Water Pollution

20

Lake Washington

CORE CASE STUDY

The U.S. city of Seattle, Washington, was founded on the western shore of Puget Sound (Figure 20-1). As it grew in the early 20th Century, it expanded eastward toward Lake Washington, which became a popular recreation site for its citizens.

The lake also became attractive to growing suburban municipal governments as a place to dispose of wastewater. By the mid-1950s, Seattle's suburbs surrounded the lake, and ten sewage treatment plants were operating near its shores, dumping huge amounts of treated wastewater into the lake every day. In 1955, researchers working with the late Dr. W. T. Edmondson of the University of Washington discovered the presence in the lake of a species of cyanobacteria, commonly called blue-green algae.

Masses of these algae quickly grew and darkened the lake's waters. Dead algae accumulated on the lakeshores where they rotted and fouled the air. The water became cloudy and populations of desirable fish declined. Edmondson, who spent decades studying the biochemistry of Lake Washington, hypothesized that the chief nutrient feeding the algae was phosphorus coming from the area's sewage treatment plants.

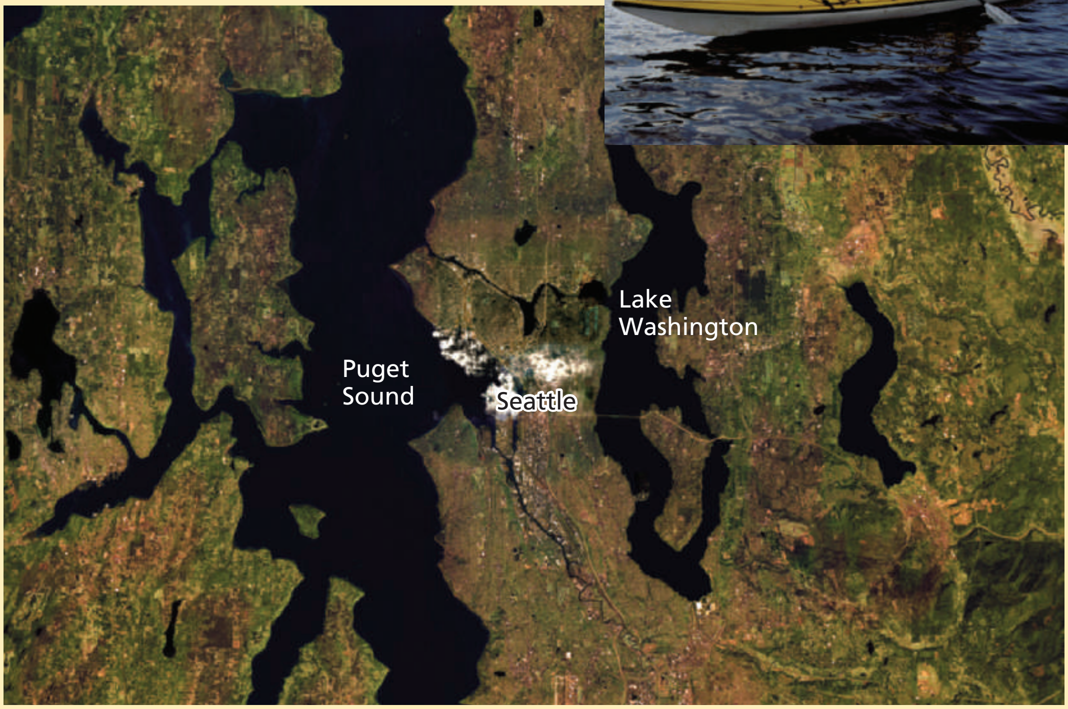
Edmondson and his colleagues wrote a technical paper for use by sewage treatment plant managers but did not get much attention from these officials. So they wrote letters and articles to educate the general public about the nature of Lake Washington's pollution and its likely sources.

The researchers' public education efforts paid off. Within 3 years, citizen pressure on elected officials led to the development of a scheme to divert nutrient-rich effluents from Seattle's sewage treatment plants into the nearby Puget Sound (Figure 20-1), where tides would mix and dilute them with ocean water. This diversion was completed by 1968, and by 1976, the blue-green algae were virtually gone. The clarity of the lake water improved dramatically, fish populations in the lake recovered, and recreationists returned to Lake Washington (Figure 20-2).

However, with the increasing popularity of the Seattle area, the human population has steadily grown. This is posing new challenges to the lake and to the sound, as we discuss throughout this chapter.

Lee Foster/Bruce Coleman USA

Figure 20-2 With the city of Seattle in the background, this kayaker enjoys the waters of Lake Washington. Although the once badly polluted lake has recovered, population pressures now threaten it again.



NASA/Goddard Space Flight Center Scientific Visualization Studio

Figure 20-1 *The Seattle, Washington (USA) area.* Seattle was founded on the shore of Puget Sound and quickly expanded eastward toward Lake Washington.

Key Questions and Concepts

20-1 What are the causes and effects of water pollution?

CONCEPT 20-1A Water pollution causes illness and death in humans and other species and disrupts ecosystems.

CONCEPT 20-1B The chief sources of water pollution are agricultural activities, industrial facilities, and mining, but growth in population and resource use makes it increasingly worse.

20-2 What are the major water pollution problems in streams and lakes?

CONCEPT 20-2A While streams are extensively polluted worldwide by human activities, they can cleanse themselves of many pollutants if we do not overload them or reduce their flows.

CONCEPT 20-2B Addition of excessive nutrients to lakes from human activities can disrupt lake ecosystems, and prevention of such pollution is more effective and less costly than cleaning it up.

20-3 What are the major pollution problems affecting groundwater and other drinking water sources?

CONCEPT 20-3A Chemicals used in agriculture, industry, transportation, and homes can spill and leak into groundwater and make it undrinkable.

CONCEPT 20-3B There are simple ways and complex ways to purify drinking water, but protecting it through pollution prevention is the least expensive and most effective strategy.

20-4 What are the major water pollution problems affecting oceans?

CONCEPT 20-4A The great majority of ocean pollution originates on land and includes oil and other toxic chemicals and solid wastes, which threaten aquatic species and other wildlife and disrupt marine ecosystems.

CONCEPT 20-4B The key to protecting the oceans is to reduce the flow of pollutants from land and air and from streams emptying into these waters.

20-5 How can we best deal with water pollution?

CONCEPT 20-5 Reducing water pollution requires preventing it, working with nature to treat sewage, cutting resource use and waste, reducing poverty, and slowing population growth.

Note: Supplements 2 (p. S4), 6 (p. S39), and 13 (p. S78) can be used with this chapter.

Today everybody is downwind or downstream from somebody else.

WILLIAM RUCKELSHAUS

20-1 What Are the Causes and Effects of Water Pollution?

▶ **CONCEPT 20-1A Water pollution causes illness and death in humans and other species and disrupts ecosystems.**

▶ **CONCEPT 20-1B The chief sources of water pollution are agricultural activities, industrial facilities, and mining, but growth in population and resource use makes it increasingly worse.**

Water Pollution Comes from Point and Nonpoint Sources

Water pollution is any chemical, biological, or physical change in water quality that harms living organisms or makes water unsuitable for desired uses.

Water pollution can come from single (point) sources, or from larger and dispersed (nonpoint) sources. **Point sources** discharge pollutants at specific locations through drain pipes (Figure 20-3), ditches, or sewer lines into bodies of surface water. Examples include factories, sewage treatment plants (which remove some, but not all, pollutants), underground mines, and oil tankers.

Because point sources are located at specific places, they are fairly easy to identify, monitor, and regulate. Most developed countries have laws that help to control point-source discharges of harmful chemicals into aquatic systems. In most developing countries, there is little control of such discharges.

Nonpoint sources are broad, and diffuse areas, rather than points, from which pollutants enter bodies of surface water or air. Examples include runoff of chemicals and sediments from cropland (Figure 20-4), livestock feedlots, logged forests, urban streets, parking lots, lawns, and golf courses. We have made little progress in controlling water pollution from nonpoint sources because of the difficulty and expense of iden-

Links: CORE CASE STUDY refers to the Core Case Study. SUSTAINABILITY refers to the book's sustainability theme. CONCEPT LINK indicates links to key concepts in earlier chapters.

age footstock/SuperStock

Figure 20-3 Point source of polluted water in Gargas, France.

tifying and controlling discharges from so many diffuse sources.

Agricultural activities are by far the leading cause of water pollution. Sediment eroded from agricultural lands (Figure 20-4) is the largest source. Other major agricultural pollutants include fertilizers and pesticides, bacteria from livestock and food processing wastes, and excess salt from soils of irrigated cropland. *Industrial facilities,* which emit a variety of harmful inorganic and organic chemicals, are a second major source of water pollution. *Mining* is the third biggest source. Surface mining disturbs the land (Figures 14-18, p. 357, and 14-19, p. 358), creating major erosion of sediments and runoff of toxic chemicals (Chapter 14 Core Case Study, p. 344).

A 2007 study by Purdue University (Indiana, USA) researchers found that parking lots are a major source of nonpoint pollution for rivers and lakes because of grease, toxic metals, and sediments that collect on their impervious surfaces. Because parking lots also disrupt the hydrologic cycle by preventing rain from soaking into the ground, they can worsen local flooding and erosion.

Another relatively new form of water pollution is caused by the widespread use of human-made materials such as plastics that make up millions of products, all of which eventually end up in the environment. The polymers that make up the plastics break down very slowly and, in the process, pollute many waterways where they have been discarded improperly. Plastics products can also harm various forms of wildlife (Figures 11-5, p. 254, and 11-10, p. 260).

Climate change from global warming will also contribute to water pollution in some areas. In a warmer world, some regions will get more precipitation and other areas will get less. Intense downpours will flush more harmful chemicals, plant nutrients, and microorganisms into waterways. Prolonged drought will reduce river flows that dilute wastes.

Major Water Pollutants Have Harmful Effects

Table 20-1 (p. 534) lists the major types of water pollutants along with examples of each and their harmful effects and sources (**Concept 20-1A**).

One of the major water pollution problems people face is exposure to infectious disease organisms (pathogens) mostly through contaminated drinking water. Scientists have identified more than 500 types of disease-causing bacteria, viruses, and parasites that can be transferred into water from the wastes of humans and animals. Table 20-2 (p. 534) lists some common diseases that can be transmitted to humans through drinking water contaminated with infectious agents (**Concept 20-1A**). Various methods are used to measure water quality (Science Focus, p. 535).

The World Health Organization (WHO) estimates that 3.2 million people—most of them children younger than age 5—die prematurely every year from infectious diseases that they get by drinking contaminated water or by not having enough clean water for adequate hygiene. This amounts to an average of almost 8,700 premature deaths a day. The WHO also estimates that about 1.2 billion people—one of every six in the world—have no access to clean drinking water. Each year, diarrhea alone kills about 1.9 million people—about 90% of them children under age 5—in developing countries. This means that diarrhea, caused mostly by exposure to polluted water, on average, kills a young child every 18 seconds.

Tim McCabe/Natural Resources Conservation Service

Figure 20-4 Nonpoint sediment from unprotected farmland flows into streams and sometimes changes their courses or dams them up. As measured by weight, it is the largest source of water pollution. **Question:** What do you think the owner of this farm could have done to prevent such sediment pollution?

Table 20-1

Major Water Pollutants and Their Sources

Type and Effects	Examples	Major sources
Infectious agents (pathogens) *Cause diseases*	Bacteria, viruses, protozoa, parasites	Human and animal wastes
Oxygen-demanding wastes *Deplete dissolved oxygen needed by aquatic species*	Biodegradable animal wastes and plant debris	Sewage, animal feedlots, food processing facilities, pulp mills
Plant nutrients *Cause excessive growth of algae and other species*	Nitrates (NO_3^-) and phosphates (PO_4^{3-})	Sewage, animal wastes, inorganic fertilizers
Organic chemicals *Add toxins to aquatic systems*	Oil, gasoline, plastics, pesticides, cleaning solvents	Industry, farms, households
Inorganic chemicals *Add toxins to aquatic systems*	Acids, bases, salts, metal compounds	Industry, households, surface runoff
Sediments *Disrupt photosynthesis, food webs, other processes*	Soil, silt	Land erosion
Heavy metals *Cause cancer, disrupt immune and endocrine systems*	Lead, mercury, arsenic	Unlined landfills, household chemicals, mining refuse, industrial discharges
Thermal *Make some species vulnerable to disease*	Heat	Electric power and industrial plants

Table 20-2

Common Diseases Transmitted to Humans through Contaminated Drinking Water

Type of Organism	Disease	Effects
Bacteria	Typhoid fever	Diarrhea, severe vomiting, enlarged spleen, inflamed intestine; often fatal if untreated
	Cholera	Diarrhea, severe vomiting, dehydration; often fatal if untreated
	Bacterial dysentery	Diarrhea, bleeding; rarely fatal except in infants without proper treatment
	Enteritis	Severe stomach pain, nausea, vomiting; rarely fatal
Viruses	Infectious hepatitis (Type B)	Fever, severe headache, loss of appetite, abdominal pain, jaundice, enlarged liver; rarely fatal but may cause permanent liver damage
	Poliomyelitis	Fever, diarrhea, backache, sore throat, aches in limbs; can infect spinal chord and cause paralysis and muscle weakness
Parasitic protozoa	Amoebic dysentery	Severe diarrhea, headache, abdominal pain, chills, fever; if not treated can cause liver abscess, bowel perforation, and death
	Giardiasis	Diarrhea, abdominal cramps, flatulence, belching, fatigue
	Cryptosporidum	Severe diarrhea, cramps for up to 3 weeks, and possible death for people with weakened immune systems
Parasitic worms	Schistosomiasis	Abdominal pain, skin rash, anemia, chronic fatigue, and chronic general ill health
	Ancylostomiasis	Severe anemia and possible symptoms of bronchial infection

SCIENCE FOCUS

Testing Water for Pollutants

Scientists use a variety of methods to measure water quality. For example, Dr. Edmondson and his students tested samples of water from Lake Washington (**Core Case Study**) for the presence of various infectious agents such as certain strains of coliform bacteria *Escherichia coli,* or *E. coli,* which live in the colons and intestines of humans and other animals and thus are present in their fecal wastes. Although most strains of coliform bacteria do not cause disease, their presence indicates that water has been exposed to human or animal wastes that are likely to contain disease-causing agents.

To be considered safe for drinking, a 100-milliliter (about 1/2 cup) sample of water should contain no colonies of coliform bacteria. To be considered safe for swimming, such a water sample should contain no more than 200 colonies of coliform bacteria. By contrast, a similar sample of raw sewage may contain several million coliform bacterial colonies.

Another indicator of water quality is its *level of dissolved oxygen* (DO). Excessive inputs of oxygen-demanding wastes can deplete DO levels in water. Figure 20-A shows the relationship between dissolved oxygen content and water quality.

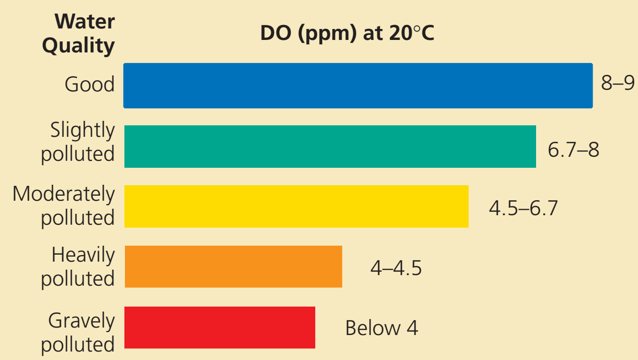


Figure 20-A Water quality as measured by dissolved oxygen (DO) content in parts per million (ppm) at 20 °C (68 °F). Only a few fish species can survive in water with less than 4 ppm of dissolved oxygen at this temperature. Some warmer water species have evolved ways to tolerate low DO levels better than cold water species can. **Question:** Would you expect the dissolved oxygen content of polluted water to increase or decrease if the water is heated? Explain.

