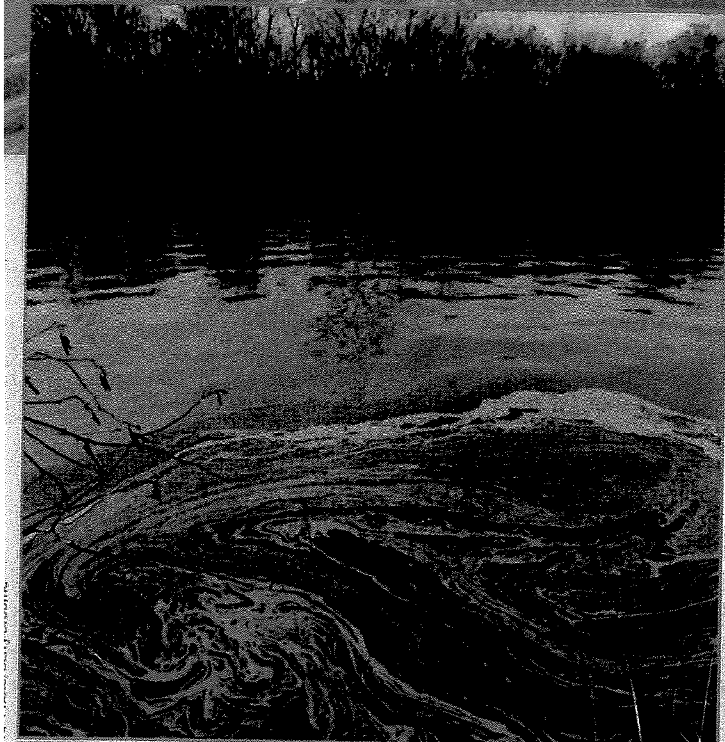
21

Water Pollution



Coal ash spill in the Dan River. Coal ash swirls in the Dan River in Danville, Virginia, downstream from the North Carolina source of the major release, Duke Energy's coal ash basin, February 5, 2014.

ossil-fuel consumption and use contaminate water in many places and in many ways. Coal, oil, and natural gas extraction all require water, often in large amounts. Oil and coal (and to a lesser extent liquefied natural gas) are transported around the world on rivers and the ocean. Power plants are invariably built near access to water, which can be used for cooling, processing, and waste management. All of these activities lead to both routine and accidental releases that affect human and ecosystem health.

Many types of water pollution are associated with oil. Oil spilled in the ocean can contaminate large areas of water and shoreline, with long-lasting impacts. Oil spilled on roads and in driveways can lead to large amounts of pollution running off into lakes, streams, and rivers. Leaky underground gasoline tanks can contaminate groundwater, and drilling for and refining oil invariably pollute groundwater and surface water.

Coal, too, can cause massive amounts of water pollution. Water passing through mined areas can pick up contaminants ranging from loose soil to highly acidic mine tailings. **Coal ash**, or fly ash, the solid material left over after coal is burned, can also cause considerable ecosystem damage. It typically contains toxic materials, including such heavy metals as nickel, arsenic, and mercury as well as radioactive uranium, radium, and thorium. While some of the ash generated around the world is used in manufacturing (e.g., to make Portland cement), most is either stored in piles or ponds where it is generated—including hundreds of U.S. sites—or is hauled to a landfill. Two coal-related accidents in early 2014 illustrate the range of water pollution risks associated with coal use. In January 2014, 10,000 gallons of MCHM, a coal-processing chemical, leaked from a ruptured storage tank directly into West Virginia's Elk River just upstream of a major water distribution facility. Water supplies were interrupted and compromised for more than 250,000 people; long-term effects are unknown.

More than 30,000 gallons of coal ash poured into North Carolina's Dan River in early February 2014, originating from a faulty pipe under an abandoned Duke Energy power plant's coal ash basin. The third worst coal ash spill in U.S. history, the accident dumped a 70-mile plume of sludge and toxins downstream (see photograph).

The nation's most catastrophic coal ash spill occurred in late 2008, when 7 million m^3 (9.2 million yd^3) of coal ash—equivalent to more than 1 billion gallons—spilled from a holding pond at a Tennessee Valley Authority coal power plant in eastern Tennessee. Triggered when heavy rains overwhelmed the pond, the spill spread liquid ash over 300 acres of land and into the Emory River. Water tests after the spill showed elevated lead and thallium levels, both of which are known to cause illness to humans. Several houses were damaged, and many plants and animals were killed. We will never be certain how big an effect the spill had on ecosystems or humans downstream.

So long as we use fossil fuels for energy, both routine activities like driving and accidents like oil and ash spills will continue to consume and pollute water. Improved technologies can help, but contamination will invariably occur. "Clean-coal" technologies may reduce carbon dioxide emissions but will have little impact on the adverse effects from coal mining and ash. Reducing reliance on fossil fuels is the best way to reduce the range of associated environmental impacts—including oil and fly ash spills, climate change, and related water pollution.

In Your Own Backyard...

What are the major surface water pollution concerns in your community?

Types of Water Pollution

LEARNING OBJECTIVES

- List and briefly describe eight categories of water pollutants.
- Discuss how sewage is related to eutrophication, biochemical oxygen demand (BOD), and dissolved oxygen.
- Define *dead zone*.

Water pollution is a global problem that varies in magnitude and type of pollutant from one region to another. In many locations, particularly in less developed countries, the main water pollution issue is lack of disease-free drinking water. Water pollutants are divided into eight categories: sewage, disease-causing agents, sediment pollution, inorganic plant and algal nutrients, organic compounds, inorganic chemicals, radioactive substances, and thermal pollution. These eight types are not exclusive; for example, sewage can contain disease-causing agents, inorganic plant and algal nutrients, and organic compounds.

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

SEWAGE

The release of **sewage** into water causes several pollution problems. First, because it carries disease-causing agents, water polluted with sewage poses a threat to public health (see the next section on disease-causing agents). Sewage also generates two serious environmental problems in water—enrichment and oxygen demand. **Enrichment**, the fertilization of a body of water, is caused by high levels of plant and algal nutrients such as nitrogen and phosphorus. Microorganisms decompose sewage and other organic materials into carbon dioxide (CO_2), water, and similar inoffensive materials. This degradation process, known as **cellular respiration**, requires the presence of oxygen. Fishes and other organisms in healthy aquatic ecosystems also use oxygen. Since only limited amounts of oxygen can dissolve in water, in an aquatic ecosystem containing high levels of sewage or other organic material, the decomposing microorganisms use up most of the dissolved oxygen. This leaves little for fishes or other aquatic animals. At extremely low oxygen levels, fishes and other animals leave or die.

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

Sewage and other organic wastes are measured in terms of their **biochemical oxygen demand (BOD)**, or **biological oxygen demand**. BOD is usually expressed as milligrams of dissolved oxygen per liter of water for a specific number of days at a given temperature. A large amount of sewage in water generates a high BOD, which robs the water of dissolved oxygen (**Figure 21.1**). When dissolved oxygen levels are low, anaerobic (without oxygen) microorganisms produce compounds with unpleasant odors, further deteriorating water quality.

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

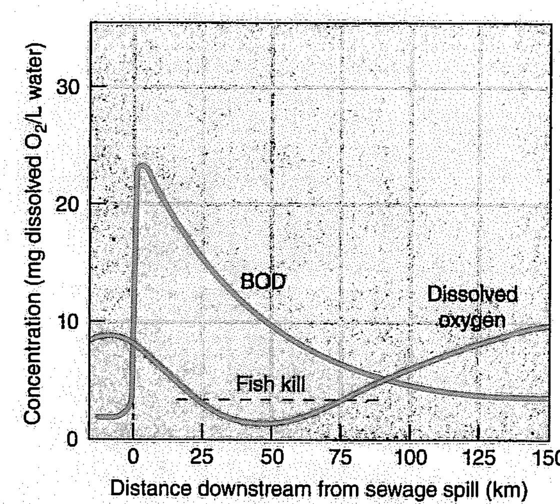


Figure 21.1 Effect of sewage on dissolved oxygen and biochemical oxygen demand (BOD). Note the initial oxygen depletion (green line) and increasing BOD (rust line) close to the sewage spill (at distance 0). The stream gradually recovers as the sewage is diluted and degraded. As indicated on the graph, fishes cannot live in water that contains less than 4 mg of dissolved oxygen per liter of water.

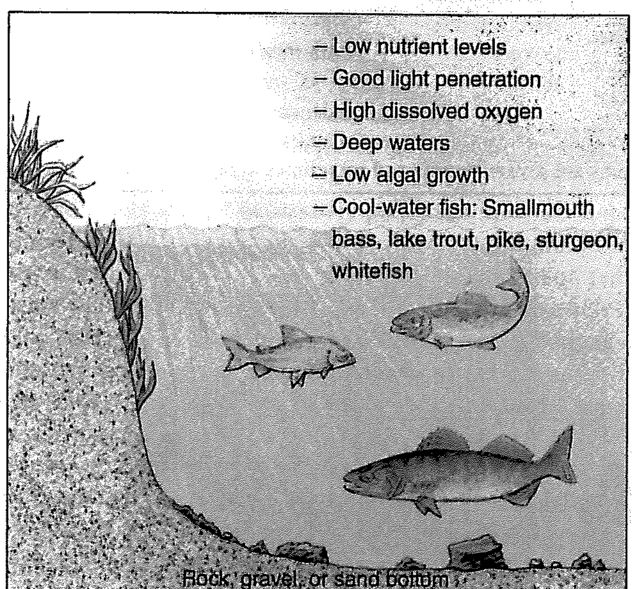
Eutrophication: An Enrichment Problem Lakes, estuaries, and slow-flowing streams that have minimal levels of nutrients are unenriched, or oligotrophic. An **oligotrophic** lake has clear water and supports small populations of aquatic organisms (**Figure 21.2a**). **Eutrophication** is the enrichment of a lake, estuary, or slow-flowing stream by inorganic plant and algal nutrients such as phosphorus; an enriched body of water is said to be **eutrophic**. The enrichment of water, which occurs gradually, results in an increased photosynthetic productivity. The water in a eutrophic lake is cloudy and usually resembles pea soup because of the presence of vast numbers of algae and cyanobacteria (**Figure 21.2b**).

Although eutrophic lakes contain large populations of aquatic animals, these organisms are different from those predominant in oligotrophic lakes. For example, an unenriched lake in the northeastern United States may contain pike, sturgeon, and whitefish (**Figure 21.2c**). All three are found in the deeper, colder part of the lake, where there is a higher concentration of dissolved oxygen. In eutrophic lakes, on the other hand, the deeper, colder levels of water are depleted of dissolved oxygen because when the excessive numbers of algae die, they settle to the lake's bottom and stimulate an increased amount of decay. Microorganisms that decompose the dead algae use up much of the lake's dissolved oxygen in the process. The lake floor has a high BOD from decomposition, and fishes such as pike, sturgeon, and whitefish die out and are replaced by warm-water fishes, such as catfish and carp, that tolerate smaller amounts of dissolved oxygen (**Figure 21.2d**).

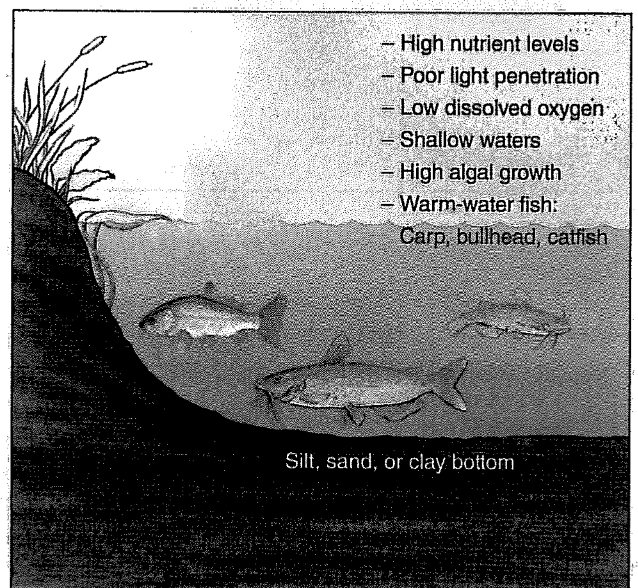
Over vast periods, oligotrophic lakes, estuaries, and slow-moving streams naturally become eutrophic. As natural eutrophication occurs, these bodies of water are slowly enriched and grow shallower from the immense number of dead organisms that have settled in the sediments over a long period. Gradually, plants

(a) Crater lake, an oligotrophic lake in Oregon.

(b) A small eutrophic lake in the Catskill Mountains, New York.



(c) An oligotrophic lake has a low level of inorganic plant and algal nutrients.



(d) A eutrophic lake has a high level of these nutrients.

Figure 21.2 Oligotrophic and eutrophic lakes.

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

such as water lilies and cattails take root in the nutrient-rich sediments and begin to fill in the shallow waters, forming a marsh. Some human activities, however, greatly accelerate eutrophication. This fast, human-induced process is usually called **artificial eutrophication**, or *cultural eutrophication*, to distinguish it from natural eutrophication. Artificial eutrophication results from the enrichment of aquatic ecosystems by nutrients found predominantly in fertilizer runoff and sewage.

DISEASE-CAUSING AGENTS

Disease-causing agents are infectious organisms that cause diseases; they come from the wastes of infected individuals, entering water in sewage. Municipal wastewater usually contains many bacteria, viruses, protozoa, parasitic worms, and other infectious agents that cause human or animal diseases (**Table 21.1**). Typhoid, cholera, bacterial dysentery, polio, and infectious hepatitis are some of the more common bacterial or viral diseases transmitted through contaminated food and water. Most of these are rare in highly developed countries but major causes of death in less developed countries. However, many human diseases, such as acquired immune deficiency syndrome (AIDS), are not transmissible through water.

