AP Environmental Science summer reading assignments.

Expectations: to be done before the first day of school. Do not wait until the end of the summer to do the assignments. It would be ideal to get them done early in the summer, and then re-read the chapters the week before school starts so the information is fresh in your mind.

1. All 2 chapters are read and understood. Each chapter will be lectured about, but with the understanding that each student has already been exposed to the overall concepts. Each chapter assignment will be graded as a homework assignment. There will be a test during the first week of school on chapters 1 and 2.

2. In chapters 1 and 2 following assignments should be done and be ready to be handed in on the first day class meets.
   i. One question from each checkpoint within each chapter.
   ii. All the multiple choice questions from the preparing for the AP Exam, and one of the two free-response questions.

3. Look up on AP Central (College Board site) the “Big ideas” and the “enduring understandings” subsections of the big ideas. Also the “Science Practices”. Be familiar with them as they are the broad outline of the course.

4. Be ready for a 60 multiple choice test during the first week back to school.

Other info:

1. Currently the Saturday session AP enviro. dates are: (sorry not yet known!) try to keep these dates free from 8:00-1:00

2. My summer contact info:
   a. Email- rmhungate@leepublicschools.net (I will only be checking once a week or so)
Are Hybrid Electric Vehicles as Environmentally Friendly as We Think?

Many people in the environmental science community believe that hybrid electric vehicles (HEV) and all-electric vehicles are some of the most exciting innovations of the last decade. Cars that use electric power or a combination of electricity and gasoline are much more efficient in their use of fuel than similarly sized internal combustion (IC) automobiles. Depending on whether the car is a hybrid, a plug-in HEV, or an all-electric vehicle, it may travel up to twice as far on a tank of gasoline as an IC car or even use no gasoline at all.

Even though they reduce our consumption of liquid fossil fuels, hybrid electric vehicles do come with environmental trade-offs. The construction of these vehicles uses scarce metals, including neodymium, lithium, and lanthanum. Neodymium is needed to form the magnets used in the electric motors, and lithium and lanthanum are used in the car’s compact high-performance batteries. At present, there appears to be just enough lanthanum available in the world to meet the demand of the Toyota Prius HEV, which has a projected production of almost 1 million vehicles in 2012. Toyota obtains its lanthanum from China. There are also supplies of lanthanum in various geologic deposits in California, Australia, Bolivia, Canada, and elsewhere, but most of these deposits have not yet been developed for mining. Until this happens, many scientists believe that the production of HEVs and all-electric vehicles will be limited by the availability of lanthanum.

In addition to the scarcity of these metals, we have to consider how we acquire them. A typical Toyota Prius HEV uses approximately 1 kg (2.2 pounds) of neodymium and 10 kg (22 pounds) of lanthanum. Mining these elements involves pumping acids into deep boreholes to dissolve the surrounding rock, and then removing the resulting acid and mineral slurry. Lithium is extracted from certain rocks, and lithium carbonate is extracted from brine pools and mineral springs adjacent to or under salt flats. Both extraction procedures are types of surface mining, which can have severe environmental impacts. The holes, open pits, and ground disturbance created by the mining of these minerals provide the opportunity for air and water to react with other minerals in the rock, such as sulfur, to form an acidic slurry. As this acid mine drainage flows over the land or underground toward rivers and streams, it dissolves metals and other elements. As a result, water near surface mining operations is highly acidic (sometimes with a pH of 2.5 or lower) and may contain harmful levels of dissolved metals and minerals.

Wherever it occurs, mining has a number of environmental consequences, including the creation of holes in the ground and road construction, both of which lead to fragmentation and alteration of habitat, erosion, and contamination of water supplies. So, while current HEV technology may reduce our dependence on certain fossil fuels, it increases our dependence on other limited resources that must be extracted from the ground.

Why are some of Earth’s mineral resources so limited? Why do certain elements occur in some locations and not in others? What processes create minerals and other Earth materials?
Key Ideas
Pay attention to the bulleted Key Ideas list that begins each chapter. Studying these concepts will help you succeed in the course and on the AP exam.

Key Ideas Revisited
Each point is revisited at the end of chapter where the Key Ideas are summarized. Make sure that your notes are consistent with the summary.

Human wastewater is a common pollutant
Human wastewater is the water produced by human activities including human sewage from toilets and gray water from bathing and washing clothes and dishes.

Checkpoint
By answering the integrated Checkpoints as you read each chapter, you will master the Key Ideas.

Key Ideas Revisited
- Distinguish between point and nonpoint sources of pollution.
- Point sources of pollution have distinct locations, such as a pipe from a factory that discharges toxic chemicals into a stream. In contrast, nonpoint sources of pollution are more diffuse and cover very large areas, such as agricultural fields that leach fertilizer into a nearby stream.
- Identify the ways in which human wastewater can cause water pollution.
- Human wastewater can have a number of effects on natural water bodies. Wastewater adds organic matter that increases the biochemical oxygen demand, nutrients that cause eutrophication and algal blooms, and disease-causing pathogens that can harm both humans and wildlife.
- Evaluate different technologies that humans have developed for treating wastewater.
- Identify the major types of heavy metals and other substances that pose serious hazards to humans and the environment.
- Discuss the impacts of oil spills and how such spills can be remediated.
- Identify contaminants that are nonchemical pollutants.
- Explain the connections among industrialization, affluence, and water-pollution legislation.
- Discuss the impacts of oil spills and how such spills can be remediated.
- Oil spills occur both from tankers that transport oil as well as from offshore drilling platforms that leak during oil extraction. There is general agreement about containing and removing the oil slicks that float on the surface of the water. However, scientists still debate whether oil spills that hit the coastline should be remediated by washing the coastline with hot water or leaving it to recover.
Learn from the art by studying the photos and figures and reading the captions carefully.

![Images of population distributions: random, uniform, and clumped]

**Photos**

As the saying goes, “A picture is worth a thousand words.”

The photos in this book are more than just pretty pictures. They have been carefully chosen to help illustrate the Key Ideas so that you will comprehend and remember them.

**Figures**

Some of the most complex ideas in the APES course are explained through the art and photos. The illustration program has been developed to help you grasp and remember the important concepts.

Take the time to read each caption and study each figure to make sure that you understand the Key Ideas.

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**FIGURE 6.3** Population distributions. Populations in nature distribute themselves in three ways. (a) Many of the tree species in this New England forest are randomly distributed, with no apparent pattern in the locations of individuals. (b) Territorial nesting birds, such as these Australasian gannets (Morus serrator), exhibit a uniform distribution, in which all individuals maintain a similar distance from one another. (c) Many pairs of eyes are better than one at detecting approaching predators. The clumped distribution of these meerkats (Suricata suricatta) provides them with extra protection.

**FIGURE 6.25** Primary succession. Primary succession occurs in areas devoid of soil. Early-arriving plants and algae can colonize bare rock and begin to form soil, making the site more hospitable for other species to colonize later. Over time, a series of distinct communities develops. In this illustration, representing an area in New England, bare rock is initially colonized by lichens and mosses and later by grasses, shrubs, and trees.
Use summary tables to make comparisons

<table>
<thead>
<tr>
<th>Energy type</th>
<th>Advantages</th>
<th>Disadvantages</th>
<th>Pollutant and greenhouse gas emissions</th>
<th>Electricity (cents/kWh)</th>
<th>Energy return on energy investment*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oil/gasoline</td>
<td>Ideal for mobile combustion (high energy/mass ratio) Quick ignition/turn-off capability Cleaner burning than coal</td>
<td>Significant refining required Oil spill potential effect on habitats near drilling sites Significant dust and emissions from fossil fuels used to power earth-moving equipment Human rights/environmental justice issues in developing countries that export oil</td>
<td>Second highest emitter of CO₂ among fossil fuels Hydrocarbons Hydrogen sulfide</td>
<td>Relatively little electricity is generated from oil</td>
<td>4.0 (gasoline) 5.7 (diesel)</td>
</tr>
<tr>
<td>Coal</td>
<td>Energy-dense and abundant—U.S. resources will last at least 200 years No refining necessary Easy, safe to transport Economic backbone of some small towns</td>
<td>Mining practices frequently risk human lives and dramatically alter natural landscapes Coal power plants are slow to reach full operating capacity A large contributing factor to acid rain in the United States</td>
<td>Highest emitter of CO₂ among energy sources Sulfur Trace amounts of toxic metals such as mercury</td>
<td>5 cents/kWh</td>
<td>14</td>
</tr>
<tr>
<td>Natural gas</td>
<td>Cogeneration power plants can have efficiencies up to 60 percent Efficient for cooking, home heating, etc. Fewer impurities than coal or oil</td>
<td>Risk of leaks/explosions Twenty-five times more effective as a greenhouse gas than CO₂ Not available everywhere because it is transported by pipelines</td>
<td>Methane Hydrocarbons Hydrogen sulfide</td>
<td>8–10 cents/kWh</td>
<td>8</td>
</tr>
<tr>
<td>Nuclear energy</td>
<td>Emits no CO₂ once plant is operational Offers independence from imported oil High energy density, ample supply</td>
<td>Very unpopular; generates protests Plants are very expensive to build because of legal challenges Meltdown could be catastrophic Possible target for terrorist attacks</td>
<td>Radioactive waste is dangerous for hundreds of thousands of years No long-term plan currently in place to manage radioactive waste No air pollution during production</td>
<td>12–15 cents/kWh</td>
<td>8</td>
</tr>
</tbody>
</table>

* Estimates vary widely.
PREPARING FOR THE AP EXAM

MULTIPLE-CHOICE QUESTIONS

1. Which of the following is not a measure of biodiversity?
   (a) Economic diversity
   (b) Ecosystem diversity
   (c) Genetic diversity
   (d) Species diversity
   (e) Species richness
   (a) Individuals produce an excess of offspring.
   (b) Humans select for predetermined traits.
   (c) Individuals vary in their phenotypes.
   (d) Phenotypic differences in individuals can be inherited.
   (e) Different phenotypes have different abilities to survive and reproduce.

2. The table below represents the number of individuals of different species that were counted in three forest communities. Which of the following statements best interprets these data?

<table>
<thead>
<tr>
<th>Species</th>
<th>Community A</th>
<th>Community B</th>
<th>Community C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deer</td>
<td>95</td>
<td>20</td>
<td>10</td>
</tr>
<tr>
<td>Rabbit</td>
<td>1</td>
<td>20</td>
<td>10</td>
</tr>
<tr>
<td>Squirrel</td>
<td>1</td>
<td>20</td>
<td>10</td>
</tr>
<tr>
<td>Mouse</td>
<td>1</td>
<td>20</td>
<td>10</td>
</tr>
<tr>
<td>Chipmunk</td>
<td>1</td>
<td>20</td>
<td>10</td>
</tr>
<tr>
<td>Stink</td>
<td>10</td>
<td></td>
<td></td>
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<tr>
<td>Opposum</td>
<td>10</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Elk</td>
<td>10</td>
<td></td>
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<tr>
<td>Raccoon</td>
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<td></td>
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<tr>
<td>Porcupine</td>
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</tbody>
</table>

   (i) Community A has greater species evenness than Community B.
   (b) Community A has greater species richness than Community B.
   (c) Community B has greater species evenness.
   (a) Genetic drift
   (b) Founder effect
   (c) Microevolution

5. In 2002, Peter and B. Rosemary Grant studied a population of Darwin's finches on one of the Galapagos Islands that feed on seeds of various sizes. After a drought that caused only large seeds to be available to the birds, they found that natural selection favored those birds that had larger beaks and bodies. Once the rains returned and smaller seeds became much more abundant, however, natural selection favored those birds that had smaller beaks and bodies. Which of the following processes is the best interpretation of this scenario?
   (a) Genetic drift
   (b) Founder effect
   (c) Microevolution

6. The northern elephant seal (Mirounga angustirostris) was once hunted to near extinction. Only 20 animals remained alive in 1890. After the species was protected from hunting, its population grew to nearly 80,000 animals, but the large population produces very low genetic variation. Which of the following processes is the best interpretation of this scenario?
   (a) Evolution by natural selection
   (b) Evolution by artificial selection
   (c) Evolution by the founder effect
   (d) Evolution by genetic drift

FREE-RESPONSE QUESTIONS

1. Look at the photograph below and answer the following questions.

   (a) Explain how this human impact on a forest ecosystem might affect the ability of some species to move to more suitable habitats as Earth's climate changes. (2 points)
   (b) Propose an alternative plan that could have preserved this forest ecosystem. (2 points)
   (c) Distinguish between the terms microevolution and macroevolution. Explain how the organisms in forest A could evolve into species different from those in forest B. (6 points)

2. Read the following article, which appears courtesy of The University of Texas Health Science Center at San Antonio, and answer the questions that follow.

   obtained in hospital and non-hospital clinical settings between 2000 and 2006, has identified drug-resistant strains of E. coli and Klebsiella bacteria in more than 50 blood, urine and respiratory samples. These resistant strains, which resemble bacteria reported in Latin America, Asia and Europe, were thought to be rare in the U.S.

   "This antibiotic resistance problem is likely to become widespread," said paper co-author Jan Evans Patterson, M.D., professor of medicine, infectious diseases and pathology at the UT Health Science Center. "It affects the way we treat infections in the future. In the past, we were concerned with antibiotic resistance in the hospital primarily, but in this review many of the strains we detected were from the community. This tells us antibiotic resistance is spreading in the community, as well, and will affect how we choose antibiotics for outpatient infections."