Scientists can use *chemical analysis* to determine the presence and concentrations of specific organic chemicals in polluted water. They can also monitor water pollution by using living organisms as *indicator species.* For example, they remove aquatic plants such as cattails from areas contaminated with fuels, solvents, and other organic chemicals, and analyze them to determine the exact pollutants contained within them. Scientists also determine water quality by analyzing bottom-dwelling species such as mussels, which feed by filtering water through their bodies.

Genetic engineers are working to develop bacteria and yeasts (single-celled fungi) that glow in the presence of specific pollutants such as toxic heavy metals in the ocean, toxins in the air, and carcinogens in food.

Scientists measure the amount of sediment in polluted water by evaporating the water in a sample and weighing the resulting sediment. They also use instruments such as colorimeters and turbidimeters to measure the color and *turbidity,* or cloudiness, of water samples containing sediment.

Critical Thinking

Runoff of fertilizer into a lake such as Lake Washington (**Core Case Study**) from farm fields, lawns, and sewage treatment plants can overload the water with nitrogen and phosphorus plant nutrients that can cause algae population explosions. How could this process lower the dissolved oxygen level of the water and lead to fish kills?

20-2 What Are the Major Water Pollution Problems in Streams and Lakes?

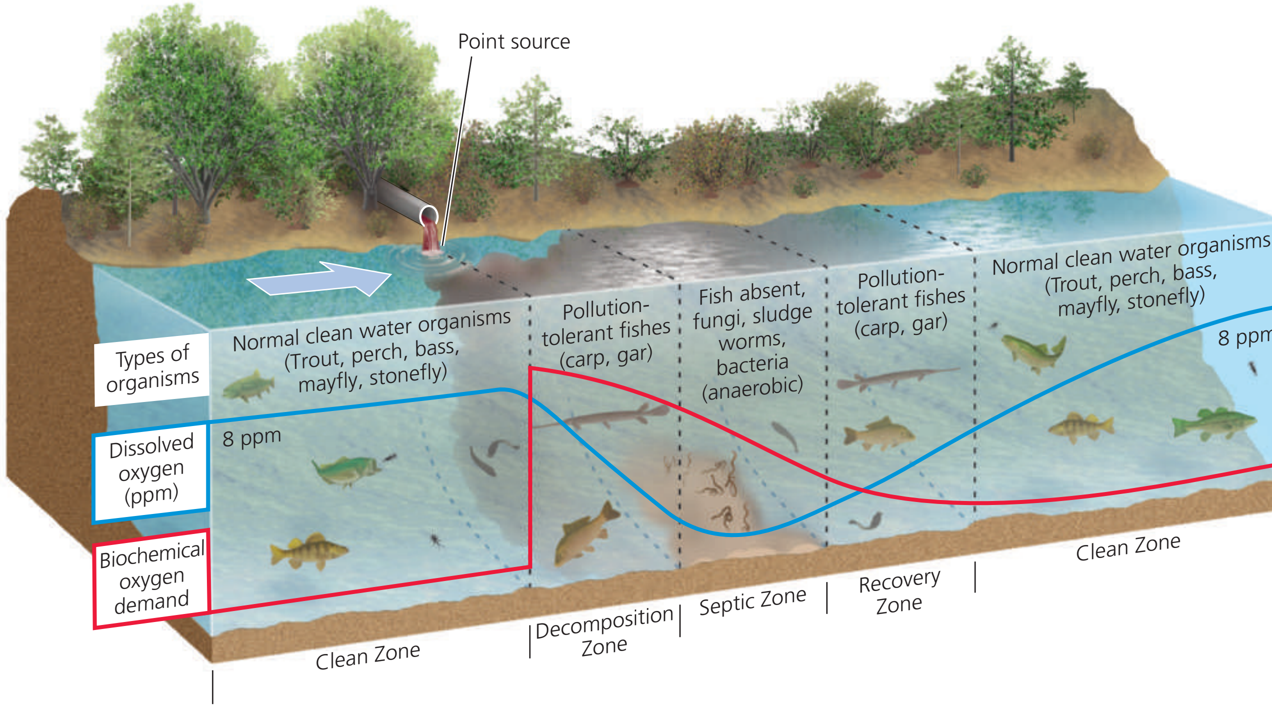
▶ **CONCEPT 20-2A While streams are extensively polluted worldwide by human activities, they can cleanse themselves of many pollutants if we do not overload them or reduce their flows.**

▶ **CONCEPT 20-2B Addition of excessive nutrients to lakes from human activities can disrupt lake ecosystems, and prevention of such pollution is more effective and less costly than cleaning it up.**

Streams Can Cleanse Themselves If We Do Not Overload Them

Flowing rivers and streams can recover rapidly from moderate levels of degradable, oxygen-demanding wastes through a combination of dilution and biodegradation of such wastes by bacteria. But this natural recovery process does not work when streams become overloaded with such pollutants or when drought, damming, or water diversions reduce their flows (**Concept 20-2A**). Also, while this process can remove biodegradable wastes, it does not eliminate slowly degradable and nondegradable pollutants.

In a flowing stream, the breakdown of biodegradable wastes by bacteria depletes dissolved oxygen and creates an *oxygen sag curve* (Figure 20-5, p. 536). This



CENGAGENOW™ **Active Figure 20-5** **Natural capital:** dilution and decay of degradable, oxygen-demanding wastes (or heated water) in a stream, showing the oxygen sag curve (blue) and the curve of oxygen demand (red). Depending on flow rates and the amount of biodegradable pollutants, streams recover from oxygen-demanding wastes and from injection of heated water if they are given enough time and are not overloaded (**Concept 20-2A**). *See an animation based on this figure at* CengageNOW™. **Question:** What would be the effect of putting another biodegradable waste discharge pipe to the right of the one in this picture?

reduces or eliminates populations of organisms with high oxygen requirements until the stream is cleansed of oxygen-demanding wastes, at which place or time, such populations can recover. Similar oxygen sag curves can be plotted when heated water from industrial and power plants is discharged into streams, because heating water decreases its levels of dissolved oxygen.

CENGAGENOW™ Learn more about how pollution affects the water in a stream and the creatures living there at CengageNOW™.

Stream Pollution in Developed Countries

Water pollution control laws enacted in the 1970s have greatly increased the number and quality of wastewater treatment plants in the United States and most other developed countries. Such laws also require industries to reduce or eliminate their point-source discharges of harmful chemicals into surface waters. This has enabled the United States to hold the line against increased pollution by disease-causing agents and oxygen-demanding wastes in most of its streams. This is an impressive accomplishment given the country's increased economic activity, resource consumption, and population growth since passage of these laws.

One success story is the cleanup of Ohio's Cuyahoga River. It was so polluted with flammable chemicals that it caught fire several times in the 1950s and 1960s as it flowed through the U.S. city of Cleveland. A highly publicized photo of this burning river in 1969 prompted elected officials to enact laws that limited the discharge of industrial wastes into the river and into local sewage systems and provided funds to upgrade sewage treatment facilities. Today, the river is cleaner, no longer flammable, and is widely used by boaters and anglers. This accomplishment illustrates the power of bottom-up pressure by citizens, who prodded elected officials to change a severely polluted river into an economically and ecologically valuable public resource.

Another spectacular cleanup occurred in Great Britain. In the 1950s, the Thames River was little more than a flowing, smelly sewer. Now, after 50 years of effort and large inputs of money from British taxpayers and private industry, the Thames has made a remarkable recovery. Commercial fishing is thriving and the number of fish species has increased 20-fold since 1960. In addition, many species of waterfowl and wading birds have returned to their former feeding grounds.

Large fish kills and drinking water contamination still occasionally occur in parts of developed countries. One cause of such problems is accidental or deliberate releases of toxic inorganic and organic chemicals by industries or mines (Chapter 14 Core Case Study, p. 344).

See *The Habitable Planet,* Video 6, at **www.learner.org/resources/series209.html** for discussion of how scientists measure water pollution that includes toxic heavy metals from mining wastes and abandoned underground mines. Another cause of such pollution is malfunctioning sewage treatment plants. A third cause is nonpoint runoff of pesticides and excess plant nutrients from cropland and animal feedlots.

Still, streams can recover if given the chance (**Concept 20-2A**). Stream restoration can be done on a large scale, as in the cases of the Cuyahoga and the Thames, or on a smaller scale, as in the case of Hamm Creek (Individuals Matter, below). In either case, anyone and everyone can play a role.

Global Outlook: Stream Pollution in Developing Countries

In most developing countries, stream pollution from discharges of untreated sewage and industrial wastes is a serious and growing problem. According to a 2003 report by the World Commission on Water in the 21st Century, half of the world's 500 rivers are heavily polluted, and most of them run through developing countries. Most of these countries cannot afford to build waste treatment plants and do not have, or do not enforce, laws for controlling water pollution.

According the Global Water Policy Project, most cities in developing countries discharge 80–90% of their untreated sewage directly into rivers, streams (Figure 20-6), and lakes whose waters are then used for drinking water, bathing, and washing clothes.

Shehzad Noorani/Peter Arnold, Inc.

Figure 20-6 A girl sits on the edge of a road beside a stream loaded with raw sewage, near her home in Baghdad, Iraq.

Industrial wastes and sewage pollute more than two-thirds of India's water resources (Case Study, p. 538) and 54 of the 78 rivers and streams monitored in China (Figure 20-7, p. 538). One-third of China's rivers are judged unfit for agricultural use, and even for industrial uses. According to a 2007 report by Chinese officials, more than half of China's 1.3 billion people, including those in 278 cities, live without any form of sewage treatment. And 300 million Chinese—an amount almost equal to the entire U.S. population—do not have access to drinkable water. In Latin America and Africa, most streams passing through urban or industrial areas suffer from severe pollution. Garbage is also dumped into rivers in some places (Figure 20-8, p. 538).

INDIVIDUALS MATTER

The Man Who Planted Trees to Restore a Stream

In 1980, heart problems forced John Beal, an engineer with the Boeing Company, to take some time off. To improve his health, he began taking daily walks. His strolls took him by Hamm Creek, a smallstream that flows from the southwest hills of Seattle, Washington (USA), into the Duwamish River, which empties into Puget Sound (Figure 20-1, **Core Case Study**). He remembered when the stream was a spawning ground for salmon and when evergreen trees lined its banks. By 1980, the polluted stream had no fish and the trees were gone.

CORE CASE STUDY

Beal decided to restore Hamm Creek. He persuaded companies to stop polluting the creek, and he hauled out many truckloads of garbage. Then he began a 15-year project of planting thousands of trees along the stream's banks. He also restored natural waterfalls and ponds and salmon spawning beds.

At first he worked alone, but word spread and other people joined him. TV news reports and newspaper articles about the restoration project brought more volunteers.

The creek's water now runs clear, its vegetation has been restored, and salmon have returned to spawn. His reward is the personal satisfaction he feels about having made a difference for Hamm Creek and his community. His dedication to making the world a better place is an outstanding example of *stewardship* based on the idea that *all sustainability is local.*

Zhao Weiming/UNEP/Peter Arnold, Inc.

Figure 20-7 **Natural capital degradation:** highly polluted river in China. Water in many of central China's rivers is greenish-black from uncontrolled pollution by thousands of factories. Water in some rivers is too toxic to touch, much less drink. The cleanup of some modernizing Chinese cities such as Beijing and Shanghai is forcing polluting refineries and factories to move to rural areas where two-thirds of China's population resides. Liver and stomach cancer, linked in some cases to water pollution, are among the leading causes of death in the countryside. Farmers too poor to buy bottled water must often drink polluted well water.

© Paul Dix/Visuals Unlimited

Figure 20-8 Trash truck disposing of garbage into a river in Peru.

■ **CASE STUDY**

India's Ganges River: Religion, Poverty, Population Growth, and Health

To India's Hindu people, the Ganges is a holy river. Each day, large numbers of Hindus bathe, drink from, or take a dip in the river for religious reasons (Figure 20-9).

But the Ganges is highly polluted. About 350 million people—almost one-third of the country's population—live in the Ganges River basin. Very little of the sewage produced by these people and by the industries and 29 large cities in the basin is treated.

This situation is complicated by the Hindu belief in cremating the dead to free the soul and in throwing the ashes into the holy Ganges to increase the chances of the soul getting into heaven. Traditionally, wood fires are used to burn most bodies. This creates air pollution and helps deplete India's forests.

It also causes water pollution. Because many people cannot afford enough wood for cremation, many unburned or partially burnt bodies are dumped into the river where they mingle with large numbers of livestock corpses. Decomposition of these bodies depletes dissolved oxygen and adds disease-carrying bacteria and viruses to the water. This problem is expected to get worse as India's population grows; about 18 million people are added to the population each year—about a third of them to the Ganges River basin.

To help clean up the river, the Indian government plans to build waste treatment plants in the basin's 29 large cities and construct along the banks of the river 32 electric crematoriums, which can burn bodies more efficiently and at a cost lower than that of wood-fired cremation. The government also introduced 25,000 snapping turtles to devour corpses.

But most of the sewage treatment plants are not yet completed or do not work very well, and only a few of the crematoriums are in operation. There is also concern that many Hindus will not abandon the traditional ritual of wood-fired cremation or will not be able to afford any type of cremation.

Another religious custom involves throwing vividly painted small statues into the river. These create another source of pollution, because paints and coatings on these objects often contain toxic metals, such as lead and mercury, and various potentially harmful organic compounds.

Global warming is almost certain to make this situation worse. About 70% of the water flowing into the Ganges comes from the country's Gangotri Glacier, which is now melting at an accelerating rate. If this continues, within decades, the Ganges will become a seasonal river that flows only during the rainy season. The resulting loss of water poses a severe threat to the more than 400 million people living within the Ganges basin in India and Bangladesh.

THINKING ABOUT
Ancient Rituals and Water Pollution

What arguments would you use to convince someone to use a newer, cleaner technology for observing an ancient religious ritual in order to help protect the Ganges River?

Argus/Peter Arnold, Inc.

Figure 20-9 *India's Ganges River.* Each day more than 1 million Hindus in India bathe, drink from, or carry out religious ceremonies in the highly polluted Ganges River, which flows from the southern slopes of the Himalayas through India and into the Bay of Bengal. This photo shows people engaging in a Hindu Puja ritual ceremony in the river.

Low Water Flow and Too Little Mixing Makes Lakes Vulnerable to Water Pollution

Lakes and reservoirs are generally less effective at diluting pollutants than streams are, for two reasons. *First,* lakes and reservoirs often contain stratified layers (Figure 8-15, p. 175) that undergo little vertical mixing. *Second,* they have little or no flow. The flushing and changing of water in lakes and large artificial reservoirs can take from 1 to 100 years, compared to several days or weeks for streams.

