CHAPTER 1

Introducing Environmental Science and Sustainability

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Industrial production of chicken requires many inputs, including feed, heating and cooling, and often antibiotics and hormones to accelerate growth. It also generates waste streams that can lead to air and water pollution if not treated or managed.

One of the best ways to understand our complex relationship with the global environment is to use food as a lens. Culture, price, personal tastes, and availability contribute to food choices. However, we rarely think about how a particular meal comes to our plate, and how its production impacts the environment.

Consider a simple chicken sandwich. Commercial bread requires wheat from input-intensive farms including large amounts of land, irrigation water, fertilizers, pesticides, and diesel-fueled trucks and tractors. Agricultural land displaces native plants and animals, excess fertilizers and pesticides enter waterways, and diesel releases pollutants into the atmosphere. Harvested wheat is sent to a plant that grinds it into flour, requiring additional energy and producing a stream of organic waste material. Wheat is then shipped to a bakery, which adds sugar, yeast, corn syrup, vitamins and minerals, preservatives, oil, and other ingredients—each of which has also been processed and transported. The bread is then bagged and delivered to stores and restaurants, hundreds or thousands of miles from where the wheat was grown. Each step uses energy, adds packaging, and generates wastes.

Commercially raised chicken also impacts the environment, since chicken feed grain has to be grown, processed, and delivered to a poultry farm (**see photograph**). Raising, processing, cooking, packaging, and delivering chickens requires inputs and generates wastes. Chickens are often given antibiotics to make them grow faster, which can lead to antibiotic-resistant diseases.

More sustainable options include producing wheat, grain, and chicken with methods that minimize environmental impacts. Buying locally grown foods reduces energy associated with transportation. Alternative pest management reduces pesticides and antibiotics. Reusable packaging and food-waste composting reduce the need for landfills. But even these practices require land, water, energy, and other inputs.

Humans developed agriculture over several thousand years, altering ecosystems, shifting waterways, and driving some plants and animals to extinction. Our agricultural practices contribute to climate change, which in turn forces us to adapt our food-production practices. Knowing how something as simple as a sandwich can have wide-ranging impacts on the environment is a great point from which to begin to understand how humans relate to our environment.

In Your Own Backyard…

Where and by whom is food grown near where you live? Look in your cupboards and refrigerator: Where and by whom are most of the foods you eat grown? How might switching to locally grown foods affect your diet and your food budget?

Human Impacts on the Environment

LEARNING OBJECTIVES

- **Explain** how human activities affect global systems.
- **Describe** the factors that characterize human development and how they impact environment and sustainability.

Earth is remarkably suited for life. Water, important both in the internal composition of organisms and as an external environmental factor affecting life, covers three-fourths of the planet. Earth's temperature is habitable—neither too hot, as on Mercury and Venus, nor too cold, as on Mars and the outer planets. We receive a moderate amount of sunlight—enough to power photosynthesis, which supports almost all the life-forms that inhabit Earth. Our atmosphere bathes the planet in gases and provides essential oxygen and carbon dioxide that organisms require. On land, soil develops from rock and provides support and minerals for plants. Mountains that arise from geologic processes and then erode over vast spans of time affect weather patterns, provide minerals, and store reservoirs of fresh water as ice and snow that melt and flow to lowlands during the warmer months. Lakes and ponds, rivers and streams, wetlands, and groundwater reservoirs provide terrestrial organisms with fresh water.

Earth's abundant natural resources have provided the backdrop for a parade of living things to evolve. Life has existed on Earth for about 3.8 billion years. Although early Earth was inhospitable by modern standards, it provided the raw materials and energy needed for early life-forms to arise and adapt. Some of these early cells evolved over time into simple multicellular organisms—early plants, animals, and fungi. Today, several million species inhabit the planet. A representative sample of Earth's biological diversity includes intestinal bacteria, paramecia, poisonous mushrooms, leafhoppers, prickly pear cacti, seahorses, dogwoods, angelfish, daisies, mosquitoes, pitch pines, polar bears, spider monkeys, and roadrunners (**Figure 1.1**).

About 300,000 years ago—a mere blip in Earth's 4.5-billion-year history—an evolutionary milestone began with the appearance of modern humans in Africa. Large brains and the ability to communicate made our species successful. Over time, our population grew; we expanded our range throughout the planet and increasingly impacted the environment with our presence and our technologies. These technologies have allowed many people in the world lives with access to well-lit and air-conditioned buildings, effective medical treatment, high-speed transportation, and uninterrupted food supplies. This has been particularly true in North America, Western Europe, and Japan; increasingly, many urban residents in China, India, South America, and parts of Africa have similar access to wealth and material goods.

FIGURE 1.1 A male greater roadrunner carries a desert spiny lizard it has captured. Life abounds on Earth, and every organism is linked to many others, including humans. Photographed in New Mexico.

Today, the human species is the most significant agent of environmental change on our planet. Our burgeoning population and increasing use of energy, materials, and land transform natural systems to meet our needs and desires. Our activities consume ever-increasing amounts of Earth's abundant but finite resources—rich topsoil, clean water, and breathable air. This alteration of natural systems eradicates many types of ecosystems and thousands upon thousands of unique species that inhabit them. Evidence continues to accumulate that human-induced climate change alters the natural environment in disruptive ways. Human activities are disrupting global **systems**.

This book introduces the major impacts that humans have on the environment. It considers ways to better manage those impacts, while emphasizing that each possible choice has the potential to cause additional impacts. Most important, it explains the value of minimizing human impact on our planet. Our lives and well-being, as well as those of future generations, depend on our ability to manage Earth's environmental resources effectively.

Increasing Human Numbers

Figure 1.2, a nighttime satellite photograph of North America, including the United States, Mexico, and Canada, depicts the home of about 484 million people. The tiny specks of light represent cities, with the great metropolitan areas, such as New York along the northeastern seacoast, ablaze with light.

The driver of all other environmental problems, the one that links all others, is the many people who live in the area shown in this picture. According to the United Nations, in 1950 only eight cities in the world had populations larger than 5 million, the largest being New York, with 12.3 million. By 2016 Tokyo, Japan had 17.8 million inhabitants, with 38.1 million inhabitants in the greater Tokyo metropolitan area. The combined population of the world's 10 largest urban agglomerations was over 200 million (see Table 9.1).

FIGURE 1.2 Satellite view of North America at night. This image shows most major cities and metropolitan areas in the United States, Mexico, and Canada.

system A set of components that interact and function as a whole.

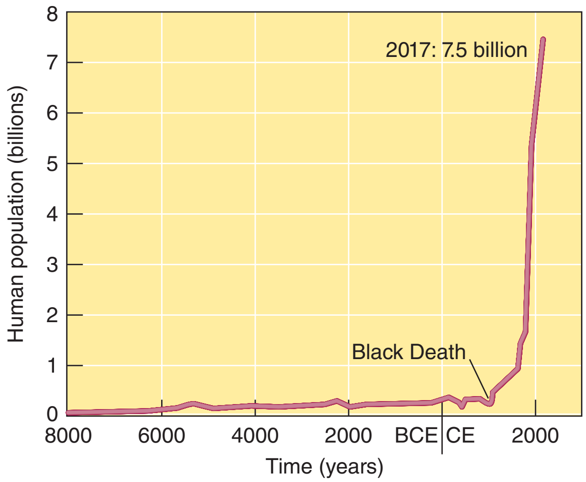


FIGURE 1.3 **Human population growth.** It took thousands of years for the human population to reach 1 billion (in 1800) but only 130 years to reach 2 billion (1930). It took only 30 years to reach 3 billion (1960), 15 years to reach 4 billion (1975), 12 years to reach 5 billion (1987), 12 years to reach 6 billion (1999), and 13 years to reach 7 billion (2011). (Population Reference Bureau)

In 2011, the human population as a whole passed a significant milestone: 7 billion individuals. Not only is this figure incomprehensibly large, but also our population grew this large in a brief span of time. In 1960, the human population was only 3 billion (**Figure 1.3**). By 1975, there were 4 billion people, and by 1999, there were 6 billion. The 7.5 billion people who currently inhabit our planet consume great quantities of food and water, use a great deal of energy and raw materials, and produce much waste.

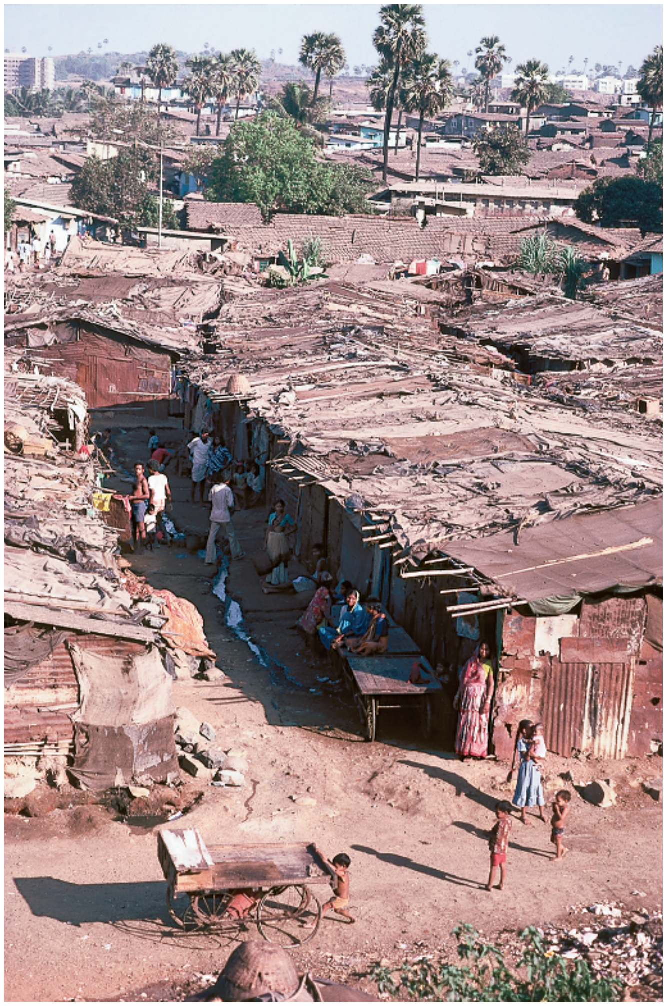
Despite family planning efforts in many countries, population growth rates do not change quickly. Several billion people will be added to the world in the twenty-first century, so even if we remain concerned about the impacts of a growing population and even if our solutions are effective, the coming decades may be clouded with tragedies. The conditions of life for many people may worsen considerably.

