CHAPTER 17
Human Health and Environmental Risks
The citizens of Norco, Louisiana, live in the shadows of chemical plants and oil refineries.

Citizen Scientists

The neighborhood of Old Diamond in Norco, Louisiana, is composed of four city blocks located between a chemical plant and an oil refinery, both owned by the Shell Oil Company. There are approximately 1,500 residents in the neighborhood, largely lower-income African Americans. In 1973, a pipeline explosion blew a house off its foundation and killed two residents. In 1988, an accident at the refinery killed seven workers and sent more than 70 million kg (159 million pounds) of potentially toxic chemicals into the air. Nearly one-third of the children in Old Diamond suffered from asthma and there were many cases of cancer and birth defects. The unusually high rates of disease raised suspicions that the residents were being affected by the two nearby industrial facilities.

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Margie Richard became a citizen scientist to help document the health risk of nearby chemical plants.

By 1989, local resident and middle school teacher Margie Richard had seen enough. Richard organized the Concerned Citizens of Norco. The primary goal of the group was to get Shell to buy the residents’ properties at a fair price so they could move away from the industries that were putting their health at risk. Richard contacted environmental scientists and quickly learned that to make a solid case to the company and to the U.S. Environmental Protection Agency (EPA), she needed to be more than an organizer; she also needed to be a scientist.
The residents all knew that the local air had a foul smell, but they had no way of knowing which chemicals were present or their concentrations. To determine whether the air they were breathing exposed the residents to chemical concentrations that posed a health risk, the air had to be tested. Richard learned about specially built buckets that could collect air samples. She organized a "Bucket Brigade" of volunteers and slowly collected the data she and her collaborators needed. As a result of these efforts, scientists were able to document that the Shell refinery was releasing more than 0.9 million kg (2 million pounds) of toxic chemicals into the air each year.

The fight against Shell met strong resistance from company officials and went on for 13 years. But in the end, Margie Richard won her battle. In 2002, Shell agreed to purchase the homes of the Old Diamond neighborhood. The company also agreed to pay an additional $5 million for community development and it committed to reducing air emissions from the refinery by 30 percent to help improve the air quality for those residents who remained in the area. In 2007, Shell agreed that it had violated air pollution regulations in several of its Louisiana plants and paid the state of Louisiana $6.5 million in penalties.

For her tremendous efforts in winning the battle in Norco, Margie Richard was the North American recipient of the Goldman Environmental Prize, which honors grassroots environmentalists. Since then, Richard has brought her message to many other minority communities located near large polluting industries. She teaches people that success requires a combination of organizing people to take action to protect their environment and learning how to be a citizen scientist.


**Key Ideas**

Health risks come from a variety of environmental sources including diseases and harmful chemicals. Some diseases have existed for millennia and others have emerged during the past few decades. In many cases, the likelihood of contracting a specific disease is associated with economic status. Harmful chemicals also pose a risk to humans and other organisms.

After reading this chapter you should be able to

- identify the three major categories of human health risk.
- list the major historical and emerging infectious diseases.
- name the five major types of toxic chemicals.
- distinguish between dose-response studies, retrospective studies, and prospective studies.
• describe the factors that help determine the chemical concentrations that organisms experience.
• explain the factors that go into a risk analysis and distinguish between the two major philosophies of chemical regulation.

17.1 Human health is affected by a large number of risk factors

The number of health risks that we face in our lives can feel overwhelming. Sometimes it seems that we hear new warnings every day. How do we evaluate and manage these risks? We can begin to answer this question by determining which risks are common and the current state of our understanding about each of them. After that, we will look at how to assess and manage these risks. As we will see, although many health risks do exist in both the developed and developing worlds, we can do a great deal to manage these risks and improve our lives.

17.1. Categories of Human Health Risk

The first step in understanding health risks is to consider the three major categories of risks that can harm human health: physical, biological, and chemical. Physical risks include environmental factors, such as natural disasters, that can cause injury and loss of life. Physical risks also include less dramatic factors such as excessive exposure to ultraviolet radiation from the Sun, which causes sunburn, and exposure to radioactive substances such as radon, which we discussed in Chapter 15. Biological risks are those associated with diseases. A disease is any impaired function of the body with a characteristic set of symptoms. Chemical risks are associated with exposure to chemicals ranging from naturally occurring arsenic to synthetic chemicals and pesticides. In this chapter, we will focus on biological and chemical risks.

17.1. Types of disease

Given these three categories of human health risk, biological risks cause the most human deaths. As you can see in FIGURE 17.1, approximately three-quarters of human deaths worldwide stem from various types of diseases. Infectious diseases are those caused by infectious agents, known as pathogens. Examples include pneumonia
and sexually transmitted diseases. Diseases not caused by pathogens include cardiovascular diseases, respiratory and digestive diseases, and most cancers.

**Figure 17.1** Leading causes of death in the world.  (a) More than three-quarters of all world deaths are caused by diseases, including respiratory and digestive diseases, various cancers, cardiovascular diseases, and infectious diseases. (b) Among the world’s deaths caused by infectious diseases, 94 percent are caused by only six types of diseases.  [Data from World Health Organization, 2004.]

The pathogens that cause most infectious diseases include viruses, bacteria, fungi, protists, and a group of parasitic worms called helminths. Only six types of illnesses account for 94 percent of all deaths caused by infectious disease. The three top types of infectious diseases are those caused by respiratory infections (such as pneumonia), those caused by the virus that causes Acquired Immune Deficiency Syndrome (or AIDS), and the variety of pathogens that cause diarrhea. The next three are tuberculosis, malaria, and childhood diseases such as measles and tetanus. We will discuss many of these important infectious diseases later in the chapter.

All diseases fall into two categories—acute and chronic. **Chronic diseases** slowly impair the functioning of a person’s body. Heart disease and most cancers, for example, are chronic diseases that develop over several decades. In contrast, **acute diseases** rapidly impair the functioning of a person’s body. In some cases, such as a disease called *Ebola hemorrhagic fever* that we will discuss later in this chapter, death can come in a matter of days or weeks.

**RISK FACTORS FOR CHRONIC DISEASE IN HUMANS** Numerous factors cause people to be at a greater risk of chronic diseases such as cancer, cardiovascular diseases, diabetes, and chronic infectious diseases. The World Health
Organization (WHO) has found that these risk factors differ substantially between low- and high-income countries. **FIGURE 17.2** shows the WHO data for a variety of risks.

![Figure 17.2: Leading health risks in the world](image)

**Figure 17.2**  **Leading health risks in the world.** If we consider all deaths that occur and separate them into different causes, we can examine which categories cause the highest percentage of all deaths. (a) The leading health risks for low-income countries include issues related to low nutrition and poor sanitation. (b) The leading risks for high-income countries include issues related to tobacco use, inactivity, obesity, and urban air pollution. [After World Health Organization, 2009.]

In low-income countries, the top 10 risk factors leading to chronic disease are associated with poverty, including unsafe drinking water, poor sanitation, and malnutrition. In **Chapter 11** we looked at some of the factors that contribute to malnutrition, including reduced government support for agriculture and higher costs of fossil fuels leading to increased food prices. As an example of poverty leading to chronic disease, nearly half of the children under the age of 5 who die from pneumonia succumb to the disease because they suffer from poor nutrition. Similarly, nearly three-quarters of children who die from diarrhea are simultaneously malnourished. With improved nutrition, these children would be better able to fight infectious diseases and many would survive.
As a nation becomes more developed over time and attains higher income levels, the risks of inadequate nutrition and sanitation decline while the risks of tobacco, obesity, and poor urban air quality rise. [After World Health Organization, 2009.]

In contrast, malnutrition and poor sanitation are not prevalent risk factors for chronic disease in high-income countries. Because people in these countries can afford better nutrition and proper sanitation, fewer die young from diseases such as pneumonia and diarrhea. Risk factors for people in high-income countries include an increased availability of tobacco, and a combination of less active lifestyles, poor nutrition, and overeating that leads to high blood pressure and obesity. In short, being affluent changes the major health risk factors for chronic disease.

The change in risk factors between low- and high-income countries occurs over time as a given country becomes more affluent. The graph in FIGURE 17.3 illustrates how this transition in economic development affects health risk. A poor country initially faces the challenge of supplying food and proper sanitation to its citizens. As it begins to accumulate wealth, the health risks will change in a predictable fashion and the health care system of the country must change as well.

CHECKPOINT

- What are the three major categories of risk for human health? Give an example of each.
- What is the difference between an acute and a chronic disease?
- How is the economic development level of a country related to disease?

17.2 Infectious diseases have killed large numbers of people
Pathogens have evolved a wide variety of ways to infect humans. Although diseases can have genetic causes, environmental scientists are generally interested in diseases that have environmental causes, especially those caused by pathogens such as fungi, bacteria, and viruses. These pathogens have evolved a wide variety of pathways for infecting humans including transmission of pathogens from other humans, other animals, the food we eat, and the water we drink. **Figure 17.4** illustrates some of these relationships.

Throughout human history, disease-causing pathogens have taken a large toll on human health and mortality. When a pathogen causes a rapid increase in disease, we call it an **epidemic**. When an epidemic occurs over a large geographic region such as an entire continent, we call it a **pandemic**. Among the diversity of human diseases that have caused epidemics and pandemics, we will consider both those that have been historically important and those that have emerged recently.

### 17.2. Historically Important Infectious Diseases

In **Chapter 7** and **Chapter 14** we looked at several diseases associated with poor sanitation and unsafe drinking water. These include cholera, hepatitis, and diarrheal...
diseases. All of these diseases are considered historical. Historical diseases that are passed between hosts include plague, malaria, and tuberculosis.