As a result, lakes and reservoirs are more vulnerable than streams are to contamination by runoff or discharge of plant nutrients, oil, pesticides, and nondegradable toxic substances, such as lead, mercury, and selenium. These contaminants can kill bottom life and fish and birds that feed on contaminated aquatic organisms. Many toxic chemicals and acids also enter lakes and reservoirs from the atmosphere (Figure 18-12, p. 479).

As they pass through food webs in lakes, the concentrations of some harmful chemicals are biologically magnified. Examples include DDT (Figure 9-19, p. 202), PCBs (Case Study, p. 449), some radioactive isotopes, and some mercury compounds (Figure 17-A, p. 450).

Cultural Eutrophication Is Too Much of a Good Thing

Eutrophication is the name given to the natural nutrient enrichment of a shallow lake, estuary, or slow-moving stream, mostly from runoff of plant nutrients such as nitrates and phosphates from surrounding land. In the case of Lake Washington (**Core Case Study**), the major nutrient was phosphorous in treated wastewater that was dumped into the lake from all sides. CORE CASE STUDY

An *oligotrophic lake* is low in nutrients and its water is clear (Figure 8-16, left, p. 175). Over time, some lakes become more eutrophic (Figure 8-16, right) as nutrients are added from natural and human sources in the surrounding watersheds.

Near urban or agricultural areas, human activities can greatly accelerate the input of plant nutrients to a lake—a process called **cultural eutrophication** involving mostly nitrate- and phosphate-containing effluents from various sources. These sources include runoff from farmland, animal feedlots, urban areas, chemically fertilized suburban yards, and mining sites, and discharges of treated and untreated municipal sewage. Some nitrogen also reaches lakes by deposition from the atmosphere.

During hot weather or drought, this nutrient overload produces dense growths or "blooms" of organisms such as algae and cyanobacteria (Figure 8-16, right, p. 175) and thick growths of water hyacinth (Figure 11-4, p. 252), duckweed, and other aquatic plants. These dense colonies of plant life can reduce lake productivity and fish growth by decreasing the input of solar energy needed for photosynthesis by phytoplankton that support fish (**Concept 20-2B**).

When the algae die, they are decomposed by swelling populations of aerobic bacteria, which deplete dissolved oxygen in the surface layer of water near the shore and in the bottom layer. This can kill fish and other aerobic aquatic animals. This is what was happening to Lake Washington (Figure 20-1) before scientists and citizens worked together to clean it up (**Core Case Study**). If excess nutrients continue to flow into a lake, anaerobic bacteria take over and produce gaseous products such as smelly, highly toxic hydrogen sulfide and flammable methane. CORE CASE STUDY

According to the U.S. Environmental Protection Agency (EPA), about one-third of the 100,000 medium to large lakes and 85% of the large lakes near major U.S. population centers have some degree of cultural eutrophication. And the International Water Association estimates that more than half of the lakes in China suffer from cultural eutrophication.

There are several ways to *prevent* or *reduce* cultural eutrophication. We can use advanced (but expensive) waste treatment to remove nitrates and phosphates before wastewater enters lakes. In Lake Washington, this approach, plus diversion of lake water to nearby Puget Sound (Figure 20-1, **Core Case Study**), were used to reduce eutrophication. We can also use a preventive approach by banning or limiting the use of phosphates in household detergents and other cleaning agents and by employing soil conservation and land-use control to reduce nutrient runoff (**Concept 20-2B**).

There are several ways to *clean up* lakes suffering from cultural eutrophication. We can mechanically remove excess weeds, control undesirable plant growth with herbicides and algicides, and pump air through lakes and reservoirs to prevent oxygen depletion, all of which are expensive and energy-intensive methods.

As usual, pollution prevention is more effective and usually cheaper in the long run than cleanup. The good news is that a lake usually can recover from cultural eutrophication, if excessive inputs of plant nutrients are stopped.

Revisiting Lake Washington and Puget Sound

We can learn two lessons from the story of Lake Washington (**Core Case Study**), both related to themes we explore throughout this book. *First,* severe water pollution can be reversed in a fairly short time, if pollutant inputs are sharply reduced. *Second,* citizen action combined with scientific research works.

However, recall that the wastewater treatment plant effluents that had been flowing into Lake Washington were diverted to the Puget Sound (Figure 20-1). Today, mostly because of continued population and economic growth in the Seattle area, the sound is becoming overloaded with these effluents. There is growing concern also about overflows of increased urban runoff and raw sewage during storms and about large inputs of toxic materials into the sound.

Despite the ecological and political success story of Lake Washington, the relentless growth of population, resource use, and urbanization are again overwhelming the lake, as well as the sound. This brings a third lesson to the Lake Washington story: Even good solutions to environmental problems cannot work indefinitely if we keep overwhelming the natural systems involved. Ultimately, **scientific principles of sustainability** (see back cover) require reducing population growth and resource use.

In 2007, the Washington state government appointed the Puget Sound Partnership to determine the condition of the sound and to develop strategies for meeting the state's goal of having a healthy Puget Sound by 2020.

■ CASE STUDY

Pollution in the Great Lakes

The five interconnected Great Lakes of North America (Figure 20-10) contain at least 95% of the fresh surface water in the United States and one-fifth of the world's fresh surface water. At least 38 million people in the United States and Canada obtain their drinking water from these lakes.

Despite their enormous size, these lakes are vulnerable to pollution from point and nonpoint sources. One reason is that less than 1% of the water entering these lakes flows out to the St. Lawrence River each year, meaning that pollutants can take as long as 100 years to be flushed out to sea.

By the 1960s, many areas of the Great Lakes were suffering from severe cultural eutrophication, huge fish kills, and contamination from bacteria and a variety of toxic industrial wastes. The impact on Lake Erie was particularly intense because it is the shallowest of the Great Lakes and has the highest concentrations of people and industrial activity along its shores.

Since 1972, Canada and the United States have joined forces and spent more than $20 billion on a Great Lakes pollution control program. This program has decreased algal blooms, increased dissolved oxygen levels and sport and commercial fishing catches in Lake Erie, and allowed most swimming beaches to reopen. These improvements occurred mainly because of new or upgraded sewage treatment plants, better treatment of industrial wastes, and bans on use of detergents, household cleaners, and water conditioners that contain phosphates—all instituted mostly because of bottom-up citizen pressure.

Despite this important progress, many problems remain. In 2006, Canadian scientists reported that cities around the lakes were releasing, on average, the equivalent of more than 100 Olympic swimming pools of raw sewage into the lakes each day. Dozens of municipal sewage systems combine storm water with wastewater and allow emergency overflows into the lakes. These systems overflow far too easily and too often, according to the scientists. Cities that use systems that separate sewage from storm water, which include Green Bay, Wisconsin, and Duluth, Minnesota, contribute the least to this problem.

Increasing nonpoint runoff of pesticides and fertilizers resulting from urban sprawl, fueled by population growth, now surpasses industrial pollution as the greatest threat to the lakes. Sediments in 26 toxic hotspots remain heavily polluted. And *biological pollution* in the form of invasions by zebra mussels and more than 180 other alien species, threaten some native species and cause billions of dollars in damages (Case Study, p. 269).

Air quality over the Great Lakes has generally improved, according to the 2007 State of the Great Lakes

Figure 20-10 *The Great Lakes of North America.* Two Canadian provinces to the north and eight U.S. states to the south surround these five lakes, which make up the world's largest freshwater system. Dozens of growing cities lie on their shores, and water pollution is a growing problem. (Provided by the SeaWiFS project, NASA/Goddard Space Flight Center, and ORBIMAGE)

report, but about half of the toxic compounds entering the lakes still come from atmospheric deposition of pesticides, mercury from coal-burning plants, and other toxic chemicals from as far away as Mexico and Russia. A survey by Wisconsin biologists found that one fish in four taken from the Great Lakes is unsafe for human consumption. Despite ongoing pollution problems, EPA funding for cleanup of the Great Lakes has dropped 80% since 1992.

The 2007 State of the Great Lakes report also notes:

- New pollutants found in the lakes include toxic polybrominated diphenyl ethers used in flame retardants and various pharmaceutical and personal care products.
- Continuing wetland loss and degradation is shrinking the habitats of birds, amphibians, and some fishes.
- Populations of native species near the base of the food web, such as some plankton, are declining in some of the lakes.
- Native populations of carnivorous fish species, such as lake trout, are declining in most of the lakes.

Some environmental and health scientists call for taking a prevention approach and banning the use of toxic chlorine compounds, such as bleach used in the pulp and paper industry, which is prominent around the Great Lakes. They would also ban new incinerators, which can release toxic chemicals into the atmosphere, and they would stop the discharge into the lakes of 70 toxic chemicals that threaten human health and wildlife. So far, officials in the industries involved have successfully opposed such bans.

In 2007, a group of economists estimated that improving the health of the Great Lakes, by rebuilding antiquated sewer systems, restoring degraded wetlands, dealing with the invasive species, and cleaning up contaminated lake and tributary sediment, would cost $26 billion. They also argued that the estimated resulting gain of $50 billion in real estate values would justify the investment.

THINKING ABOUT
Pollution in the Great Lakes

What are three steps you would take to sharply reduce pollution in the Great Lakes?

20-3 What Are the Major Pollution Problems Affecting Groundwater and Other Drinking Water Sources?

▶ **CONCEPT 20-3A Chemicals used in agriculture, industry, transportation, and homes can spill and leak into groundwater and make it undrinkable.**

▶ **CONCEPT 20-3B There are simple ways and complex ways to purify drinking water, but protecting it through pollution prevention is the least expensive and most effective strategy.**

Groundwater Cannot Cleanse Itself Very Well

Drinking water for about half of the U.S. population and 95% of those who live in rural areas comes from groundwater. According to many scientists, groundwater pollution is a serious threat to human health.

Common pollutants such as fertilizers, pesticides, gasoline, and organic solvents can seep into groundwater from numerous sources (Figure 20-11). People who dump or spill gasoline, oil, and paint thinners and other organic solvents onto the ground also contaminate groundwater (**Concept 20-3A**).

Once a pollutant from a leaking underground storage tank or other source contaminates groundwater, it fills the aquifer's porous layers of sand, gravel, or bedrock like water saturates a sponge. This makes removal of the contaminant difficult and costly. The slowly flowing groundwater disperses the pollutant in a widening *plume* of contaminated water. If the plume reaches a well used to extract groundwater, the toxic pollutants can get into drinking water and into water used to irrigate crops (Figure 20-12).

When groundwater becomes contaminated, it cannot cleanse itself of *degradable wastes* as quickly as flowing surface water does. Groundwater flows so slowly—

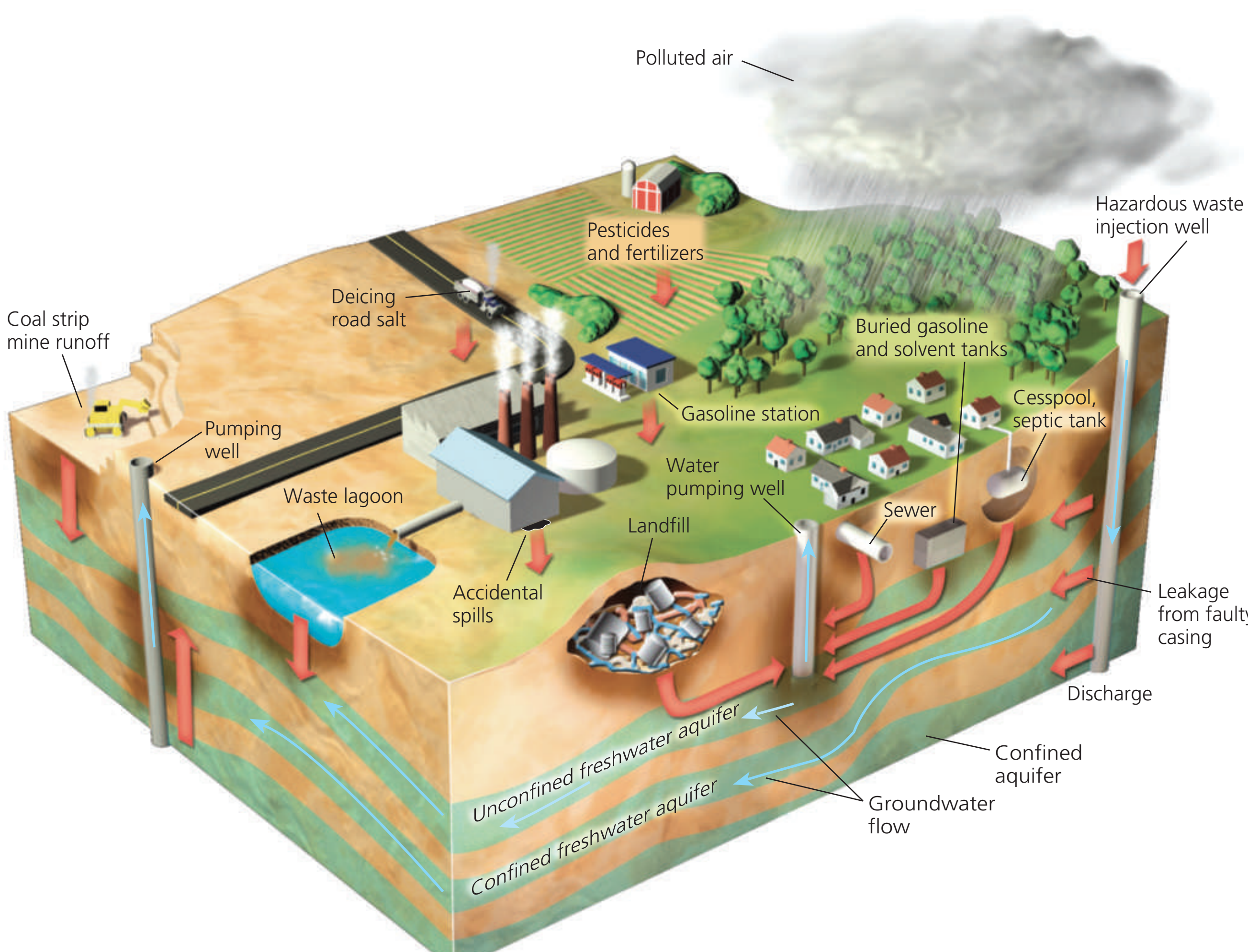


Figure 20-11 Natural capital degradation: principal sources of groundwater contamination in the United States (**Concept 20-3A**). Another source is saltwater intrusion from excessive groundwater withdrawal in coastal areas. (Figure is not drawn to scale.) **Question:** What are three sources shown in this picture that might be affecting groundwater in your area?

