CHAPTER 14
Water Pollution
The Chesapeake Bay Watershed. The Chesapeake Bay receives water from a large area geographic area that carries sediments, nutrients, and chemicals from a variety of urban, suburban, and agricultural areas.

The Chesapeake Bay
The Chesapeake Bay is the largest estuary in the United States and it faces some of the biggest environmental challenges. Located between Virginia, Maryland, and Delaware, the Chesapeake Bay receives fresh water from numerous rivers and streams that mixes with the salt water of the ocean to produce an extremely productive estuary. Many of the rivers and streams that dump into the bay travel long distances and drain water from a large watershed of urban, suburban, and agricultural areas. Indeed, the watershed that supplies the bay extends from northern Virginia all the way up into central New York State. One of the consequences of receiving water from such a large watershed is that the water coming into the bay contains an abundance of nutrients, sediments, and chemicals. Anthropogenic chemicals appeared to be responsible for the discovery that 82 percent of male smallmouth bass developed into hermaphrodites with male sex organs that grow female eggs.

Among the major nutrients that enter the bay are 272 million kg (600 million pounds) of nitrogen and 14 million kg (30 million pounds) of phosphorus. The nitrogen and phosphorus come from three major sources. The first source is water discharged from sewage treatment facilities that carries high amounts of nutrients from human waste. The second source is animal waste produced by concentrated animal feeding operations generating large amounts of manure that can make its way into nearby streams and rivers. The third source is fertilizer that is spread on both agricultural fields and suburban lawns. Much of this fertilizer leaches out of the soil and into local streams, eventually making its way to the Chesapeake Bay. When these nutrients reach the bay, the algae in the bay experience an explosive population growth that is known as an algal bloom.

Increased sediments are also an issue in the Chesapeake Bay. Sediments are soils washed away from fields and forests as well as soils washed away from the banks of streams and the ocean shoreline. The current estimate is that 8.2 billion kg (18.7 billion pounds) of sediments come into the bay each year. The tiniest soil particles stay suspended in the water, make the water cloudy, and prevent sunlight from reaching the grasses that have been historically abundant in the bay. These grasses are important because they serve as a habitat for fish and blue crabs (*Callinectes sapidus*).
The Chesapeake Bay watershed extends from New York down to Virginia. The Chesapeake Bay also receives inputs of anthropogenic chemicals. Many of these are pesticides that are sprayed throughout the water-shed for growing crops and controlling pests. They can arrive in the bay by direct application over water, by running off the surface of the land when it rains, or by being carried by the wind immediately after application. The bay also contains pharmaceutical drugs that pass through the human body and enter sewage treatment plants, eventually discharging into the streams and rivers that feed the bay. In 2009, the U.S. Fish and Wildlife Service announced that anthropogenic chemicals appeared to be responsible for the discovery that 23 percent of male largemouth bass and 82 percent of male smallmouth bass developed into hermaphrodites with male sex organs that grow female eggs. This impact is not only a concern for fish, but also a concern for humans who share many similarities in their endocrine systems. The enormous size of the Chesapeake Bay watershed means that cleaning it up will require a monumental effort. In 2000 the surrounding states formed a partnership along with multiple federal departments to develop the Chesapeake Bay Action
Plan. This plan outlines a series of goals to reduce the impacts of nutrients, sediments, and chemicals coming into the bay. In 2010 the governors of the surrounding states, along with many local leaders, announced that many of the Action Plan’s goals were being met, including a reduction in nitrogen, an increase in water clarity, and an increase in the number of blue crabs. In fact, the improved water quality combined with earlier reductions in the number of blue crabs that could be harvested allowed the blue crab population to increase 60 percent from 2009 to 2010. This represents the largest crab population in the bay in 13 years. The story of Chesapeake Bay serves as an excellent example of the wide variety of pollutants that can impact aquatic ecosystems and of effective and substantial efforts that can only be made when all parties work together toward a common goal.


**Key Ideas**

Water is a key resource for life on Earth. All organisms, including humans, require water to live, but growing human populations combined with industrialization have led to the contamination of water supplies. Water contamination has a wide variety of causes. The consequences for people and ecosystems can be severe. After reading this chapter you should be able to

- distinguish between point and nonpoint sources of pollution.
- identify the ways in which human wastewater can cause water pollution.
- evaluate the different technologies that humans have developed for treating wastewater.
- identify the major types of heavy metals and other substances that pose serious hazards to humans and the environment.
- discuss the impacts of oil spills and how such spills can be remediated.
- identify contaminants that are nonchemical pollutants.
- explain the connections among industrialization, affluence, and water-pollution legislation.

14.1 Pollution can come from specific sites or broad areas

**Water pollution** is generally defined as the contamination of streams, rivers, lakes, oceans, or groundwater with substances produced through human activities and that negatively affect organisms. As we will see, this broad
definition encompasses a wide range of substances that vary in their sources, prevalence, and impact. Although this chapter focuses on the contaminants that exist in water and their effects on aquatic organisms and humans, it is important to remember that there are many ecological connections between aquatic and terrestrial ecosystems. As a result, water pollution has the potential to impact both aquatic and terrestrial organisms.

Regardless of the specific contaminant, pollution can come from either point sources or nonpoint sources (FIGURE 14.1). Point sources are distinct locations such as a particular factory that pumps its waste into a nearby stream or a sewage treatment plant that discharges its wastewater from a pipe into the ocean. Nonpoint sources are more diffuse areas such as an entire farming region, a suburban community with many lawns and septic systems, or storm runoff from parking lots. It is important to differentiate between the two types of pollution sources because the distinction can help in controlling pollutant inputs to waterways. For example, if a municipality determines that the bulk of water pollution is coming from one or two point sources, it can target those specific sources to reduce their pollution output. It can be more difficult to control pollution from nonpoint sources. As we discussed in Chapter 10, pollution represents an externality because the cost to the environment is not reflected in the cost of making the products that generate pollution.

Figure 14.1 Two types of pollution sources. Pollution can enter water bodies either as (a) point sources, as in sewage pipes, or as (b) nonpoint sources, as in rainwater that runs off hundreds of square kilometers of agricultural fields and into streams.
The broad range of pollutants that can be found in water includes human and animal waste, inorganic substances, organic compounds, synthetic organic compounds, and nonchemical pollutants. For each of these pollutant groups, we need to consider where the pollutant comes from, its negative effects on humans and the environment, and what can be done to reduce these effects.

**CHECKPOINT**

- What is water pollution? Why is it important to learn about water pollution?
- What are point and nonpoint sources? How do they differ?
- What are the most common types of pollutants in the water?

1. **14.2 Human wastewater is a common pollutant**

**Figure 14.2  Washing clothes in the Tuo River of China.** Using water for bathing, washing, and disposing of sewage without contaminating sources of drinking water is a long-standing challenge.

Human wastewater is the water produced by human activities including human sewage from toilets and gray water from bathing and washing clothes and dishes. For centuries, one of the biggest challenges has been to keep human wastewater from
contaminating human drinking water. This can be difficult because throughout the world
many people routinely use the same water source for drinking, bathing, washing, and
disposing of sewage(FIGURE 14.2). Environmental scientists are concerned about
human wastewater as a pollutant for three major reasons. First, wastewater dumped
into bodies of water naturally undergoes decomposition by bacteria, which creates a
large demand for oxygen in the water. Second, the nutrients that are released from
wastewater decomposition can make the water more fertile. Third, wastewater can carry
a wide variety of disease-causing organisms.

14.2. Oxygen demand

1

Oxygen-demanding waste is organic matter that enters a body of water and feeds
the growth of the microbes that are decomposers. Because these microbes require
oxygen to decompose the waste, the more waste that enters the water, the more the
microbes grow and the more oxygen they demand. Oxygen-demanding waste is
measured in terms of biochemical oxygen demand, or BOD—the amount of oxygen
a quantity of water uses over a period of time at a specific temperature. Lower BOD
values indicate that a water body is less polluted by wastewater, whereas higher BOD
values indicate that a water body is more polluted by waste-water. If we were to test
the BOD of natural waters over a five-day period in a liter of water, for example, we
might find a BOD of 5 to 20 mg of oxygen coming from the decomposition of
leaves, twigs, and perhaps a few dead organisms. In contrast, domestic wastewater
might have a BOD of 200 mg of oxygen.

When bodies of water have a high oxygen demand due to microbial decomposition, the
amount of oxygen remaining for other organisms can be very low. Low oxygen
concentrations are lethal to many organisms including fish. Low oxygen can also be
lethal to organisms that cannot move, such as many plants and shellfish. In some
areas, there is so little oxygen, and therefore so little life, that we call such areas dead
zones. Such dead zones can be self-perpetuating, with the dying organisms
subsequently decomposing and causing continued oxygen demand by microbes.

14.2. Nutrient release

2

The oxygen required to decompose large amounts of wastewater is clearly an important
factor in water pollution. We also have to think about the products of
decomposition, which include nitrogen and phosphorus. Additional sources of these
nutrients include soaps and detergents. As you may recall from Chapter 3, nitrogen and
phosphorus are generally the two most important elements for limiting the abundance
of producers in aquatic ecosystems. The decomposition of waste-water—because it adds these elements—can provide an abundance of fertility to a water body, a phenomenon known as eutrophication. As noted in the chapter opener, the Chesapeake Bay experiences this problem of nutrients from wastewater decomposition as well as from nutrients that are leached from agricultural lands during periods of precipitation. When a body of water experiences an increase in fertility due to anthropogenic inputs of nutrients, it is called cultural eutrophication.