**PLAGUE Plague** is one of the most familiar diseases of human history. Also known by several historical names including bubonic plague and Black Death, plague is caused by an infection from a bacterium (*Yersinia pestis*) that is carried by fleas. Fleas attach to rodents such as mice and rats, giving the fleas tremendous mobility. When humans live in close contact with mice and rats, the bacterium can be transmitted either by flea bites or by handling the rodents. Individuals who become infected often experience swollen glands, black spots on their skin, and extreme pain. Plague is estimated to have killed hundreds of millions of people throughout history, including nearly one-fourth of the European population in the 1300s (FIGURE 17.5). The last major pandemic of plague occurred in Asia in the early 1900s. Today there are still occasional small outbreaks of plague around the world, including in the southwestern United States, but modern antibiotics are highly effective at killing the bacterium and preventing human death.

![Figure 17.5 The Black Death in Europe.](image-url)

As depicted in Carlo Coppola’s *The Marketplace in Naples During the Plague of 1656*, plague pandemics repeatedly swept through Europe from the 1300s through the 1800s, and killed millions of people. Because the disease caused black sores on people’s bodies, it also had the name Black Death.
MALARIA  Malaria is another widespread disease that has killed millions of people over the centuries. Malaria is caused by an infection from any one of several species of protists in the genus Plasmodium. The parasite spends one stage of its life inside a mosquito and another stage of its life inside a human. Infections cause recurrent flulike symptoms. Each year, 350 to 500 million people in the world contract the disease and 1 million people, mostly children under 5 years of age, die from it. The regions hardest hit include sub-Saharan Africa, Asia, the Middle East, and Central and South America. Since 1951, the malaria parasite has been eradicated from the United States by mosquito eradication programs. Although more than 1,000 cases of malaria are diagnosed in the United States each year, these are found in people who have returned from regions of the world where the malaria parasite lives.

The traditional approach to combating malaria was widespread spraying of insecticides such as DDT to eradicate the mosquitoes. Eradication efforts have proven to be ineffective in many parts of the world. Moreover, as we will see later in this chapter, the widespread use of many insecticides can create new problems. At the end of this chapter, Working Toward Sustainability "The Global Fight Against Malaria" examines the latest approaches toward combating malaria.

TUBERCULOSIS  Tuberculosis is a highly contagious disease caused by a bacterium (Mycobacterium tuberculosis) that primarily infects the lungs. Tuberculosis is spread when a person coughs and expels the bacteria into the air. The bacteria can persist in the air for several hours and infect a person who inhales them. Symptoms of an infection include weakness, night sweats, and coughing up blood. As is the case with many pathogens, a person can be infected but not develop the tuberculosis disease. Indeed, it is estimated that one-third of the world’s population is infected with tuberculosis. Each year 9 million people develop the disease and 2 million of them die.
Most tuberculosis infections can be easily treated by taking antibiotics for a year. In countries such as the United States, where the medicines are readily available, there has been a dramatic fall in both the number of new cases and the number of deaths from tuberculosis. FIGURE 17.6 shows the decline of tuberculosis in the United States since the mid-1950s. In other parts of the world, especially in developing countries, the medicines are not as available or affordable and those who receive the medicine sometimes do not take the prescribed dose for the full duration of time. When a patient stops taking antibiotics before the last bacteria have been killed, there are two consequences. First, the pathogen can quickly rebuild its population inside the person’s body. Second, because the last few bacteria are generally the most drug-resistant, stopping the antibiotics before the bacteria are eradicated selects for drug-resistant strains. Drug-resistant strains of tuberculosis are becoming a major concern, particularly in parts of Africa and Russia, where up to 20 percent of the people infected with tuberculosis carry a drug-resistant strain. Such strains are much harder to kill and therefore require newer antibiotics that can cost 100 times more than the traditional drugs.

17.2. Emergent Infectious Diseases

In recent decades, we have witnessed the appearance of many emergent infectious diseases, which are defined as infectious diseases that were previously not described or have not been common for at least the prior 20 years. FIGURE 17.7 locates some of
the best-known emergent infectious diseases. Since the 1970s, the world has observed an average of one emergent disease each year. Many of these new diseases have come from pathogens that normally infect animal hosts but then unexpectedly jump to human hosts. This typically occurs because the diseases can mutate rapidly, eventually producing a genotype that can infect humans. Some of the most high-profile diseases that have jumped from animals to humans include HIV/AIDS, Ebola, mad cow disease, bird flu, and West Nile virus. These new diseases are of particular concern in the world today because the rapid movement of people and cargo can spread them to nearly any place on Earth within 24 hours.

**Figure 17.7** The emergence of new diseases. Since the 1970s, new diseases, or diseases that have been rare for more than 20 years, have been appearing throughout the world at a rate of approximately one per year. [After http://www.niaid.nih.gov/SiteCollectionImages/about/whoweare/emerging_diseases1.gif.]

**HIV/AIDS** In the late 1970s, rare types of pneumonia and cancer began appearing in individuals with weak immune systems, a condition that was soon named **Acquired Immune Deficiency Syndrome (AIDS)**. In 1983, scientists discovered that the weak immune system was caused by a previously unknown virus that they named **Human Immunodeficiency Virus (HIV)**. This virus was spread both through sexual contact and by drug users who were sharing needles that had not been sanitized between uses.
The origin of this new virus remained a mystery until 2006 when researchers found a genetically similar virus in a wild population of chimpanzees living in the African nation of Cameroon (FIGURE 17.8). The researchers hypothesized that local hunters were exposed to the virus when butchering or eating the chimps (a common practice in this part of the world). With this exposure, the virus was able to infect a new host, humans. Today, more than 33 million people in the world are infected with HIV and 25 million people have died from AIDS-related illnesses. Fortunately, new antiviral drugs are able to maintain low HIV populations inside the human body and thereby substantially extend life. From the lessons learned in combating other diseases such as tuberculosis, combinations of antiviral drugs are being used to reduce the risk that the virus will evolve resistance to any single drug. Unfortunately, many of these drugs are quite expensive and not affordable to most people living in low-income countries. This is changing, however, and both the distribution and the availability of these drugs to those who cannot afford them have greatly improved.
EBOLA HEMORRHAGIC FEVER In 1976, researchers first discovered Ebola hemorrhagic fever, a disease caused by the Ebola virus. First discovered in the Democratic Republic of Congo near the Ebola River, the virus has infected several hundred humans and a variety of other primates from several countries in central Africa. Although infections of humans have been sporadic and have not reached epidemic proportions, the Ebola virus is of particular concern because it kills a large percentage of those infected. Infected individuals have suffered a 50 to 89 percent death rate from different outbreaks of the disease. Those infected quickly begin to experience fever, vomiting, and sometimes internal and external bleeding (FIGURE 17.9). Death occurs within 2 weeks, and there are no drugs available to fight the virus. Unlike the progress that has been made with identifying the origin of HIV, the natural source of the Ebola virus remains unknown. Because the virus also kills other primates at high rates, leaving no primate hosts for the virus, primates are not a likely long-term source of the virus.

Figure 17.9  Ebola hemorrhagic fever. The Ebola virus is highly lethal to humans and there are no drugs for treatment. When treating a person infected with the virus, researchers and medical workers have to exercise extreme caution.
Mad cow disease. Cows that have been fed the remains of dead cows and sheep can become infected with harmful prions. These prions cause the cows to develop glazed eyes, body tremors, and a loss of coordination, eventually leading to death. Humans who consume the beef from infected cows can become infected and suffer a similar fate.

MAD COW DISEASE In the 1980s, scientists first described a neurological disease, later known as mad cow disease, in which a pathogen slowly damages a cow’s nervous system. The cow loses coordination of its body (a condition compared to a person going mad), and then dies (FIGURE 17.10). Scientists now know that small, beneficial proteins in brains of cattle, called prions, occasionally mutate into deadly proteins that act as pathogens and subsequently cause mad cow disease. Prions are not well understood and represent a new category of pathogen.

In 1996, scientists in Great Britain announced that mad cow disease, also known as bovine spongiform encephalopathy (BSE), could be transmitted to humans who ate meat from infected cattle. Unlike harmful bacteria that can be killed with proper cooking, prions are difficult to destroy by cooking. Infected humans developed variant Creutzfeldt-Jakob disease (vCJD) and suffered a fate similar to the infected cattle. Mutant prions cannot be transmitted among cattle living together. Transmission requires an uninfected cow to consume the nervous system of an infected cow. As a result, when cattle feed on grass together in a pasture, a rare mutation in a prion would be restricted to a single cow and not spread to other cattle. In the 1980s, however, cattle diets in Europe commonly included the ground-up remains of dead cattle as a source of additional protein. If these remains happened to contain a mutant prion, the prions spread rapidly through the entire cattle population and, in turn, infected humans who ate the beef. In Britain, a total of 180,000 cattle were infected and 166 people had died as of 2009. It is estimated that several thousand people are currently infected, but the prions can exist in the human body for many years before they begin to cause symptoms of the disease. In response, the European Union temporarily banned British beef imports in 1996 and the British government
destroyed tens of thousands of cattle. Since that time, the disease has been found in several other countries including Canada and the United States, but only in a few cattle and no humans. Today, new rules exist that forbid the feeding of animal remains to cattle. As a result, the current risk of mad cow disease to humans has been greatly reduced.

**BIRD FLU** Humans commonly contract many types of flu viruses. As we saw in Chapter 5, the *Spanish flu* of 1918 killed up to 100 million people. Spanish flu was an avian influenza, also known as *bird flu*, caused by the H1N1 virus. This virus is similar to a flu virus that humans normally contract, but H1N1 normally infects only birds. Infections are rarely deadly to wild birds but can frequently cause domesticated birds such as ducks, chickens, and turkeys to become very sick and die. In 2006, reports emerged from Asia that a related virus, known as H5N1, had jumped from birds to people, primarily to people who were in close contact with birds (FIGURE 17.11). Although humans often contract a variety of flu viruses, they have no evolutionary history with the H5N1 virus and, as a result, have few defenses against it. As of 2009, more than 400 people had become infected by H5N1 and more than half of them died. Governments responded to this risk by destroying large numbers of infected birds. Currently the H5N1 virus is not easily passed among people, but if a future mutation makes transmission easier, scientists estimate that H5N1 has the potential to kill 150 million people.
WEST NILE VIRUS The West Nile virus lives in hundreds of species of birds and is transmitted among birds by mosquitoes. Although the virus can be highly lethal to some species of birds, including blue jays (Cyanocitta cristata), American crows (Corvus brachyrhynchos), and American robins (Turdus migratorius), most species of birds survive the infection. During the latter half of the twentieth century there were increasing reports that the virus could sometimes infect horses and humans who had been bitten by mosquitoes. The first human case was identified in 1937 in the West Nile region of Uganda, thus giving the virus its name. In humans, the virus causes an inflammation of the brain leading to illness and sometimes death. In 1999, the virus appeared in New York and quickly spread throughout much of the United States. Figure 17.12 shows the history of the West Nile virus in the United States. The highest numbers of infections and deaths from the virus occurred in 2002 and 2003. Increased efforts to combat mosquito populations and protect against mosquito bites are causing a decline in the disease.