   If the trend continues, it may become difficult to select appropriate antibiotic therapy for urinary tract infections. For example, "The trend over the last decade has been to treat urinary infections empirically, to pick the drug that has worked," said James Jorgensen, Ph.D., professor of pathology, medicine, microbiology and clinical laboratory sciences at the Health Science Center. "Now it is important for physicians to culture the patient's urine to be sure they have selected the right antibiotic. The top three drugs that are often prescribed may not be effective with these resistant bacteria."

   (a) Explain how drug-resistant strains of bacteria could evolve in a hospital. (4 points)
   (b) According to the article, what is it that the

Free-Response Questions

Each chapter has two AP-style FRQs. The points listed at the end of each part of the question tell you how a complete, correct answer would be scored on the AP exam. The more practice you have in writing FRQ answers, the better you will do on the exam.
# Evaluate your environmental impact

## Measuring Your Impact

Use simple calculations to solve problems and answer questions about the impact decisions you make have on the environment.

## Measuring Your Impact

Choosing a Car: Conventional or Hybrid? One person buys a compact sedan that costs $15,000 and gets 20 miles per gallon. Another person pays $22,000 for the hybrid version of the same compact sedan, which gets 50 miles per gallon. Each owner drives 12,000 miles per year and plans on keeping the vehicle for 10 years.

(a) A gallon of gas emits 20 pounds of CO₂ when burned in an internal combustion engine. The average cost of a gallon of gas over the 10-year ownership period is $3.00.

(i) Calculate how many gallons of gas each vehicle uses per year.

(ii) Calculate the cost of the gas that each vehicle uses per year.

(iii) Calculate the amount of CO₂ that each vehicle emits per year.

(b) Based on your answers to questions i–iii, complete the data table below.

<table>
<thead>
<tr>
<th>Year of operation</th>
<th>Sedan: total costs—purchase and gas ($)</th>
<th>Sedan: cumulative CO₂ emissions (pounds)</th>
<th>Hybrid: total costs—purchase and gas ($)</th>
<th>Hybrid: cumulative CO₂ emissions (pounds)</th>
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<tbody>
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<td>1</td>
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</table>

(c) Use the data in the table to answer the following questions:

(i) Over the 10-year ownership period, which vehicle is the more economically and environmentally costly to operate (in terms of dollars and CO₂ emissions), and by how much?

(d) Suggest ways that the owner of the conventional car could reduce the overall yearly CO₂ emissions from the vehicle.

(e) Suggest ways that the hybrid owner could become carbon-neutral in terms of operating the vehicle.

(iii) After the amount of time determined in (i), compare and comment on the total costs (purchase and gas) for each vehicle at that time.
Be inspired by individuals who are making a difference in the United States and around the world

WORKING TOWARD SUSTAINABILITY

In certain parts of the world, such as the United States, sanitation regulations impose such high standards on household wastewater that we classify relatively clean water from bathtubs and washing machines as contaminated. This water must then be treated as sewage. We also use clean, drinkable water to flush our toilets and water our lawns. Can we combine these two observations to come up with a way of save water? One idea that is gaining popularity throughout the developed world is to reuse some of the water we normally discard as waste.

This idea has led creative homeowners and plumbers to identify two categories of wastewater in the home: gray water and contaminated water. Gray water is defined as the wastewater from baths, showers, bathroom sinks, and washing machines. Although no one would want to drink it, gray water is perfectly suitable for watering lawns and plants, washing cars, and flushing toilets. In contrast, water from toilets, kitchen sinks, and dishwashers contains a good deal of waste and contaminants and should therefore be disposed of in the usual fashion.

Around the world, there are a growing number of commercial and homemade systems in use for storing gray water to flush toilets and water lawns or gardens. For example, a Turkish inventor has designed a house-

At the end of each section, read about how the science studied is used, or misused, to make decisions about environmental issues

science applied

How Should We Prioritize the Protection of Species Diversity?

As a result of human activities, we have seen a widespread decline in biodiversity across the globe. Many people agree that we should try to slow or even stop this loss. But how do we proceed? Ideally, we might want to preserve all biodiversity. In reality, preserving biodiversity requires compromises. For example, in order to preserve the biodiversity of an area, we might have to set aside land that would otherwise be used for housing developments, shopping malls, or strip mines. If we cannot preserve all biodiversity, how do we decide which species receive our attention?

Conservation priorities. As of 2010, Conservation International had identified the 34 biodiversity hotspots shown in Figure 5A.1. Although these hotspots collectively represent only 2.3 percent of the world's land area, 50 percent of all plant species, and 42 percent of all vertebrate species are confined to these areas. As a result of this categorization, major conservation organizations have adjusted their funding priorities and are spending hundreds of millions of dollars to conserve these areas. What does environmental science tell us about the hotspot approach to conserving biodiversity?
The Mysterious Neuse River Fish Killer

Over the course of a few days in 1991, roughly a billion fish died in North Carolina’s Neuse River. Researchers at North Carolina State University (NCSU), led by Professor JoAnn Burkholder, identified the cause of this disaster as a microscopic free-living aquatic organism in the river water. This particular organism, of the genus *Pfiesteria* (fis-teer-ee-uh), emits a potent toxin that rapidly kills fish. When members of the research team working with the organism began to develop skin sores and experience nausea, vomiting, memory impairment, and confusion, they became concerned that people using the river for fishing, crabbing, or recreation could also be in danger.

The discovery of *Pfiesteria* in North Carolina rivers created panic among the area’s recreation and fishing industries. The organism was subsequently found in many other locations from Delaware to Florida, where it infected fisheries and discouraged tourism. Concern over *Pfiesteria* led to a $40 million loss in seafood sales in the Chesapeake Bay region alone.

While the NCSU researchers proceeded with their investigations, other investigators suggested that the “*Pfiesteria* hysteria” was overblown. Studies of humans exposed to *Pfiesteria* along rivers were inconclusive, despite additional anecdotal evidence of the symptoms that the initial researchers had experienced. Some investigators were unable to replicate the findings of Burkholder’s team regarding certain *Pfiesteria* life stages. A few researchers even argued that *Pfiesteria* did not produce toxins at all. It wasn’t until 2007—16 years after the fish kill that drew so much attention—that other investigators confirmed the identity of the toxin released by *Pfiesteria*.

Despite the beautiful appearance of North Carolina’s Neuse River, shown here, runoff from agriculture and housing development contributed to an environmental catastrophe in 1991.
The *Pfiesteria* story is a particularly good introduction to the study of environmental science. It shows us that human activities—for example, releasing waste material into a river—can affect the environment in complex and unexpected ways. Such unintended consequences of human activities are a key concern for environmental scientists.

The case of *Pfiesteria* also tells us that environmental science can be controversial. Following a new discovery, individuals, commercial interests, and the media may overstate the problem, understate it, or disagree with the initial report. Many years may pass before scientists understand the true nature and extent of the problem. Because the findings of environmental science often have an impact on industry, tourism, or recreation, they can create conflicts between scientific study and economic interests.

Finally, the story shows us that findings in environmental science are not always as clear-cut as they first appear. As we begin our study of environmental science, it’s important to recognize that the process of scientific inquiry always builds on the work of previous investigators. In this way we accumulate a body of knowledge that eventually resolves important questions—such as what killed the fish in the Neuse River. Only with this knowledge in hand can we begin to make informed decisions on questions of appropriate policy.


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**KEY IDEAS**

Humans are dependent on Earth’s air, water, and soil for our existence. However, we have altered the planet in many ways, large and small. The study of environmental science can help us understand how humans have changed the planet and identify ways of responding to those changes. After reading this chapter you should be able to

- define the field of environmental science and discuss its importance.
- identify ways in which humans have altered and continue to alter our environment.

- describe key environmental indicators that help us evaluate the health of the planet.
- define sustainability and explain how it can be measured using the ecological footprint.
- explain the scientific method and its application to the study of environmental problems.
- describe some of the unique challenges and limitations of environmental science.

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Environmental science offers important insights into our world and how we influence it

Stop reading for a moment and look up to observe your surroundings. Consider the air you breathe, the heating or cooling system that keeps you at a comfortable temperature, and the natural or artificial light that helps you see. Our environment is the sum of all the conditions surrounding us that influence life. These conditions include living organisms as well as nonliving components such as soil, temperature, and the availability of water. The influence of humans is an important part of the environment as well. The environment we live in determines how healthy we are, how fast we grow, how easy it is to move around, and even how much food we can obtain. One environment may be strikingly different from another—a hot, dry desert versus a cool, humid tropical rainforest, or a coral reef teeming with marine life versus a crowded city street.

We are about to begin a study of environmental science, the field that looks at interactions among human systems and those found in nature. By system we mean any set of interacting components that influence one another by exchanging energy or materials. We have already seen that a change in one part of a system—for example, nutrients released into the Neuse River—can cause changes throughout the entire system.

An environmental system may be completely human-made, like a subway system, or it may be natural, like weather. The scope of an environmental scientist’s work can vary from looking at a small population of individuals, to multiple populations that make up a species, to a community of interacting species, or even larger systems, such as the global climate system. Some environmental scientists are interested in regional problems. The specific case of *Pfiesteria* in the Neuse River, for example, was a regional problem. Other environmental scientists work on global issues, such as species extinction and climate change.

Many environmental scientists study a specific type of natural system known as an ecosystem. An ecosystem is a particular location on Earth whose interacting components include living, or biotic, components and nonliving, or abiotic, components.
Humans alter natural systems

Think of the last time you walked in a wooded area. Did you notice any dead or fallen trees? Chances are that even if you did, you were not aware that living and nonliving components were interacting all around you. Perhaps an insect pest killed the tree you saw and many others of the same species. Over time, dead trees in a forest lose moisture. The increase in dry wood makes the forest more vulnerable to intense wildfires. But the process doesn’t stop there. Wildfires trigger the germination of certain tree seeds, some of which lie dormant until after a fire. And so what began with the activity of insects leads to a transformation of the forest. In this way, biotic, or living, factors interact with abiotic, or nonliving, factors to influence the future of the forest.

The global environment is composed of small-scale and large-scale systems. Within a given system, biotic and abiotic components can interact in surprisingly complex ways. In the forest example, the species of trees that are present in the forest, the insect pests, and the wildfires interact with one another: they form a system. This small forest system is part of many larger systems and, ultimately, one global system that generates, circulates, and utilizes oxygen and carbon dioxide, among other things.

Humans manipulate their environment more than any other species. We convert land from its natural state into urban, suburban, and agricultural areas (FIGURE 1.2). We change the chemistry of our air, water, and soil, both intentionally—for example, by adding fertilizers—and unintentionally, as a consequence of activities that generate pollution. Even where we don’t manipulate the environment directly, the simple fact that we are so abundant affects our surroundings.

FIGURE 1.2 The impact of humans on Earth. Housing development is one example of the many ways in which humans convert land from its natural state.

CHECKPOINT

- What factors make up an organism’s environment?
- In what ways is the field of environmental studies interdisciplinary?
- Why is environmental science research important?
FIGURE 1.3 It is impossible for millions of people to inhabit an area without altering it. (a) In 1880, fewer than 6,000 people lived in Los Angeles. (b) In 2009, Los Angeles had a population of 3.8 million people, and the greater Los Angeles metropolitan area was home to nearly 13 million people.

Humans and their direct ancestors (other members of the genus *Homo*) have lived on Earth for about 2.5 million years. During this time, and especially during the last 10,000 to 20,000 years, we have shaped and influenced our environment. As tool-using, social animals, we have continued to develop a capacity to directly alter our environment in substantial ways. *Homo sapiens*—genetically modern humans—evolved to be successful hunters: when they entered a new environment, they often hunted large animal species to extinction. In fact, early humans are thought to be responsible for the extinction of mammoths, mastodons, giant ground sloths, and many types of birds. More recently, hunting in North America led to the extinction of the passenger pigeon (*Ectopistes migratorius*) and nearly caused the loss of the American bison (*Bison bison*).

But the picture isn’t all bleak. Human activities have also created opportunities for certain species to thrive. For example, for thousands of years Native Americans on the Great Plains used fire to capture animals for food. The fires they set kept trees from encroaching on the plains, which in turn created a window for an entire ecosystem to develop. Because of human activity, this ecosystem—the tallgrass prairie—is now home to numerous unique species.

During the last two centuries, the rapid and widespread development of technology, coupled with dramatic human population growth, has increased both the rate and the scale of our global environmental impact substantially. Modern cities with electricity, running water, sewer systems, Internet connections, and public transportation systems have improved human well-being, but they have come at a cost. Cities cover land that was once natural habitat. Species relying on that habitat must adapt, relocate, or go extinct. Human-induced changes in climate—for example, in patterns of temperature and precipitation—affect the health of natural systems on a global scale. Current changes in land use and climate are rapidly outpacing the rate at which natural systems can evolve. Some species have not “kept up” and can no longer compete in the human-modified environment.

Moreover, as the number of people on the planet has grown, their effect has multiplied. Six thousand people can live in a relatively small area with only minimal environmental effects. But when 4 million people live in a modern city like Los Angeles, their combined activity will cause greater environmental damage that will inevitably pollute the water, air, and soil and introduce other consequences as well (FIGURE 1.3).

CHECKPOINT

- In what ways do humans change the environment?
- What is the relationship between the development of technology and environmental impacts?
- How does human development have an impact on natural systems?

