demand (BOD), or biological oxygen demand.** BOD is usually expressed as milligrams of dissolved oxygen per liter of water for a specific number of days at a given temperature. A large amount of sewage in water generates a high BOD, which robs the water of dissolved oxygen (Figure 10.16).

Effect of sewage on dissolved oxygen and biochemical oxygen demand (BOD) • Figure 10.16

Note the initial oxygen depletion (blue line) and increasing BOD (red line) close to the sewage spill (at distance 0). The stream gradually recovers as the sewage is diluted and degraded. As indicated by the dashed line, fishes can't live in water that contains less than 4 mg of dissolved oxygen per liter of water.



Adapted from Joesten, M.D., and J.L. Wood. *World of Chemistry*, 2nd edition. Philadelphia: Saunders College Publishing (1996).

Interpreting Data

Are fish located 60 km downstream of the spill likely to survive? What about those located 5 km from the spill? Explain why dissolved oxygen is lower slightly farther from the spill than right next to it.

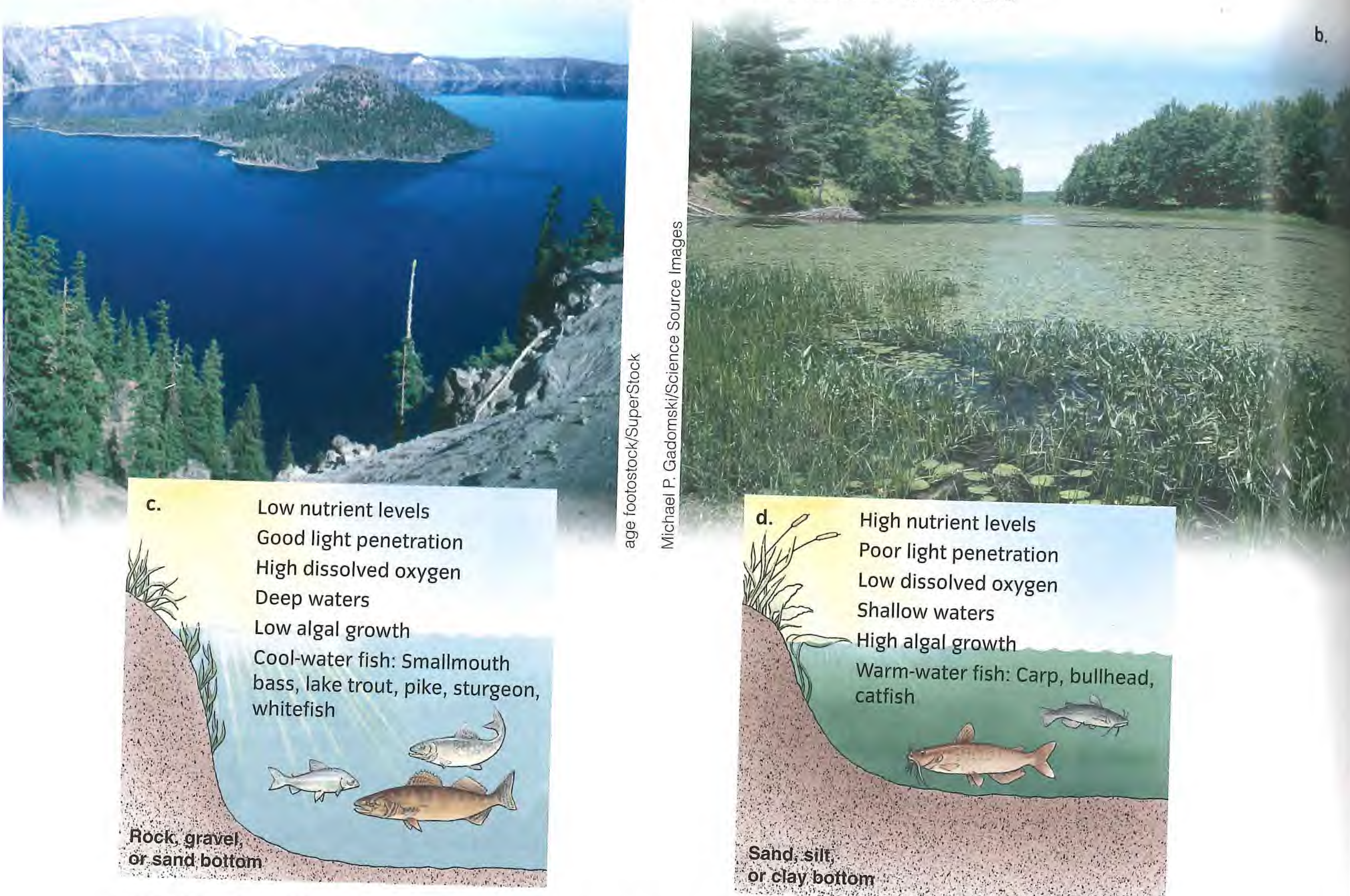
Types of water pollution • Table 10.1

Type of pollution	Source	Examples	Effects
Sewage 	Wastewater from drains or sewers	Human wastes, soaps, detergents	Threatens public health; causes enrichment and high biochemical oxygen demand (BOD)
Disease-causing agents 	Wastes of infected individuals	Bacteria, viruses, protozoa, parasitic worms	Spread infectious diseases, including cholera, dysentery, typhoid, infectious hepatitis, and poliomyelitis.
Sediment pollution 	Erosion of agricultural lands, forest soils exposed by logging, degraded stream banks, overgrazed rangelands, strip mines, construction	Clay, silt, sand, and gravel, suspended in water and eventually settling out	Reduces light penetration, limiting photosynthesis and disrupting food chain; clogs gills and feeding structures of aquatic animals; carries and deposits disease-causing agents and toxic chemicals
Inorganic plant and algal nutrients 	Human and animal wastes, plant residues, atmospheric deposition, fertilizer runoff from agricultural and residential land	Nitrogen and phosphorus	Stimulate growth of excess plants and algae, which disrupt natural balance between producers and consumers and cause enrichment, bad odors, and high BOD; suspected of causing red tides, explosive blooms of toxic pigmented algae that threaten the health of humans and aquatic animals in coastal areas
Organic compounds 	Landfills, agricultural runoff, industrial wastes	Synthetic chemicals: pesticides, cleaning solvents, industrial chemicals, plastics	Contaminate groundwater and surface water; threaten drinking water supply; found in some bottled water; some are suspected endocrine disrupters
Inorganic chemicals 	Industries, mines, irrigation runoff, oil drilling, urban runoff from storm sewers, deposition from industrial emissions, especially coal burning	Acids, salts, heavy metals such as lead, mercury, and arsenic	Contaminate groundwater and surface water; threaten drinking water supply; found in some bottled water; don't easily degrade or break down
Radioactive substances 	Nuclear power plants, nuclear weapons industry, medical and scientific research facilities	Unstable isotopes of radioactive minerals such as uranium and thorium	Contaminate groundwater and surface water; threaten drinking water supply
Thermal pollution 	Industrial runoff	Heated water produced during industrial processes, then released into waterways	Depletes water of oxygen and reduces amount of oxygen that water can hold; reduced oxygen threatens fishes

WHAT A SCIENTIST SEES

Oligotrophic and Eutrophic Lakes