On a global level, nearly one of every two people live in extreme **poverty** (**Figure 1.4**). One measure of poverty is having a per capita income of less than $2.50 per day, expressed in U.S. dollars adjusted for purchasing power. Approximately 3 billion people—about 40% of the total world population—currently live at this level of poverty. Poverty is associated with low life expectancy, high infant mortality, illiteracy, and inadequate access to health services, safe water, and balanced nutrition. According to the UN Food and Agricultural Organization, at least 1 billion people (many of them children) lack access to the food needed for healthy, productive lives.

Most demographers (people who study human populations) expect the world population to stabilize before the end of the current century. Worldwide, fertility rates have decreased to a current average of about three children per family, and this average is projected to continue to decline in coming decades. Expert projections for world population at the end of the twenty-first century range from about 9.3 billion to 10.5 billion, depending largely on how fast the fertility rate decreases (see Figures 8.2 and 8.3).

No one knows whether Earth can support so many people indefinitely. Among the tasks we must accomplish is feeding a world population considerably larger than the present one without undermining the natural resources that support us. Our ability to achieve this goal will determine the quality of life for our children and grandchildren.

poverty A condition in which people cannot meet their basic needs for adequate food, clothing, shelter, education, or health.



Jerry Cooke/Science Source

FIGURE 1.4 **Slum in Mumbai, India.** Many of the world's people live in extreme poverty. One trend associated with poverty is the increasing movement of poor people from rural to urban areas. As a result, the number of poor people living in or around the fringes of cities is mushrooming.

Development, Environment, and Sustainability

Until recently, demographers differentiated countries as highly developed, moderately developed, and less developed. The United States, Canada, Japan, and most of Europe, which represent 18% of the world's population but about 50% of global economic activity, are **highly developed countries**. Development in this context is based mainly on total wealth of the country. The world's poorest countries, including Bangladesh, Kenya, and Nicaragua, are considered **less developed countries (LDCs)**. Cheap, unskilled labor is abundant in LDCs, but capital for investment is scarce. Most LDC economies are agriculturally based, often for only one or a few crops. As a result, crop failure or a lower world market value for that crop is catastrophic to the economy. Hunger, disease, and illiteracy are common in LDCs.

However, recent decades have seen substantial increases in wealth for many urban residents in previously less developed countries, including China, India, Brazil, and Mexico. These countries have substantial *income disparities,* meaning that other urban residents and most of the rural inhabitants of those remain poor, and lack access to transportation, electricity, fresh water, and modern medical technology. Consequently, using the total wealth or income of a country may not usefully describe the well-being of people in that country. More appropriate measures can include the percentage of residents who make more than $2.50 per day, have access to fresh water and electricity, or have access to education.

Review

1. What is one example of a global system?
2. How do the total wealth of a country and income disparity relate to sustainability?

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FIGURE 1.5 **Consumption of natural resources.**

Population, Resources, and the Environment

LEARNING OBJECTIVES

- **Differentiate** between renewable and nonrenewable resources.
- **Explain** the impact of population and affluence on consumption.
- **Define** *ecological footprint.*
- **Describe** the three most important factors that determine human impact on the environment.

The relationships among population growth, use of natural resources, and environmental degradation are complex. We address the details of resource management and environmental problems in this and later chapters, but for now, let us consider two useful generalizations: (1) The resources essential to each individual's survival are small, but a rapidly increasing population tends to overwhelm and deplete local soils, forests, and other natural resources (**Figure 1.5a**). (2) In highly developed countries, individual resource demands are large, far above what is needed for survival. Consumption by people in affluent nations can exhaust resources and degrade the environment on a global scale (**Figure 1.5b**).

highly developed countries Countries with complex industrial bases, low rates of population growth, and high per capita incomes.

less developed countries (LDCs) Developing countries with a low level of industrialization, a high fertility rate, a high infant mortality rate, and a low per capita income (relative to highly developed countries).

Types of Resources

When examining the effects of humans on the environment, it is important to distinguish between two types of natural resources: nonrenewable and renewable (**Figure 1.6**). **Nonrenewable resources**, which include minerals (such as aluminum, copper, and uranium) and fossil fuels (coal, oil, and natural gas), are present in limited supplies and are depleted by use. Natural processes do not replenish nonrenewable resources within a reasonable period on the human time scale. Fossil fuels, for example, took millions of years to form.

In addition to a nation's population, several other factors affect how nonrenewable resources are used, including how efficiently the resource is extracted and processed as well as how

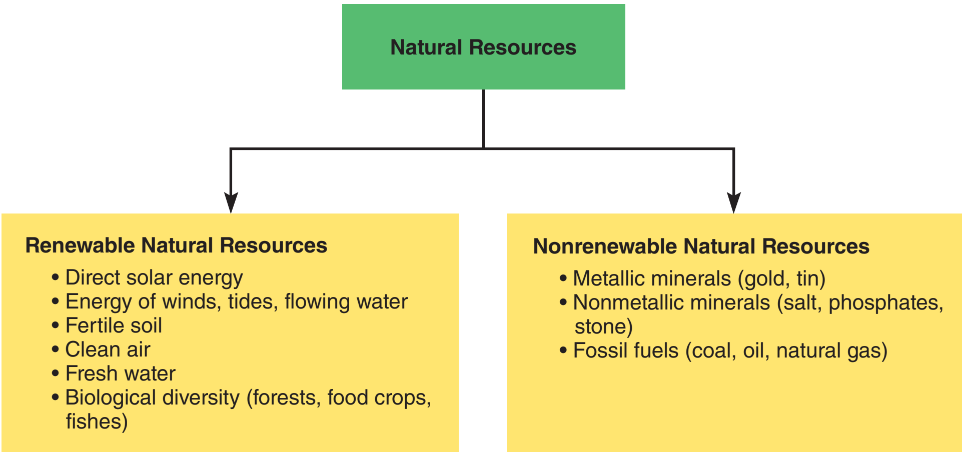


FIGURE 1.6 Natural resources. Nonrenewable resources are replaced on a geologic time scale, and their supply diminishes with use. Renewable resources can be (but are not always) replaced on a fairly short time scale; as will be explained in later chapters, most renewable resources are derived from the sun's energy.

much of it is required or consumed by different groups. People in the United States, Canada, and other highly developed nations tend to consume most of the world's nonrenewable resources. Nonetheless, Earth has a finite supply of nonrenewable resources that sooner or later will be exhausted. In time, technological advances may provide substitutes for some nonrenewable resources. Slowing the rate of population growth and consumption will buy time to develop such alternatives.

Some examples of **renewable resources** are trees, fishes, fertile agricultural soil, and fresh water. Nature replaces these resources fairly rapidly (on a scale of days to centuries), and they can be used indefinitely as long as they are not overexploited in the short term. In developing countries, forests, fisheries, and agricultural land are particularly important renewable resources because they provide food. Indeed, many people in developing countries are subsistence farmers who harvest just enough food so that they and their families can survive.

Rapid population growth can cause the overexploitation of renewable resources. For example, large numbers of poor people must grow crops on land inappropriate for farming, such as on mountain slopes or in tropical rain forests. Although this practice may provide a short-term solution to the need for food, it does not work in the long term: When these lands are cleared for farming, their agricultural productivity declines rapidly, and severe environmental deterioration occurs. Renewable resources are usually only *potentially* renewable. They must be used in a *sustainable* way—in a manner that gives them time to replace or replenish themselves.

The effects of population growth on natural resources are particularly critical in developing countries. The economic growth of developing countries is often tied to the exploitation of their natural resources, usually for export to highly developed countries. Developing countries are faced with the difficult choice of exploiting natural resources to provide for their expanding populations in the short term (to pay for food or to cover debts) or conserving those resources for future generations.

It is instructive to note that the economic growth and development of the United States, Canada, and other highly developed nations came about through the exploitation and, in some cases, the destruction of resources. Continued economic growth in highly developed countries now relies significantly on the importation of these resources from less developed countries. One of the reasons economic growth in highly developed countries has been possible is the uneven distribution of both renewable and nonrenewable resources around the world. Many very poor countries—Ethiopia, for example—have only limited fossil-fuel resources.

Resource Consumption

Consumption is the human use of materials and energy. Consumption, which is both an economic and a social act, provides the consumer with a sense of identity as well as status among peers. Advertisers promote consumption as a way to achieve happiness. Western culture encourages spending and consumption well beyond that which is necessary for survival.

In general, people in highly developed countries are extravagant consumers; their use of resources is greatly out of proportion to their numbers. A single child born in a highly developed country may have a greater impact on the environment and on resource depletion than 12 or more children born in a developing country. Many natural resources are used to provide automobiles, air conditioners, disposable diapers, cell phones, computers, clothes, athletic shoes, furniture, boats, and other comforts of life in highly developed countries. Yet such consumer goods represent a small fraction of the total materials and energy required to produce and distribute them. According to the Worldwatch Institute, a private research institution in Washington, D.C., Americans collectively consume almost 10 billion tons of materials every year. The disproportionately large consumption of resources by highly developed countries affects natural resources and the environment as much as or more than the population explosion in the developing world.

Unsustainable Consumption Consumption in a country is unsustainable when the level of demand on its resource base damages the environment or depletes resources to such an extent that future generations will have lower qualities of life. In comparing human impact on the environment in developing and highly developed countries, we see that unsustainable consumption can occur in two ways. First, environmental quality and resource depletion can result from too many people, even if those people consume few resources per person. This is the current situation in many developing nations.

