CHAPTER 19

Water Pollution and Treatment

Dredging began in 2009 to remove contaminant sediment from the Hudson River in New York.

LEARNING OBJECTIVES

Degradation of our surface-water and groundwater resources is a serious problem. Although all of its effects are not yet fully known, we can and should begin taking steps to treat water and to minimize pollution. After reading this chapter, you should understand . . .

- What constitutes water pollution and what the major categories of pollutants are;
- Why the lack of disease-free drinking water is the primary water-pollution problem in many locations around the world;
- How point and nonpoint sources of water pollution differ;
- What biochemical oxygen demand is, and why it is important;
- What eutrophication is, why it is an ecosystem effect, and how human activity can cause it;
- Why sediment pollution is a serious problem;
- What acid mine drainage is, and why it is a problem;
- How urban processes can cause shallow-aquifer pollution;
- What the various methods of wastewater treatment are, and why some are environmentally preferable to others;
- Which environmental laws protect water resources and ecosystems.

CASE STUDY

America's "First River": A Success Story

The Hudson River is sometimes referred to as America's first river. It is named after Henry Hudson, who sailed up the river from the Atlantic in 1609 looking for a route to Asia. Native Americans, however, called the river by a name meaning "flows in two directions." This is because, for much of its lower course, the river ebbs and flows with the ocean tides, flowing upstream, then downstream, and sometimes part of the river is flowing up while part is flowing down. The total length of the river from the Adirondack Mountains to the Atlantic Ocean is just over 480 kilometers, but it's the lower 160 kilometers that has gained the most attention. Before emptying into New York Harbor, the lower Hudson flows past New Jersey communities such as Fort Lee, Union City, and Hoboken on its western shore and Mt Vernon, Yonkers, and Manhattan Island on its eastern shore. Farther upstream, about 50 to 150 km from Manhattan, the river flows through the scenic Hudson River Highlands. The high hills that border the river have a core of ancient hard igneous and metamorphic rock that erosion has carved into beautiful scenery, such as Storm King Mountain.

The story of the Hudson River and the environment go back to the 1800s. The nation's first military academy, West Point, was established along the river in 1802, and during the War of 1812 industrial activity sprang up along the river. A foundry opened near West Point to manufacture such products as cannonballs, pipes, and railroad engines. The foundry closed after about 100 years, but other factories became established along the river, including the Anaconda Wire and Cable Company. That plant closed in 1974, leaving behind a legacy of toxic pollution that helped turn the Hudson River into an environmental battleground in the 20th century between people who revered the river and those deemed responsible for making it unsafe to swim in its waters and making the fish that lived in it unsafe to eat.[1] In one of the nation's earliest battles to eliminate water pollutants, activists and others in the early 1970s sued the company, which was fined about $200,000, a very large fine for pollution violations at that time.

Those who thought that from then on the river would be clean again for future generations were mistaken: From around 1950 to 1977, General Electric discharged (dumped) over a million pounds of polychlorinated biphenyls (PCBs) into the Hudson River from two manufacturing plants. PCBs are highly stable man-made chemical compounds produced by combining chlorine and biphenyl (an organic compound). Because they are good electrical insulators and were considered safe, PCBs were widely used to prevent fires in electric transformers and capacitors. GE operated the plants for decades. Then, in the early 1970s, the story of the catastrophe unfolding in the Hudson River became common knowledge. Commercial fishing for striped bass and other fish was banned in 1976, and fishermen blamed GE for destroying a fishing industry, a way of life, and a culture that had been going on for centuries in the river valley.

PCBs were found to cause liver disease and are a suspected carcinogen in humans and a known carcinogen in other animals. PCBs were found to be persistent in the environment and entered the food chain to damage the river ecosystem, especially fish and invertebrates. As a result, they were banned in the United States in 1977. During this period, environmentalism became important and federal water laws were passed, including the Clean Water Act of 1972. In that year the U.S. government started dealing with hazardous waste and passed the Resource Conservation and Recovery Act, followed a few years later by the Comprehensive Environmental Response Compensation and Liability Act of 1980, which established the so-called Superfund to clean up several hundred of the most hazardous sites in the country.

At the top of the list was the Hudson River, and in 1983 a roughly 300-kilometer reach of the river was classified as the largest and one of the most serious Superfund sites in the country. The new law also changed the way the federal government dealt with industries that polluted the environment. Companies became responsible for their previous pollution of Superfund sites and liable for cleanup.

Today, however, over 100 tons of PCBs are still in the Hudson River sediments, with concentrations thousands of times greater than what is considered safe. PCBs accumulate in food chains in a process known as bioaccumulation. For example, organisms in the sediment contain a concentration of PCBs that increases as these organisms are eaten by fish, and these concentrations may increase further when the fish are eaten by predators such as eagles or people. Health advisories were issued in the mid-1970s and these remain in place today, warning women and children not to eat fish from the Hudson River.

A battle raged on as to what should be done about the PCBs. The two major alternatives were either to dredge areas where PCB concentrations are particularly high or just let natural processes in the river clean up the PCBs. The second option assumed that the sources of PCBs have been nearly eliminated and that the river would naturally cleanse itself of approximately half of the PCBs in three or four years.[2,3] Those arguing for dredging said the pollution was far too great to leave the cleanup to natural processes, and that dredging would greatly shorten the time necessary for the river to clean itself. To dredge or not to dredge was a several-hundred-million-dollar question. General Electric spent millions in an attempt to avoid spending hundreds of millions to clean up the river by dredging. The company said dredging would just stir up the PCBs in the riverbed, moving them up into the water and thus into the food chain.

The issue was settled in 2001: General Electric would have to pay several hundred million dollars to clean up the river by dredging. The work on mapped PCB hotspots began in 2009, using barges to dredge the contaminated sediment from the river bottom and place it in hopper barges. From there it is sent to a processing facility, and then finally transported by train about 3,000 kilometers to a waste-disposal site in west Texas. The cleanup is expected to take until 2015, ending an era of water pollution and toxic legacy in the Hudson.

The lower Hudson River Valley is urbanizing. There are more parking lots and cars than ever before. There is concern that runoff from streets and parking lots and urban houses will lead to a new wave of urban pollution. On the other hand, more and more people are experiencing the Hudson River in very positive ways. Numerous river groups focus their time and effort on cleaning up the river and promoting activities such as boating, hiking, and bird-watching. Parks of all sizes are being established at scenic sites along the river, factories have been removed, making room for some of the new parks, and there is an attempt to join these together in a greenbelt that would stretch many miles up the river from Manhattan. Some of the river culture from times past is reappearing.

In sum, the future of the Hudson River seems secure as progress in its cleanup and preservation continues. Some say that modern environmentalism was born on the Hudson River, one of the few American rivers to be designated an American Heritage River. Many people made important personal sacrifices to their careers, reputations, and livelihoods to protect the river.

These people truly revered the Hudson River and were in the forefront of fighting to protect our natural environment. An organization known as Scenic Hudson led the fight to protect the river. It was joined in 1969 by Clearwater, which included the folksinger, activist, and environmentalist Pete Seeger. Clearwater built a sloop that took people up and down the river, educating them on environmental concerns, fighting to control and eliminate pollution, and encouraging river restoration. Both Scenic Hudson and Clearwater remain active today.

The story of PCB pollution is a powerful reminder that individuals and groups can make a difference in correcting past environmental errors and working toward sustainability.

19.1 Water Pollution

Water pollution refers to degradation of water quality. In defining pollution, we generally look at the intended use of the water, how far the water departs from the norm, its effects on public health, or its ecological impacts. From a public-health or ecological view, a pollutant is any biological, physical, or chemical substance that, in an identifiable excess, is known to be harmful to desirable living organisms. Water pollutants include heavy metals, sediment, certain radioactive isotopes, heat, fecal coliform bacteria, phosphorus, nitrogen, sodium, and other useful (even necessary) elements, as well as certain pathogenic bacteria and viruses. In some instances, a material may be considered a pollutant to a particular segment of the population, although it is not harmful to other segments. For example, excessive sodium as a salt is not generally harmful, but it may be harmful to people who must restrict salt intake for medical reasons.

Today, the world's primary water-pollution problem is a lack of clean, disease-free drinking water. In the past, epidemics (outbreaks) of waterborne diseases such as cholera have killed thousands of people in the United States. Fortunately, we have largely eliminated epidemics of such diseases in the United States by treating drinking water prior to consumption. This certainly is not the case worldwide, however. Every year, several billion people are exposed to waterborne diseases. For example, an epidemic of cholera occurred in South America in the early 1990s, and outbreaks of waterborne diseases continue to be a threat even in developed countries.

Many different processes and materials may pollute surface water or groundwater. Some of these are listed in Table 19.1. All segments of society—urban, rural, industrial, agricultural, and military—may contribute to the problem of water pollution. Most of it results from runoff and leaks or seepage of pollutants into surface water or groundwater. Pollutants are also transported by air and deposited in bodies of water.

Increasing population often results in the introduction of more pollutants into the environment as well as greater demands on finite water resources.[4] As a result, we can expect sources of drinking water in some locations to be degraded in the future.[5,6]

Table 19.1 SOME SOURCES AND PROCESSES OF WATER POLLUTION

SURFACE WATER	GROUNDWATER
Urban runoff (oil, chemicals, organic matter, etc.) (U, I, M) Agricultural runoff (oil, metals, fertilizers, pesticides, etc.) (A)	Leaks from waste-disposal sites (chemicals, radioactive materials, etc.) (I, M)
Accidental spills of chemicals including oil (U, R, I, A, M)	Leaks from buried tanks and pipes (gasoline, oil, etc.) (I, A, M)
Radioactive materials (often involving truck or train accidents) (I, M)	Seepage from agricultural activities (nitrates, heavy metals, pesticides, herbicides, etc.) (A)
Runoff (solvents, chemicals, etc.) from industrial sites (factories, refineries, mines, etc.) (I, M)	Saltwater intrusion into coastal aquifers (U, R, I, M) Seepage from cesspools and septic systems (R)
Leaks from surface storage tanks or pipelines (gasoline, oil, etc.) (I, A, M)	Seepage from acid-rich water from mines (I) Seepage from mine waste piles (I)
Sediment from a variety of sources, including agricultural lands and construction sites (U, R, I, A, M)	Seepage of pesticides, herbicide nutrients, and so on from urban areas (U)
Air fallout (particles, pesticides, metals, etc.) into rivers, lakes, oceans (U, R, I, A, M)	Seepage from accidental spills (e.g., train or truck accidents) (I, M)
	Inadvertent seepage of solvents and other chemicals including radioactive materials from industrial sites or small businesses (I, M)

Key: U = urban; R = rural; I = industrial; A = agricultural; M = military.

The U.S. Environmental Protection Agency has set thresholds limiting the allowable levels for some (but not all) drinking-water pollutants. Because it is difficult to determine the effects of exposure to low levels of pollutants, thresholds have been set for only a small fraction of the more than 700 identified drinking-water contaminants. If the pollutant exceeds an established threshold, then the water is unsatisfactory for a particular use. Table 19.2 lists selected pollutants included in the national drinking-water standards for the United States.

Water withdrawn from surface or groundwater sources is treated by filtering and chlorinating before distribution to urban users. Sometimes it is possible to use the natural environment to filter the water as a service function, saving treatment cost (see A Closer Look 19.1).

The following sections focus on several water pollutants to emphasize principles that apply to pollutants in general. (See Table 19.3 for categories and examples of water pollutants.) Before proceeding to our discussion of pollutants, however, we first consider biochemical oxygen demand and dissolved oxygen. Dissolved oxygen is not a pollutant but rather is needed for healthy aquatic ecosystems.

Table 19.2 NATIONAL DRINKING-WATER STANDARDS

CONTAMINANT	MAXIMUM CONTAMINANT LEVEL (MG/L)
Inorganics	
Arsenic	0.05
Cadmium	0.01
Lead	0.015 action level[a]
Mercury	0.002
Selenium	0.01
Organic chemicals	
Pesticides	
Endrin	0.0002
Lindane	0.004
Methoxychlor	0.1
Herbicides	
2,4-D	0.1
2,4,S-TP	0.01
Silvex	0.01
Volatile organic chemicals	
Benzene	0.005
Carbon tetrachloride	0.005
Trichloroethylene	0.005
Vinyl chloride	0.002
Microbiological organisms	
Fecal coliform bacteria	1 cell/100 ml

[a] Action level is related to the treatment of water to reduce lead to a safe level. There is no maximum contaminant level for lead.

Source: U.S. Environmental Protection Agency.

A CLOSER LOOK 19.1

What Is the Value of Clean Water to New York City?

The forest of the Catskill Mountains in upstate New York (Figure 19.1) provides water to about 9 million people in New York City. The total contributing area in the forest is about 5,000 km^2 (2,000 square miles), of which the city of New York owns less than 8%. The water from the Catskills has historically been of high quality and in fact was once regarded as one of the largest municipal water supplies in the United States that did not require extensive filtering. Of course, what we are talking about here is industrial filtration plants, where the water enters from reservoirs and groundwater and is then treated before being dispersed to users.

In the past, the water from the Catskills has been filtered very effectively by natural processes. When rain or melting snow drips from trees or melts on slopes in the spring, some of it infiltrates the soil and moves down into the rocks below as groundwater. Some emerges to feed streams that flow into reservoirs. During its journey, the water enters into a number of physical and chemical processes that naturally treat and filter the water. These natural-service functions that the Catskill forest ecosystem provides to the people of New York were taken for granted until about the 1990s, when it became apparent that the water supply was becoming vulnerable to pollution from uncontrolled development in the watershed.

A particular concern was runoff from buildings and streets, as well as seepage from septic systems that treat wastewater from homes and buildings, partly by allowing it to seep through soil.

The city is also concerned that drilling for natural gas, that uses water and contaminates the groundwater, could damage surface water resources (see Chapter 15). Drilling for natural gas in the watershed supplying New York City was virtual banned in 2010.