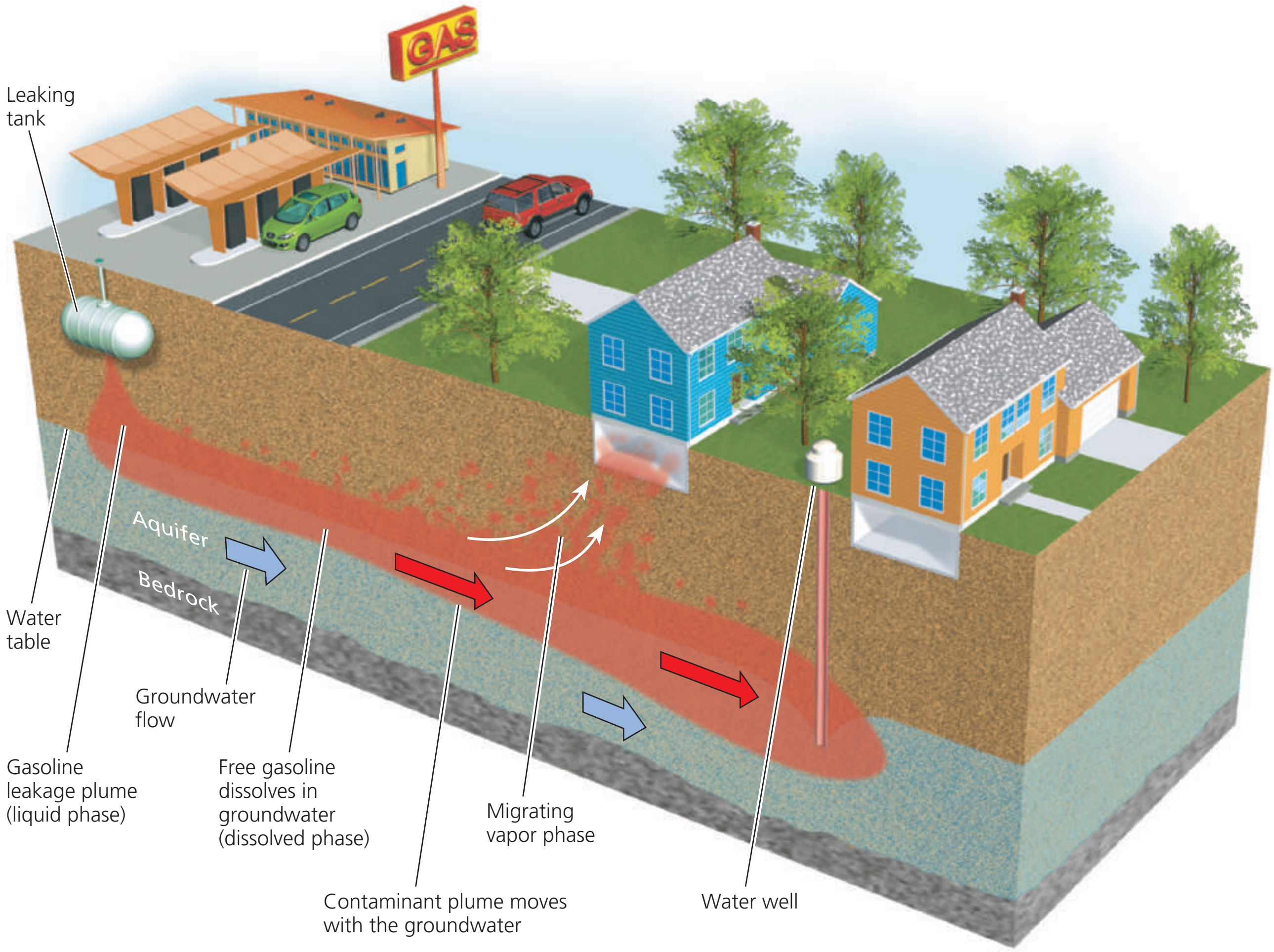


Figure 20-12 **Natural capital degradation:** groundwater contamination from a leaking gasoline tank. As the contaminated water spreads from its source in a widening plume, it can be extracted by wells used to provide water for drinking and irrigation.

usually less than 0.3 meter (1 foot) per day—that contaminants are not diluted and dispersed effectively. In addition, groundwater usually has much lower concentrations of dissolved oxygen (which helps to decompose many contaminants) and smaller populations of decomposing bacteria. Also, the usually cold temperatures of groundwater slow down chemical reactions that decompose wastes.

Thus, it can take decades to thousands of years for contaminated groundwater to cleanse itself of *slowly degradable wastes* (such as DDT). On a human time scale, *nondegradable wastes* (such as toxic lead and arsenic) remain in the water permanently.

Groundwater Pollution Is a Serious Hidden Threat

On a global scale, we do not know much about groundwater pollution because few countries go to the great expense of locating, tracking, and testing aquifers. But the results of scientific studies in scattered parts of the world are alarming.

China has limited water resources for its huge population. Groundwater is crucial because it provides about 70% of the country's drinking water. In 2006, the Chinese government reported that aquifers in about nine of every ten Chinese cities are polluted or overexploited, and could take hundreds of years to recover.

In the United States, an EPA survey of 26,000 industrial waste ponds and lagoons found that one-third of them had no liners to prevent toxic liquid wastes from seeping into aquifers. One-third of these sites are within 1.6 kilometers (1 mile) of a drinking water well. In addition, almost two-thirds of America's liquid hazardous wastes are injected into deep disposal wells underground, some of which leak water into aquifers used as sources of drinking water.

By 2006, the EPA had completed the cleanup of about 350,000 of the more than 460,000 underground tanks in the United States that were leaking gasoline, diesel fuel, home heating oil, or toxic solvents into groundwater. During this century, scientists expect many of the millions of such tanks, which have been installed around the world, to corrode, leak, contaminate groundwater, and become a major global health problem. Determining the extent of a leak from a single underground tank can cost $25,000–250,000, and cleanup costs range from $10,000 to more than $250,000. If the chemical reaches an aquifer, effective cleanup is often not possible or is too costly. *Bottom line:* Wastes that we think we have thrown away or stored safely can escape and come back to haunt us.

Another problem in the United States is groundwater pollution by MTBE (methyl tertiary butyl ether)—a gasoline additive used since 1979. MTBE is a suspected carcinogen. By the time this was discovered in the 1990s, about 250,000 leaking gasoline tanks had contaminated aquifers in many parts of the country. Use of MTBE is being phased out, but plumes of contaminated groundwater will move through aquifers for decades. Oil companies may face thousands of lawsuits from health problems related to this chemical.

Groundwater used as a source of drinking water can also be contaminated with *nitrate ions* (NO_3^-), especially in agricultural areas where nitrates in fertilizer are often leached into groundwater. Nitrite ions (NO_2^-) in the stomach, colon, and bladder can convert some of the nitrate ions in drinking water to organic compounds that have been shown to cause cancer in more than 40 test animal species. The conversion of nitrates in tap water to nitrites in infants under 6 months old can cause a potentially fatal condition known as "blue baby syndrome," in which a baby's blood cannot carry sufficient oxygen to body cells.

■ **CASE STUDY**

A Natural Threat from Arsenic in Groundwater

Toxic *arsenic* contaminates drinking water when a well is drilled into aquifers where soils and rock are naturally rich in arsenic. Some rivers used for drinking water also are contaminated naturally, having originated in springs that have high levels of arsenic. Human activities such as mining and ore processing can also release arsenic into drinking water supplies. The accepted standard for safe levels of arsenic is 10 parts per billion (ppb). But according to a 2007 study by the WHO, more than 140 million people in 70 countries are drinking water with arsenic concentrations of 5–100 times that level. Levels are especially high in parts of Bangladesh and China and India's state of West Bengal.

The WHO estimates that long-term exposure to nondegradable arsenic in drinking water is likely to cause hundreds of thousands of premature deaths from cancer of the skin, bladder, and lung. In 2007, researchers reported that bladder and lung cancer death rates in a part of northern Chile were 3 to 14 times higher than normal. People there had been exposed to high levels of arsenic in their drinking water for decades.

There is also concern over arsenic levels in drinking water in parts of the United States. According to the EPA, some 13 million people in several thousand communities, mostly in the western half of the country, have arsenic levels of 3–10 ppb in their drinking water. Scientists from the WHO and other organizations warn that even the 10 ppb standard is not safe. At that level, say EPA scientists, the lifelong cancer risk from ingesting arsenic is 30 times as high as that for any carcinogen regulated by the EPA. Many scientists call for lowering the standard to 3–5 ppb, but it would be costly to comply with such a lower standard.

In 2006, researchers from Rice University in Houston, Texas (USA), reported that transforming a common mineral similar to rust into a powder of tiny nanocrystals (see p. S45 in Supplement 6) and using it to purify drinking water could greatly reduce the threat of arsenic in the water at a cost of a few cents a day for families. Stay tuned while this process is evaluated.

THINKING ABOUT
Preventing Arsenic Pollution

Would you be willing to pay more for drinking water if the higher price was necessary to guarantee arsenic concentrations lower than 5 ppb? How much more (expressed as a percent over what is paid now) would you pay? Explain.

Pollution Prevention Is the Only Effective Way to Protect Groundwater

Treating a contaminated aquifer involves eliminating the source of pollution and drilling monitoring wells to determine how far, in what direction, and how fast the contaminated plume is moving. Then a computer model is used to project future dispersion of the contaminant in the aquifer. The final step is to develop and implement a strategy to clean up the contamination. Pumping polluted groundwater to the surface, cleaning it up, and returning it to the aquifer is very expensive.

Figure 20-13 lists ways to prevent and clean up groundwater contamination (**Concept 20-3B**). Because of the difficulty and expense of cleaning up a contaminated aquifer, *preventing contamination is the least expensive and most effective way to protect groundwater resources* (Figure 20-13, left, and **Concept 20-3B**).

There Are Many Ways to Purify Drinking Water

Most developed countries have laws establishing drinking water standards, but most developing countries do not have such laws or, if they do have them, they do not enforce them. There are many simple ways and many complex ways to purify drinking water (**Concept 20-3B**).

SOLUTIONS

Groundwater Pollution

Prevention

Find substitutes for toxic chemicals

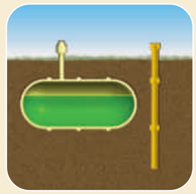
Keep toxic chemicals out of the environment

Install monitoring wells near landfills and underground tanks

Require leak detectors on underground tanks

Ban hazardous waste disposal in landfills and injection wells

Store harmful liquids in aboveground tanks with leak detection and collection systems



Cleanup

Pump to surface, clean, and return to aquifer (very expensive)

Inject microorganisms to clean up contamination (less expensive but still costly)

Pump nanoparticles of inorganic compounds to remove pollutants (still being developed)

Figure 20-13 Methods for preventing and cleaning up contamination of groundwater (**Concept 20-3B**). **Question:** Which two of the preventive solutions (left) do you think are the most important? Why?

In developed countries, wherever people depend on surface water, it is usually stored in a reservoir for several days. This improves clarity and taste by increasing dissolved oxygen content and allowing suspended matter to settle. The water is then pumped to a purification plant and treated to meet government drinking water standards. In areas with very pure groundwater or surface water sources, little treatment is necessary. Some cities have found that protecting watersheds that supply their drinking water is a lot cheaper than building water purification plants (see Case Study, p. 546).

Japan and several other countries are beginning to develop plants that process sewer water into drinking water. El Paso, Texas (USA), gets 40% of its drinking water from recycling and purifying wastewater. In 2007, Orange County, California, completed the world's largest plant devoted to making sewer water as pure as distilled water. If it receives approval by state health officials, it will be used to supply drinking water and to recharge aquifers. We have the technology to convert sewer water into pure drinking water and to help reduce water shortages. However, using such toilet-to-tap systems is expensive. And it faces opposition from citizens and health officials who are unaware of the advances in this technology.

Simpler measures can be used to purify drinking water. In tropical countries that lack centralized water treatment systems, the WHO urges people to purify drinking water by exposing a clear plastic bottle filled with contaminated water to intense sunlight. The sun's heat and UV rays can kill infectious microbes in as little as 3 hours. Painting one side of the bottle black can improve heat absorption in this simple solar disinfection method, which applies one of the four **scientific principles of sustainability** (see back cover). Where this measure has been used, incidence of dangerous childhood diarrhea has decreased by 30–40%.

Researchers are also developing nanofilters to clean contaminated water. The goal is to develop a low-cost water filter that can be cleaned and reused. Vermont-based Seldon Technologies, for example, is developing a hand-held, carbon, nanotube filter that can quickly purify water from any source—a river, mud puddle, or sample of groundwater.

Vestergaard Frandsen, a Danish company, has developed the LifeStraw, a similar inexpensive, portable water filter that eliminates many viruses and parasites from water drawn into it (Figure 20-14). It has been particularly useful in Africa, where aid agencies are distributing it.

Vestergaard Frandsen

Figure 20-14 The *LifeStraw*, designed by Torben Vestergaard Frandsen, is a personal water purification device that gives many poor people access to safe drinking water. **Question:** Do you think the development of such devices should make prevention of water pollution less of a priority? Explain.

■ CASE STUDY

Protecting Watersheds Instead of Building Water Purification Plants

Several major U.S. cities have avoided building expensive water treatment facilities by investing in protection of the forests and wetlands in the watersheds that provide their water (**Concept 20-3B**). Examples are New York City, N.Y; Boston, Massachusetts; Seattle, Washington; and Portland, Oregon.

New York City's drinking water is known for its purity. The city gets 90% of the water for its 9 million residents from reservoirs in New York State's Catskill Mountains. Forests cover more than three-fourths of this watershed. Underground tunnels transport the water to the city.

To continue providing quality drinking water for its citizens, the city faced spending $6 billion to build water purification facilities. Instead, the city decided to negotiate an agreement with towns, farmers, the state, and other interests in the Catskills watershed. The city would pay this diverse group of governments and private citizens $1.5 billion over 10 years for protecting and restoring the forests, wetlands, and streams in the watershed.

After many years of negotiations, this historic agreement was signed in 1997. The $1.5 billion to be spent on watershed protection will save New York City the $6 billion cost of building water purification facilities plus $300 million a year in filtration costs. This is an excellent example of working with nature to provide a sustainable supply of clean drinking water.

THINKING ABOUT
Protecting the Sources of Drinking Water

Where does the community in which you live get its drinking water? Could it save money and help to protect biodiversity by finding ways to protect its watershed or the aquifers that supply this water?

Using Laws to Protect Drinking Water Quality

About 54 countries, most of them in North America and Europe, have standards for safe drinking water. The U.S. Safe Drinking Water Act of 1974 requires the EPA to establish national drinking water standards, called *maximum contaminant levels,* for any pollutants that may have adverse effects on human health. But such laws do not exist or are not enforced in most developing countries.

Despite passage of the Clean Water Act in 1972, the United Nations estimates that 5.6 million Americans drink water that does not meet EPA safety standards for one or more contaminants. And according to the EPA, one in five Americans drinks water supplied by a water treatment plant that has violated one or more safety standards during part of a year.

Health scientists call for strengthening the U.S. Safe Drinking Water Act in several ways. One way is to combine many of the drinking water treatment systems that serve fewer than 3,300 people with nearby larger systems to make it cheaper for small systems to meet federal standards. Another is to strengthen and enforce public notification requirements about violations of drinking water standards. Scientists also call for banning all toxic lead in new plumbing pipes, faucets, and fixtures. Current law allows for fixtures with up to 10% lead content to be sold as lead-free. According to the Natural Resources Defense Council (NRDC), such improvements would cost each U.S. household an average of about $30 a year.

However, water-polluting industries are pressuring elected officials to weaken the Safe Drinking Water Act. One proposal is to eliminate national tests of drinking water and public notification requirements about violations of drinking water standards. Another such proposal is to allow states to give waivers to drinking water providers, allowing them a permanent right to violate the standard for a given contaminant if they claim they cannot afford to comply. Another suggestion is to eliminate the requirement that water systems use affordable, feasible technology to remove cancer-causing contaminants. Finally, there are suggestions to greatly reduce the EPA's already low budget for enforcing the U.S. Safe Drinking Water Act.

HOW WOULD YOU VOTE? ✓

Should the U.S. Safe Drinking Water Act be strengthened? Cast your vote online at **academic.cengage.com/biology/miller**.

Is Bottled Water the Answer?