In highly developed countries, unsustainable consumption results when individuals consume substantially more resources than necessary for survival. Both types of unsustainable consumption have the same effect—pollution, environmental degradation, and resource depletion. Many affluent, highly developed countries, including the United States, Canada, Japan, and most of Europe, consume unsustainably: *Highly developed countries represent less than 20% of the world's population, yet they consume significantly more than half of its resources*.

According to the Worldwatch Institute, highly developed countries account for the lion's share of total resources consumed:

- 86% of aluminum used
- 76% of timber harvested
- 68% of energy produced
- 61% of meat eaten
- 42% of the fresh water consumed

These nations also generate 75% of the world's pollution and waste.

Ecological Footprint

Environmental scientists **Mathis Wackernagel** and **William Rees** developed the concept of ecological footprint to help people visualize what they use from the environment. Each person has an **ecological footprint**, an amount of productive land, fresh water, and ocean required on a continuous basis to supply that person with food, wood, energy, water, housing, clothing, transportation, and waste disposal. The *Living Planet Report 2016*, produced by scientists at the Global Footprint Network, World Wildlife Fund, and Zoological Society of London, estimates that since about 1975, the human population has been consuming more of the productive land, water, and other resources than Earth can support (**Figure 1.7**). In 2012, annual consumption was about 50% more than Earth produces. This is an unsustainable consumption rate.

The *Living Planet Report* estimates that Earth has about 11.4 billion hectares (28.2 billion acres) of productive land and water. If we divide this area by the global human population, we see that each person is allotted about 1.5 hectares (3.7 acres). However, the average global ecological footprint is currently about 2.7 hectares (6.7 acres) per person, which means we humans have an *ecological overshoot*. We can see the short-term results around us—forest destruction, degradation of croplands, loss of biological diversity, declining ocean fisheries, local water shortages, and increasing pollution. The long-term outlook, if we do not seriously address our consumption of natural resources, is potentially disastrous. Either per-person consumption will drop, population will decrease, or both.

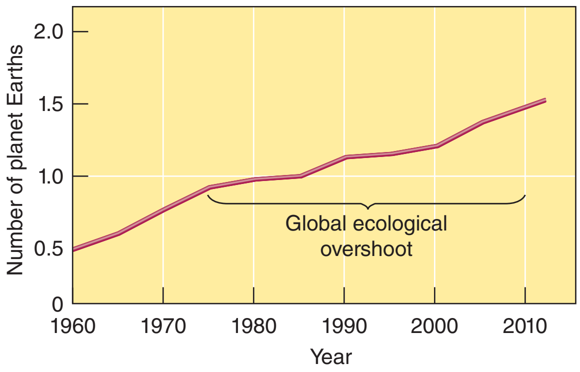


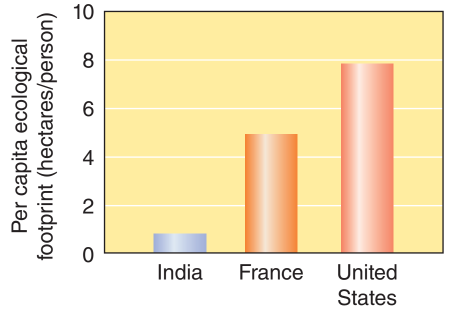
FIGURE 1.7 Global ecological overshoot. Earth's ecological footprint has been increasing over time. By 2010, humans were using the equivalent of 1.5 Earths, a situation that is not sustainable. (Data from World Wildlife Fund, *Living Planet Report 2016*)

In the developing nation of India, the per capita ecological footprint is 0.8 hectare (2.0 acres); India is the world's second-largest country in terms of population, so even though its per capita footprint is low, the country's footprint is high: 986.3 million hectares (**Figure 1.8**). In France, the per capita ecological footprint is 4.9 hectares (12.1 acres); although its per capita footprint is high, France's footprint as a country is 298.1 million hectares, which is lower than India's, because its population is much smaller. In the United States, the world's third-largest country, the per capita ecological footprint is 7.9 hectares (19.5 acres); the U.S. footprint as a country is 2457 million hectares! If all people in the world had the same lifestyle and level of consumption as the average North American, and assuming no changes in technology, we would need about four additional planets the size of Earth.

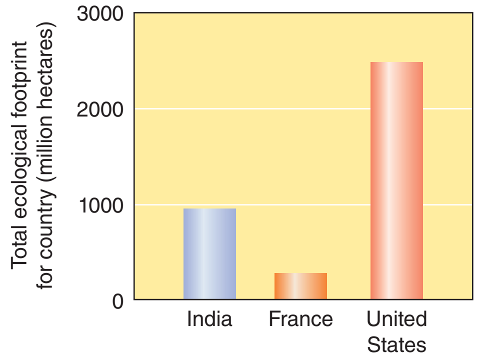
As developing countries increase their economic growth and improve their standard of living, more and more people in those nations purchase consumer goods. More new cars are now sold annually in Asia than in North America and Western Europe combined. These new consumers may not consume at the high level of the average consumer in a highly developed country, but their consumption has increasingly adverse effects on the environment. For example, air pollution caused by automotive traffic in urban centers in developing countries is terrible and getting worse every year. Millions of dollars are lost because of air pollution–related health problems in these cities. One of society's challenges is to provide new consumers in developing countries (as well as ourselves) with less polluting, less consuming forms of transportation.

The *IPAT* Model

Generally, when people turn on the tap to brush their teeth in the morning they do not think about where the water comes from or about the environmental consequences of removing it from a river or the ground. Similarly, most North Americans do not think about where the energy comes from when they



(a) The average ecological footprint of a person living in India, France, or the United States. For example, each Indian requires .8 hectare (2.0 acres) of productive land and ocean to meet his or her resource requirements.



(b) The total ecological footprint for the countries of India, France, and the United States. Note that India, although having a low per capita ecological footprint, has a significantly higher ecological footprint as a country because of its large population. If everyone in the world had the same level of consumption as the average American, it would take the resources and area of five Earths.

FIGURE 1.8 **Ecological footprints.** (Data from World Wildlife Fund, *Living Planet Report 2016*)

Question

The population of India in 2010 was about 1.2 billion, and that of the United States, about 310 million. Use this and the data in Figure 1.8a to confirm the values in Figure 1.8b. (Note that your calculation may disagree slightly due to rounding).

flip on a light switch or start a car. We generally don't think about the environmental impacts that each of our actions will have in terms of renewable and nonrenewable resource consumption and waste generation.

While these environmental impacts are difficult to assess, we can estimate them using the three factors most important in determining environmental impact *(I)*:

1. The number of people *(P)*
2. Affluence, which is a measure of the consumption or amount of resources used per person *(A)*
3. The environmental effects (resources needed and wastes produced) of the technologies used to obtain and consume the resources *(T)*

These factors are related in this way:

$$I = P \times A \times T$$

In science, a **model** is a formal statement that describes the behavior of a system. The *IPAT* model, which biologist **Paul Ehrlich** and physicist **John Holdren** first proposed in the 1970s, shows the mathematical relationship between environmental impacts and the forces driving them.

For example, to determine the environmental impact of emissions of the greenhouse gas CO_2 from motor vehicles, multiply the population times the number of cars per person (affluence/consumption per person) times the average car's annual CO_2 emissions per year (technological impact). This model demonstrates that although increasing motor vehicle efficiency and developing cleaner technologies will reduce pollution and environmental degradation, a larger reduction will result if population and per capita consumption are also controlled.

The *IPAT* equation, though useful, must be interpreted with care, in part because we often do not understand all the environmental impacts of a particular technology on complex environmental systems. Motor vehicles are linked not only to global warming from CO_2 emissions but also to local air pollution (tailpipe exhaust), water pollution (improper disposal of motor oil and antifreeze), and solid waste (disposal of nonrecyclable automobile parts in sanitary landfills). There are currently more than one billion motor vehicles on the planet, and the number is rising rapidly.

The three factors in the *IPAT* equation are always changing in relation to one another. Consumption of a particular resource may increase, but technological advances may decrease the environmental impact of the increased consumption. For example, there are more television and computer screens in the average household than there were 20 years ago (increased affluence) and more households (increased population). However, current computers have flat screens that require fewer materials to produce and less energy to operate than did old, tube-based screens. Consumer trends and choices affect environmental impact.

Similarly, the average fuel economy of new cars and light trucks (sport-utility vehicles, vans, and pickup trucks) in the United States declined from 22.1 miles per gallon in 1988 to 20.4 miles per gallon in the early 2000s, in part because of the popularity of sport-utility vehicles (SUVs). In addition to being less fuel efficient than cars, SUVs emit more emissions per vehicle mile. More recently, hybrids have helped to increase the average fuel economy, which in 2015 was 24.8 miles per gallon (**Figure 1.9**). Such trends and uncertainties make the *IPAT* equation of limited usefulness for long-term predictions.

The *IPAT* equation is valuable because it helps identify what we do not know or understand about consumption and its environmental impact. The National Research Council of the U.S. National Academy of Sciences[1] has identified research areas we must address, including the following: Which kinds of consumption have the greatest destructive impact on the environment? Which groups in society are responsible for the greatest

model A representation of a system; describes the system as it exists and predicts how changes in one part of the system will affect the rest of the system.

[1] The National Research Council is a private, nonprofit society of distinguished scholars. It was organized by the National Academy of Sciences to advise the U.S. government on complex issues in science and technology.

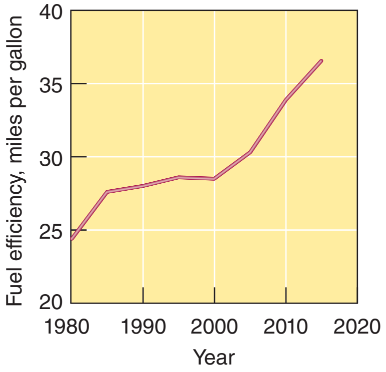


FIGURE 1.9 Average fuel efficiency of U.S. passenger cars, 1980–2015. Policies to improve vehicle fuel efficiency have been highly effective. From 1980 to 2015, average fuel efficiency of passenger cars in the United States increased by 50%.

environmental disruption? How can we alter the activities of these environmentally disruptive groups? It will take years to address such questions, but the answers should help decision makers in government and business formulate policies to alter consumption patterns in an environmentally responsible way. Our ultimate goal should be to reduce consumption so that our current practices do not compromise the ability of future generations to use and enjoy the riches of our planet.