The vulnerability of public water supplies to waterborne disease–causing agents was dramatically demonstrated in 1993 when a microorganism (*Cryptosporidium*) contaminated the water supply in the greater Milwaukee area. About 370,000 people developed diarrhea, making it the largest outbreak of a waterborne disease ever recorded in the United States, and several people

Table 21.1 Some Human Diseases Transmitted by Polluted Water

Disease	*Infectious Agent*	*Type of Organism*	*Symptoms*
Cholera	*Vibrio cholerae*	Bacterium	Severe diarrhea, vomiting; fluid loss of as much as 20 quarts per day causes cramps and collapse
Dysentery	*Shigella dysenteriae*	Bacterium	Infection of the colon causes painful diarrhea with mucus and blood in the stools; abdominal pain
Enteritis	*Clostridium perfringens*, other bacteria	Bacterium	Inflammation of the small intestine causes general discomfort, loss of appetite, abdominal cramps, and diarrhea
Typhoid	*Salmonella typhi*	Bacterium	Early symptoms include headache, loss of energy, fever; later, a pink rash appears along with (sometimes) hemorrhaging in the intestines
Infectious hepatitis	Hepatitis virus A	Virus	Inflammation of liver causes jaundice, fever, headache, nausea, vomiting, severe loss of appetite, muscle aches, and general discomfort
Poliomyelitis	Poliovirus	Virus	Early symptoms include sore throat, fever, diarrhea, and aching in limbs and back; when infection spreads to spinal cord, paralysis and atrophy of muscles occur
Cryptosporidiosis	*Cryptosporidium* sp.	Protozoon	Diarrhea and cramps last up to 22 days
Amoebic dysentery	*Entamoeba histolytica*	Protozoon	Infection of the colon causes painful diarrhea with mucus and blood in the stools; abdominal pain
Schistosomiasis	*Schistosoma* sp.	Fluke	Tropical disorder of the liver and bladder causes blood in urine, diarrhea, weakness, lack of energy, repeated attacks of abdominal pain
Ancylostomiasis	*Ancylostoma* sp.	Hookworm	Symptoms are severe anemia and sometimes symptoms of bronchitis

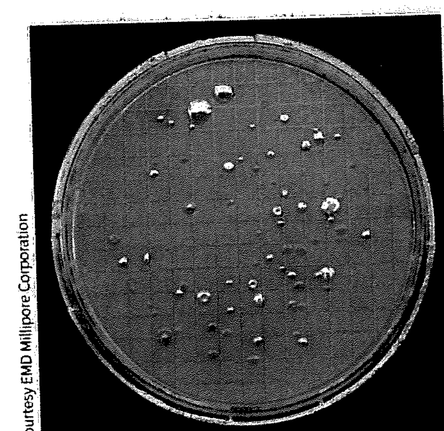
with weakened immune systems died. Smaller outbreaks of contamination by salmonella and other bacteria have occurred in several cities and towns since the Milwaukee episode. Nonetheless, deaths from waterborne diseases remain rare in highly developed countries: Fewer than 10 deaths occur over a typical year in the United States.

Monitoring for Disease from Sewage Because sewage-contaminated water is a threat to public health, periodic tests are made for the presence of sewage in our water supplies. Although many different microorganisms thrive in sewage, the common intestinal bacterium *Escherichia coli* (*E. coli*) is typically used as an indication of the amount of sewage present in water and as an indirect measure of the presence of disease-causing agents. *E. coli* is perfect for monitoring sewage because it is not present in the environment except from human and animal feces, where it is found in large numbers. To test for the presence of *E. coli* in water, a **fecal coliform test** is performed (**Figure 21.3**). A small sample of water is passed through a filter to trap all bacteria. The filter is then transferred to a petri dish that contains nutrients. After an incubation period, the number of greenish colonies present indicates the number of *E. coli*. Safe drinking water should contain no more than 1 coliform bacterium per 100 mL of water (about half a cup), safe swimming water should have no more than 200 per 100 mL of water, and general recreational water (for boating) should have no more than 2000 per 100 mL. In contrast, raw sewage may contain several million coliform bacteria per 100 mL of water. Although most strains of coliform bacteria do not cause disease, the fecal coliform test is a reliable way to indicate the likely presence of pathogens, or disease-causing agents, in water.

fecal coliform test A water quality test for the presence of fecal bacteria, which indicates a chance that pathogenic organisms may be present as well.

When dangerous levels of fecal coliform bacteria are discovered in a stream or other body of water, it is important to determine

(a) A water sample is first passed through a filtering apparatus. The filter disk is then placed on a medium that supports coliform bacteria for a period of 24 hours.



(b) After incubation, the number of bacterial colonies is counted. Each colony of *Escherichia coli* arose from a single coliform bacterium in the original water sample.

Figure 21.3 Fecal coliform test.

the source of contamination. Finding the source is not always easy because coliform bacteria reside in the intestinal tracts of many animals. The contamination could be coming from human wastes, such as from septic systems that are not operating effectively (discussed later in the chapter); from animal feedlots; or even from the droppings of raccoons, birds, and other wildlife. **Bacterial source tracking (BST)** allows investigators to identify subtle differences in strains of *E. coli* on the basis of their animal hosts.

SEDIMENT POLLUTION

Clay, silt, sand, and gravel can be suspended and carried in water. When a river flows into a lake or ocean, its flow velocity decreases, and the sediments often settle out. Over time, as sediments accumulate, new land is formed. A river delta is a flat, low-lying plain created from deposited sediments. River deltas, with their abundant wildlife and waterways for trade routes, have always been important settlement sites for people. Today, river deltas are among the most densely populated areas in the world. Sediments are also deposited on land when a river overflows its banks during a flood.

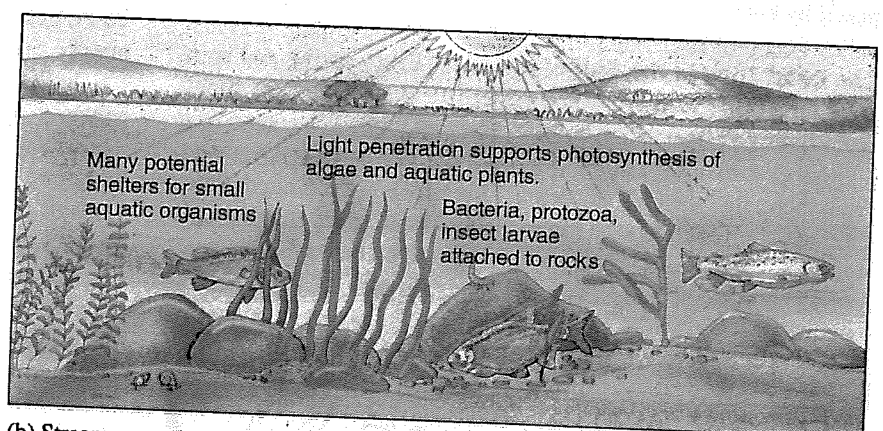
Sediments are not necessarily pollutants; they are important, for example, in regenerating soils in agricultural areas and providing essential nutrients to wetland areas. **Sediment pollution** occurs when excessive amounts of suspended soil particles eventually settle out and accumulate on the bottom of a body of water. Sediment pollution comes from erosion of agricultural lands, forest soils exposed by logging, degraded stream banks, overgrazed rangelands, strip mines, and construction. Control of soil erosion reduces sediment pollution in waterways.

Sediment pollution reduces light penetration, covers aquatic organisms, brings insoluble toxic pollutants into the water, and fills in waterways. When sediment particles are suspended in the water, they make the water turbid (cloudy), which in turn decreases the distance that light penetrates (**Figure 21.4a**). Because the base of the food web in an aquatic ecosystem consists of photosynthetic algae and plants that require light for photosynthesis, turbid water lessens the ability of producers to photosynthesize. Extreme turbidity reduces the number of photosynthesizing organisms, which in turn causes a decrease in the number of aquatic organisms that feed on the primary producers (**Figure 21.4b, c**). Sediment that settles out of the water and forms a layer over coral reefs or shellfish beds can clog the gills and feeding structures of many aquatic animals.

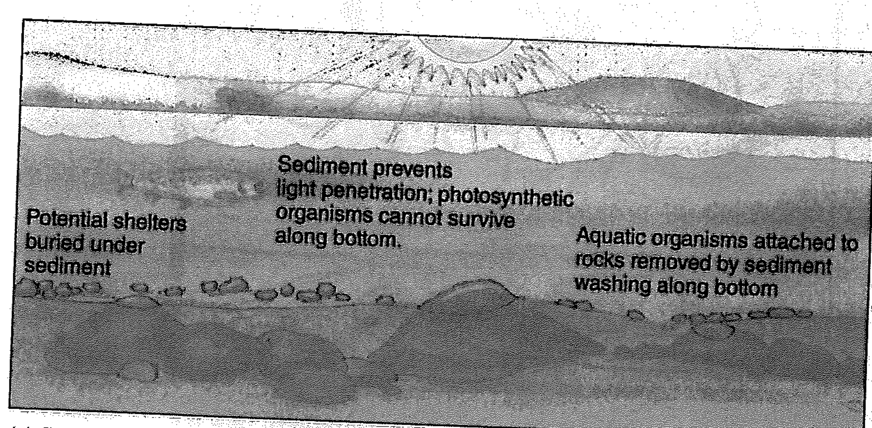
Sediments adversely affect water quality by carrying toxic chemicals, both inorganic and organic, into the water. The sediment particles provide surface area to which some insoluble, toxic compounds adhere, so that when sediments get into water, the toxic chemicals get in as well. Disease-causing agents are also transported into water via sediments.

On the basis of the growing recognition that most of the toxic pollutants in water are stored in

(a) A turbid stream in Costa Rica carries a heavy sediment load.



(b) Stream ecosystem with low level of sediment.



(c) Same stream with high level of sediment.

Figure 21.4 Sediment pollution.

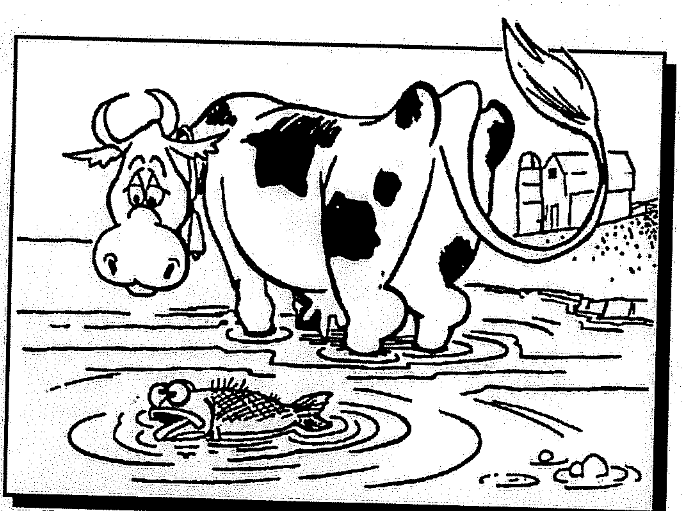
and released from sediments, the U.S. Environmental Protection Agency (EPA) evaluated data from more than 21,000 sampling stations in 1363 U.S. watersheds. The resulting survey determined that sediments in 7% of watersheds are so seriously contaminated with toxic pollutants that eating fishes from those waterways would potentially threaten human health.

When sediments settle out of solution, they fill in waterways. This problem is particularly serious in lakes and channels through which ships must pass. Thus, sediment pollution may adversely affect the shipping industry.

INORGANIC PLANT AND ALGAL NUTRIENTS

Chemicals such as nitrogen and phosphorus that stimulate the growth of plants and algae, known as **inorganic plant and algal nutrients**, are essential for the normal functioning of healthy ecosystems but are harmful in larger concentrations. Nitrates and phosphates come from such sources as human and animal wastes, plant residues, atmospheric deposition, and fertilizer runoff from agricultural and residential land. Inorganic plant and algal nutrients encourage excessive growth of algae and aquatic plants. Although algae and aquatic plants are the base of the food web in aquatic ecosystems, their excessive growth disrupts the natural balance between producers and consumers and causes other problems, including enrichment and bad odors. In addition, high BOD occurs when the excessive numbers of algae die and are decomposed by bacteria.

The Dead Zone in the Gulf of Mexico Every spring and summer, fertilizer runoff from midwestern fields and manure runoff from livestock operations in such states as Iowa, Wisconsin, and Illinois eventually find their way into the Mississippi River and, from there, into the Gulf of Mexico. Livestock in the United States produce approximately 20 times the feces and urine that humans do, yet many of these wastes are not covered by water quality laws and do not go to sewage treatment plants (**Figure 21.5**).



Courtesy University of Wisconsin-Extension and the Wisconsin Department of Natural Resources

Figure 21.5 Water pollution from livestock operations. How is it that a dairy farm in Wisconsin can contribute to fish deaths off the coast of Louisiana? Why is the effect seasonal?

Nitrogen and phosphorus from the Mississippi River are largely responsible for a huge **dead zone** in the Gulf of Mexico (**Figure 21.6**). The dead zone extends from the seafloor up into the water column, sometimes to within a few meters of the surface. Floods, droughts, and temperature change its size and shape. It generally persists from March or April, as snowmelt and spring rains flow from the Mississippi River into the Gulf, to September. It is most severe in June, July, and August. Although the size of the dead zone varies with weather conditions, overall it seems to be growing. In 2013, the Gulf of Mexico dead zone covered about 15,100 km^2 (5,800 mi^2), an area the size of Connecticut.

dead zone A section of the ocean or a sea in which oxygen has been depleted to the point that most animals and bacteria cannot survive; often caused by runoff of chemical fertilizers or plant and animal wastes.

Other than bacteria that thrive in oxygen-free environments, no life exists in the dead zone. The water does not contain enough dissolved oxygen to support fishes or other aquatic organisms. Fishes, shrimp, and other active swimmers avoid the area, while bottom dwellers such as sea stars, brittle stars, worms, and clams suffocate and die.

This low-oxygen condition, known as **hypoxia**, occurs when algae grow rapidly because of the presence of nutrients in the water. Dead algae sink to the bottom and are decomposed by bacteria, which deplete the water of dissolved oxygen, leaving too little for other sea life. In 2010, hypoxia was reported in more than 400 coastal areas around the world. The dead zone in the Gulf of Mexico is one of the largest in the ocean but is smaller than the dead zone in the Black Sea. Ocean warming associated with global climate change may be exacerbating these dead zones.

In 2001, the EPA recommended reductions of nitrogen in the Mississippi River by 30% by 2015. Such reductions, however, require that farms reduce their use of fertilizer. (The Mississippi River drains all or part of 31 states and 2 Canadian provinces, and its watershed contains more than half of all U.S. farms.) In 2004, the EPA added phosphorus pollution as a cause of the dead zone and recommended a focus on cleaning up phosphorus as well as nitrogen.

Other potential inorganic nutrient sources, such as sewage treatment plants and airborne nitrogen oxides from automobile emissions, also must be addressed. Restoring former wetlands in the Mississippi River watershed would reduce the nitrate and phosphate load from fertilizers entering the Gulf of Mexico. The EPA recognizes that the dead zone problem is immense in scope and will take billions of dollars and decades of effort to fix.

ORGANIC COMPOUNDS

Organic compounds are chemicals that contain carbon atoms; a few examples of natural organic compounds are sugars, amino acids, and oils. Most of the thousands of organic compounds found in water are human-produced chemicals; these synthetic chemicals include pharmaceuticals, pesticides, solvents, industrial chemicals, and plastics. (Several examples of synthetic organic compounds sometimes found in polluted water are given in **Table 21.2**). Some organic compounds seep from landfills into surface water and groundwater. Others, such as pesticides, leach downward through the soil into groundwater or get into surface water via runoff from farms and residences. Some industries dump organic compounds directly into waterways.