The Environmental Protection Agency has warned that unless the water quality improved, New York City would have to build a water treatment plant to filter the water. The cost of such a facility was estimated at $6–8 billion, with an annual operating expense of several hundred million dollars. As an alternative, New York City chose to attempt to improve the water quality at the source. The city built a sewage treatment plant upstate in the Catskill Mountains at a cost of about $2 billion. This seems very expensive but was about one-third the cost of building the treatment plant to filter water. Thus, the city chose to invest in the "natural capital" of the forest, hoping that it will continue its natural service function of providing clean water. It will probably take several decades to tell whether New York City's gamble will work in the long term.[4]

There have been unanticipated benefits from maintaining the Catskill Mountain forest ecosystem. These benefits come from recreational activities, particularly trout fishing, which is a multibillion-dollar enterprise in upstate New York. In addition to the trout fishermen are people wanting to experience the Catskill Mountains through hiking, winter sports, and wildlife observation, such as bird-watching.

You might wonder why the city has been successful in its initial attempt to maintain high-quality water when it owns only about 8% of the land the water comes from. The reason is that the city has offered farmers, homeowners, and other people living in the forest financial incentives to maintain high-quality water resources. Although the amount of money is not large, it is sufficient to provide a sense of stewardship among the landowners, and they are attempting to abide by guidelines that help protect water quality.

New York isn't the only U.S. city that has chosen to protect watersheds to produce clean, high-quality drinking water rather than constructing and maintaining expensive water treatment plants. Others include Boston, Massachusetts; Seattle, Washington; and Portland, Oregon.

The main point of this story is that we mustn't undervalue the power of natural ecosystems to provide a variety of important services, including improved water and air quality.[4]

FIGURE 19.1 The Catskill Mountains of upstate New York are an ecosystem and landscape that provide high-quality water to millions of people in New York City as a natural-service function.

Table 19.3 CATEGORIES OF WATER POLLUTANTS

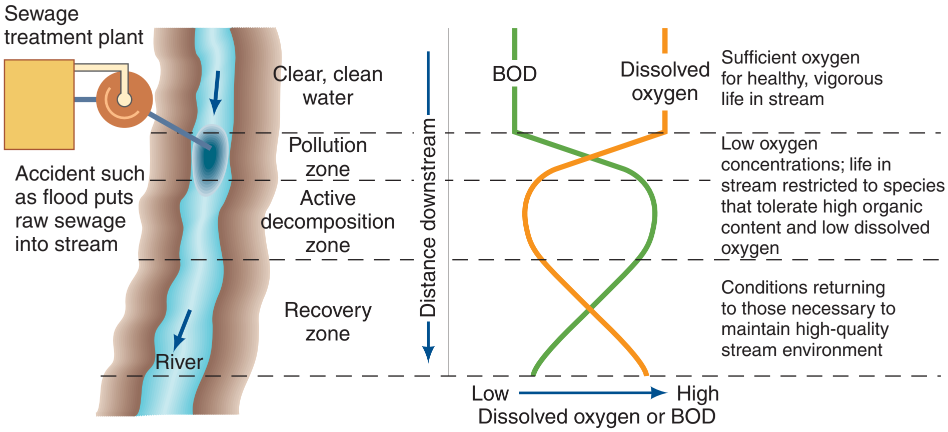
POLLUTANT CATEGORY	EXAMPLES OF SOURCES	COMMENTS
Dead organic matter	Raw sewage, agricultural waste, urban garbage	Produces biochemical oxygen demand and diseases.
Pathogens	Human and animal excrement and urine	Examples: Recent cholera epidemics in South America and Africa; 1993 epidemic of cryptosporidiosis in Milwaukee, Wisconsin. See discussion of fecal coliform bacteria in Section 22.3.
Drugs	Urban wastewater, painkillers, birth control pills, antidepressants, antibiotics	Pharmaceuticals flushed through our sewage treatment plants are contaminating our rivers and groundwater. Hormone residues or hormone mimickers are thought to be causing genetic problems in aquatic animals.
Organic chemicals	Agricultural use of pesticides and herbicides (Chapter 11); industrial processes that produce dioxin (Chapter 10)	Potential to cause significant ecological damage and human health problems. Many of these chemicals pose hazardous-waste problems (Chapter 23).
Nutrients	Phosphorus and nitrogen from agricultural and urban land use (fertilizers) and wastewater from sewage treatment	Major cause of artificial eutrophication. Nitrates in groundwater and surface waters can cause pollution and damage to ecosystems and people.
Heavy metals	Agricultural, urban, and industrial use of mercury, lead, selenium, cadmium, and so on (Chapter 10)	Example: Mercury from industrial processes that is discharged into water (Chapter 10). Heavy metals can cause significant ecosystem damage and human health problems
Acids	Sulfuric acid (H_2SO_4) from coal and some metal mines; industrial processes that dispose of acids improperly	Acid mine drainage is a major water pollution problem in many coal mining areas, damaging ecosystems and spoiling water resources.
Sediment	Runoff from construction sites, agricultural runoff, and natural erosion	Reduces water quality and results in loss of soil resources.
Heat (thermal pollution)	Warm to hot water from power plants and other industrial facilities	Causes ecosystem disruption (Chapter 10).
Radioactivity	Contamination by nuclear power industry, military, and natural sources (Chapter 17)	Often related to storage of radioactive waste. Health effects vigorously debated (Chapters 10 and 17).

19.2 Biochemical Oxygen Demand (BOD)

Dead organic matter in streams decays. Bacteria carrying out this decay use oxygen. If there is enough bacterial activity, the oxygen in the water available to fish and other organisms can be reduced to the point where they may die. A stream with low oxygen content is a poor environment for fish and most other organisms. A stream with an inadequate oxygen level is considered polluted for organisms that require dissolved oxygen above the existing level.

The amount of oxygen required for biochemical decomposition processes is called the **biological** or **biochemical oxygen demand (BOD)**. BOD is commonly used in water-quality management (Figure 19.2a). It measures the amount of oxygen consumed by microorganisms as they break down organic matter within small water samples, which are analyzed in a laboratory. BOD is routinely measured at discharge points into surface water, such as at wastewater treatment plants. At treatment plants, the BOD of the incoming sewage water from sewer lines is measured, as is water from locations both upstream and downstream of the plant. This allows comparison of upstream, or background, BOD, with the BOD of the water being discharged by the plant.

Dead organic matter—which produces BOD—enters streams and rivers from natural sources (such as dead leaves from a forest) as well as from agricultural runoff and urban sewage. Approximately 33% of all BOD in streams results from agricultural activities. However, urban areas, particularly those with older, combined sewer systems (in which stormwater runoff and urban sewage share the same line), also considerably increase BOD in streams. This is because during times of high flow, when sewage treatment plants are unable to handle the total volume of water, raw sewage mixed with storm runoff overflows and is discharged untreated into streams and rivers.



(a) (b)

FIGURE 19.2 **(a)** Pollution-control officer measuring oxygen content of the River Severn near Shrewsbury, England. **(b)** The relationship between dissolved oxygen and biochemical oxygen demand (BOD) for a stream after the input of sewage.

When BOD is high, as suggested earlier, the *dissolved oxygen content* of the water may become too low to support life in the water. The U.S. Environmental Protection Agency defines the threshold for a water-pollution alert as a dissolved oxygen content of less than 5 mg/l of water. Figure 19.2b illustrates the effect of high BOD on dissolved oxygen content in a stream when raw sewage is introduced as a result of an accidental spill. Three zones are identified:

1. *A pollution zone*, where a high BOD exists. As waste decomposes, microorganisms use the oxygen, decreasing the dissolved oxygen content of the water.
2. *An active decomposition zone*, where the dissolved oxygen reaches a minimum owing to rapid biochemical decomposition by microorganisms as the organic waste is transported downstream.
3. *A recovery zone*, where dissolved oxygen increases and BOD is reduced because most of the oxygen-demanding organic waste from the input of sewage has decomposed and natural stream processes are replenishing the water's dissolved oxygen. For example, in quickly moving water, the water at the surface mixes with air, and oxygen enters the water.

All streams have some ability to degrade organic waste. Problems result when the stream is overloaded with oxygen-demanding waste, overpowering the stream's natural cleansing function.

19.3 Waterborne Disease

As mentioned earlier, the primary water-pollution problem in the world today is the lack of clean drinking water. Each year, particularly in less-developed countries, several billion people are exposed to waterborne diseases whose effects vary in severity from an upset stomach to death. As recently as the early 1990s, epidemics of cholera, a serious waterborne disease, caused widespread suffering and death in South America.

In the United States, we tend not to think much about waterborne illness. Although historically epidemics of waterborne disease killed thousands of people in U.S. cities, such as Chicago, public-health programs have largely eliminated such epidemics by treating drinking water to remove disease-carrying microorganisms and not allowing sewage to contaminate drinking-water supplies. As we will see, however, North America is not immune to **outbreaks**—or sudden occurrences—of waterborne disease.

Fecal Coliform Bacteria

Because it is difficult to monitor disease-carrying organisms directly, we use the count of **fecal coliform bacteria** as a standard measure and indicator of disease potential. The presence of fecal coliform bacteria in water indicates that fecal material from mammals or birds is present, so organisms that cause waterborne diseases may be present as well. Fecal coliform bacteria are usually (but not always) harmless bacteria that normally inhabit the intestines of all animals, including humans, and are present in all their waste. The EPA's threshold for swimming water is not more than 200 cells of fecal coliform bacteria per 100 ml of water; if fecal coliform is above the threshold level, the water is considered unfit for swimming (Figure 19.3). Water with *any* fecal coliform bacteria is unsuitable for drinking.

One type of fecal coliform bacteria, *Escherichia coli*, or *E. coli 0157*, has caused human illness and death. In the U.S., there are about 73,000 cases and 60 deaths per year from *E. coli 0157*. Outbreaks have resulted from eating contaminated meat (fecal transmission from humans and other animals) and drinking contaminated juices or water.[7-10] Table 19.4 lists some recent outbreaks of disease resulting from *E. coli 0157*.

FIGURE 19.3 This beach in Southern California is occasionally closed as a result of contamination by bacteria.

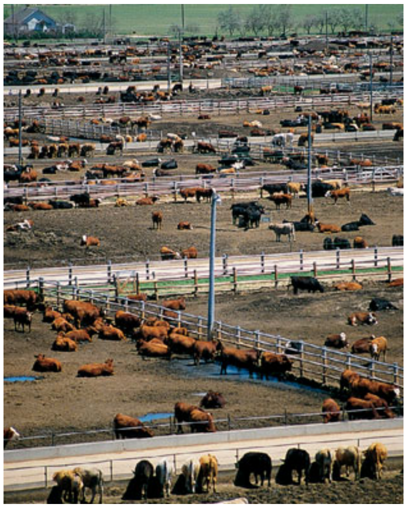


FIGURE 19.4 Cattle feedlot in Colorado. High numbers of cattle in small areas have the potential to pollute both surface water and groundwater because of runoff and infiltration of urine.

19.4 Nutrients

Two important nutrients that cause water-pollution problems are phosphorus and nitrogen, and both are released from sources related to land use. Stream waters on forested land have the lowest concentrations of phosphorus and nitrogen because forest vegetation efficiently removes phosphorus and nitrogen. In urban streams, concentrations of these nutrients are greater because of fertilizers, detergents, and products of sewage treatment plants. Often, however, the highest concentrations of phosphorus and nitrogen are found in agricultural areas, where the sources are fertilized farm fields and feedlots (Figure 19.4). Over 90% of all nitrogen added to the environment by human activity comes from agriculture.

Eutrophication

Eutrophication is the process by which a body of water develops a high concentration of nutrients, such as nitrogen and phosphorus (in the forms of nitrates and phosphates). The nutrients increase the growth of aquatic plants in general, as well as production of photosynthetic blue-green bacteria and algae. Algae may form surface mats that shade the water and block light to algae below the surface, greatly reducing photosynthesis. The bacteria and algae die, and as they decompose, BOD increases, reducing the water's oxygen content, sometimes to the point where other organisms, such as fish, will die.[11,12] They die not from phosphorus poisoning but from a chain of events that started with

Table 19.4 RECENT OUTBREAKS OF *E. COLI 0157* INFECTIONS[1]

YEAR	WHERE	SOURCE	COMMENT
1993	Washington State (fast-food restaurant)	Meat	5 children died; several hundred illnesses
1998	Georgia (water park)	Water in park pools	26 illnesses in children
1998	Town in Wyoming	Water supply	1 death
2000	Walkerton, Canada	Water supply	5 deaths
2006	23 states	Spinach	5 deaths; over 100 illnesses
2007	Hawaii (restaurant)	Lettuce	several illnesses (mostly tourists)
2009	Across the U.S.	Peanut butter	several deaths; several hundred illnesses
2009	29 states	Raw cookie dough	65 illnesses
2010	Several states, especially California, Colorado and N. Carolina	Raw eggs	at least 1,500 illnesses; 500 million eggs recalled

[a] *E. coli* 0157, a strain of *E. coli* bacteria, has been responsible for many human illnesses and deaths. *E. coli 0157* produces strong toxins in humans that may lead to bloody diarrhea, dehydration, kidney failure, and death.