Review

1. How do renewable resources differ from nonrenewable resources?
2. How are human population growth and affluence related to natural resource depletion?
3. What is an ecological footprint?
4. What does the *IPAT* model demonstrate?

Sustainability

LEARNING OBJECTIVES

- **Define** *sustainability.*
- **Relate** Garrett Hardin's description of the tragedy of the commons in medieval Europe to common-pool resources today.
- **Briefly** describe sustainable development.

One of the most important concepts in this text is **sustainability**. A sustainable world is one in which humans can have economic development and fair allocation of resources without the environment going into a decline from the stresses imposed by human society on the natural systems (such as fertile soil, water, and air) that maintain life. When the environment is used sustainably, humanity's present needs are met without endangering the welfare of future generations (**Figure 1.10**). Environmental sustainability applies at many levels, including individual, community, regional, national, and global levels.

sustainability The ability to meet current human economic and social needs without compromising the ability of the environment to support future generations.

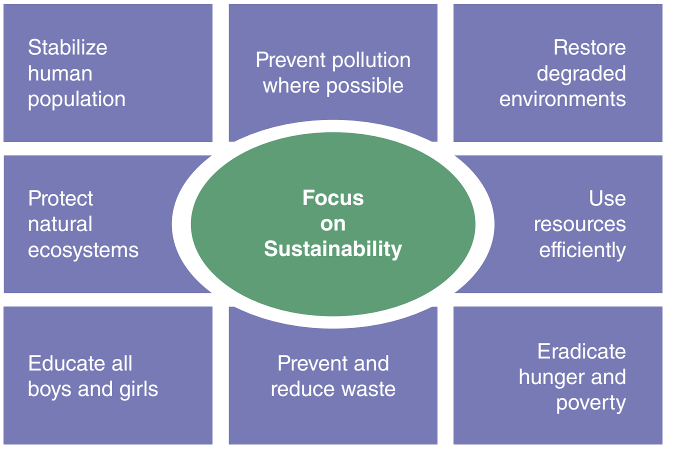


FIGURE 1.10 Sustainability. Sustainability requires a long-term perspective to protect human welfare and natural resource assets, such as the efforts shown here.

- Our actions can affect the health and well-being of natural *ecosystems*, including all living things.
- Earth's resources are not present in infinite supply; our access is constrained by ecological limits on how rapidly renewable resources such as fresh water regenerate for future needs.
- The products we consume can impose costs to the environment and to society beyond those captured in the price we pay for those products.
- Sustainability requires a concerted and coordinated effort of people on a global scale.

Many experts in environmental problems think human society is not operating sustainably because of the following human behaviors:

- We extract nonrenewable resources such as fossil fuels as if they were present in unlimited supplies.
- We consume renewable resources such as fresh water and forests faster than natural systems can replenish them (**Figure 1.11**).
- We pollute the environment with toxins as if the capacity of the environment to absorb them is limitless.
- A small fraction of the human population dominates a large percentage of Earth's resources.
- Our numbers continue to grow despite Earth's finite ability to feed us, sustain us, and absorb our wastes.

Left unchecked, these activities could threaten Earth's life-support systems to such a degree that recovery is impossible. If major resources like agricultural land, fisheries, and fresh water are exhausted to the point that they cannot recover quickly, substantial human suffering would result. Thus managing these resources sustainably means more than protecting the environment: Sustainability promotes human well-being.

Topham/The Image Works

FIGURE 1.11 A logger cuts down the last standing tree on a clear-cut forest slope. Logging destroys the habitat for forest organisms and increases the rate of soil erosion on steep slopes. Photographed in Canada.

At first glance, the issues may seem simple. Why do we not just reduce consumption, improve technology, and limit population growth? The answer is that various interacting ecological, societal, and economic factors complicate the solutions. Our inadequate understanding of how the environment works and how human choices affect the environment is a major reason that problems of sustainability are difficult to resolve. The effects of many interactions between the environment and humans are unknown or difficult to predict, and we generally do not know if we should take corrective actions before our understanding is more complete.

Sustainability and the Tragedy of the Commons

Garrett Hardin (1915–2003) was a professor of human ecology at the University of California–Santa Barbara who wrote about human environmental dilemmas. In 1968, he published his classic essay, "The Tragedy of the Commons," in the journal *Science*. He contended that our inability to solve many environmental problems is the result of a struggle between short-term individual welfare and long-term environmental sustainability and societal welfare.

Hardin used the commons to illustrate this struggle. In medieval Europe, the inhabitants of a village shared pastureland, called the commons, and each herder could bring animals onto the commons to graze. If the villagers did not cooperatively manage the commons, each might want to bring more animals onto it. If every herder in the village brought as many animals onto the commons as possible, the plants would be killed from overgrazing, and the entire village would suffer. Thus, an unmanaged commons would inevitably be destroyed by the people who depended on it.

Hardin argued that one of the outcomes of the eventual destruction of the commons would be private ownership of land, because when each individual owned a parcel of land, it was in that individual's best interest to protect the land from overgrazing. A second outcome Hardin considered was government ownership and management of such resources, because the government had the authority to impose rules on users of the resource and thereby protect it.

Hardin's essay has stimulated a great deal of research in the decades since it was published. In general, scholars agree that degradation of the self-governing commons—now called **common-pool resources**—typically is not a problem in closely knit communities. Indeed, sociologist **Bill Freudenberg** has pointed out that medieval commons were successfully managed but became degraded after they were privatized. Economist **Elinor Ostrum** demonstrated that common pool resources can be sustainably managed by communities with shared interests, strong local governance, and community-enforced accountability.

As one goes from local to regional to global common-pool resources, the challenges of sustainably managing resources become more complex. In today's world, Hardin's parable has particular relevance at the global level. These modern-day commons are experiencing increasing environmental stress (see, for example, the discussion of climate change in Chapter 20). No individual, jurisdiction, or country owns common-pool resources, and they are susceptible to overuse. Although exploitation may benefit only a few, everyone on Earth must pay for the environmental cost of exploitation.

The world needs effective legal and economic policies to prevent the short-term degradation of common-pool resources and ensure their long-term well-being. We have no quick fixes because solutions to global environmental problems are not as simple or short term as are solutions to some local problems. Most environmental ills are inextricably linked to other persistent problems such as poverty, overpopulation, and social injustice—problems beyond the capacity of a single nation to resolve. The large number of participants who must organize, agree on limits, and enforce rules complicates the creation of global treaties to manage common-pool resources. Cultural and economic differences among participants make finding solutions even more challenging.

Sustainability works best when individuals, governments, and non-governmental organizations (including not-for-profit groups and corporations) collaborate in effective **stewardship**, or shared responsibility for the care of our planet. Cooperation and commitment at the international level are essential if we are to alleviate poverty, stabilize the human population, and preserve our environment and its resources for future generations.

Global Plans for Sustainable Development

In 1987, the World Commission on Environment and Development released a groundbreaking report, *Our Common Future* (see Chapter 24). A few years later, in 1992, representatives from most of the world's countries met in Rio de Janeiro, Brazil, for the *UN Conference on Environment and Development*. Countries attending the conference examined environmental problems that are international in scope: pollution and deterioration of the planet's atmosphere and oceans, a decline in the number and kinds of organisms, and destruction of forests.

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common-pool resources Those parts of our environment available to everyone but for which no single individual has responsibility—the atmosphere and climate, fresh water, forests, wildlife, and ocean fisheries.

stewardship Shared responsibility for the sustainable care of our planet.

In addition, the Rio participants adopted *Agenda 21*, an action plan of **sustainable development** in which future economic development, particularly in developing countries, will be reconciled with environmental protection. The goals of sustainable development are achieving improved living conditions for all people while maintaining a healthy environment in which natural resources are not overused and excessive pollution is not generated. Three factors—environmentally sound decisions, economically viable decisions, and socially equitable decisions—are necessary for truly sustainable development. To use sustainability as a guiding principle for environmental management requires that we think about how these three factors interact as parts of a complex and interlinked system (**Figure 1.12**).

A serious application of the principles of environmental sustainability to economic development will require many changes in such fields as population policy, agriculture, industry, economics, and energy use. In 2015, representatives from nearly 200 countries, as well as other public and private organizations, committed to an international plan to reduce poverty and food insecurity, improve global human well-being and education, and preserve biodiversity (see Chapters 8 and 24).

Through such international summits, we have made considerable progress in improving the quality of life for poor people, and have solved some pressing environmental issues. Nonetheless, many challenges to a sustainable planet remain, including terrorism, worsening international tensions, and severe economic problems. Furthermore, scientific warnings about important environmental problems such as global climate change have increased.

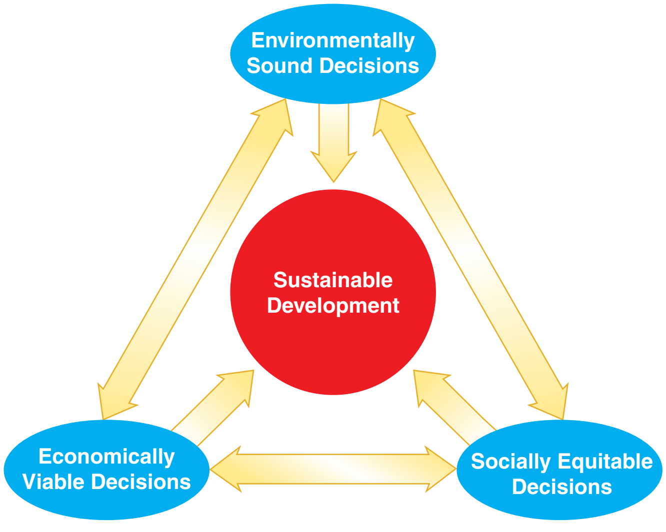


FIGURE 1.12 Sustainable development, a systems concept. Using sustainable development as an organizing principle for environmental management requires us to recognize that economic development, social justice, and the environment are linked in many and complex ways. We must consider whether economic decisions harm the environment or deplete natural resources, whether resource management decisions are socially equitable, and whether societal decisions impact economic opportunities for current and future generations.

sustainable development Economic development that meets the needs of the present generation without compromising the ability of future generations to meet their own needs.