Environmental scientists monitor natural systems for signs of stress

One of the critical questions that environmental scientists investigate is whether the planet’s natural
TABLE 1.1 Some common environmental indicators

<table>
<thead>
<tr>
<th>Environmental Indicator</th>
<th>Unit of measure</th>
<th>Chapter where indicator is discussed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Human population</td>
<td>Individuals</td>
<td>7</td>
</tr>
<tr>
<td>Ecological footprint</td>
<td>Hectares of land</td>
<td>1</td>
</tr>
<tr>
<td>Total food production</td>
<td>Metric tons of grain</td>
<td>11</td>
</tr>
<tr>
<td>Food production per unit area</td>
<td>Kilograms of grain per hectare of land</td>
<td>11</td>
</tr>
<tr>
<td>Per capita food production</td>
<td>Kilograms of grain per person</td>
<td>11</td>
</tr>
<tr>
<td>Carbon dioxide</td>
<td>Concentration in air (parts per million)</td>
<td>19</td>
</tr>
<tr>
<td>Average global surface temperature</td>
<td>Degrees centigrade</td>
<td>19</td>
</tr>
<tr>
<td>Sea level change</td>
<td>Millimeters</td>
<td>19</td>
</tr>
<tr>
<td>Annual precipitation</td>
<td>Millimeters</td>
<td>4</td>
</tr>
<tr>
<td>Species diversity</td>
<td>Number of species</td>
<td>5, 18</td>
</tr>
<tr>
<td>Fish consumption advisories</td>
<td>Present or absent; number of fish allowed per week</td>
<td>17</td>
</tr>
<tr>
<td>Water quality (toxic chemicals)</td>
<td>Concentration</td>
<td>14</td>
</tr>
<tr>
<td>Water quality (conventional pollutants)</td>
<td>Concentration; presence or absence of bacteria</td>
<td>14</td>
</tr>
<tr>
<td>Deposition rates of atmospheric compounds</td>
<td>Milligrams per square meter per year</td>
<td>15</td>
</tr>
<tr>
<td>Fish catch or harvest</td>
<td>Kilograms of fish per year or weight of fish per effort expended</td>
<td>11</td>
</tr>
<tr>
<td>Extinction rate</td>
<td>Number of species per year</td>
<td>5</td>
</tr>
<tr>
<td>Habitat loss rate</td>
<td>Hectares of land cleared or “lost” per year</td>
<td>18</td>
</tr>
<tr>
<td>Infant mortality rate</td>
<td>Number of deaths of infants under age 1 per 1,000 live births</td>
<td>7</td>
</tr>
<tr>
<td>Life expectancy</td>
<td>Average number of years a newborn infant can be expected to live under current conditions</td>
<td>7</td>
</tr>
</tbody>
</table>

Life-support systems are being degraded by human-induced changes. Natural environments provide what we refer to as ecosystem services—the processes by which life-supporting resources such as clean water, timber, fisheries, and agricultural crops are produced. We often take a healthy ecosystem for granted, but we notice when an ecosystem is degraded or stressed because it is unable to provide the same services or produce the same goods. To understand the extent of our effect on the environment, we need to be able to measure the health of Earth’s ecosystems.

To describe the health and quality of natural systems, environmental scientists use environmental indicators. Just as body temperature and heart rate can indicate whether a person is healthy or sick, environmental indicators describe the current state of an environmental system. These indicators do not always tell us what is causing a change, but they do tell us when we might need to look more deeply into a particular issue. Environmental indicators provide valuable information about natural systems on both small and large scales. Some of these indicators are listed in Table 1.1.

In this book we will focus on the five global-scale environmental indicators listed in Table 1.2: biological diversity, food production, average global surface temperature and carbon dioxide concentrations in the atmosphere, human population, and resource depletion. These key environmental indicators help us analyze the health of the planet. We can use this information to guide us toward sustainability, by which we mean living on Earth in a way that allows us to use its resources without depriving future generations of those resources. Many scientists maintain that achieving sustainability is the single most important goal for the human species. It is also one of the most challenging tasks we face.

Biological Diversity

Biological diversity, or biodiversity, is the diversity of life forms in an environment. It exists on three scales: genetic, species, and ecosystem diversity. Each of these is an important indicator of environmental health and quality.

GENETIC DIVERSITY Genetic diversity is a measure of the genetic variation among individuals in a population. Populations with high genetic diversity are better able to respond to environmental change than populations with lower genetic diversity. For example, if a population of fish possesses high genetic diversity for disease resistance, at least some individuals are likely to survive...
TABLE 1.2 Five key global environmental indicators

<table>
<thead>
<tr>
<th>Indicator</th>
<th>Recent trend</th>
<th>Outlook for future</th>
<th>Overall impact on environmental quality</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biological diversity</td>
<td>Large number of extinctions, extinction rate increasing</td>
<td>Extinctions will continue</td>
<td>Negative</td>
</tr>
<tr>
<td>Food production</td>
<td>Per capita production possibly leveling off</td>
<td>Unclear</td>
<td>May affect the number of people Earth can support</td>
</tr>
<tr>
<td>Average global surface temperature and CO₂ concentrations</td>
<td>CO₂ concentrations and temperatures increasing</td>
<td>Probably will continue to increase, at least in the short term</td>
<td>Effects are uncertain and varied, but probably detrimental</td>
</tr>
<tr>
<td>Human population</td>
<td>Still increasing, but growth rate slowing</td>
<td>Population leveling off Resource consumption rates are also a factor</td>
<td>Negative</td>
</tr>
<tr>
<td>Resource depletion</td>
<td>Many resources are being depleted at rapid rates. But human ingenuity frequently develops “new” resources, and efficiency of resource use is increasing in many cases</td>
<td>Unknown</td>
<td>Increased use of most resources has negative effects</td>
</tr>
</tbody>
</table>

whatever diseases move through the population. If the population declines in number, however, the amount of genetic diversity it can possess is also reduced, and this reduction increases the likelihood that the population will decline further when exposed to a disease.

**SPECIES DIVERSITY** Species diversity indicates the number of species in a region or in a particular type of habitat. A species is defined as a group of organisms that is distinct from other groups in its morphology (body form and structure), behavior, or biochemical properties. Individuals within a species can breed and produce fertile offspring. Scientists have identified and cataloged approximately 2 million species on Earth. Estimates of the total number of species on Earth range between 5 million and 100 million, with the most common estimate at 10 million. This number includes a large array of organisms with a multitude of sizes, shapes, colors, and roles (FIGURE 1.4). Scientists have observed that ecosystems with more species, that is, higher species diversity, are more resilient and productive. For example, a tropical forest with a large number of plant species growing in the understory is likely to be more productive, and more resilient to change, than a nearby tropical forest plantation with one crop species growing in the understory.

Environmental scientists often focus on species diversity as a critical environmental indicator. The number of frog species, for example, is used as an indicator of regional environmental health because frogs are exposed to both the water and the air in their ecosystem. A decrease in the number of frog species in a particular ecosystem may be an indicator of environmental problems there. Species losses in several ecosystems can indicate larger-scale environmental problems.

Not all species losses are indicators of environmental problems, however. Species arise and others go extinct as part of the natural evolutionary process. The evolution of new species, known as speciation, typically happens very slowly—perhaps on the order of one to three new species per year worldwide. The average rate at which species go extinct over the long term, referred to as the background extinction rate, is also very slow: about one species in a million every year. So with 2 million identified species on Earth, the background extinction rate should be about two species per year.

Under conditions of environmental change or biological stress, species may go extinct faster than new ones evolve. Some scientists estimate that more than 10,000 species are currently going extinct each year—5,000 times the background rate of extinction. Habitat destruction and habitat degradation are the major causes of species extinction today, although climate change, overharvesting, and pressure from introduced species also contribute to species loss. Human intervention has saved certain species, including the American bison, peregrine falcon (*Falco peregrinus*), bald eagle (*Haliaeetus leucocephalus*), and American alligator (*Alligator mississippiensis*). But other large animal species, such as the Bengal tiger (*Panthera tigris*), snow leopard (*Panthera uncia*), and West Indian manatee (*Trichechus manatus*), remain endangered and may go extinct if present trends are not reversed. Overall, the number of species has been declining (FIGURE 1.5).

**ECOSYSTEM DIVERSITY** Ecosystem diversity is a measure of the diversity of ecosystems or habitats that exist in a given region. A greater number of healthy and productive ecosystems means a healthier environment overall.

As an environmental indicator, the current loss of biodiversity tells us that natural systems are facing strains
unlike any in the recent past. It is clearly an important topic in the study of environmental science, and we will look at it in greater detail in Chapters 5 and 18 of this book.

Some measures of biodiversity are given in terms of land area, so becoming familiar with measurements of land area is important to understanding them. As Do the Math “What Is a Hectare?” describes, a hectare

**DO THE MATH**

**What Is a Hectare?**

Some environmental indicators are expressed in hectares. A hectare is a measure of land area, abbreviated “ha,” that represents an area that is 100 meters by 100 meters. In the United States we measure land area in terms of square miles and acres. However, the rest of the world measures land in terms of hectares. Let’s see how the two systems compare:

1 mile² = 640 acres

Given that there are 5,280 feet in a mile:

1 mi² = (5,280 ft)² = 27,878,400 ft²

Using this information, we can determine the number of square feet in 1 acre, as follows:

$$\frac{1 \text{ mi}^2}{640 \text{ acres}} \times \frac{27,878,400 \text{ ft}^2}{1 \text{ mi}^2} = 43,560 \text{ ft}^2/\text{acre}$$

So—what is a hectare?
1 ha = 10,000 m²—that is, a square that is 100 m on each side, and 1 kilometer (km) = 1,000 m. Thus:

1 km² = (1,000 m)² = 1,000,000 m²

Using this information, we can determine the number of hectares in 1 square kilometer.

$$\left( \frac{1,000,000 \text{ m}^2}{1 \text{ km}^2} \right) \times \frac{1 \text{ ha}}{10,000 \text{ m}^2} = 100 \text{ ha/km}^2$$

Notice how neatly the metric system handles all these calculations. Everything is in powers of 10—unlike feet, miles, acres, and sections.

How can we compare hectares to acres? To do so, we first need to use common units. Let’s convert square kilometers to square feet. If 1 km = 0.6214 mi, then:

$$1 \text{ km}^2 = (0.6214 \text{ mi})^2 \times \frac{27,878,400 \text{ ft}^2}{1 \text{ mi}^2} = 10,764,908 \text{ ft}^2$$

Now, finally, we can determine the number of acres in 1 hectare as follows:

$$10,764,908 \text{ ft}^2/\text{km}^2 \times \frac{1 \text{ km}^2}{100 \text{ ha}} \times \frac{1 \text{ acre}}{43,560 \text{ ft}^2} = 2.47 \text{ acres}$$
is a unit of area used primarily in the measurement of land.

Food Production

The second of our five global indicators is food production: our ability to grow food to nourish the human population. Just as a healthy ecosystem supports a wide range of species, a healthy soil supports abundant and continuous food production. Food grains such as wheat, corn, and rice provide more than half the calories and protein humans consume. Still, the growth of the human population is straining our ability to grow and distribute adequate amounts of food.

In the past we have used science and technology to increase the amount of food we can produce on a given area of land. World grain production has increased fairly steadily since 1950 as a result of expanded irrigation, fertilization, new crop varieties, and other innovations. At the same time, worldwide production of grain per person, also called per capita world grain production, has leveled off. FIGURE 1.6 shows a downward trend in wheat production since about 1985.

In 2008, food shortages around the world led to higher food prices and even riots in some places. Why did this happen? The amount of grain produced worldwide is influenced by many factors. These factors include climatic conditions, the amount and quality of land under cultivation, irrigation, and the human labor and energy required to plant, harvest, and bring the grain to market. Why is grain production not keeping up with population growth? In some areas, the productivity of agricultural ecosystems has declined because of soil degradation, crop diseases, and unfavorable weather conditions such as drought or flooding. In addition, demand is outpacing supply. The rate of human population growth has outpaced increases in food production. Furthermore, humans currently use
more grain to feed livestock than they consume themselves. Finally, some government policies discourage food production by making it more profitable to allow land to remain uncultivated, or by encouraging farmers to grow crops for fuels such as ethanol and biodiesel instead of food.

Will there be sufficient grain to feed the world’s population in the future? In the past, whenever a shortage of food loomed, humans have discovered and employed technological or biological innovations to increase production. However, these innovations often put a strain on the productivity of the soil. Unfortunately, if we continue to overexploit the soil, its ability to sustain food production may decline dramatically. We will take a closer look at soil quality in Chapter 8 and food production in Chapter 11.

Average Global Surface Temperature and Carbon Dioxide Concentrations

We have seen that biodiversity and abundant food production are necessary for life. One of the things that makes them possible is a stable climate. Earth’s temperature has been relatively constant since the earliest forms of life began, about 3.5 billion years ago. The temperature of Earth allows the presence of liquid water, which is necessary for life.

What keeps Earth’s temperature so constant? As FIGURE 1.7 shows, our thick planetary atmosphere contains many gases, some of which act like a blanket trapping heat near Earth’s surface. The most important of these heat-trapping gases, called greenhouse gases, is carbon dioxide (CO₂). During most of the history of life on Earth, greenhouse gases have been present in the atmosphere at fairly constant concentrations for relatively long periods. They help keep Earth’s surface within the range of temperatures at which life can flourish.