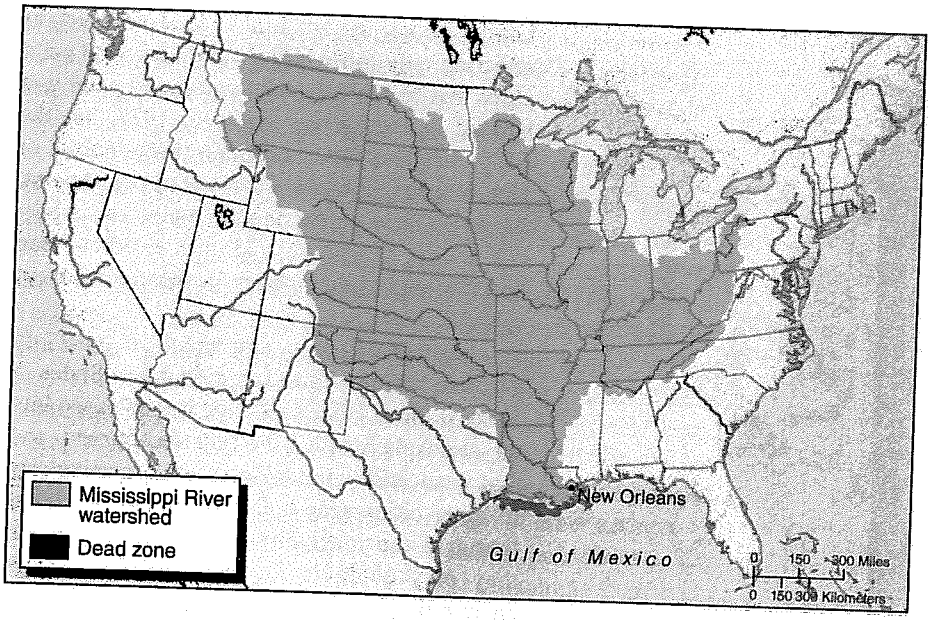


Figure 21.6 The dead zone in the Gulf of Mexico. Pollution from the Mississippi River's water basin is responsible for the dead zone (red). Climate modelers expect more rain in the central United States over the next several decades. Do you think this will impact the dead zone? How?

In 2006, the U.S. Geological Survey (USGS) conducted the most recent study of **volatile organic compounds (VOCs)** in the nation's groundwater. Researchers found one or more VOCs in 20% of the over 3000 samples taken from domestic and public wells for the study. Fifteen types of VOCs, including trihalomethanes (including chloroform and bromoform), refrigerants, MTBE (a gasoline additive), and toluene (a component of gasoline), were present in more than 1% of the wells. **Figure 21.7** shows the distribution of VOCs in aquifers around the United States.

A similar USGS study in 2002 tested 139 U.S. streams for 95 different synthetic organic compounds, including antibiotics, ibuprofen, acetaminophen, insect repellents, antimicrobial substances, fragrances, caffeine, and steroids such as hormones from birth-control pills and hormone therapy. Low concentrations—in the range of **parts per billion**—of 82 of these organic compounds were detected in 80% of the streams studied.

The effects on human health of ingesting drinking water containing traces of these VOCs and synthetic organic chemicals are generally unknown. However, the hormone contaminants cause problems in many aquatic organisms (see Chapter 7). Of the organic chemicals found in the 2002 study, 33 are suspected **endocrine disrupters** that cause hormonal effects (see Chapter 7).

Table 21.2 Some Synthetic Organic Compounds Found in Polluted Water

Compound	*Some Reported Health Effects*
Aldicarb (pesticide)	Attacks nervous system
Benzene (solvent)	Associated with blood disorders (bone marrow suppression); leukemia
Carbon tetrachloride (solvent)	Possibly causes cancer; liver damage; may also attack kidneys and vision
Chloroform (solvent)	Possibly causes cancer
Dioxins (TCDD) (chemical contaminants)	Some cause cancer; may harm reproductive, immune, and nervous systems
Ethylene dibromide (EDB) (fumigant)	Probably causes cancer; attacks liver and kidneys
Polychlorinated biphenyls (PCBs) (industrial chemicals)	Attack liver and kidneys; possibly cause cancer
Trichloroethylene (TCE) (solvent)	Probably causes cancer; induces liver cancer in mice
Vinyl chloride (plastics industry)	Causes cancer

Source: Adapted from the International Agency for Research on Cancer, an agency of the World Health Organization.

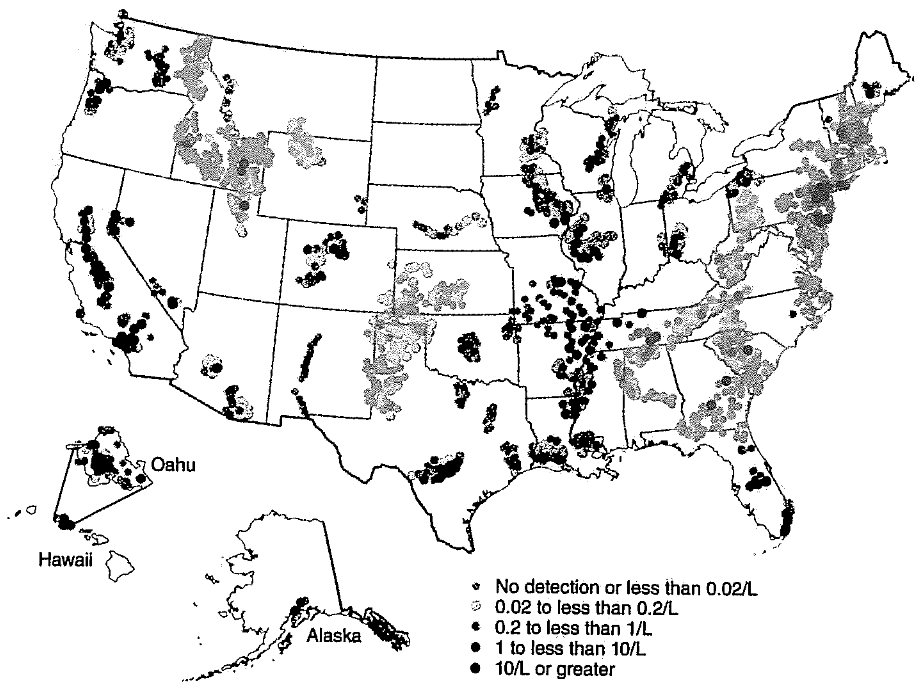


Figure 21.7 Volatile organic compounds in U.S. groundwater. Volatile organic compounds (VOCs) are found in groundwater around the United States. While often found in low concentrations (<0.02 μg/L), concentrations exceed 10 μg/L in some public and domestic wells. ("Volatile Organic Compounds in the Nation's Ground Water and Drinking-Water Supply Wells," U.S. Geological Survey Circular 1292, 2006 [USGS])

There are several ways to control the presence of organic compounds in our water. Everyone, from individual homeowners to large factories, should take care to prevent organic compounds from ever finding their way into water. Alternative organic compounds, which are less toxic and degrade more readily so that they are not as persistent in the environment, can be developed and used. Tertiary water treatment, considered later in this chapter, eliminates many synthetic organic compounds in water.

INORGANIC CHEMICALS

Inorganic chemicals are contaminants that contain elements other than carbon; examples include acids, salts, and heavy metals. Inorganic chemicals do not easily degrade, or break down. When they are introduced into a body of water, they remain there for a long time. Many inorganic chemicals find their way into both surface water and groundwater from sources such as industries, mines, irrigation runoff, oil drilling, and urban runoff from storm sewers. Some of these inorganic pollutants are toxic to aquatic organisms. Their presence may make water unsuitable for drinking or other purposes.

Here we consider the heavy metals lead and mercury, two inorganic chemicals that sometimes contaminate water and accumulate in the tissues of humans and other organisms (see the discussion of bioaccumulation and biological magnification in Chapter 7). Arsenic, another heavy metal, is discussed later in this chapter.

Lead People used to think of lead poisoning as affecting only inner-city children who ate paint chips that contained lead. Lead-based paint was banned in the United States in 1978, but the EPA estimates that more than three-fourths of U.S. homes still contain some lead-based paint. Although lead-based paint remains an important source of lead poisoning in children, lead lurks in many other places in the environment as well.

Lead-containing anti-knock agents in gasoline were outlawed in the United States in 1986; prior to 1986, lead dust was released into the atmosphere when the fuel was burned, and that lead still contaminates soil, particularly in inner cities near major highways. Children living in the inner city may be at risk when they play outdoors in their schoolyards and backyards. Lead contaminates the soil, surface water, and groundwater when incinerator ash from solid waste facilities is dumped into ordinary sanitary landfills. Factories that lack pollution-control devices release lead into the air, from which it can settle on soil or water. We can ingest lead from pesticide and fertilizer residues on produce, from food cans soldered with lead, and even from certain types of dinnerware on which our food is served. Low amounts of lead also originate from natural sources such as volcanoes and windblown dust.

Millions of U.S. residents, many of them children, have damaging levels of lead in their bodies. At least 2% of U.S. children age one to five have blood lead levels that exceed 10 micrograms (μg) per deciliter (dL) of blood. A blood lead level above 10 μg per dL is considered dangerous, and recent data suggest that even lower concentrations of lead are harmful to the brain.

The three groups of people at greatest risk from lead poisoning are middle-aged men, pregnant women, and young children. Middle-aged men with high levels of lead are more likely to develop **hypertension**, or high blood pressure. High lead levels in pregnant women increase the risk of miscarriages, premature deliveries, and stillbirths. Children with even low levels of lead in their blood may suffer from a variety of mental and physical impairments, including partial hearing loss, hyperactivity, attention deficit, lowered IQ, and learning disabilities. Male juvenile delinquency and high bone lead concentrations have been linked, and in 2001 the American Medical Association reported a link between murder rates and lead levels in the air.

According to the EPA, in the mid-1990s more than 10% of all large and medium-sized municipal water supplies contained lead levels that exceeded the maximum permitted by the Safe Drinking Water Act (discussed later in this chapter). In addition, tap water often contains higher levels of lead than exist in municipal water supplies; the extra lead comes from the corrosion of old lead water pipes or of lead solder in newer pipes. Some treatments to clean water can have the unfortunate side effect of causing more lead to leach from pipes and solder.

Mercury Mercury is a metal that vaporizes at room temperature; this characteristic poses special environmental challenges. Small amounts of mercury occur naturally in the environment, but most mercury pollution comes from human activities.

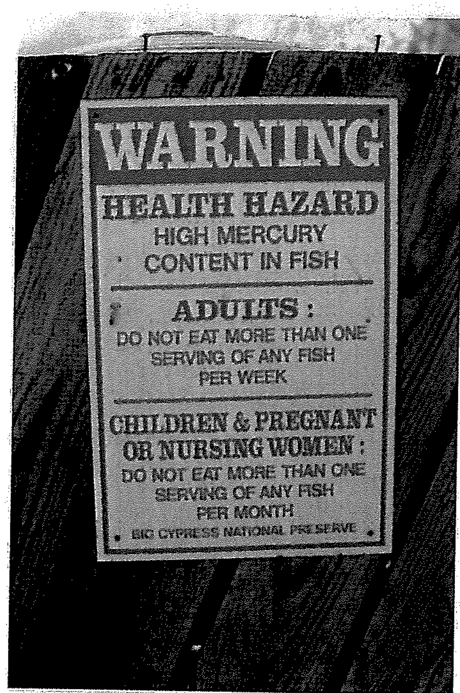
According to the EPA, coal-fired power plants release the largest amount (40%) of mercury into the environment. Coal contains traces of mercury that vaporize and are released into the atmosphere with the flue gases when the coal is burned. This mercury then moves from the atmosphere to the water via precipitation. Technology exists to control mercury emissions from coal-burning power plants, but it is expensive, and the trapped mercury would have to be properly disposed of in a hazardous waste landfill or it could recontaminate the environment. After many years of legal wrangling, in 2011 the EPA issued the Mercury and Air Toxics Standards, the first national standards to regulate mercury emissions from power plants, as well as the release of other toxins.

Municipal waste and medical waste incinerators also release mercury (when incinerators burn materials containing mercury). Fluorescent lights and thermostats are examples of municipal wastes that contain mercury, whereas thermometers and blood-pressure cuffs are examples of medical waste. The EPA now regulates mercury emissions from municipal and medical incinerators. Many hospitals, recognizing the risks posed by mercury, have switched away from mercury-containing equipment.

Significant amounts of mercury are released into the environment during the smelting of metals such as lead, copper, and zinc. Mercury is used in a variety of industrial processes, such as chemical plants that manufacture chlorine and caustic soda. Some of this mercury vaporizes, thereby entering the atmosphere. In addition, when industries release their wastewater, some metallic mercury may enter natural bodies of water along with the wastewater. Mercury sometimes enters water by precipitation after household trash containing batteries, paints, and plastics is burned in incinerators.

Once mercury enters a body of water, it settles into the sediments, where bacteria convert it to methyl mercury compounds, a more toxic form that readily enters the food web. Mercury bioaccumulates in the muscles of albacore tuna, swordfish, sharks, king mackerel, and marine mammals—the top predators of the open ocean. Human exposure to mercury is primarily from eating fishes and marine mammals containing high levels of mercury. At least 48 states in the United States have released health advisories on the human consumption of mercury-tainted seafood from lakes and reservoirs (**Figure 21.8**).

Methyl mercury compounds remain in the environment for a long time and are highly toxic to organisms, including humans. Prolonged exposure to methyl mercury compounds causes kidney disorders and severely damages the nervous and cardiovascular systems. The exposure of developing human fetuses to mercury is linked to a variety of conditions, such as diminished cognitive function, cerebral palsy, and developmental delays. Methyl mercury compounds are unusual in that they can cross the body's blood-brain barrier (many materials do not pass from the blood to the cerebrospinal fluid and brain). Low levels of mercury in the brain cause neurological problems such as headache, depression, and quarrelsome behavior.



© David R. Frazier Photolibrary, Inc./Alamy

Figure 21.8 Mercury contamination warning. Mercury is a common fish contaminant. Warnings like this one photographed in Florida are commonly found in popular fishing areas in the United States.

RADIOACTIVE SUBSTANCES

Radioactive substances contain atoms of unstable isotopes that spontaneously emit radiation. They get into water from several sources, some natural and others anthropogenic (human-caused). Examples of the latter include the mining and processing of radioactive minerals such as uranium and thorium. Many industries use radioactive substances; although nuclear power plants and the nuclear weapons industry use the largest amounts, medical and scientific research facilities also employ them. It is possible for radiation to inadvertently escape from any of these facilities, polluting the air, water, and soil. Radiation from natural sources, particularly radon, can contaminate groundwater.