While significant change at the international level has had mixed results, some nations, states, and municipalities have made important environmental progress. Many countries have enacted more stringent air pollution laws, including the phasing out of leaded gasoline. More than 100 countries have created sustainable development commissions. Corporations that promote environmentally responsible business practices have joined to form the World Business Council for Sustainable Development. The World Bank, which makes loans to developing countries, has invested billions of dollars in sustainable development projects around the world.

Review

1. What is sustainability?
2. What is the tragedy of the commons?
3. What are the three foundations of sustainable development?

Environmental Science

LEARNING OBJECTIVES

- **Define** *environmental science,* including the role of Earth systems in environmental science.
- **Outline** the scientific method.

Environmental science encompasses the many interconnected issues involving human population, Earth's natural resources, and environmental pollution. Environmental science combines information from many disciplines, such as biology, geography, chemistry, geology, physics, economics, sociology, demography (the study of populations), cultural anthropology, natural resources management, agriculture, engineering, law, politics, and ethics. **Ecology**, the branch of biology that studies the interrelationships between organisms and their environment, is a basic tool of environmental science.

Environmental scientists try to establish general principles about how the natural world functions. They use these principles to develop viable solutions to environmental problems—solutions based as much as possible on scientific knowledge. Environmental problems are generally complex, so our understanding of them is often less complete than we would like it to be. Environmental scientists are often asked to reach a consensus before they fully understand the systems that they study. As a result, they often make recommendations based on probabilities rather than precise answers.

Many of the environmental problems discussed in this book are serious, but environmental science is not simply a "doom-and-gloom" listing of problems coupled with

environmental science The interdisciplinary study of humanity's relationship with other organisms and the nonliving physical environment.

predictions of a bleak future. To the contrary, its focus is, and our focus as individuals and as world citizens should be, on identifying, understanding, and finding better ways to manage the stresses that human activities place on environmental resources and systems.

Earth Systems and Environmental Science

One of the most exciting aspects of environmental science and many other fields of science is working out how *systems* that consist of many interacting parts function as a whole. Earth's climate, for example, is a system that in turn is composed of smaller, interdependent systems, such as the atmosphere and ocean; these smaller systems are linked and interact with one another in the overall climate system.

A systems approach provides a broad look at overall processes, as opposed to the details of individual parts or steps. A commuter in city traffic may be quite familiar with the production of CO_2 by a car engine, but that knowledge does not automatically translate into an understanding of the global effect of millions of motor vehicles emitting CO_2. Thus, using a systems perspective helps scientists gain valuable insights that are not always obvious from looking at individual components within the system.

Also, problems arise from *not* thinking about systems. For example, if a company decides to burn waste oil to avoid its leaking into groundwater, pollution shifts from groundwater to the air. A systems perspective would require company executives to think about the trade-offs between the two disposal methods and, more importantly, about alternatives that might avoid generating waste oil in the first place.

Environmental scientists often use models to describe the interactions within and among environmental systems. Many of these models are computer simulations that represent the overall effect of competing factors to describe an environmental system in numerical terms. Models help us understand how the present situation developed from the past or how to predict the future course of events, including the long-term impacts of decisions or choices we make today. Models also generate additional questions about environmental issues.

A natural system consisting of a community of organisms and its physical environment is known as an **ecosystem**. In ecosystems, biological processes (such as photosynthesis) interact with physical and chemical processes to modify the composition of gases in the atmosphere, transfer energy from the sun through living organisms, recycle waste products, and respond to environmental changes with resilience. Natural ecosystems are the foundation for our concept of environmental sustainability.

Ecosystems are organized into larger and larger systems that interact with one another (discussed in Chapter 3). At a global level are Earth systems, which include Earth's climate, atmosphere, land, coastal zones, and the ocean. Environmental scientists use a systems approach to try to understand how human activities are altering global environmental parameters such as temperature, CO_2 concentration in the atmosphere, land cover, changes in nitrogen levels in coastal waters, and declining fisheries in the ocean.

Many aspects of Earth systems are in a steady state or, more accurately, a **dynamic equilibrium**, in which the rate of change in one direction is the same as the rate of change in the opposite direction. *Feedback* occurs when a change in one part of a system leads to a change in another part. Feedback can be negative or positive. In a **negative feedback system**, a change in some condition triggers a response that counteracts, or reverses, the changed condition (**Figure 1.13a**). A negative feedback mechanism works to keep an undisturbed system in dynamic equilibrium. For example, consider fish in a pond. As the number of fish increases, available food decreases and fewer fish survive; thus, the fish population declines.

In a **positive feedback system**, a change in some condition triggers a response that intensifies the changing condition (**Figure 1.13b**); a positive feedback mechanism leads to greater change from the original condition. Positive feedback can be very disruptive to an already disturbed system. For example, melting of polar and glacial ice can lead to greater absorption of solar heat by the exposed land area, which in turn leads to more rapid melting. Numerous negative and positive feedback mechanisms operate in the natural environment.

Science as a Process

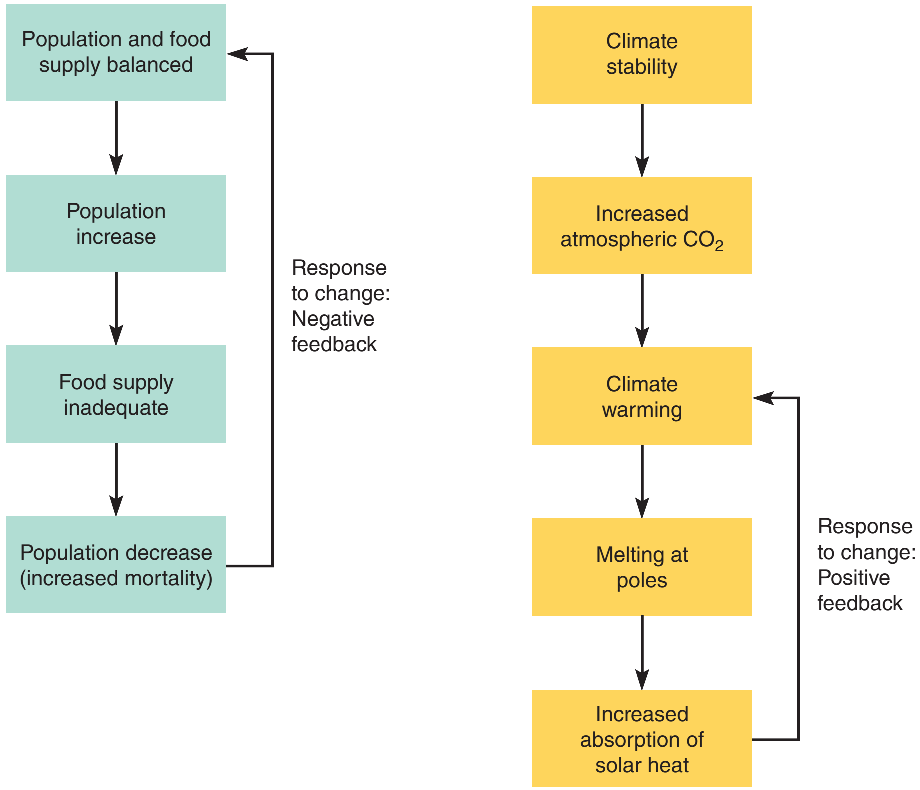
One key to the successful solution of any environmental problem is a careful evaluation of conditions, causes, and effects. Science—a system for managing and producing information—is the most effective way to do this evaluation. It is important to understand clearly just what science is, as well as what it is not. Many people think of science as a body of knowledge—a collection of facts about the natural world and a search for relationships among these facts. However, science is also a dynamic *process,* a systematic way to investigate the

On Campus

Sustainability Education

Colleges and universities around the world have offered environmental studies and science degree programs since the early 1970s, and students can now earn everything from certificates to PhD's in environmental studies and sciences. In many such programs, students have opportunities to directly study the science underlying our understanding of the environment. For example, environmental chemistry courses often include labs in which students test the capacity of various gases to absorb infrared radiation and store it as heat, which is the foundational idea behind climate change. In ecology classes, students visit freshwater lakes, rivers, and ponds to evaluate water chemistry and temperature, identify and count species, and compare those data to historical trends. Through sustainability classes and clubs, students evaluate different strategies to reduce energy use or garbage production in campus buildings, often comparing results across different buildings or even with groups at other schools. These opportunities to directly research environmental issues strengthen students' understanding of how science is done and of the challenges to developing effective solutions.

You can learn more about environmental studies and sciences programs through the Association of Environmental Studies and Sciences, the National Council for Science and the Environment, and the Association for the Advancement of Sustainability in Higher Education.



(a) **Negative feedback.** In this simplified example, the initial balance between a population of fish and its food supply is ultimately restored. Thus, in a negative feedback system, the response to change opposes the change.

(b) **Positive feedback.** In this simplified example of a positive feedback system, the response to change increases, or amplifies, the deviation from the original point.

FIGURE 1.13 **Feedback systems.**

natural world. Scientists seek to describe the apparent complexity of our world with general scientific laws (also called *natural laws*). Scientific laws are then used to make predictions, solve problems, or provide new insights.

Scientists collect objective **data** (singular, *datum*), the information with which science works. Data are collected by observation and experimentation and then analyzed or interpreted. Conclusions are inferred from the available data and are not based on faith, emotion, or intuition.