In the past two centuries, however, the concentrations of CO₂ and other greenhouse gases in the atmosphere have risen. During roughly the same period, as the graph in FIGURE 1.8 shows, global temperatures have fluctuated considerably, but have shown an overall increase. Many scientists believe that the increase in atmospheric CO₂ during the last two centuries is anthropogenic—derived from human activities. The two major sources of anthropogenic CO₂ are the combustion of fossil fuels and the net loss of forests and other habitat types that would otherwise take up and store CO₂ from the atmosphere. We will discuss climate in Chapter 4 and global climate change in Chapter 19.
Resource Depletion

Natural resources provide the energy and materials that support human civilization. But as the human population grows, the resources necessary for our survival become increasingly depleted. In addition, extracting these natural resources can affect the health of our environment in many ways. Pollution and land degradation caused by mining, waste from discarded manufactured products, and air pollution caused by fossil fuel combustion are just a few of the negative environmental consequences of resource extraction and use.

Some natural resources, such as coal, oil, and uranium, are finite and cannot be renewed or reused. Others, such as aluminum or copper, also exist in finite quantities, but can be used multiple times through reuse or recycling. Renewable resources, such as timber, can be grown and harvested indefinitely, but in some locations they are being used faster than they are naturally replenished. Do the Math "Rates of Forest Clearing" provides an opportunity to calculate rates of one type of resource depletion.

Sustaining the global human population requires vast quantities of resources. However, in addition to the total amounts of resources used by humans, we must consider resource use per capita.

Patterns of resource consumption vary enormously among nations depending on their level of development. What exactly do we mean by development? Development is defined as improvement in human well-being.

Human Population

In addition to biodiversity, food production, and global surface temperature, the size of the human population can tell us a great deal about the health of our global environment. The human population is currently 6.8 billion and growing. The increasing world population places additional demands on natural systems, since each new person requires food, water, and other resources. In any given 24-hour period, 364,000 infants are born and 152,000 people die. The net result is 212,000 new inhabitants on Earth each day, or over a million additional people every 5 days. The rate of population growth has been slowing since the 1960s, but world population size will continue to increase for at least 50 to 100 years. Most population scientists project that the human population will be somewhere between 8.1 billion and 9.6 billion in 2050 and will stabilize between 6.8 billion and 10.5 billion by 2100.

Can the planet sustain so many people (FIGURE 1.9)? Even if the human population eventually stops growing, the billions of additional people will create a greater demand on Earth's finite resources, including food, energy, and land. Unless humans work to reduce these pressures, the human population will put a rapidly growing strain on natural systems for at least the first half of this century. We discuss human population issues in Chapter 7.

FIGURE 1.8 Changes in average global surface temperature and in atmospheric CO₂ concentrations. Earth's average global surface temperature has increased steadily for at least the past 100 years. Carbon dioxide concentrations in the atmosphere have varied over geologic time, but have risen steadily since 1960. [After http://data.giss.nasa.gov/gistemp/2008/, http://mb-software.com/public3/co2hist.gif.]

FIGURE 1.9 Kolkata, India. The human population will continue to grow for at least 50 years. Unless humans can devise ways to live more sustainably, these population increases will put additional strains on natural systems.
through economic advancement. Development influences personal and collective human lifestyles—things such as automobile use, the amount of meat in the diet, and the availability and use of technologies such as cell phones and personal computers. As economies develop, resource consumption also increases: people drive more automobiles, live in larger homes, and purchase more goods. These increases can often have implications for the natural environment.

According to the United Nations Development Programme, people in developed nations—including the United States, Canada, Australia, most European countries, and Japan—use most of the world’s resources. Figure 1.10 shows that the 20 percent of the global population that lives in developed nations owns 87 percent of the world’s automobiles and consumes 58 percent of all energy, 84 percent of all paper, and 45 percent of all fish and meat. The poorest 20 percent of the world’s people consume 5 percent or less of these resources. Thus, even though the number of people in the developing countries is much larger than the number in the developed countries, their total consumption of natural resources is relatively small.

So while it is true that a larger human population has greater environmental impacts, a full evaluation requires that we look at economic development and consumption patterns as well. We will take a closer look at resource depletion and consumption patterns in Chapters 7, 12, and 13.

**CHECKPOINT**

- What is an environmental indicator and what does it tell us?
- What are the five global-scale environmental indicators we focus on in this book, and how do they help us monitor the health of the environment?
- How do human activities contribute to changes in the five global-scale environmental indicators?

**DO THE MATH**

**Rates of Forest Clearing**

A Web search of environmental organizations yielded a range of estimates of the amount of forest clearing that is occurring worldwide:

- **Estimate 1:** 1 acre per second
- **Estimate 2:** 80,000 acres per day
- **Estimate 3:** 32,000 ha per day

Convert all three estimates into hectares per year and compare them.

There are 2.47 acres per hectare (see Do the Math "What is a Hectare?"). Therefore, 1 acre = 0.40 ha.

**Estimate 1:**

\[
1 \text{ acre/second} \times 0.40 \text{ ha/acre} = 0.40 \text{ ha/second}
\]

**Estimate 2:**

\[
80,000 \text{ acres/day} \times 0.40 \text{ ha/acre} = 32,000 \text{ ha cleared per day}
\]

**Estimate 3:**

\[
32,000 \text{ ha/day} \times 365 \text{ days/year} = 11,680,000 \text{ ha cleared per year}
\]

The second and third estimates are exactly the same. Both are equivalent to 32,000 ha per day (as seen in the intermediate step of the conversion above).

There is a difference of less than 1,000,000 ha per year, or roughly 9%, between the estimates, suggesting that they are similar in scope.

Why might environmental organizations choose to present similar information in different ways?
Human well-being depends on sustainable practices

We have seen that people living in developed nations consume a far greater share of the world’s resources than do people in developing countries. What effect does this consumption have on our environment? It is easy to imagine a very small human population living on Earth without degrading its environment; there simply would not be enough people to do significant damage. Today, however, Earth’s population is 6.8 billion people and growing. Many environmental scientists ask how we will be able to continue to produce sufficient food, build needed infrastructure, and process pollution and waste. Our current attempts to sustain the human population have already modified many environmental systems. Can we continue our current level of resource consumption without jeopardizing the well-being of future generations?

Easter Island, in the South Pacific, provides a cautionary tale (FIGURE 1.11). This island, also called Rapa Nui, was once covered with trees and grasses. When humans settled the island hundreds of years ago, they quickly multiplied in its hospitable environment. They cut down trees to build homes and canoes for fishing, and they overused the island’s soil and water resources. By the 1870s, almost all of the trees were gone. Without the trees to hold the soil in place, massive erosion occurred, and the loss of soil caused food production to decrease. While other forces, including diseases introduced by European visitors, were also involved in the destruction of the population, the unsustainable use of natural resources on Easter Island appears to be the primary cause for the collapse of its civilization.

Most environmental scientists believe that there are limits to the supply of clean air and water, nutritious foods, and other life-sustaining resources our environment can provide, as well as a point at which Earth will no longer be able to maintain a stable climate. We must meet several requirements in order to live sustainably:

- Environmental systems must not be damaged beyond their ability to recover.
- Renewable resources must not be depleted faster than they can regenerate.
- Nonrenewable resources must be used sparingly.

Sustainable development is development that balances current human well-being and economic advancement with resource management for the benefit of future generations. This is not as easy as it sounds. The issues involved in evaluating sustainability are complex, in part because sustainability depends not only on the number of people using a resource, but also on how that resource is being used. For example, eating chicken is sustainable when people raise their own chickens and allow them to forage for food on the land. However, if all people, including city dwellers, wanted to eat chicken six times a week, the amount of resources needed to raise that many chickens would probably make the practice of eating chicken unsustainable.

Living sustainably means acting in a way such that activities that are crucial to human society can continue. It includes practices such as conserving and finding alternatives to nonrenewable resources as well as protecting the capacity of the environment to continue to supply renewable resources (FIGURE 1.12).

Iron, for example, is a nonrenewable resource derived from ore removed from the ground. It is the major constituent of steel, which we use to make many things, including automobiles, bicycles, and strong frames for tall buildings. Historically, our ability to smelt iron for steel limited our use of that resource. But as we have improved steel manufacturing technology, steel has become more readily available, and the demand for it has grown. Because of this, our current use of iron is unsustainable. What would happen if we ran out of iron? Not too long ago the depletion of iron ore might have been a catastrophe. But today we have developed materials that can substitute for certain uses of steel—for example, carbon fiber—and we also know how to recycle steel. Developing substitutes and recycling materials are two ways to address the problem of resource depletion and increase sustainability.

The example of iron leads us to a question that environmental scientists often ask: How do we determine
the importance of a given resource? If we use up a resource such as iron for which substitutes exist, it is possible that the consequences will not be severe. However, if we are unable to find an alternative to the resource—for example, something to replace fossil fuels—people in the developed nations may have to make significant changes in their consumption habits.

**Defining Human Needs**

We have seen that sustainable development requires us to determine how we can meet our current needs without compromising the ability of future generations to meet their own needs. Let's look at how environmental science can help us achieve that goal. We will begin by defining needs.

If you have ever experienced an interruption of electricity to your home or school, you know how frustrating it can be. Without the use of lights, computers, televisions, air-conditioning, heating, and refrigeration, many people feel disconnected and uncomfortable. Almost everyone in the developed world would insist that they need—cannot live without—electricity. But in other parts of the world, people have never had these modern conveniences. When we speak of basic needs, we are referring to the essentials that sustain human life, including air, water, food, and shelter.

But humans also have more complex needs. Many psychologists have argued that we require meaningful human interactions in order to live a satisfying life; therefore, a community of some sort might be considered a human need. Biologist Edward O. Wilson wrote that humans exhibit biophilia—that is, love of life—which is a need to make “the connections that humans subconsciously seek with the rest of life.” Thus our needs for access to natural areas, for beauty, and for social connections can be considered as vital to our well-being as our basic physical needs and must be considered as part of our long-term goal of global sustainability (FIGURE 1.13).

**The Ecological Footprint**

We have begun to see the multitude of ways in which human activities affect the environment. As countries prosper, their populations use more resources. But economic development can sometimes improve environmental conditions. For instance, wealthier countries may be able to afford to implement pollution controls and invest money to protect native species. So although people in developing countries do not consume the same quantity of resources as those in developed nations, they may be less likely to use environmentally friendly technologies or to have the financial resources to implement environmental protections.

How do we determine what lifestyles have the greatest environmental impact? This is an important question for environmental scientists if we are to understand the effects of human activities on the planet and develop sustainable practices. Calculating sustainability, however, is more difficult than one might think. We have to consider the impacts of our activities and lifestyles on different aspects of our environment. We use land to grow food, to build on, and for parks and recreation. We require

**FIGURE 1.12** Living sustainably. Sustainable choices such as bicycling to work or school can help protect the environment and conserve resources for future generations.

**FIGURE 1.13** Central Park, New York City. New Yorkers have set aside 341 ha (843 acres) in the center of the largest city in the United States—a testament to the compelling human need for interactions with nature.
water for drinking, for cleaning, and for manufacturing products such as paper. We need clean air to breathe. Yet these goods and services are all interdependent: using or protecting one has an effect on the others. For example, using land for conventional agriculture may require water for irrigation, fertilizer to promote plant growth, and pesticides to reduce crop damage. This use of land reduces the amount of water available for human use; the plants consume it and the pesticides pollute it.

One method used to assess whether we are living sustainably is to measure the impact of a person or country on world resources. The tool many environmental scientists use for this purpose, the ecological footprint, was developed in 1995 by Professor William Rees and his graduate student Mathis Wackernagel. An individual's ecological footprint is a measure of how much that person consumes, expressed in area of land. That is, the output from the total amount of land required to support a person's lifestyle represents that person's ecological footprint (FIGURE 1.14).

Rees and Wackernagel maintained that if our lifestyle demands more land than is available, then we must be living unsustainably—using up resources more quickly than they can be produced, or producing wastes more quickly than they can be processed. For example, each person requires a certain number of food calories each day. We know the number of calories in a given amount of grain or meat. We also know how much farmland or rangeland is needed to grow the grain to feed people or livestock such as sheep, chickens, or cows. If a person eats only grains or plants, the amount of land needed to provide that person with food is simply the amount of land needed to grow the plants they eat. If that person eats meat, however, the amount of land required to feed that person is greater, because we must also consider the land required to raise and feed the livestock that ultimately become meat. Thus one factor in the size of a person's ecological footprint is the amount of meat in the diet. Meat consumption is a lifestyle choice, and per capita meat consumption is much greater in developed countries.

We can calculate the ecological footprint of the food we eat, the water and energy we use, and even the activities we perform that contribute to climate change. All of these impacts determine our ecological footprint on the planet as individuals, cities, states, or nations. Calculating the ecological footprint is complex, and the details are subject to debate, but it has at least given scientists a concrete measure to discuss and refine.

Scientists at the Global Footprint Network, where Wackernagel is now president, have calculated that the human ecological footprint has reached 14 billion hectares (34.6 billion acres), or 125 percent of Earth's total usable land area. Furthermore, they have calculated that if every person on Earth lived the average lifestyle of people in the United States, we would require the equivalent of five Earths (FIGURE 1.15). Even to support the entire human population with the lifestyles we have now, we would need more than one Earth. Clearly, this level of resource consumption is not sustainable.

According to Wackernagel and Rees, if we are to sustain human life, we must ensure that our total consumption leads to an ecological footprint of no more than 11 billion hectares (27.2 billion acres). This number will need to be significantly less if we wish to preserve land for species other than humans. In order to achieve this goal, humans will have some important choices to make.

**CHECKPOINT**

- What is meant by basic human needs?
- What does it mean to live sustainably?
- What does an ecological footprint tell us? Why is it important to calculate?
follow a process known as the scientific method. The scientific method is an objective way to explore the natural world, draw inferences from it, and predict the outcome of certain events, processes, or changes. It is used in some form by scientists in all parts of the world and is a generally accepted way to conduct science.