Despite some problems, experts say the United States has some of the world's cleanest drinking water. Municipal water systems in the United States are required to test their water regularly for a number of pollutants and to make the results available to citizens. Yet about half of all Americans worry about getting sick from tap water contaminants, and many drink bottled water or install expensive water purification systems. Some other countries rely on bottled water wherever their tap water is too polluted to drink.

Between 1976 and 2006, average bottled water consumption per person in the United States increased from 7.5 liters (2 gallons) to 113 liters (30 gallons) a year. Studies reveal that in the United States, bottled water costs 240 to 100,000 times more than tap water. Yet studies also indicate that about one-fourth of it is ordinary tap water in a bottle, and that bacteria or fungi contaminate about 40% of bottled water. And the government testing standards for bottled water in the United States are not as high as those for tap water.

Each year, consumers worldwide spend about $100 billion on bottled water ($1–2 billion in the United States). Compare this to the cost of providing access to safe drinking water for the 1.1 billion people who now lack it, which the U.N. estimates to be $11.9 billion.

Use of bottled water also causes environmental problems, according to a 2007 study by the Worldwatch Institute. Each year, the number of plastic water bottles thrown away, if lined up end-to-end, could circle the earth's equator eight times. Toxic gases and liquids are released during the manufacture of plastic water bottles, and greenhouse gases and other air pollutants are emitted by the fossil fuels burned to make them and to deliver bottled water to suppliers. For example, a bottle of Fiji water used in the United States travels on average about 8,900 kilometers (5,500 miles). According to the Pacific Institute, the oil used to produce the plastic for the nearly 30 billion water bottles used in the United States each year would fuel 100,000 cars for a year. If we include the energy used to pump, process, transport, and refrigerate the water, it would be enough to run 3 million cars a year. And withdrawing water for bottling is helping to deplete some underground aquifers.

Because of these harmful environmental impacts and the high cost of bottled water, there is a growing *back-to-the-tap* movement based on boycotting bottled water. From San Francisco to New York to Paris, city governments, high-class restaurants, schools, religious groups, and many consumers are refusing to buy bottled water as this trend picks up steam.

Health officials suggest that, before drinking expensive bottled water or buying costly home water purifiers, consumers have their water tested by local health departments or private labs (but not by companies trying to sell water purification equipment). The goals for such testing are to identify what contaminants (if any) must be removed and to determine the type of purification needed to remove such contaminants. Independent experts contend that unless tests show otherwise, for most urban and suburban people served by large municipal drinking water systems, home water treatment systems are not worth the expense and maintenance hassles.

Buyers should check out companies selling water purification equipment and be wary of claims that the EPA has approved a treatment device. Although it does *register* such devices, the EPA neither tests nor approves them.

HOW WOULD YOU VOTE? ✓

Should we establish standards for bottled water that are as strict as those for water from public tap water systems? Cast your vote online at **academic.cengage.com/biology/miller**.

20-4 What Are the Major Water Pollution Problems Affecting Oceans?

▶ **CONCEPT 20-4A The great majority of ocean pollution originates on land and includes oil and other toxic chemicals and solid wastes, which threaten aquatic species and other wildlife and disrupt marine ecosystems.**

▶ **CONCEPT 20-4B The key to protecting the oceans is to reduce the flow of pollutants from land and air and from streams emptying into these waters.**

Ocean Pollution Is a Growing and Poorly Understood Problem

Coastal areas—especially wetlands, estuaries, coral reefs, and mangrove swamps—bear the brunt of our enormous inputs of pollutants and wastes into the ocean (**Concept 20-4A**) (Figure 20-15, p. 548). This is not surprising, because about 40% of the world's population (53% in the United States) lives on or near the coast. See T*he Habitable Planet,* Video 5, at **www.learner.org/resources/series209.html** to learn how scientists are studying the effects of population growth and development on nitrogen pollution of coastal aquatic systems in Cape Cod, Massachusetts (USA). Of the world's 15 largest metropolitan areas (each with 10 million people or more), 14 are near coastal waters. Coastal populations are expected to double by 2050.

According to a 2006 *State of the Marine Environment* study by the U.N. Environment Programme (UNEP), an estimated 80% of marine pollution originates on land (**Concept 20-4A**), and this percentage could rise significantly by 2050 if coastal populations double as projected. The report says that 80–90% of the municipal sewage from most coastal developing countries and from some coastal developed countries is dumped into oceans untreated. This dumping often overwhelms the ability of some coastal waters to biodegrade such wastes.

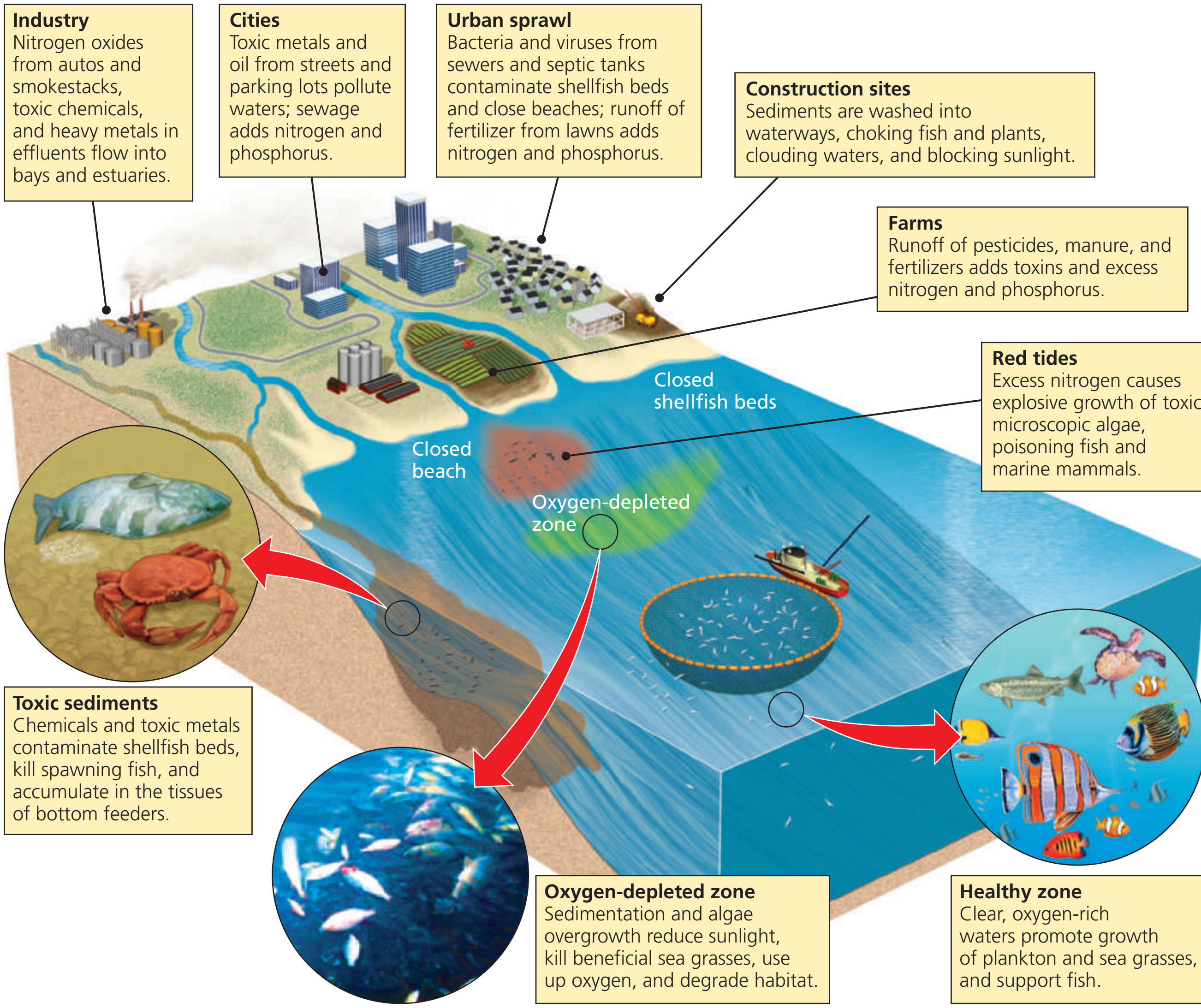


Figure 20-15 **Natural capital degradation:** residential areas, factories, and farms all contribute to the pollution of coastal waters and bays. According to the U.N. Environment Programme, coastal water pollution costs the world $16 billion annually—more than $30,000 a minute—due to ill health and premature death. **Question:** What are three changes you could make in your lifestyle that might help to prevent this pollution?

This problem is much worse than what we experienced in Lake Washington (**Core Case Study**), and its effects are equally apparent. Lake Washington had the potential to recover and had a larger body of water nearby that could dilute and help degrade such wastes. But the coastline of China, for example, is so choked with algae growing on the nutrients provided by sewage, that some scientists believe large areas of China's coastal waters can no longer sustain marine ecosystems.

In deeper waters, the oceans can dilute, disperse, and degrade large amounts of raw sewage and other types of degradable pollutants. Some scientists suggest that it is safer to dump sewage sludge and most other harmful wastes into the deep ocean than to bury them on land or burn them in incinerators. Other scientists disagree, pointing out that we know less about the deep ocean than we do about the moon. They add that dumping harmful wastes into the ocean would delay urgently needed pollution prevention measures and promote further degradation of this vital part of the earth's life-support system.

Scientists also point to a little known problem of cruise ship pollution. A cruise liner can carry as many as 2,000 passengers and 1,000 crew members and generate as much waste as a small city produces. Much of this waste, including perchloroethylene from dry-cleaning and benzene from paint and solvents, is highly toxic. Cruise ships also generate huge amounts of plastic garbage and waste oil. For decades, cruise ships and other ocean vessels, which often sail through fragile ecosystems such as Florida's coral reefs, have been dumping their wastes at sea.

In U.S. waters, such dumping is illegal, but some ships continue dumping secretively, usually at night. Ship owners can save large amounts of money by such illegal dumping. However, since 2002, a few of these companies have been caught in the act of illegal dumping and fined millions of dollars. And some vacationers are refusing to go on cruise ships that do not have sophisticated systems for dealing with the wastes they produce.

THINKING ABOUT
Ocean Pollution

Should we dump sewage sludge and other harmful pollutants into the deep ocean? Explain.

Recent studies of some U.S. coastal waters have found vast colonies of viruses thriving in raw sewage and in effluents from sewage treatment plants (which do not remove viruses) and leaking septic tanks. According to one study, one-fourth of the people using coastal beaches in the United States develop ear infections, sore throats, eye irritations, respiratory disease, or gastrointestinal disease.

In its 2005 report on the environmental health of coastal areas in the 48 continental U.S. states, the EPA classified four of five estuaries as threatened or impaired. It found one in four coastal sites unsuitable for swimming, and one in five of the sites had fish contaminated with unsafe levels of mercury and various other pollutants.

Runoffs of sewage and agricultural wastes into coastal waters introduce large quantities of nitrate (NO_3^-) and phosphate (PO_4^{3-}) plant nutrients, which can cause explosive growths of harmful algae. These *harmful algal blooms* are called red, brown, or green toxic tides (Figure 20-16). They release waterborne and airborne toxins that damage fisheries, kill some fish-eating birds, reduce tourism, and poison seafood. Each year, harmful algal blooms lead to the poisoning of about 60,000 Americans who eat shellfish contaminated by the algae.

Figure 20-16 *A brown tide.* This harmful algal bloom off the cost of Mexico contains organisms that give the water a reddish brown tint. They make the water unappealing to tourists and can be toxic to fish, wildlife, people, and their pets. **Question:** What are two ways in which this sort of pollution could be prevented?

Each year, because of harmful algal blooms, at least 200 *oxygen-depleted zones* form in coastal waters around the world, according to a 2006 report by the UNEP They occur mostly in temperate coastal waters and in landlocked seas such as the Baltic and Black Seas. About 43 of these zones occur in U.S. waters (Science Focus, p. 550).

These zones are incorrectly called *dead zones*. Because of low oxygen levels (hypoxia), they contain few oxygen-consuming fish and bottom-dwelling organisms, but they abound with decomposing bacteria. The low oxygen levels are caused by the rapid growth of algae in nutrient-rich waters, which are decomposed by colonies of oxygen-consuming bacteria. Evidence indicates that oxygen-depleted zones result mostly from excessive inputs of nitrates and phosphates from runoff of fertilizers and animal wastes, and also deposition of nitrogen compounds from the atmosphere.

Ocean Oil Pollution Is a Serious Problem

Crude petroleum (oil as it comes out of the ground) and *refined petroleum* (fuel oil, gasoline, and other processed petroleum products, Figure 15-4, p. 375) reach the ocean from a number of sources and become highly disruptive pollutants (**Concept 20-4A**).

In 1989, the *Exxon Valdez* oil tanker went off course, hit rocks, and released 40.8 million liters (10.8 million gallons) of oil into Alaska's Prince William Sound—an accident that ended up costing Exxon Mobil billions of dollars in cleanup costs, fines, and damages to 34,000 fishers and other Alaskans. The oil killed large numbers of seabirds, fish, and sea otters. The cleanup cost around $2.5 billion and the estimated total cost, including claims settlements and fines, was $4 billion.

In 2002, the oil tanker *Prestige* sank off the coast of Spain and, during the next 2 years, leaked about twice as much oil as the *Exxon Valdez* had lost. This and other spills also killed and harmed large numbers of seabirds (Figure 15-7, p. 379).

Tanker accidents and blowouts at offshore drilling rigs (when oil escapes under high pressure from a borehole in the ocean floor) get most of the publicity because of their high visibility. But *studies show that the largest source of ocean oil pollution is urban and industrial runoff from land,* much of it from leaks in pipelines and oil-handling facilities.

At least 37%—and perhaps even half—of the oil reaching the oceans is waste oil, dumped, spilled, or leaked onto the land or into sewers by cities, industries, and people changing their own motor oil. Some good news: according to a 2006 UNEP study, since the mid-1980s the amount of oil entering the marine

SCIENCE FOCUS

Oxygen Depletion in the Northern Gulf of Mexico

The world's third largest oxygen-depleted zone (after those in the Baltic Sea and the northwestern Black Sea) forms every spring and summer in a narrow stretch of the northern Gulf of Mexico off the mouth of the Mississippi River (Figure 20-B). The low oxygen levels suffocate fish, crabs, and shrimp that cannot move to less polluted areas.

The Mississippi River basin drains all or parts of 31 U.S. states and two Canadian provinces. Its watershed contains almost two-thirds of the continental U.S. land area and more than half of all U.S. croplands; it is one of the world's most productive agricultural regions.

According to a 2005 study of sediment cores by geologist Lisa Osterman, seasonal oxygen-depleted zones in the northern Gulf of Mexico existed as long ago as the 1800s. But since 1950, when fertilizer use began increasing sharply, the sizes of the zones and levels of oxygen-depletion have been increasing on average, even though it shrank in some years. In many years, it covers an area larger than the U.S. state of Connecticut.