17.2. The Future of Human Health

Humans face a large number of health risks, but we have an excellent understanding of the risk factors that are important and the ways to combat many historical and emerging infectious diseases. To combat diseases in low-income countries, the primary needs are improvements in nutrition, wider availability of clean drinking water, and proper sanitation. In high-income countries, public health efforts should promote healthier lifestyle choices such as increased physical activity, a balanced diet, and limiting excess food consumption and tobacco use. In all countries, continued education...
is needed to reduce the spread of diseases such as HIV and tuberculosis. Though many historical diseases are either currently under control or likely to be so soon if the financial resources become available, emerging infectious diseases may present a greater challenge. New diseases often arise from new pathogens with which we have no experience. Since we cannot predict which diseases will emerge next, public health officials throughout the world must develop rapid response plans when a particular disease does appear. These include rapid worldwide notification of newly identified diseases and strategies to isolate infected persons, which will slow the spread of the disease and provide time for researchers to develop appropriate tactics to combat the threat.

CHECKPOINT

• What is the difference between historical and emergent infectious diseases?
• Which diseases that affect humans are transmitted from animals to humans?
• What is the outlook for disease in both developing and developed nations? How is each different?

17.3 Toxicology is the study of chemical risks

The complexity of the biological risks humans face is matched by the complexity of chemical risks. Our modern society has developed an incredible array of chemicals to improve human life around the world, including pharmaceuticals, insecticides, herbicides, and fungicides. In addition to these beneficial chemicals manufactured to improve human health and food production, we have seen other chemicals that are often part of the by-products from industry and the generation of energy, some of which have proven harmful to humans and the environment. The large number of chemicals released into the environment naturally raises questions about potential effects these chemicals have on humans and other organisms. Many pharmaceuticals, for example, have unexpected consequences when released into the environment. In this section we will look at the types of chemicals that can have harmful effects, how scientists study these chemicals, and what kinds of effects they have.

17.3. Types of Harmful Chemicals

Chemicals can have many different effects on organisms, and some of the most harmful are common in our environment; TABLE 17.1 lists those of current concern. They can
be grouped into five categories: neurotoxins, carcinogens, teratogens, allergens, and endocrine disruptors.

**TABLE 17.1 Some chemicals of major concern**

<table>
<thead>
<tr>
<th>Chemical</th>
<th>Sources</th>
<th>Type</th>
<th>Effects</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lead</td>
<td>Paint, gasoline</td>
<td>Neurotoxin</td>
<td>Impaired learning, nervous system disorders, death</td>
</tr>
<tr>
<td>Mercury</td>
<td>Coal burning, fish consumption</td>
<td>Neurotoxin</td>
<td>Damaged brain, kidneys, liver, and immune system</td>
</tr>
<tr>
<td>Arsenic</td>
<td>Mining, groundwater</td>
<td>Carcinogen</td>
<td>Cancer</td>
</tr>
<tr>
<td>Asbestos</td>
<td>Building materials</td>
<td>Carcinogen</td>
<td>Impaired breathing, lung cancer</td>
</tr>
<tr>
<td>Polychlorinated biphenyls (PCBs)</td>
<td>Industry</td>
<td>Carcinogen</td>
<td>Cancer, impaired learning, liver damage</td>
</tr>
<tr>
<td>Radon</td>
<td>Soil, water</td>
<td>Carcinogen</td>
<td>Lung cancer</td>
</tr>
<tr>
<td>Vinyl chloride</td>
<td>Industry, water from vinyl chloride pipes</td>
<td>Carcinogen</td>
<td>Cancer has</td>
</tr>
<tr>
<td>Alcohol</td>
<td>Alcoholic beverages</td>
<td>Teratogen</td>
<td>Fetuses with reduced fetal growth, brain and nervous system damage</td>
</tr>
<tr>
<td>Atrazine</td>
<td>Herbicide</td>
<td>Endocrine disruptor</td>
<td>Feminization of males, low sperm counts</td>
</tr>
<tr>
<td>DDT</td>
<td>Insecticide</td>
<td>Endocrine disruptor</td>
<td>Feminization of males, thin eggshells of birds</td>
</tr>
<tr>
<td>Phthalates</td>
<td>Plastics, cosmetics</td>
<td>Endocrine disruptor</td>
<td>Feminization of males</td>
</tr>
</tbody>
</table>

**Figure 17.13 The decline of lead in children over time.** Lead poses a particular risk to childhood development. Lead was gradually phased out of gasoline and paint in the 1970s. Since that time, the
The average concentration of lead in the bloodstream of children between 1 and 5 years old has declined dramatically. [Data from CDC NHANES survey of blood lead levels in children.]

**Neurotoxins** are chemicals that disrupt the nervous systems of animals. Many insecticides, for example, are neurotoxins that interfere with an insect’s ability to control its nerve transmissions. Insects and other invertebrates are highly sensitive to neurotoxin insecticides. These animals can become completely paralyzed, cannot obtain oxygen, and quickly die. Other important neurotoxins include lead and mercury. As we discussed in Chapter 14 and Chapter 15, lead and mercury are very harmful heavy metals that can damage a person’s kidneys, brain, and nervous system. Mercury remains a major problem. Since the federal government required a gradual elimination of lead in gasoline and paint in the 1970s, lead exposure in the United States has declined sharply (FIGURE 17.13). However, lead contamination in children remains a serious problem in low-income neighborhoods due to the presence of old lead paint in buildings.

**Carcinogens** are chemicals that cause cancer. Carcinogens cause cell damage and lead to uncontrolled growth of these cells either by interfering with the normal metabolic processes of the cell or by damaging the genetic material of the cell. Carcinogens that cause damage to the genetic material of a cell are called mutagens (although not all mutagens are carcinogens). Some of the most well-known carcinogens include asbestos, radon, formaldehyde, and the chemicals found in tobacco.
Thalidomide was widely prescribed to pregnant women in the late 1950s to alleviate the symptoms of morning sickness, but it had the unanticipated effect of causing birth defects in tens of thousands of newborn children.

**TERATOGENS** Teratogens are chemicals that interfere with the normal development of embryos or fetuses. One of the most infamous teratogens was the drug thalidomide, prescribed to pregnant women during the late 1950s and early 1960s to combat morning sickness. Sadly, tens of thousands of these mothers around the world gave birth to children with defects before the drug was taken off the market in 1961. One of the most common modern teratogens is alcohol. Excessive alcohol consumption reduces the growth of the fetus and damages the brain and nervous system, a condition known as fetal alcohol syndrome. This is why physicians recommend that women not consume alcoholic beverages while they are pregnant.
**ALLERGENS**  
**Allergens** are chemicals that cause allergic reactions. Although allergens are not pathogens, allergens are capable of causing an abnormally high response from the immune system. In some cases, this response can cause breathing difficulties and even death. Typically, a given allergen only causes allergic reactions in a small fraction of people. Some common chemicals that cause allergic reactions include the chemicals naturally found in peanuts and milk and several drugs including penicillin and codeine.

**ENDOCRINE DISRUPTORS**  
**Endocrine disruptors** are chemicals that interfere with the normal functioning of hormones in an animal’s body. Hormones are normally manufactured in the endocrine system and released into the bloodstream in very low concentrations. As the hormones move through the body, they bind to specific cells. Binding stimulates the cell to respond in a way that regulates the functioning of the body.

As noted in our discussion of water pollution in Chapter 14, wastewater may contain hormones from animal-rearing facilities, hormones from human birth control pills found in residential sewage, and pesticides that mimic animal hormones. In waterways containing this wastewater, scientists are increasingly finding that male fish, reptiles, and amphibians are becoming feminized, with males possessing testes that have low sperm counts and, in some cases, testes that produce both eggs and sperm. This change occurs because males normally convert the female hormone estrogen into the male chemical testosterone. As **FIGURE 17.15** shows, some endocrine disruptors appear to interfere with the production of testosterone, resulting in males having higher concentrations of estrogen and lower concentrations of testosterone in their bodies. Such discoveries raise serious concerns about whether endocrine disruptors might affect the normal functioning of human hormones. These effects include low sperm counts in men and increased risks of breast cancer in women.
Male animals normally make estrogen and then convert it to testosterone, an important hormone for male reproduction. Some endocrine disrupting hormones are thought to interfere with this process, causing less testosterone to be produced. As a result, these males can have low sperm counts and eggs may develop inside their testes.

**CHECKPOINT**

- What are some of the beneficial ways humans use chemicals?
- What is the impact on humans of each of the five major types of chemicals?
- How are chemical and biological risks related?

**17.4 Scientists can determine the concentrations of chemicals that harm organisms**

To assess the risk a chemical poses to any organism, we need to determine the concentrations that cause harm. To learn this, scientists use *dose-response studies*, *prospective studies*, and *retrospective studies*.

**17.4. Dose-Response Studies**

*Dose-response studies* expose animals or plants to different amounts of a chemical and then observe a variety of possible responses including mortality or changes in behavior or reproduction. These chemical amounts can be measured as the *concentration* of a chemical in the air, water, or food. They can also be measured as
the dose of a chemical, which is the amount of chemical that is absorbed or consumed by an organism. For reasons of efficiency, most dose-response studies only last for 1 to 4 days. Because of their short duration, such experiments are called **acute studies**.