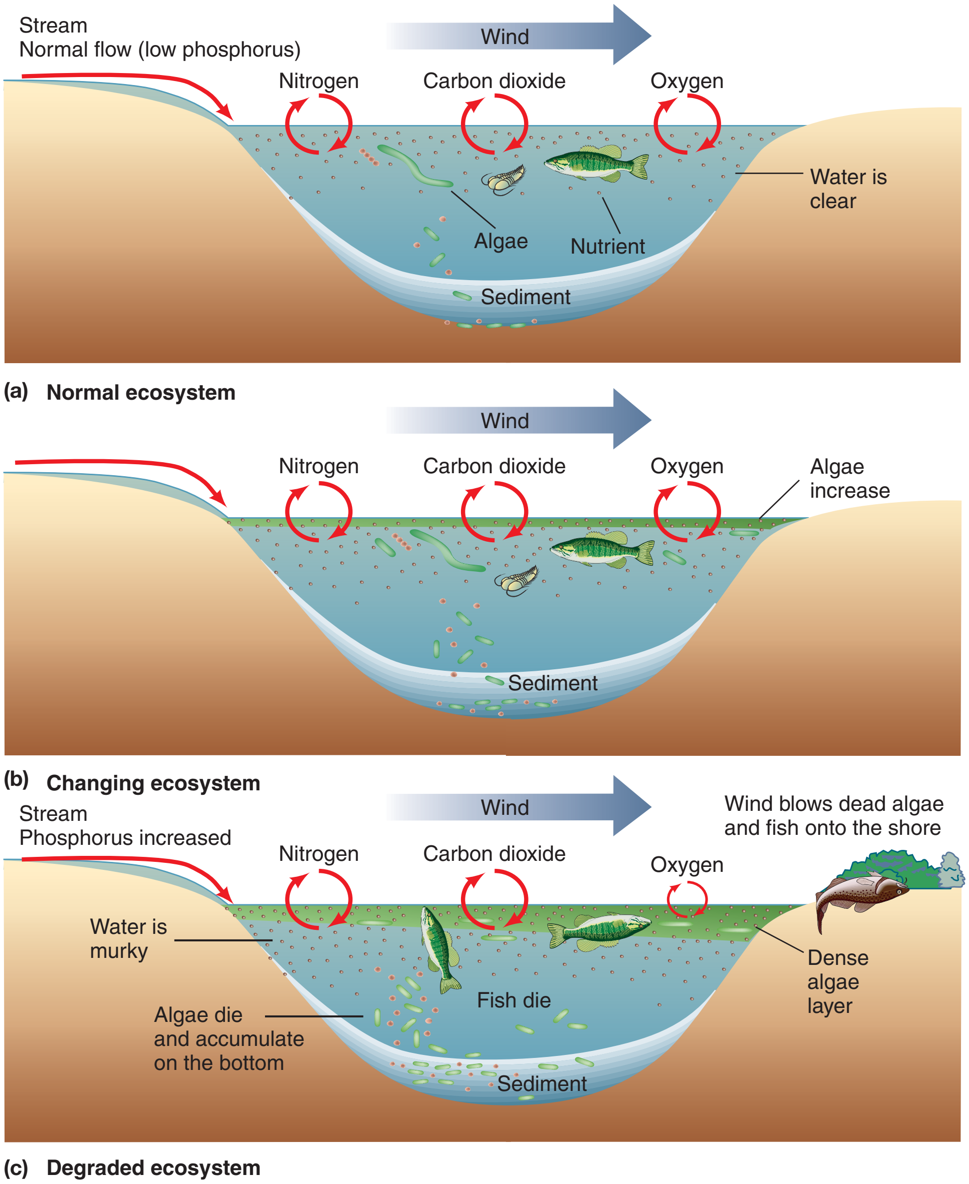


FIGURE 19.5 The eutrophication of a lake. **(a)** In an oligotrophic, or low-nutrient, lake, the abundance of green algae is low, the water clear. **(b)** Phosphorus is added to streams and enters the lake. Algae growth is stimulated, and a dense layer forms. **(c)** The algae layer becomes so dense that the algae at the bottom die. Bacteria feed on the dead algae and use up the oxygen. Finally, fish die from lack of oxygen.

the input of phosphorus and affected the whole ecosystem. The unpleasant effects result from the interactions among different species, the effects of the species on chemical elements in their environment, and the condition of the environment (the body of water and the air above it). This is what we call an **ecosystem effect**.

The process of eutrophication of a lake is shown in Figure 19.5. A lake that has a naturally high concentration of the chemical elements required for life is called a *eutrophic lake*. A lake with a relatively low concentration of chemical elements required by life is called an *oligotrophic lake*. The water in oligotrophic lakes is clear and pleasant for swimmers and boaters and has a relatively low abundance of life. Eutrophic lakes have an abundance of life, often with mats of algae and bacteria and murky, unpleasant water.

When eutrophication is accelerated by human processes that add nutrients to a body of water, we say that **cultural eutrophication** is occurring. Problems associated with the artificial eutrophication of bodies of water are not restricted to lakes (see A Closer Look 19.2). In recent years, concern has grown about the outflow of sewage from urban areas into tropical coastal waters and cultural eutrophication on coral reefs.[13, 14] For example, parts of the famous Great Barrier Reef of Australia, as well as some reefs that fringe the Hawaiian Islands, are being damaged by eutrophication.[15, 16] The damage to corals occurs as nutrient input stimulates algal growth on the reef, which smothers the coral.

The solution to artificial eutrophication is fairly straightforward and involves ensuring that high concentrations of nutrients from human sources do not enter lakes and other bodies of water. This can be accomplished by using phosphate-free detergents, controlling nitrogen-rich runoff from agricultural and urban lands, disposing of or reusing treated wastewater, and using more advanced water treatment methods, such as special filters and chemical treatments that remove more of the nutrients.

A CLOSER LOOK 19.2

Cultural Eutrophication in the Gulf of Mexico

Each summer, a so-called dead zone develops off the nearshore environment of the Gulf of Mexico, south of Louisiana. The zone varies in size from about 13,000 to 18,000 km^2 (5,000 to 7,000 mi^2), an area about the size of the small country of Kuwait or the state of New Jersey. Within the zone, bottom water generally has low concentrations of dissolved oxygen (less than 2 mg/l; a water-pollution alert occurs if the concentration of dissolved oxygen is less than 5 mg/l). Shrimp and fish can swim away from the zone, but bottom dwellers such as shellfish, crabs, and snails are killed. Nitrogen is believed to be the most significant cause of the dead zone (Figure 19.6).

The low concentration of oxygen occurs because the nitrogen causes cultural eutrophication. Algae bloom, and as the algae die and sink, their decomposition depletes the oxygen in the water. The source of nitrogen is believed to be in one of the richest, most productive agricultural regions of the world—the Mississippi River drainage basin.

The Mississippi River drains about 3 million km^2, which is about 40% of the land area of the lower 48 states. The use of nitrogen fertilizers in that area greatly increased beginning in the mid-20th century but leveled off in the 1980s and 1990s. The level of nitrogen in the river has also leveled off, suggesting that the dead zone may have reached its maximum size. This gives us time to study the cultural eutrophication problem carefully and make sound decisions to reduce or eliminate it.

We can partially reduce the amount of nitrogen (nitrates) reaching the Gulf of Mexico via the Mississippi River if we do the following:[12]

- Use fertilizers more effectively and efficiently.
- Restore and create river wetlands between farm fields and streams and rivers, particularly in areas known to contribute high amounts of nitrogen. The wetland plants use nitrogen, lowering the amount that enters the river.
- Implement nitrogen-reduction processes at wastewater treatment plants for towns, cities, and industrial facilities.
- Implement better flood control in the upper Mississippi River to confine floodwaters to floodplains, where nitrogen can be used by riparian vegetation.

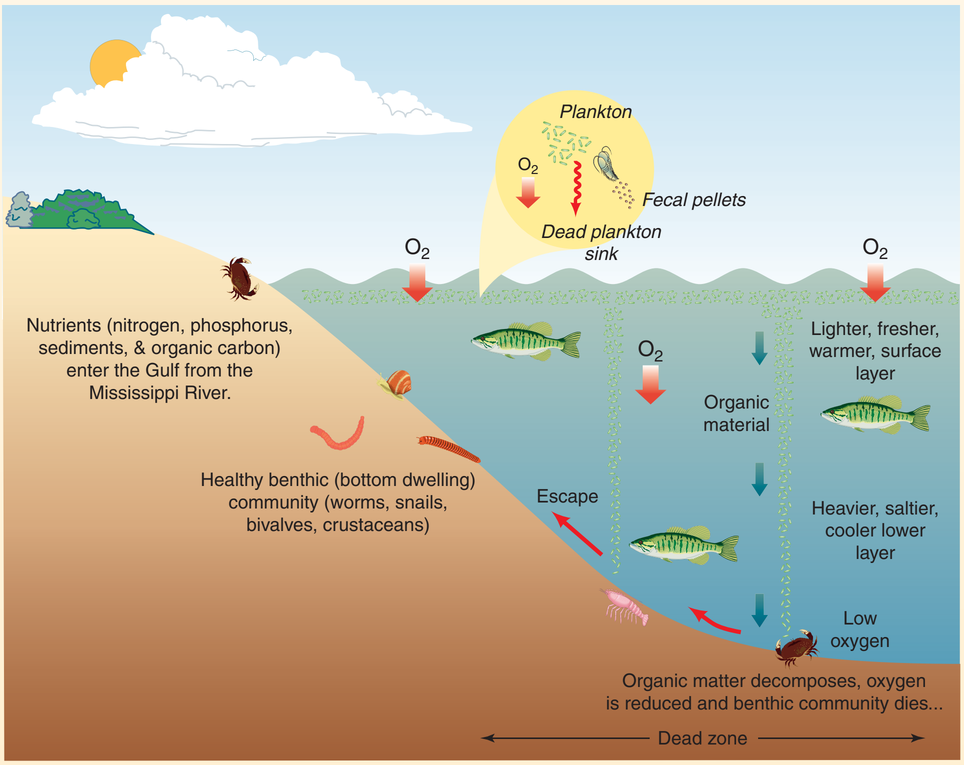


FIGURE 19.6 Idealized drawing showing some of the processes in the dead zone. Low oxygen from cultural eutrophication produces the dead zone. (*Source*: Modified after U.S. Environmental Protection Agency, www.epa.gov, accessed May, 30, 2005).

- Divert floodwater from the Mississippi to backwaters and coastal wetlands of the Mississippi River Delta. At present, levees in the delta push river waters directly into the gulf. Plants in coastal wetlands will use the nitrogen, reducing the concentration that reaches the Gulf of Mexico.

Better agricultural practices could reduce the amount of nitrogen reaching the Mississippi by up to 20%. But this would require reducing fertilizer use by about 20%, which farmers say would harm productivity. Still, restoring and creating river wetlands and riparian forests hold the promise of reducing nitrogen input to the river by up to 40%. This would require some combination of about 10 million hectares (24 million acres) of wetlands and forest, which is about 3.4% of the Mississippi River Basin.[11] That is a lot of land!

There is no easy solution to cultural eutrophication in the Gulf of Mexico. Clearly, however, we need to reduce the amount of nitrogen entering the Gulf. Also needed is a more detailed understanding of the nitrogen cycle within the Mississippi River basin and Delta. Gaining this understanding will require monitoring nitrogen and developing mathematical models of sources, sinks, and rates of nitrogen transfer. With an improved understanding of the nitrogen cycle, a management strategy to reduce or eliminate the dead zone can be put in place.

The dead zone in the Gulf of Mexico is not unique in the world. Other dead zones exist offshore of Europe, China, Australia, South America, and the northeastern United States. In all, about 150 dead zones in the oceans of the world have been observed. Most are much smaller than the zone in the Gulf of Mexico.

As with the Gulf, the other dead zones are due to oxygen depletion resulting from nitrogen, mostly from agricultural runoff. A few result from industrial pollution or runoff from urban areas, especially untreated sewage.

19.5 Oil

Oil discharged into surface water—usually in the ocean but also on land and in rivers—has caused major pollution problems. Several large oil spills from underwater oil drilling have occurred in recent years (for example the 2010 spill in the Gulf of Mexico, discussed in detail in Chapter 24). However, although spills make headlines, normal shipping activities probably release more oil over a period of years than is released by the occasional spill. The cumulative impacts of these releases are not well known.

Some of the best-known oil spills are caused by tanker accidents. On March 24, 1989, the supertanker *Exxon Valdez* ran aground on Bligh Reef south of Valdez in Prince William Sound, Alaska. Alaskan crude oil that had been delivered to the *Valdez* through the Trans-Alaska Pipeline poured out of the vessel's ruptured tanks at about 20,000 barrels per hour. The tanker was loaded with about 1.2 million barrels of oil, and about 250,000 barrels (11 million gal) entered the sound. The spill could have been larger than it was, but fortunately some of the oil in the tanker was offloaded (pumped out) into another vessel. Even so, the *Exxon Valdez* spill produced an environmental shock that resulted in passage of the Oil Pollution Act of 1990 and a renewed evaluation of cleanup technology.

The long-term effects of large oil spills are uncertain. We know that the effects can last several decades; toxic levels of oil have been identified in salt marshes 20 years after a spill.[17, 18]

19.6 Sediment

Sediment consisting of rock and mineral fragments—ranging from gravel particles greater than 2 mm in diameter to finer sand, silt, clay, and even finer colloidal particles—can produce a *sediment pollution* problem. In fact, by volume and mass, sediment is our greatest water pollutant. In many areas, it chokes streams; fills lakes, reservoirs, ponds, canals, drainage ditches, and harbors; buries vegetation; and generally creates a nuisance that is difficult to remove. Sediment pollution is a twofold problem: It results from erosion, which depletes a land resource (soil) at its site of origin (Figure 19.7), and it reduces the quality of the water resource it enters.[19]

Many human activities affect the pattern, amount, and intensity of surface water runoff, erosion, and sedimentation. Streams in naturally forested or wooded areas may be nearly stable, with relatively little excessive erosion or sedimentation. However, converting forested land to agriculture generally increases the runoff and sediment yield or erosion of the land. Applying soil-conservation procedures to farmland can minimize but not eliminate soil loss. The change from agricultural, forested, or rural land to highly urbanized land has even more dramatic effects. But although the construction phase of urbanization can produce large quantities of sediment, sediment production and soil erosion can be minimized by on-site erosion control.[20]

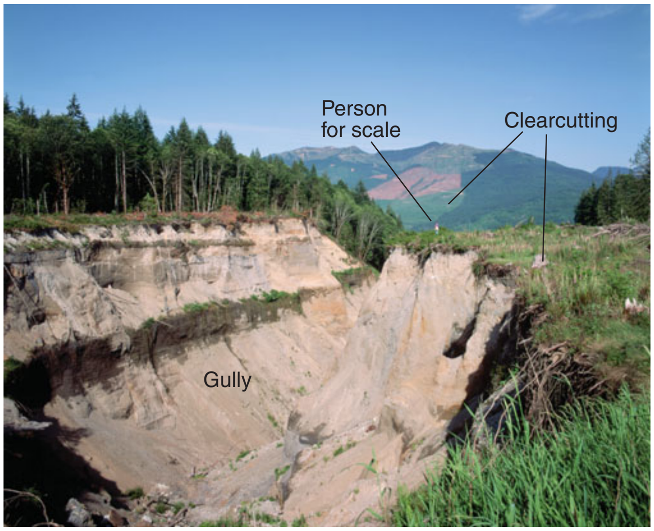


FIGURE 19.7 Massive erosion has produced this large, canyon-size gully, near Rockport Washington (see person in white, looks like a dot, at the top of gully). Note area of clearcutting (timber harvesting on right) and on mountain in background. Clearcutting is a practice that may result in accelerated soil erosion.