Before scientists publish their findings in scientific journals, other scientists examine and critique their work, a process called **peer review**. Confirming the validity of new results by *repeatability* is a requirement of science—observations and experiments must produce consistent results when other scientists repeat them. Scrutiny by other scientists reveals any inconsistencies in results or interpretation, and these errors are discussed openly. Thus, science is *self-correcting* over time.

No absolute certainty or universal agreement exists about anything in science. Science is an ongoing enterprise, and generally accepted ideas must be reevaluated in light of newly discovered data. Scientists never claim to know the "final answer" about anything because scientific understanding changes. However, this does not prevent us from using current knowledge in environmental science to make environmental decisions. Science represents the best information, and thus the best opportunity to make informed decisions.

Uncertainty does not mean that scientific conclusions are invalid. Overwhelming evidence links exposure to tobacco smoke and the incidence of lung cancer. We cannot state with absolute certainty which smokers will get lung cancer, but this uncertainty does not mean no correlation exists between smoking and lung cancer. On the basis of the available evidence, we say each individual who smokes has an increased *risk* of developing lung cancer, and we can say with great confidence that far more smokers will develop lung cancer than will nonsmokers.

Importantly, science cannot tell what we *should* do when faced with an environmental challenge, only what result we can expect given different choices. Science can provide better guidance than can religion or political preference on what will happen if we release pesticides that eventually reach the ocean or greenhouse gases that can change the climate. But values, politics, religion, and culture must determine whether we find

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peer review the process by which a scientific finding is scrutinized and validated or rejected by other experts in the field.

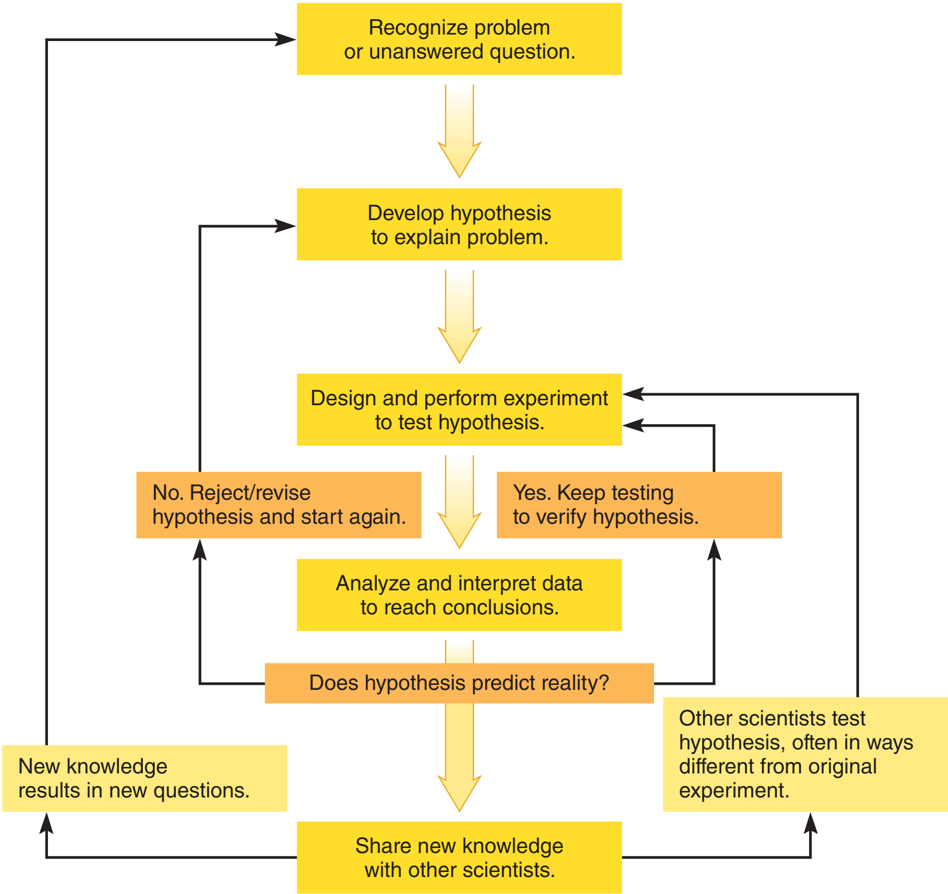

FIGURE 1.14 **Scientific method.** The basic steps of the scientific method are shown in yellow. Scientific work rarely proceeds in so straightforward a manner; examples of additional paths are shown in orange.

the loss of waterfowl or changes in the climate worth the benefits we get from spraying pesticides or burning fossil fuels.

The Scientific Method

The established processes scientists use to answer questions or solve problems are collectively called the **scientific method** (**Figure 1.14**). Although the scientific method has many variations, it basically involves five steps:

1. **Recognize a problem or unexplained occurrence in the natural world.** After a problem is recognized, one investigates relevant scientific literature to determine what is already known about it.
2. **Develop a *hypothesis*, or educated guess, to explain the problem.** A good hypothesis makes a prediction that can be tested and possibly disproved. The same factual evidence is often used to formulate several alternative hypotheses; each must be tested.
3. **Design and perform an experiment to test the hypothesis.** An experiment involves collecting data by making careful observations and measurements. Much of the creativity in science involves designing experiments that sort out the confusion caused by competing hypotheses. The process never "proves" anything; instead, it disproves or falsifies alternative hypotheses until only the most plausible hypothesis is left.
4. **Analyze and interpret the data to reach a conclusion.** Does the evidence match the prediction stated in the hypothesis—that is, do the data support or refute the hypothesis? Should the hypothesis be modified or rejected based on the observed data?
5. **Share new knowledge.** Publishing articles in scientific journals or books and presenting the information at meetings permits others to understand and critique methods and findings, and repeat the experiment or design new experiments that either verify or refute the work.

Although the scientific method is usually described as a linear sequence of events, science is rarely as straightforward or tidy as the scientific method implies. Good science involves creativity and openness to new ideas in recognizing questions, developing hypotheses, and designing experiments. Scientific knowledge progresses by trial and error. Many creative ideas end up as dead ends, and temporary setbacks or reversals of direction often occur as knowledge progresses. Scientific knowledge often expands haphazardly, with the "big picture" emerging slowly from confusing and sometimes contradictory details.

scientific method The way a scientist approaches a problem by formulating a hypothesis and then testing it by means of an experiment.

Scientific work is often incorrectly portrayed in the media as "new facts" that have just come to light. At a later time, additional "new facts" that question the validity of the original study are reported. If one were to read the scientific papers on which such media reports are based, one would find that the scientists made tentative conclusions based on their data. Science progresses from uncertainty to less uncertainty, not from certainty to greater certainty. Science leads to a better understanding of nature over time, despite the fact that science never "proves" anything.

Most often, many factors influence the processes scientists want to study. Each factor that influences a process is a **variable**. Ideally, to evaluate alternative hypotheses about a given variable, we run experiments that hold all other variables constant so that they do not confuse or mislead us. To test a hypothesis about a variable, two forms of the experiment are done in parallel. In an **experimental group**, we alter the chosen variable in a known way. In a **control group**, we do not alter that variable. In all other respects the two groups are the same. We then ask, "What is the difference, if any, between the outcomes for the two groups?" Any difference is the result of the influence of that variable because all other variables remained the same. Much of the challenge of environmental science lies in designing control groups and in successfully isolating a single variable from all other variables.

Theories

Theories explain scientific laws. A **theory** is an integrated explanation of numerous hypotheses, each supported by a large body of observations and experiments and evaluated by the peer review process. A theory condenses and simplifies many data that previously appeared unrelated. A good theory grows as additional information becomes known. It predicts new data and suggests new relationships among a range of natural phenomena.

A theory simplifies and clarifies our understanding of the natural world because it demonstrates relationships among classes of data. Theories are the solid ground of science, the explanations of which we are most sure. This definition contrasts sharply with the general public's use of the word *theory*, implying lack of knowledge or a guess—as in, "I have a theory about the existence of life on other planets." In this book, the word *theory* is always used in its scientific sense, to refer to a broadly conceived, logically coherent, and well-supported explanation.

Absolute truth is not possible in science, only varying degrees of uncertainty. Science is continually evolving as new evidence comes to light, and its conclusions are always provisional or uncertain. It is always possible that the results of future experiments will contradict a prevailing theory, which will then be replaced by a new or modified theory that better explains the scientific laws of the natural world.

Climate Change: Hypotheses and Theory

Carbon dioxide (CO_2) and other gases released from burning fossil fuels has caused and will continue to cause Earth's climate to change. This is a well-established theory from a scientific perspective, yet remains controversial in political conversations. Clearly, however, the climate is a complex system, with many variables that change over a long period. We cannot run an experiment to test the hypothesis that adding greenhouse gases to the atmosphere over a century causes global temperatures to increase. Understanding climate change requires us to observe what is happening, compare those observations to what existing theory predicts will happen, and adapt our theories based on new observations. The theory of climate change draws on physics, chemistry, oceanography, atmospheric science, astronomy, and other scientific fields.

Many of the components of climate theory can be tested directly (**Figure 1.15**). As one example, scientists have tested the hypothesis that some gases, which we call greenhouse gases, can absorb energy (where energy absorption is a variable). In one such experiment, they filled identical containers with air, varied the concentrations of CO_2 in the containers, and then

FIGURE 1.15 Climate change analysis. This equipment is part of a long-term project to explore the release of carbon dioxide (a greenhouse gas) from the melting tundra in Alaska.

Question

Carbon dioxide is released by warming, and contributes to warming. Is this an example of a positive feedback or a negative feedback?

added heat. They observed temperature increases in the containers with more CO_2. While such experiments do not prove that CO_2 absorbs heat, they demonstrate that it is reasonable to think the hypothesis is correct. Indeed, heat absorption by CO_2 has been understood for over a century.