a. and **b.** The average person looking at these two photographs would notice the dramatic differences between them but wouldn't understand the environmental conditions responsible for the differences. **a.** Shows Crater Lake, an oligotrophic lake in Oregon; **b.** shows a small eutrophic lake in the Catskill Mountains, New York.



c. and **d.** Aquatic ecologists understand the characteristics of oligotrophic and eutrophic lakes. **c.** An oligotrophic lake has a low level of inorganic plant and algal nutrients; its fish species require cool, oxygen-rich water. **d.** A eutrophic lake has a high level of these nutrients; its fish species tolerate warm, low-oxygen water.

BOD measures how fast microorganisms remove oxygen from a body of water. When dissolved oxygen levels are low, anaerobic (without oxygen) microorganisms produce compounds with unpleasant odors, further deteriorating water quality.

Eutrophication: An Enrichment Problem Lakes, estuaries, and slow-flowing streams that have minimal levels of nutrients are considered unenriched, or oligotrophic. An **oligotrophic** lake has cool, clear water and supports small populations of aquatic organisms (see *What a Scientist Sees,* parts **a** and **c**). **Eutrophication** is the enrichment of a lake, an estuary, or a slow-flowing stream by inorganic plant and algal nutrients such as phosphorus; an enriched body of water is said to be **eutrophic**. The enrichment of water results in an increased photosynthetic productivity. The water in a eutrophic lake is cloudy and usually resembles pea soup because of the presence of vast numbers of algae and cyanobacteria (see parts **b** and **d**). When these organisms die, microorganisms that decompose them use up much of the lake's oxygen. The lake floor has a high BOD, and the only fish that survive there are warm-water species that tolerate low levels of oxygen.

Over vast periods, oligotrophic lakes, estuaries, and slow-moving streams become eutrophic naturally. The bodies of water are slowly enriched and grow shallower from the immense number of dead organisms that have settled in the sediments. Gradually, plants take root, slowly forming marshes. Some human activities, however, greatly accelerate eutrophication. This fast, human-induced process is usually called **artificial eutrophication** to distinguish it from natural eutrophication. Artificial eutrophication results from enrichment of aquatic ecosystems by nutrients found predominantly in fertilizer runoff and sewage.

artificial eutrophication Overnourishment of an aquatic ecosystem by nutrients such as nitrates and phosphates due to human activities such as agriculture and discharge from sewage treatment plants.

Sources of Water Pollution

Water pollutants come from both natural sources and human activities. Natural sources of pollution such as mercury and arsenic tend to be local concerns, but human-generated pollution is generally more widespread.

The sources of water pollution are classified into two types: point source pollution and nonpoint source pollution. **Point source pollution** is discharged into the environment through pipes, sewers, or ditches from specific sites such as factories or sewage treatment plants (**Figure 10.17a**). Point source pollution is relatively easy to control legislatively, but accidents still occur.

point source pollution Water pollution that can be traced to a specific point of entry.

nonpoint source pollution Pollution that enters bodies of water over large areas rather than being concentrated at a single point of entry.

The enormous damage sustained by a nuclear reactor in Fukushima, Japan, following a March 2011 earthquake and tsunami, produced point source pollution in the form of tainted reactor water. A year after the disaster, technicians struggled to prevent the release of radioactive water from the leaking reactor compound.