19.7 Acid Mine Drainage

Acid mine drainage is water with a high concentration of sulfuric acid (H_2SO_4) that drains from mines—mostly coal mines but also metal mines (copper, lead, and zinc). Coal and the rocks containing coal are often associated with a mineral known as fool's gold or pyrite (FeS_2), which is iron sulfide. When the pyrite, which may be finely disseminated in the rock and coal, comes into contact with oxygen and water, it weathers. A product of the chemical weathering is sulfuric acid. In addition, pyrite is associated with metallic sulfide deposits, which, when weathered, also produce sulfuric acid. The acid is produced when surface water or shallow groundwater runs through or moves into and out of mines or tailings (Figure 19.8). If the acidic water runs off to a natural stream, pond, or lake, significant pollution and ecological damage may result. The acidic water is toxic to the plants and animals of an aquatic ecosystem; it damages biological productivity, and fish and other aquatic life may die. Acidic water can also seep into and pollute groundwater.

Acid mine drainage is produced by complex geochemical and microbial reactions. The general equation is as follows:

$$4\,FeS_2 + 15\,O_2 + 14\,H_2O \rightarrow 4\,Fe(OH)_3 + 8\,H_2SO_4$$

Pyrite + Oxygen + Water → Ferric Hydroxide + Sulfuric Acid

Acid mine drainage is a significant water-pollution problem in Wyoming, Indiana, Illinois, Kentucky, Tennessee, Missouri, Kansas, and Oklahoma, and is probably the most significant water-pollution problem in West Virginia, Maryland, Pennsylvania, Ohio, and Colorado. The total impact is significant because thousands of kilometers of streams have been damaged.

Even abandoned mines can cause serious problems. Subsurface mining for sulfide deposits containing lead and zinc began in the tristate area of Kansas, Oklahoma, and Missouri in the late 19th century and ended in some areas in the 1960s. When the mines were operating, they were kept dry by pumping out the groundwater that seeped in. However, since the mining ended, some of them have flooded and overflowed into nearby creeks, polluting the creeks with acidic water. The problem was so severe in the Tar Creek area of Oklahoma that it was at one time designated by the U.S. Environmental Protection Agency as the nation's worst hazardous-waste site.

One solution being used in Tar Creek and other areas is passive treatment methods that use naturally occurring chemical and/or biological reactions in controlled environments to treat acid mine drainage. The simplest and least expensive method is to divert acidic water to an open limestone channel, where it reacts with crushed limestone and the acid is neutralized. A general reaction that neutralizes the acid is

$$H_2SO_4 + CaCO_3 \rightarrow CaSO_4 + H_2O + CO_2$$

Sulfuric Acid + Calcium Carbonate (crushed limestone) → Calcium Sulfate + Water + Carbon Dioxide

Another solution is to divert the acidic water to a bioreactor (an elongated trough) containing sulfate-reducing bacteria and a bacteria nutrient to encourage bacterial growth. The sulfate-reducing bacteria are held in cells that have a honeycomb structure, forcing the acidic water to follow a tortuous path through the bacteria-laden cells of the reactor. Complex biochemical reactions between the acidic

FIGURE 19.8 Aerial view of an acid mine drainage holding pond adjacent to an iron mine (located in the mountains of southwestern Colorado).

water and bacteria in the reactor produce metal sulfides and in the process reduce the sulfuric acid content of the water. Both methods result in cleaner water with a lower concentration of acid being released into the environment.

19.8 Surface-Water Pollution

Pollution of surface water occurs when too much of an undesirable or harmful substance flows into a body of water, exceeding that body of water's natural ability to remove it, dilute it to a harmless concentration, or convert it to a harmless form.

Water pollutants, like other pollutants, are categorized as being emitted from point or nonpoint sources (see Chapter 10). **Point sources** are distinct and confined, such as pipes from industrial and municipal sites that empty into streams or rivers (Figure 19.9). In general, point source pollutants from industries are controlled through on-site treatment or disposal and are regulated by permit. Municipal point sources are also regulated by permit. In older cities in the northeastern and Great Lakes areas of the United States, most point sources are outflows from combined sewer systems. As mentioned earlier, such systems combine stormwater flow with municipal wastewater. During heavy rains, urban storm runoff may exceed the capacity of the sewer system, causing it to overflow and deliver pollutants to nearby surface waters.

FIGURE 19.9 This pipe is a point source of chemical pollution from an industrial site entering a river in England.

Nonpoint sources, such as runoff, are diffused and intermittent and are influenced by factors such as land use, climate, hydrology, topography, native vegetation, and geology. Common urban nonpoint sources include runoff from streets or fields; such runoff contains all sorts of pollutants, from heavy metals to chemicals and sediment. Rural sources of nonpoint pollution are generally associated with agriculture, mining, or forestry. Nonpoint sources are difficult to monitor and control.

Reducing Surface-Water Pollution

From an environmental view, two approaches to dealing with surface-water pollution are (1) to reduce the sources and (2) to treat the water to remove pollutants or convert them to forms that can be disposed of safely. Which option is used depends on the specific circumstances of the pollution problem. Reduction at the source is the environmentally preferable way of dealing with pollutants. For example, air-cooling towers, rather than water-cooling towers, may be used to dispose of waste heat from power plants, thereby avoiding thermal pollution of water. The second method—water treatment—is used for a variety of pollution problems. Water treatments include chlorination to kill microorganisms such as harmful bacteria, and filtering to remove heavy metals.

There is a growing list of success stories in the treatment of water pollution. One of the most notable is the cleanup of the Thames River in Great Britain. For centuries, London's sewage had been dumped into that river, and there were few fish to be found downstream in the estuary. In recent decades, however, improved water treatment has led to the return of a number of species of fish, some not seen in the river for centuries.

Many large cities in the United States—such as Boston, Miami, Cleveland, Detroit, Chicago, Portland, and Los Angeles—grew on the banks of rivers, but the rivers were often nearly destroyed by pollution and concrete. Today, there are grassroots movements all around the country dedicated to restoring urban rivers and adjacent lands as greenbelts, parks, and other environmentally sensitive developments. For example, the Cuyahoga River in Cleveland, Ohio, was so polluted by 1969 that sparks from a train ignited oil-soaked wood in the river, setting the surface of the river on fire! The burning of an American river became a symbol for a growing environmental consciousness. The Cuyahoga River today is cleaner and no longer flammable—from Cleveland to Akron, it is a beautiful greenbelt (Figure 19.10). The greenbelt changed part of the river from a sewer into a valuable public resource and focal point for economic and environmental renewal.[21] However, in downtown Cleveland and Akron, the river remains an industrial stream, and parts remain polluted.

FIGURE 19.10 The Cuyahoga River (lower left) flows toward Cleveland, Ohio, and the Erie Canal (lower right) is in the Cuyahoga National Park. The skyline is that of industrial Cleveland.

Two of the newer techniques are nanotechnology and urban-runoff naturalization. **Nanotechnology** uses extremely small material particles (10^{-9}m size, about 100,000 times thinner than human hair) designed for a number of purposes. Some nano particles can capture heavy metals such as lead, mercury, and arsenic from water. The nano particles have a tremendous surface area to volume. One cubic centimeter of particles has a surface area exceeding a football field and can take up over 50% of its weight in heavy metals.[22]

FIGURE 19.12 Bioswales collect runoff from Manzaneta Village Dormitory Complex at the University of California, Santa Barbara. **(a)** Plants in bioswales **(b)** help filter water and remove nutrients, reducing cultural eutrophication.

Urban-runoff naturalization is an emerging bioengineering technology to treat urban runoff before it reaches streams, lakes, or the ocean. One method is to create a "closed-loop" local landscape that does not allow runoff to leave a property. Plants may be located as "rain gardens" below downspouts, and parking-lot drainage is directed to plants instead of the street (Figure 19.11).[23] Runoff from five large building complexes such as Manzaneta Village at the University of California, Santa Barbara, can be directed to engineered wetlands (bioswales) where wetland plants remove contaminants before water is discharged into the campus lagoon and then the ocean. Removing nutrients has helped reduce cultural eutrophication of the lagoon (Figure 19.12).

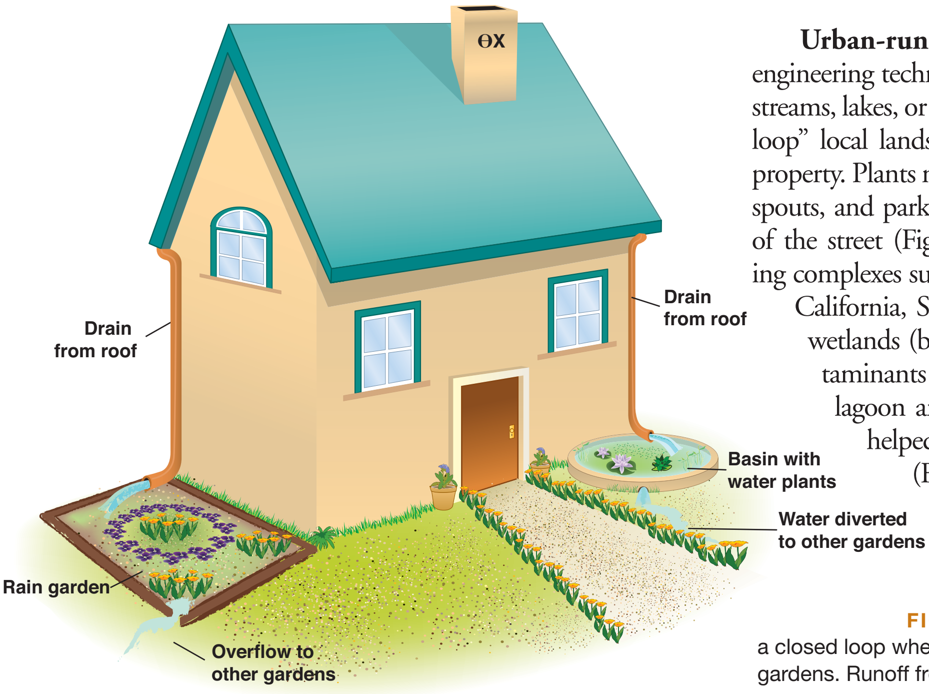


FIGURE 19.11 Water from roof runoff is part of a closed loop where water remains on the site and is used in rain gardens. Runoff from parking areas is diverted to other gardens.

19.9 Groundwater Pollution

Approximately half of all people in the United States today depend on groundwater as their source of drinking water. (Water for domestic use in the United States is discussed in A Closer Look 19.3.) People have long believed that groundwater is, in general, pure and safe to drink. In fact, however, groundwater can be easily polluted by any one of several sources (see Table 19.1), and the pollutants, though very toxic, may be difficult to recognize. (Groundwater processes were discussed in Section 19.1, and you may wish to review them.)

In the United States today, only a small portion of the groundwater is known to be seriously contaminated. However, as mentioned earlier, the problem may become worse as human population pressure on water resources increases. Our realization of the extent of the problem is growing as the testing of groundwater becomes more common. For example, Atlantic City and Miami are two eastern cities threatened by polluted groundwater that is slowly migrating toward their wells.

It is estimated that 75% of the 175,000 known waste-disposal sites in the United States may be spewing plumes of hazardous chemicals that are migrating into groundwater resources. Because many of the chemicals are toxic or are suspected carcinogens, it appears that we have inadvertently been conducting a large-scale experiment on how people are affected by chronic low-level exposure to potentially harmful chemicals. The final results of the experiment will not be known for many years.[24]

The hazard presented by a particular groundwater pollutant depends on several factors, including the concentration or toxicity of the pollutant in the environment and the degree of exposure of people or other organisms to the pollutants.[25] (See the section on risk assessment in Chapter 10.)

Principles of Groundwater Pollution: An Example

Some general principles of groundwater pollution are illustrated by an example. Pollution from leaking underground gasoline tanks belonging to automobile service stations is a widespread environmental problem that no one thought very much about until only a few years ago. Underground tanks are now strictly regulated. Many thousands of old, leaking tanks have been removed, and the surrounding soil and groundwater have been treated to remove the gasoline. Cleanup can be a very expensive process, involving removal and disposal of soil (as a hazardous waste) and treatment of the water using a process known as vapor extraction (Figure 19.13). Treatment may also be accomplished underground by microorganisms that consume the gasoline. This is known as **bioremediation** and is much less expensive than removal, disposal, and vapor extraction.

Pollution from leaking buried gasoline tanks emphasizes some important points about groundwater pollutants:

- Some pollutants, such as gasoline, are lighter than water and thus float on the groundwater.
- Some pollutants have multiple phases: liquid, vapor, and dissolved. Dissolved phases chemically combine with the groundwater (e.g., salt dissolves into water).