Climate scientists have combined this experimental evidence about greenhouse gases with our understanding of other parts of the climate, such as natural variability, solar variability, and reflectivity of ice and other surfaces, to establish a theory of climate change. This theory has uncertainties, but it predicts that as greenhouse gas concentrations increase, global atmospheric temperature will increase, sea level will rise, precipitation patterns will change, and glaciers and ice caps will melt (**Figure 1.16**). As we will see in Chapter 20, observations have confirmed this general theory, while allowing us to refine it and make more reliable predictions about the future. Climate theory does not tell us what we should do to avoid climate change, only what we can expect from different possible decisions.

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FIGURE 1.16 Melting iceberg. Water streams from an iceberg that was once part of the Ilulisat Kangerlua Glacier, Greenland. While icebergs have broken off of glaciers throughout geologic history, evidence shows that the rate at which glaciers are melting has accelerated rapidly over the past hundred years.

Review

1. What is environmental science? Why is a systems perspective so important in environmental science?
2. What are the steps of the scientific method? Does the scientific process usually follow these steps? Why or why not?

Addressing Environmental Problems

LEARNING OBJECTIVES

- **List** the five stages in addressing environmental problems.
- **Briefly** describe the history of Lake Washington pollution in the 1950s.

We have shown the strengths and limitations of science—what science can and cannot do. Before examining the environmental problems in the remaining chapters of this text, let us consider the elements that contribute to addressing those problems. What is the role of science? Given that we can never achieve complete certainty in science, at what point are scientific conclusions considered certain enough to warrant action? Who makes the decisions, and what are the trade-offs?

Addressing Environmental Problems

Viewed simply, there are five stages in addressing an environmental problem (**Figure 1.17**):

1. **Scientific assessment.** The first stage in addressing any environmental problem is scientific assessment, the gathering of information. The problem is defined. Data are then collected, and experiments or simulations are performed.
2. **Risk analysis.** Using the results of a scientific investigation, we can analyze the potential effects of doing nothing or of intervening—what is expected to happen if a particular course of action is followed, including any adverse effects the action might generate. In other words, the risks of one or more remediation (correction or cleanup) options are considered.
3. **Public engagement.** Public participation and commitment are an essential part of addressing most environmental problems. The public can be a source of both knowledge and values, and many individuals and groups have a stake in the outcome of decisions. People are generally more willing to work together to solve a problem if they have the opportunity to participate from the start.
4. **Political action.** Affected parties select and implement a course of action. Ideally, science provides information on

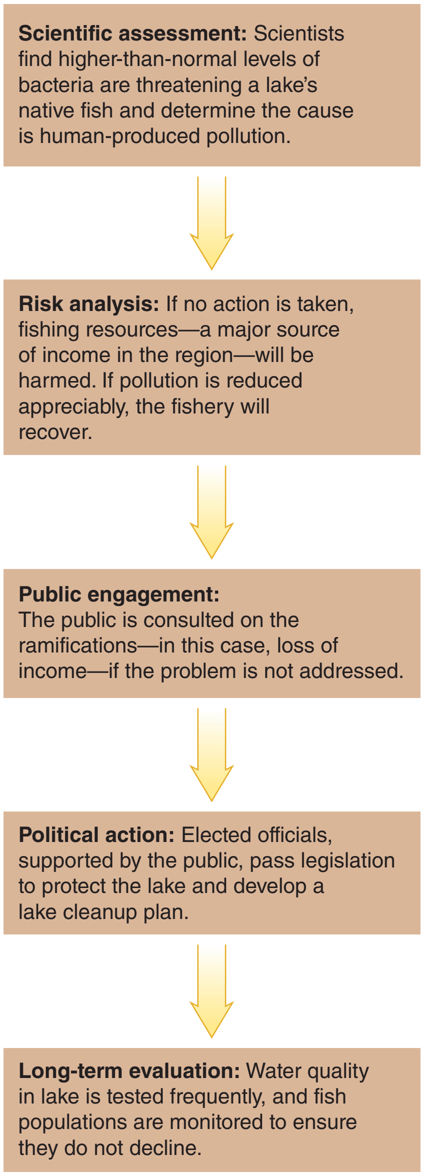


FIGURE 1.17 Addressing environmental problems. These five steps provide a framework for addressing environmental problems, such as the hypothetical example given. Solving environmental problems rarely proceeds in such a straightforward manner.

what *can* be done, but in the political process, opinions often differ about how to interpret evidence when selecting a course of action. Often, what people think *should* be done affects their beliefs about science and scientists.

5. **Long-term evaluation.** The results of any action taken should be carefully monitored, both to see if the environmental problem is being addressed and to improve the initial assessment and modeling of the problem.

These five stages represent an ideal approach to systematically addressing environmental problems. In real life, addressing environmental problems is rarely so neat and tidy, particularly when the problem is of regional or global scale, or when those bearing the costs are not those who stand to benefit from a new policy. Quite often, the public becomes aware of a problem, which triggers discussion regarding remediation before the problem has been clearly identified. Also, we often do not know what scientific information is needed until stage 2, 3, or even 4, which means that to make informed decisions, we often need to ask scientists to develop additional research.

To demonstrate the five steps as they operate in an ideal situation, let us consider a relatively simple environmental problem recognized and addressed in the 1950s—pollution in Lake Washington. This problem, unlike many environmental issues we face today, was relatively easy to diagnose and solve.

Environmental Science in Practice: Lake Washington

Lake Washington is a large, deep freshwater lake on the eastern boundary of Seattle (**Figure 1.18**). During the first part of the twentieth century, the Seattle metropolitan area expanded eastward toward the lake from the shores of Puget Sound, putting Lake Washington under increasingly intense environmental pressures. Between 1941 and 1954, 10 suburban sewage treatment plants began operating around the lake. Each plant treated the raw sewage to break down the organic material within it and released the effluent (treated sewage) into the lake. By the mid-1950s, a great deal of treated sewage had been poured into the lake.

Scientists at the University of Washington were the first to note the effects of this discharge on the lake. Their studies indicated that large masses of cyanobacteria (photosynthetic bacteria) were growing in the lake. Cyanobacteria require a plentiful supply of nutrients such as nitrogen and phosphorus, and deepwater lakes such as Lake Washington do not usually have many dissolved nutrients. The increase in filamentous cyanobacteria indicated that the quality of water in Lake Washington was diminishing.

FIGURE 1.18 Lake Washington. This large freshwater lake forms the eastern boundary of Seattle, Washington.

In 1955, the Washington Pollution Control Commission, citing the scientists' work, concluded that the treated sewage effluent was raising the levels of dissolved nutrients to the point of serious pollution. The sewage treatment was not eliminating many chemicals, particularly phosphorus, a major component of detergents. Mats of cyanobacteria formed a smelly green scum over the surface of the water. The bacteria that decompose cyanobacteria when they die multiplied explosively, consuming vast quantities of oxygen, until the lake's deeper waters could no longer support oxygen-requiring organisms such as fishes and small invertebrates.

Scientific assessment of an environmental problem verifies that a problem exists and builds a sound set of observations on which to base a solution. Scientists predicted that the lake's decline could be reversed: If the pollution was stopped, the lake would slowly recover. They outlined three steps necessary to save the lake:

1. Comprehensive regional planning by the many suburbs surrounding the lake
2. Complete elimination of sewage discharge into the lake
3. Research to identify the key nutrients causing the cyanobacteria to grow

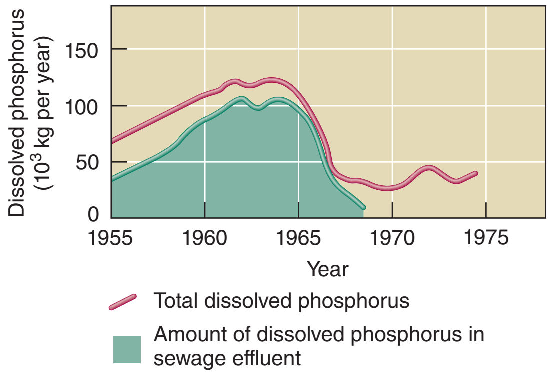
It is one thing to suggest that treated sewage no longer be added to Lake Washington and quite another to devise an acceptable remediation option. Further treatment of sewage could remove some nutrients, but it might not be practical to remove all of them. The alternative was to dump the sewage somewhere else—but where? In this case, officials decided to discharge the treated sewage into Puget Sound. In their plan, a ring of sewers built around the lake would collect the treated sewage and treat it further before discharging it into Puget Sound.

The plan to further treat the sewage was formulated to minimize the environmental impact on Puget Sound. It was assumed that the treated effluent would have less of an impact on the greater quantity of water in Puget Sound. Also, phosphate does not control cyanobacterial growth in Puget Sound as it does in Lake Washington. The growth of photosynthetic bacteria and algae in Puget Sound is largely limited by tides, which mix the water and transport the tiny organisms into deeper water, where they cannot get enough light to grow rapidly.

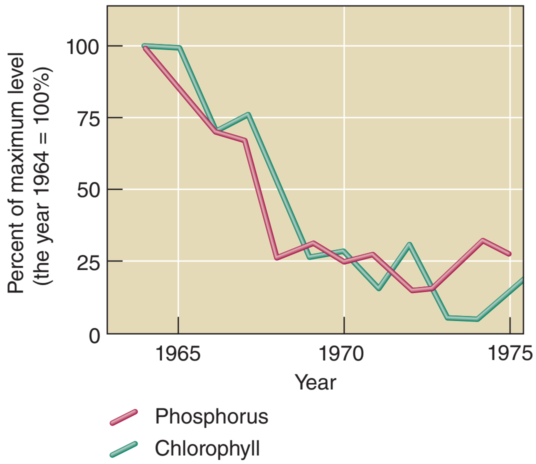
Despite the Washington Pollution Control Commission's conclusions, local sanitation authorities were not convinced that urgent action was necessary. Public action required further education, and scientists played a key role. They wrote articles for the general public that explained what nutrient enrichment is and what problems it causes. The general public's awareness increased as local newspapers published these articles.