As we can see in Figure 1.16, the scientific method has a number of steps, including observations and questions, forming hypotheses, collecting data, interpreting results, and disseminating findings.

Observations and Questions JoAnn Burkholder and her team observed a mass die-off of fish in the Neuse River and wanted to know why it happened. Such observing and questioning is where the process of scientific research begins.

Forming Hypotheses Observation and questioning lead a scientist to formulate a hypothesis. A hypothesis is a testable conjecture about how something works. It may be an idea, a proposition, a possible mechanism of interaction, or a statement about an effect. For example, we might hypothesize that when the air temperature rises, certain plant species will be more likely, and others less likely, to persist.

What makes a hypothesis testable? We can test the idea about the relationship between air temperature and plant species by growing plants in a greenhouse at different temperatures. “Fish kills are caused by something

Science is a process

In the past century humans have learned a lot about the impact of their activities on the natural world. Scientific inquiry has provided great insights into the challenges we are facing and has suggested ways to address those challenges. For example, a hundred years ago, we did not know how significantly or rapidly we could alter the chemistry of the atmosphere by burning fossil fuels. Nor did we understand the effects of many common materials, such as lead and mercury, on human health. Much of our knowledge comes from the work of researchers who study a particular problem or situation to understand why it occurs and how we can fix or prevent it. We will now look at the process scientists use to ask and answer questions about the environment.

The Scientific Method

To investigate the natural world, scientists like JoAnn Burkholder and her colleagues, who examined the large-scale fish kill in the Neuse River, have to be as objective and methodical as possible. They must conduct their research in such a way that other researchers can understand how their data were collected and agree on the validity of their findings. To do this, scientists

Figure 1.16 The scientific method has a number of steps. In an actual investigation, a researcher might reject a hypothesis and investigate further with a new hypothesis, several times if necessary, depending on the results of the experiment.
in the water" is a testable hypothesis; it speculates that there is an interaction between something in the water and the observed dead fish.

Sometimes it is easier to prove something wrong than to prove it is true beyond doubt. In this case, scientists use a null hypothesis. A null hypothesis is a statement or idea that can be falsified, or proved wrong. The statement "Fish deaths have no relationship to something in the water" is an example of a null hypothesis.

**COLLECTING DATA** Scientists typically take several sets of measurements—a procedure called replication. The number of times a measurement is replicated is the sample size (sometimes referred to as n). A sample size that is too small can cause misleading results. For example, if a scientist chose three men out of a crowd at random and found that they all had size 10 shoes, she might conclude that all men have a shoe size of 10. If, however, she chose a larger sample size—100 men—it is very unlikely that all 100 individuals would happen to have the same shoe size.

Proper procedures yield results that are accurate and precise. They also help us determine the possible relationship between our measurements or calculations and the true value. Accuracy refers to how close a measured value is to the actual or true value. For example, an environmental scientist might estimate how many songbirds of a particular species there are in an area of 1,000 ha by randomly sampling 10 ha and then projecting or extrapolating the result up to 1,000 ha. If the extrapolation is close to the true value, it is an accurate extrapolation. Precision is how close to one another the repeated measurements of the same sample are. In the same example, if the scientist counted birds five times on five different days and obtained five results that were similar to one another, the estimates would be precise. Uncertainty is an estimate of how much a measured or calculated value differs from a true value. In some cases, it represents the likelihood that additional repeated measurements will fall within a certain range. Looking at **FIGURE 1.17**, we see that high accuracy and high precision is the most desirable result.

**INTERPRETING RESULTS** We have followed the steps in the scientific method from making observations and asking questions, to forming a hypothesis, to collecting data. What happens next? Once results have been obtained, analysis of data begins. A scientist may use a variety of techniques to assist with data analysis, including summaries, graphs, charts, and diagrams.

As data analysis proceeds, scientists begin to interpret their results. This process normally involves two types of reasoning: inductive and deductive. Inductive reasoning is the process of making general statements from specific facts or examples. If the scientist who sampled a songbird species in the preceding example made a statement about all birds of that species, she would be using inductive reasoning. It might be reasonable to make such a statement if the songbirds that she sampled were representative of the whole population. Deductive reasoning is the process of applying a general statement to specific facts or situations. For example, if we know that, in general, air pollution kills trees, and we see a single, dead tree, we may attribute that death to air pollution. But a conclusion based on a single tree might be incorrect, since the tree could have been killed by something else, such as a parasite or fungus. Without additional observations or measurements, and possibly experimentation, the observer would have no way of knowing the cause of death with any degree of certainty.

The most careful scientists always maintain multiple working hypotheses; that is, they entertain many possible explanations for their results. They accept or reject certain hypotheses based on what the data show and do not show. Eventually, they determine that certain explanations are the most likely, and they begin to generate conclusions based on their results.

**DISSEMINATING FINDINGS** A hypothesis is never confirmed by a single experiment. That is why scientists not only repeat their experiments themselves, but also present papers at conferences and publish the results of their investigations. This dissemination of scientific findings allows other scientists to repeat the original experiment and verify or challenge the results. The process of science involves ongoing discussion among scientists, who frequently disagree about hypotheses, experimental conditions, results, and the interpretation of results. Two investigators may even obtain different results from similar measurements and experiments, as happened in the *Pfiesteria* case. Only when the same results are obtained over and over by different investigators can we begin to trust that those results are valid. In the meantime the disagreements and discussion about contradictory findings are a valuable part of the scien-
tific process. They help scientists refine their research to arrive at more consistent, reliable conclusions.

Like any scientist, you should always read reports of "exciting new findings" with a critical eye. Question the source of the information, consider the methods or processes that were used to obtain the information, and draw your own conclusions. This process, essential to all scientific endeavor, is known as critical thinking.

A hypothesis that has been repeatedly tested and confirmed by multiple groups of researchers and has reached wide acceptance becomes a theory. Current theories about how plant species distributions change with air temperature, for example, are derived from decades of research and evidence. Notice that this sense of theory is different from the way we might use the term in everyday conversation ("But that's just a theory!"). To be considered a theory, a hypothesis must be consistent with a large body of experimental results. A theory cannot be contradicted by any replicable tests.

Scientists work under the assumption that the world operates according to fixed, knowable laws. We accept this assumption because it has been successful in explaining a vast array of natural phenomena and continues to lead to new discoveries. When the scientific process has generated a theory that has been tested multiple times, we can call that theory a natural law. A natural law is a theory to which there are no known exceptions and which has withstood rigorous testing. Familiar examples include the law of gravity and the laws of thermodynamics, which we will look at in the next chapter. These theories are accepted as fact by the scientific community, but they remain subject to revision if contradictory data are found.

Case Study: The Chlorpyrifos Investigation

Let's look at what we have learned about the scientific method in the context of an actual scientific investigation. In the 1990s, scientists suspected that organophosphates—a group of chemicals commonly used in insecticides—might have serious effects on the human central nervous system. By the early part of the decade, scientists suspected that organophosphates might be linked to such problems as neurological disorders, birth defects, ADHD, and palsy. One of these chemicals, chlorpyrifos (klor-PEER-i-fos), was of particular concern because it is among the most widely used pesticides in the world, with large amounts applied in homes in the United States and elsewhere.

The researchers investigating the effects of chlorpyrifos on human health formulated a hypothesis: chlorpyrifos causes neurological disorders and negatively affects human health. Because this hypothesis would be hard to prove conclusively, the researchers also proposed a null hypothesis: chlorpyrifos has no observable negative effects on the central nervous system. We can follow the process of their investigation in Figure 1.18.

To test the null hypothesis, the scientists designed experiments using rats. One experiment used two groups of rats, with 10 individuals per group. The first group—the experimental group—was fed small doses of chlorpyrifos for each of the first 4 days of life. No chlorpyrifos was fed to the second group. That second group was a control group: a group that experiences exactly the same conditions as the experimental group, except for the single variable under study. In this experiment, the only difference between the control group and the

![Question: Do organophosphate pesticides have detrimental effects on the central nervous system?](image)

![Null hypothesis: Chlorpyrifos has no observable negative effects on the central nervous system.](image)

![Conduct experiment:](image)

![Experimental group](image)

![Control group (normal food)](image)

![Measure enzyme activity in order to test for the effect of chlorpyrifos on the brain.](image)

![Results: Enzyme activity](image)

![Hypothesis results](image)

**Figure 1.18** A typical experimental process. An investigation of the effects of chlorpyrifos on the central nervous system illustrates how the scientific method is used.
experimental group was that the control group was not fed any chlopyrifos. By designating a control group, scientists can determine whether an observed effect is the result of the experimental treatment or of something else in the environment to which all the subjects are exposed. For example, if the control rats—those that were not fed chlopyrifos—and the experimental rats—that were exposed to chlopyrifos—showed no differences in their brain chemistry, researchers could conclude that the chlopyrifos had no effect. If the control group and experimental group had very different brain chemistry after the experiment, the scientists could conclude that the difference must have been due to the chlopyrifos. At the end of the experiment, the researchers found that the rats exposed to chlopyrifos had much lower levels of the enzyme choline acetyltransferase in their brains than the rats in the control group. But without a control group for comparison, the researchers would never have known whether the chlopyrifos or something else caused the change observed in the experimental group.

The discovery of the relationship between ingesting chlopyrifos and a single change in brain chemistry might seem relatively small. But that is how most scientific research works: very small steps establish that an effect occurs and, eventually, how it occurs. In this way, we progress toward a more thorough understanding of how the world works. This particular research on chlopyrifos, combined with numerous other experiments testing specific aspects of the chemical’s effect on rat brains, demonstrated that chlopyrifos was capable of damaging developing rat brains at fairly low doses. The results of this research have been important for our understanding of human health and toxic substances in the environment.

**Controlled Experiments and Natural Experiments**

The chlopyrifos experiment we have just described was conducted in the controlled conditions of a laboratory. However, not all experiments can be done under such controlled conditions. For example, it would be difficult to study the interactions of wolves and caribou in a controlled setting because both species need large amounts of land and because their behavior changes in captivity. Other reasons that a controlled laboratory experiment may not be possible include prohibitive costs and ethical concerns.

Under these circumstances, investigators look for a *natural experiment*. A *natural experiment* occurs when a natural event acts as an experimental treatment in an ecosystem. For example, a volcano that destroys thousands of hectares of forest provides a natural experiment for understanding large-scale forest regrowth (FIGURE 1.19). We would never destroy that much forest just to study regrowth, but we can study such natural disasters.
when they occur. Still other cases of natural experiments do not involve disasters. For example, we can study the process of ecological succession by looking at areas where forests have been growing for different amounts of time and comparing them. We can study the effects of species invasions by comparing uninverted ecosystems with invaded ones.

Because a natural experiment is not controlled, many variables can change at once, and results can be difficult to interpret. Ideally, researchers compare multiple examples of similar systems in order to exclude the influences of different variables. For example, after a forest fire, researchers might not only observe how a burned forest responds to the disturbance, but also compare it with a nearby forest that did not burn. In this case, the researchers are comparing similar forests that differ in only one variable: fire. If, however, they tried to compare the burned forest with a different type of forest, perhaps one at a different elevation, it would be difficult to separate the effects of the fire from the effects of elevation. Still, because they may be the only way to obtain vital information, natural experiments are indispensable.

Returning to the study of chlorpyrifos, researchers wanted to know if human brains that were exposed to the chemical would react in the same way as rat brains. For obvious ethical reasons, researchers would never feed pesticides to humans to study their effects. Instead, they conducted a natural experiment. They looked for groups of people in similar circumstances (income, age, level of education) that varied mostly in their exposure to chlorpyrifos. That variation came from their use of pesticides containing chlorpyrifos, the frequency and location of that use, and the brand used. Researchers found that tissue concentrations of chlorpyrifos were highest in groups that worked with the chemical and among poor urban families whose exposure to residential pesticides was high. Among these populations, a number of studies connected exposure to chlorpyrifos with low birth weight and other developmental abnormalities.

Science and Progress

The chlorpyrifos experiment is a good example of the process of science. Based on observations, the scientists proposed a hypothesis and null hypothesis. The null hypothesis was tested and rejected. Multiple rounds of additional testing gave researchers confidence in their understanding of the problem. Moreover, as the research progressed, the scientists informed the public, as well as the scientific community, about their results. Finally, in 2000, as a result of the step-by-step scientific investigation of chlorpyrifos, the U.S. Environmental Protection Agency (EPA) decided to prohibit its use for most residential applications. It also prohibited agricultural use on fruits that are eaten without peeling, such as apples and pears, or those that are especially popular with children, such as grapes.

CHECKPOINT

- What is the scientific method, and how do scientists use it to address environmental problems?
- What is a hypothesis? What is a null hypothesis?
- How are controlled and natural experiments different? Why do we need each type?

Environmental science presents unique challenges

Environmental science has many things in common with other scientific disciplines. However, it presents a number of challenges and limitations that are not usually found in most other scientific fields. These challenges and limitations are a result of the nature of environmental science and the way research in the field is conducted.

Lack of Baseline Data

The greatest challenge to environmental science is the fact that there is no undisturbed baseline—no "control planet"—with which to compare the contemporary Earth. Virtually every part of the globe has been altered by humans in some way (FIGURE 1.20). Even though some remote regions appear to be undisturbed, we can still find quantities of lead in the Greenland ice sheet, traces of the anthropogenic compound PCB in the fatty tissue of penguins in Antarctica, and invasive species from many locations carried by ship to remote tropical

FIGURE 1.20 Human impacts are global. The trash washed up onto the beach of this remote Pacific Island vividly demonstrates the difficulty of finding any part of Earth unaffected by human activities.
islands. This situation makes it difficult to know the original levels of contaminants or numbers of species that existed before humans began to alter the planet. Consequently, we can only speculate about how the current conditions deviate from those of pre-human activity.