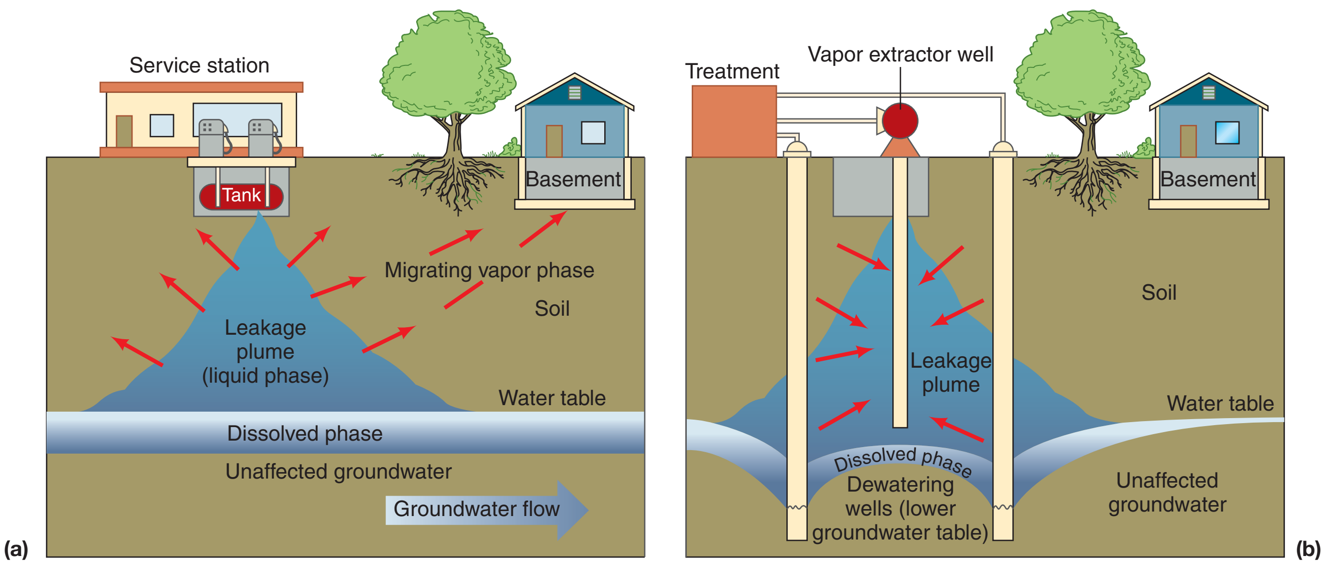


FIGURE 19.13 Diagram illustrating **(a)** a leak from a buried gasoline tank and **(b)** possible remediation using a vapor extractor system. Notice that the liquid gasoline and the vapor from the gasoline are above the water table; a small amount dissolves into the water. All three phases of the pollutant (liquid, vapor, and dissolved) float on the denser groundwater. The extraction well takes advantage of this situation. The function of the dewatering wells is to pull the pollutants in where the extraction is most effective. (*Source*: Courtesy of the University of California Santa Barbara Vadose Zone Laboratory and David Springer.)

- Some pollutants are heavier than water and sink or move downward through groundwater. Examples of sinkers include some particulates and cleaning solvents. Pollutants that sink may become concentrated deep in groundwater aquifers.
- The method used to treat or eliminate a water pollutant must take into account the physical and chemical properties of the pollutant and how these interact with surface water or groundwater. For example, the extraction well for removing gasoline from a groundwater resource (Figure 19.13) takes advantage of the fact that gasoline floats on water.
- Because cleanup or treatment of water pollutants in groundwater is very expensive, and because undetected or untreated pollutants may cause environmental damage, the emphasis should be on preventing pollutants from entering groundwater in the first place.

Groundwater pollution differs in several ways from surface-water pollution. Groundwater often lacks oxygen, a situation that kills aerobic types of microorganisms (which require oxygen-rich environments) but may provide a happy home for anaerobic varieties (which live in oxygen-deficient environments). The breakdown of pollutants that occurs in the soil and in material a meter or so below the surface does not occur readily in groundwater. Furthermore, the channels through which groundwater moves are often very small and variable. Thus, the rate of movement is low in most cases, and the opportunity for dispersion and dilution of pollutants is limited.

Long Island, New York

Another example—that of Long Island, New York—illustrates several groundwater pollution problems and how they affect people's water supply. Two counties on Long Island, New York (Nassau and Suffolk), with a population of several million people, depend entirely on groundwater. Two major problems with the groundwater in Nassau County are intrusion of saltwater and shallow-aquifer contamination.[27] Saltwater intrusion, where subsurface salty water migrates to wells being pumped, is a problem in many coastal areas of the world. The general movement of groundwater under natural conditions for Nassau County is illustrated in Figure 19.14. Salty groundwater is restricted from migrating inland by the large wedge of freshwater moving beneath the island.

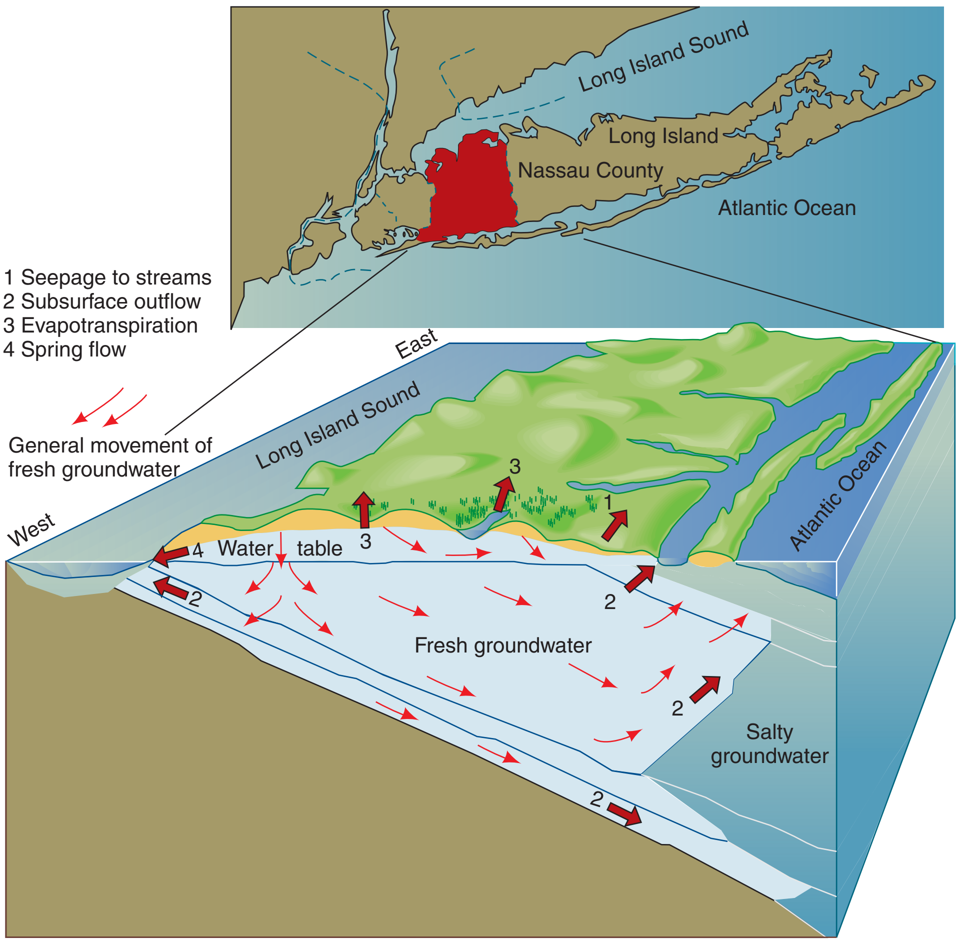


FIGURE 19.14 The general movement of fresh groundwater for Nassau County, Long Island. (*Source*: G.L. Foxworth, Nassau County, Long Island, New York, "Water Problems in Humid County," in G.D. Robinson and A.M. Spieke, eds., *Nature to Be Commanded*, U.S. Geological Survey Professional Paper 950, 1978, pp. 55–68.)

A CLOSER LOOK 19.3

Water for Domestic Use: How Safe Is It?

Water for domestic use in the United States is drawn from surface waters and groundwater. Although some groundwater sources are high quality and need little or no treatment, most are treated to conform to national drinking water standards (revisit Table 19.2).

Before treatment, water is usually stored in reservoirs or special ponds. Storage allows for solids, such as fine sediment and organic matter, to settle out, improving the clarity of water. The water is then run through a water plant, where it is filtered and chlorinated before it is distributed to individual homes. Once in people's homes, it may be further treated. For example, many people run their tap water through readily available charcoal filters before using it for drinking and cooking.

A growing number of people prefer not to drink tap water and instead drink bottled water. As a result, bottled water has become a multibillion-dollar industry. A lot of bottled water is filtered tap water delivered in plastic containers, and health questions have arisen regarding toxins leaching from the plastic, especially if bottles are left in the sun. Hot plastics can leach many more chemicals into the water than cool plastic. In any case, the plastic bottles should be used only once, then recycled.[26]

Some people prefer not to drink water that contains chlorine or that runs through metal pipes. Furthermore, water supplies vary in clarity, hardness (concentration of calcium and magnesium), and taste; and the water available locally may not be to some people's liking. A common complaint about tap water is a chlorine taste, which may be detectable at chlorine concentrations as low as 0.2–0.4 mg/l. People may also fear contamination by minute concentrations of pollutants.

The drinking water in the United States is among the safest in the world. There is no doubt that treating water with chlorine has nearly eliminated waterborne diseases, such as typhoid and cholera, which previously caused widespread suffering and death in the developed world and still do in many parts of the world. However, we need to know much more about the long-term effects of exposure to low concentrations of toxins in our drinking water. How safe is the water in the United States? It's much safer than it was 100 years ago, but low-level contamination (below what is thought dangerous) of organic chemicals and heavy metals is a concern that requires continued research and evaluation.

Notice also that the aquifers are layered, with those closest to the surface being the most salty.

In spite of the huge quantities of water in Nassau County's groundwater system, intensive pumping in recent years has lowered water levels by as much as 15 m (50 ft) in some areas. As groundwater is removed near coastal areas, the subsurface outflow to the ocean decreases, allowing saltwater to migrate inland. Saltwater intrusion has become a problem for south shore communities, which now must pump groundwater from a deeper aquifer, below and isolated from the shallow aquifers that have saltwater-intrusion problems.

The most serious groundwater problem on Long Island is shallow-aquifer pollution associated with urbanization. Sources of pollution in Nassau County include urban runoff, household sewage from cesspools and septic tanks, salt used to de-ice highways, and industrial and solid waste. These pollutants enter surface waters and then migrate downward, especially in areas of intensive pumping and declining groundwater levels.[27] Landfills for municipal solid waste have been a significant source of shallow-aquifer pollution on Long Island because pollutants (garbage) placed on sandy soil can quickly enter shallow groundwater. For this reason, most Long Island landfills were closed in the last two decades.

19.10 Wastewater Treatment

Water used for industrial and municipal purposes is often degraded during use by the addition of suspended solids, salts, nutrients, bacteria, and oxygen-demanding material. In the United States, by law, these waters must be treated before being released back into the environment.

Wastewater treatment—sewage treatment—costs about $20 billion per year in the United States, and the cost keeps rising, but it will continue to be big business. Conventional wastewater treatment includes septic-tank disposal systems in rural areas and centralized wastewater treatment plants in cities. Recent, innovative approaches include applying wastewater to the land and renovating and reusing wastewater. We discuss the conventional methods in this section and some newer methods in later sections.

Septic-Tank Disposal Systems

In many rural areas, no central sewage systems or wastewater treatment facilities are available. As a result, individual septic-tank disposal systems, not connected to sewer systems, continue to be an important method of sewage disposal in rural areas as well as outlying areas of cities. Because not all land is suitable for a septic-tank disposal system, an evaluation of each site is required by law before a permit can be issued. An alert buyer should make sure that the site is satisfactory for septic-tank disposal before purchasing property in a rural setting or on the fringe of an urban area where such a system is necessary.

The basic parts of a septic-tank disposal system are shown in Figure 19.15. The sewer line from the house leads to an underground septic tank in the yard. The tank is designed to separate solids from liquid, digest (biochemically change) and store organic matter through a period of detention, and allow the clarified liquid to discharge into the drain field (absorption field) from a piping system through which the treated sewage seeps into the surrounding soil. As the wastewater moves through the soil, it is further treated by the natural processes of oxidation and filtering. By the time the water reaches any freshwater supply, it should be safe for other uses.

Sewage drain fields may fail for several reasons. The most common causes are failure to pump out the septic tank when it is full of solids, and poor soil drainage, which allows the effluent to rise to the surface in wet weather. When a septic-tank drain field does fail, pollution of groundwater and surface water may result. Solutions to septic-system problems include siting septic tanks on well-drained soils, making sure systems are large enough, and practicing proper maintenance.

Wastewater Treatment Plants

In urban areas, wastewater is treated at specially designed plants that accept municipal sewage from homes, businesses, and industrial sites. The raw sewage is delivered to the plant through a network of sewer pipes. Following treatment, the wastewater is discharged into the surface-water environment (river, lake, or ocean) or, in some limited cases, used for another purpose, such as crop irrigation. The main purpose of standard treatment plants is to break down and reduce the BOD and kill bacteria with chlorine. A simplified diagram of the wastewater treatment process is shown in Figure 19.16.

Wastewater treatment methods are usually divided into three categories: **primary treatment**, **secondary treatment**, and **advanced wastewater treatment**. Primary and secondary treatments are required by federal law for all municipal plants in the United States. However, treatment plants may qualify for a waiver exempting them from secondary treatment if installing secondary treatment facilities poses an excessive financial burden. Where secondary treatment is not sufficient to protect the quality of the surface water into which the treated water is discharged—for example, a river with endangered fish species that must be protected—advanced treatment may be required.[28]

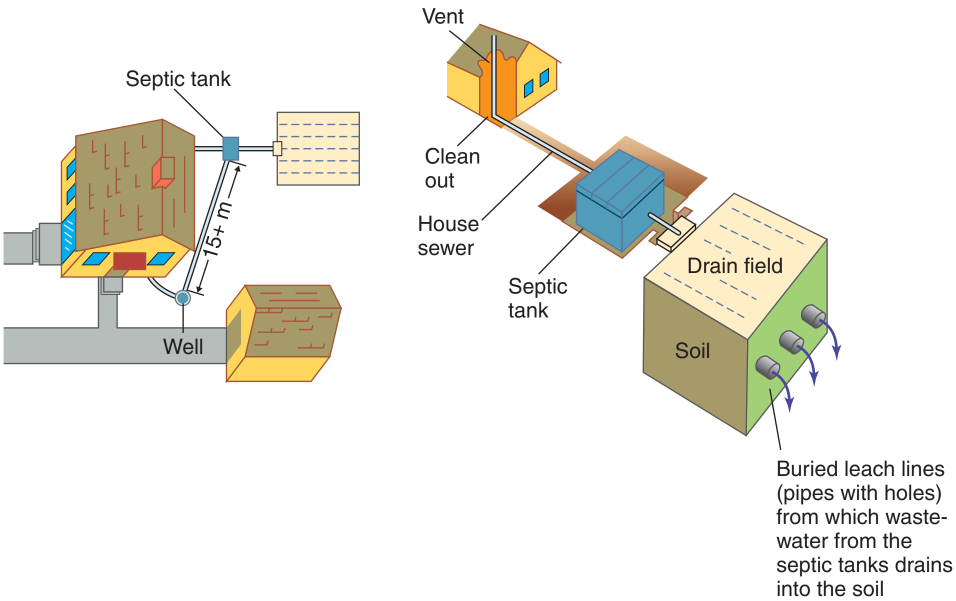


FIGURE 19.15 Septic-tank sewage system and location of the drain field with respect to the house and well. (*Source*: Based on Indiana State Board of Health.)