Since the mid-1980s, low levels of radioactive substances have been measured in the wastewater of several sewage treatment plants in the United States. The EPA reports that radioactive materials may concentrate in sludge (a slimy solid mixture formed during the treatment of sewage). Guidelines from the EPA help municipal sewage treatment plants identify radioactive materials in sewage sludge and, when present, reduce or eliminate the contamination.

THERMAL POLLUTION

Thermal pollution occurs when heated water produced during certain industrial processes is released into waterways. Many industries, such as steam-generated electric power plants and nuclear power plants (Chapter 12), use water to remove excess heat from their operations. Afterward, the heated water is allowed to cool a little before it is returned to waterways, but its temperature is still warmer than it was originally. The result is that the waterway is warmed slightly.

Increasing the temperature of a lake, stream, or river leads to several chemical, physical, and biological effects. Chemical reactions, including decomposition of wastes, occur faster, depleting the water of oxygen. Moreover, less oxygen dissolves in warm water than in cool water, and the amount of oxygen dissolved in water has important effects on aquatic life (**Figure 21.9**). When the level of dissolved oxygen is lowered due to thermal pollution, a fish ventilates its gills more frequently to obtain enough oxygen. Gill ventilation, however, requires an increased consumption of oxygen. This situation puts a great deal of stress on the fish as it tries to obtain a greater supply of oxygen from a smaller supply dissolved in the water.

Other subtle changes may take place in the activities and behavior of aquatic organisms in thermally polluted water because temperature affects reproductive cycles, digestion rates, and respiration rates. At warmer temperatures, fishes require more food to maintain body weight. They typically have shorter life spans and smaller populations. In cases of extreme thermal pollution, fishes and other aquatic organisms die.

REVIEW

1. What are the eight main groups of water pollutants? Give an example of each main type.
2. What is biochemical oxygen demand (BOD)? How is BOD related to sewage?
3. What causes the dead zone in the Gulf of Mexico?

Water Quality Today

LEARNING OBJECTIVES

- Contrast point source pollution and nonpoint source pollution.
- Provide examples of agricultural, municipal, and industrial water pollution.

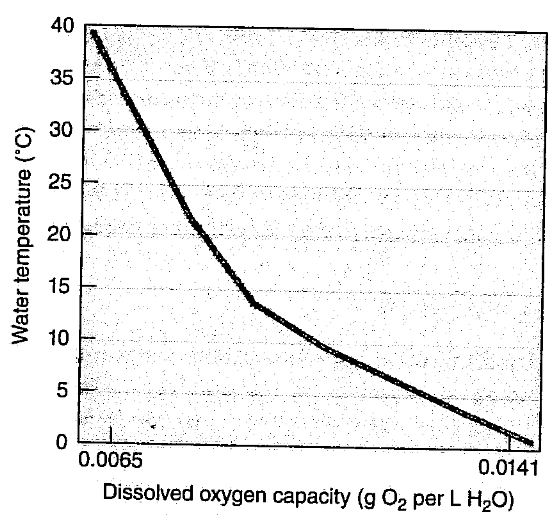


Figure 21.9 Dissolved oxygen in water at various temperatures. As water temperature rises, its capacity to contain dissolved oxygen goes down. These data are for water in contact with air at 760 mm mercury pressure.

Water pollutants come from both natural sources and human activities. For example, some of the mercury that contaminates the biosphere is from natural sources in Earth's crust; the remainder comes from human activities. Nitrate pollution has both natural and human sources—the nitrate that occurs in soil and the inorganic fertilizers added to it, respectively. Although natural sources of pollution are sometimes of local concern, human-generated pollution is generally more widespread.

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

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

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

Nonpoint source pollution, also called *polluted runoff*, is caused by pollutants that enter bodies of water over large areas rather than at a single point. Nonpoint source pollution of water occurs when precipitation moves over and through the soil, picking up and carrying away pollutants that eventually are deposited in lakes, rivers, wetlands, groundwater, estuaries, and the ocean. Although nonpoint sources are diffuse, their cumulative effect is often huge. Nonpoint source pollution includes agricultural runoff (such as fertilizers, pesticides, livestock wastes, and salt from irrigation), mining wastes (such as acid mine drainage), municipal wastes (such as inorganic plant and algal nutrients), and construction sediments. Soil erosion from fields, logging operations, eroding stream banks, and construction sites is a major cause of nonpoint source pollution.

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

Three major sources of human-induced water pollution that we now examine in greater detail are agriculture, municipalities (i.e., domestic activities), and industries. We then consider groundwater pollution and water pollution in other countries.

WATER POLLUTION FROM AGRICULTURE

According to the EPA, agriculture is the leading source of water quality impairment of surface waters nationwide: 72% of the water pollution in rivers is attributed to agriculture. As detailed in the previous section, agricultural practices produce several types of pollutants that contribute to nonpoint source pollution. Fertilizer runoff causes water enrichment. Animal wastes and plant residues in waterways produce high BODs and high levels of suspended solids as well as water enrichment. Amid growing concern about polluted runoff from animal wastes, the U.S. Department of Agriculture has developed guidelines to help the 450,000 livestock operations in the United States develop Comprehensive Nutrient Management Plans, focusing on six areas: feed management, manure and wastewater handling/storage, nutrient fertilizer management, land treatment practices, alternative manure and wastewater management, and record keeping.

Chemical pesticides used in agriculture may leach into the soil and from there into water. These chemicals are highly toxic and adversely affect human health as well as the health of aquatic organisms. The National Water Quality Assessment Program, an ongoing study of pesticides and their degradation products, indicates that pesticides are widespread in U.S. rivers, streams, and groundwater. More than 95% of the river and stream samples and almost 50% of groundwater samples examined by the program contained traces of at least one pesticide. More than 50% of streams sampled contained 5 or more pesticides, and about 10% contained 10 or more pesticides.

Soil erosion from fields and rangelands causes sediment pollution in waterways. In addition, some agricultural chemicals that are not very soluble in water, such as certain pesticides, find their way into waterways by adhering to sediment particles. Thus, soil conservation methods both conserve soil and reduce water pollution.

MUNICIPAL WATER POLLUTION

Although sewage is the main pollutant produced by cities and towns, municipal water pollution also has a nonpoint source: urban runoff from storm sewers (**Figure 21.10**; see You Can Make a Difference: Preventing Water Pollution on page 427). The water quality of urban runoff from city streets is often worse than that of sewage. Urban runoff carries salt from roadways, untreated garbage, animal wastes (especially from dogs), construction sediments, and traffic emissions (via rain that washes pollutants out of the air). It may often contain such contaminants as asbestos, chlorides, copper, cyanides, grease, hydrocarbons, lead, motor oil, organic wastes, phosphates, sulfuric acid, and zinc.

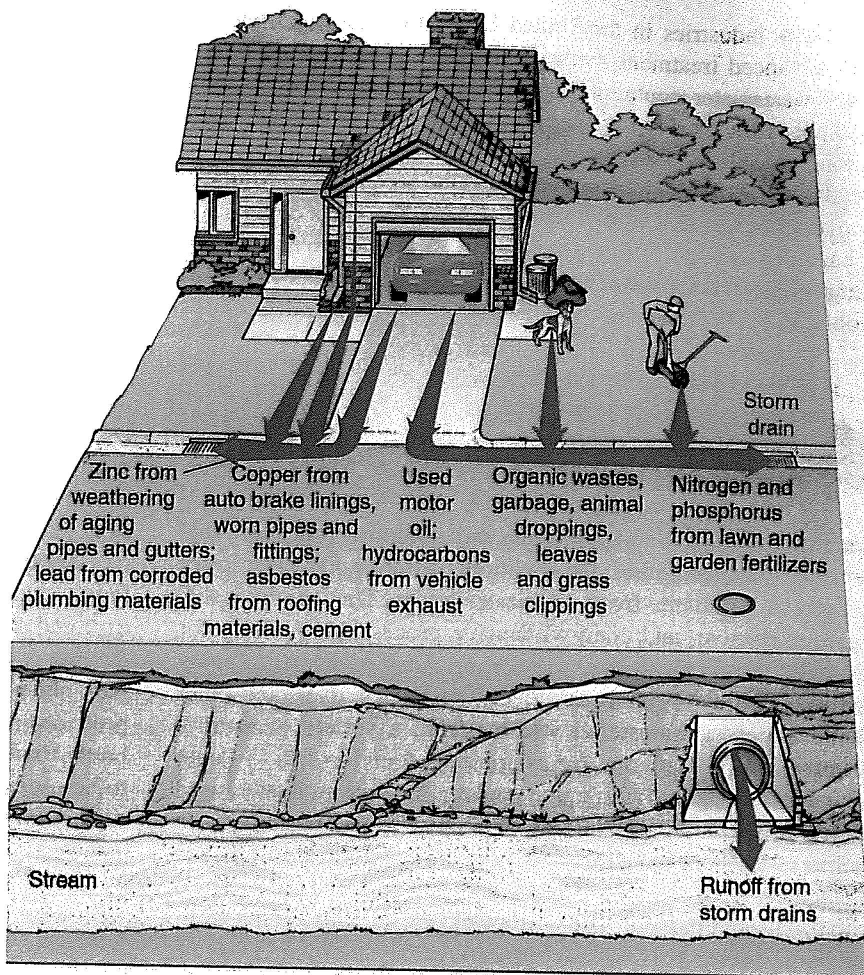


Figure 21.10 Urban runoff. The largest single pollutant in urban runoff is organic waste, which removes dissolved oxygen from water as it decays. Fertilizers cause excessive algal growth, which further depletes the water of oxygen. Other everyday pollutants include used motor oil, which is often illegally poured into storm drains, and heavy metals. These pollutants may be carried from storm drains on streets to streams and rivers.

Nearly 800 U.S. cities, including New York, San Francisco, Pittsburgh, and Boston, have **combined sewer systems** in which human and industrial wastes are mixed with urban runoff from storm sewers before flowing into the sewage treatment plant. A problem arises following a heavy rainfall or a large snowmelt because even the largest sewage treatment plant can process only a given amount of wastewater each day. When too much water enters the system, the excess, known as **combined sewer overflow**, flows into nearby waterways without being treated. Combined sewer overflow, which contains raw sewage, has been illegal since passage of the Clean Water Act of 1972 (discussed shortly), but cities have only recently begun to address the problem. According to the EPA, 1.2 trillion gallons of combined sewer overflow are discharged into U.S. waterways every year.

Some cities with combined sewer systems, such as St. Paul, Minnesota, have installed two separate sewers, one for sewage and industrial wastes and one for urban runoff. However, such an installation is expensive and requires that every street be dug up. Other cities, such as Birmingham, Michigan, have kept their combined sewer systems but installed huge retention basins to hold the overflow until it is treated. The basin in Birmingham, which was installed in 1998, holds 21 million L (5.5 million gal). Such tanks are less expensive to install than separate sewer systems, but there are concerns that after several days of heavy rain or snow, the basin itself could overflow.

INDUSTRIAL WASTES IN WATER

Different industries generate different types of pollutants. Food-processing industries produce organic wastes that are readily decomposed but have a high BOD. Pulp and paper mills produce toxic compounds and sludge in addition to a high BOD. The paper industry, however, has begun to adopt new manufacturing methods, such as the production of paper without the use of chlorine as a bleaching agent, that produce significantly less toxic effluents.

Many industries in the United States treat their wastewater with advanced treatment methods. The electronics industry produces wastewater containing high levels of heavy metals such as copper, lead, and manganese but uses special techniques such as ion exchange and electrolytic recovery to reclaim those heavy metals. Metal plates with commercial value are produced from the recovered metals that would otherwise have become a component of hazardous sludge. Although most U.S. industries do not usually dump highly toxic wastes into water, accidental spills remain a problem.

CASE IN POINT

GREEN CHEMISTRY

For many industrial, agricultural, and domestic processes that generate water pollution, the traditional solution has been to try to remove pollutants from the waste stream. This can be a difficult, expensive, and energy-intensive process, particularly for synthetic chemicals that occur, often in small amounts, in many settings. Pesticides, pharmaceuticals, cosmetics, dyes, and other chemicals enter wastewater streams from a variety of sources (**Figure 21.11**). Caffeine, for example, is found in fish in Puget Sound (near Seattle, Washington) and musks—the molecules used to provide scent in deodorants, aftershaves, and perfumes—in catfish taken from Lake Mead (near Las Vegas, Nevada). Unused medicines, both over-the-counter and prescription, are dumped into toilets and pass through wastewater treatment systems without being altered or removed. Eventually, they are found in rivers and lakes—and in the plants and animals that live there.

These chemicals—there are thousands of them—occur in relatively small amounts compared to other pollutants we often worry about, such as oil, organic matter, and nitrogen. So why should we be concerned? First, they are difficult to remove. Most organic matter eventually breaks down into carbon dioxide; synthetic molecules, on the other hand, are not easily broken down. Indeed, as in the case of dyes, longevity is something that manufacturers *want* in their products. Second, these chemicals can have substantial environmental impacts, even at low concentrations. Synthetic chemicals can disrupt many species' growth, especially their reproductive development. Even at low concentrations, some chemicals—endocrine disrupters—can affect the ratio of male to female fish and cause developmental damage, including deformities and cancer.

From a systems perspective, a variety of ways exist to deal with this problem. Several fall under the general term **green chemistry** (also known as sustainable chemistry), or chemistry designed to reduce or halt the use and production of hazardous substances. One approach of green chemistry is to find new ways to remove the chemicals from the waste stream. Researchers at the Institute for Green Oxidation Chemistry at Carnegie Mellon University have worked on this problem for years. One promising solution is a class of chemicals called TAMLs (tetra-amido macrocyclic ligands) that serve as catalysts to speed the breakdown of synthetic chemicals.

Another approach is to change chemical processes and use fewer synthetic chemicals. This branch of green chemistry is explored at laboratories around the world. For example, the production of plastic containers can involve the release of many complex chemicals. Alternatively, biodegradable containers can be produced from sugars, with few or no chemical byproducts. Such bottles have the added advantage that they can last long enough to be useful—but not for the decades that a plastic bottle would remain in the environment.

Perchloroethylene (or "perc") is a hydrocarbon responsible for the highly recognizable odor of dry cleaners. It is also a common water and air contaminant associated with a range of health problems. In parts of southern California, it is no longer legal to use perc in new or upgraded dry-cleaning facilities. Several companies now provide alternatives, including less damaging hydrocarbons, silicon-based cleaners, and even a new "wet-cleaning" approach that uses water and alternative soaps to clean delicate fabrics without harming them.