Eutrophication initially causes a rapid growth of algae, known as an algal bloom. As we discussed in Chapter 3, this enormous amount of algae eventually dies, microbes rapidly begin digesting the dead algae, and the increase in microbes consumes most of the oxygen in the water (see FIGURE 3.14 on page 73). In short, the release of nutrients from wastewater initiates a chain of events that eventually leads to a lack of oxygen and the creation of dead zones once again. One of the most impressive dead zones in the world occurs where the Mississippi River dumps into the Gulf of Mexico. The Mississippi River receives water from 41 percent of the land of the continental United States. Each summer there is an influx of wastewater and fertilizer that causes large algal blooms followed by substantial decreases in oxygenated water and massive die-offs of fish (FIGURE 14.3). In 2006, the United Nations estimated that there were nearly 200 dead zones caused by pollution around the world.

14.2. Disease-causing organisms

Figure 14.3 Dead zone. When raw sewage is dumped directly into bodies of water, subsequent decomposition by microbes can consume nearly all of the oxygen in the water and cause a dead zone to develop. Shown here are (a) oxygen concentrations in Gulf Coast waters and (b) a massive fish die-off as a result of low oxygen conditions in Lake Trafford, Florida.
Human wastewater can carry a variety of illness-causing viruses, bacteria, and parasites that we collectively call pathogens. Pathogens in wastewater are responsible for a number of diseases that can be contracted by humans or other organisms that come in contact with or ingest the water. These pathogens cause cholera, typhoid fever, various types of stomach flu, and diarrhea. Worldwide, the major waterborne diseases are cholera and hepatitis. Cholera, which claims thousands of lives annually in developing countries (FIGURE 14.4), is not common in the United States. However, hepatitis A is appearing more frequently, usually originating in restaurants that lack adequate sanitation practices. The bacterium Cryptosporidium has caused a number of outbreaks of gastrointestinal illness in this country. Large-scale disease outbreaks from municipal water systems are relatively rare in the United States, but they do occasionally occur. They are relatively common in many parts of the developing world.

![Children playing in raw sewage](image)

**Figure 14.4 Cholera is prevalent in raw sewage.** Children who play in water contaminated by raw sewage, such as this girl in Cambodia, face a high risk of contracting the cholera pathogen.

The World Health Organization estimates that 1.1 billion people, nearly one-sixth of the world’s population, do not have access to sufficient supplies of safe drinking water. In addition, half of the 3.1 million annual deaths from diarrheal diseases and malaria could be prevented with safe drinking water, proper sanitation, and proper hygiene. Approximately 42 percent of the world’s population lacks access to proper sanitation and over half of these people live in China and India. In sub-Saharan Africa, only 36 percent of the people have access to improved sanitation.
Given the risk that so many pathogens pose, we need to be able to easily test whether pathogens are in our drinking water. It is not feasible to test for all of the many different pathogens that can exist in drinking water. Instead, scientists have settled on using an indicator species, an organism that indicates whether or not disease-causing pathogens are likely to be present. The best indicators for potentially harmful water are fecal coliform bacteria, a group of generally harmless microorganisms that live in the intestines of human beings and other animals. One of the most common species of fecal coliform bacteria is Escherichia coli, abbreviated E. coli. Most strains of E. coli live naturally in humans and are not harmful, although there are strains that can be deadly to people who are very young, very old, or possess weak immune systems. Given that E. coli is commonly found in human intestines, detecting E. coli in a body of water indicates that human waste has entered the water. This does not necessarily mean that the water is harmful to drink, but the presence of E. coli does indicate that there is an increased risk of other wastewater pathogens being in the water.

Public water supplies, such as drinking water sources and swimming pools, are routinely tested. Homeowners with a single-family well might test their water less frequently or not at all. Public health authorities recommend declaring water unsuitable for human consumption if any bacteria are present. For safe swimming and fishing, the acceptable level of E. coli is higher; for example, swimming at a public beach or in a river is considered safe as long as the fecal coliform bacteria levels are less than 500 to 10,000 colonies per 100 mL of water. A pool, beach, or campground with contaminated water likely would be posted with a sign such as “The Department of Health has closed this water supply because of the presence of fecal coliform bacteria.”

CHECKPOINT

- How does high BOD influence water quality?
- What is a “dead zone” How do nitrogen and phosphorus contribute to dead zones?
- What pathogens are common in poorly treated wastewater? Where are they the biggest threat?

14.3 We have technologies to treat wastewater from humans and livestock

Given the importance of proper sanitation, we need ways of treating human wastewater to reduce the risk of waterborne pathogens. Humans have devised a number of ways to handle wastewater. The various solutions all have the same basic approach—bacteria break down the organic matter into carbon dioxide and inorganic compounds such as...
nitrate and phosphate. The two most widespread systems for treating human sewage are septic systems and sewage treatment plants. The most prevalent system to treat waste from large livestock operations is a manure lagoon.

### 14.3. Septic systems

[Notes/Highlighting]

**Figure 14.5 A septic system.** Wastewater from a house is held in a large septic tank where solids settle to the bottom and bacteria break down the sewage. The liquid moves through a pipe at the top of the tank and passes through perforated pipes that distribute the water through a leach field.

In rural areas of low population density, houses often have their own sewage treatment system called a septic system. As shown in **FIGURE 14.5**, this is a relatively small and simple system with two components: a septic tank and a leach field.

The septic tank is a large container that receives wastewater from the house. Having a capacity of 1,900 to 4,700 liters (500–1,250 gallons), the septic tank is buried underground adjacent to the house. Wastewater from the house flows into the tank at one end and leaves the tank at the other. After the tank has been operating for some time, three layers develop. Anything that will float rises to the top of the tank and forms a scum layer. Anything heavier than water sinks to form the sludge layer. In the middle is a fairly clear water layer called septage. The septage contains large quantities of bacteria and also may contain pathogenic organisms and inorganic nutrients such as nitrogen and phosphorus.

The septage moves out of the septic tank by gravity into several underground pipes laid out across a lawn below the surface. The combination of pipes and lawn makes up the leach field. The pipes contain small perforations so the water can slowly seep out and spread across the leach field. The septage that seeps out of the pipes is slowly absorbed and filtered by the surrounding soil. The harmful pathogens can settle and
become part of the sludge, be outcompeted by other microorganisms in the septic tank and therefore diminish in abundance, or be degraded by soil microorganisms in the leach field. The organic matter is broken down into carbon dioxide and inorganic nutrients. Eventually, the water and nutrients are taken up by plants or enter a nearby stream or aquifer.

There are significant environmental advantages to septic systems. Because most septic systems rely on gravity—water from the house flows downhill to the septic tank, and water from the septic tank flows downhill to the leach field—no electricity is needed to run a septic system. However, sludge from the septic tank must be pumped out periodically (every five to ten years) and taken to a sewage treatment plant.

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14.3. Sewage treatment plants

Household septic systems work well for rural areas in which each house has sufficient land for a leach field. This is not a feasible solution for more developed areas with greater population densities and little open land. In developed countries, municipalities use centralized sewage treatment plants that receive the wastewater from hundreds or thousands of households via a network of underground pipes. In a traditional sewage treatment plant, wastewater is handled using a primary treatment followed by a secondary treatment. **FIGURE 14.6** gives an overview of the process.
The goal of the primary treatment in a sewage plant is for the solid waste material to settle out of the wastewater. This solid material is then dried and classified as sludge. To reduce the volume of material and help remove many of the pathogens, sludge is typically exposed to bacteria that can digest it. Most of the water is then removed from the sludge to reduce its volume and weight prior to transporting it away from the sewage treatment plant. This final form of sludge can be placed into a landfill, burned, or converted into fertilizer pellets for agricultural fields, lawns, and gardens.

After the sludge has settled out of the wastewater and been treated, the remaining wastewater undergoes a secondary treatment. The goal of the secondary treatment is to use bacteria to break down 85 to 90 percent of the organic matter in the water and convert it to carbon dioxide and inorganic nutrients such as nitrogen and phosphorus. The secondary treatment typically includes aeration of the water to promote the growth of aerobic bacteria, which emit less offensive odors than anaerobic
bacteria. This treated water sits for several days to allow particles to settle out. These settled particles are added to the sludge from a primary treatment. The remaining water is disinfected, using chlorine, ozone, or ultraviolet light to kill any remaining pathogens. The treated water is then released into a nearby river or lake, where it is once again part of the global water cycle.

Sewage treatment plants are very effective at breaking down the organic matter into carbon dioxide and inorganic nutrients. Unfortunately, these inorganic nutrients can still have undesirable effects on the waterways into which they are released. Although nitrogen and phosphorus are important nutrients for increasing primary productivity, when high concentrations of these nutrients are released into bodies of water from sewage treatment plants, they fertilize the water, which can lead to large increases in the abundance of algae and aquatic plants. In response to this problem, large sewage treatment plants are now developing tertiary treatments that remove nitrogen and phosphorus from the wastewater. The ultimate goal is to release wastewater similar in quality to the waterway receiving it.