![Figure 17.16 LD50 studies. To determine the dose of a chemical that causes a 50 percent death rate, scientists expose animals to different doses of a chemical and determine what proportion of the animals die at each dose. Such an experiment typically produces an S-shaped curve.](image)

Dose-response studies most commonly measure mortality as a response. At the end of a dose-response experiment, scientists count how many individuals die after exposure to each concentration. When the data are graphed, the data generally follow an S-shaped curve, like the one in **FIGURE 17.16**. If you examine the purple curve, you will see that at the lowest dose no individuals die. At slightly higher doses, a few individuals die. The dose at which an effect can be detected is called the **threshold**. These individuals generally are in poorer health or genetically are not very tolerant to the chemical. As the dose is further increased, many more individuals begin to die. At the highest concentrations all individuals die.

A helpful measurement for comparing the harmful effects of different chemicals is the **LD50**, which is an abbreviation for the lethal dose that kills 50 percent of the individuals. The LD50 value is important for assessing the relative toxicity of a chemical. By quantifying the LD50 value for a new chemical, for example, scientists can compare the value to thousands of previous tests. In doing so, they can determine whether a new chemical is more or less lethal in comparison to other chemicals that are being used.

The amount of death that a chemical causes can differ among species and among different groups of species, including mammals, birds, fish, and invertebrates. Since conducting LD50 studies on humans would be unethical, studies are conducted on animals such as mice and rats and the results are extrapolated to humans. To understand the effects of chemicals on nonhuman animals, test results from mice and rats are used to represent all mammals, birds such as pigeons and quail are used to
represent all birds, fish such as trout are used to represent all fish, and common invertebrates such as water fleas are used to represent all invertebrates. Not all dose-response experiments measure death as a response. In many cases, scientists are interested in other harmful effects that a chemical might have, including its acting as a teratogen, carcinogen, or neurotoxin that could alter the behavior of an individual. We call these **sublethal effects**. In these cases, the experiments are conducted to determine the effective dose that causes 50 percent of the individuals to display the harmful, but nonlethal, effect. This dose is known as the **ED50**.

**TESTING STANDARDS** In the United States, the effects of chemicals on humans and wildlife are regulated by the Environmental Protection Agency (EPA). The Toxic Substances Control Act of 1976 gives the EPA the authority to regulate many chemicals, though excluding food, cosmetics, and pesticides. Pesticides are regulated under a separate law—the Federal Insecticide, Fungicide, and Rodenticide Act of 1996. Under this act, a manufacturer must demonstrate that a pesticide "will not generally cause unreasonable adverse effects on the environment."

With approximately 10 million species of organisms on Earth, no chemical can be tested on every organism. As a result, scientists have devised a system of testing a few species—a bird, mammal, fish, and invertebrate—that are thought to be among the most sensitive in the world. The particular species tested from each of the four animal groups can vary, depending on which species is thought to be the most sensitive to a particular chemical. The logic is that if we know the sensitivity of the most sensitive species in a group, then any regulations that are devised to protect it would automatically protect all other species in that group.

You might have noticed that the four groups of animals required to be tested do not include amphibians or reptiles. Unfortunately, the standards for testing chemicals were set up before there was much interest in protecting amphibians and reptiles. Currently, test results from fish are used to represent aquatic amphibians and reptiles, whereas test results from birds are used to represent terrestrial amphibians and reptiles. Because amphibians and reptiles are now experiencing population declines throughout the world, there is increased interest in requiring tests of these two groups as well.

Using the LD50 and ED50 values from dose-response experiments, regulatory agencies such as the EPA can determine the concentrations in the environment that should cause no harm. For most animals, a safe concentration is obtained by taking the LD50 value and dividing it by 10. The logic is that if the LD50 value causes 50 percent of the animals to die, then 10 percent of the LD50 value should cause few or no animals to die.
For humans, however, the regulatory agencies are much more conservative in setting concentrations. As mentioned earlier, dose-response tests cannot be conducted on humans. Therefore scientists conduct dose-response experiments on rats and mice and then extrapolate the results to humans. The LD50 or ED50 values are then divided by 10 to determine a safe concentration for rats and mice. This value is divided by 10 again to reflect that rats and mice may be less sensitive to a chemical than humans. Finally, this value is often divided by 10 again to ensure an extra level of caution. In short, the LD50 and ED50 values obtained from rats and mice are divided by 1,000 to set the safe values for humans. Do the Math "Estimating LD50 Values and Safe Exposures" shows you how to make this calculation.

**CHRONIC STUDIES** Although the vast majority of toxicology studies are only conducted for a few days, some studies are conducted for longer periods of time. These experiments of longer duration are called **chronic studies**. Chronic studies will often last from the time an organism is very young to when it is old enough to reproduce. For some species such as fish, chronic experiments can take several months. The goal of chronic studies is to examine the long-term effects of chemicals, including their effects on survival and their impacts on reproduction (**FIGURE 17.18**).

**DO THE MATH**

**Estimating LD50 Values and Safe Exposures**

Using our knowledge of how scientists conduct LD50 studies, we can consider an example. Let’s imagine that you are a scientist charged with determining the safe levels for mammals of a pesticide in the environment. Using lab rats, you feed them a diet that contains different amounts of the pesticide, ranging from 0 to 4 mg of pesticide per kg of the rat’s mass. After feeding them these diets for 4 days, you count how many rats are still alive. When you plot the data, you obtain the graph in **FIGURE 17.17**.
Figure 17.17 Calculating safe doses. When a rat is fed increased amounts of a chemical, the amount of mortality increases.

What is the LD50 value for lab rats? To determine this, we can draw a horizontal line at the point of 50 percent mortality on the y axis. Where this line intersects the purple line, we can draw another line straight down to the x axis. This second line crosses the x axis at 2 mg/kg of mass.

Based on this LD50 study, what amount of pesticide would be considered safe for mammals to ingest? Recall that we can calculate this number by taking the LD50 value and dividing it by 10. Thus the safe amount of pesticide for a rat is:

\[ \frac{2 \text{ mg/kg of mass}}{10} = 0.2 \text{ mg/kg of mass} \]

Your Turn
Using the same LD50 study, what amount of pesticide would be considered safe for a human to ingest?
Figure 17.18 Conducting dose-response experiments. (a) Researchers determine how chemicals affect the mortality, behavior, and reproduction of animals using both acute and chronic dose-response experiments. (b) In the experiment shown, researchers are examining the effects of different insecticide concentrations on the survival of tadpoles.

17.4. Retrospective versus Prospective Studies

Estimating the effects of chemicals on humans is a major challenge. One approach that we have discussed conducts dose-response experiments on rats and mice and extrapolates the results to humans. An alternative approach examines large populations of humans or animals who are exposed to chemicals in their everyday lives and then determines whether these exposures are associated with any health problems. Such investigations fall within the study of epidemiology, a field of science that strives to understand the causes of illness and disease in human and wildlife populations. There are two ways of conducting this type of research: retrospective studies and prospective studies.

**Retrospective studies** monitor people who have been exposed to a chemical at some time in the past. In such studies, scientists identify a group of people who have been exposed to a potentially harmful chemical and a second group of people who have not been exposed. Both groups are then monitored for many years to see if the exposed group experiences greater health problems than the unexposed group. In 1984, for example, there was an accidental release of methyl isocyanate gas from a Union Carbide pesticide factory in Bhopal, India. More than 36,000 kg (80,000 pounds) of hazardous gas spread through the city of 500,000 inhabitants. An estimated 2,000 people died that night and another 15,000 died later from effects related to the exposure. Scientists have now been monitoring many citizens of Bhopal for more than
two decades to determine if survivors of the accident have developed any additional health problems over time. The retrospective studies have found that approximately 100,000 people are still suffering illness from the accident. As shown in FIGURE 17.19, the survivors have higher rates of respiratory symptoms and still births; they also have higher rates of genetic abnormalities, infant mortality, kidney failure, and learning disabilities.

In contrast to retrospective studies, prospective studies monitor people who might become exposed to harmful chemicals in the future. In this case, scientists might select a group of 1,000 participants and ask them to keep track of the food they eat, the tobacco they use, and the alcohol they drink for the next 40 years. As time passes, the researchers can determine if the habits of the participants have any association with future health problems. Prospective studies can be quite challenging because a participant’s habits, such as tobacco use, can also be associated with many other risk factors including socioeconomic status. Of particular concern is when multiple risks cause synergistic interactions, in which two risks together cause more harm than
one would expect based on their individual risks. For example, the health impact of a carcinogen such as asbestos can be much higher if an individual also smokes tobacco. Studies of lead in children are often conducted using prospective studies. In one study conducted by researchers at Harvard University on the effects of lead on children’s intelligence, 276 children in Rochester, New York, were followed from 6 months to 5 years of age. At the age of 5, children can take reliable IQ tests. In addition to lead exposure, the researchers also accounted for other factors that might affect childhood IQ including the mother’s IQ, exposure to tobacco, and the intellectual environment of their homes. After controlling for these other factors, the researchers found that among children who had been exposed to lead in the environment, primarily from lead dust and consumed lead paint chips, those with higher lead exposures scored lower on the subsequent IQ tests. Such prospective studies can be very helpful in helping regulators determine acceptable levels of chemical exposure.

17.4. **Factors That Determine Concentrations of Chemicals Organisms Experience**

Knowing the concentrations of chemicals that can harm humans or other animals is important, but it is only useful when combined with information about the concentrations that an individual might actually experience in the environment. If a chemical is quite harmful at some moderate concentration but individuals only experience lower concentrations, we might not be particularly concerned. Therefore, to identify and understand the effects of chemical concentrations that organisms experience, we need to know something about how the chemicals behave in the environment.
Despite a multitude of potential routes of exposure to chemicals, most chemicals have a limited number of major routes. The ways in which an individual might come into contact with a chemical are known as routes of exposure. As Figure 17.20 illustrates, the full range of possibilities is complex because it includes potential exposures from the air, from water used for drinking, bathing, or swimming, from food, and from the environments of places where people live, work, or visit. For any particular chemical, however, the major routes of exposure are usually limited to just a few of the many possible routes. For example, bisphenol A is a chemical used in the manufacturing of hard plastic items such as toys, food containers, and baby bottles. Recent research has raised concerns that bisphenol A may be responsible for early puberty and increased rates of cancer. While these effects are being debated and investigated, it is clear that a child’s exposure to bisphenol A is limited to toys, food containers, and baby bottles. Knowing this, scientists can then determine the chemical’s solubility and its potential for bioaccumulation and biomagnification.