Green chemistry has the potential to change or replace many highly toxic industrial or household chemicals. The challenge is to find alternatives that work as well as and cost no more than traditional synthetic chemicals. ■

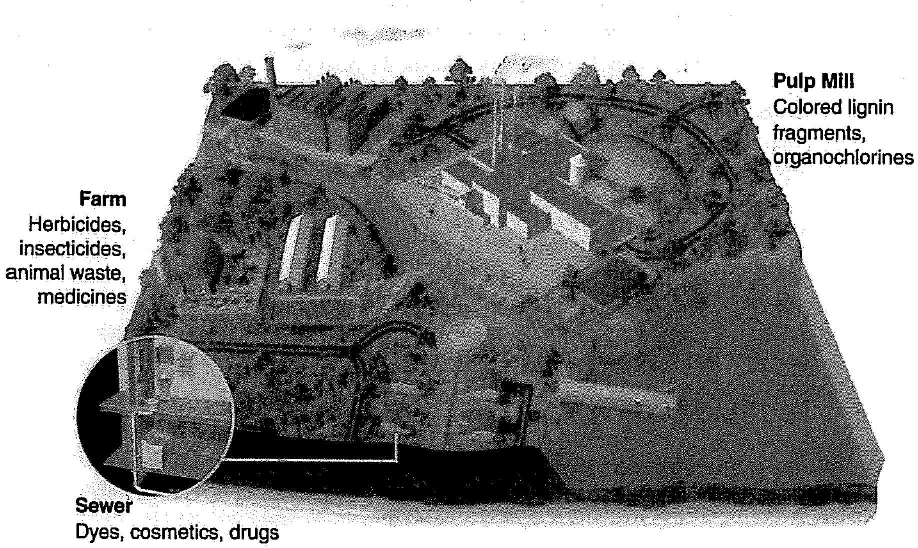
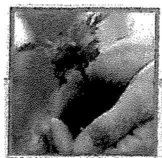


Figure 21.11 Sources of synthetic pollutants in water. Water pollution containing small amounts of synthetic chemicals can come from a variety of sources: industrial (e.g., pulp mills), agricultural, and municipal (e.g., sewers).



YOU CAN MAKE A DIFFERENCE

Preventing Water Pollution

Although individuals produce little water pollution, the collective effect of municipal water pollution, even in a small neighborhood, can be quite large. You can do many things to protect surface waters and groundwater from water pollution.

1. Many household chemicals, such as oven cleaners, mothballs, drain cleaners, and paint thinners, are quite toxic. Use such products sparingly, and try to substitute less hazardous chemicals wherever possible. When disposing of these chemicals, contact the solid waste management office in your county for information about local hazardous waste collection centers. Never put them down a drain or toilet, because they may disrupt your septic system or contaminate sewage sludge produced at municipal sewage treatment facilities. Never pour these chemicals on the ground because they may contaminate runoff when it rains. Here are some safer alternatives (note that these chemicals are not nontoxic, just less toxic than many commercial products):
   - Ammonia, to clean appliances and windows.
   - Bleach, to disinfect. Never mix ammonia and bleach because the mixture releases toxic chlorine gas.
   - Borax, to remove stains and mildew.
   - Baking soda, to remove stains, deodorize, and clean household utensils.
   - Vinegar, to clean surfaces, polish metals, and remove stains and mildew.
2. Never throw unwanted medicines down the toilet. Several studies have shown that traces of many drugs are present in tap water. In some places, pharmacies can collect unwanted medicines and return them to drug manufacturers.
3. Never pour used motor oil or antifreeze down storm drains or on the ground. Recycle these chemicals by dropping them off at a service station or local hazardous waste collection center.
4. Pick up pet waste and dispose of it in the garbage or toilet. If left on the ground, it eventually washes into waterways, where it can increase BOD and fecal coliform levels.
5. Drive less. Air pollution emissions from automobiles eventually enter ground water and surface water. Toxic metals and oil by-products deposited on the road by automobiles—are washed into surface waters by precipitation.
6. If you are a homeowner, replace some of your grass lawn with trees, shrubs, and ground covers, which absorb up to 14 times more precipitation and require little or no fertilizer. To reduce erosion, use mulch to cover bare ground (see Chapter 14).
7. Use fertilizer sparingly because excess fertilizer leaches into groundwater or waterways. If you hire a professional lawn care service to apply fertilizer and pesticides, use one that monitors soil fertility and applies chemicals only when they are needed.
8. Never apply fertilizer near a body of water. Always allow a buffer zone of at least 20 to 40 feet.
9. Make sure that gutters and downspouts drain onto water-absorbing grass or graveled areas instead of paved surfaces.
10. Clean up spilled oil, brake fluid, and antifreeze, and sweep sidewalks and driveways instead of hosing them off. Dispose of the dirt properly not into gutters or storm drains.
11. Likewise, do not let grass clippings or leaves wash into gutters or storm drains.
12. Use pesticides sparingly, both indoors and outdoors, and incorporate integrated pest management techniques (see Chapter 18). Dispose of unwanted pesticides at hazardous waste collection centers.
13. Replace paved driveways and sidewalks with porous surfaces, such as interlocking bricks or stones; build wood decks instead of concrete patios. These features allow precipitation to seep into the ground, decreasing runoff.

GROUNDWATER POLLUTION

Roughly half of the people in the United States obtain their drinking water from groundwater, which is also withdrawn for irrigation and industry. The most common groundwater pollutants, such as pesticides, fertilizers, and organic compounds, seep into groundwater from municipal sanitary landfills, underground storage tanks, backyards, golf courses, and intensively cultivated agricultural lands (**Figure 21.12**). More than 250,000 underground petroleum storage tanks may be leaking at service stations in the United States. Cleanup of leaking gas tanks is expensive—$500,000 or more per tank—but state gasoline taxes help pay for the cleanup in some states (such as California).

Nitrates sometimes contaminate shallow groundwater—30 m (100 ft) or less from the surface—with fertilizer being the most common source. High nitrate levels are a concern in some rural areas, where 80% to 90% of residents use shallow groundwater for drinking water. When nitrates get into the human body, they are converted to nitrites, which reduce the blood's ability to transport oxygen. This condition is one of the causes of cyanosis (the *blue baby* syndrome), a serious disorder in young children. The level of nitrate in drinking water is monitored for municipal systems, so it is generally not of concern. Users of well water should have water nitrate levels checked periodically.

Contamination of groundwater is a relatively recent environmental concern. People used to think that the underlying soil and rock through which surface water must seep to become groundwater filtered out any contaminants, thereby ensuring the purity of groundwater. This assumption proved false when groups began to monitor the quality of groundwater and discovered contaminants at certain sites. It appears that the natural capacity of soil and rock to remove pollutants from groundwater varies widely from one area to another.

Concern over groundwater safety has grown over the recent boom in hydraulic fracturing, known as fracking, a water-intensive process used to release natural gas and oil from underground rock formations (see Chapter 11). Many local conflicts have arisen over the potential contamination of drinking water by fracking chemicals.

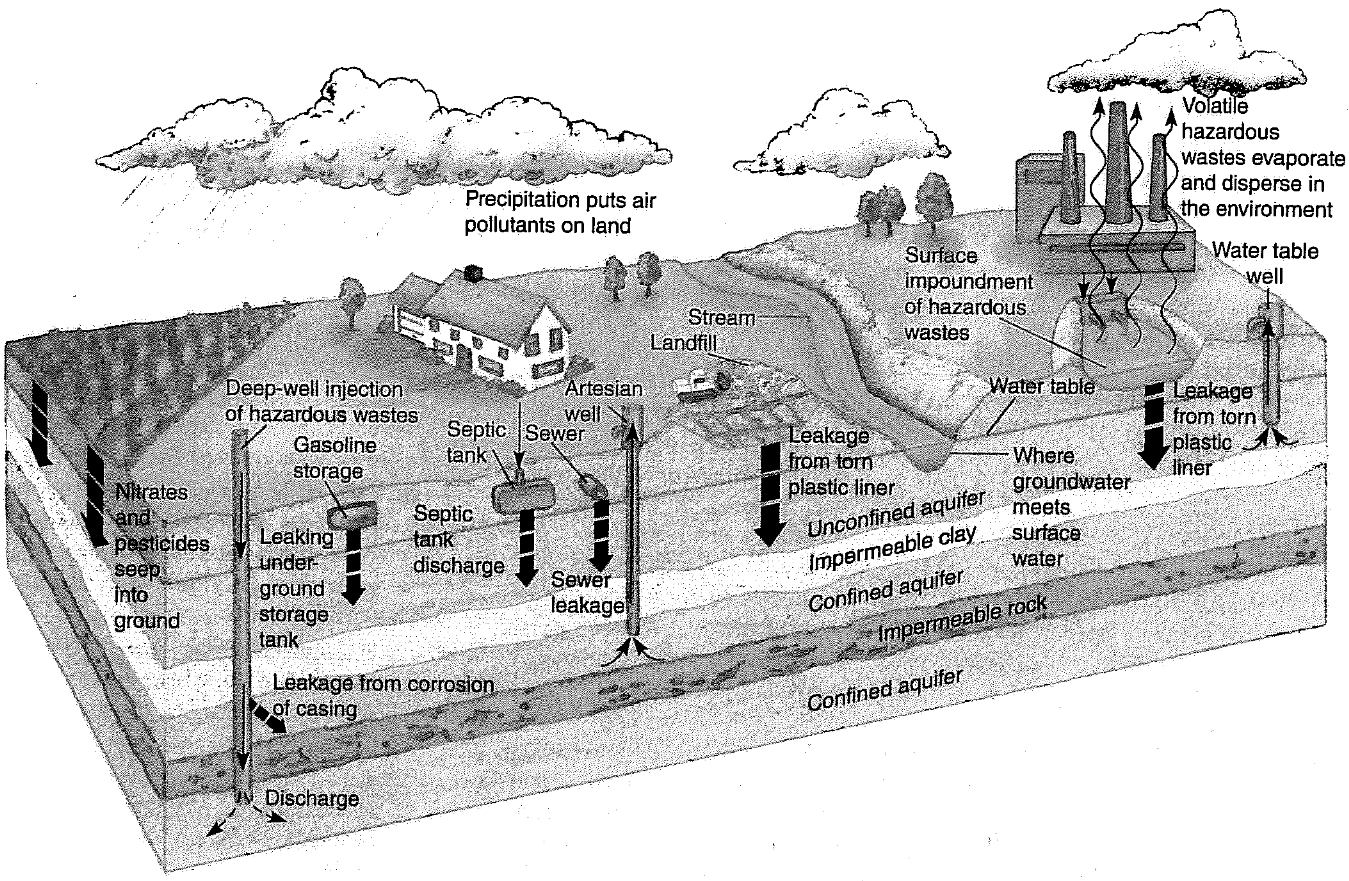


Figure 21.12 Sources of groundwater contamination. Agricultural practices, sewage (both treated and untreated), landfills, industrial activities, and septic systems are some of the sources of groundwater pollution. Once groundwater is contaminated, it does not readily cleanse itself by natural processes. We do not know the degree of groundwater contamination because access is difficult and because contaminants do not disperse quickly (groundwater moves very slowly). (Figure is not drawn to scale.)

Currently, most U.S. groundwater supplies are of good quality and do not violate standards established to protect human health. There are some local problems, however, that have led to well closures and raised public health concerns. For example, in 1996 Santa Monica, California, closed 7 of its 11 municipal wells when methyl tertiary butyl ether (MTBE), a gasoline additive that reduces tailpipe emissions, was detected in the groundwater. The groundwater became polluted primarily from leaking underground gas-storage tanks. MTBE, which may cause cancer, persists in groundwater for years. A 2006 study by the USGS found that MTBE was detected in groundwater samples around the United States. Some states now ban the addition of MTBE to gasoline.

Cleanup of polluted groundwater is costly, takes years, and in some cases is not technically feasible. Compounding the cleanup problem is the challenge of safely disposing of the toxic materials removed from groundwater, which, if not handled properly, could contaminate the groundwater once again.

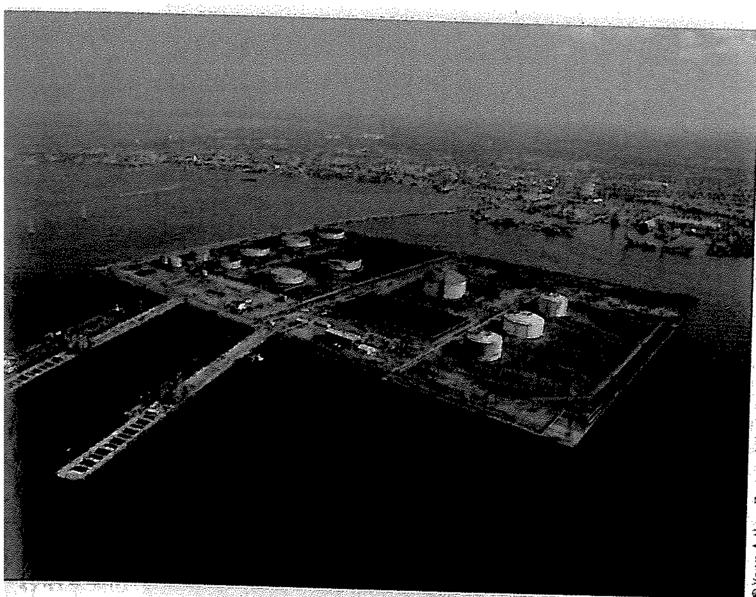
WATER POLLUTION IN OTHER COUNTRIES

According to the World Health Organization, an estimated 768 million people lack access to safe drinking water, and about 2.5 billion people do not have access to adequate sanitation systems; most of these people live in rural areas of developing countries. Worldwide, more than 3.4 million people die of water-related illnesses each year, an estimated 800,000 of them children younger than five with diarrheal illnesses.

Municipal water pollution from sewage is a greater problem in developing countries, many of which lack water treatment facilities, than in highly developed ones. Sewage from many densely populated cities in Asia, Latin America, and Africa is dumped directly into rivers or coastal harbors.

Almost every nation in the world faces problems of water pollution. For an international perspective on water pollution, let's examine some specific issues in South America, Europe, Asia, and Africa.

Lake Maracaibo, Venezuela Lake Maracaibo in Venezuela is the largest lake in South America (**Figure 21.13**). It receives fresh water from several rivers, and water flows from it into the Caribbean Sea. Larger than the state of Connecticut, Lake Maracaibo suffers from the effects of oil pollution and human wastes as well as contamination from farms and factories. About 10,000 oil wells tap the oil and natural gas reserves under the shallow lake. An underwater network of old oil pipes about 15,400 km (9600 mi) long leaks oil into the lake.



© Yann-Arthus-Bertrand/Corbis

Figure 21.13 Lake Maracaibo, Venezuela. Drilling platforms are located throughout the lake, and pipelines join the oil wells to refineries on land. Shown are storage and export facilities in the foreground and the town of Cabimas in the background. An oil tanker is docked at the leftmost pier.