Primary Treatment

Incoming raw sewage enters the plant from the municipal sewer line and first passes through a series of screens to remove large floating organic material. The sewage next enters the "grit chamber," where sand, small stones, and grit are removed and disposed of. From there, it goes to the primary sedimentation tank, where particulate matter settles out to form sludge. Sometimes, chemicals are used to help the settling process. The sludge is removed and transported to the "digester" for further processing. Primary treatment removes approximately 30 to 40% of BOD by volume from the wastewater, mainly in the form of suspended solids and organic matter.[28]

Secondary Treatment

There are several methods of secondary treatment. The most common treatment is known as *activated sludge*, because it uses living organisms—mostly bacteria. In this procedure, the wastewater from the primary sedimentation tank enters the aeration tank (Figure 19.16), where it is mixed with air (pumped in) and with some of the sludge from the final sedimentation tank. The sludge contains aerobic bacteria that consume organic material (BOD) in the waste. The wastewater then enters the final sedimentation tank, where sludge settles out. Some of this "activated sludge," rich in bacteria, is recycled and mixed again in the aeration tank with air and new, incoming wastewater acting as a starter. The bacteria are used again and again. Most of the sludge from the final sedimentation tank, however, is transported to the sludge digester. There, along with sludge from the primary sedimentation tank, it is treated by anaerobic bacteria (bacteria that can live and grow without oxygen), which further degrade the sludge by microbial digestion.

Methane gas (CH_4) is a product of the anaerobic digestion and may be used at the plant as a fuel to run equipment or to heat and cool buildings. In some cases, it is burned off. Wastewater from the final sedimentation tank is next disinfected, usually by chlorination, to eliminate disease-causing organisms. The treated wastewater is then discharged into a river, lake, or ocean (see A Closer Look 19.4), or in some limited cases used to irrigate farmland. Secondary treatment removes about 90% of BOD that enters the treatment plant in the sewage.[28]

The sludge from the digester is dried and disposed of in a landfill or applied to improve soil. In some instances, treatment plants in urban and industrial areas contain many pollutants, such as heavy metals, that are not removed in the treatment process. Sludge from these plants is too polluted to use in the soil, and sludge must

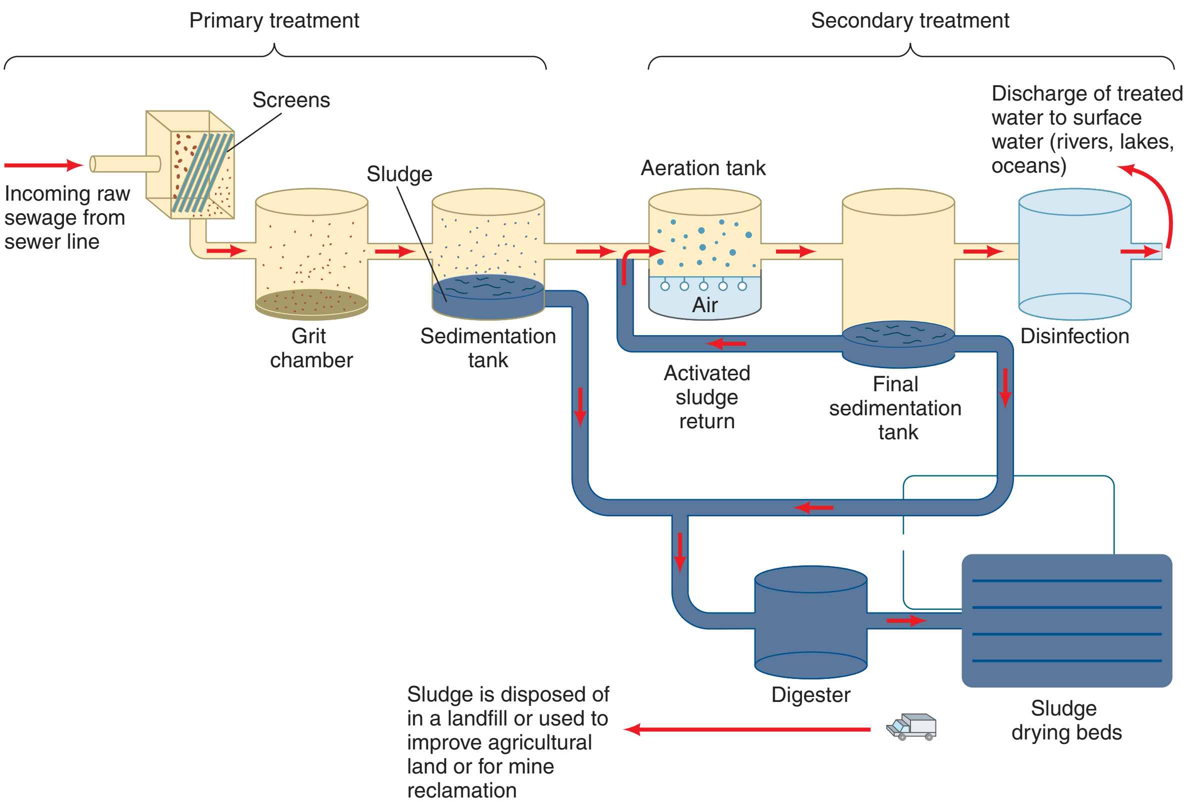


FIGURE 19.16 Diagram of sewage treatment processes. The use of digesters is relatively new, and many older treatment plants do not have them.

be disposed of. Some communities, however, require industries to pretreat sewage to remove heavy metals before the sewage is sent to the treatment plant; in these instances, the sludge can be more safely used for soil improvement.

Advanced Wastewater Treatment

As noted above, primary and secondary treatments do not remove all pollutants from incoming sewage. Some additional pollutants, however, can be removed by adding more treatment steps. For example, phosphates and nitrates, organic chemicals, and heavy metals can be removed by specifically designed treatments, such as sand filters, carbon filters, and chemicals applied to assist in the removal process.[28] Treated water is then discharged into surface water or may be used for irrigating agricultural lands or municipal properties, such as golf courses, city parks, and grounds surrounding wastewater treatment plants.

Advanced wastewater treatment is used when it is particularly important to maintain good water quality. For example, if a treatment plant discharges treated wastewater into a river and there is concern that nutrients remaining after secondary treatment may cause damage to the river ecosystem (eutrophication), advanced treatment may be used to reduce the nutrients.

Chlorine Treatment

As mentioned, chlorine is frequently used to disinfect water as part of wastewater treatment. Chlorine is very effective in killing the pathogens responsible for outbreaks of serious waterborne diseases that have killed many thousands of people. However, a recently discovered potential is that chlorine treatment also produces minute quantities of chemical by-products, some of which are potentially hazardous to people and other animals. For example, a recent study in Britain revealed that in some rivers, male fish sampled downstream from wastewater treatment plants had testes containing both eggs and sperm. This is likely related to the concentration of sewage effluent and the treatment method used.[30] Evidence also suggests that these by-products in the water may pose a risk of cancer and other human health effects. The degree of risk is controversial and currently being debated.[31]

A CLOSER LOOK **19.4**

Boston Harbor: Cleaning Up a National Treasure

The city of Boston is steeped in early American history. Samuel Adams and Paul Revere immediately come to mind when considering the late 1700s, when the colonies were struggling for freedom from Britain. In 1773, Samuel Adams led a group of patriots who boarded three British ships and dumped their cargo of tea into Boston Harbor. The patriots were protesting what they considered an unfair tax on tea, and the event came to be known as the Boston Tea Party. The tea they dumped overboard did not pollute the harbor, but the growing city and the dumping of all sorts of waste eventually did.

Late in the 20th century, after more than 200 years of using Boston Harbor as a disposal site for dumping sewage, sewer overflows during storms, and treated wastewater into Massachusetts Bay, the courts demanded that measures be taken to clean up the bay. Studies concluded that the harbor had become polluted because waste being placed there moved into a small, shallow part of Massachusetts Bay, and despite vigorous tidal action between the harbor and the bay, the flushing time is about one week. It was decided that relocating the areas of waste discharge (called "outfalls") farther offshore, where the water is deeper and currents are stronger, would lower the pollution levels in Boston Harbor.

Moving the wastewater outfalls offshore was definitely a step in the right direction, but the long-term solution to protecting the marine ecosystem from pollutants will require additional measures. Even when placed farther offshore, in deeper water with greater circulation, pollutants will eventually accumulate and cause environmental damage. As a result, any long-term solution must include source reduction of pollutants. To this end, the Boston Regional Sewage Treatment Plan included a new treatment plant designed to significantly reduce the levels of pollutants discharged into the bay. This acknowledges that dilution by itself cannot solve the urban waste-management problem. Moving the sewage outfall offshore, when combined with source reduction of pollutants, is a positive example of what can be done to better manage our waste and reduce environmental problems.[29]

19.11 Land Application of Wastewater

The practice of applying wastewater to the land arose from the fundamental belief that waste is simply a resource out of place. Land application of untreated human waste was practiced for hundreds if not thousands of years before the development of wastewater treatment plants, which have sanitized the process by reducing BOD and using chlorination.

Many sites around the United States are now recycling wastewater, and the technology for wastewater treatment is rapidly evolving. An important question is: Can we develop environmentally preferred, economically viable wastewater treatment plants that are fundamentally different from those in use today? An idea for such a plant, called a resource-recovery wastewater treatment plant, is shown in Figure 19.17. The term *resource recovery* here refers to the production of resources, including methane gas (which can be burned as a fuel), as well as ornamental plants and flowers that have commercial value.[32]

Wastewater and Wetlands

Wastewater is being applied successfully to natural and constructed wetlands at a variety of locations.[33–35] Natural or man-made wetlands can be effective in treating the following water-quality problems:

- municipal wastewater from primary or secondary treatment plants (BOD, pathogens, phosphorus, nitrate, suspended solids, metals)
- stormwater runoff (metals, nitrate, BOD, pesticides, oils)
- industrial wastewater (metals, acids, oils, solvents)
- agricultural wastewater and runoff (BOD, nitrate, pesticides, suspended solids)
- mining waters (metals, acidic water, sulfates)
- groundwater seeping from landfills (BOD, metals, oils, pesticides)

Using wetlands to treat wastewater is particularly attractive to communities that find it difficult to purchase traditional wastewater treatment plants. For example,

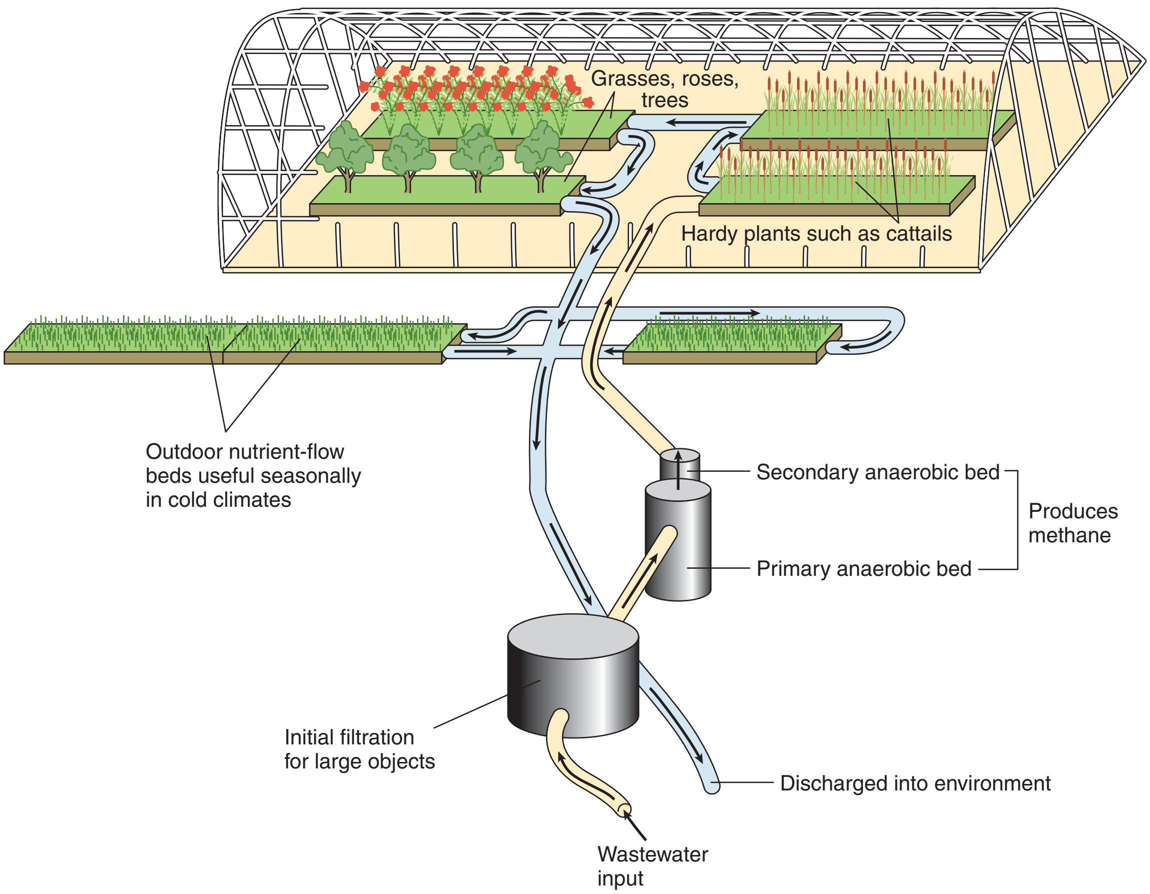


FIGURE 19.17 Components of a resource-recovery wastewater treatment plant. For this model, two resources are recovered: methane, which can be burned to produce energy from the anaerobic beds; and ornamental plants, which can be sold. (*Source*: Based on W.J. Jewell, “Resource-Recovery Wastewater Treatment,” *American Scientist* [1994] 82:366–375.)