**SOLUBILITY OF CHEMICALS, BIOACCUMULATION, AND BIOMAGNIFICATIONS** The movement of a chemical in the environment depends in part on its solubility—how well a chemical can dissolve in a liquid. Some chemicals are
readily soluble in water whereas others are much more soluble in fats and oils. Water-soluble chemicals can be pervasive in groundwater and surface waters including rivers and lakes. In contrast, chemicals that are soluble in fats and oils are not commonly found in water, but are found in higher concentrations in soils, including the benthic soils that underlie bodies of water. Oil-soluble chemicals are also readily stored in the fat tissues of animals. Continued exposure to oil-soluble chemicals can cause bioaccumulation, an increased concentration of a chemical within an organism over time. The process of bioaccumulation begins when an individual incorporates small amounts of a chemical from the environment into its body. As the chemical continually accumulates over time, often in fat tissues, the concentration of the chemical inside the organism increases. Fish, for example, are exposed to low concentrations of methyl mercury when they drink water, pass water over their gills to breathe, and consume food that contains mercury. A fish stores mercury in its fat tissues and, over time, the mercury accumulates. The rate of accumulation for any animal will depend on the concentration of the chemical in the environment, the rate that the animal takes up each source of the chemical, the rate at which the chemical breaks down inside the animal, and the rate at which it is excreted by the animal.

**Biomagnification** is the increase in chemical concentration in animal tissues as the chemical moves up the food chain. For example, primary consumers can obtain an oil-soluble chemical from the environment and the chemical bioaccumulates in their fat tissues. Secondary consumers then consume the primary consumers and the chemical that they contain. The secondary consumers bioaccumulate the chemical they have ingested by consuming the chemical that is stored in the fat tissues of the primary consumers. The chemical is now stored in the secondary consumer’s fat tissues. As we continue to move up the food chain, each trophic level is exposed to higher concentrations of chemicals from the food it consumes. In this way, the original concentration in the environment is magnified to occur at a much higher concentration in the top predator of the community.
The biomagnification of DDT. The initial exposure is primarily in a low trophic group such as the plankton in a lake. Consumption causes the upward movement of the chemical where it is accumulated in the bodies at each trophic level. The combination of bioaccumulation at each trophic level and upward movement by consumption allows the concentration to magnify to the point where it can be substantially more concentrated in the top predator than it was in the water. [Data from G. M. Woodwell, C. F. Wurster, Jr., and Peter A. Isaacson, DDT residues in an East Coast estuary: A case of biological concentration of a persistent insecticide, Science, New Series, 156 (3776) (May 12, 1967): 821–824. http://www.jstor.org/stable/1722018.]

The classic example of biomagnifications is the case of DDT, an insecticide that has been widely used to kill insect pests in agriculture and to kill the mosquitoes that carry malaria and other diseases. DDT is not soluble in water, so when sprayed over water it quickly binds to particulates in the water and the underlying soil or is quickly taken up
by the tiny zooplankton that act as primary consumers on algae. As we see in FIGURE 17.21, the very low concentration of DDT in the water bioaccumulates in the bodies of the zooplankton where it becomes approximately 1,000 times more concentrated. Small fish eat the zooplankton for many weeks or months and the DDT is further concentrated approximately 6-fold. Large fish spend their lives eating the contaminated smaller fish and the DDT in the large fish is further concentrated approximately 5-fold. Finally, fish-eating birds such as pelicans and eagles spend years eating the large fish and further magnify the DDT in their own bodies. Because of biomagnification along the food chain, the concentration of DDT in the birds is nearly 276,000 times higher than the concentration in the water. The concentrated DDT caused fish-eating birds to produce thin-shelled eggs that often broke when the parent birds incubated the eggs. This was a primary cause in the decline of these birds in the 1960s. Since DDT was banned in the United States in 1972, the populations of these birds have dramatically increased.

**PERSISTENCE** The persistence of a chemical refers to how long the chemical remains in the environment. Persistence depends on a number of factors including temperature, pH, whether the chemical is in water or soil, whether the chemical can be degraded by sunlight, and whether the chemical can be broken down by microbes. Scientists often measure persistence by observing the time needed for a chemical to degrade to half its original concentration, or the half-life of the chemical (TABLE 17.2). DDT, for example, has a half-life in soil of up to 30 years. Thus, even after DDT is no longer sprayed in an area, half of the chemical that was absorbed in the soil would still be present after 30 years, and one-fourth would be present after 60 years. Chemicals that cause harmful effects on humans and other organisms may become even larger risks when they persist for many years. For this reason, many modern chemicals are designed to break down much more rapidly so that any unintended effects will be short-lived.
Why is it difficult to test the potential effects of chemicals on humans?

How does route of exposure influence toxicity? How does solubility affect exposure to chemicals?

In what ways are persistence and bioaccumulation similar concepts? How are they related to one another?

17.5 Risk analysis helps us assess, accept, and manage risk

Many of our actions involve some amount of risk from environmental hazards. For our purposes, an environmental hazard is anything in our environment that can potentially cause harm. Environmental hazards include substances such as pollutants or other chemical contaminants, human activities such as draining swamps or logging forests, or natural catastrophes such as volcanoes and earthquakes. The hazards we face may be voluntary, as when we make a decision to smoke tobacco, or they may be involuntary, as when we are exposed to air pollution.

When assessing the risk of different environmental hazards, regulatory agencies, environmental scientists, and policy makers usually follow the three steps listed in **FIGURE 17.22**. These are risk assessment, risk acceptance, and risk management.

<table>
<thead>
<tr>
<th>Chemical</th>
<th>Half-life</th>
</tr>
</thead>
<tbody>
<tr>
<td>Malathion insecticide</td>
<td>1 day</td>
</tr>
<tr>
<td>Radon</td>
<td>4 days in air</td>
</tr>
<tr>
<td>Vinyl chloride</td>
<td>4.5 days in air</td>
</tr>
<tr>
<td>Phthalates</td>
<td>4.5 days in water</td>
</tr>
<tr>
<td>Roundup herbicide</td>
<td>7 to 70 days in water</td>
</tr>
<tr>
<td>Atrazine herbicide</td>
<td>224 days in wetland soils</td>
</tr>
<tr>
<td>Polychlorinated biphenyls (PCBs)</td>
<td>8 to 15 years in water</td>
</tr>
<tr>
<td>DDT</td>
<td>30 years in soil</td>
</tr>
</tbody>
</table>

Risk assessment seeks to identify a potential hazard and determine the magnitude of the potential harm. There are two types of risk assessment—qualitative and quantitative.

**QUALITATIVE RISK ASSESSMENT** Each of us has some idea of the risk associated with different environmental hazards. We generally make qualitative judgments in which we might categorize our decisions as having low, medium, or high risks. When we choose to slow down on a wet highway or to buy a more expensive car because it is safer, for example, we are making qualitative judgments of the relative risks of various decisions. That is, we make judgments that are based on our perceptions but that are not based on actual data. It would be unusual for us to consider the actual probability—that is, the statistical likelihood—of an event occurring and the probability of that event causing us harm. Because our personal risk assessments are not quantitative, they often do not match the actual risk.

**PERCEIVED RISK VERSUS ACTUAL RISK** The perception that certain behaviors or activities carry a high risk does not always match the reality. For example, some people find air travel very stressful because they are afraid the plane might crash. These same people often prefer riding in a car, which they perceive to be much safer. Or, a person may be very cautious about safety while walking in an area with heavy traffic but never consider the health dangers of smoking or a lack of exercise. To manage our risk effectively, we need to ask how closely our perceptions of risk match the reality of actual risk.

In the United States, the actual risks of various hazards are well known based on death statistics that are kept by the government. By knowing the total number of people who die in a year and their different causes of death, researchers can calculate the probability of an individual dying from each cause. **FIGURE 17.23** provides current data on causes of death in the United States. Because these risk estimates are based on real data, they are quantitative rather than qualitative. If we examine this figure, we see that the probability of dying in an automobile is far greater than the probability of dying in an airplane. Similarly, the probability of dying from heart disease is
monumentally greater than the risk of dying in a pedestrian accident. These numbers underscore the fact that our perceptions of risk can often be very different from the actual risk. Because a catastrophic event, such as a nuclear plant meltdown or a plane crash, can do a great deal of harm and receives great media attention, people believe that it is very risky to use nuclear reactors or to fly in airplanes. However, as these events rarely occur the risk of harm is low. In contrast, we tend to downplay the risk of activities that provide us with cultural, political, or economic advantages such as drinking alcohol or working in a coal mine.

Figure 17.23 The probabilities of death in the United States. Some factors that people perceive as having high risks of death, such as dying in an airplane crash, actually are quite low. In contrast, some factors that people rate as low risk, such as dying from heart disease, actually pose the greatest risk. [After National Geographic Society (2006); data from National Safety Council (2005).]
**QUANTITATIVE RISK ASSESSMENT** The most common approach to conducting a quantitative risk assessment can be expressed with a simple equation:

\[
\text{Risk} = \text{probability of being exposed to a hazard} \times \text{probability of being harmed if exposed}
\]

Using this equation, we could ask whether it is riskier to fly on commercial airlines for 1,000 miles per year or to eat 40 tablespoons of peanut butter per year (which contains tiny amounts of a carcinogenic chemical produced naturally by a fungus that sometimes occurs in peanut butter). The risk of dying in a plane crash depends on the probability of your plane crashing(which is very low) multiplied by your probability of dying if the plane does crash (which approaches 100 percent). The risk of dying of cancer from consuming peanut butter depends upon your probability of eating peanut butter (which is near 100 percent) multiplied by the probability that consuming peanut butter will cause you to develop lethal cancer (which is very small). It turns out that both behaviors produce a 1 in 1 million chance of dying. This example demonstrates a fundamental rule of risk assessment: the risk of a rare event that has a high likelihood of causing harm can be equal to the risk of a common event that has a low likelihood of causing harm.