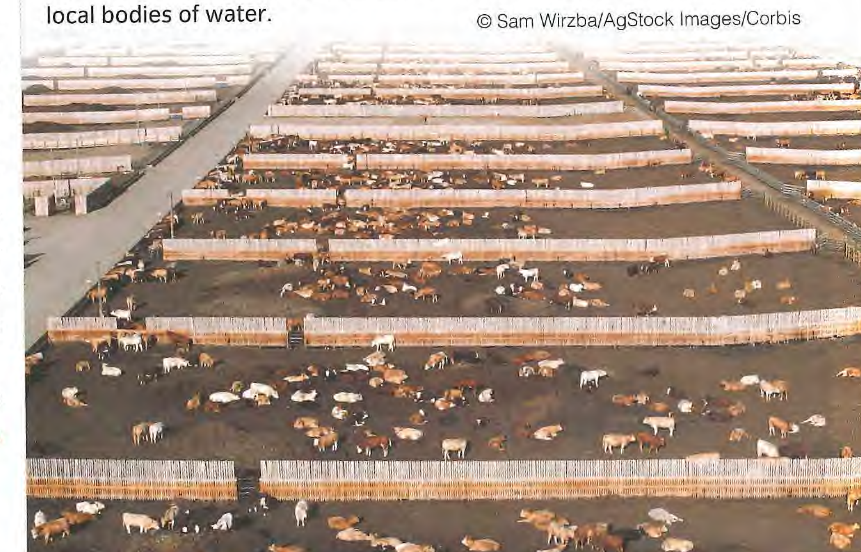
Pollutants that enter bodies of water over large areas rather than at a single point cause **nonpoint source pollution**, also called *polluted runoff.* Nonpoint source pollution occurs when precipitation moves over and through the soil, picking up and carrying away pollutants that are eventually deposited in lakes, rivers, wetlands, groundwater, estuaries, and the ocean (**Figure 10.17b**). Nonpoint source pollution includes agricultural runoff (such as fertilizers, pesticides, livestock wastes, and salt from irrigation), mining wastes (such as acid mine drainage), municipal wastes (such as inorganic plant and algal nutrients), construction sediments, and soil erosion (from fields, logging operations, and eroding stream banks). Although nonpoint sources cover more than one site and can be hard to identify, their combined effect can be huge.

Source of water pollution • Figure 10.17

a. Point source pollution. Landfill leachate flows out of a pipe in Vashon, Washington.

b. Nonpoint source pollution. Livestock wastes from a feedlot such as this one in Alberta, Canada, can be carried by runoff to local bodies of water.

© Sam Wirzba/AgStock Images/Corbis



According to the Environmental Protection Agency (EPA), agriculture is the leading source of water quality impairment of surface waters nationwide and is responsible for 72 percent of the water pollution in U.S. rivers. Agricultural practices produce several types of pollutants that contribute to nonpoint source pollution. Fertilizer runoff causes water enrichment. Animal wastes and plant residues in waterways, even treated human wastes applied to fields as fertilizer, produce high BODs and high levels of suspended solids as well as water enrichment. Highly toxic chemical pesticides may leach into the soil and from there into water or may find their way into waterways by adhering to sediment particles. Soil erosion from fields and rangelands causes sediment pollution in waterways. To address the problem of runoff from animal wastes, the U.S. Department of Agriculture developed guidelines to help livestock operations prepare Comprehensive Nutrient Management Plans to prevent manure from becoming polluted runoff.

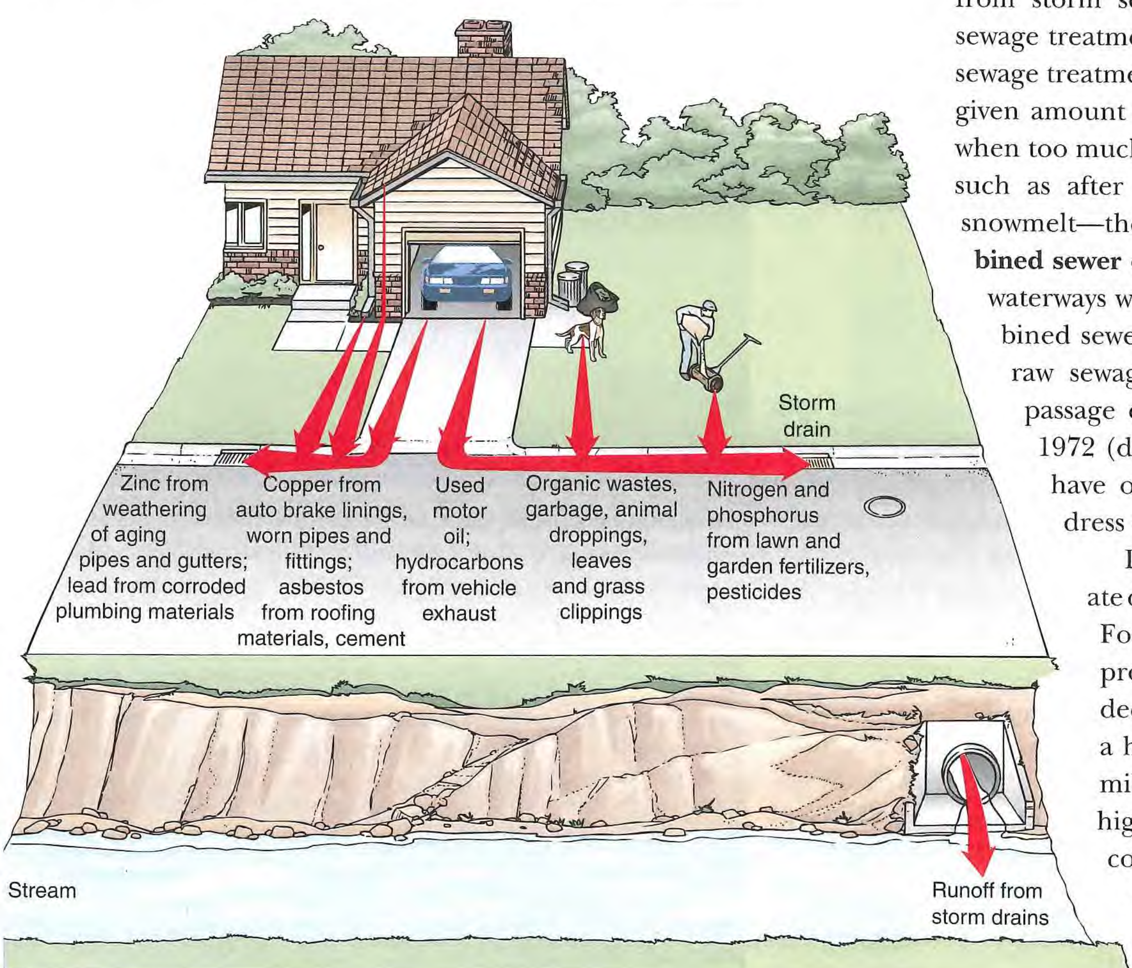
Although sewage is the main pollutant produced by cities and towns, municipal water pollution also has a nonpoint source: urban runoff from storm sewers (Figure 10.18). The water quality of urban runoff from city streets is often worse than that of sewage. Urban runoff carries salt from roadways, untreated garbage, animal wastes, construction sediments, and traffic emissions (via rain carrying air pollutants). It may often contain such contaminants as asbestos, chlorides, copper, cyanides, grease, hydrocarbons, lead, motor oil, organic wastes, phosphates, sulfuric acid, and zinc.