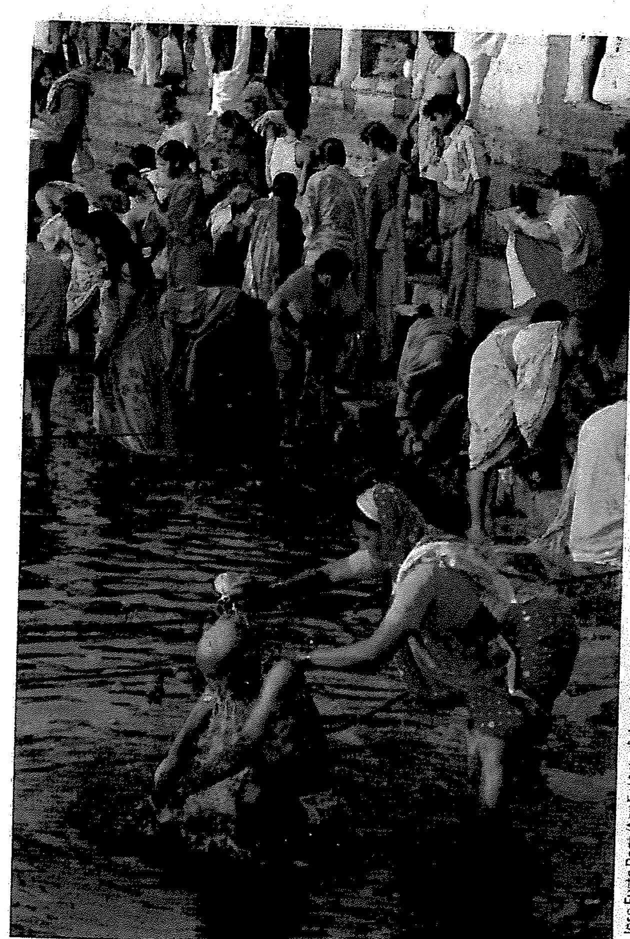
Fertilizers and other agricultural chemicals drain into the lake from nearby farms, providing the nutrients for an overgrowth of algae. Until recently, raw sewage from the city of Maracaibo's 2.1 million people and many smaller communities was discharged directly into the water, contributing to the nutrient overload. Modern sewage treatment facilities were installed during the 1990s to take care of human wastes, but Lake Maracaibo's other pollution problems must still be addressed.

Po River, Italy The Po River, which flows across northern Italy, empties into the Adriatic Sea. The Po, Italy's equivalent of the Mississippi River, is heavily polluted. Many cities, including Milan, with more than 4 million residents in its metropolitan area, historically have dumped treated and untreated sewage into the Po. Industry is responsible for half the pollutants that enter the river. Italian agriculture, including large poplar plantations, relies heavily on chemicals and is responsible for massive amounts of nonpoint source pollution. Soil erosion has resulted in so much sediment deposition at the mouth of the river that the Po River delta is advancing about 81 hectares (200 acres) into the Adriatic Sea each year.

About 17 million people—almost one-third of all Italians—live in the Po River basin. The health of many Italians is potentially threatened because the Po is the source of their drinking water. In addition, pollution from the Po has jeopardized tourism and fishing in the Adriatic Sea. Pollution has temporarily closed swimming at some beaches. Beginning in 2009, the Po Basin Water Board began to manage the river under an Integrated Management Plan. The cleanup of the Po will take place over a period of several decades.

Ganges River, India The Ganges River is a holy river that symbolizes the spirituality and culture of the Indian people. The river, widely used for bathing and washing clothes (**Figure 21.14**), is highly polluted. Little of the sewage and industrial waste produced by the 400 million people who live in the Ganges River basin is treated. Another major source of contamination is the 35,000 human bodies that are cremated annually in the open air in Varanasi, the holy city of the Hindus. (The Hindus cremate the body to free the soul; dumping the ashes into the Ganges increases the chances of the soul getting into heaven.) Incompletely burned bodies are dumped into the Ganges, where their decomposition adds BOD to the river. In addition, people who cannot afford cremation costs for their dead dump human remains into the river.

In 1985, the Indian government initiated the Ganga Action Plan, an ambitious cleanup project that was to include water treatment plants in 29 large cities and 32 electric crematoriums along the banks of the Ganges. Although the government has spent about $100 million constructing sewage treatment plants in major cities along the Ganges, most are not completed or are not working effectively. Most cities in the river basin still discharge raw sewage into the river. Costs have escalated, and many delays in the Ganga Action Plan have occurred. According to critics, the government plan has not worked in part because it has not tried to get people involved at the community level.



© Jose Fuste Raga/Age Fotostock America, Inc.

Figure 21.14 Ganges River. Bathing and washing clothes in the Ganges River are common practices in India. The river is contaminated by raw sewage discharged directly into the river at many locations.

Zimbabwe A cholera outbreak throughout Zimbabwe in 2008–2010 led to over 4000 deaths from almost 100,000 cases of the disease. This epidemic was exacerbated by extreme poverty and shortages of food. In addition, many Zimbabweans are unaware of the cause of cholera—a bacterium found in water contaminated with human or animal wastes. Cholera infects the lower intestine, causing severe diarrhea and dehydration. Death can occur in as little as 18 hours after initial infection. Robert Mugabe, president of Zimbabwe, accused Western countries of intentionally causing a 2008 outbreak, and doctors and nurses protesting the government's lack of response were stopped by riot police in Harare, the Zimbabwean capitol.

Arsenic Poisoning in Bangladesh During the 1980s, world health organizations, concerned about illnesses caused by drinking contaminated surface water in Bangladesh, funded the installation there of more than 2.5 million wells with hand pumps. Tragically, the groundwater in many of these wells is contaminated with high levels of naturally occurring arsenic. An estimated 57,000 people now suffer from chronic arsenic poisoning, which initially causes skin lesions, particularly on the hands and feet. Eventually, when the cumulative dose is large enough, arsenic poisoning leads to death from cancer. Health authorities do not know how many people are at risk. Estimates range from hundreds of thousands to as many as 70 million.

International agencies are currently providing funding to test all the wells. Meanwhile, the Bangladeshi people continue to drink the groundwater because they have no other option. Scientists have developed an inexpensive bucket filtration system to remove arsenic from well water using iron shavings. However, the arsenic-rich sediments produced by the filtration system would have to be safely disposed of if this procedure were to be widely adopted.

Bangladesh is not the only place in the world with naturally occurring arsenic contamination of groundwater. Arsenic is also found in shallow aquifers in parts of Argentina, Chile, China, Hungary, India, Mexico, Mongolia, Romania, Taiwan, Thailand, the western United States, and Vietnam.

REVIEW

1. How do point source and nonpoint source pollution differ?
2. What are some major agricultural, industrial, and municipal water pollutants?

Improving Water Quality

LEARNING OBJECTIVES

- Describe how most drinking water is purified in the United States, and discuss the chlorine dilemma.
- Distinguish among primary, secondary, and tertiary treatments for wastewater.

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

PURIFICATION OF DRINKING WATER

The United States has nearly 60,000 municipal water facilities that serve over 300 million people. Surface-water sources of municipal water supplies include streams, rivers, and lakes. Often a dam is built across a river or stream to form an artificial lake, or reservoir. Reservoirs accumulate water when there is an adequate supply and store it for use during periods of drought.

In the United States, most municipal water supplies are treated before being used so that the water is safe to drink (**Figure 21.15**). Turbid water is treated with a chemical coagulant (aluminum sulfate) that causes the suspended particles to clump together and settle out. The water is then filtered through sand to remove remaining suspended materials as well as many microorganisms. A few cities, such as Cincinnati, pump the water through activated carbon granules to remove many of the dissolved organic compounds.

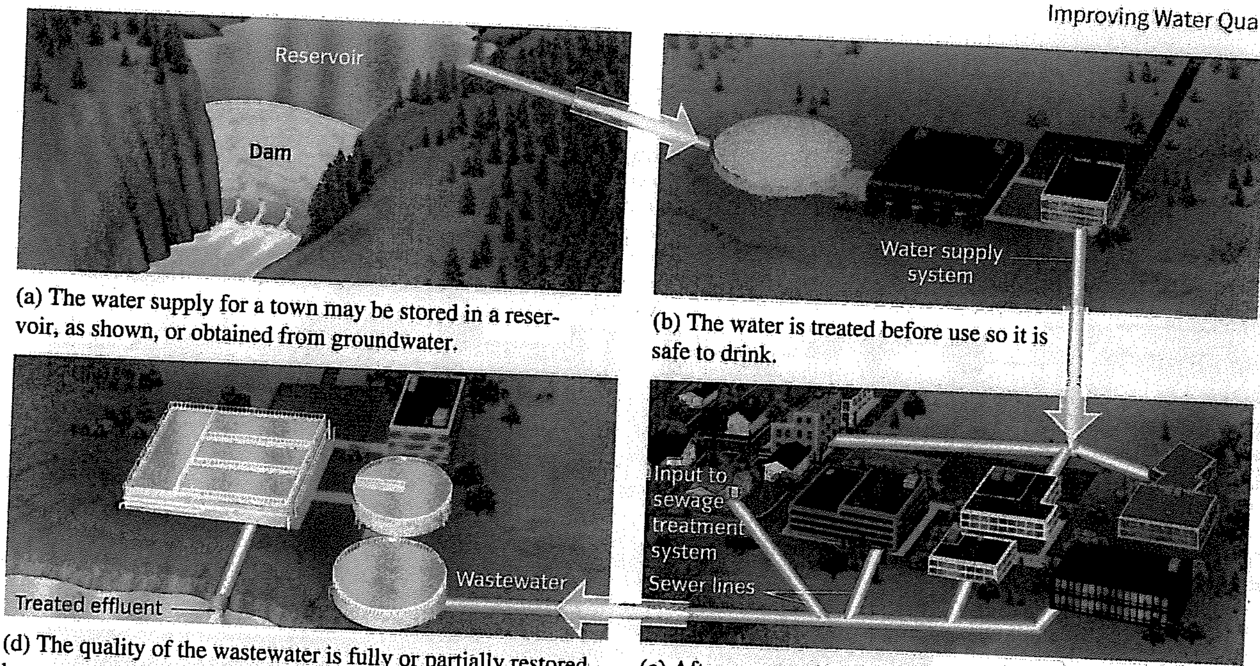
In the final purification step before distribution in the water system, the water is disinfected to kill any remaining disease-causing agents. The most common way to disinfect water is to add chlorine. A small amount of chlorine is left in the water to provide protection during its distribution through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

The Chlorine Dilemma During the 19th century, waterborne disease-causing organisms often contaminated drinking water supplies in the United States. The discovery that chlorine kills these organisms allowed 20th-century Americans to drink water with little fear of contracting typhoid, cholera, or dysentery. The addition of chlorine to our drinking water supply has undoubtedly saved millions of lives.

At the same time, chlorine by-products, formed when chlorine reacts with and oxidizes organic matter in treated wastewater, are tentatively linked to several kinds of cancer (rectal, pancreatic, and bladder), an increased risk of miscarriages, and the possibility of some rare birth defects. As a result, use of chlorine to disinfect drinking water has triggered a debate over the costs and benefits of chlorinating water. The concern is whether low levels of chlorine in drinking water present a long-term hazard.

Because there are few viable alternatives to chlorination, the EPA was initially reluctant to reduce the level of chlorine permissible in drinking water, despite the evidence of potential risks. The EPA did not want what happened in Peru to occur in the United States. In 1991, a terrible cholera epidemic swept much of Peru, infecting more than 300,000 people and killing at least 3500. This outbreak occurred after Peruvian officials decided to stop chlorinating much of the country's drinking water in response to the slightly increased cancer risk due to chlorination. Peru has since resumed chlorinating its drinking water.

After a detailed review of current evidence linking chlorine to cancer, the EPA proposed in 1994 that water treatment facilities reduce the maximum permissible level of chlorine in drinking water. One alternative to chlorination is to use *chloramine*, a disinfectant produced by combining chlorine with ammonia. Chloramine does not form potentially harmful by-products, although preliminary studies suggest that its use may cause an increase in lead levels in drinking-water systems. (Chloramine may make lead



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

(b) The water is treated before use so it is safe to drink.

(c) After use, municipal sewer lines collect the wastewater.

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

Figure 21.15 **Water treatment for municipal use.**

atoms adhering to water pipes more soluble in the water.) Another alternative is to filter water through activated carbon granules, as is done in Cincinnati; one-third less chlorine is then needed in the final step. Much of Europe has adopted another alternative to chlorination, UV disinfection, which has also gained ground in U.S. cities as an additional level of treatment to kill microorganisms not eliminated by chlorine. In 2013, New York City launched the world's largest UV treatment facility.

Fluoridation Small amounts of fluoride have been added to municipal drinking water since the mid-1940s to reduce tooth decay. (Fluoride is added to many toothpastes for the same reason.) This practice is somewhat controversial, with opponents questioning the safety and effectiveness of fluoride and supporters saying it is completely safe and effective in preventing decay. More than 40 years of research have failed to link fluoridation at the levels in U.S. drinking water to cancer, kidney disease, birth defects, or any other serious medical condition. Most dental health officials think fluoride is the main reason for the 50% to 60% decrease in tooth decay observed in children during the past several decades, based on comparisons of cavity rates in schoolchildren between cities with fluoridation and without.

As of 2012, almost 75% of the U.S. population received fluoridated water through public water supplies. Currently, fluoridation is more common in the eastern half of the country than in the western half, although it was mandated in California in 1995 and in Nevada in 2002.

MUNICIPAL SEWAGE TREATMENT

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

Primary treatment removes suspended and floating particles, such as sand and silt, by mechanical processes such as screening and gravitational settling (**Figure 21.16**, left side). The solid material that settles out at this stage is **primary sludge**. Primary treatment does little to eliminate the inorganic and organic compounds that remain suspended in the wastewater. The wastewater treatment facilities for about 11% of the U.S. population have primary treatment only.

primary treatment Treating wastewater by removing suspended and floating particles by mechanical processes.

primary and secondary sludge The solids remaining after sewage treatment has been completed.

Secondary treatment uses microorganisms (aerobic bacteria) to decompose the suspended organic material in wastewater (Figure 21.16, right side). One of the several types of secondary treatment is *trickling filters*, in which wastewater trickles through aerated rock beds that contain bacteria and other microorganisms, which degrade the organic material in the water. In another type of secondary treatment, the *activated sludge process*, wastewater is aerated and circulated through bacteria-rich particles; the bacteria degrade suspended organic material. After several hours, the particles and microorganisms are allowed to settle out, forming **secondary sludge**, a slimy mixture of bacteria-laden solids. Water that has undergone primary and secondary treatment is clear and free of organic wastes such as sewage. The wastewater treatment facilities for about 62% of the U.S. population have both primary and secondary treatments.