Quantitative risk assessments bring together tremendous amounts of data. The estimates of harm can come from acute and chronic dose-response experiments, retrospective studies, and prospective studies. The estimates of which concentrations of a chemical an organism will experience in the environment incorporates the concentrations found in nature, routes of exposure, solubility, persistence, and the potential for the chemical to bioaccumulate or biomagnify. Together, these two groups of data are integrated to estimate the probability of harm.

**A CASE STUDY IN RISK ASSESSMENT** As we saw in Chapter 14 on water pollution, from the 1940s to the 1970s some companies manufacturing electrical components dumped PCBs (polychlorinated biphenyls) into rivers. Beginning in the 1960s, there was increasing evidence that PCBs might have harmful health effects on organisms that came into contact with them, including liver damage in animals and impaired learning in human infants.

Once the EPA identified PCBs as a potential hazard, it began a risk assessment. The agency brought together a range of data. First, scientists had to determine which concentrations of PCBs might cause cancer. To accomplish this objective, they examined dose-response studies on laboratory rats exposed to different concentrations of PCBs. They also examined retrospective studies of cancer cases in workers employed by industries that used PCBs. Next, they had to determine what concentrations people might experience. To accomplish this, scientists examined data on current
concentrations in the air, soil, and water and considered the half-life of the chemical. Because PCBs were found throughout the environment and because they are very persistent, the probability of coming into contact with PCBs was considered relatively high. They also considered the potential routes of exposure: eating contaminated fish, drinking contaminated water, and breathing contaminated air. The final result of the risk assessment on PCBs showed that the risk from eating contaminated fish is higher than the risk from drinking contaminated water and much higher than breathing contaminated air. As a result, signs were posted on the Hudson River instructing anglers not to consume the fish that they had caught (FIGURE 17.24). With limited fish consumption, the EPA concluded that the absolute risk of an individual developing cancer from PCB exposure was low. As discussed in Chapter 14, however, the risk was high enough to cause the EPA to recommend a dredging of the Hudson River to remove a large fraction of the PCBs that had settled at the bottom of the river.

![Image of warning sign]

**Figure 17.24** The outcome of a risk assessment of PCBs. Based on a risk assessment of humans consuming fish, the EPA determined that the fish living in the Hudson River in New York State and in Silver Lake in Massachusetts had unacceptably high concentrations of PCBs due to illegal dumping of PCBs by General Electric. As a result, anglers were not allowed to keep and consume the fish that they caught.

### 17.5. Risk Acceptance

Once the risk assessment is completed, the second step is determining risk acceptance—the level of risk that can be tolerated. Risk acceptance may be the most difficult of the three steps in the risk-analysis process. No amount of information on the
extent of the risk will overcome the conflict between those who are willing to live with some amount of risk and those who are not. Even among those people who are willing to accept some risk, the precise amount of acceptable risk is open to heated disagreement. For example, according to the EPA, a 1 in 1 million risk is acceptable for most environmental hazards. Some people believe this is too high. Others feel that a 1 in 1 million chance of death from radiation leaks is a small price to pay for the electricity generated by nuclear energy. While personal preferences will always complicate the determination of risk acceptance, environmental scientists, economists, and others can help us weigh the options as objectively as possible by providing accurate estimates of the costs and benefits of activities that affect the environment.

17.5. Risk Management

Risk management, the third part of the risk-analysis process, seeks to balance possible harm against other considerations. Risk management integrates the scientific data on risk assessment and the analysis of acceptable levels of risk with a number of additional factors including economic, social, ethical, and political issues. Whereas risk assessment is the job of environmental scientists, risk management is a regulatory activity that is typically carried out by local, national, or international government agencies. The regulation of arsenic in drinking water provides an excellent example of the difference between risk assessment and risk management. As we saw in Chapter 14, despite the fact that scientists knew that 50 μg/L of arsenic could cause cancer in people, from 1942 to 1999 the federal government set the acceptable concentration of arsenic at 50 μg/L. In 1999, the EPA announced it was lowering the maximum concentration of arsenic in drinking water to 10 μg/L, which matched the standards set by the European Union and the World Health Organization. This new regulation threatened to place a new economic burden on mining companies that produced arsenic as a by-product of mining and on several municipalities in western states with naturally high concentrations of arsenic in their drinking water. Both groups lobbied hard against the lower arsenic limits because the lower limits would require a large financial investment to remove the arsenic from drinking water. In 2001, weeks before the new lower limits were to go into effect, the EPA announced that it would return to the 50 μg/L limit. The agency argued that further risk assessments needed to be conducted and any risk assessment had to be balanced by economic interests. Later in 2001, the National Academy of Sciences concluded that the acceptable amount of arsenic was actually 5 μg/L, which was lower than some previous estimates. This new risk assessment played a key role in striking a balance between the scientific data and
economic interests and the EPA revised its ruling, setting the safe arsenic concentration at 10 μg/L.

17.5. Worldwide Standards of Risk

There are currently about 80,000 registered chemicals in the world but they are not regulated the same way around the globe. A key factor determining the type of chemical regulation is whether the regulations are guided by the *innocent-until-proven-guilty principle* or the *precautionary principle*, outlined in FIGURE 17.25. The *innocent-until-proven-guilty principle* is based on the philosophy that a potential hazard should not be considered a hazard until the scientific data can definitively demonstrate that a potential hazard actually causes harm. This philosophy allows the introduction of beneficial chemicals more quickly. The downside of this philosophy is that harmful chemicals can affect humans or wildlife for decades before sufficient scientific evidence accumulates to confirm that they are harmful.

In contrast, the *precautionary principle* is based on the philosophy that when a hazard is plausible but not yet certain, we should take actions to reduce or remove the hazard. The plausibility of the risk must have a scientific basis, rather than simple speculation. In addition, the intervention should be in proportion to the potential harm that might be caused by the hazard. The benefit of this philosophy is that fewer harmful
chemicals will enter the environment. However, the introduction of beneficial chemicals that are ultimately found not to pose harm could be delayed for many years if the initial assessment indicates a plausible risk. Moreover, the slower pace of approval can reduce the financial motivation of manufacturers to invest in research for new chemicals. In short, there is a trade-off between greater safety with slower introduction of beneficial chemicals versus greater potential risk with a greater rate of discovery of helpful chemicals. Use of the precautionary principle has been growing throughout many parts of the world and was instituted by the European Union in 2000. The United States, however, continues to use the innocent-until-proven-guilty principle.

**Figure 17.26** The risks of asbestos dust. Despite nearly a century of studies on the risks of asbestos dust to human health, only recently have workers been required to go to great lengths to prevent exposure. Today, they dress in chemical suits and respirators when removing asbestos from a building. Applying the precautionary principle would have required protection of workers many decades earlier and saved hundreds of thousands of lives.
The potential benefit of the precautionary principle can be illustrated using the case of asbestos. Asbestos is a white, fibrous mineral that is very resistant to burning. This made asbestos a popular building material throughout much of the twentieth century. It is now widely accepted that dust from asbestos can cause a number of deadly diseases including asbestosis (a painful inflammation of the lungs) and several types of cancer. When asbestos was first mined in 1879, there was no evidence that it harmed humans. The first report of deaths in humans was in 1906 and the first experiment showing harmful effects in rats was conducted in 1911. In 1930, it was reported that 66 percent of workers in an asbestos factory suffered from asbestosis. In 1955, researchers found that asbestos workers had a higher risk of lung cancer than other groups. In 1965, a study linked a rare form of cancer with workers who were exposed to asbestos dust. Despite all of the growing scientific evidence that asbestos was harming human health, little was done to reduce the exposure of workers and the public. Indeed, it was not until 1998 that the European Union banned asbestos. Today, workers go to great lengths not to be exposed to asbestos dust (FIGURE 17.26). A study in the Netherlands estimated that had asbestos been banned in 1965 when the harm to health became clear, the country would have had 34,000 fewer deaths from asbestos and would have saved approximately $25 billion in cleanup and compensation costs. Because the effects of asbestos can take several decades to harm a person’s health, the European Union estimates that from 2005 to 2040 they will have 250,000 to 400,000 more people die as a result of past exposures to asbestos. Had the European Union been using the precautionary principle decades earlier, the number of deaths would have been considerably less.

**INTERNATIONAL AGREEMENTS ON HAZARDOUS CHEMICALS** In 2001 a group of 127 nations gathered in Stockholm, Sweden, to reach an agreement on restricting the global use of some chemicals. The agreement, known as the [Stockholm Convention](https://www.paulcruickshank.com/), produced a list of 12 chemicals to be banned, phased out, or reduced. These 12 chemicals came to be known as the "dirty dozen" and included pesticides such as DDT, industrial chemicals such as PCBs, and certain chemicals that are by-products of manufacturing processes. All of the chemicals were known to be endocrine disruptors, and a number of them had already been banned or were experiencing declining use in many countries. However, bringing countries together in a forum to discuss controlling the most harmful chemicals was the great achievement of the Stockholm Convention. In 2009, 9 additional chemicals were added to the original list of 12 and several more have been suggested for future listing. In 2007, the 27 nations of the European Union put into effect an agreement on how chemicals should be regulated within the European Union. Known as [REACH](https://www.paulcruickshank.com/), an acronym for registration, evaluation, authorisation, and restriction of chemicals, the
agreement embraces the precautionary principle by putting more responsibility on chemical manufacturers to confirm that chemicals used in the environment pose no risk to people or the environment. This regulation was enacted because many chemicals used for decades in the European Union had not been subjected to rigorous risk analyses. The new regulations are being phased in over several years to permit sufficient time for chemical manufacturers to complete the required testing.