**LEGAL SEWAGE DUMPING** Sewage treatment plants are critical to human health because they remove a great deal of harmful organic matter and associated pathogens that cause human illness. It might surprise you to know that even in the most developed countries, raw sewage can sometimes be directly pumped into rivers and lakes. Sewage treatment plants are typically built to handle wastewater from local households and industries. However, many older sewage treatment plants also receive water from storm-water drainage systems. During periods of heavy rain, the combined volume of storm water and wastewater overwhelms the capacity of the plants. When this happens, the treatment plants are allowed to bypass their normal treatment protocol and pump vast amounts of water directly into an adjacent body of water.

How big a problem is this? According to the U.S. Environmental Protection Agency, overflows of raw sewage occur approximately 40,000 times per year in the United States. In Indianapolis, for example, more than 3.8 billion liters (1 billion gallons) of raw sewage are dumped into surrounding water bodies each year during periods of high rain. Around the country, such incidents result in the contamination of drinking water, beaches, fish, and shellfish, and can lead to human illness. Between 1.8 million and 3.5 million illnesses are associated with swimming in sewage-contaminated water in the United States each year, and 500,000 illnesses are linked to drinking sewage-contaminated water. Illnesses caused by eating contaminated shellfish are estimated to cost $2.5 million to $22 million annually. The solution to this problem is straightforward but quite expensive. Municipalities facing sewage overflow will need to modernize their sewage treatment systems at considerable expense to prevent the influx of storm water from overwhelming their capacity to treat human wastewater.
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FIGURE 14.6 A sewage treatment plant. In large municipalities, great volumes of wastewater are handled by separating the sludge from the water and then using bacteria to break down both components.

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14.3. Animal feed lots and manure lagoons

Although the impact of human waste on the environment and human health is generally well appreciated, less well known is the issue of animal waste. The problem of animal waste is actually quite similar to the problem of human waste, since it is only a major problem when large numbers of animals live in one place. On a small scale, animal manure can contaminate waters when farm animals are allowed access to streams for food and water. Inevitably, they will defecate in the stream. As you may recall from Chapter 11, large-scale manure issues arise with concentrated animal feeding operations that raise thousands of cattle, hogs, and poultry. The manure from these operations not only contains digested animal food, but also can contain a variety of hormones and antibiotics given to animals to improve their growth and health when living under crowded conditions.

Raising thousands of animals in a single location poses the interesting challenge of how to handle the tremendous amount of manure that is produced. Rather than dumping the manure into bodies of water, many of these farms have built manure lagoons (FIGURE 14.7). Manure lagoons are large, human-made ponds lined with rubber to prevent the manure from leaking into the groundwater. After the manure has been broken down by bacteria—the same process that occurs in sewage treatment plants—the manure can be spread onto farm fields to serve as a fertilizer. A major risk of manure lagoons is the possibility of developing a leak in the liner. A leak would allow the waste to seep into the underlying groundwater, contaminating it. A possible overflow into adjacent water bodies is another danger. Like human wastewater, overflow of animal waste into rivers can lead to disease outbreaks in humans and wildlife. Finally, the application of manure as fertilizer can create runoff that moves into nearby water bodies. Do the Math “Building a Manure Lagoon” shows you how to calculate the appropriate size for a manure lagoon.
Figure 14.7 Feedlot and manure lagoon. Large-scale agricultural operations, such as this one in Georgia, produce great amounts of waste that can be held in lagoons until pumped out and removed.

DO THE MATH

Building a Manure Lagoon

Concentrated animal feeding operations typically use manure lagoons to hold the manure produced by the cattle that are being held. If an individual animal produces 53 L of manure each day and the average concentrated animal feeding operation holds 900 cattle on any given day, how much manure is produced each day?

\[
\text{Daily manure production} = 53 \text{ L/animal} \times 900 \text{ animals} = 47,700 \text{ L/day}
\]

Your Turn

1. If a manure lagoon needs to hold 30 days’ worth of manure production, what is the minimum capacity of the lagoon?

2. After the manure has broken down, you need to spread the manure onto farm fields. A modern manure spreader can hold 40,000 L of liquid manure. How many trips will it take for the manure spreader to remove the 30 days’ worth of manure that is held in the manure lagoon?

CHECKPOINT

- What problems are associated with sewage?
- Describe and contrast the two most common ways to treat wastewater.
- Describe the advantages and disadvantages of both septic systems and sewage plants.
- What is the role of bacteria in the treatment of human and animal waste?
Heavy metals and other substances can pose serious threats to human health and the environment.

Some compounds such as nitrogen and phosphorus cause environmental problems by overfertilizing the water. Other inorganic compounds, including heavy metals (lead, arsenic, and mercury), acids, and synthetic compounds (pesticides, pharmaceuticals, and hormones), can directly harm humans and other organisms.

14.4. Lead

Lead is a heavy metal that poses a serious health threat. Lead is rarely found in natural sources of drinking water. Instead, it contaminates water when the water passes through the pipes of older homes that contain lead-lined pipes, brass fittings containing lead, and lead-containing materials such as solder used to fasten pipes together. Fetuses and infants are the most sensitive to lead, and exposure can damage the brain, nervous system, and kidneys. A series of federal guidelines for building construction implemented during the past three decades now requires the installation of lead-free pipes, pipe fittings, and pipe solders. These changes and the increased use of water filtration systems in many homes are gradually reducing the problem of lead in drinking water.

14.4. Arsenic

Arsenic is a compound that occurs naturally in Earth’s crust and can dissolve into groundwater. As a result, naturally occurring arsenic in rocks can lead to high concentrations of arsenic in groundwater and drinking water. Human activity also contributes to higher arsenic concentrations in groundwater. For example, mining breaks up rocks deep underground, and industrial uses of arsenic for items such as wood preservatives can add to the amount of arsenic found in drinking water. Fortunately, arsenic can be removed from water via fine membrane filtration, distillation, and reverse osmosis (see FIGURE 9.14 on page 245). FIGURE 14.8 indicates where high concentrations of arsenic have been found in well water throughout the United States. As you can see, concentrations are highest in the Midwest and West. Arsenic in drinking water is associated with cancers of the
skin, lungs, kidneys, and bladder. These illnesses can take 10 years or more after exposure to develop. Even very low concentrations of arsenic, such as those found in many wells around the world and measured in micrograms (μg, or $10^{-6}$ grams) per liter, can cause severe health problems. In fact, though cancers can develop with less than 50 μg/L of arsenic in drinking water, 50 μg/L was set as the upper “safe” limit for U.S. drinking water from 1942 to 1999. In 1999, the EPA lowered the upper limit to 10 μg/L, a compromise reached after much debate between environmental groups pushing for 5 μg/L and water, mining, and wood preservative industries arguing that even the 10 μg/L limit would be too expensive to implement. In 2001, the EPA delayed the implementation of the 10 μg/L standard until more data could be evaluated. Later that year, the U.S. National Academy of Sciences recommended a standard of 5 μg/L and the EPA decided to implement a standard of 10 μg/L. As a result, after substantial investment required to improve many water treatment facilities, people in the United States will now have lower amounts of cancer-causing arsenic in their drinking water.

![Arsenic in U.S. well water](image)

**Figure 14.8** Arsenic in U.S. well water. The highest concentrations of arsenic are generally found in the upper Midwest and the West.
The problem of arsenic in drinking water is a worldwide issue. During the 1980s and 1990s, for example, water engineers in regions of Bangladesh and eastern India drilled millions of very deep wells in an attempt to find sources of groundwater that were not contaminated by local pollution. While this had the desired effect of obtaining less-polluted water, officials were not aware that this deeper groundwater was contaminated by naturally occurring arsenic. Currently, 140 million people in this region drink arsenic-contaminated water and thousands of individuals have been diagnosed with arsenic poisoning. Current efforts to solve this problem include plans to collect uncontaminated rainwater as a source of drinking water and research to develop inexpensive filters that can remove arsenic from the well water.


Mercury is another naturally occurring heavy metal found in increased concentrations in water as a result of human activities. **FIGURE 14.9** shows mercury releases from different regions of the world as the result of activities such as burning coal (see **Chapter 12**). Among regions of the world, 7 percent of human-produced mercury comes from North America and more than half comes from Asia, including 28 percent from China.

Approximately two-thirds of all mercury produced by human activities comes from the burning of fossil fuels, especially coal. Other important sources of mercury include the incineration of garbage, hazardous waste, medical supplies, and dental supplies. One of the less well-known sources of mercury comes from the raw materials that go into the manufacturing of cement for construction. The limestone used to make cement can contain mercury that is released during the heating process. Moreover, the source of heat is often coal that also releases mercury when it is burned. Petroleum exploration is
a source of both mercury and lead pollution. Each petroleum well produces roughly 180,000 gallons of contaminated wastewater and mud over its lifetime. This water is usually dumped at the drilling site and, depending on the soils and topography, can either run into nearby waterways or infiltrate the soil and contaminate the underlying groundwater.

The mercury emitted by these activities eventually finds its way into water. Inorganic mercury (Hg) is not particularly harmful, but its release into the environment can be hazardous because of a chemical transformation it undergoes. In wetlands and lakes, bacteria convert inorganic mercury to methylmercury, which is highly toxic to humans. Methylmercury damages the central nervous system, particularly in young children and in the developing embryos of pregnant women. The result is impairment of coordination and the senses of touch, taste, and sight.