Nearly 800 U.S. cities, including New York and San Francisco, have **combined sewer systems**, in which human and industrial wastes mix with urban runoff from storm sewers before flowing into sewage treatment plants. Even the largest sewage treatment plant can process only a given amount of wastewater each day, so when too much water enters the system—such as after a heavy rainfall or large snowmelt—the excess, known as **combined sewer overflow**, flows into nearby waterways without being treated. Combined sewer overflow, which contains raw sewage, has been illegal since passage of the Clean Water Act of 1972 (discussed shortly), but cities have only recently begun to address the problem.

Different industries generate different types of pollutants. Food-processing industries produce organic wastes that decompose quickly but have a high BOD. Pulp and paper mills also release wastes with a high BOD and produce toxic compounds and sludge. The paper industry, however, has begun to adopt new manufacturing

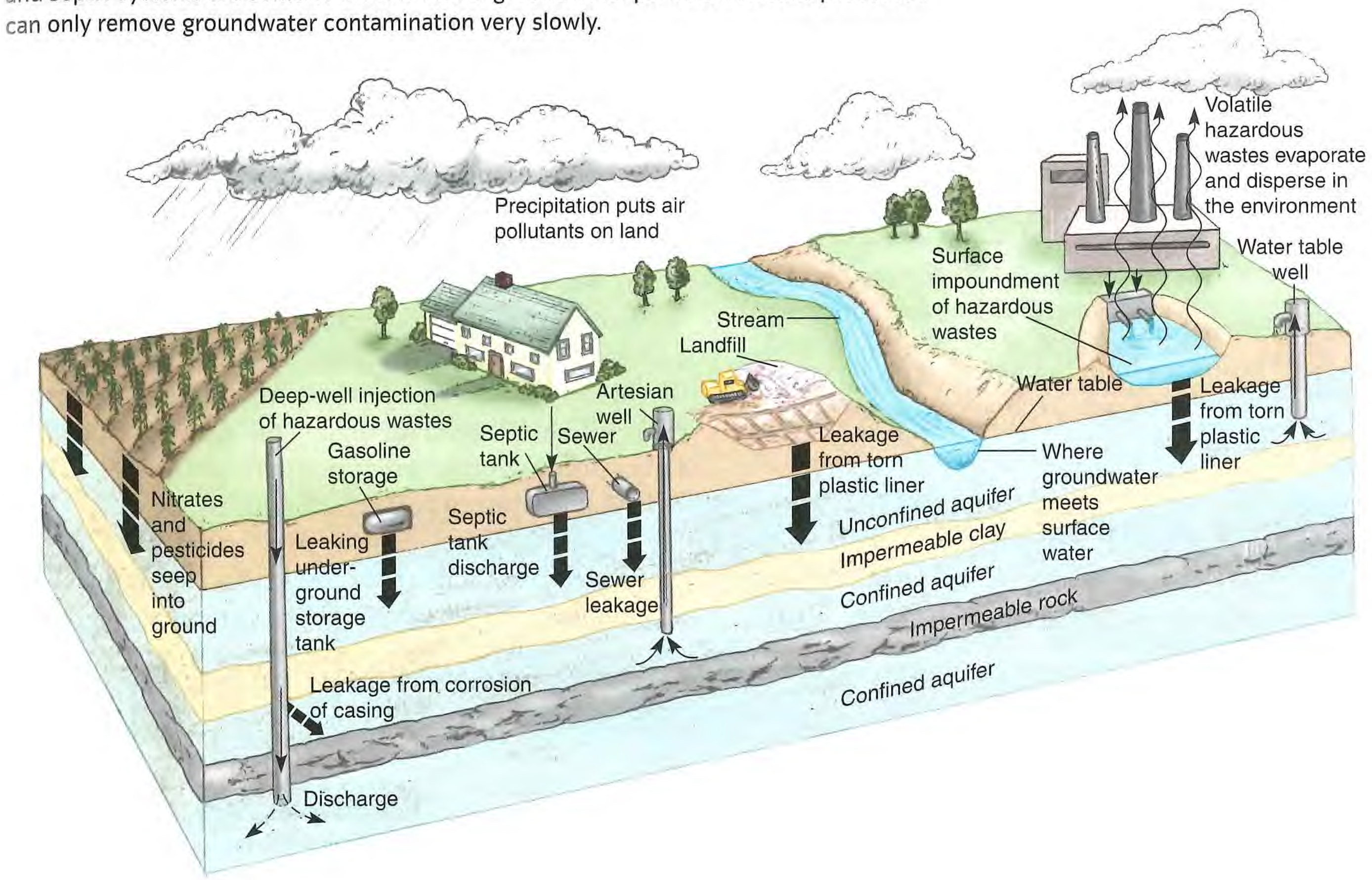
Urban runoff • Figure 10.18

Many pollutants may be carried from storm drains on streets to streams and rivers. The largest single pollutant in urban runoff is organic waste, which removes dissolved oxygen from water as it decays. Fertilizers cause excessive algal growth, further depleting oxygen levels. Other everyday pollutants include used motor oil, which is often illegally poured into storm drains, and heavy metals.