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

Even after primary and secondary treatments, wastewater still contains pollutants, such as dissolved minerals, heavy metals, viruses, and organic compounds (including pharmaceuticals, fragrances, and pesticides) (**Figure 21.17**). Advanced wastewater treatment methods, or **tertiary treatment**,

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

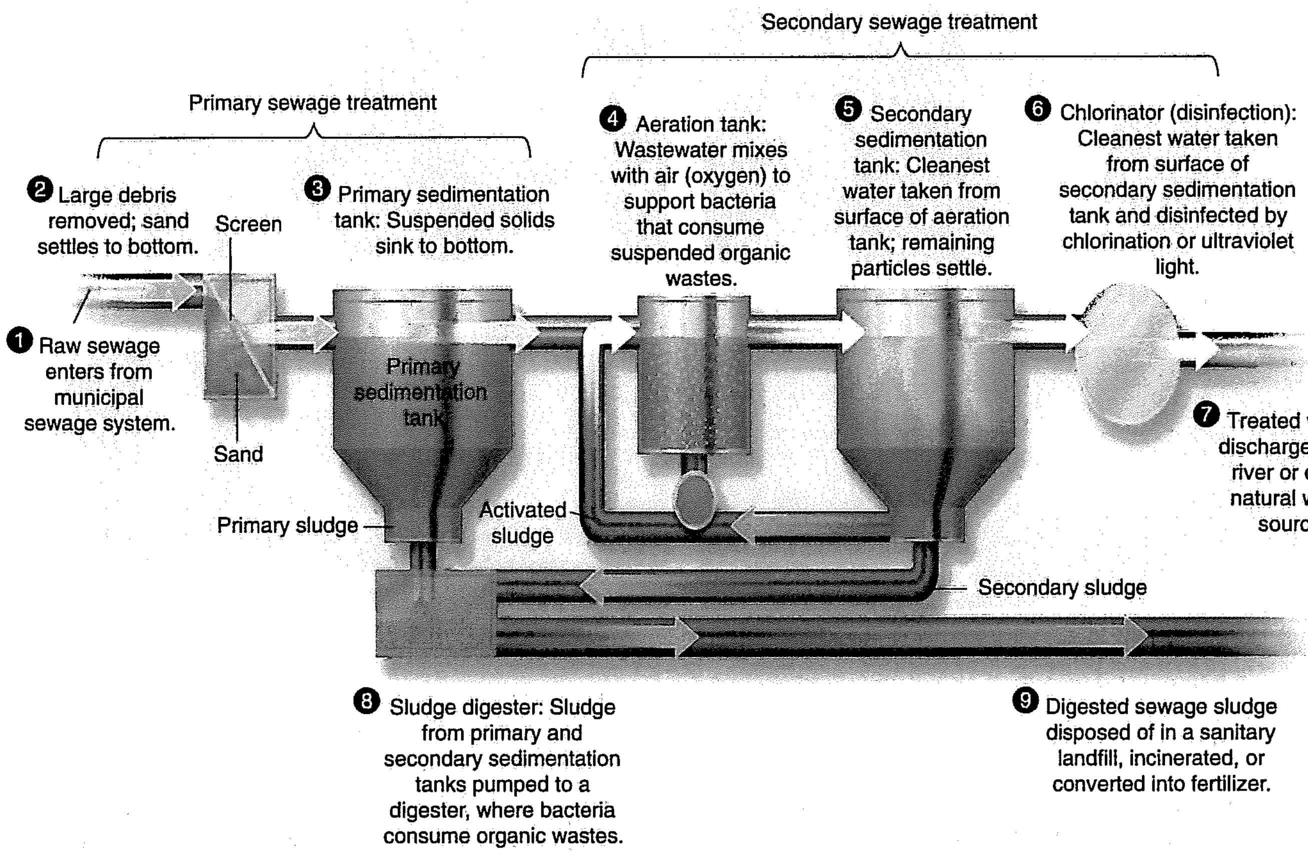


Figure 21.16 Primary and secondary sewage treatment. This sort of sewage treatment system is standard for municipalities in highly developed countries but often nonexistent in less developed ones.

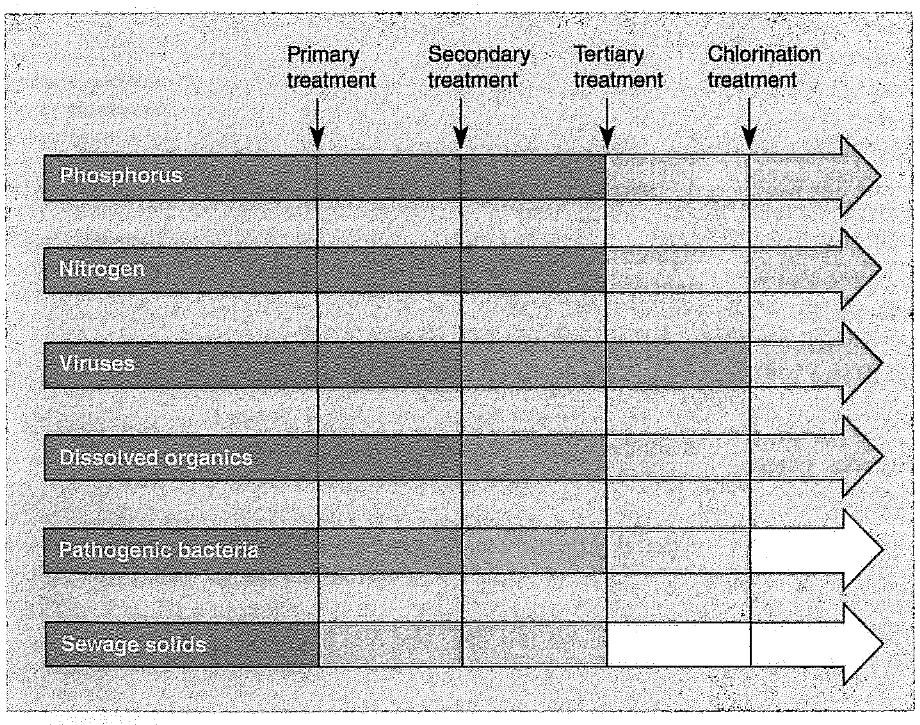


Figure 21.17 Effectiveness of primary, secondary, and tertiary sewage treatment. This figure shows the relative concentrations of various water pollutants after each treatment. The most intense color represents the greatest concentration of a given pollutant, whereas white means all of that specific pollutant is removed. Note how ineffective secondary treatment is in removing certain contaminants, such as phosphorus and nitrogen. Also note that even after tertiary treatment, some pollutants are still detectable, though at greatly reduced levels.

include a variety of biological, chemical, and physical processes. Tertiary treatment reduces phosphorus and nitrogen, the nutrients most commonly associated with enrichment. Tertiary treatment purifies wastewater for reuse in communities where water is scarce. The wastewater treatment facilities for about 27% of the U.S. population include tertiary treatments.

Disposal of Sludge A major problem associated with wastewater treatment is disposal of the primary and secondary sludge formed during primary and secondary treatments. Five possible ways to handle sludge are anaerobic digestion, application to soil as a fertilizer, incineration, ocean dumping, and disposal in a sanitary landfill. In anaerobic digestion, the sludge is placed in large, circular digesters and kept warm (about 35°C, or 95°F), which allows anaerobic bacteria to break down the organic material into gases such as methane and CO_2. The methane can be trapped and burned to heat the digesters.

After a few weeks of digestion, the sludge resembles humus and can be used as a nutrient-rich fertilizer. Not all sludge can be used this way, in particular when sewer systems mix industrial waste, which may contain toxic substances, with household waste. Farmers have long used sludge to

ENVIRONEWS

Pharmaceuticals in Wastewater

Many countries have policies that promote the return of unused pharmaceuticals to pharmacies and prohibit disposing of them in the garbage or in sewers. U.S. consumers, however, have had limited options for dealing with unused medicines, and many of these substances are flushed down toilets. With 70% of Americans now taking prescription medicines, up from 48% in 2009, the potential threat to the U.S. water supply is growing. Disposal options are now expanding, to combat drug abuse as well as reduce environmental damage. Major U.S. pharmacy chains offer special envelopes for shipping unused medications to incinerator facilities, and they partner with law enforcement to set up drop boxes for the drugs. Communities also sponsor medicine take-back days. In 2014, California legislators promoted a bill calling for the pharmaceutical industry to voluntarily participate in the collection and disposal of unused medications.

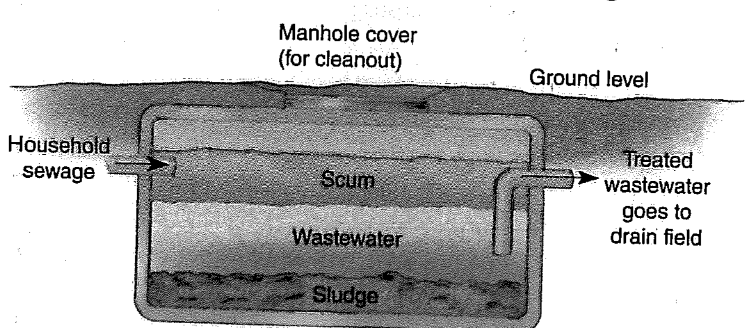
fertilize hay and feed-grain crops. However, many farmers are reluctant to use it on crops for direct human consumption because consumers might not purchase the food grown in sludge out of concern that it may pose a threat to human health. Nonetheless, over half of dried municipal sludge generated in the United States is applied to land.

Although sludge can be used to condition soil, it is generally treated as a solid waste. Dried sludge is often incinerated, which may contribute to air pollution, although sometimes the heat is used constructively—to generate electricity, for example. In the past, coastal cities such as New York dumped their sludge into the ocean. In 1988, Congress passed the **Ocean Dumping Ban Act**, which barred ocean dumping of sludge and industrial waste, beginning in 1991. Alternatively, sludge is disposed of in sanitary landfills (see Chapter 23). As landfill space becomes more costly, many cities are looking for other ways to handle sludge.

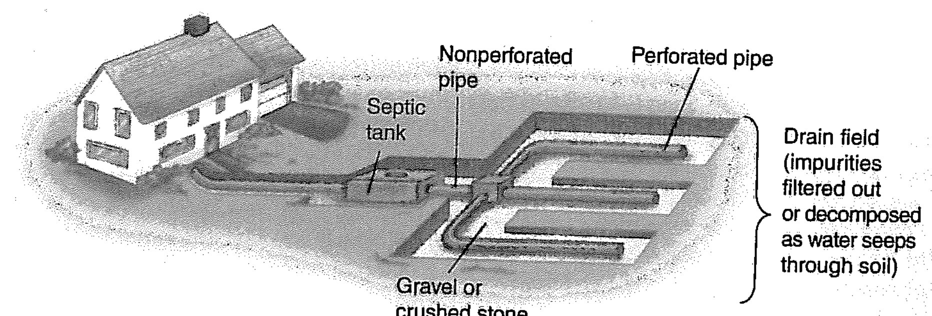
INDIVIDUAL SEPTIC SYSTEMS

Many private residences, particularly in rural areas, use individual septic systems for sewage disposal instead of using municipal sewage treatment. Household sewage is piped to the septic tank, where particles settle to the bottom (**Figure 21.18a**). Grease and oils form a scummy layer at the top, where bacteria decompose much of it. Wastewater containing suspended organic and inorganic material then flows into the drain field through a network of small, perforated pipes set in trenches of gravel or crushed stone (**Figure 21.18b**). The drain field is located just below the soil's surface, and bacteria decompose the remaining organic material in the well-aerated soil. The purified wastewater then percolates into the groundwater or evaporates from the soil.

Septic tank systems require care to operate properly. Household chemicals such as bleach and drain cleaners must be used sparingly because they could kill the bacteria that break down the organic wastes. A kitchen garbage disposal could overload the system. Every two to five years, depending on use, the sludge that collects at the bottom of the septic tank is removed and taken to a municipal sewage treatment plant for proper disposal. If a septic system is not maintained properly, it can malfunction or overflow, releasing bacteria and nutrients into groundwater or waterways.



(a) The septic tank works much like primary treatment in municipal sewage treatment. Sewage from the house is piped to the septic tank, where particles settle to the bottom.



(b) Wastewater containing suspended organic and inorganic material flows into the drain field and gradually seeps into the soil.

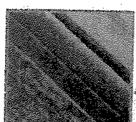
Figure 21.18 Septic tank systems. Many private homes in rural areas use a septic tank and drainage field. Both are located underground.

ALTERNATIVE WASTEWATER TREATMENT SYSTEMS

A number of innovative wastewater treatment systems are designed to mimic natural processes to manage some wastewater, particularly sewage. *Constructed wetlands* channel contaminated water through a series of sand beds and plants. The sand beds filter the water, while the plants absorb many of the nutrients. Water leaving constructed wetlands can be as clean as water subjected to many tertiary treatment systems, and the plants can be harvested for biofuels or mulch (but usually not for human consumption). Elsewhere, *composting toilets* provide conditions under which human wastes break down slowly into a useful fertilizer, while at the same time eliminating disease and unpleasant odors.

REVIEW

1. How is most drinking water purified in the United States?
2. Why is chlorine added to drinking water? What is the potential problem with adding chlorine to drinking water?
3. Distinguish among primary sewage treatment, secondary sewage treatment, tertiary sewage treatment, and septic tanks.



Laws Controlling Water Pollution

LEARNING OBJECTIVES

- Compare the goals of the Safe Drinking Water Act and the Clean Water Act.
- Define *maximum contaminant level* and *national emission limitation*, and specify the water legislation each relates to.

Many governments have passed legislation to control water pollution. Point source pollutants lend themselves to effective control more readily than nonpoint source pollutants. Governments generally control point source pollution in one of two ways—by imposing penalties on polluters (a common approach in the United States) or by taxing polluters to pay for the cleanup (common in Japan).

Although most countries have passed laws to control water pollution, monitoring and enforcement are difficult, even in highly developed countries (see Meeting the Challenge: Using Citizen Watchdogs to Monitor Water Pollution). The United States has attempted to control water pollution through legislation since the passage of the **Refuse Act** of 1899, which was intended to reduce the release of pollutants into navigable rivers. The two federal laws that have the most impact on water quality today are the Safe Drinking Water Act and the Clean Water Act.