Human exposure to methylmercury occurs mostly through eating fish and shellfish. Methylmercury can move up the food chain in aquatic ecosystems, which results in the top consumers containing the highest concentrations of mercury in their bodies. Given that oceans are contaminated with mercury and that tuna are top predators, it is not surprising that these fish contain high concentrations of mercury. In 2008, a reporter for the New York Times purchased tuna sushi from 20 locations in New York City and, after analysis by a private laboratory, found that, at most restaurants, a diet of six pieces of sushi per week would exceed the EPA standard for human consumption of mercury.

What can be done about mercury pollution? In 2009 the United States announced a new effort to work with other governments around the world to reduce global mercury production. In one of the first steps toward this goal, the EPA has proposed that cement manufacturing plants reduce mercury emissions by 81 percent. New EPA rules on reducing mercury emissions from other major sources, including coal-burning power plants, are expected in the near future.

About 40 years ago, people throughout the northeastern United States, northern Europe, China, and Russia began to notice that the forests, lakes, and streams were becoming more and more acidic. As a consequence, some trees were killed and some bodies of water became too acidic to sustain fish. After much debate, it became clear that the source of the lower pH of the water was the presence of very tall smokestacks of industrial plants that were burning coal and releasing sulfur dioxide and nitrogen dioxide into the air. These tall smoke-stacks kept the emissions away from local populations, but sent the chemicals into the atmosphere where they were converted to...
sulfuric acid and nitric acid. These acids returned to Earth hundreds of kilometers away as **acid deposition**. Wet-acid deposition occurs in the form of rain and snow (also known as acid precipitation or acid rain, described in Chapter 8), whereas dry-acid deposition occurs as gases and particles that attach to the surfaces of plants, soil, and water. Acid deposition reduced the pH of water bodies from 5.5 or 6 to below 5, which can be lethal to many aquatic organisms, leaving these water bodies devoid of many species. To combat the problem of acids being released into the atmosphere, many coal-burning facilities have installed coal scrubbers. Coal scrubbers pass the hot gases through a limestone mixture. The limestone reacts with the acidic gases and removes them from the hot gases that subsequently leave the smoke-stack. We will look at the issues raised by acid deposition in greater detail in Chapter 15 on air pollution.

Low pH in water bodies also occurs when very acidic water comes from belowground. This problem begins with the development of underground mines that, once abandoned, flood with groundwater. The combination of water and air allows a type of rock, named pyrite, to break down and produce iron and hydrogen ions. This chemical reaction produces acidic water with a low pH. Water in the mine containing these ions can find its way up to the surface in the form of springs that feed into streams. As we discussed in Chapter 8, a similar effect occurs during mountaintop mining operations in which the tops of mountains are removed and the soil dumped into stream valleys. In either case, low-pH water can also cause many other harmful metal ions to become soluble, including zinc, copper, aluminum, and manganese. The streams that are fed by springs from these mines are infiltrated with water that can have a pH close to zero. Although some water bodies such as bogs are naturally acidic and contain species that are adapted to acidic conditions, the combination of very low pH and toxic metals can produce environments that are too harsh for most organisms to survive. Because much of the dissolved iron precipitates out of solution as the low-pH water of the mine mixes with the high-pH water of the stream, these streams often have a striking red or yellow color (FIGURE 14.10).
Acid mine drainage. The low pH of water emerging from abandoned mines mixes with stream water to lower the pH of streams, causing iron to precipitate out of solution and form a rusty red oxidized iron. This problem occurs around the world, including this stream in Colline Metallifere, Italy.

A number of strategies are being examined to counteract the acidity of these streams, including passing stream water through limestone treatment facilities that raise the pH of the water and remove toxic metals to levels tolerable to stream organisms. Unfortunately, many mining companies responsible for making streams uninhabitable for fish and other organisms are no longer in business. As a result, they are often not held accountable for the environmental damage they caused, which presents a major challenge for dealing with the problem of acidic water from mines and the toxic metals that are produced.

14.4.5 Synthetic organic compounds

Synthetic, or human-made, compounds can enter the water supply either from industrial point sources where they are manufactured or from nonpoint sources when they are applied over very large areas. These organic (carbon-containing) compounds include pesticides, pharmaceuticals, and industrial cleaners. Synthetic organic compounds have a variety of effects on organisms. They can be toxic, cause genetic
defects, and, in the case of compounds that resemble animal hormones, interfere with growth and sexual development (see Chapter 17).

**Figure 14.11 Applying pesticides.** Pesticides provide benefits to humans, but they also can have unexpected effects on humans and other nonpest organisms that are not fully understood and have not been adequately investigated. These airplanes are spraying insecticides over a lake to help control mosquito populations.

**PESTICIDES AND INERT INGREDIENTS** Pesticides serve an important role in helping to control pest organisms that pose a threat to crop production and human health (FIGURE 14.11). Although natural pesticides such as arsenic have been used for centuries, the first generation of synthetic pesticides was developed during World War II. As we discussed in Chapter 11, these chemicals proved to be very effective in killing a variety of undesired plants (herbicides), fungi (fungicides), and insects (insecticides). In the decades that have followed, however, environmental scientists have identified a number of concerns about the unintended effects of pesticides.

The first concern is that most pesticides do not target particular species of organisms, but generally kill a wide variety of related organisms. For example, an insecticide that is sprayed to kill mosquitoes is typically lethal to many other species of invertebrates, including insects that might be desirable as predators of the pest. Some pesticides are lethal to unrelated species. It has recently been discovered that the insecticide endosulfan, a chemical designed to kill insects, is highly lethal to amphibians even at very low concentrations. Even a pesticide that is not directly lethal to a species can indirectly affect organisms by altering the species composition of the community.

The second concern is that although synthetic pesticides are generally designed specifically to target particular aspects of a pest species’ physiology, they can also alter other physiological functions. Conceptually, the unintended side effects of pesticides are similar to the unintended side effects of pharmaceutical chemicals. Designed to target one physiological function, they often have other significant side effects. For
example, most insecticides target the nervous system of insects, yet they can have unintended impacts on pests as well as on many other nonpest species. The insecticide DDT (dichlorodiphenyltrichloroethane) is a prime example. While DDT was designed to target nerve transmissions in insects, the chemical can move up an aquatic food chain all the way to eagles that consume fish. Eagles that consumed DDT-contaminated fish produced eggs with thinner shells that would prematurely break during incubation. After the United States banned the spraying of DDT in 1972, the bald eagle and other birds of prey increased in numbers. However, DDT is still manufactured in developed nations and sprayed in developing countries as a preferred way to control the mosquitoes that carry the deadly malaria virus.

The third concern is the role of inert ingredients added to commercial formulations of pesticides. Inert ingredients are additives that make a pesticide more effective, allowing it to dissolve in water for spraying or to penetrate inside a pest species. Although the term “inert” may suggest that these chemicals are harmless, this is often not true. The popular herbicide Roundup, for example, is composed of a chemical that is highly effective at killing plants but has difficulty getting past the waxy outer layer of leaves without the help of an added inert ingredient. Since inert ingredients are legally classified as trade secrets and most are not required to be tested for safety, their effects are not always known before a product comes to market. In the case of Roundup, recent research has discovered that the herbicide is highly toxic to amphibians, not because of the plant-killing chemical but because of this inert ingredient. It appears that the same properties that allow the penetration of leaves also allow the penetration of tadpole gill cells. The gills burst and the tadpoles suffocate. Unintended consequences such as these have roused interest in both Europe and North America to require that inert ingredients be tested for potentially harmful effects.
Streams contain a wide variety of chemicals including pharmaceutical drugs and hormones. These come from a combination of wastewater inputs, agriculture, forestry, and industry. [After Pharmaceuticals, hormones, and other organic wastewater contaminants in U.S. streams, 1999–2000: A national reconnaissance, Environmental Science & Technology 36: 1202–1211.]

**PHARMACEUTICALS AND HORMONES** While most people know that pesticides are commonly found in the environment, they often are surprised to learn that pharmaceutical drugs are also common. For example, the U.S. Geological Survey tested 139 streams across the United States for a variety of chemical contaminants. **FIGURE 14.12** shows data for the frequency of detection. Among the different types of chemicals that were present at detectable levels, approximately 50 percent of all streams contained antibiotics and reproductive hormones, 80 percent contained nonprescription drugs, and 90 percent contained steroids. In most cases the concentrations of these chemicals are quite low and currently are not thought to pose a risk to environmental or human health. Some chemicals such as hormones, however, operate at very low concentrations inside the tissues of organisms and we have a poor understanding of their effects. As noted in the Chesapeake Bay example at the beginning of this chapter, it is now clear that low concentrations of pharmaceutical drugs that mimic estrogen are connected to male fish growing female eggs in their testes. The extent of hormone effects on humans and wildlife around the
world is currently unknown but is receiving increased attention by environmental scientists.

**MILITARY COMPOUNDS** In regions of the world where military rockets are manufactured, tested, or dismantled, a group of harmful chemicals known as perchlorates sometimes contaminate the soil. Used for rocket fuel, perchlorates come in many forms. The United States Space Shuttle, for example, uses a booster rocket that contains 70 percent ammonium perchlorate. Perchlorates are easily leached from contaminated soil into the groundwater where they can persist for many years. Human exposure to perchlorates comes primarily through consumption of contaminated food and water. In the human body, perchlorates can affect the thyroid gland and reduce the production of hormones necessary for proper functioning of the human body.