Sources of groundwater contamination • Figure 10.19

Agricultural practices, sewage (both treated and untreated), landfills, industrial activities, and septic systems are some of the sources of groundwater pollution. Natural processes can only remove groundwater contamination very slowly.



methods, such as eliminating chlorine as a bleaching agent, that produce significantly less toxic effluents.

Groundwater Pollution

Roughly half the people in the United States obtain their drinking water from groundwater, which is also withdrawn for irrigation and industry. In recent years, the quality of the nation's groundwater has become a concern. The most common pollutants, such as pesticides, fertilizers, and organic compounds, seep into groundwater from municipal sanitary landfills, underground storage tanks, backyards, golf courses, and intensively cultivated agricultural lands (Figure 10.19). Concern over groundwater safety has grown over the recent boom in hydraulic fracturing, a water-intensive process used to release natural gas and oil from underground rock formations. Many local conflicts have arisen over the potential contamination of drinking water by fracturing chemicals.

Currently, most of the groundwater supplies in the United States are of good quality and don't violate standards established to protect human health. However, areas that do experience local groundwater contamination face quite a challenge: Cleanup of polluted groundwater is costly, takes years, and in some cases is not technically feasible.

CONCEPT CHECK STOP

1. **What** is water pollution?
2. **What** is biochemical oxygen demand? How is BOD related to sewage?
3. **How** does point source pollution differ from nonpoint source pollution? What are some examples of each?
4. **What** are some common sources of groundwater pollutants?

Improving Water Quality

LEARNING OBJECTIVES

1. **Describe** how most drinking water is purified in the United States.
2. **Distinguish** among primary, secondary, and tertiary treatments for wastewater.
3. **Compare** the goals of the Safe Drinking Water Act and the Clean Water Act.

Water quality is improved by removing contaminants from the water supply before and after it is used. Technology assists in both processes.

Purification of Drinking Water

Most U.S. municipal water supplies are treated before the water is used so it is safe to drink (**Figure 10.20**).

Turbid water is treated with a chemical coagulant that causes the suspended particles to clump together and settle out. The water is then filtered through sand to remove remaining suspended materials as well as many microorganisms.

In the final purification step before distribution in the water system, the water is disinfected to kill any remaining disease-causing agents. The most common way to disinfect water is to add chlorine. A small amount of chlorine is left in the water to provide protection during its distribution through many kilometers of pipes. Other disinfection systems use ozone or ultraviolet (UV) radiation in place of chlorine.

Although adding chlorine to drinking water has undoubtedly saved millions of lives, chlorine by-products are tentatively linked to several kinds of cancer, increased risk of miscarriages, and possibly rare birth defects. After reviewing these potential threats, the EPA proposed in 1994 that water treatment facilities reduce the maximum permissible level of chlorine in drinking water. Alternatives to chlorination include using *chloramine*, a disinfectant that does not form harmful by-products, and filtering water through activated carbon granules, a method requiring less chlorine that is used by the city of Cincinnati. Europe has widely adopted UV disinfection.

Treatment of water for municipal use • Figure 10.20 THE PLANNER WileyPLUS

1 The water supply for a town may be stored in a reservoir, as shown, or obtained from groundwater.

2 The water is treated before use so it is safe to drink.

3 After use, municipal sewer lines collect the wastewater.

4 The quality of the wastewater is fully or partially restored by sewage treatment before the treated effluent is dispersed into a nearby body of water.

Municipal Sewage Treatment

Wastewater, including sewage, usually undergoes several treatments at a sewage treatment plant to prevent environmental and public health problems. The treated wastewater is then discharged into rivers, lakes, or the ocean.

Primary treatment removes suspended and floating particles, such as sand and silt, through mechanical processes such as screening and gravitational settling (**Figure 10.21**, left side). The solid material that settles out at this stage is called **primary sludge**. **Secondary treatment** uses microorganisms (aerobic bacteria) to decompose the suspended organic material in wastewater (Figure 10.21, right