CHECKPOINT

- Why is risk acceptance the most complex and difficult of the three steps in risk analysis?
- What is the difference between the innocent-until-proven-guilty principle and the precautionary principle?
- Why might the United States be resistant to the precautionary principle approach?

WORKING TOWARD SUSTAINABILITY

The Global Fight Against Malaria

Bill Gates is best known as the founder of Microsoft, the computer software company, but he is also an active philanthropist. In 2007 he stood up in front of a large group of scientists in Seattle, Washington, and declared that the world needed to eradicate malaria. In challenging the scientists of the world, he asked, "Why would anyone want to follow a long line of failures by becoming the umpteenth person to declare the goal of eradicating malaria?"

Bill Gates knew the history of malaria. People have died from this disease for thousands of years. In modern times, 350 million to 500 million people are infected each year and 1 million of them die. Most malaria cases are in Africa and most of those who die are children. Several eradication efforts have been attempted over the past six decades, mostly focused on eradicating the mosquitoes that carry the malaria pathogen. In the United States, eradication was achieved in 1951 through widespread spraying of the insecticide DDT as well as the application of numerous other public health measures. This spraying program became controversial in the 1960s and 1970s because DDT was found to be widely distributed around the globe and it was linked to the thinning of egg shells in large birds of prey due to its biomagnification. DDT is still sprayed in many parts of the world to assist in the eradication of malaria, but malaria has not been eradicated.
Malaria is difficult to eliminate for a number of reasons. First, mosquito populations that are impacted by spraying insecticides can rebound quickly. In Sri Lanka, for example, consistent spraying to kill mosquitoes reduced the number of malaria cases from 1 million to a mere 18. Because of this great success, the spraying program was stopped there, but within a few years, malaria cases rapidly increased to a half million. In short, the spraying program was ended before the job was done. Moreover, if one country is spraying to kill mosquitoes and neighboring countries are not, mosquitoes will continue to enter from the neighboring countries. Second, mosquitoes can rapidly evolve resistance to insecticides such as DDT. Third, the malaria pathogen can rapidly evolve resistance to antimalaria drugs. Finally, eradicating malaria is expensive. Typically, countries use multiple strategies including insecticide spraying, antimalarial drugs, and the distribution of mosquito tents in which people can sleep and avoid being bitten during the night (FIGURE 17.27). Collectively, these strategies can carry a price tag that many poor countries cannot afford. Additionally, other social and economic priorities of these countries, as well as social disruption, have precluded or curtailed malaria control programs.

So in 2007, after so many past failures, why did Bill Gates think there was now a possibility of eradicating malaria? Earlier that year, scientists had reported that a new drug, combined with a new style of mosquito net, produced large reductions in malaria cases—as much as a 97 percent reduction in Uganda. The new nets, which were
impregnated with more modern insecticides, could last 3 to 5 years. This was a big improvement from the earlier nets that only lasted up to 3 months. In addition to having a new drug and longer-lasting nets, the key to the success of the Ugandan program was to pay for and distribute the drug and nets to everyone who needed them. Employing this strategy around the world is an expensive endeavor, and that’s where Bill Gates comes in.

The Bill and Melinda Gates Foundation funds projects that have been historically underfunded. Equally important, by throwing its prominent name and financial resources behind a cause like malaria eradication, the foundation can rally significant financial support from other foundations and from developed countries. Western governments joined the movement and increased malaria funding from $50 million to $1.1 billion. This gave new hope to the declared goal of eradicating malaria from the globe within 50 years.

Many challenges remain. One of the largest is simply organizing distribution systems to hand out the drugs and millions of mosquito tents. In some regions, there are no roads into the villages and the items must be brought in by foot or by boat. There is also the challenge to continue research into new strategies against the pathogen and the mosquito. Currently, a new antimalaria drug from China has proven very effective against the pathogen and is quite inexpensive to manufacture. The manufacturer of this drug agreed to sell it at less than the cost of manufacturing it, making the drug a very attractive option for low-income countries. The company estimates that this decision cost it $253 million in profits but saved 550,000 lives and brought the company very positive publicity. Another possibility is the development of a vaccine that would provide immunity to malaria infections. Research is ongoing.

Today there is tremendous hope that Bill Gates’s dream of eradicating malaria is gaining ground. Most experts agree that malaria cases could be reduced by at least 85 percent in most African countries. The reduction in illness and death would also be highly beneficial to the economies of these low-income countries by realizing reduced health costs and a healthier, and therefore more productive, workforce. The success of the global fight against malaria critically depends on sustained financial support from foundations and governments, continued discovery of new drugs and vaccines, and the recognition that we cannot stop fighting malaria until the job is done.

References
**KEY IDEAS REVISITED**

- **Identify the three major categories of human health risk.**
  The major categories of human health risk are physical risks such as natural catastrophes, biological risks such as diseases, and chemical risks such as pesticides.

- **List the major historical and emerging infectious diseases.**
  Some of the major historical infectious diseases include plague, malaria, and tuberculosis. Some of the emerging infectious diseases include HIV/AIDS, Ebola hemorrhagic fever, mad cow disease, bird flu, and West Nile virus.

- **Name the five major types of toxic chemicals.**
  The five major types of toxic chemicals are neurotoxins, carcinogens, teratogens, allergens, and endocrine disruptors.

- **Distinguish between dose-response studies, retrospective studies, and prospective studies.**
  Dose-response studies expose animals to a range of chemical concentrations to determine which concentrations cause harmful effects. Retrospective studies identify a group of people who have been exposed to a chemical in the past and follow them through time to determine if they suffer any harmful effects. Prospective studies identify a group of people and determine whether future exposures to chemicals are associated with any harmful effects.

- **Describe the factors that help determine the chemical concentrations that organisms experience.**
  The amount of exposure to a chemical depends on the potential routes of exposure, how soluble the chemical is in the environment and in the human body, whether the chemical can bioaccumulate with an organism, and whether the chemical can biomagnify up a food chain.

- **Explain the factors that go into a risk analysis and distinguish between the two major philosophies of chemical regulation.**
  A risk analysis starts by identifying a potential hazard and assessing the risk that concentrations in the environment pose to humans or other organisms. The analysis then determines an acceptable level of risk. Finally, social, economic, political, and ethical considerations are weighed to ultimately manage the risk. The innocent-until-proven-guilty principle requires scientists to demonstrate that a chemical causes harm to humans or the environment before any restrictions are imposed. According to the precautionary principle, if scientists have made a plausible association between a chemical and harm to humans or the environment, then the use of the chemical should be restricted until scientists can demonstrate that the chemical is safe.

**PREPARING FOR THE AP EXAM**

**MULTIPLE-CHOICE QUESTIONS**
1. Which statement is true regarding human health risks?
   - (a) More people die from infectious diseases than from noninfectious diseases.
   - (b) More people die from accidents than from any other cause.
   - (c) More people die from chemical risks than from physical or biological risks.
   - (d) More people die from cancer than from any other cause.
   - (e) More people die from heart disease than from any other cause.

   [Answer Field]

2. Which statement is true regarding the relationship between health risks and income?
   - (a) A major risk in high-income countries is a lack of food.
   - (b) A major risk in high-income countries is poor sanitation.
   - (c) A major risk in low-income countries is obesity.
   - (d) A major risk in low-income countries is a lack of food.
   - (e) The major risks in high- and low-income countries are similar.

   [Answer Field]

3. Which statement about historical infectious diseases is not true?
   - (a) Plague is a disease that is carried by fleas attached to rodents.
   - (b) Malaria is a disease that is carried by mosquitoes.
   - (c) Tuberculosis is a disease that is transmitted through the air.
   - (d) The pathogen that causes tuberculosis can become drug-resistant.
   - (e) Historically important infectious diseases no longer pose a health risk.

   [Answer Field]

4. Which statement about emerging infectious diseases is not true?
   - (a) HIV is a virus that most likely came from chimps.
   - (b) Ebola hemorrhagic fever causes a high rate of death.
   - (c) Mad cow disease is spread by feeding grass to cows.
   - (d) Bird flu is a virus that jumps from birds to people.
   - (e) West Nile virus is a virus that comes from birds.

   [Answer Field]

5. Which statement about toxins is correct?
   - (a) Neurotoxins impair the nervous system.
   - (b) Carcinogens cause birth defects.
   - (c) Teratogens cause cancer.
   - (d) Allergens mimic naturally occurring hormones.
   - (e) Endocrine disruptors cause allergic reactions.

   [Answer Field]

6. Which statement about dose-response studies is not true?
   - (a) Dose-response studies test chemicals across a range of concentrations.
   - (b) Dose-response studies only test for lethal effects.
   - (c) Dose-response studies can last for days or months.
• (d) LD50 values are divided by 10 to determine safe concentrations for wildlife.
• (e) LD50 values are divided by 1,000 to determine safe concentrations for humans.

7. Which statement about retrospective and prospective toxicity studies is incorrect?
• (a) Retrospective studies are not conducted on humans.
• (b) Prospective studies are only conducted on wildlife.
• (c) Retrospective studies monitor health effects from future chemical exposures.
• (d) Prospective studies monitor health effects from future chemical exposures.
• (e) Prospective studies monitor health effects from past chemical exposures.

8. The concentration of chemical exposure does not depend on
• (a) the persistence of the chemical.
• (b) the solubility of the chemical.
• (c) the ability of the chemical to bioaccumulate.
• (d) the ability of the chemical to biomagnify.
• (e) the LD50 value of the chemical.

9. Which statement is not correct?
• (a) Risk assessment quantifies the potential harm that a chemical poses.
• (b) Risk assessment does not include social, political, and economic considerations.
• (c) Risk acceptance determines the amount of permissible risk.
• (d) Risk management includes social, political, and economic considerations.
• (e) Risk management does not consider the potential harm that a chemical poses.