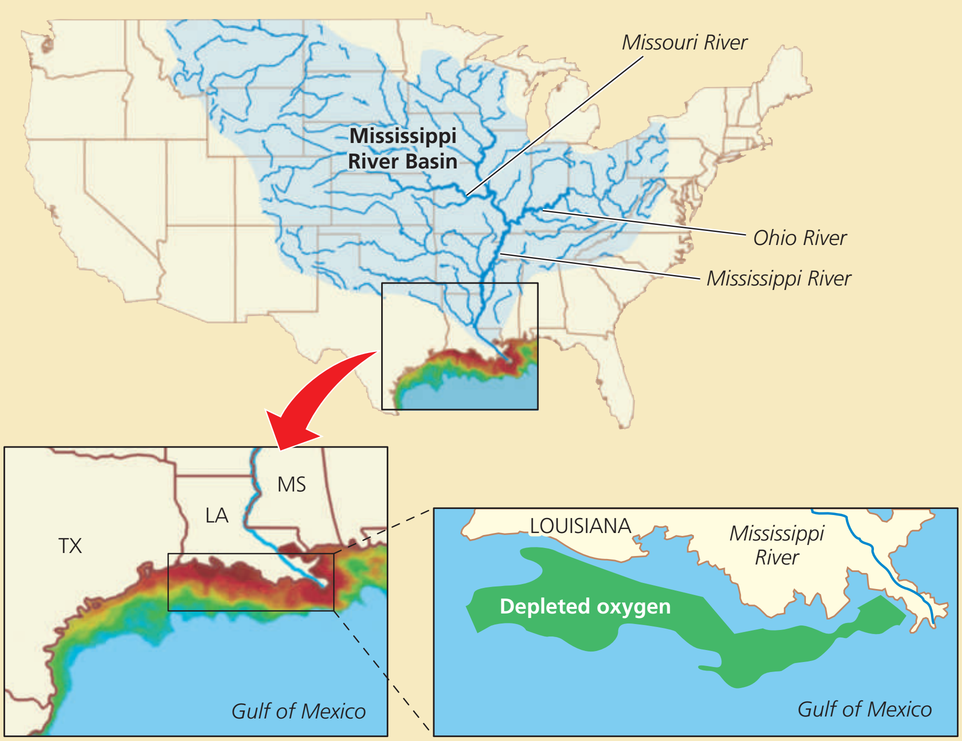


Figure 20-B **Natural capital degradation:** a large zone of oxygen-depleted water (containing less than 2 ppm dissolved oxygen) forms each year during the spring and summer in the Gulf of Mexico as a result of oxygen-depleting algal blooms. Evidence indicates that it is created mostly by huge inputs of nitrate (NO_3^-) plant nutrients from farms, cities, factories, and sewage treatment plants in the vast Mississippi River basin. The drawing (bottom left) based on a satellite image, shows the inputs of such nutrients into the Gulf of Mexico during the summer of 2006. In the image, reds and greens represent high concentrations of phytoplankton and river sediment. This problem was worsened by losses of wetlands, which would have filtered out some of these plant nutrients. **Question:** Can you think of a product you used today that was directly connected to this sort of pollution? (NASA)

In 2007, scientists projected that the 15% increase in the size of the heavily fertilized U.S. corn crop, resulting from increased demand for corn to make ethanol fuel for cars (Figure 16-27, p. 426), would cause the zone to grow in size. They later found that the zone was larger that summer than it had been in the previous 22 years. Thus, despite a commitment in 2001 by state and federal governments and Native American tribes to reduce the size of the zone by 75% by 2015, it is still growing.

Because of the size and agricultural importance of the Mississippi River basin, there are no easy solutions to the severe cultural eutrophication of this overfertilized coastal zone. Preventive measures include applying less fertilizer, injecting fertilizer below the soil surface, using controlled-release fertilizers that have water-insoluble coatings, planting strips of forests and grasslands along waterways to soak up excess nitrogen, and restoring and creating wetlands between crop fields and streams emptying into the Mississippi River.

Other measures involve improving flood control, to prevent the release of nitrogen from floodplains during major floods, and upgrading sewage treatment to reduce discharges of nitrates into waterways. In addition, deposition of nitrogen compounds from the atmosphere could be reduced by requiring lower emissions of nitrogen oxides from motor vehicles and phasing in forms of renewable energy to replace the burning of fossil fuels.

Some scientists who have studied this problem fear that it could reach a tipping point where many of the organisms living in this part of the gulf simply can no longer move far enough away to avoid the oxygen-depletion or to enable their populations to recover.

Critical Thinking

How do you think each of the preventive measures described above would help to prevent pollution in the Gulf of Mexico? Can you think of other possible preventive solutions?

environment from oil tanker accidents has decreased 75% and oil discharges from industry and cities have dropped by nearly 90%.

Volatile organic hydrocarbons in oil immediately kill many aquatic organisms, especially in their vulnerable larval forms. Other chemicals in oil form tar-like globs that float on the surface and coat the feathers of birds (especially diving birds) and the fur of marine mammals. This oil coating destroys their natural heat insulation and buoyancy, causing many of them to drown or die of exposure from loss of body heat.

Heavy oil components that sink to the ocean floor or wash into estuaries can smother bottom-dwelling organisms such as crabs, oysters, mussels, and clams, or make them unfit for human consumption. Some oil spills have killed coral reefs. See *The Habitable Planet,* Video 9, at **www.learner.org/resources/series209.html** for discussion of how scientists measure the effects of oil spills on coral reefs and fish populations.

Research shows that populations of many forms of marine life recover from exposure to large amounts of *crude oil* within about 3 years. But recovery from exposure to *refined oil,* especially in estuaries and salt marshes, can take 10–20 years. Oil slicks that wash onto beaches can have a serious economic impact on coastal residents, who lose income normally gained from fishing and tourist activities. In 2006, some 17 years after the *Exxon Valdez* spill, researchers found patches of oil remaining on some parts of the shoreline of Prince William Sound. These areas continue to be hazardous for sea otters, shore birds, and other wildlife.

If they are not too large, oil spills can be partially cleaned up by mechanical means including floating booms, skimmer boats, and absorbent devices such as large pillows filled with feathers or hair. Chemical, fire, and natural methods, such as using bacteria to speed up oil decomposition, are also used.

But scientists estimate that current cleanup methods can recover no more than 15% of the oil from a major spill. Thus, *preventing* oil pollution is the most effective and, in the long run, the least costly approach (**Concept 20-4B**). One of the best ways to prevent tanker spills is to use only oil tankers with double hulls. After the *Exxon Valdez* accident, oil companies promised that they would do so. But 19 years later, in 2008, about half of the world's 10,000 oil tankers still had the older and more vulnerable single hulls.

Figure 20-17 lists ways to prevent and reduce pollution of coastal waters. The key to protecting the oceans is to reduce the flow of pollution from land and air and from streams emptying into these waters (**Concept 20-4B**). Thus, ocean pollution control must be linked with land-use and air pollution control policies, which in turn are linked to energy policies (Figure 16-33, p. 432) and climate policies (Figures 19-13 and 19-14, p. 515).

SOLUTIONS

Coastal Water Pollution

Prevention

- Reduce input of toxic pollutants
- Separate sewage and storm lines
- Ban dumping of wastes and sewage by ships in coastal waters
- Ban ocean dumping of sludge and hazardous dredged material
- Regulate coastal development, oil drilling, and oil shipping
- Require double hulls for oil tankers

Cleanup

- Improve oil-spill cleanup capabilities
- Use nanoparticles on sewage and oil spills to dissolve the oil or sewage (still under development)
- Require secondary treatment of coastal sewage
- Use wetlands, solar-aquatic, or other methods to treat sewage

Figure 20-17 Methods for preventing and cleaning up excessive pollution of coastal waters (**Concept 20-4B**). **Question:** Which two of these solutions do you think are the most important? Why?

20-5 How Can We Best Deal with Water Pollution?

▶ **CONCEPT 20-5 Reducing water pollution requires preventing it, working with nature to treat sewage, cutting resource use and waste, reducing poverty, and slowing population growth.**

We Need to Reduce Surface Water Pollution from Nonpoint Sources

There are a number of ways to reduce nonpoint-source water pollution, most of which comes from agriculture. Farmers can reduce soil erosion by keeping cropland covered with vegetation. They can also reduce the amount of fertilizer that runs off into surface waters and leaches into aquifers by using slow-release fertilizer, using no fertilizer on steeply sloped land, and planting buffer zones of vegetation between cultivated fields and nearby surface water. See *The Habitable Planet,* Video 7, at **www.learner.org/resources/series209.html** to learn how scientists have reduced excessive nitrogen runoff from fertilizers to decrease their harmful impacts on aquatic systems.

Organic farming techniques also offer ways to prevent water pollution. For example, organic farmers use manure for fertilizer, in which nitrogen is contained within organic matter that clings to the soil.

Industrialized agriculture applies fertilizer as granules to cropland, which can more easily wash into streams.

Applying pesticides only when needed and relying more on integrated pest management (p. 300) can reduce pesticide runoff. Farmers can control runoff and infiltration of manure from animal feedlots by planting buffers and locating feedlots and animal waste sites away from steeply sloped land, surface water, and flood zones.

Tougher pollution control regulations for U.S. livestock operations are spurring scientists to come up with better ways to deal with animal waste. They are exploring techniques for converting it to natural gas, recycling undigested nutrients in manure back into animal feed, and extracting valuable chemicals from manure to make plastics or even cosmetics. For example, Smithfield Foods, a large pork producer, plans to build a facility in the state of Utah to convert the wastes from 500,000 hogs into renewable biodiesel fuel for vehicles.

HOW WOULD YOU VOTE? ✓

Should we greatly increase efforts to reduce water pollution from nonpoint sources even though this could be quite costly? Cast your vote online at **academic.cengage.com/biology/miller**.

Laws Can Help Reduce Water Pollution from Point Sources

The Federal Water Pollution Control Act of 1972 (renamed the Clean Water Act when it was amended in 1977) and the 1987 Water Quality Act form the basis of U.S. efforts to control pollution of the country's surface waters. (See Case Study at right.) The Clean Water Act sets standards for allowed levels of key water pollutants and requires polluters to get permits limiting how much of various pollutants they can discharge into aquatic systems.

The EPA is experimenting with a *discharge trading policy*, which uses market forces to reduce water pollution (as has been done with sulfur dioxide for air pollution control, p. 490) in the United States. Under this program, a permit holder can pollute at higher levels than allowed in its permit if it buys credits from permit holders who are polluting below their allowed levels.

Environmental scientists warn that the effectiveness of such a system depends on how low the cap on total pollution levels in any given area is set, along with how regularly the cap is lowered. They also warn that discharge trading could allow pollutants to build up to dangerous levels in areas where credits are bought. They call for careful scrutiny of the cap levels and for gradual lowering of the caps to encourage prevention of water pollution and development of better pollution control technology. Neither adequate scrutiny of the cap levels nor gradual lowering of caps is a part of the current EPA discharge trading system.

CASE STUDY

The U.S. Experience with Reducing Point-Source Pollution

According to the EPA, the Clean Water Act of 1972 led to numerous improvements in U.S. water quality. Between 1992 and 2002 (the latest figures available):

- The number of Americans served by community water systems that met federal health standards increased from 79% to 94%.
- The percentage of U.S. stream lengths found to be fishable and swimmable increased from 36% to 60% of those tested.
- The amount of topsoil lost through agricultural runoff was cut by about 1.1 billion metric tons (1 billion tons) annually.
- The proportion of the U.S. population served by sewage treatment plants increased from 32% to 74%.
- Annual wetland losses decreased by 80%.

These are impressive achievements given the increases in the U.S. population and per capita consumption of water and other resources since 1972. But there is more work to be done. In 2006, the EPA, found that 45% of the country's lakes and 40% of the streams surveyed were still too polluted for swimming or fishing, and that runoff of animal wastes from hog, poultry, and cattle feedlots and meat processing facilities pollutes seven of every ten U.S. rivers.

Even where sewage treatment plants are in place, treated wastewater can serve as a nutrient leading to algal blooms as it did in Lake Washington (**Core Case Study**) CORE CASE STUDY. Population growth and increasing levels of resource use and waste can overwhelm these sewage treatment systems.

Fish caught in more than 1,400 different waterways and more than a fourth of the nation's lakes are unsafe to eat because of high levels of pesticides, mercury, and other toxic substances. Also, a 2003 study by the EPA found that at least half of the country's 6,600 largest industrial facilities and municipal wastewater treatment plants have illegally discharged toxic or biological wastes into waterways for years without government enforcement actions or fines. And according to a 2007 study by the U.S. Public Interest Research Group, more than half of the country's industrial and wastewater facilities exceeded the limits of their Clean Water Act pollution permits one or more times in 2005, with the average facility discharging close to four times its legal limit of water pollutants.

Finally, the U.S. government reported in 2007 that tens of thousands of gasoline storage tanks are leaking (Figure 20-12), possibly affecting groundwater, and cleanup of most of these leaks has yet to begin. In 43 states, these numbers are expected to increase by thousands before 2020. The estimated cost of cleanup is

$12 billion, but the government in 2007 was planning to spend about 3% of that amount on the problem.

Some environmental scientists call for strengthening the Clean Water Act. Suggested improvements include shifting the emphasis to water pollution prevention instead of focusing mostly on end-of-pipe removal of specific pollutants. One EPA inspector general's report called for increased funding and authority to control nonpoint sources of pollution, greatly increased monitoring for compliance with the law, much larger mandatory fines for violators, and stronger programs to prevent and control toxic water pollution.

Other suggestions include providing more funding and authority for integrated watershed and airshed planning to protect groundwater and surface water from contamination, and regulating irrigation water quality, for which there is no federal regulation. Another suggestion is to expand the rights of citizens to bring lawsuits to ensure that water pollution laws are enforced. Studies have shown that many violators of federal water pollution standards receive no fines or only small ones. The National Academy of Sciences has called for prohibiting the destruction of wetlands, instituting higher standards for wetland restoration (Figure 11-13, p. 267), and requiring that before any natural wetland is destroyed, a new one be created.

Many people oppose these proposals, contending that the Clean Water Act's regulations and government wetlands regulations are already too restrictive and costly. Farmers and developers see these laws as limitations on their rights as property owners to fill in wetlands. They also believe they should be compensated for any property value losses due to federal wetland protection.

In 2006, the EPA weakened its application of the Clean Water Act by ruling that pesticides can be applied over or near bodies of water without a permit, if the application is needed to control aquatic weeds, mosquitoes or other pests. Critics fear that this ruling will result in more toxic pollutants winding up in streams and lakes. Funding cuts have also weakened the act.

Also among critics of the Clean Water Act are some state and local officials who want more discretion in testing for and meeting water quality standards. They argue that in many communities, it is unnecessary and too expensive to test for all the water pollutants as required by federal law. In this and other areas, federal laws require states and localities to spend a great deal of money to meet federal water pollution standards without reimbursing them for most of the costs from federal tax revenues. Many local officials object to these so-called "unfunded mandates" from Congress. Many small cities cannot afford such costs.

HOW WOULD YOU VOTE?

Should the U.S. Clean Water Act be strengthened? Cast your vote online at **academic.cengage.com/biology/miller**.

Sewage Treatment Reduces Water Pollution

In rural and suburban areas with suitable soils, sewage from each house usually is discharged into a **septic tank** with a large drainage field (Figure 20-18). In this system, household sewage and wastewater is pumped into a settling tank, where grease and oil rise to the top and solids fall to the bottom and are decomposed by bacteria. The resulting partially treated wastewater is discharged in a large drainage (absorption) field through small holes in perforated pipes embedded in porous gravel or crushed stone just below the soil's surface. As these wastes drain from the pipes and percolate downward, the soil filters out some potential pollutants and soil bacteria decompose biodegradable materials.