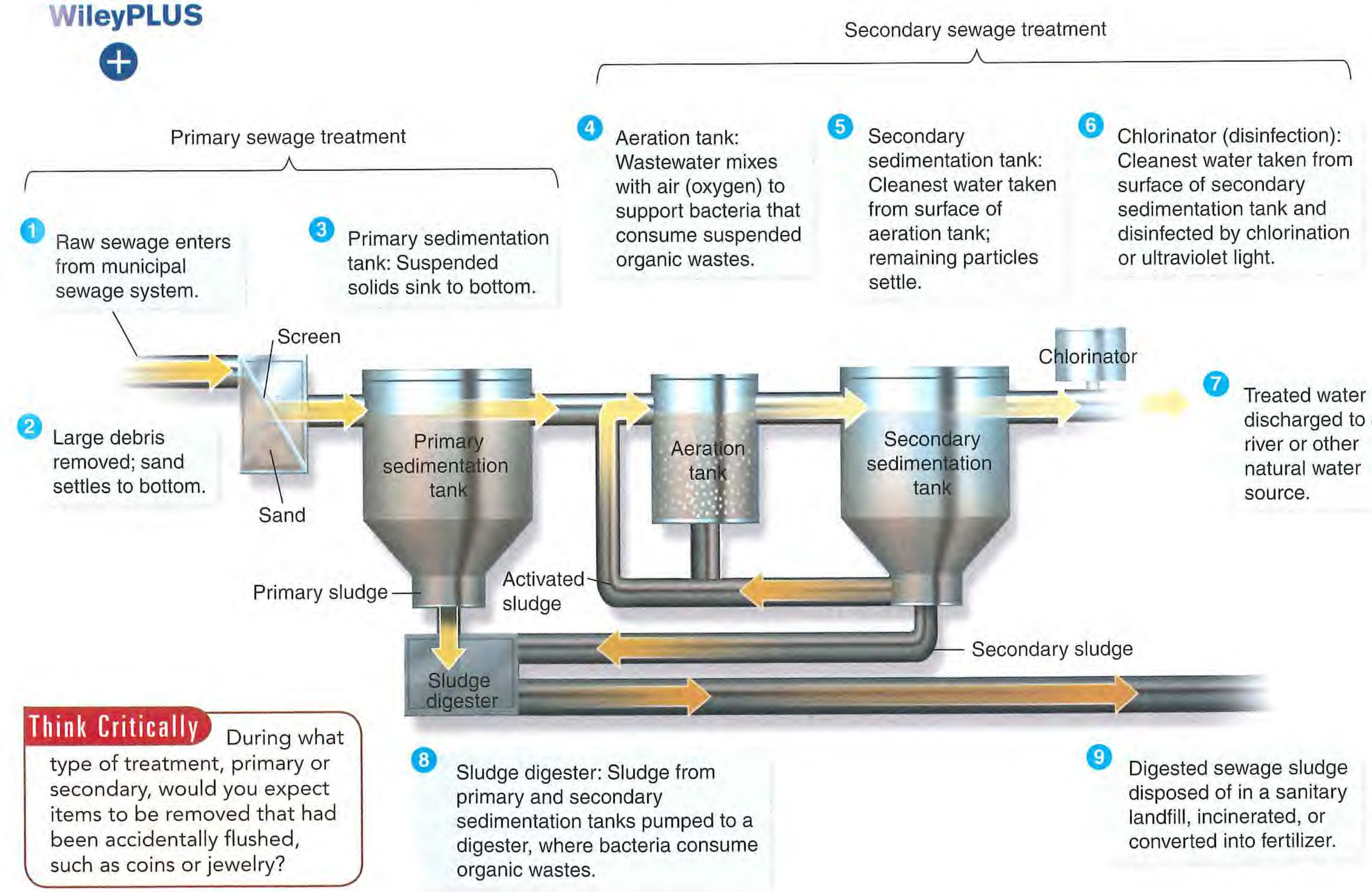
primary treatment Treatment of wastewater that involves removing suspended and floating particles through mechanical processes.

secondary treatment Biological treatment of wastewater to decompose suspended organic material; secondary treatment reduces the water's biochemical oxygen demand.

PROCESS DIAGRAM

Primary and secondary sewage treatment • Figure 10.21 THE PLANNER

WileyPLUS



Think Critically During what type of treatment, primary or secondary, would you expect items to be removed that had been accidentally flushed, such as coins or jewelry?

Wastewater treatment in constructed wetlands, Orlando, Florida • Figure 10.22

Influent is pumped in at the Orlando Wetlands Park, where more than 2 million aquatic plants and 200,000 trees planted remove excess nutrients from reclaimed wastewater influent.

© Carrie Garcia/Alamy

side). After several hours of processing, the particles and microorganisms are allowed to settle out, forming **secondary sludge**, a slimy mixture of bacteria-laden solids. Water that has undergone primary and secondary treatment is clear and free of organic wastes such as sewage. About 11 percent of U.S. wastewater treatment facilities have primary treatment only; about 62 percent have both primary and secondary treatments.

Even after primary and secondary treatments, wastewater still contains pollutants, such as dissolved minerals, heavy metals, viruses, and organic compounds. Advanced wastewater treatment methods, or **tertiary treatment**, include a variety of biological, chemical, and physical processes. Tertiary treatment reduces phosphorus and nitrogen, the nutrients most commonly associated with enrichment, and purifies wastewater for reuse in communities where water is scarce. The wastewater treatment facilities for about 27 percent of the U.S. population have primary, secondary, and tertiary treatments.

> **tertiary treatment** Advanced wastewater treatment methods that are sometimes employed after primary and secondary treatments.

Disposal of primary and secondary sludge is a major problem associated with wastewater treatment. Sludge is generally handled by application to soil as fertilizer, incineration, disposal in a sanitary landfill, or anaerobic digestion. (In anaerobic digestion, bacteria break down the organic material in sludge in the absence of oxygen.)

Alternative Wastewater Treatment Some communities have adopted an environmentally innovative and economical approach to wastewater treatment. In the mid-1980s the city of Orlando, Florida, constructed artificial wetlands to treat reclaimed water from a municipal wastewater treatment plant. The Orlando Wetlands Park treats 61 million liters (16 million gallons) each day of treated effluent, across three separate wetland communities established on 494 hectares (1220 acres) of former pastureland (Figure 10.22). In what could be called an "advanced tertiary" process, the wetlands absorb and assimilate contaminants normally removed through more expensive treatment methods. The park also provides wildlife habitat for many organisms and opportunities for human recreation.

Controlling Water Pollution

Many governments have passed legislation to control water pollution. In part because they are more easily identified, point source pollutants lend themselves to effective control more readily than do nonpoint source pollutants.