**Subjectivity**

A second challenge unique to environmental science lies in the dilemmas raised by subjectivity. For example, when you go to the grocery store, the bagger may ask, "Paper or plastic?" How can we know for certain which type of bag has the least environmental impact? There are techniques for determining what harm may come from using the petrochemical benzene to make a plastic bag and from using chlorine to make a paper bag. However, different substances tend to affect the environment differently: benzene may pose more of a risk to people, whereas chlorine may pose a greater risk to organisms in a stream. It is difficult, if not impossible, to decide which is better or worse for the environment overall. There is no single measure of environmental quality. Ultimately, our assessments and our choices involve value judgments and personal opinions.

**Interactions**

A third challenge is the complexity of natural and human-dominated systems. All scientific fields examine interacting systems, but those systems are rarely as complex and as intertwined as they are in environmental science. Because environmental systems have so many interacting parts, the results of a study of one system cannot always be easily applied to similar systems elsewhere.

There are also many examples in which human preferences and behaviors have as much of an effect on environmental systems as the natural laws that describe them. For example, many people assume that if we build more efficient automobiles, the overall consumption of gasoline in the United States would decrease. To decrease gas consumption, however, it is necessary not only to build more efficient automobiles, but also to get people to purchase those vehicles and use them in place of less efficient ones. During the 1990s and early 2000s, even though there were many fuel-efficient cars available, the majority of buyers in the United States continued to purchase larger, heavier, and less fuel-efficient cars, minivans, light trucks, and sport-utility vehicles. Environmental scientists thought they knew how to reduce gasoline consumption, but they neglected to account for consumer behavior. Science is the search for natural laws that govern the world around us, whereas environmental science may involve politics, law, and economics as well as the traditional natural sciences. This complexity often makes environmental science challenging and its findings the subject of vigorous and lively debate.

**Human Well-Being**

As we continue our study of environmental science, we will see that many of its topics touch on human well-being. In environmental science, we study how humans impact the biological systems and natural resources of the planet. We also study how changes in natural systems and the supply of natural resources affect humans.

We know that people who are unable to meet their basic needs are less likely to be interested in or able to be concerned about the state of the natural environment. The principle of environmental equity—the fair distribution of Earth's resources—adds a moral issue to questions raised by environmental science. Pollution and environmental degradation are inequitably distributed, with the poor receiving much more than an equal share. Is this a situation that we, as fellow humans, can tolerate? The ecological footprint and other environmental indicators show that it would be unsustainable for all people on the planet to live like the typical North American. But as more and more people develop an ability to improve their living conditions, how do we think about apportioning limited resources? Who has the right and the responsibility to make such decisions? Environmental justice is a social movement and field of study that works toward equal enforcement of environmental laws and the elimination of disparities, whether intended or unintended, in how pollutants and other environmental harms are distributed among the various ethnic and socioeconomic groups within a society (FIGURE 1.21).

Our society faces many environmental challenges. The loss of biodiversity, the growing human demand for

![Figure 1.21](image-url) A village on the outskirts of New Delhi, India. The poor are exposed to a disproportionate amount of pollutants and other hazards. The people shown here are recycling circuit boards from discarded electronics products.
resources, and climate change are all complex problems. To solve them, we will need to apply thoughtful analysis, scientific innovation, and strategies that consider human behavior. Around the globe today, we can find people who are changing the way their governments work, changing the way they do business, and changing the way they live their lives, all with a common goal: they are working toward sustainability. Here, and at the end of each chapter of this book, we will tell a few of their stories.

**CHECKPOINT**

- In what ways is environmental science different from other sciences?
- Why (or when) is the lack of baseline data a problem in environmental science?
- What makes environmental systems so complex?

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**WORKING TOWARD SUSTAINABILITY**

We have seen that environmental indicators can be used to monitor conditions across a range of scales, from local to global. They are also being used by people looking for ways to apply environmental science to the urban planning process in countries as diverse as China, Brazil, and the United States.

San Francisco, California, is one example. In 1997, the city adopted a sustainability plan to go along with its newly formed Department of the Environment. The San Francisco Sustainability Plan focuses on 10 environmental concerns:

- Air quality
- Biodiversity
- Energy, climate change, and ozone depletion
- Food and agriculture
- Hazardous materials
- Human health
- Parks, open spaces, and streetscapes
- Solid waste
- Transportation
- Water and wastewater

Although some of these topics may not seem like components of urban planning, the drafters of the plan recognized that the everyday choices of city dwellers can have wide-ranging environmental impacts, both in and beyond the city. For example, purchasing local produce or organic food affects the environments and economies of both San Francisco and the agricultural areas that serve it.

For each of the 10 environmental concerns, the sustainability plan sets out a series of 5-year and long-term objectives as well as specific actions required to achieve them. These actions include public education through information sources such as Web sites and newsletters and hands-on activities such as replacing non-native plants with native trees and shrubs.

To monitor the effectiveness of the various actions, San Francisco chose specific environmental indicators for each of the 10 environmental concerns. These indicators had to indicate a clear trend toward or away from environmental sustainability, demonstrate cost-effectiveness, be understandable to the nonscientist, and be easily presented to the media. For example, to evaluate biodiversity, San Francisco uses four indicators:

<table>
<thead>
<tr>
<th>Environmental Indicator</th>
<th>Desired trend</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of volunteer hours dedicated to managing, monitoring, and conserving San Francisco's biodiversity</td>
<td>INCREASING</td>
</tr>
<tr>
<td>Number of square feet of the worst non-native species removed from natural areas</td>
<td>INCREASING</td>
</tr>
<tr>
<td>Number of surviving native plant species planted in developed parks, private landscapes, and natural areas</td>
<td>INCREASING</td>
</tr>
<tr>
<td>Abundance and species diversity of birds, as indicated by the Golden Gate Audubon Society's Christmas bird counts</td>
<td>INCREASING</td>
</tr>
</tbody>
</table>

Together, these indicators provide a relatively inexpensive and simple way to summarize the level of biodiversity, the threat to native biodiversity from non-native species, and the amount of effort going into biodiversity protection.

More than 13 years later, what do the indicators show? In general, there has been a surprising amount of improvement. For example, in the category of solid waste, San Francisco has increased the amount of waste...
Key Ideas Revisited

- Define the field of environmental science and discuss its importance.
  Environmental science is the study of the interactions among human-dominated systems and natural systems and how those interactions affect environments. Studying environmental science helps us identify, understand, and respond to anthropogenic changes.

- Identify ways in which humans have altered and continue to alter our environment.
  The impact of humans on natural systems has been significant since early humans hunted some large animal species to extinction. However, technology and population growth have dramatically increased both the rate and the scale of human-induced change.

- Describe key environmental indicators that help us evaluate the health of the planet.
  Five important global-scale environmental indicators are biological diversity, food production, average global surface temperature and atmospheric CO₂ concentrations, human population, and resource depletion.

- Define sustainability and explain how it can be measured using the ecological footprint.
  Sustainability is the use of Earth’s resources to meet our current needs without jeopardizing the ability of future generations to meet their own needs. The ecological footprint is the land area required to support a person’s (or a country’s) lifestyle. We can use that information to say something about how sustainable that lifestyle would be if it were adopted globally.

- Explain the scientific method and its application to the study of environmental problems.
  The scientific method is a process of observation, hypothesis generation, data collection, analysis of results, and dissemination of findings. Repetition of measurements or experiments is critical if one is to determine the validity of findings. Hypotheses are tested and often modified before being accepted.

- Describe some of the unique challenges and limitations of environmental science.
  We lack an undisturbed “control planet” with which to compare conditions on Earth today. Assessments and choices are often subjective because there is no single measure of environmental quality. Environmental systems are so complex that they are poorly understood, and human preferences and policies may have as much of an effect on them as natural laws.

Reference

Figure 1.22
A “green” city. San Francisco’s adoption of environmental indicators has helped it achieve many of its sustainability goals.

San Francisco recycled from 30 to 70 percent, with a goal of 75 percent by 2020, and it now has the largest urban composting program in the country. San Francisco has also improved its air quality, reducing the number of days in which fine particulate matter exceeded the EPA air quality safe level, from 27 days in 2000 to 10 days in 2006. These and other successes have won the city numerous accolades: it has been selected as one of “America’s Top Five Cleanest Cities” by Reader’s Digest and as one of the “Top 10 Green Cities” by The Green Guide. In 2005, San Francisco was named the most sustainable city in the United States by SustainLane (Figure 1.22).
1. Which of the following events has increased the impact of humans on the environment?
   I Advances in technology
   II Reduced human population growth
   III Use of tools for hunting
   (a) I only   (d) I and III only
   (b) I and II only   (e) I, II, and III
   (c) II and III only

2. As described in this chapter, environmental indicators
   (a) always tell us what is causing an environmental change.
   (b) can be used to analyze the health of natural systems.
   (c) are useful only when studying large-scale changes.
   (d) do not provide information regarding sustainability.
   (e) take into account only the living components of ecosystems.

3. Which statement regarding a global environmental indicator is not correct?
   (a) Concentrations of atmospheric carbon dioxide have been rising quite steadily since the Industrial Revolution.
   (b) World grain production has increased fairly steadily since 1950, but worldwide production of grain per capita has decreased dramatically over the same period.
   (c) For the past 130 years, average global surface temperatures have shown an overall increase that seems likely to continue.
   (d) World population is expected to be between 8.1 billion and 9.6 billion by 2050.
   (e) Some natural resources are available in finite amounts and are consumed during a one-time use, whereas other finite resources can be used multiple times through recycling.

4. Figure 1.8 (on page 10) shows atmospheric carbon dioxide concentrations over time. The measured concentration of CO₂ in the atmosphere is an example of
   (a) a sample of air from over the Antarctic.
   (b) an environmental indicator.
   (c) replicate sampling.
   (d) calculating an ecological footprint.
   (e) how to study seasonal variation in Earth's temperatures.

5. In science, which of the following is the most certain?
   (a) Hypothesis   (d) Observation
   (b) Idea   (e) Theory
   (c) Natural law

6. All of the following would be exclusively caused by anthropogenic activities except
   (a) combustion of fossil fuels.
   (b) overuse of resources such as uranium.
   (c) forest clearing for crops.
   (d) air pollution from burning oil.
   (e) forest fires.

7. Use Figure 1.6 (on page 9) to calculate the approximate percentage change in world grain production per person between 1950 and 2000.
   (a) 10 percent   (d) 40 percent
   (b) 20 percent   (e) 50 percent
   (c) 30 percent

8. The populations of some endangered animal species have stabilized or increased in numbers after human intervention. An example of a species that is still endangered and needs further assistance to recover is the
   (a) American bison.   (d) American alligator.
   (b) peregrine falcon.   (e) snow leopard.
   (c) bald eagle.

Questions 9 and 10 refer to the following experimental scenario:

An experiment was performed to determine the effect of caffeine on the pulse rate of five healthy 18-year-old males. Each was given 250 mL of a beverage with or without caffeine. The men had their pulse rates measured before they had the drink (time 0 minutes) and again after they had been sitting at rest for 30 minutes after consuming the drink. The results are shown in the following table.

<table>
<thead>
<tr>
<th>Subject</th>
<th>Beverage</th>
<th>Caffeine content (mg/serving)</th>
<th>Pulse rate at time 0 minutes</th>
<th>Pulse rate at time 30 minutes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Water</td>
<td>0</td>
<td>60</td>
<td>59</td>
</tr>
<tr>
<td>2</td>
<td>Caffeine-free soda</td>
<td>0</td>
<td>55</td>
<td>56</td>
</tr>
<tr>
<td>3</td>
<td>Caffeinated soda</td>
<td>10</td>
<td>58</td>
<td>68</td>
</tr>
<tr>
<td>4</td>
<td>Coffee, decaffeinated</td>
<td>3</td>
<td>62</td>
<td>67</td>
</tr>
<tr>
<td>5</td>
<td>Coffee, regular</td>
<td>45</td>
<td>58</td>
<td>81</td>
</tr>
</tbody>
</table>
9. Before the researchers began the experiment, they formulated a null hypothesis. The best null hypothesis for the experiment would be that caffeine
(a) has no observable effect on the pulse rate of an individual.
(b) will increase the pulse rates of all test subjects.
(c) will decrease the pulse rates of all test subjects.
(d) has no observable effects on the pulse rates of 18-year-old males.
(e) from a soda will have a greater effect on pulse rates than caffeine from coffee.

10. After analyzing the results of the experiment, the most appropriate conclusion would be that caffeine
(a) increased the pulse rates of the 18-year-old males tested.
(b) decreased the pulse rates of the 18-year-old males tested.
(c) will increase the pulse rate of any individual that is tested.
(d) increases the pulse rate and is safe to consume.
(e) makes drinks better than decaffeinated beverages.