SAFE DRINKING WATER ACT

Prior to 1974, individual states set their own standards for drinking water, which, of course, varied a great deal from state to state. In 1974, the **Safe Drinking Water Act** (SDWA) was passed, which set uniform federal standards for drinking water to guarantee safe public water supplies throughout the United States. This law required the EPA to determine the **maximum contaminant level**, which is the maximum permissible amount of any water pollutant that might adversely affect human health. The EPA oversees the states to ensure that they adhere to the maximum contaminant levels for specific water pollutants. Private wells, which supply about 10% of U.S. residents, are not covered by the SDWA, although such wells are regulated in some states.

maximum contaminant level The upper limit for the concentration of a particular water pollutant in water intended for human consumption.

MEETING THE CHALLENGE

Using Citizen Watchdogs to Monitor Water Pollution

Insufficient staff and lack of funds prevent well-intentioned government agencies from effectively monitoring and enforcing environmental laws such as the Safe Drinking Water Act. For example, the San Francisco Bay Conservation and Development Commission is California's federally designated management agency charged with patrolling 1600 km (1000 mi) of shoreline and 1500 km^2 (600 mi^2) of water to ascertain that no one is illegally polluting San Francisco Bay. In addition, it handles hundreds of cases arising from its monitoring activities. The agency is severely understaffed and cannot adequately protect the bay. San Francisco Bay, like most other aquatic ecosystems, is endangered by the combined impact of many different pollution sources. Thus, continual monitoring is necessary to ensure that many small polluters do not collectively do irreparable harm to the bay.

A growing number of private citizens have become actively involved in monitoring and enforcing environmental laws to protect waterways in their communities. Provisions in the Clean Water Act, the Safe Drinking Water Act, and other key environmental laws allow citizens to file suit when the government does not enforce the laws. Citizen action groups also pressure firms to clean up.

In San Francisco, hundreds of citizen watchdogs called Baykeepers monitor the bay from boats, airplanes, and helicopters. Law students at local universities advise the keepers on issues of litigation.

The San Francisco Baykeeper program is modeled after New York's Riverkeeper program, which was first organized in 1966 as a coalition of commercial and recreational fisherman who wanted to reclaim the Hudson River from its polluters. In 1983, using money obtained from successful lawsuits against polluters, the Riverkeeper program hired its first full-time riverkeeper. A network of community fishermen and environmentalists inform the riverkeeper of any suspicious activity on the river. The riverkeeper monitors water quality by boat, attends board meetings, educates the public, and employs litigation as a last resort. The riverkeeper position is described as part investigator, scientist, lawyer, lobbyist, and public relations agent.

More than 100 river, sound, bay, inlet, channel, and coast keeper groups have organized across the United States, from the Cook Inletkeeper in Alaska to the Emerald Coastkeeper on Florida's Gulf Coast. The umbrella organization for keeper groups is the Waterkeeper Alliance, which launched in 1992. Its philosophy is based on the idea that daily vigilance by citizens is required to protect a community's natural resources. The Waterkeeper Alliance helps new keeper programs organize, both in the United States and other countries. More than 200 keeper programs have been established on six continents, including in Bolivia, Canada, Mexico, Senegal, the Czech Republic, the United Kingdom, Iraq, India, China, Russia, and Australia.

Most water suppliers take few or no steps to prevent the contamination of the watershed or groundwater from which they draw. The vast majority of water utilities do not use modern water treatment technologies such as activated carbon granules or UV disinfection to reduce chemical contamination by pesticides, arsenic, and chlorine disinfection byproducts. Also, the average water pipe in the United States is 100 or more years old before it is replaced. Many aging pipes are cracked, which permits contaminated water to seep into them and increases the risk of waterborne diseases.

The Safe Drinking Water Act was amended in 1986 and again in 1996. The 1996 version requires municipal water suppliers to tell consumers what contaminants are present in their city's water and whether these contaminants pose a health risk. The act also requires that the EPA regularly update its regulations, which it last did in 2002.

CLEAN WATER ACT

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

national emission limitation The ıaximum permissible ıount of a water polıtant that can be disarged from a sewage tment plant, factory, ır other point source.

Overall, the Clean Water Act effectively improved the quality of water from point sources, despite the relatively low fines it imposes on polluters. It is not hard to identify point sources, which must obtain permits from the **National Pollutant Discharge Elimination System (NPDES)** to discharge untreated wastewater.

According to the EPA, nonpoint source pollution is a major cause of water pollution. However, nonpoint source pollution is much more difficult and expensive to control than point source pollution. The 1987 amendments to the Clean Water Act expanded the NPDES to include nonpoint sources, such as sediment erosion from construction sites.

To date, U.S. environmental policies have not effectively addressed many nonpoint sources of pollution, which requires regulating land use, mining, agricultural practices, and many other activities. Such regulation necessitates the interaction and cooperation of many government agencies, environmental organizations, and private citizens, which can be enormously challenging.

The United States has improved its water quality in the past several decades, thereby demonstrating that the environment recovers once pollutants are eliminated. Much remains to be done, however. The most recent data available from the EPA's National Water Quality Inventory (collected by state between 2006 and 2012) indicated that 29% of the nation's rivers, 43% of its lakes, and 38% of its estuaries are too polluted for swimming, fishing, or drinking.

LAWS THAT PROTECT GROUNDWATER

Several federal laws attempt to control groundwater pollution. The Safe Drinking Water Act contains provisions to protect underground aquifers that are important sources of drinking water. In addition, the Safe Drinking Water Act regulates underground injection of wastes in an effort to prevent groundwater contamination. The **Resource Conservation and Recovery Act** deals with the storage and disposal of hazardous wastes and helps prevent groundwater contamination (see Chapter 23). Several miscellaneous laws related to pesticides, strip mining, and cleanup of abandoned hazardous waste sites indirectly protect groundwater. The many laws that directly or indirectly affect groundwater quality were passed at different times and for different reasons. These laws provide a disjointed and, at times, inconsistent protection of groundwater. The EPA makes an effort to coordinate all these laws, but groundwater contamination still occurs.

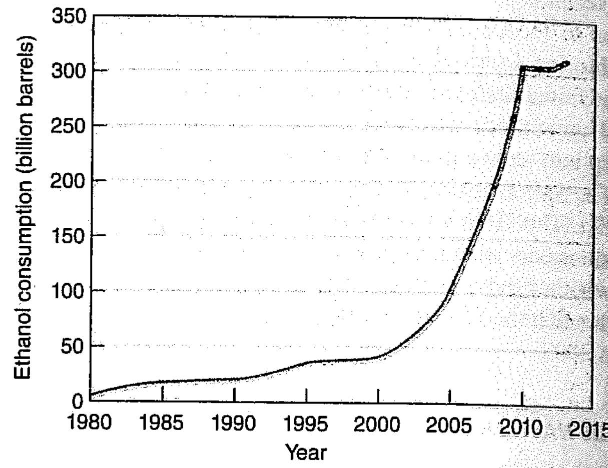
REVIEW

1. What are the main goals of the Safe Drinking Water Act? The Clean Water Act?
2. How do maximum contaminant levels and national emission limitations differ?

ENERGY AND CLIMATE CHANGE

Dead Zones

Dead zones appear to be increasing in some areas due to climate change, as warmer waters generally hold less oxygen. Unfortunately, one potential solution to climate change—more use of the biofuel ethanol (see Chapter 12)—also appears to contribute to at least one dead zone. Ethanol use in the United States has increased substantially over the past three decades (see the figure). Wastes associated with the production of ethanol from corn grown in the Midwest flow down the Mississippi River; researchers have concluded that these wastes are at least partly responsible for the large dead zone in the Gulf of Mexico. In contrast, scientists think that Hurricane Dolly in 2008 may have reduced the same dead zone by churning the water; the dead zone that year was half the size of the 2007 and 2009 dead zones. Climate scientists expect hurricanes to get stronger, which could mean more churning and thus smaller dead zones. Biofuel wastes and more intense hurricanes remind us that human activities have complex impacts on large-scale environmental systems.



Ethanol consumption in the United States, 1980–2014. Over the past three and a half decades, ethanol consumption has increased substantially in the United States. Has ethanol use increased at a linear or exponential rate? (Monthly Energy Review, Energy Information Agency, April 2014)

REVIEW OF LEARNING OBJECTIVES WITH SELECTED KEY TERMS

- **List and briefly describe eight categories of water pollutants.**

Water pollution consists of any physical or chemical change in water that adversely affects the health of humans and other organisms. **Sewage** is the release of wastewater from drains or sewers (such as from toilets, washing machines, and showers); it includes human wastes, soaps, and detergents. **Disease-causing agents**, such as bacteria, viruses, protozoa, and parasitic worms, are transmitted in sewage. **Sediment pollution**, primarily from soil erosion, increases water turbidity, thereby reducing photosynthetic productivity in the water. **Inorganic plant and algal nutrients**, such as nitrogen and phosphorus, contribute to **enrichment**, the fertilization of a body of water. Many **organic compounds**, such as pesticides, pharmaceuticals, solvents, and industrial chemicals, are quite toxic to organisms. **Inorganic chemicals** include toxins such as lead and mercury. **Radioactive substances** include the wastes from mining, refining, and using radioactive metals. **Thermal pollution** occurs when heated water, produced during many industrial processes, is released into waterways.

- **Discuss how sewage is related to eutrophication, biochemical oxygen demand (BOD), and dissolved oxygen.**

Sewage supplies nutrients that contribute to eutrophication and a high biochemical oxygen demand. **Eutrophication**, the nutrient enrichment of lakes, estuaries, or slow-moving streams, results in high photosynthetic productivity, supporting an overpopulation of algae. Eutrophication kills fishes and causes a decline in water quality as these algae die and decompose. **Biochemical oxygen demand (BOD)** is the amount of oxygen needed by microorganisms to decompose biological wastes into carbon dioxide, water, and minerals. A large amount of sewage generates a high BOD, which lowers the level of dissolved oxygen in the water.

- **Define *dead zone*.**

A **dead zone** is a section of the ocean or a sea in which oxygen has been depleted to the point that most animals and bacteria cannot survive; it is often caused by runoff of chemical fertilizers or plant and animal wastes.

- **Contrast point source pollution and nonpoint source pollution.**

Point source pollution is water pollution that can be traced to a specific spot. **Nonpoint source pollution** consists of pollutants that enter bodies of water over large areas rather than being concentrated at a single point of entry.

- **Provide examples of agricultural, municipal, and industrial water pollution.**

Agriculture is the biggest contributor to surface-water pollution, including fertilizers, pesticides, plant and animal wastes, and eroded soil. Municipal waste can include surface runoff containing a variety of chemical and organic contaminants, as well as sewage. Industrial wastes vary, based on the type of industry, and can include a variety of chemicals, organic materials, and radioactive materials.

- **Describe how most drinking water is purified in the United States, and discuss the chlorine dilemma.**

Most municipal water supplies are treated before being used so that the water is safe to drink. Water is usually treated with aluminum sulfate to cause suspended particles to clump and settle out, filtered through sand, and disinfected by adding chlorine. There is concern that chlorine in drinking water creates health hazards, so alternatives, including UV radiation and ozonation, are being developed.

- **Distinguish among primary, secondary, and tertiary treatments for wastewater.**

Primary treatment is treating wastewater by removing suspended and floating particles by mechanical processes. **Secondary treatment** is treating wastewater biologically to decompose suspended organic material; secondary treatment reduces the water's biochemical oxygen demand. Primary and secondary treatment generate **primary** and **secondary sludge**, which consist of the solids remaining after sewage treatment has been completed. Some sludge can be safely used as fertilizer, while other sludge must be disposed of in landfills. **Tertiary treatment** is advanced wastewater treatment methods that are sometimes employed after primary and secondary treatments.

- **Compare the goals of the Safe Drinking Water Act and the Clean Water Act.**

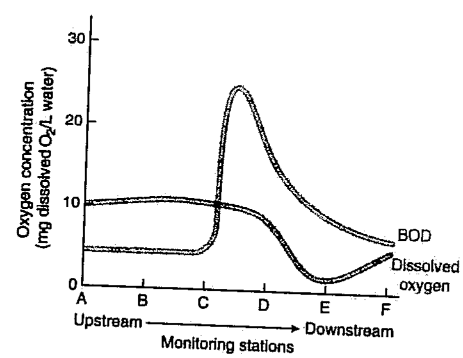
The **Safe Drinking Water Act** sets uniform federal standards for drinking water to guarantee safe public water supplies throughout the United States. The **Clean Water Act** has two basic goals: to eliminate the discharge of pollutants into U.S. waterways and to attain water quality levels that make these waterways safe to fish and swim in.

- **Define *maximum contaminant level* and *national emission limitation*, and specify the water legislation each relates to.**

The **maximum contaminant level** is the upper limit for the concentration of a particular pollutant in water intended for human consumption. The EPA determines maximum contaminant levels for water pollutants that might affect human health as mandated by the Safe Drinking Water Act. The **national emission limitation** is the maximum permissible amount of a water pollutant that can be discharged from a sewage treatment plant, factory, or other point source. The Clean Water Act instructs the EPA to set up and monitor national emission limitations.

Critical Thinking and Review Questions

1. What is sustainable water use?
2. What is water pollution? Why is wastewater treatment an important part of sustainable water use?
3. Describe the relationship between biochemical oxygen demand and dissolved oxygen available for fish.
4. Distinguish between oligotrophic and eutrophic lakes.
5. How do midwestern farmers threaten the livelihood of fishermen in the Gulf of Mexico?
6. How does thermal pollution typically affect organisms? What causes this affect?
7. Contrast organic compounds and inorganic chemicals as types of water pollution.
8. Tell whether each of the following represents point source pollution or nonpoint source pollution: fertilizer runoff from farms, thermal pollution from a power plant, urban runoff, sewage from a ship, erosion sediments from deforestation.
9. What is the source of arsenic contamination of groundwater in Bangladesh?
10. Why is chlorine added to drinking water? Why does the Environmental Protection Agency recommend that public water treatment facilities find alternatives to chlorine?
11. What is removed during each of the three stages of wastewater treatment: primary, secondary, and tertiary? During which stage would you expect items to be recovered that were accidentally flushed, such as jewelry or coins?
12. What is sludge? How is it disposed of?
13. Taking a systems perspective, suggest how to prevent BOD from animal sewage and milk processing on a dairy farm from reaching an adjacent river.
14. In what ways might climate change make dead zones in the ocean worse? Better?
15. Which water pollution law regulates industrial waste discharge to a river?
16. The following graph reflects the monitoring of dissolved oxygen concentrations at six stations along a river. The stations are located 20 m apart, with A the farthest upstream and F the farthest downstream. Where along the river did a sewage spill occur? At which station would you most likely discover dead fish?



Food for Thought

Agriculture can be affected by water pollution but can also contribute to it. Which types of water pollution are most likely to affect food production, particularly in your region? Which types of water pollution are at least in some part generated by agriculture? How might sustainable food production reduce the risk of polluting water sources?