the city of Arcata, in northern California, makes use of a wetland as part of its wastewater treatment system. The wastewater comes mostly from homes, with minor inputs from the numerous lumber and plywood plants in Arcata. It is treated by standard primary and secondary methods, then chlorinated and dechlorinated before being discharged into Humboldt Bay.[33]

Louisiana Coastal Wetlands

The state of Louisiana, with its abundant coastal wetlands, is a leader in the development of advanced treatment using wetlands after secondary treatment (Figure 19.18). Wastewater rich in nitrogen and phosphorus, applied to coastal wetlands, increases the production of wetland plants, thereby improving water quality as these nutrients are used by the plants. When the plants die, their organic material (stems, leaves, roots) causes the wetland to grow vertically (or accrete), partially offsetting wetland loss due to sea-level rise.[36] There are also significant economic savings in applying treated wastewater to wetlands, because the financial investment is small compared with the cost of advanced treatment at conventional treatment plants. Over a 25-year period, a savings of about $40,000 per year is likely.[35]

In sum, the use of isolated wetlands, such as those in coastal Louisiana, is a practical way to improve water quality in small, widely dispersed communities in the coastal zone. As water-quality standards are tightened, wetland wastewater treatment will become a viable, effective alternative that is less costly than traditional treatment.[36, 37]

Phoenix, Arizona: Constructed Wetlands

Wetlands can be constructed in arid regions to treat poor-quality water. For example, at Avondale, Arizona, near Phoenix, a wetland treatment facility for agricultural wastewater is sited in a residential community (Figure 19.19). The facility is designed to eventually treat about 17,000 m^3/day (4.5 million gal/day) of water. Water entering the facility has nitrate (NO_3) concentrations as high as 20 mg/l. The artificial wetlands contain naturally occurring bacteria that reduce the nitrate to below the maximum contaminant level of 10 mg/l. Following treatment, the water flows by pipe to a recharge basin on the nearby Agua Fria River, where it seeps into the ground to become a groundwater resource. The cost of the wetland treatment facility was about $11 million, about half the cost of a more traditional treatment facility.

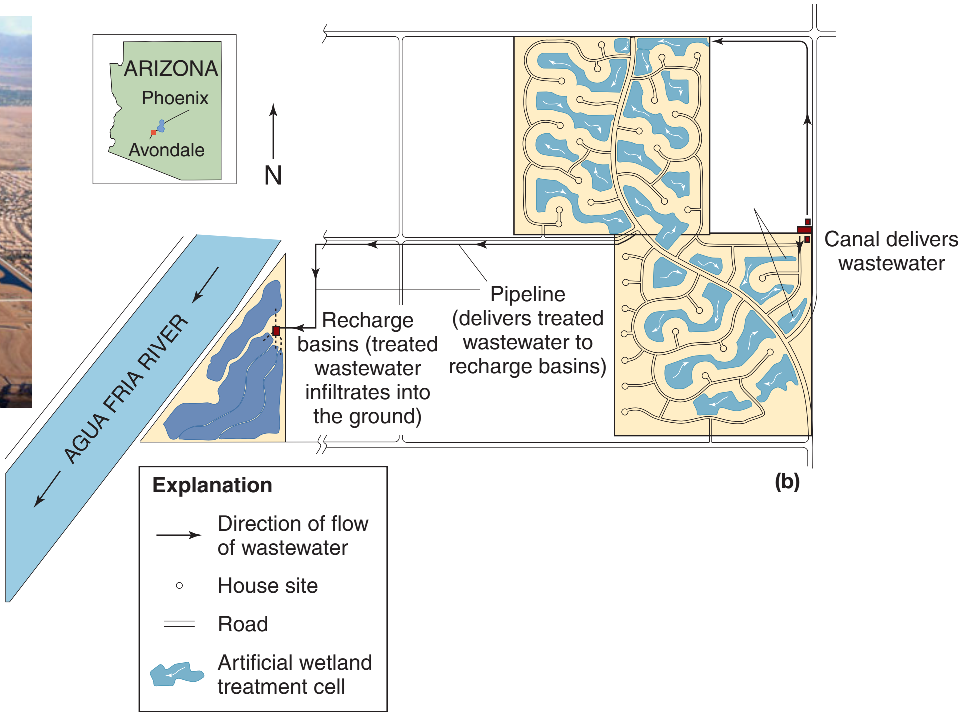
(a)

(c)

(b)

FIGURE 19.18 **(a)** Wetland Pointe au Chene Swamp, three miles south of Thibodaux, Louisiana, receives wastewater; **(b)** one of the outfall pipes delivering wastewater; and **(c)** ecologists doing field work at the Pointe au Chene Swamp to evaluate the wetland.

(a)



(b)

FIGURE 19.19 **(a)** Photograph of the site, showing wetlands integrated with housing development (lower left), and **(b)** map of an artificial wetlands for treating agricultural wastewater at Avondale, Arizona (near Phoenix). (*Source*: Integrated Water Resources, Inc., Santa Barbara, California.)

19.12 Water Reuse

Water reuse can be inadvertent, indirect, or direct. *Inadvertent water reuse* results when water is withdrawn, treated, used, treated, and returned to the environment, followed by further withdrawals and use. Inadvertent water reuse is very common and a fact of life for millions of people who live along large rivers. Many sewage treatment plants are located along rivers and discharge treated water into the rivers. Downstream, other communities withdraw, treat, and consume the water.

Several risks are associated with inadvertent reuse:

1. Inadequate treatment facilities may deliver contaminated or poor-quality water to downstream users.
2. Because the fate of all disease-causing viruses during and after treatment is not completely known, the health hazards of treated water remain uncertain.
3. Every year, new and potentially hazardous chemicals are introduced into the environment. Harmful chemicals are often difficult to detect in the water; and if they are ingested in low concentrations over many years, their effects on people may be difficult to evaluate.[33]

Indirect water reuse is a planned endeavor. For example, in the United States, several thousand cubic meters of treated wastewater per day have been applied to numerous sites to recharge groundwater and then reused for agricultural and municipal purposes.

Direct water reuse refers to use of treated wastewater that is piped directly from a treatment plant to the next user. In most cases, the water is used in industry, in agricultural activity, or for irrigating golf courses, institutional grounds (such as university campuses), and parks. Direct water reuse is growing rapidly and is the norm for industrial processes in factories. In Las Vegas, Nevada, new resort hotels that use a great deal of water for fountains, rivers, canals, and lakes are required to treat wastewater and reuse it (Figure 19.20). Because of perceived risks and negative cultural attitudes toward using treated wastewater, there has been little direct reuse of water for human consumption, except in emergencies. However, that is changing in Orange County, California, where an ambitious program to reuse treated wastewater is under way. The program processes 70 million gallons a day by injecting treated wastewater into the groundwater system to be further filtered underground. The water is then pumped out, further treated, and used in homes and businesses.[38]

FIGURE 19.20 Water reuse at a Las Vegas, Nevada, resort hotel.

19.13 Conditions of Stream Ecosystems in the United States

Assessment of stream ecosystem conditions in the United States has been an important research goal since passage of the Clean Water Act of 1977. Until recently, no straightforward way to do this had been seriously attempted, so the condition of small streams that can be waded was all but unknown. That void is now partly filled by recent studies aimed at providing a credible, broad-scale assessment of small streams in the United States. A standardized field collection of data was an important step, and the data at each site include the following:

- measurement of stream channel morphology and habitat characteristic
- measurement of the streamside and near-stream vegetation, known as the *riparian vegetation*
- measurement of water chemistry
- measurement of the assemblage and composition of the stream environment (biotic environment)

The evaluation includes two key biological indicators: (1) an index of how pristine a stream ecosystem is and (2) an index that represents a loss of biodiversity. Results of the study are shown in Figure 19.21. The top graph is for the entire United States, while the three lower graphs are done on a regional basis. The ratings range from poor conditions—that is, those most disturbed by environmental stress—to good conditions that mostly correspond with undisturbed stream systems. Streams with poor quality are most numerous in the northeastern part of the United States, as well as in the midsection of the country. The percentage of stream miles in good condition is considerably higher in the West.

This is not surprising, given the extent of stream-channel modifications and changes in land use in the eastern half of the country compared to the western half. Western states tend to have more mountains and more areas of natural landscape that have not been modified by agriculture and other human activities. However, streams in the West were deemed to have a higher risk of future degradation than those in other areas because there are more pristine streams to measure changes against and because there are more high-quality stream ecosystem conditions to potentially be degraded in the West than there are in other parts of the country.[39]

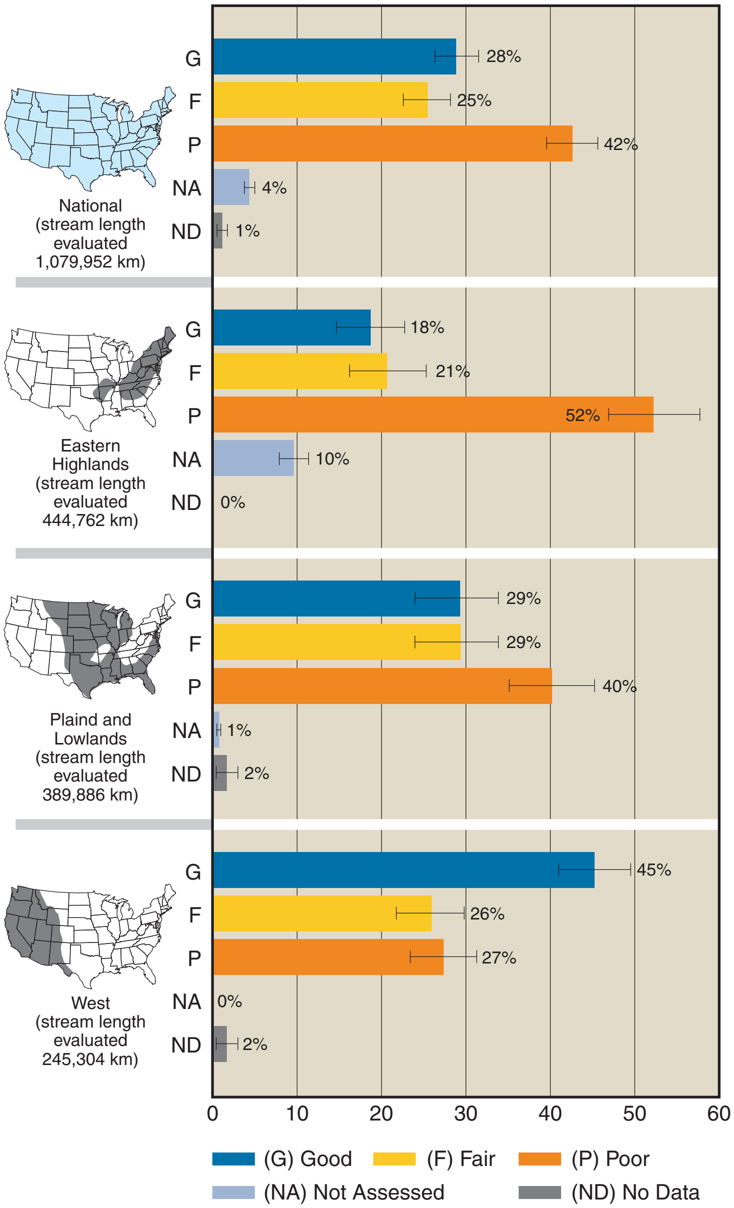


FIGURE 19.21 Condition of ecosystems of small streams that can be waded in the U.S. (*Source*: Modified after J.M. Faustini et al. 2009, "Assessing Stream Ecosystem Condition in the United States." *EOS, Transactions, American Geophysical Union* 36: 309–310).

19.14 Water Pollution and Environmental Law

Environmental law, the branch of law dealing with conservation and use of natural resources and control of pollution, is very important as we debate environmental issues and make decisions about how best to protect our environment. In the United States, laws at the federal, state, and local levels address these issues.

Federal laws to protect water resources go back to the Refuse Act of 1899, which was enacted to protect navigable streams, rivers, and lakes from pollution. Table 19.5 lists major federal laws that have a strong water-resource/pollution component. Each of these major pieces of legislation has had a significant impact on water-quality issues. Many federal laws have been passed with the purpose of cleaning up or treating pollution problems or treating wastewater. However, there has also been a focus on preventing pollutants from entering water. Prevention has the advantage of avoiding environmental damage and costly cleanup and treatment.

From the standpoint of water pollution, the mid-1990s in the United States was a time of debate and controversy. In 1994, Congress attempted to rewrite major environmental laws, including the Clean Water Act (1972, amended in 1977). The purpose was to give industry greater flexibility in choosing how to comply with environmental regulations concerning water pollution. Industry interests favored proposed new regulations that, in their estimation, would be more cost-effective without causing increased environmental degradation. Environmentalists, on the other hand, viewed attempts to rewrite the Clean Water Act as a giant step backward in the nation's fight to clean up our water resources. Apparently, Congress had incorrectly assumed it knew the public's values on this issue. Survey after survey has established that there is strong support for a clean environment in the United States and that people are willing to pay to have clean air and clean water. Congress has continued to debate changes in environmental laws, but little has been resolved.[40]

Table 19.5 FEDERAL WATER LEGISLATION

DATE	LAW	OVERVIEW
1899	Refuse Act	Protects navigable water from pollution
1956	Federal Water and Pollution Control Act	Enhances the quality of water resources and prevents, controls, and abates water pollution.
1958	Fish and Wildlife Coordination Act	Mandates the coordination of water resources projects such as dams, power plants, and flood control must coordinate with U.S Fish and Wildlife Service to enact wildlife conservation measures
1969	National Environmental Policy Act	Requires environmental impact statement prior to federal actions (development) that significantly affect the quality of the environment. Included are dams and reservoirs, channelization, power plants, bridges, and so on
1970	Water Quality Improvement Act	Expands power of 1956 act through control of oil pollution and hazardous pollutants and provides for research and development to eliminate pollution in Great Lakes and acid mine drainage.
1972 (amended in 1977)	Federal Water Pollution Control Act (Clean Water Act)	Seeks to clean up nation's water. Provides billions of dollars in federal grants for sewage treatment plants. Encourages innovative technology, including alternative water treatment methods and aquifer recharge of wastewater.
1974	Federal Safe Drinking Water Act	Aims to provide all Americans with safe drinking water. Sets contaminant levels for dangerous substances and pathogens
1980	Comprehensive Environmental Response, Compensation, and Liability Act	Established revolving fund (Superfund) to clean up hazardous waste disposal sites, reducing ground water pollution.
1984	Hazardous and Solid Waste Amendments to the Resource Conservation and Recovery Act	Regulates underground gasoline storage tanks. Reduces potential for gasoline storage tanks. Reduces potential for gasoline to pollute groundwater
1987	Water Quality Act	Established national policy to control nonpoint sources of water pollution. Important in development of state management plants to control nonpoint water pollution sources.