Every few years, when the settling tank becomes full, it must be pumped out into a tank truck and taken to a municipal sewage treatment plant for proper disposal. About one-fourth of all homes in the United States are served by septic tanks.

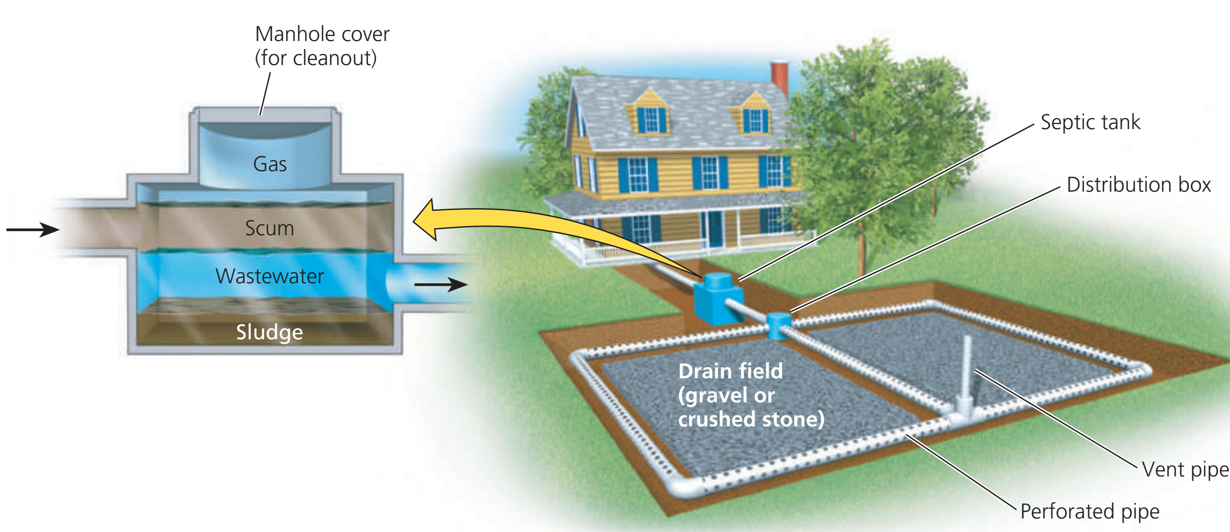


Figure 20-18 **Solutions:** *septic tank system* used for disposal of domestic sewage and wastewater in rural and suburban areas.

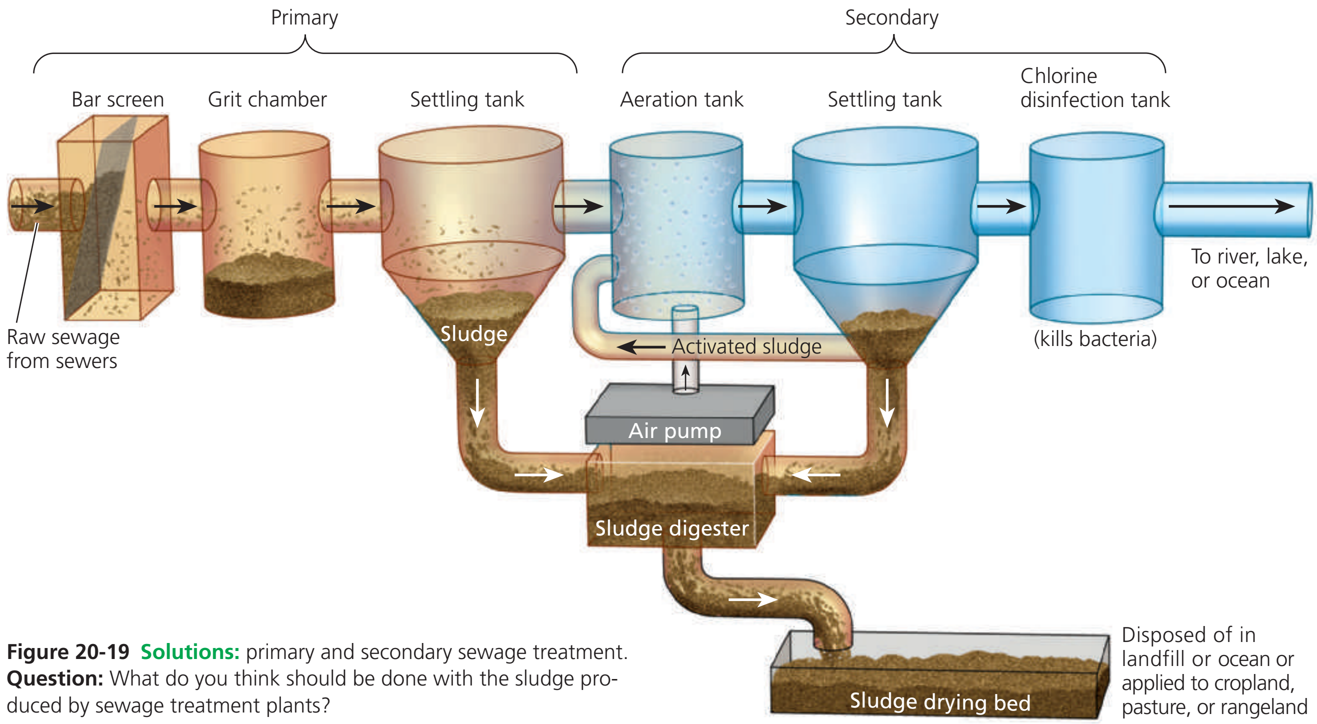


Figure 20-19 **Solutions:** primary and secondary sewage treatment. **Question:** What do you think should be done with the sludge produced by sewage treatment plants?

If these systems are not installed correctly or maintained properly, they can cause sewage to backup into homes or to pollute nearby groundwater and surface water. Chlorine bleaches, drain cleaners, and antibacterial soaps should not be used in these systems, because they can kill the bacteria that decompose the wastes. Kitchen sink garbage disposals should not be used either, because they can overload septic systems.

In urban areas in the United States and most developed countries, most waterborne wastes from homes, businesses, and storm runoff flow through a network of sewer pipes to *wastewater* or *sewage treatment plants.* Raw sewage reaching a treatment plant typically undergoes one or two levels of wastewater treatment. The first is **primary sewage treatment**—a *physical* process that uses screens and a grit tank to remove large floating objects and to allow solids such as sand and rock to settle out. Then the waste stream flows into a primary settling tank where suspended solids settle out as sludge (Figure 20-19, left). By itself, primary treatment removes about 60% of the suspended solids and 30–40% of the oxygen-demanding organic wastes from sewage. It removes no pathogens, phosphates, nitrates, salts, radioisotopes, or pesticides.

The second level is **secondary sewage treatment**—a *biological* process in which aerobic bacteria remove as much as 90% of dissolved and biodegradable, oxygen-demanding organic wastes (Figure 20-19, right). A combination of primary and secondary treatment removes 95–97% of the suspended solids and oxygen-demanding organic wastes, 70% of most toxic metal compounds and nonpersistent synthetic organic chemicals, 70% of the phosphorus, and 50% of the nitrogen. But this process removes only a tiny fraction of long-lived radioactive isotopes and persistent organic substances such as some pesticides, and it does not kill pathogens.

A third level of cleanup, *advanced* or *tertiary sewage treatment,* uses a series of specialized chemical and physical processes to remove specific pollutants left in the water after primary and secondary treatment. Its most common form makes use of special filters to remove phosphates and nitrates from wastewater before it is discharged into surface waters to help reduce nutrient overload from nitrates and phosphates. Because of its high costs it is not widely used.

Before discharge, water from sewage treatment plants usually undergoes *bleaching* to remove water coloration and *disinfection* to kill disease-carrying bacteria and some (but not all) viruses. The usual method for accomplishing this is *chlorination.* But chlorine can react with organic materials in water to form small amounts of chlorinated hydrocarbons. Some of these chemicals cause cancers in test animals, can increase the risk of miscarriages, and may damage the human nervous, immune, and endocrine systems. Use of other disinfectants, such as ozone and ultraviolet light, is increasing, but they cost more and their effects do not last as long as those of chlorination.

Officials in Peru decided to stop chlorinating the country's drinking water because of concern over the increased risk of cancer from organic compounds that form during chlorination. However, the country resumed chlorinating its drinking water after a 1991 cholera outbreak infected more than 300,000 people and caused at least 3,500 deaths.

U.S. federal law requires primary and secondary treatment for all municipal sewage treatment plants, but exemptions from secondary treatment are possible when the cost of installing such treatment poses an excessive financial burden. And according to the EPA, at least two-thirds of the country's sewage treatment plants have sometimes violated water pollution regulations. Also, 500 cities have failed to meet federal standards for sewage treatment plants, and 34 East Coast cities simply screen out large floating objects from their sewage before discharging it into coastal waters.

Some cities have a separate network of pipes for carrying runoff of storm water from streets and parking lots. But 1,200 U.S. cities have combined the sewer lines for these two systems because it is cheaper. Heavy rains or too many users hooked up to such combined systems can cause them to overflow and discharge untreated sewage directly into surface waters such as the Great Lakes (Case Study, p. 540). According to the EPA, at least 40,000 such overflows occur each year in the United States.

The EPA estimates that each year, 7.1 million people get sick from swimming in waters contaminated by sewage overflows and storm-water runoff. These numbers may increase. In 2005, the EPA authorized sewage treatment plants to bypass secondary treatment, blend the partially treated sewage with fully treated wastewater, and dump the mixture into waterways anytime it rains or snows. Before 2005, they could do this only under the most extreme emergency circumstances, such as during hurricanes and tropical storms.

Research by health and environmental scientists indicates that the health risks from swimming in waters containing blended sewage wastes will be 100 times greater than they would be if the wastewater were fully treated. They say that this new policy may save sewage treatment plants money, but it will cause more illnesses, close more beaches, kill more fish, destroy more shellfish beds, and hurt the fishing and tourism industries.

THINKING ABOUT
Sewage Treatment

Should the EPA rule allowing U.S. sewage treatment plants to blend partially treated sewage with fully treated sewage and to dump it into waterways anytime it rains or snows be overturned? Explain.

We Can Improve Conventional Sewage Treatment

Environmental scientist Peter Montague calls for redesigning the conventional sewage treatment system shown in Figure 20-19. The idea is to prevent toxic and hazardous chemicals from reaching sewage treatment plants and thus from getting into sludge and water discharged from such plants (**Concept 1-4**, p. 16). CONCEPT LINK

Montague suggests several ways to do this. One is to require industries and businesses to remove toxic and hazardous wastes from water sent to municipal sewage treatment plants. Another is to encourage industries to reduce or eliminate use and waste of toxic chemicals.

HOW WOULD YOU VOTE?

Should we ban the discharge of toxic chemicals into pipes leading to sewage treatment plants? Cast your vote online at **academic.cengage.com/biology/miller**.

Another suggestion is to require or encourage more households, apartment buildings, and offices to eliminate sewage outputs by switching to waterless, odorless *composting toilet systems,* to be installed, maintained, and managed by professionals. These systems, pioneered several decades ago in Sweden, convert nutrient-rich human fecal matter into a soil-like humus that can be used as a fertilizer supplement. About once a year, vendors collect the humus and sell it as a soil conditioner. This process returns plant nutrients in human waste to the soil and thus mimics the natural chemical cycling **principle of sustainability**. It also reduces the need for energy-intensive commercial inorganic fertilizers.

Such systems would be cheaper to install and maintain than current sewage systems are, because they do not require vast systems of underground pipes connected to centralized sewage treatment plants. They also save large amounts of water, reduce water bills, and decrease the amount of energy used to pump and purify water. The EPA lists several brands of dry composting toilets approved for use in the United States. One of the authors of this book (Miller) used a composting toilet for over a decade with no problems in his office-home facility. This more environmentally sustainable replacement for the conventional toilet is now being used in more than a dozen countries, including China, India, Mexico, Syria, and South Africa.

Many communities are using unconventional, but highly effective, *wetland-based sewage treatment systems,* which work with nature (Science Focus, p. 556). This approach will become increasingly important, according to sustainability expert Lester Brown. In what Brown calls the conventional "flush and forget" water-based systems, we take nutrients originating in the soil and processed through our food, and we eventually dump them into streams, lakes, and oceans. These systems are expensive and water-intensive, and they spread disease and disrupt nutrient cycling.

Wetland-based sewage treatment systems would be ideal in some developing countries where water is short and disease is rampant. They would also be useful in areas where valuable wetlands have been destroyed, such as on the U.S. Gulf Coast. In these areas, such wetland systems could replace devastated coastal marshlands, which were economically and ecologically vital natural resources.

Oysters, mussels, clams, scallops, and other shellfish consume algae and help to filter out and reduce

SCIENCE FOCUS

Treating Sewage by Working with Nature

Some communities and individuals are seeking better ways to purify sewage by working with nature (**Concept 20-5**). Biologist John Todd has developed an ecological approach to treating sewage, which he calls *living machines* (Figure 20-C).

This purification process begins when sewage flows into a passive solar greenhouse or outdoor site containing rows of large open tanks populated by an increasingly complex series of organisms. In the first set of tanks, algae and microorganisms decompose organic wastes, with sunlight speeding up the process. Water hyacinths, cattails, bulrushes, and other aquatic plants growing in the tanks take up the resulting nutrients. After flowing though several of these natural purification tanks, the water passes through an artificial marsh of sand, gravel, and bulrushes, which filters out algae and remaining organic waste. Some of the plants also absorb (sequester) toxic metals such as lead and mercury and secrete natural antibiotic compounds that kill pathogens.

Next, the water flows into aquarium tanks, where snails and zooplankton consume microorganisms and are in turn consumed by crayfish, tilapia, and other fish that can be eaten or sold as bait. After 10 days, the clear water flows into a second artificial marsh for final filtering and cleansing. The water can be made pure enough to drink by using ultraviolet light or by passing the water through an ozone generator, usually immersed out of sight in an attractive pond or wetland habitat. Operating costs are about the same as those of a conventional sewage treatment plant.

Ocean Arks International

Figure 20-C **Solutions:** ecological wastewater purification by a *living machine.* At the Providence, Rhode Island, Solar Sewage Treatment Plant, biologist John Todd demonstrates an ecological process he invented for purifying wastewater by using the sun and a series of tanks containing living organisms. Todd and others are conducting research to perfect such solar-aquatic sewage treatment systems based on working with nature.

More than 800 cities and towns around the world and 150 in the United States (including West Palm Beach, Florida, and Phoenix, Arizona) use natural or artificially created wetlands to treat sewage as a lower-cost alternative to expensive waste treatment plants. For example, Arcata, California—a coastal town of 16,000 people—created some 65 hectares (160 acres) of wetlands between the town and the adjacent Humboldt Bay. The marshes and ponds, developed on land that was once a dump, act as a natural waste treatment plant. The project cost was less than half the estimated price of a conventional treatment plant.

This system returns purified water to Humboldt Bay, and the sludge that is removed is processed for use as fertilizer. The marshes and ponds also serve as an Audubon Society bird sanctuary, which provides habitats for thousands of otters, seabirds, and marine animals. The town even celebrates its natural sewage treatment system with an annual "Flush with Pride" festival.

This approach and the living machine system developed by John Todd apply three of the four **scientific principles of sustainability**: using solar energy, using natural processes to remove and recycle nutrients and other chemicals, and relying on a diversity of organisms and natural processes.