**INDUSTRIAL COMPOUNDS** Industrial compounds are chemicals that are used in manufacturing. Unfortunately, some of these compounds have been dumped directly into bodies of water as a method of disposal. Over the years in the United States, this was a common practice. One of the most widely publicized consequences of this occurred in the Cuyahoga River of Ohio. For more than 100 years, industries along the river had dumped industrial wastes that formed a slick of pollution along the surface, killing virtually all animal life. The problem became so bad that the river actually caught fire and burned several times over the decades (FIGURE 14.13). The fire on the river in 1969 garnered national attention and led to a movement to clean up America’s waterways. Today, the Cuyahoga River and most other rivers in the United States are much cleaner because of legislation that substantially reduced the amount of industrial and other waste that can be legally dumped into waterways.
Polychlorinated biphenyls, or PCBs, represent one group of industrial compounds that has caused many environmental problems. PCBs were used in manufacturing plastics and insulating electrical transformers until 1979. Although they are no longer manufactured or used in the United States, because of their long-term persistence PCBs are still present in the environment. Ingested PCBs are lethal and carcinogenic, or cancer-causing. One particularly high-profile case revolves around two General Electric manufacturing plants in New York State that dumped 590,000 kg (1.3 million pounds) of PCBs into the Hudson River from 1947 to 1977. In 2002, the EPA ruled that General Electric must pay for the dredging and removal of approximately 2.03 million cubic meters (2.65 million cubic yards) of PCB-contaminated sediment from a 64-km (40-mile) stretch of the upper Hudson River in New York State. General Electric argued that the dredging should not occur because it would stir up the sediments and resuspend the PCBs in the river water, causing further problems. The courts and EPA scientists disagreed and in 2009 the dredging of the PCBs finally began. As this case demonstrates, though it can take decades of scientific research and debate, in the end we can partially reverse the contamination of our water bodies.

While PCBs have long been a concern, there is a growing uneasiness over compounds known as PBDEs (polybrominated diphenyl ethers). PBDEs are most commonly known as flame retardants added to a wide variety of items including construction materials, furniture, electrical components, and clothing. They make buildings and their contents considerably less flammable than they would be otherwise. Since the 1990s, however, scientists have been detecting PBDEs in some unexpected places, including fish, aquatic birds, and human breast milk. Exposure to some types of PBDEs can lead to brain damage, especially in children. As a result, the European Union and several states including Washington and California have banned the manufacture of several types of PBDEs.

**CHECKPOINT**

- Describe the primary dangers associated with heavy metals in water.
- Explain the role of acid deposition in water pollution.
- Name examples of synthetic compounds that have been found in our water supply and explain why they are a concern.
In Chapter 12 we noted that the pollution of Earth’s oceans and shorelines from crude oil and other petroleum products can be an environmental catastrophe as well as an ongoing problem. Petroleum products are highly toxic to many marine organisms, including birds, mammals, and fish, as well as to the algae and microorganisms that form the base of the aquatic food chain. Oil is a persistent substance that can spread below and across the surface of the water for hundreds of kilometers and leave a thick, viscous covering on shorelines that is extremely difficult to remove.

One source of oil in the water comes from drilling for undersea oil using offshore platforms. There are approximately 5,000 offshore oil platforms in North America and another 3,000 in other parts of the world. These oil platforms often experience leaks. The best estimate for the amount of petroleum leaking into North American waters is 146,000 kg (322,000 pounds) per year. In other parts of the world, antipollution regulations are often less stringent. Estimates of the amount of petroleum leaking into the ocean annually from foreign oil platforms range from 0.3 million to 1.4 million kg (0.6 million–3.1 million pounds).

One of the most famous oil leaks from an offshore platform occurred in 2010 on a BP operation in the Gulf of Mexico. In this case, an explosion on the Deepwater Horizon platform caused a pipe to break on the ocean floor nearly 1.6 km (1 mile) below the surface of the ocean. From the time of the explosion in April until the well was sealed in August 2010, the broken pipe released an estimated 780 million liters (206 million gallons) of crude oil into the Gulf of Mexico. Given the magnitude of the oil spill and its potential to contaminate beaches, wildlife, and the estuaries that serve as habitats for the reproduction of commercially important fish and shellfish, this accident has the potential to be one of the largest environmental disasters in history.
In 1989, the oil tanker ran aground and spilled millions of liters of crude oil onto the shores of Alaska, where the oil killed thousands of animals.

Oil and other petroleum products can also enter the oceans as spills from oil tankers. One of the best-known spills involved the tanker Exxon Valdez that ran aground off the coast of Alaska in 1989 (FIGURE 14.14). As we discussed in Chapter 12, the ship spilled 41 million liters (11 million gallons) of crude oil that spread across the surface of several kilometers of ocean and coastline. The spill killed 250,000 seabirds, 2,800 sea otters, 300 harbor seals, and 22 killer whales. Cleanup efforts have been going on for two decades.

In 2009, 20 years after the spill, scientists evaluated the state of the contaminated Alaskan ecosystem. They concluded that the harmed populations of many species have rebounded, including bald eagles and salmon. Those that have not include killer whales (Orcinus orca) and sea otters (Enhydra lutris). Nor has the oil been completely removed from the environment. Pits dug into the shoreline suggest that approximately 55,000 liters (14,500 gallons) of oil remain. It is estimated that this oil will take more than 100 years to break down and the long-lasting effects will only become apparent over the coming decades. For its part, Exxon has paid $1 billion for the cleanup and $500 million in damages. The company also changed the ship’s name, although the ship
has been banned from carrying oil in North America. The Valdez accident sparked new rules that oil tankers in North America must have a double-hull design, requiring the ship’s body to be constructed of two steel walls that would help contain leaking oil if there were an accident.

Though it is an often underappreciated aspect of oil pollution, a large fraction of oil in the ocean occurs naturally. In fact, the U.S. National Academy of Sciences recently estimated that natural releases of oil from seeps in the bottom of the ocean account for 60 percent of all oil in the waters surrounding North America and 45 percent of all oil in water worldwide. **FIGURE 14.15** shows the proportion of different sources of oil in water for both North American and worldwide marine waters. In the waters controlled by the United States, the ocean seeps more than 270,000 liters (70,000 gallons) of oil every day. This means that when we assess the environmental impact of oil in our oceans, we must consider the combination of both natural and anthropogenic releases of oil.

**FIGURE 14.15 Sources of oil in the ocean.** Oil contamination in the ocean, both (a) in North America and (b) worldwide, comes from a variety of sources including natural seeps, extraction of oil from underneath the ocean, transport of oil by tanker or pipeline, and consumption of petroleum-based products. [After http://oceanworld.tamu.edu/resources/oceanography-book/contents.htm.]

### 14.5. Ways to remediate oil pollution

Since the 1989 Exxon Valdez oil spill, experiments have been underway to determine how best to remediate oil spills. For contaminated mammals and waterfowl, there is little debate about what to do; they must be cleaned by hand. Bird feathers that are
covered with oil, for example, become heavy and lose their ability to insulate. The best approach to cleaning up the spilled oil, however, is not always clear.

Oil spilled in the ocean can either float on the surface or remain far below in the form of *underwater plumes*. For oil floating on the surface of the open ocean, a common approach is to contain the oil within an area and then suck it off the surface of the water. Containment occurs by laying out oil containment booms that consist of plastic barriers floating on the surface of the water and extending down into the water for several meters. These plastic walls keep the floating oil from spreading further. Once the oil is contained, boats equipped with giant oil vacuums suck up as much oil as possible (**FIGURE 14.16**). In shallow areas and along the coastline, absorbent materials are used to suck up the spilled oil.

![Figure 14.16 Oil-spill containment.](image)

A second approach to treating oil floating on the surface is to apply chemicals that help break up the oil, making it disperse before it hits the shoreline and causes damage to the coastal ecosystems. Although the dispersants can be effective, they can also be toxic to marine life. Current research is examining ways to make chemical dispersants more environmentally friendly.

A third approach to cleaning up oil uses genetically engineered bacteria. Several years ago scientists discovered a naturally occurring bacterium that obtained its energy by consuming oil emerging from natural seeps. These bacteria were typically rare in the ocean, but very abundant in areas where oil spills or seeps occurred. Scientists, currently trying to determine the genes that confer the bacteria’s
ability to consume oil, hope to insert copies of these genes into genetically modified bacteria to consume oil spills even faster.

Oil in underwater plumes persists as a mixture of water and oil, similar to the mixture of vinegar and oil in a salad dressing. In the case of the BP platform explosion in the Gulf of Mexico, scientists reported observing an oil plume moving approximately 1,000 meters (3,000 feet) below the surface of the ocean. The plume was approximately 24 to 32 km (15–20 miles) long, 8 km (5 miles) wide, and hundreds of meters thick. There is currently no agreed-upon method of removing underwater plumes from the water. There is some debate over the best way to treat rocky coastlines after an oil spill. Scientists have been monitoring parts of Prince William Sound that were treated in different ways after the Exxon Valdez spill. Workers cleaned some areas with high-pressure hot water to remove the oil. Unfortunately, this also removed the plants and animals that inhabited the rocks and, in some cases, removed the fine-grained sediments containing nutrients. The hot water sprayers not only removed the oil, but also removed most of the marine life. Without the fine-grained sediment, many organisms were unable to recolonize the coast. Other parts of the coastline received no human intervention. Over the years since the spill, the repeated action of waves and tides slowly removed much of the oil. However, the remaining oil existing in crevices of the rocky shoreline continues to have a negative effect on organisms that live among the rocks. Thus, leaving the beaches uncleaned also poses problems. At present, there is no clear consensus on the best way to respond to oil spills on coastlines.