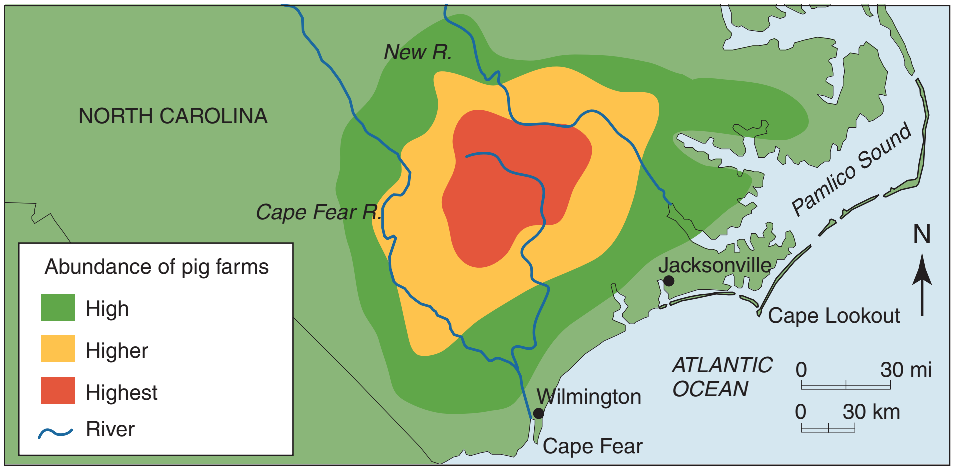
CRITICAL THINKING ISSUE

Is Water Pollution from Pig Farms Unavoidable?

Hurricane Floyd struck the Piedmont area of North Carolina in September 1999. The killer storm took a number of lives while flooding many homes and forcing some 48,000 people into emergency shelters. The storm had another, more unusual effect as well. Floodwaters containing thousands of dead pigs, along with their feces and urine, flowed through schools, churches, homes, and businesses. The stench was reportedly overwhelming, and the count of pig carcasses may have been as high as 30,000. The storm waters had overlapped and washed out over 38 pig lagoons with as much as 950 million liters (250 million gal) of liquid pig waste, which ended up in flooded creeks, rivers, and wetlands. In all, something like 250 large commercial pig farms flooded out, drowning hogs whose floating carcasses had to be collected and disposed of (Figure 19.22).

Prior to Hurricane Floyd, the pig farm industry in North Carolina had been involved in a scandal reported by newspapers and television—and even by *60 Minutes*. North Carolina has a long history of hog production, and the population of pigs swelled from about 2 million in 1990 to nearly 10 million in 1997. At that time, North Carolina became the second-largest pig-farming state in the nation.[41] As the number of large commercial pig farms grew, the state allowed the hog farmers to build automated and very confining farms housing hundreds or thousands of pigs. There were no restrictions on farm location, and many farms were constructed on floodplains.

Each pig produces approximately 2 tons of waste per year. The North Carolina herd was producing approximately 20 million tons of waste a year, mostly manure and urine, which was flushed out of the pig barns and into open, unlined lagoons about the size of football fields. Favorable regulations, along with the availability of inexpensive waste-disposal systems (the lagoons), were responsible for the tremendous growth of the pig population in North Carolina in the 1990s.



(a)

(b)

FIGURE 19.22 North Carolina's "Bay of Pigs." **(a)** Map of areas flooded by Hurricane Floyd in 1999 with relative abundance of pig farms. **(b)** Collecting dead pigs near Boulaville, North Carolina. The animals were drowned when floodwaters from the Cape Fear River inundated commercial pig farms

After the hurricane, mobile incinerators were moved into the hog region to burn the carcasses, but there were so many that hog farmers had to bury some animals in shallow pits. The pits were supposed to be at least 1 meter deep, and dry, but there wasn't always time to find dry ground, and for the most part the pits were dug and filled on floodplains. As these pig carcasses rot, bacteria will leak into the groundwater and surface water for some appreciable time.

An early warning occurred in 1995, when a pig-waste lagoon failed and sent approximately 950 million liters (250 million gal) of concentrated pig feces down the New River past the city of Jacksonville, South Carolina, and into the New River estuary. The spill's adverse effects on marine life lasted for approximately three months.

The lesson to be learned from North Carolina's so-called Bay of Pigs is that we are vulnerable to environmental catastrophes caused by large-scale industrial agriculture. Economic growth and production of livestock must be carefully planned to anticipate problems, and waste-management facilities must be designed so as not to pollute local streams, rivers, and estuaries.

Was the lesson learned in North Carolina? The pig farmers had powerful friends in government and big money. Incredible as it may seem, following the hurricane, the farmers asked for $1 billion in grants to help repair and replace the pig facilities, including waste lagoons, destroyed by the hurricane. Furthermore, they asked for exemptions from the Clean Water Act for a period of six months so that waste from the pig lagoons could be discharged directly into streams.[42] This was not allowed.

With regard to future management, considering that North Carolina is frequently struck by hurricanes, barring pig operations from floodplains seems obvious. However, this is only the initial step. The whole concept of waste lagoons needs to be rethought and alternative waste-management practices put into effect if pollution of surface waters and groundwaters is to be avoided. To this end, North Carolina in 2007 passed legislation to ban construction or expansion of new waste lagoons and encouraged pig farms to treat pig waste to extract methane (gas) as an energy source. Other methods of on-site treatment to reduce organic matter and nutrients is ongoing

North Carolina's pig problem led to the formation of what is called the "Hog Roundtable," a coalition of civic, health, and environmental groups with the objective of controlling industrial-scale pig farming. Its efforts, with others, resulted in a mandate to phase out pig-waste lagoons and expand regulations to require buffers between pig farms and surface waters and water wells. The coalition also halted construction of a proposed slaughterhouse that would have allowed more pig farms to be established.

Critical Thinking Questions

1. Can future pollution from large pig farms in areas with recurring hurricane hazards be eliminated or minimized? If so, how?
2. Do you think the pollution caused by pig farm flooding as a result of hurricanes is a natural event, a so-called act of God? Pig farmers blamed the hurricane for the water pollution. Are they right, or are people responsible?
3. Do you think the actions of the Hog Roundtable can succeed over the long term in minimizing environmental problems caused by large pig farms?
4. Discuss the moral and ethical issues of industrial-scale agriculture that confines large numbers of animals, often in small spaces. Is there a better way to produce our food? What are alternatives?

SUMMARY

- The primary water-pollution problem in the world today is the lack of disease-free drinking water.
- Water pollution is degradation of quality that renders water unusable for its intended purpose.
- Major categories of water pollutants include disease-causing organisms, dead organic material, heavy metals, organic chemicals, acids, sediment, heat, and radioactivity.
- Sources of pollutants may be point sources, such as pipes that discharge into a body of water, or nonpoint sources, such as runoff, which are diffused and intermittent.
- Eutrophication of water is a natural or human-induced increase in the concentration of nutrients, such as phosphorus and nitrogen, required for living things. A high concentration of such nutrients may cause a population explosion of photosynthetic bacteria. As the bacteria die and decay, the concentration of dissolved oxygen in the water is lowered, leading to the death of fish.
- Sediment is a twofold problem: Soil is lost through erosion, and water quality suffers when sediment enters a body of water.
- Acid mine drainage is a serious water-pollution problem because when water and oxygen react with sulfide minerals that are often associated with coal or metal sulfide deposits, they form sulfuric acid. Acidic water draining from mines or tailings pollutes streams and other bodies of water, damaging aquatic ecosystems and degrading water quality.
- Urban processes—for example, waste disposal in landfills, application of fertilizers, and dumping of chemicals such as motor oil and paint—can contribute to shallow-aquifer contamination. Overpumping of aquifers near the ocean may cause saltwater, found below the freshwater, to rise closer to the surface, contaminating the water resource by a process called saltwater intrusion.

- Wastewater treatment at conventional treatment plants includes primary, secondary, and, occasionally, advanced treatment. In some locations, natural ecosystems, such as wetlands and soils, are being used as part of the treatment process.
- Water reuse is the norm for millions of people living along rivers where sewage treatment plants discharge treated wastewater back into the river. People who withdraw river water downstream are reusing some of the treated wastewater.
- Industrial reuse of water is the norm for many factories.
- Deliberate use of treated wastewater for irrigating agricultural lands, parks, golf courses, and the like is growing rapidly as demand for water increases.
- Cleanup and treatment of both surface water and groundwater pollution are expensive and may not be completely successful. Furthermore, environmental damage may result before a pollution problem i s identified and treated. Therefore, we should continue to focus on preventing pollutants from entering water, which is a goal of much water-quality legislation.

REEXAMINING THEMES AND ISSUES

Human Population

We state in this chapter that the number one water-pollution problem in the world today is the lack of disease-free drinking water. This problem is likely to get worse in the future as the number of people, particularly in developing countries, continues to increase. As population increases, so does the possibility of continued water pollution from a variety of sources relating to agricultural, industrial, and urban activities.

Sustainability

Any human activity that leads to water pollution—such as the building of pig farms and their waste facilities on floodplains—is antithetical to sustainability. Groundwater is fairly easy to pollute and, once degraded, may remain polluted for a long time. Therefore, if we wish to leave a fair share of groundwater resources to future generations, we must ensure that these resources are not polluted, degraded, or made unacceptable for use by people and other living organisms.

Global Perspective

Several aspects of water pollution have global implications. For example, some pollutants may enter the atmosphere and be transported long distances around the globe, where they may be deposited and degrade water quality. Examples include radioactive fallout from nuclear reactor accidents or experimental detonation of nuclear devices. Waterborne pollutants from rivers and streams may enter the ocean and circulate with marine waters around the ocean basins of the world.

Urban World

Urban areas are centers of activities that may result in serious water pollution. A broad range of chemicals and disease-causing organisms are present in large urban areas and may enter surface waters and groundwaters. An example is bacterial contamination of coastal waters, resulting in beach closures. Many large cities have grown along the banks of streams and rivers, and the water quality of those streams and rivers is often degraded as a result. There are positive signs that some U.S. cities are viewing their rivers as valuable resources, with a focus on environmental and economic renewal. Thus, rivers flowing through some cities are designated as greenbelts, with parks and trail systems along river corridors. Examples include New York City; Cleveland, Ohio; San Antonio, Texas; Corvallis, Oregon; and Sacramento and Los Angeles, California.

People and Nature

Polluting our water resources endangers people and ecosystems. When we dump our waste in rivers, lakes, and oceans, we are doing what other animals have done for millions of years—it is natural. For example, a herd of hippopotamuses in a small pool may pollute the water with their waste, causing problems for other living things in the pond. The difference is that we understand that dumping our waste damages the environment, and we know how to reduce our impact.

Science and Values

It is clear that the people of the United States place a high value on the environment and, in particular, on critical resources such as water. Attempts to weaken water-quality standards are viewed negatively by the public. There is also a desire to protect water resources necessary for the variety of ecosystems found on Earth. This has led to research and development aimed at finding new technologies to reduce, control, and treat water pollution. Examples include development of new wastewater treatments and support of laws and regulations that protect water resources.

KEY TERMS

acid mine drainage **409**
advanced wastewater treatment **415**
biological or biochemical oxygen demand (BOD) **403**
bioremediation **412**
cultural eutrophication **406**
ecosystem effect **406**
environmental law **421**
eutrophication **405**
fecal coliform bacteria **404**
nanotechnology **411**
nonpoint sources **410**
outbreaks **404**
point sources **410**
primary treatment **415**
urban-runoff naturalization **411**
secondary treatment **415**
wastewater treatment **414**
water reuse **420**

STUDY QUESTIONS

1. Do you think outbreaks of waterborne diseases will be more common or less common in the future? Why? Where are outbreaks most likely to occur?

2. What was learned from the *Exxon Valdez* oil spill that might help reduce the number of future spills and their environmental impact?

3. What is meant by the term *water pollution*, and what are several major processes that contribute to water pollution?

4. Compare and contrast point and nonpoint sources of water pollution. Which is easier to treat, and why?

5. What is the twofold effect of sediment pollution?

6. In the summer, you buy a house with a septic system that appears to function properly. In the winter, effluent discharges at the surface. What could be the environmental cause of the problem? How could the problem be alleviated?

7. Describe the major steps in wastewater treatment (primary, secondary, advanced). Can natural ecosystems perform any of these functions? Which ones?

8. In a city along an ocean coast, rare waterbirds inhabit a pond that is part of a sewage treatment plant. How could this have happened? Is the water in the sewage pond polluted? Consider this question from the birds' point of view and from your own.

9. How does water that drains from coal mines become contaminated with sulfuric acid? Why is this an important environmental problem?

10. What is eutrophication, and why is it an ecosystem effect?

11. How safe do you believe the drinking water is in your home? How did you reach your conclusion? Are you worried about low-level contamination by toxins in your water? What could be the sources of contamination?

12. Do you think our water supply is vulnerable to terrorist attacks? Why? Why not? How could potential threats be minimized?

13. Would you be willing to use treated wastewater in your home for personal consumption, as they are doing in Orange County, California? Why? Why not?

14. How would you design a system to capture runoff where you live before it enters a storm drain?

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