FREE-RESPONSE QUESTIONS

1. Your neighbor has fertilized her lawn. Several weeks later, she is alarmed to see that the surface of her ornamental pond, which sits at the bottom of the sloping lawn, is covered with a green layer of algae.
(a) Suggest a possible explanation for the algal bloom in the pond. (2 points)
(b) Design an experiment that would enable you to validate your explanation. (7 points) Include and label in your answer:
   (i) a testable hypothesis. (2 points)
   (ii) the variable that you will be testing. (1 point)
   (iii) the data to be collected. (1 point)
   (iv) a description of the experimental procedure. (2 points)
   (v) a description of the results that would validate your hypothesis. (1 point)

(c) Based on the data from your experiment and your explanation of the problem, think of, and suggest, one action that your neighbor could take to help the pond recover. (1 point)

2. The study of environmental science sometimes involves examining the overuse of environmental resources.
(a) Identify one general effect of overuse of an environmental resource. (3 points)
(b) For the effect you listed above, describe a more sustainable strategy for resource utilization. (3 points)
(c) Describe how the events from Easter Island can be indicative of environmental issues on Earth today. (4 points)

MEASURING YOUR IMPACT

Exploring Your Footprint Make a list of the activities you did today and attempt to describe their impact on the five global environmental indicators described in this chapter. For each activity, such as eating lunch or traveling to school, make as complete a list as you can of the resources and fuels that went into the activity and try to determine the impacts of using those resources.

After completing your inventory, visit the Web site of the Global Footprint Network (www.footprintnetwork.org) and complete the personal footprint calculator. Compare the impact you described with the impacts you are asked to identify in the personal footprint calculator.

EXPLORING THE LITERATURE


Located between the deserts of the Great Basin and the mountains of the Sierra Nevada, California's Mono Lake is an unusual site. It is characterized by eerie tufa towers of limestone rock, unique animal species, glassy waters, and frequent dust storms. Mono Lake is a terminal lake, which means that water flows into it, but does not flow out. As water moves through the mountains and desert soil, it picks up salt and other minerals, which it deposits in the lake. As the water evaporates, these minerals are left behind. Over time, evaporation has caused a buildup of salt concentrations so high that the lake is actually saltier than the ocean, and no fish can survive in its water.

The Mono brine shrimp (Artemia monica) and the larvae of the Mono Lake alkali fly (Ephydra hians) are two of only a few animal species that can tolerate the conditions of the lake. The brine shrimp and the fly larvae consume microscopic algae, millions of tons of which grow in the lake each year. In turn, large flocks of migrating birds, such as sandpipers, gulls, and flycatchers, use the lake as a stopover, feeding on the brine shrimp and fly larvae to replenish their energy stores. The lake is an oasis on the migration route for these birds. They have come to depend on its food and water resources. The health of Mono Lake is therefore critical for many species.

In 1913, the city of Los Angeles drew up a controversial plan to redirect water away from Mono Lake and its neighbor, the larger and shallower Owens Lake. Owens Lake was diverted first, via a 359 km (223-mile) aqueduct that drew water away from the springs and streams that kept Owens Lake full. Soon, the lake began to dry up, and by the 1930s, only an empty salt flat remained. Today the dry lake bed covers roughly 440 km² (109,000 acres). It is one of the nation's largest sources of windblown dust, which lowers visibility in the area's national parks. Even worse, because of the local geology, the dust contains high concentrations of arsenic—a major threat to human health.

In 1941, despite the environmental degradation at Owens Lake, Los Angeles extended the aqueduct to draw water from the streams feeding Mono Lake. By 1982, with less fresh water feeding the lake, its depth had decreased by half, to an average of 14 m (45 feet), and the salinity of the water had doubled to more than twice that of the ocean. The salt killed the lake's algae. Without algae to eat, the Mono brine shrimp also died. Most birds stayed away, and newly exposed land bridges allowed coyotes from the desert to prey on those colonies of nesting birds that remained.

However, just when it appeared that Mono Lake would not recover, circumstances changed. In 1994, after years of litigation led by the National Audubon Society and tireless work by environmentalists, the Los Angeles Department of Water and Power agreed to reduce the amount of water it diverted and allow the lake to refill to about two-thirds of its historical depth. By summer 2009, lake levels had risen to just short of that goal, and the ecosystem was slowly recovering. Today brine shrimp are thriving, and many birds are returning to Mono Lake. ▶

Just when it appeared that Mono Lake would not recover, circumstances changed.
Water is a scarce resource in the Los Angeles area, and demand there is particularly high. To decrease the amount of water diverted from Mono Lake, the city of Los Angeles had to reduce its water consumption. The city converted water-demanding grass lawns to drought-tolerant native shrubs, and it imposed new rules requiring low-flow shower heads and water-saving toilets. Through these seemingly small, but effective, measures, Los Angeles inhabitants were able to cut their water consumption and, in turn, protect nesting birds, Mono brine shrimp, and algae populations, as well as the rest of the Mono Lake ecosystem. 

Sources: J. Kay, It's rising and healthy, San Francisco Chronicle, July 29, 2006; Mono Lake Committee, Mono Lake (2010), http://www.molonake.org/.

Key Ideas
Most problems of interest to environmental scientists involve more than one organism and more than one physical factor. Organisms, nonliving matter, and energy all interact in natural systems. Taking a systems approach to an environmental issue, rather than focusing on only one piece of the puzzle, decreases the chance of overlooking important components of that issue.

After reading this chapter you should be able to
- define systems within the context of environmental science.
- explain the components and states of matter.
- distinguish between various forms of energy and discuss the first and second laws of thermodynamics.
- describe the ways in which ecological systems depend on energy inputs.
- explain how scientists keep track of inputs, outputs, and changes to complex systems.
- describe how natural systems change over time and space.

Earth is a single interconnected system

The story of Mono Lake shows us that the activities of humans, the lives of other organisms, and processes in the environment are interconnected. Humans, water, animals, plants, and the desert environment all interact at Mono Lake to create a complex environmental system. The story also demonstrates a key principle of environmental science: that a change in any one factor can have other, often unexpected, effects.

In Chapter 1, we learned that a system is a set of interacting components connected in such a way that a change in one part of the system affects one or more other parts of the system. The Mono Lake system is relatively small. Other complex systems exist on a much larger scale.

A large system may contain many smaller systems within it. FIGURE 2.1 shows an example of complex, interconnecting systems that operate at multiple space and time scales: the fisheries of the North Atlantic. A physiologist who wants to study how codfish survive in the North Atlantic’s freezing waters must consider all the biological adaptations of the cod to be part of one system. In this case, the fish and its internal organs are the system being studied. In the same environment, a marine biologist might study the predator-prey relationship between cod and herring. That relationship constitutes another system, which includes two fish species and the environment they live in. At an even larger scale, an oceanographer might focus on how ocean currents in a particular area affect the dispersal of cod and other fish species. A fisheries management official might study a system that includes all of the systems above as well as people, fishing technology, policy, and law.

The largest system that environmental science considers is Earth. Many of our most important current environmental issues—including human population growth and climate change—exist at the global scale. Throughout this book we will define a given system in terms of the environmental issue we are studying and the scale in which we are interested.

Whether we are investigating ways to reduce pollution, increase food supplies, or find alternatives to fossil fuels, environmental scientists must have a thorough understanding of matter and energy and their interactions within and across systems. We will begin this chapter by exploring the properties of matter. We will then discuss the various types of energy and how they influence and limit systems.

Checkpoint

- What is an environmental system? Name some examples.
- How do systems vary in scale, and how does a large system include a smaller system?
- What are the largest systems in the Mono Lake ecosystem? What are some examples of smaller systems within that system?
forms of matter. Matter is anything that occupies space and has mass. The mass of an object is defined as a measure of the amount of matter it contains. Note that the words mass and weight are often used interchangeably, but they are not the same thing. Weight is the force that results from the action of gravity on mass. Your own weight, for example, is determined by the amount of gravity pulling you toward the planet’s center. Whatever your weight is on Earth, you would have a lesser weight on the Moon, where the action of gravity is less. In contrast, mass stays the same no matter what gravitational influence is acting on an object. So although your weight would change on the Moon, your mass would remain the same because the amount of matter you are made of would be the same.

Atoms and Molecules

All matter is composed of tiny particles that cannot be broken down into smaller pieces. The basic building blocks of matter are known as atoms. An atom is the smallest particle that can contain the chemical properties of an element. An element is a substance composed of atoms that cannot be broken down into smaller, simpler components. At Earth’s surface temperatures, elements can occur as solids (such as gold), liquids (such as bromine), or gases (such as helium). Atoms are so small that a single human hair measures about a few hundred thousand carbon atoms across.

Ninety-four elements occur naturally on Earth, and another 24 have been produced in laboratories. The periodic table lists all of the elements currently known. (For a copy of the periodic table, turn to Appendix A.) Each element is identified by a one- or two-letter symbol; for example, the symbol for carbon is C, and the symbol for oxygen is O. These symbols are used to describe the atomic makeup of molecules, which are particles containing more than one atom. Molecules that contain more than one element are called compounds. For example, a carbon dioxide molecule (CO₂) is a compound composed of one carbon atom (C) and two oxygen atoms (O₂).

As we can see in FIGURE 2.2a, every atom has a nucleus, or core, which contains protons and neutrons. Protons and neutrons have roughly the same mass—both minutely small. Protons have a positive electrical charge, like the “plus” side of a battery. The number of protons in the nucleus of a particular element—called the atomic number—is unique to that element. Neutrons have no electrical charge, but they are critical to the stability of nuclei because they keep the positively charged protons together. Without them, the protons would repel one another and separate.

As FIGURE 2.2b shows, the space around the nucleus of the atom is not empty. In this space, electrons exist in orbitals, which are electron clouds that extend different distances from the nucleus. Electrons are negatively
as a mixture of carbon isotopes. All carbon isotopes behave the same chemically. However, biological processes sometimes favor one isotope over another. Thus certain isotopic "signatures" (that is, different ratios of isotopes) can be left behind by different biological processes. These signatures allow environmental scientists to learn about certain processes by determining the proportions of different isotopes in soil, air, water, or ice.

Radioactivity

The nuclei of isotopes can be stable or unstable, depending on the mass number of the isotope and the number of neutrons it contains. Unstable isotopes are radioactive.

Radioactive isotopes undergo radioactive decay, the spontaneous release of material from the nucleus. Radioactive decay changes the radioactive element into a different element. For example, uranium-235 (\(^{235}\text{U}\)) decays to form thorium-231 (\(^{231}\text{Th}\)). The original atom (uranium) is called the parent and the resulting decay product (thorium) is called the daughter. The radioactive decay of \(^{235}\text{U}\) and certain other elements emits a great deal of energy that can be captured as heat. Nuclear power plants use this heat to produce steam that turns turbines to generate electricity.

We measure radioactive decay by recording the average rate of decay of a quantity of a radioactive element. This measurement is commonly stated in terms of the element’s half-life: the time it takes for one-half of the original radioactive parent atoms to decay. An element’s half-life is a useful parameter to know because some elements that undergo radioactive decay emit harmful radiation. Knowledge of the half-life allows scientists to determine the length of time that a particular radioactive element may be dangerous. For example, using the half-life allows scientists to calculate the period of time that people and the environment must be protected from depleted nuclear fuel, like that generated by a nuclear power plant. As it turns out, many of the elements produced during the decay of \(^{235}\text{U}\) have half-lives of tens of thousands of years and more. From this we can see why long-term storage of radioactive nuclear waste is so important.

The measurement of isotopes has many applications in environmental science as well as in other scientific fields. For example, carbon in the atmosphere exists in a known ratio of the isotopes carbon-12 (99 percent), carbon-13 (1 percent), and carbon-14 (which occurs in trace amounts, on the order of one part per trillion). Carbon-14 is radioactive and has a half-life of 5,730 years. Carbon-13 and carbon-12 are stable isotopes. Living organisms incorporate carbon into their tissues at roughly the known atmospheric ratio. But after an organism dies, it stops incorporating new carbon into its tissues. Over time, the radioactive carbon-14 in the organism decays to nitrogen-14. By calculating
the proportion of carbon-14 in dead biological material—a technique called carbon dating—researchers can determine how many years ago an organism died.

**Chemical Bonds**

We have seen that matter is composed of atoms, which form molecules or compounds. In order to form molecules or compounds, atoms must be able to interact or join together. This happens by means of chemical bonds of various types. Chemical bonds fall into three categories: covalent bonds, ionic bonds, and hydrogen bonds.

**COVALENT BONDS** Elements that do not readily gain or lose electrons form compounds by sharing electrons. These compounds are said to be held together by covalent bonds. FIGURE 2.3 illustrates the covalent bond in a molecule of methane (CH₄, also called natural gas). A methane molecule is made up of one carbon (C) atom surrounded by four hydrogen (H) atoms. Covalent bonds form between the single carbon atom and each hydrogen atom. Covalent bonds also hold the two hydrogen atoms and the oxygen atom in a water molecule together.

**IONIC BONDS** In a covalent bond, atoms share electrons. Another kind of bond between two atoms involves the transfer of electrons. When such a transfer happens, one atom becomes electron deficient (positively charged), and the other becomes electron rich (negatively charged). This charge imbalance holds the two atoms together. The charged atoms are called ions, and the attraction between oppositely charged ions forms a chemical bond called an ionic bond. FIGURE 2.4 shows an example of this process. Sodium (Na) donates one electron to chlorine (Cl), which gains one electron, to form sodium chloride (NaCl), or table salt.

![Covalent bonds](image)

**FIGURE 2.3** Covalent bonds. Molecules such as methane (CH₄) are associations of atoms held together by covalent bonds, in which electrons are shared between the atoms. As a result of the four hydrogen atoms sharing electrons with a carbon atom, each atom has a complete set of electrons in its outer shell—two for the hydrogen atoms and eight for the carbon atom.