CHECKPOINT
- Name several ways in which oil gets into the ocean.
- Describe the effects of an oil spill.
- What are three ways to remediate an oil spill?

Previous Sec

14.6

Not all water pollutants are chemicals

When we think about water pollution, we most commonly envision scenes of dirty water contaminated with toxic chemicals. Though such scenarios certainly receive a great deal of public attention, there are other, less familiar types of water pollution that include solid waste, sediment, heat, and noise.

14.6. Solid waste pollution
Solid waste consists of discarded materials from households and industries that do not pose a toxic hazard to humans and other organisms. Much solid waste is what we call garbage. In the United States, solid waste is generally disposed of in land-fills, but in some cases it is dumped into bodies of water and can later wash up on coastal beaches. In 1997, scientists discovered a large area of solid waste, composed mostly of discarded plastics, floating in the North Pacific gyre (see FIGURE 4.11 on page 96). This area, named the Great Pacific Garbage Patch, appears to collect much of the solid waste that is dumped into waters and to concentrate it in the middle of the rotating currents in an area the size of Texas. The other ocean gyres appear to have the same ability to collect garbage. Given the vastness of these areas, no one is certain how much solid waste is floating but current estimates are in the range of hundreds of millions of kilograms.

Garbage on beaches and in the ocean is not only unsightly, but also dangerous to both marine organisms and people. Plastic rings from beverage six-packs, for instance, can strangle many animals. Medical waste poses a threat to people on the beach, particularly children. During the 1970s and 1980s, the dumping of garbage off the coasts of the United States by both municipalities and cruise ships received increased attention and public outcry, especially when it was found to include medical waste such as used hypodermic needles. As a result, this practice was curtailed in the early 1980s. Today, garbage being dumped in U.S. waters is not nearly the problem that it is in many developing countries where there is often a lack of political mechanism and economic ability to manage proper garbage disposal (FIGURE 14.17).
Another major source of solid waste pollution is the coal ash and coal slag that remain behind when coal is burned. As we saw in Chapter 12, such waste contains a number of harmful chemicals including mercury, arsenic, and lead. The solid waste products from burning coal can contaminate groundwater since they are typically dumped into landfills, ponds, or abandoned mines. In the United States, the Environmental Protection Agency considers the waste from burning coal and other fossil fuels to be “special waste” and exempt from federal regulations for the disposal of hazardous waste. In addition, most states have either no regulations or weak regulations governing this waste.

14.6. Thermal pollution

A third type of nonchemical water pollution, thermal pollution, occurs when human activities cause a substantial change in the temperature of water. Although temperature can become either warmer or cooler, the most common cause of thermal pollution occurs when cold water is removed from a natural supply, used to absorb heat as part of some industrial process, and then returned as heated water back to the natural supply. A variety of industries make use of water for cooling, including steel mills that need to cool their machines and electric power plants. For example, as described in Chapter 12, electric power plants use nearly half of all water extracted for cooling purposes. The plant must cool the steam converted from water back into water. Thus, power plants bring in cold water from rivers, lakes, or oceans, use it to cool the steam, and then return it back to nature at significantly warmer temperatures—from 10°C to 15°C (18°F–27°F) warmer.

Since species in a given community are generally adapted to a particular natural range of temperatures, a dramatic change in temperature can kill many species, a phenomenon called thermal shock. High temperatures also cause organisms to increase their respiration rate, yet warmer water does not contain as much dissolved oxygen as cold water. When both effects are present, many animals will simply suffocate. In recent years, steps have been taken to help reduce thermal pollution, including pumping the heated water into outdoor holding ponds where it can further cool before being pumped back into natural water bodies (FIGURE 14.19).
Nuclear reactors, such as the Svartsengi power plant in Iceland, use water to generate steam. To cool this steam, they either use cooling towers or empty the water into holding ponds. In both cases, the water must be cooled before it is returned to the natural source of water such as a lake or river.

The EPA regulates how much heated water can be returned to natural water bodies. Compliance is measured by the number of degrees the temperature of the water body can be increased. This becomes a real challenge in the summer when high demand for electricity causes an increased demand for cooling water even though the water in rivers and lakes will probably be at its lowest volume and at its highest temperature. One common solution to this problem has been the construction of cooling towers that release the excess heat into the atmosphere instead of into the water. A cooling tower relies on the cooling power of evaporation to reduce the temperature of the water, much as we depend on our own sweat and a breeze to cool ourselves on a hot day. Some industries have built closed systems in which they cool the hot water in a cooling tower and then recycle the water to be heated again. In this way, the industries do not extract water from natural water bodies, nor do they release any heated water back into nature.

It may strike you as odd to think of noise as a type of water pollution. Indeed, noise pollution has received the least amount of attention from environmental scientists and, as a result, we know the least about it. Sounds emitted by ships and submarines that interfere with animal communication are the major concern. Especially loud sonar
could negatively affect species such as whales that rely on low-frequency, long-distance communication. Several instances of beached whales in the Bahamas, the Canary Islands, and the Gulf of California have been connected to the use of military sonar and loud, underwater air guns. As a result, in 2003 a federal judge rejected the U.S. Navy's request to install a network of long-range sonar systems across the ocean floor to detect incoming submarines, because of suspected negative impacts on endangered whales and other species of marine animals. In 2008, however, the U.S. Supreme Court ruled that the president of the United States could exempt the navy from environmental laws that were related to potential sonar effects on ocean life.

CHECKPOINT

- Name three types of nonchemical water pollution.
- How can nonchemical water pollution be addressed?
- What are some examples of noise pollution as it relates to water?

14.7 A nation’s water quality is a reflection of the nation’s water laws and their enforcement

Around the world, water quality improves when citizens demand it and nations can afford it. In the United States, the most important water-pollution laws are the Clean Water Act and Safe Drinking Water Act. Similar laws can be found around the world, although they are more common in developed countries than in developing ones.

14.7. Clean Water Act

Water quality in much of the United States was quite bad in the 1960s but growing awareness of the problem encouraged a series of laws to fight water pollution. The Federal Water Pollution Control Act of 1948 was the first major piece of legislation affecting water quality, and it was substantially expanded in 1972 into what is now known as the Clean Water Act.

The Clean Water Act supports the “protection and propagation of fish, shellfish, and wildlife and recreation in and on the water” by maintaining and, when necessary, restoring the chemical, physical, and biological properties of natural waters. Note that this objective does not include the protection of groundwater. The Clean Water Act originally focused mostly on the chemical properties of surface waters. More recently, there has been increased focus on ensuring that the biological component, including the abundance and diversity of various species, also receives
attention. Most importantly, the Clean Water Act issued water quality standards that defined acceptable limits of various pollutants in U. S. waterways. Associated with these limits, the act allowed the EPA and state governments to issue permits to control how much pollution industries can discharge into the water. Over time, more and more categories of pollutants have been brought under the jurisdiction of the Clean Water Act, including animal feedlots and storm runoff from municipal sewer systems.

### 14.7. Safe Drinking Water Act

In addition to the Clean Water Act, other legislation has been passed to regulate water pollution, including the Safe Drinking Water Act (1974, 1986, 1996), which sets the national standards for safe drinking water. Under the Safe Drinking Water Act, the EPA is responsible for establishing **maximum contaminant levels (MCL)** for 77 different elements or substances in both surface water and groundwater. This list includes some well-known microorganisms, disinfectants, organic chemicals, and inorganic chemicals (Table 14.1). These maximum concentrations consider both the concentration of each compound that can cause harm as well as the feasibility and cost of reducing the compound to such a concentration.

<table>
<thead>
<tr>
<th>Contaminant category</th>
<th>Contaminant</th>
<th>Maximum contaminant level (ppb)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Microorganism</td>
<td>Giardia</td>
<td>0</td>
</tr>
<tr>
<td>Microorganism</td>
<td>Fecal coliform</td>
<td>0</td>
</tr>
<tr>
<td>Inorganic chemical</td>
<td>Arsenic</td>
<td>10</td>
</tr>
<tr>
<td>Inorganic chemical</td>
<td>Mercury</td>
<td>2</td>
</tr>
<tr>
<td>Organic chemical</td>
<td>Benzene</td>
<td>5</td>
</tr>
<tr>
<td>Organic chemical</td>
<td>Atrazine</td>
<td>3</td>
</tr>
</tbody>
</table>

**Source:** U.S. Environmental Protection Agency, [http://www.epa.gov/safewater/contaminants/index.html](http://www.epa.gov/safewater/contaminants/index.html).

MCLs are somewhat subjective and are subject to political pressures. For example, the MCL for arsenic was kept at 50 ppb for many years because it was argued that despite the evidence that 50 ppb caused harm in humans, reducing arsenic in drinking water to 10 ppb was too expensive for many communities to afford.