The two U.S. laws that have the most impact on water quality today are the Safe Drinking Water Act and the Clean Water Act. The **Safe Drinking Water Act**, passed in 1974, set uniform federal standards for drinking water, to guarantee safe public water supplies throughout the United States. This law required the EPA to determine the **maximum contaminant level**, which is the maximum permissible amount of any water pollutant that might adversely affect human health. The EPA oversees the states to ensure that they adhere to the maximum contaminant levels for specific water pollutants. A 1996 amendment to the Safe Drinking Water Act requires municipal water suppliers to tell consumers what contaminants are present in their city's water and whether these contaminants pose a health risk.

The **Clean Water Act** affects the quality of rivers, lakes, aquifers, estuaries, and coastal waters in the United States. Originally passed as the Water Pollution Control Act of 1972, it was amended and renamed the Clean Water Act of 1977; additional amendments were made in 1981 and 1987. The Clean Water Act has two basic goals: to eliminate the discharge of pollutants in U.S. waterways and to attain water quality levels that make these waterways safe for fishing and swimming. Under the provisions of this act, the EPA is required to set up and monitor **national emission limitations**, the maximum permissible amounts of water pollutants that can be discharged from a sewage treatment plant, factory, or other point source.

Overall, the Clean Water Act has effectively improved the quality of water from point sources. According to the EPA, nonpoint source pollution is a major cause of water pollution, yet it is much more difficult and expensive to control than point source pollution. Controlling nonpoint source pollution can require regulating land use, agricultural practices, and many other activities. Such regulation necessitates the interaction and cooperation of many government agencies, environmental organizations, and private citizens, which can be enormously challenging. The 1987 amendments to the Clean Water Act expanded regulations on nonpoint sources.

The United States has improved its water quality in the past several decades and demonstrated that the environment recovers once pollutants are eliminated. Much remains to be done, however. The EPA's 2004 *National Water Quality Inventory* indicated that water pollution has increased in U.S. rivers, lakes, estuaries, and coastal areas in recent years. According to the report, 44 percent of the nation's rivers, 64 percent of its lakes, and 30 percent of its estuaries were too polluted to support one or more designated uses, including recreation, fishing, or providing drinking water.

Preventing Water Pollution at Home Although individuals produce little water pollution, the collective effect of municipal water pollution, even in a small neighborhood, can be quite large. There are many things you can do to protect surface waters and groundwater from water pollution (see Table 10.2); many municipalities have specific regulations or requirements that cover these measures.

Preventing water pollution at home • Table 10.2

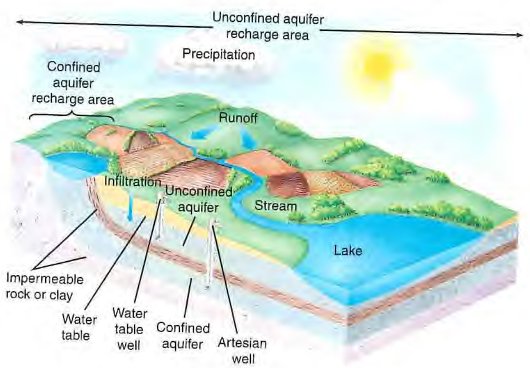
Location	What you can do
Bathroom 	Never throw unwanted medicines down the toilet.
Kitchen 	Use the smallest effective amount of toxic household chemicals such as oven cleaners, mothballs, drain cleaners, and paint thinners. Substitute less hazardous chemicals wherever possible. Dispose of unwanted hazardous household chemicals at hazardous waste collection centers. Avoid disposing of cooking wastes and uneaten food in the sink drain. Most foods increase BOD levels in sewage. Grease and oils can be hard on wastewater treatment plants. Consider composting fruit and vegetable wastes.
Driveway/car 	Never pour used motor oil or antifreeze down storm drains or on the ground. Recycle these chemicals at service stations or local hazardous waste collection centers. Clean up spilled oil, brake fluid, and antifreeze, and sweep sidewalks and driveways instead of hosing them off. Dispose of dirt properly; don't sweep it into gutters or storm drains. Drive less: Air pollution emissions from automobiles eventually get into surface water and groundwater. Toxic metals and oil by-products deposited on roads by vehicles are washed into surface waters by precipitation.
Lawn and garden 	Pick up pet waste and dispose of it in the garbage or toilet. If left on ground, it eventually washes into waterways, where it can contaminate shellfish and enrich water. Replace some grass lawn areas with trees, shrubs, and ground covers, which absorb up to 14 times more precipitation and require little or no fertilizer. To reduce erosion, use mulch to cover bare ground. Use fertilizer sparingly; excess fertilizer leaches into groundwater or waterways. Never apply fertilizer near surface water. Make sure that gutters and downspouts drain onto water-absorbing grass or graveled areas instead of onto paved surfaces.

Summary

THE PLANNER

1 The Importance of Water 244

1. Water molecules are **polar**: The negatively charged (oxygen) end of one molecule is attracted to the positively charged (hydrogen) end of another molecule, forming a **hydrogen bond**.
2. Hydrogen bonds are the basis for many of water's properties, including its high melting point, high boiling point, high heat capacity, and dissolving ability.
3. In the **hydrologic cycle**, water continuously circulates through the abiotic environment. **Surface water** is precipitation that remains on the surface. **Runoff** is the movement of fresh water from precipitation and snowmelt to rivers, lakes, wetlands, and the ocean. **Groundwater** is the supply of fresh water that is stored in **aquifers**, and underground reservoirs.



2 Water Resource Problems 246

1. **Aquifer depletion** is the removal of groundwater faster than it can be recharged. **Saltwater intrusion** is the movement of seawater into a freshwater aquifer near the coast. Overdrawing surface water causes **wetlands** to dry up and **estuaries** to become saltier. **Salinization** is the gradual accumulation of salt in soil, often due to improper irrigation.
2. Farmers on the U.S. High Plains are depleting water from the **Ogallala Aquifer** much faster than nature replaces it. In the Colorado River Basin, rapid population growth upstream threatens the water supply of users downstream.
3. Most of the world's major watersheds are shared between at least two nations. International cooperation is often required to manage shared water use.