Cleaning up the lake presented serious political problems because there was no regional mechanism in place to permit the many local suburbs to act together on matters such as sewage disposal. In late 1957, the state legislature passed a bill permitting a public referendum in the Seattle area regarding the formation of a regional government with six functions: water supply, sewage disposal, garbage disposal, transportation, parks, and planning. The referendum was defeated, apparently because suburban voters felt the plan was an attempt to tax them for the city's expenses. An advisory committee immediately submitted a revised bill limited to sewage disposal to the voters. Over the summer there was widespread discussion of the lake's future, and when the votes were counted, the revised bill passed by a wide margin.

At the time it was passed, the Lake Washington plan was the most ambitious and most expensive pollution-control project in the United States. Every household in the area had to pay additional taxes for construction of a massive trunk sewer to ring the lake, collect the effluent, treat it, and discharge it into Puget Sound. Meanwhile, the lake had deteriorated further. Visibility had declined from 4 m (12 ft) in 1950 to less than 1 m (3 ft) in 1962 because the water was clouded with cyanobacteria. In 1963, the first of the waste treatment plants around the lake began to divert its effluent into the new trunk sewer. One by one, the others diverted theirs, until the last effluent was diverted in 1968. The lake's condition began to improve (**Figure 1.19**).



(a) Dissolved phosphorus in Lake Washington from 1955 to 1974. Note that the level of dissolved phosphorus declined in the lake as the phosphorus contributed by sewage effluent (shaded area) declined.



(b) Cyanobacterial growth from 1964 to 1975, during Lake Washington's recovery, as measured indirectly by the amount of chlorophyll, the pigment involved in photosynthesis. Note that as the level of phosphorus dropped in the lake, the number of cyanobacteria (that is, the chlorophyll content) declined.

FIGURE 1.19 Nutrients in Lake Washington compared with cyanobacterial growth. Based on data from Edmondson and Lehman (1981). "The effect of changes in the nutrient income on the condition of Lake Washington." *Limnology and Oceanography* 26, pp 1–29.

Water transparency returned to normal within a few years. Cyanobacteria persisted until 1970 but eventually disappeared. By 1975, the lake was back to normal, and today the lake remains clear. Continuing to protect the water quality even as population around the lake grows has required a systems perspective. Rather than just clean up wastewater, more recent efforts have included strategies that reduce the generation of wastes, such as water recycling and efforts to reduce oil and other industrial wastes.

Review

1. What are the steps used to solve an environmental problem?
2. What was the Lake Washington pollution problem of the 1950s? How was it addressed?

Review of Learning Objectives with Selected Key Terms

- Explain how human activities affect global systems.

Earth consists of many physical and biological **systems**. Its abundant resources have allowed many forms of life to thrive and evolve. Humans, through our growing population and technology, have exploited these resources to the point that we are putting the environment at risk.

- Describe the factors that characterize human development and how they impact environment and sustainability.

Human development is typically characterized by factors associated with wealth, such as access to energy resources and medical technology. Historically, **highly developed countries** have represented less than 20% of the global population but account for more than 50% of resource use. **Less developed countries (LDCs)** are developing countries with high **poverty** rates, low levels of industrialization, high fertility rates, high infant mortality rates, and very low per capita incomes (relative to highly developed countries). Increasingly, many of the world's countries, such as China and India, have mixed development, with some urban residents owning considerable wealth but other urban and most rural residents living in poverty.

- Differentiate between renewable and nonrenewable resources.

Renewable resources are those that nature replaces fairly rapidly (on a scale of days to centuries), and can be used forever as long as they are not overexploited in the short term. **Nonrenewable resources** are present in limited supplies and are depleted by use.

- Explain the impact of population and affluence on consumption.

As population increases, people can exceed the capacity of a region to support basic needs for food, shelter, and clean water. When **consumption** by individuals substantially exceeds these basic needs, the resources in a region will be exceeded even more quickly. In either case, consumption that exhausts both **nonrenewable** and **renewable resources** is unsustainable.

- Define *ecological footprint*.

An individual's **ecological footprint** is the amount of productive land, fresh water, and ocean required on a continuous basis to supply that person with food, energy, water, housing, material goods, transportation, and waste disposal.

- Describe the three most important factors that determine human impact on the environment.

One **model** of environmental impact *(I)* has three factors: the number of people *(P)*; the affluence per person *(A),* which is a measure of the consumption or amount of resources used per person; and the environmental effect of the technologies used to obtain and consume those resources *(T).* This model uses an equation to represent the relationship between environmental impacts and the forces that drive them:

$$I = P \times A \times T$$

- Define *sustainability*.

Sustainability is the ability to meet current human natural resource needs without compromising the ability of future generations to meet their needs; in other words, it is the ability of humans to manage natural resources indefinitely without the environment going into a decline from the stresses imposed by human society on the natural systems that maintain life.

- Relate Garrett Hardin's description of the tragedy of the commons in medieval Europe to common-pool resources today.

Garrett Hardin contended that our inability to solve many environmental problems is the result of a struggle between short-term individual welfare and long-term environmental sustainability and societal welfare. In today's world, Hardin's parable has particular relevance at the global level. **Common-pool resources** are those parts of our environment that are available to everyone but for which no single individual has responsibility—shared resources such as the atmosphere, fresh water, forests, wildlife, and ocean fisheries.

- Briefly describe *sustainable development*.

Sustainable development is economic development that meets the needs of the present generation without compromising the ability of future generations to meet their own needs. Three factors—environmentally sound decisions, economically viable decisions, and socially equitable decisions—interact to promote sustainable development.

- Define *environmental science*, including the role of Earth systems in environmental science.

Environmental science is the interdisciplinary study of humanity's relationship with other organisms and the nonliving physical environment. Environmental scientists study *systems*; each system is a set of components that interact and function as a whole. A natural system consisting of a community of organisms and its physical environment is an **ecosystem**. Ecosystems are organized into larger and larger systems that interact with one another. At a global level are Earth systems, which include Earth's climate, atmosphere, land, coastal zones, and the ocean.

- Outline the scientific method.

The **scientific method** is the way a scientist approaches a problem by formulating a hypothesis and then testing it by means of an experiment. There are many variations of the scientific method, which basically involves these steps: State the problem or unanswered question; develop a **hypothesis**; design and perform an experiment to test the hypothesis; analyze and interpret the **data**; and share the conclusion with others.

- List the five stages in addressing environmental problems.

1. Scientific assessment involves gathering information about a potential environmental problem.
2. Risk analysis evaluates the potential effects of intervention.
3. Public education and involvement occur when the results of scientific assessment and risk analysis are placed in the public arena.
4. Political action is the implementation of a particular course of action by elected or appointed officials.
5. Long-term evaluation monitors the effects of the action taken.

- Briefly describe the history of Lake Washington pollution in the 1950s.

Lake Washington exemplifies a successful approach to addressing a relatively simple environmental problem. The pouring of treated sewage into Lake Washington had raised its level of nutrients to the point where the lake supported excessive growth of cyanobacteria. Disposal of the sewage in another way solved the lake's pollution problem.

Critical Thinking and Review Questions

1. Explain why a single child born in the United States can have a greater effect on the environment than 12 or more children born in a developing country.

2. Do you think it is possible for the world to sustain its present population of 7.5 billion indefinitely? Why or why not?

3. Is consumption driven more by population than affluence in highly developed countries? Less developed countries? Explain the difference.

4. In this chapter, we said the current global ecological footprint is 2.7 hectares (6.7 acres) per person. Do you think it will be higher, lower, or the same in 15 years? Explain your answer.

5. How are the concepts of ecological footprint and the *IPAT* model similar? Which concept do you think is easier for people to grasp?

6. Explain the following proverb as it relates to the concept of environmental sustainability: We have not inherited the world from our ancestors; we have borrowed it from our children.

7. Name an example of a common-pool resource other than those mentioned in this chapter.

8. Explain why economic well-being, environment, and ethics all contribute to sustainable development.

9. Give an example of an Earth system.

10. Thomas Henry Huxley once wrote, "The great tragedy of science—the slaying of a beautiful hypothesis by an ugly fact." Explain what he meant, based on what you have learned about the nature of science.

11. In the chapter, the term *model* is defined as a formal statement that describes a situation and that can be used to predict the future course of events. On the basis of this definition, is a model the same thing as a hypothesis? Explain your answer.

12. Some people want scientists to give them precise, definitive answers to environmental problems. Explain why this is not possible, and explain its implications for making decisions about climate change.

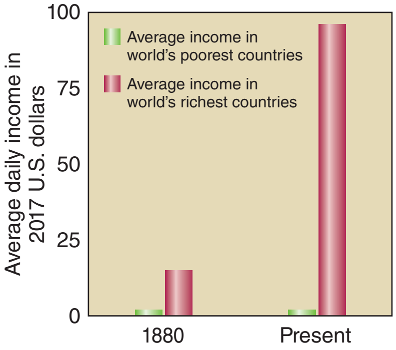
13. Explain why it might be difficult to make a decision about whether to allow farmers to spray pesticides even if we all agree about the negative health effects of the pesticide.

14. Place the following stages in addressing environmental problems in order and briefly explain each: long-term evaluation, public engagement, risk analysis, scientific assessment, political action.

15. What does the term *system* mean in environmental science?

16. In what ways do decisions about energy use and climate change that we make today limit the possibilities available to the next generation? Explain your answer.

17. Examine the graph, which shows an estimate of the discrepancy between the wealth of the world's poorest countries and that of the richest countries.



a. How has the distribution of wealth changed from the 1880s to the present? What explains this difference?

b. Based on the trend evident in this graph and what you have learned in this chapter, predict what the graph might look like in 100 years.

c. Some economists think that our current path of economic growth is unsustainable. Are the data consistent with this idea? Explain your answer.

Food for Thought

For one week, keep track of the food you eat. Where does your food come from? How is it packaged? Did you produce any of it yourself, or do you know the individuals who did? Would you be able to eat only foods grown within 100 km of your house? 500 km? Explain the benefits and challenges of trying to do so.