What has been the impact of these water-pollution laws? In general, they have been very successful. The EPA defines bodies of water in terms of their designated uses, including aesthetics, recreation, protection of fish, and as a source of safe
drinking water. The EPA then determines if a particular waterway fully supports all of the designated uses. In 2004 (the most recent data), the EPA determined that 56 percent of all streams, 35 percent of lakes and ponds, and 70 percent of bays and estuaries in the United States now fully support their designated uses. This is a large improvement from decades past but, as TABLE 14.2 shows, we still have a lot of work to do to improve the remaining waterways. Today, the water in municipal water systems in the United States is generally safe. Water regulations have greatly reduced contamination of waters and nearly eliminated major point sources of water pollution. But nonpoint sources such as oil from parking lots and nutrients and pesticides from suburban lawns are not covered under existing regulations.

<table>
<thead>
<tr>
<th>TABLE 14.2</th>
<th>The current leading causes and sources of impaired waterways in the United States</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Causes of impairment</td>
</tr>
<tr>
<td>Streams and rivers</td>
<td>Bacterial pathogens, habitat alteration, oxygen depletion</td>
</tr>
<tr>
<td>Lakes, ponds, and reservoirs</td>
<td>Mercury, PCBs, nutrients</td>
</tr>
<tr>
<td>Bays and estuaries</td>
<td>Bacterial pathogens, oxygen depletion, mercury</td>
</tr>
</tbody>
</table>


# Previous Section

## 14.7.3 Legislation in the developing world

If we look at water-pollution legislation around the world, there is a clear difference between developed and developing countries. Developed countries, including those in North America and Europe, experienced tremendous industrialization many decades ago and widely polluted their air and water. More recently they have turned their attention to cleaning up their polluted areas and to addressing the problem of pollution with legislation. Developing countries are still in the process of industrializing, have less restrictive environmental laws, and have less money to fund water-quality improvements such as wastewater treatment plants. In some cases, contaminating industries move from developed countries to developing countries. Although the developing countries suffer from the additional pollution, they benefit economically from the additional jobs that the new industries bring with them.

Water-pollution problems are prevalent in many of the developing nations of Africa, Asia, Latin America, and eastern Europe. China and India, for example, have
undergone rapid industrialization and have many areas of dense human population—a recipe for major water-pollution problems. However, as a nation becomes more affluent, there is often more interest in the environment with resources made available to address environmental issues. In Brazil, for example, industrialization began to take off in the 1950s. By the 1990s, the Tietê River, which passes through the large city of São Paulo, was badly polluted. More than a million Brazilians signed a petition in 1992 requesting that the government regulate the industrial and municipal pollution being dumped into the river. Today the Tietê River is a much cleaner place (FIGURE 14.20).

Figure 14.20 The Tietê River in Brazil. The Tietê River, which passes through the large city of São Paulo, was badly polluted in the 1950s but is much cleaner today.

CHECKPOINT

- What is an MCL?
- What is the relationship between economic development and clean water?
- Describe some of the legislative actions taken to protect clean water and why they are significant.

WORKING TOWARD SUSTAINABILITY

Building “Green” Solutions to Wastewater Treatment
As we have seen, one of the major sources of water pollution is human wastewater from toilets, showers, washing machines, and sinks. While the EPA has set regulations for towns and cities on the proper treatment of wastewater, many municipalities find it difficult to afford modern wastewater treatment plants. What alternative solutions can be used to allow for the safe treatment of sewage?

The small town of Ashfield, Massachusetts, had a hard time affording a traditional sewage treatment facility. In 1972, the town was notified that it was in violation of the Clean Water Act because much of its wastewater was being dumped directly into a nearby stream. For the next 25 years, the residents of the town debated how they could address this federal violation and its potential health risks in an affordable way. If they could find a way to do so in an environmentally friendly manner, they could obtain grants from the state and federal governments that would cover about 70 percent of the construction costs.

On the other side of the state, in Ipswich, New England BioLabs was facing a similar problem. As a major manufacturer of biological chemicals, the company was large enough to produce a substantial volume of sewage, but too far away from the nearest central sewage treatment plant.

The town of Ashfield and New England BioLabs each needed to build sewage treatment facilities. Each wanted a facility that was aesthetically pleasing, odor-free, and used environmentally friendly technologies. In each town, a proposal was made to use a system of greenhouses and wetlands that would help purify wastewater. This solution would be effective and affordable, with no unpleasant odor, and it would be aesthetically pleasing as well.
The citizens of Ashfield, Massachusetts, voted to build a more environmentally friendly wastewater plant. The plant includes greenhouses that decompose the organic material and remove excess nitrogen. The greenhouse technology contains many of the same processes found in traditional wastewater treatment plants, but executes these processes in some unique ways (FIGURE 14.21). Like a traditional system, wastewater from homes and businesses flows through pipes to a holding tank at the facility, but then the liquid is pumped into a series of 3,785 L (1,000-gallon) transparent tanks that sit in a greenhouse where communities of microbes, algae, plants, and snails grow and consume the excess nutrients present in the wastewater. Air is bubbled into tanks so that the tanks experience aerobic bacterial decomposers—as opposed to the anaerobic decomposers that produce the offensive odor in many treatment plants. The liquid coming out of these tanks is held to allow the solids to settle and then the water is filtered through sand and pumped into a human-made wetland inside a greenhouse. Here denitrifying bacteria remove most of the nitrogen in the water by converting it to nitrogen gas. This water is then exposed to ultra-violet light to kill any harmful viruses or bacteria and released into a leach field where the liquid can slowly be filtered through the soil. Because these alternative sewage treatment plants are essentially giant greenhouses, they fit in well with the aesthetics of many towns. To make them even more appealing, designers planted bananas, figs, and flowers throughout the greenhouses, often with walkways built to allow educational tours. The fruits that are produced are not eaten by people since the plants take up sewage water during growth that may contain harmful chemicals. Instead, fruits and dead plants are removed to a compost pile.
In northern latitudes the greenhouses require heat to maintain proper temperatures during the winter months, and this is a major challenge in using this more environmentally friendly technology. As the price of heating fuels climbed sharply during the past decade, the annual costs of running sewage greenhouses has also increased. A decade ago the annual cost of maintaining the greenhouse sewage facility was similar to traditional facilities. Today, the high cost of heating oil and natural gas makes this type of alternative sewage treatment better suited for municipalities in warmer climates. For some communities and industries, however, the higher costs of operating the greenhouses are worth the benefit of having a local, environmentally friendly sewage treatment plant.

References

KEY IDEAS REVISITED
• **Distinguish between point and nonpoint sources of pollution.**
  Point sources of pollution have distinct locations, such as a pipe from a factory that discharges toxic chemicals into a stream. In contrast, nonpoint sources of pollution are more diffuse and cover very large areas, such as agricultural fields that leach fertilizer into a nearby stream.
• **Identify the ways in which human wastewater can cause water pollution.**
  Human wastewater can have a number of effects on natural water bodies. Wastewater adds organic matter that increases the biochemical oxygen demand, nutrients that cause eutrophication and algal blooms, and disease-causing pathogens that can harm both humans and wildlife.
• **Evaluate the different technologies that humans have developed for treating wastewater.**
  Single residences in rural areas with sufficient land space use simple septic systems that consist of a holding tank and leach field. In large communities with denser human populations and less open land, wastewater treatment plants are needed. These systems are much more complex and can be constructed either in a traditional way or by using newer, more environmentally friendly technologies.
• **Identify the major types of heavy metals and other substances that pose serious hazards to humans and the environment.**
  The major inorganic compounds that are of concern for water pollution are mercury, arsenic, and acids. Most arsenic occurs in well water through natural
processes, but pollution from mercury, acid precipitation, and acid mine drainage largely occur as a result of human industrial activities. The major organic compounds composing water pollution are pesticides and their inert ingredients; pharmaceuticals, including hormones; and industrial compounds, including PCBs.

- **Discuss the impacts of oil spills and how such spills can be remediated.**
  Oil spills occur both from tankers that transport oil as well as from offshore drilling platforms that leak during oil extraction. There is general agreement about containing and removing the oil slicks that float on the surface of the water. However, scientists still debate whether oil spills that hit the coastline should be remediated by washing the coastline with hot water or leaving it to recover without human intervention.

- **Identify contaminants that are nonchemical pollutants.**
  Though nonchemical pollutants receive much less attention, they can be very harmful. These pollutants include sediments, heat, noise, and solid waste such as garbage.

- **Explain the connections among industrialization, affluence, and water-pollution legislation.**
  Most modern nations have experienced periods of industrialization and widespread pollution followed by greater affluence that allows an improvement in the quality of their waterways. Developed countries have the resources to address pollution issues. Many developing countries are still in the phase of rapid industrial growth and consequently have poor water quality.

**PREPARING FOR THE AP EXAM**

**MULTIPLE-CHOICE QUESTIONS**

[Notes/Highlighting]

1. Which of the following statements about nonpoint source (NPS) pollution is *not* correct?
   - (a) NPS results from rain or snowmelt moving over or permeating through the ground.
   - (b) NPS is a form of water pollution that is more difficult to control, measure, and regulate.
   - (c) NPS includes sediment from improperly managed construction sites as a pollutant.
   - (d) NPS is water pollution that originates from a distinct source such as a pipe or tank.
   - (e) NPS disperses pollutants over a large area, such as oil and grease in a parking lot.