10. What is not true about the two philosophies of regulating chemicals?
• (a) The innocent-until-proven-guilty principle assumes chemicals are safe unless harm can be demonstrated.
• (b) The precautionary principle is used in the United States.
• (c) The precautionary principle assumes chemicals are harmful unless safety can be demonstrated.
• (d) The innocent-until-proven-guilty principle allows rapid approval of chemicals by regulatory agencies but increases the risk of harmful chemicals being approved.
• (e) The precautionary principle can cause delays in the use of beneficial chemicals but reduces the risk of harmful chemicals being approved.

FREE-RESPONSE QUESTIONS
1. You are an employee of the Environmental Protection Agency. You are given the task of conducting risk management for the spraying of insecticides to kill the mosquitoes that carry West Nile virus.
• (a) How might you determine the proper concentration needed to kill mosquitoes? (2 points)
• (b) How might you determine whether the concentration used to kill mosquitoes might also kill other species of insects? (2 points)
• (c) If you knew the insecticide’s LD50 value for humans, what concentration would be the safe upper limit for humans? (2 points)
• (d) Given the information you have accumulated as part of your risk assessment, describe the factors that might be important in the risk management of spraying insecticides to kill the mosquitoes that carry West Nile virus. (4 points)

2. Given the differences in health risks that exist between low- and high-income countries, consider the following issues.
• (a) What strategies might you use to reduce the health risks of low-income countries? (3 points)
• (b) What strategies might you use to reduce the health risks of high-income countries? (3 points)
• (c) Suppose a low-income country discovers oil and is projected to become a high-income country within a decade. What changes in the country’s healthcare system might you suggest? (4 points)

MEASURING YOUR IMPACT

[Notes/Highlighting]

1. How Does Risk Affect Your Life Expectancy? An interesting way of examining risky behaviors is to determine how different behaviors reduce your life expectancy. Using U.S. government statistics, we know that the life expectancy for men is 75.6 years and the life expectancy for women is 80.8 years.
• (a) If you choose to smoke, the loss of life expectancy will be 6.6 years for the average man and 3.9 years for the average woman. What is the life expectancy for men and women who smoke?
• (b) Alcoholism leads to a 12-year decline in life expectancy in both sexes. What would your life expectancy be if you were an alcoholic man who also smoked?
• (c) Being overweight causes a loss of 36 days of life expectancy for every pound that you are overweight. If you become 20 pounds overweight, by how many years will your life expectancy be reduced?
(d) Based on the above numbers, what is the life expectancy of an alcoholic woman who smokes and is 20 pounds overweight?

Is Recycling Always Good for the Environment?

One of the three ways to reduce solid waste is to recycle. As we discussed in Chapter 16, when we recycle items such as paper, plastic, bottles, and cans, less material ends up in landfills and fewer natural resources need to be extracted to produce these items in the future. At first glance, recycling appears to make a lot of sense both economically and environmentally. Indeed, many state and local governments have encouraged or required recycling programs and the public generally associates recycling as being good for the environment (FIGURE SA7.1). But what do the data tell us? When we decide to recycle, what are the measurable benefits for the environment? How do these benefits compare to benefits from other decisions we make, such as the type of car we drive? The answers to these questions may surprise you.
• **Figure SA7.1 Recycling.** There is increasing interest in recycling many materials. From a perspective of energy savings, some items are more important to recycle than others.

• **How do we begin to assess the benefits of recycling?**

To determine the overall effect of recycling any type of waste, we need to consider the full range of costs and benefits of recycling and then compare these to the costs and benefits of manufacturing the same item from raw materials. For example, to assess the benefits of recycling paper, we need to compare the cost of recycling old paper into new paper products versus the cost of manufacturing new paper products from trees.
Figure SA7.2 Recycling aluminum cans. Converting old aluminum cans into new aluminum cans requires only 6 percent of the energy used to convert aluminum ore from a mine into new aluminum cans.

As we saw in Chapter 16, the best way to answer these questions is to complete a life-cycle analysis. Let’s look at two examples: aluminum cans and plastic containers. To compare the environmental and economic costs of transporting and manufacturing these items from recycled materials versus raw materials, we begin at the manufacturing facility.

The recycling of aluminum, primarily from aluminum cans, is widespread in the United States. According to the Aluminum Association, 51 billion cans are recycled in the United States each year, representing more than 50 percent of all aluminum cans that are manufactured (Figure SA7.2). To manufacture aluminum cans from raw materials, aluminum ore or bauxite must be mined and processed into pure aluminum. Not only does mining have environmental impacts as discussed in Chapter 8, but this processing of aluminum from ore also takes a substantial amount of energy while manufacturing aluminum cans from recycled cans requires only 6 percent of this energy. In short, making new cans from recycled cans saves a large amount of energy and therefore saves manufacturers a lot of money. When this energy comes from burning fossil
fuels, it also means that manufacturing recycled cans reduces the amount of carbon dioxide and other pollutants in the atmosphere.

- The recycling of plastic containers is also widely practiced. According to the American Chemistry Council and the Association of Postconsumer Plastic Recyclers, the recycling of plastic continues to grow each year with 1.1 billion kg (2.4 billion pounds) of bottles recycled annually, representing 27 percent of all plastic bottles that are manufactured. However, in contrast to aluminum cans, the cost of energy required to make new plastic bottles from raw material—in this case petroleum—is substantially less. As a result, manufacturing plastic bottles from recycled plastic bottles results in much smaller energy savings; it requires nearly 50 percent of the energy required in manufacturing plastic bottles from oil. This means that the economic and environmental benefits of using recycled plastic are much smaller than the economic benefits of using recycled aluminum.

- **What other costs of recycling do we need to consider?**

  - Regardless of the type of material that is being recycled, we have to remember that there are several additional costs of recycling beyond the cost of energy. To understand these costs, let’s start at your house. If you rinse out your cans and bottles before recycling, energy is needed to get the water to your sink, particularly if you use hot water. If you use hot water to rinse out the peanut butter from a plastic peanut butter jar, for example, you are very likely using more energy to clean the jar than is saved when you recycle the jar.

  - After they are cleaned, the recycled materials must be transported to a central recycling facility. Depending on location, the homeowner must either set out recycled items on the curb for pickup by a collection truck (FIGURE SA7.3) or bring them to a central facility. Both scenarios require burning fossil fuels for transportation. Additional fossil fuels must be consumed to transport the recycled items from the collection facility to the manufacturing facility. Although transportation costs will vary among different towns and cities, in terms of energy consumed and pollutants produced, they reduce the benefits of recycling. However, we can easily compare the cost of transporting recycled materials to manufacturers against the cost of transporting raw materials from their source, such as an aluminum mine. In addition, when homeowners pay for transporting the items to the collection center through taxes or trash collection fees, they will avoid the costs of putting the waste in a landfill.
Figure SA7.3  Transportation costs. Although early recycling programs had garbage trucks make separate trips to pick up trash and recycling materials, modern trucks have separate compartments that allow both garbage and recycled items to be picked up at the curb in a single trip. A single trip saves time and money, and reduces consumption of fossil fuels as well as the production of air pollutants.

What other benefits of recycling do we need to consider?

The primary argument for recycling is that it reduces the need for raw materials and keeps solid waste out of landfills. During the 1990s, there was a growing concern that the United States was running out of landfill space and that recycling was critical to extending the life of existing landfills. While it is true that many landfills are nearing capacity particularly in the northeastern United States, there is still a large amount of land throughout the country that could serve as landfill space if people in those areas agreed to the construction of new landfills.

Reducing the amount of solid waste going into landfills allows existing landfills to operate longer. This, in turn, reduces the costs of closing and monitoring existing landfills. It also reduces the costs of building more landfills in the future and the costs of trucking the waste to new landfills likely to be farther away. Increased trucking raises both the economic cost and the environmental impact.
How do the benefits of recycling compare to other choices we could make to help our environment?

- Public support of recycling has grown tremendously in recent years. But how does recycling compare to other actions that affect the environment? For example, based only on the energy used in the manufacturing processes, the energy saved by recycling aluminum cans is 0.15 percent of all energy used in the United States. The energy saved by recycling plastics is 0.008 percent of all energy used in the United States. How do these values compare to other choices we can make to save energy?

- One easy comparison is the decision about the type of vehicle to purchase. According to the Bureau of Transportation Statistics, in 1989 cars comprised 69 percent of all passenger vehicles whereas light trucks and SUVs comprised 31 percent. By 2006, the fraction of light trucks and SUVs climbed to 42 percent. As we discussed in Chapter 12, such a shift in vehicle choice affects the use of fossil fuels; the average car built in 2009 achieved approximately 10.1 km per liter (24 miles per gallon) whereas the average light truck or SUV achieved 7.6 km per liter (18 mpg). A recent analysis of such data demonstrated that if consumers had not increased their purchases of light trucks and SUVs beyond the 1989 levels, the energy savings would be 0.6 percent of all energy used in the United States. In other words, deciding to replace your car with another car instead of switching to a light truck or SUV saves 4 times more energy than deciding to recycle aluminum cans and 75 times more energy than the decision to recycle plastic.

- Of course, a person could decide to drive a more fuel-efficient car and to recycle plastic and aluminum. But when we consider how we can improve the environment it is often helpful to gather the scientific data to make objective comparisons rather than simply make decisions based on perceptions. In the case of recycling, the analysis of the data makes it clear that recycling certain materials will have much greater environmental and economic benefit than recycling other materials. This helps us understand why manufacturers might be much more inclined to promote the recycling of certain items such as aluminum cans. Identifying the full range of costs and benefits also helps us identify the complexity of the question. The energy costs of recycling, for example, are wide-ranging and include homeowner costs, transportation costs, manufacturing costs, and landfill costs. By identifying all of the costs and benefits, we can strive to design more efficient recycling programs. Finally, examining the costs and benefits of a particular effort to help our environment versus other efforts gives
some perspective on which provides the greatest benefits. In many cases, of course, we do not have to choose between two actions. We can simultaneously recycle and drive a more fuel-efficient vehicle.