Critical Thinking

Can you think of any disadvantages of using such a nature-based system instead of a conventional sewage treatment plant? Do you think any such disadvantages outweigh the advantages? Why or why not?

excessive inputs of nitrogen and phosphorus nutrients that cause oxygen-depleting algal blooms in coastal waters. For this reason, some coastal communities use shellfish farms to help remove excessive plant nutrients from coastal waterways. Studies show that using this approach is less expensive than using sewage treatment plants for this purpose.

There Are Sustainable Ways to Reduce and Prevent Water Pollution

It is encouraging that, since 1970, most developed countries have enacted laws and regulations that have significantly reduced point-source water pollution. These improvements were largely the result of *bottom-up* political pressure on elected officials by individuals and groups.

Conversely, little has been done to reduce water pollution in most developing countries. However, within a decade, China plans to provide all of its cities with small sewage treatment plants that will cleanse wastewater enough to be recycled back into the urban water supply systems. If China is successful in this ambitious plan, it could become a world leader in developing systems that tackle both pollution and water scarcity by recycling water, in keeping with the nutrient cycling **principle of sustainability**. Still, technological solutions can be temporary if they become overwhelmed by increased population growth and resource use, as the **Core Case Study** on Lake Washington illustrates.

SOLUTIONS

Water Pollution

- Prevent groundwater contamination
- Reduce nonpoint runoff
- Reuse treated wastewater for irrigation
- Find substitutes for toxic pollutants
- Work with nature to treat sewage
- Practice the three R's of resource use (reduce, reuse, recycle)
- Reduce air pollution
- Reduce poverty
- Slow population growth

Figure 20-20 Methods for preventing and reducing water pollution (**Concept 20-5**). **Question:** Which two of these solutions do you think are the most important? Why?

To environmental and health scientists, the next step is to increase efforts to reduce and prevent water pollution in developed and developing countries. They would begin by asking the question: *How can we avoid producing water pollutants in the first place?* (**Concept 20-5**). Figure 20-20 lists ways to achieve this goal over the next several decades.

This shift to pollution prevention will not take place unless citizens put political pressure on elected officials. Also, developing countries will need financial and technical aid from developed countries. Finally, the daily choices of each and every individual will help to determine whether the shift to pollution prevention can be achieved. Figure 20-21 lists some actions you can take to help reduce water pollution.

WHAT CAN YOU DO?

Reducing Water Pollution

- Fertilize garden and yard plants with manure or compost instead of commercial inorganic fertilizer
- Minimize your use of pesticides, especially near bodies of water
- Prevent yard wastes from entering storm drains
- Do not use water fresheners in toilets
- Do not flush unwanted medicines down the toilet
- Do not pour pesticides, paints, solvents, oil, antifreeze, or other products containing harmful chemicals down the drain or onto the ground

Figure 20-21 **Individuals matter:** ways to help reduce water pollution. **Question:** Which three of these actions do you think are the most important? Why?

REVISITING Lake Washington and Sustainability

CORE CASE STUDY SUSTAINABILITY

The story of Lake Washington (**Core Case Study**) is an example of people loving a natural resource and abusing it at the same time. For many years, Seattle residents assumed the lake could easily absorb their treated sewage and remain a good place for swimming and boating. Eventually, with the help of scientific inquiry and investigation, they learned that the numbers of people using it could overwhelm this natural system. A technical solution was found for dealing with sewage treatment effluent, but now continually increasing pressures due to a growing population, are again overwhelming the natural systems of Lake Washington and Puget Sound.

This story is instructive for dealing with pollution problems in other developed countries and in rapidly growing developing countries. Pollution control for the world's water supplies is within our reach. But even more hopeful is the possibility of shifting our emphasis from cleaning up water pollution to reducing and preventing it.

The four **scientific principles of sustainability** (back cover) can guide us in reducing and preventing pollution. We can use solar energy to purify the water we use. Recycling more water will help us to reduce water waste, and natural nutrient cycles can be used to treat our waste in wetland-based sewage treatment systems (Science Focus, p. 556). Preserving biodiversity by avoiding disruption of aquatic systems and their bordering terrestrial systems, which in turn help to reduce pollution, is a key factor in maintaining water supplies and water quality. And controlling human population growth and levels of resource use and waste is fundamental to maintaining water quality.

It is a hard truth to swallow,
but nature does not care if we live or die.
We cannot survive without the oceans,
for example, but they can do just fine without us.

ROGER ROSENBLATT

REVIEW

1. Review the Key Questions and Concepts for this chapter on p. 532. Describe the cleanup of Lake Washington near Seattle (**Core Case Study**) and list the three lessons learned from this process.
2. What is **water pollution?** Distinguish between **point sources** and **nonpoint sources** of water pollution and give an example of each. List nine major types of water pollutants and give an example of each. List three diseases transmitted to humans by polluted water. Describe chemical and biological methods that scientists use to measure water quality.
3. Describe how streams can cleanse themselves and how these cleansing processes can be overwhelmed. Describe the state of stream pollution in developed and developing countries. Describe the pollution problems of the Ganges River, which runs through part of India.
4. Give two reasons why lakes cannot cleanse themselves as readily as streams can. Distinguish between **eutrophication** and **cultural eutrophication.** List three ways to prevent or reduce cultural eutrophication. Describe pollution of the Great Lakes and the progress made in reducing this pollution.
5. Explain why groundwater cannot cleanse itself very well. What are the major sources of groundwater contamination in the United States? Describe the threat from arsenic in groundwater. List ways to prevent or clean up groundwater contamination.
6. Describe U.S. laws for protecting drinking water quality. Describe the environmental problems caused by the widespread use of bottled water.
7. How are coastal waters and deeper ocean waters polluted? What causes harmful algal blooms and what are their harmful effects? Describe oxygen depletion in the northern Gulf of Mexico. How serious is oil pollution of the oceans, what are its effects, and what can be done to reduce such pollution?
8. List two ways to reduce water pollution from **(a)** nonpoint sources and **(b)** point sources. Describe the U.S. experience with reducing point-source water pollution. What is a **septic tank** and how does it work? Describe how **primary sewage treatment** and **secondary sewage treatment** are used to help purify water.
9. How would Peter Montague improve conventional sewage treatment? What is a composting toilet system? Describe how wetlands can be used to treat sewage. Describe the use of living machines to treat sewage. List six ways to prevent and reduce water pollution. List five steps you can take to reduce water pollution.
10. Describe connections between the cleanup of Lake Washington (**Core Case Study**) and the four **scientific principles of sustainability**.

Note: Key Terms are in **bold** type.

CRITICAL THINKING

1. What were two important roles played by the scientists who studied Lake Washington as discussed in the **Core Case Study** that opens this chapter? Explain how the story might have been different if the scientists had not fulfilled each of these roles.
2. Lake Washington and Puget Sound now face new problems similar to those of the past, as suggested in the **Core Case Study**. Describe the nature of those problems and suggest possible solutions.
3. A large number of dead fish are found floating in a lake. How would you determine whether they died from cultural eutrophication or from exposure to toxic chemicals?
4. If you were a regulator charged with drawing up plans for controlling water pollution, briefly describe one idea for controlling water pollution from each of the following sources: **(a)** an effluent pipe from a factory going into a stream, **(b)** a parking lot at a shopping mall bordered by a stream, **(c)** a farmer's field on a slope next to a stream.
5. What role does population growth play in **(a)** groundwater pollution problems and **(b)** coastal water pollution problems?
6. When you flush your toilet, where does the wastewater go? Trace the actual flow of this water in your community from your toilet through sewers to a wastewater treatment plant and from there to the environment. Try to visit a local sewage treatment plant to see what it does with your wastewater. Compare the processes it uses with those shown in Figure 20-19. What happens to the sludge produced by this plant? What improvements, if any, would you suggest for this plant?
7. In your community,
   - **a.** What are the principal nonpoint sources of contamination of surface water and groundwater?
   - **b.** What is the source of drinking water?
   - **c.** How is drinking water treated?
   - **d.** How many times during each of the past 5 years have levels of tested contaminants violated federal standards? Were violations reported to the public?
   - **e.** What problems related to drinking water, if any, have arisen in your community? What actions, if any, has your local government taken to solve such problems?
   - **f.** Is groundwater contamination a problem? If so, where, and what has been done about the problem?

g. Is there a vulnerable aquifer or critical recharge zone that needs protection to ensure the quality of groundwater? Is your local government aware of this? What action (if any) has it taken?

8. List three ways in which you could apply **Concept 20-5** to make your lifestyle more environmentally sustainable.

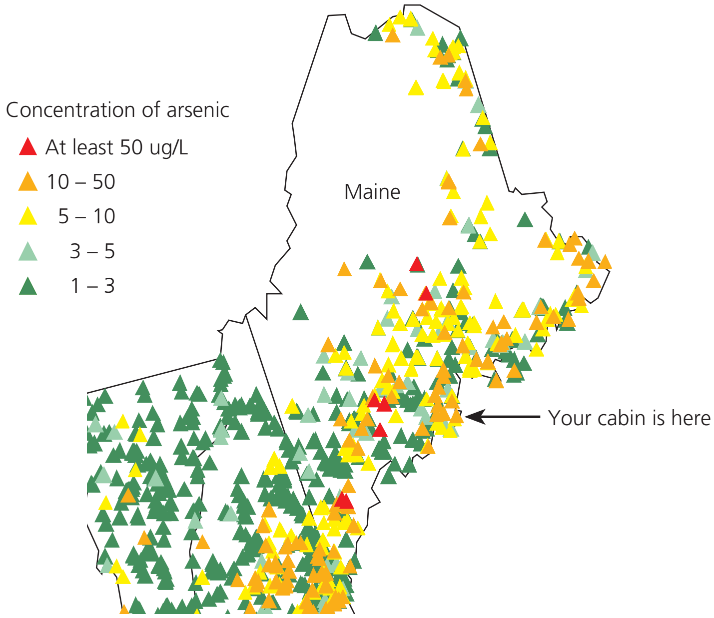
9. Congratulations! You are in charge of the world. What are three actions you would take to **(a)** sharply reduce point-source water pollution in developed countries, **(b)** sharply reduce nonpoint-source water pollution throughout the world, **(c)** sharply reduce groundwater pollution throughout the world, and **(d)** provide safe drinking water for the poor and for other people in developing countries?

10. List two questions that you would like to have answered as a result of reading this chapter.

Note: See Supplement 13 (p. S78) for a list of Projects related to this chapter.

DATA ANALYSIS

You have inherited the family cabin on the southerly coast of Maine overlooking the Atlantic Ocean where your source of drinking water is a well.



1. You learn that your drinking water could be contaminated with unsafe levels of arsenic. Referring to the above map, what range of arsenic levels can you expect to find in your well water?

2. The EPA requires all public water utilities to have no more than 10 micrograms of arsenic per liter of water (10 ug/L) in drinking water. Although domestic wells are not regulated, you must comply if you decide to sell your family cabin. Does your well comply? Explain.

3. To reduce your exposure to arsenic, you could install a reverse osmosis treatment system. It is 95% effective and can produce 11 liters (3.0 gallons) of water a day. Assuming your water contains 50 micrograms of arsenic per liter, what would the arsenic concentration be after the reverse osmosis treatment? Does this comply with the EPA-accepted safe level?

LEARNING ONLINE

Log on to the Student Companion Site for this book at **academic.cengage.com/biology/miller**, and choose Chapter 20 for many study aids and ideas for further reading and research. These include flash cards, practice quizzing, Weblinks, information on Green Careers, and InfoTrac® College Edition articles.

AP* Review Questions for Chapter 20

1. Parts of a river associated with a point-source pollutant are shown below. Which of the combinations is incorrectly paired?
(A) Clean zone–high levels of dissolved oxygen
(B) Point of input–rapid increase of biological oxygen demand
(C) Decomposition zone–only pollution-tolerant fishes found
(D) Septic zone–most fish absent, low levels of dissolved oxygen
(E) Recovery zone–normal levels of dissolved oxygen

2. Lakes near areas with high human population densities will frequently experience large growths of algae or other unwanted bacteria and phytoplankton, often due to a lack of secondary waste treatment. This is the result of
(A) power companies dumping heated water from cooling towers.
(B) the development of lakefront shorelines with beaches.
(C) sediment runoff from construction sites.
(D) nonpoint source–pollution runoff from sidewalks and parking lots.
(E) large nutrient influxes from sewage treatment plants.

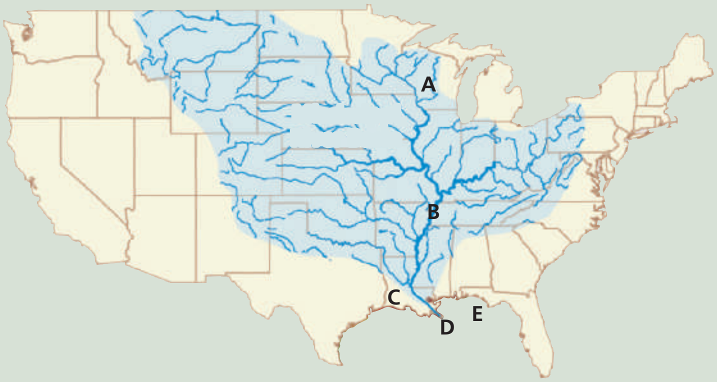
3. Which of the water pollutants below is **incorrectly** paired with its source?
(A) Oxygen-demanding wastes–sewage
(B) Organic chemicals–industry and farms
(C) Sediments–unlined landfills
(D) Heavy metals–mining refuse
(E) Thermal–electric power plants

4. Which of the examples below is a point-source pollutant?
(A) Ballast water discharge from a ship offshore
(B) Runoff from parking lots
(C) Organic waste from animal feed lots
(D) Sediments from land erosion
(E) Nutrients from golf courses and lawns

5. Which of the common diseases below is transmitted through contaminated drinking water?
(A) Chicken pox
(B) Cholera
(C) Flu
(D) Measles
(E) Lead poisoning

6. The natural aging process of a shallow lake or slow-moving stream, as nutrients enrich the water body, is called
(A) bioaccumulation.
(B) infiltration
(C) natural services.
(D) eutrophication.
(E) ecological efficiency.

Questions 7 and 8 refer to the diagram of the Mississippi River drainage basin below.



7. Which letter best shows the location of depleted oxygen caused by the Mississippi River?

8. The depleted oxygen zone caused by the Mississippi River is primarily a result of
(A) sediment runoff from construction sites.
(B) wakes from boats traveling up and down the Mississippi River.
(C) lack of current flow in the main stem of the river.
(D) nitrate runoff from agricultural fields and sewage treatment plants.
(E) the river's freshwater dissolving in the Gulf of Mexico and precipitating out organic chemicals.

9. Which law sets standards for the allowed levels of key water pollutants and requires polluters to obtain permits limiting how much of various pollutants they can discharge into aquatic systems?
(A) National Environmental Policy Act (NEPA) 1969
(B) Water Pollution Control Act of 1972
(C) Clean Water Act 1977
(D) Coastal Zone Management Act 1980
(E) Water Quality Act 1987

Questions 10–12 are based on the steps of wastewater treatment shown below.

(A) Primary treatment
(B) Secondary treatment
(C) Disinfection
(D) Advanced treatment
(E) Discharge

10. Water flows slowly through grit chambers allowing sand and small particles to settle out.

11. This is not used except when warranted by local regulations.

12. Nitrates and phosphates are removed during this step.