3 Water Management 254

1. **Sustainable water use** is the wise use of water resources, without harming the hydrologic cycle or the ecosystems on which humans depend.
2. Dams and reservoirs allow rivers to be tapped for hydroelectric power and are used to supply municipal and industrial water, but they are expensive to build and significantly alter the natural environment.
3. **Microirrigation** is an innovative type of irrigation that conserves water by piping it to crops through sealed systems. Industries and cities can employ measures to recapture, purify, and reuse water in homes and buildings.

4 Water Pollution 258

1. **Water pollution** is a physical, biological, or chemical change in water that adversely affects the health of humans and other organisms.
2. **Sewage** is wastewater from drains or sewers. It carries disease-causing agents and causes **enrichment**, the fertilization of a body of water due to high levels of nutrients. **Artificial eutrophication** is overnourishment of an aquatic ecosystem due to human activities. Sewage in water also raises the **biochemical oxygen demand (BOD)**, the amount of oxygen that microorganisms need to decompose biological wastes. A high BOD decreases water quality.
3. **Point source pollution** is water pollution that can be traced to a specific point of entry, such as wastewater released from a factory or sewage treatment plant. **Nonpoint source pollution** includes pollutants that enter bodies of water over large areas, such as agricultural runoff or municipal wastes.
4. Most of the nation's groundwater supplies are of good quality but are threatened by pollutants such as pesticides, fertilizers, and organic compounds.

5 Improving Water Quality 264

1. Most U.S. municipal water supplies are treated so that the water is safe to drink. A chemical coagulant traps suspended particles, filtration removes suspended materials and microorganisms, and disinfection kills disease-causing agents.
2. Wastewater usually undergoes several treatments at a sewage treatment plant. **Primary treatment** removes suspended and floating particles from wastewater by mechanical processes. **Secondary treatment**, which reduces water's biochemical oxygen demand, treats wastewater biologically to decompose suspended organic material. **Tertiary treatment** reduces pollutants such as phosphorus and nitrogen.
3. The **Safe Drinking Water Act** protects the safety of the nation's drinking water. The **Clean Water Act** affects the quality of U.S. rivers, lakes, aquifers, estuaries, and coastal waters.

Key Terms

- aquifer depletion 248
- artificial eutrophication 261
- biochemical oxygen demand (BOD) 258
- groundwater 245
- microirrigation 256
- nonpoint source pollution 261
- point source pollution 261
- primary treatment 265
- runoff 245
- salinization 250
- saltwater intrusion 248
- secondary treatment 265
- sewage 258
- surface water 245
- sustainable water use 254
- tertiary treatment 266
- water pollution 258

What is happening in this picture?

Tyrone Turner/National Geographic Society

- Rain soaks the streets of New Orleans' French Quarter.
- How might the hydrologic cycle be linked to potential groundwater pollution in this type of urban setting?
- What unique property of water allows it to carry pollutants?
- What about the structure of water molecules determines why water on Earth is most often found in this liquid form?

Critical and Creative Thinking Questions

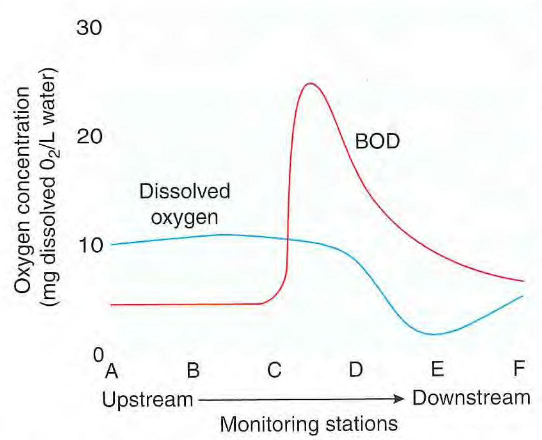
1. Which water resource problems likely played a role in the lack of access to fresh water in developing nations such as Nigeria? If they could be implemented, which approaches to water management and water conservation might improve access to water?
2. Briefly describe the complexity of international water use, comparing the Rhine River and the Aral Sea examples.

Sustainable Citizen Question

3. Outline a brief water conservation plan for your own daily use. Take into account both the quantity and quality of water you use. How could you use water more sustainably?

4. What role, if any, do aquifer depletion, overdrawing of surface waters, and salinization of irrigated soil play in the water problems associated with the Ogalla Aquifer and the Colorado River Basin? How are these issues affected by drought and by development?
5. Explain whether each of the following represents point or nonpoint source pollution: fertilizer runoff, thermal pollution from a power plant, urban runoff, sewage from a ship, and erosion sediments from deforestation. Which is more difficult to control, nonpoint pollution or point source pollution? why?
6. What steps are taken in the purification of drinking water to kill disease-causing agents?
7. What roles, if any, do bacteria play in primary and secondary treatment of wastewater?
8. Is the Clean Water Act related to the quality of U.S. public drinking water? Explain your answer.
9. Compare the benefits and drawbacks of China's Three Gorges Dam. Do you think the dam will do more harm or more good for China? Explain your answer.

10–11. The graph reflects the monitoring of dissolved oxygen concentrations at six stations along a river. The stations are located 20 m (66 ft) apart, with A the farthest upstream and F the farthest downstream.



Adapted from Joesten, M.D., and J.L. Wood. *World of Chemistry*, 2nd edition. Philadelphia: Saunders College Publishing (1996).

10. Where along the river did a sewage spill occur?
11. At which station would you most likely discover dead fish?

THE PLANNER