[Answer Field]
2. Human wastewater results in which of the following water-pollution problems?
   - I The organic matter decomposes and reduces dissolved oxygen levels.
   - II Decomposition of organic matter releases great quantities of nutrients.
   - III Pathogenic organisms are carried into surface waters.
   - (a) I only
   - (b) II only
   - (c) III only
   - (d) I and III
   - (e) I, II, and III
   [Answer Field]

3. Which of the following would be an indication that a body of water was contaminated by human waste-water?
   - (a) Low BOD and a fecal coliform bacteria count of zero
   - (b) High levels of nutrients, such as nitrogen and phosphorus, and high BOD
   - (c) Low BOD and low levels of nutrients, such as nitrogen and phosphorus
   - (d) Low levels of nutrients, such as nitrogen and phosphorus, and a fecal coliform bacteria count of zero
   - (e) A lack of dead zones
   [Answer Field]

4. Both septic systems and sewage treatment plants utilize bacteria to break down organic matter. Where in each system does this process occur?
   - (a) Septic tank and leach field; primary treatment and secondary treatment
   - (b) Septic tank only; primary treatment and chlorination
   - (c) Leach field only; secondary treatment only
   - (d) Septic tank and leach field; secondary treatment only
   - (e) Leach field only; secondary treatment and chlorination
   [Answer Field]

5. Under which of the following circumstances is a sewage treatment plant legally permitted to bypass normal treatment protocol and discharge large amounts of sewage directly into a lake or river?
   - (a) When the receiving surface water is designated for swimming only
   - (b) When the population of the surrounding community surpasses the plant’s capacity
   - (c) When combined volumes of storm water and wastewater exceed the capacity of an older plant
   - (d) When a permit to modernize the plant is denied by the Environmental Protection Agency
   - (e) When an extended period of drought restricts water flow in a lake or river
   [Answer Field]
6. Which of the following inorganic substances is naturally occurring in rocks, soluble in groundwater, and toxic at low concentrations?
   - (a) Mercury
   - (b) Lead
   - (c) PCBs
   - (d) Copper
   - (e) Arsenic

[Answer Field]

7. Acid mine drainage results from acidic water formed belowground that makes its way to the surface; the acidic water is formed as a result of the flooding of abandoned mines where the underground water
   - (a) reacts with a type of rock, pyrite, which releases iron and hydrogen ions.
   - (b) reacts with sulfur dioxide and nitrogen dioxide to form sulfuric and nitric acids.
   - (c) flushes out the chemicals used in the mining process.
   - (d) permeates a limestone layer that lowers the pH.
   - (e) reacts with copper and aluminum to form pyrite rock and hydrogen ions.

[Answer Field]

8. All of the following are problems that result from the use of pesticides except
   - (a) most pesticides are not target-specific and kill other related and nonrelated species.
   - (b) pesticide runoff enters surface waters and increases the solubility of heavy metals.
   - (c) pesticides affect nontarget organisms by changing community relationships.
   - (d) pesticides target specific physiological functions, but also disrupt other functions.
   - (e) most inert ingredients are not tested for safety and may pose unacceptable risks.

[Answer Field]

9. Based on FIGURE 14.12, which of the following pharmaceuticals was detected most often in the streams studied by the U.S. Geological Survey?
   - (a) Nonprescription drugs
   - (b) Antibiotics
   - (c) Steroids
   - (d) Reproductive hormones
   - (e) Other prescription drugs

[Answer Field]

10. All of the following are the result of the Exxon Valdez oil tanker running aground off the coast of Alaska in 1989 except
    - (a) millions of gallons of crude oil spread over the ocean and shoreline.
(b) thousands of animals were killed; some species have recovered, others have not.
(c) the oil that contaminated the shoreline is now completely broken down.
(d) Exxon paid $500 million in damages and changed the name of the ship.
(e) all oil tankers in North America must have a double-hull design to resist leaking.

11. Successful remediation of oil spills floating on the surface of the ocean from leaking oil tankers or offshore platforms includes which of the following?
   - I Containment and vacuuming up the oil
   - II High-pressure hot water
   - III Chemicals that break down oil
   (a) I only
   (b) II only
   (c) III only
   (d) I and III
   (e) II and III

12. All of the following are nonchemical forms of water pollution except
   - (a) industrial waste.
   - (b) solid waste or garbage.
   - (c) sediments.
   - (d) noise.
   - (e) thermal pollution.

13. Which of the following provisions is defined in the Safe Drinking Water Act?
   - (a) Support the protection and propagation of fish, shellfish, wildlife, and recreation in and on the water.
   - (b) Maintain and restore the chemical, physical, and biological properties of natural waters.
   - (c) Protect the abundance and diversity of various species in and on the water.
   - (d) Issue permits to control how much pollution industries can discharge into the water.
   - (e) Establish maximum contaminant levels (MCLs) for specific substances in both surface water and groundwater.

14. The passage of water-pollution legislation is most likely to occur when
   - (a) a developing country is still in the process of industrialization and rapid population growth.
   - (b) a developed country has experienced industrialization and can afford the control measures demanded by its citizens.
- (c) a developing country has not yet industrialized and water quality is still good.
- (d) contaminating industries relocate in a developing country and begin to abuse the less-restrictive environmental laws.
- (e) nonpoint sources of water pollution outnumber point sources.

FREE-RESPONSE QUESTIONS

1. Based on the data collected by the Maryland Department of Natural Resources and the Chesapeake Bay Program (see the figure below), answer the following questions.

Blue crab population trends, 1990–2009

- (a) Calculate the difference between the 1990–1997 average blue crab population and the 1998–2009 average blue crab population. Predict the average blue crab population for 2010–2020 and explain your answer. (4 points)
- (b) Identify and explain three possible factors related to water pollution that could have contributed to the decline in the total blue crab population in the Chesapeake Bay. (3 points)
- (c) Select one factor stated in (b) and describe how that source of water pollution could be managed and controlled. (2 points)
- (d) What federal legislation would apply to the Chesapeake Bay and the blue crabs? (1 point)

2. The Food and Drug Administration (FDA) has developed guidelines for the consumption of canned tuna fish. These guidelines were developed particularly for children, pregnant women, or women who were planning to become pregnant, because
mercury poses the most serious threat to these segments of society. However, the guidelines can be useful for everyone.

- (a) Identify two major sources of mercury pollution and one means of controlling mercury pollution. (6 points)
- (b) Explain how mercury is altered and finds its way into albacore tuna fish. (2 points)
- (c) Identify two health effects of methylmercury on humans. (2 points)

**MEASURING YOUR IMPACT**

1. **Gaining Access to Safe Water and Proper Sanitation**

One of the main causes of diarrheal disease is the transmission of pathogenic microorganisms through contaminated fresh water. One way to compare countries is to assess the percentage of a country’s population that has access to technologies that ensure safe water and sanitation (defined by the World Health Organization as *improved water sources* and *improved sanitation*). Based on the data in the table below, answer the following questions.

<table>
<thead>
<tr>
<th>Country</th>
<th>2000 %Total population with sustainable access to improved drinking water sources</th>
<th>2006 %Total population with sustainable access to improved drinking water sources</th>
<th>2000 %Total population with sustainable access to improved sanitation</th>
<th>2006 %Total population with sustainable access to improved sanitation</th>
<th>2000 Deaths among children under five years of age due to diarrheal diseases (%)</th>
<th>Water footprint* (m³/capita/year)</th>
<th>% Water derived from outside the country</th>
</tr>
</thead>
<tbody>
<tr>
<td>United States</td>
<td>99.0</td>
<td>99.0</td>
<td>100.0</td>
<td>100.0</td>
<td>0.1</td>
<td>2,483</td>
<td>19</td>
</tr>
<tr>
<td>China</td>
<td>80.0</td>
<td>88.0</td>
<td>59.0</td>
<td>65.0</td>
<td>11.8</td>
<td>702</td>
<td>7</td>
</tr>
<tr>
<td>India</td>
<td>82.0</td>
<td>89.0</td>
<td>23.0</td>
<td>28.0</td>
<td>20.3</td>
<td>980</td>
<td>2</td>
</tr>
<tr>
<td>Japan</td>
<td>100.0</td>
<td>100.0</td>
<td>100.0</td>
<td>100.0</td>
<td>0.4</td>
<td>1,153</td>
<td>64</td>
</tr>
</tbody>
</table>

* Water footprint is defined by the Water Footprint Network as "the volume of water needed for the production of goods and services by the inhabitants of the country."

Sources: Water Footprint Network, [http://www.waterfootprint.org/?page=files/home](http://www.waterfootprint.org/?page=files/home); World Health Organization Core Health Indicators, [http://apps.who.int/whosis/database/core/core_select_process.cfm](http://apps.who.int/whosis/database/core/core_select_process.cfm)

- (a) 
  o (i) List the countries in order from the highest to lowest percentage of deaths among children under five due to diarrheal diseases.
  o (ii) How does this compare with access to improved drinking water sources and improved sanitation for the year 2000?
(iii) For each country, predict how the 2006 data will affect the deaths among children under five due to diarrheal diseases.

- (b) Based on your answers to (a), how could each country reduce the death rate due to diarrheal diseases of children under five years of age?
- (c) For each country, calculate the ratio of its water footprint to the global average. Based on the definition of water footprint, state a relationship between the ratios calculated and water pollution.
- (d) Even if each of these countries was able to achieve zero water pollution, discuss two reasons why poor water quality could still be a problem.