11 electrons 17 electrons
Sodium (Na) atom Chlorine (Cl) atom
Loses electron Gains electron

Sodium ion (Na⁺) Chloride ion (Cl⁻)
10 electrons 18 electrons
Sodium chloride (NaCl)

**FIGURE 2.4** Ions and ionic bonds. A sodium atom and a chlorine atom can readily form an ionic bond. The sodium atom loses an electron, and the chlorine atom gains one. As a result, the sodium atom becomes a positively charged ion (Na⁺) and the chlorine atom becomes a negatively charged ion (Cl⁻, known in ionic form as chloride). The attraction between the oppositely charged ions—an ionic bond—forms sodium chloride (NaCl), or table salt.

An ionic bond is not usually as strong as a covalent bond. This means that the compound can readily dissolve. As long as sodium chloride remains in a salt shaker, it remains in solid form. But if you shake some into water, the salt dissolves into sodium and chloride ions (Na⁺ and Cl⁻).

**HYDROGEN BONDS** The third type of chemical bond is weaker than either covalent or ionic bonds. A hydrogen bond is a weak chemical bond that forms when hydrogen atoms that are covalently bonded to one atom are attracted to another atom on another molecule. When atoms of different elements form bonds, their electrons may be shared unequally; that is, shared electrons may be pulled closer to one atom than to the other. In some cases, the strong attraction of the hydrogen electron to other atoms creates a charge imbalance within the covalently bonded molecule.
on Earth. Among these properties are surface tension, capillary action, a high boiling point, and the ability to dissolve many different substances—all essential to physiological functioning.

**SURFACE TENSION AND CAPILLARY ACTION** We don’t generally think of water as being sticky, but hydrogen bonding makes water molecules stick strongly to one another (cohesion) and to certain other substances (adhesion). The ability to cohere or adhere underlies two unusual properties of water: surface tension and capillary action.

Surface tension, which results from the cohesion of water molecules at the surface of a body of water, creates a sort of skin on the water’s surface. Have you ever seen an aquatic insect, such as a water strider, walk across the surface of the water? This is possible because of surface tension (FIGURE 2.6). Surface tension also makes water droplets smooth and more or less spherical as they cling to a water faucet before dropping.

Capillary action happens when adhesion of water molecules to a surface is stronger than cohesion between the molecules. The absorption of water by a paper towel or a sponge is the result of capillary action. This property is important in thin tubes, such as the water-conducting vessels in tree trunks, and in small pores in soil. It is also important in the transport of underground water, as well as dissolved pollutants, from one location to another.

**BOILING AND FREEZING** At the atmospheric pressures found at Earth’s surface, water boils (becomes a gas) at
100°C (212°F) and freezes (becomes a solid) at 0°C (32°F). If water behaved like structurally similar compounds such as hydrogen sulfide (H₂S), which boils at −60°C (−76°F), it would be a gas at typical Earth temperatures, and life as we know it could not exist. Because of its cohesion, however, water can be a solid, a gas, or—most importantly for living organisms—a liquid at Earth’s surface temperatures. In addition, the hydrogen bonding between water molecules means that it takes a great deal of energy to change the temperature of water. Thus the water in organisms protects them from wide temperature swings. Hydrogen bonding also explains why geographic areas near large lakes or oceans have moderate climates. The water body holds summer heat, slowly releasing it as the atmosphere cools in the fall, and warms only slowly in spring, thereby preventing the adjacent land area from heating up quickly.

Water has another unique property: it takes up a larger volume in solid form than it does in liquid form. Figure 2.7 illustrates the difference in structure between liquid water and ice. As liquid water cools, it becomes denser, until it reaches 4°C (39°F), the temperature at which it reaches maximum density. As it cools from 4°C down to freezing at 0°C, however, its molecules realign into a crystal lattice structure, and its volume expands. You can see the result any time you add an ice cube to a drink: ice floats on liquid water.

What does this unique property of water mean for life on Earth? Imagine what would happen if water acted like most other liquids. As it cooled, it would continue to become denser. Its solid form (ice) would sink, and lakes and ponds would freeze from the bottom up. As a result, very few aquatic organisms could survive in temperate and cold climates.

**WATER AS A SOLVENT** In our table salt example, we saw that water makes a good solvent. Many substances, such as table salt, dissolve well in water because their polar molecules bond easily with other polar molecules. This explains the high concentrations of dissolved ions in seawater as well as the capacity of living organisms to store many types of molecules in solution in their cells. Unfortunately, many toxic substances also dissolve well in water, which makes them easy to transport through the environment.

**Acids, Bases, and pH**

Another important property of water is its ability to dissolve hydrogen- or hydroxide-containing compounds known as acids and bases. An acid is a substance that contributes hydrogen ions to a solution. A base is a substance that contributes hydroxide ions to a solution. Both acids and bases typically dissolve in water.

When an acid is dissolved in water, it dissociates into positively charged hydrogen ions (H⁺) and negatively charged ions. Two important acids we will discuss in this book are nitric acid (HNO₃) and sulfuric acid (H₂SO₄),
the primary constituents of acidic deposition, one form of which is acid rain.

Bases, on the other hand, dissociate into negatively charged hydroxide ions (OH⁻) and positively charged ions. Some examples of bases are sodium hydroxide (NaOH) and calcium hydroxide (Ca(OH)₂), which can be used to neutralize acidic emissions from power plants.

The pH scale is a way to indicate the strength of acids and bases. In FIGURE 2.8, the pH of many familiar substances is indicated on the pH scale, which ranges from 0 to 14. A pH value of 7 on this scale—the pH of pure water—is neutral, meaning that the number of hydrogen ions is equal to the number of hydroxide ions. Anything above 7 is basic, or alkaline, and anything below 7 is acidic. The lower the number, the stronger the acid, and the higher the number, the more basic the substance is. The pH scale is logarithmic, meaning that there is a factor of 10 difference between each number on the scale. For example, a substance with a pH of 5 has 10 times the hydrogen ion concentration of a substance with a pH of 6 (it is 10 times more acidic). Water in equilibrium with Earth’s atmosphere typically has a pH of 5.65 because carbon dioxide from the atmosphere dissolves in that water, making it weakly acidic.

**Chemical Reactions and the Conservation of Matter**

A chemical reaction occurs when atoms separate from the molecules they are a part of or recombine with other molecules. In a chemical reaction, no atoms are ever destroyed or created. The bonds between particular atoms may change, however. For example, when methane (CH₄) is burned in air, it reacts with two molecules of oxygen (O₂) to create one molecule of carbon dioxide (CO₂) and two molecules of water (H₂O):

\[
\text{CH}_4 + 2 \text{O}_2 \rightarrow \text{CO}_2 + 2 \text{H}_2\text{O}
\]

Notice that the number of atoms of each chemical element is the same on each side of the reaction.

Chemical reactions can occur in either direction. For example, during the combustion of fuels, nitrogen gas (N₂) combines with oxygen gas (O₂) from the atmosphere to form two molecules of nitrogen oxide (NO₃), which is an air pollutant:

\[
\text{N}_2 + \text{O}_2 \rightarrow 2 \text{NO}_3
\]

This reaction can also proceed in the opposite direction:

\[
2 \text{NO} \rightarrow \text{N}_2 + \text{O}_2
\]

The observation that no atoms are created or destroyed in a chemical reaction leads us to the law of conservation of matter, which states that matter cannot be created or destroyed; it can only change form. For example, when paper burns, it may seem to vanish, but no atoms are lost; the carbon and hydrogen that make up the paper combine with oxygen in the air to produce carbon dioxide, water vapor, and other materials, which either enter the atmosphere or form ash. Combustion converts most of the solid paper into gases but all of the original atoms remain. The same process occurs in a forest fire, but on a much larger scale (FIGURE 2.9). The only known exception to the law of conservation of matter occurs in nuclear reactions, in which small amounts of matter change into energy.

The law of conservation of matter tells us that we cannot easily dispose of hazardous materials. For example, when we burn material that contains heavy metals, such as an automotive battery, the atoms of these metals in the battery do not disappear. They turn up elsewhere in the environment, where they may cause a hazard to humans and other organisms. For this and other reasons, understanding the law of conservation of matter is crucial to environmental science.
Biological Molecules and Cells

We now have a sense of how chemical compounds form and how they respond to various processes such as burning and freezing. To further our understanding of chemical compounds, we will divide them into two basic types: inorganic and organic. Inorganic compounds are compounds that either (a) do not contain the element carbon or (b) do contain carbon, but only carbon bond to elements other than hydrogen. Examples include ammonia (NH₃), sodium chloride (NaCl), water (H₂O), and carbon dioxide (CO₂). Organic compounds are compounds that have carbon-carbon and carbon-hydrogen bonds. Examples of organic compounds include glucose (C₆H₁₂O₆) and fossil fuels, such as natural gas (CH₄).

Organic compounds are the basis of the biological molecules that are important to life: carbohydrates, proteins, nucleic acids, and lipids. Because these four types of molecules are relatively large, they are also known as macromolecules.

CARBOHYDRATES Carbohydrates are compounds composed of carbon, hydrogen, and oxygen atoms. Glucose (C₆H₁₂O₆) is a simple sugar (a monosaccharide, or single sugar) easily used by plants and animals for quick energy. Sugars can link together in long chains called complex carbohydrates, or polysaccharides ("many sugars"). For example, plants store energy as starch, which is made up of long chains of covalently bonded glucose molecules. The starch can also be used by animals that eat the plants. Cellulose, a component of plant leaves and stems, is another polysaccharide consisting of long chains of glucose molecules. Cellulose is the raw material for cellulosic ethanol, a type of fuel that has the potential to replace or supplement gasoline.

PROTEINS Proteins are made up of long chains of nitrogen-containing organic molecules called amino acids. Proteins are critical components of living organisms, playing roles in structural support, energy storage, internal transport, and defense against foreign substances. Enzymes are proteins that help control the rates of chemical reactions. The antibodies that protect us from infections are also proteins.

NUCLEIC ACIDS Nucleic acids are organic compounds found in all living cells. Long chains of nucleic acids form DNA and RNA. DNA (deoxyribonucleic acid) is the genetic material organisms pass on to their offspring that contains the code for reproducing the components of the next generation. RNA (ribonucleic acid) translates the code stored in the DNA and allows for the synthesis of proteins.

LIPIDS Lipids are smaller biological molecules that do not mix with water. Fats, waxes, and steroids are all lipids. Lipids form a major part of the membranes that surround cells.

CELLS We have looked at the four types of macromolecules required for life. But how do they work as part of a living organism? The smallest structural and functional component of organisms is known as a cell.
A cell is a highly organized living entity that consists of the four types of macromolecules and other substances in a watery solution, surrounded by a membrane. Some organisms, such as most bacteria and some algae, consist of a single cell. That one cell contains all of the functional structures, or organelles, needed to keep the cell alive and allow it to reproduce (FIGURE 2.10a). Larger and more complex organisms, such as Mono Lake’s brine shrimp, are multicellular (FIGURE 2.10b).

**CHECKPOINT**

- What are the three types of chemical bonds?
- What are the unique properties of water? In what ways do those properties make life possible on Earth?
- What are the four types of biological molecules, and how do they differ from one another?

**Energy is a fundamental component of environmental systems**

Earth’s systems cannot function, and organisms cannot survive, without energy. Energy is the ability to do work, or transfer heat. Water flowing into a lake has energy because it moves and can move other objects in its path. All living systems absorb energy from their surroundings and use it to organize and reorganize molecules within their cells and to power movement. Plants absorb solar energy and use it in photosynthesis to convert carbon dioxide and water into sugars, which they then use to survive, grow, and reproduce. The sugars in plants are also an important energy source for many animals. Humans, like other animals, absorb the energy they need for cellular respiration from food. This provides the energy for our daily activities, from waking to sleeping and everything in between.

Ultimately, most energy on Earth derives from the Sun. The Sun emits electromagnetic radiation, a form of energy that includes, but is not limited to, visible light, ultraviolet light, and infrared energy, which we perceive as heat. The scale at the top of FIGURE 2.11 shows these and other types of electromagnetic radiation.

Electromagnetic radiation is carried by photons, massless packets of energy that travel at the speed of light and can move even through the vacuum of space. The amount of energy contained in a photon depends on its wavelength—the distance between two peaks or troughs in a wave, as shown in the inset in Figure 2.11. Photons with long wavelengths, such as radio waves, have very low energy, while those with short wavelengths, such as X-rays, have high energy. Photons of different wavelengths are used by humans for different purposes.

**Forms of Energy**

The basic unit of energy in the metric system is the joule (abbreviated J). A joule is the amount of energy used when a 1-watt light bulb is turned on for 1 second—a very small amount. Although the joule is the preferred energy unit in scientific study, many other energy units are commonly used. Conversions between these units and joules are given in Table 2.1.

**ENERGY AND POWER** Energy and power are not the same thing, even though we often use the words inter-
Energy is the ability to do work, whereas power is the rate at which work is done:

\[
\text{energy} = \text{power} \times \text{time}
\]

\[
\text{power} = \text{energy} + \text{time}
\]

When we talk about generating electricity, we often hear about kilowatts and kilowatt-hours. The kilowatt (kW) is a unit of power. The kilowatt-hour (kWh) is a unit of energy. Therefore, the capacity of a turbine is given in kW because that measurement refers to the turbine's power. Your monthly home electricity bill reports energy use—the amount of energy from electricity that you have used in your home—in kWh. Do the Math “Calculating Energy Use and Converting Units” gives you an opportunity to practice working with these units.

**KINETIC AND POTENTIAL ENERGY** Energy takes a variety of forms. Many stationary objects possess a large amount of potential energy—energy that is stored but has not yet been released. Water impounded behind a dam contains a great deal of potential energy. When the water is released and flows downstream, that potential energy becomes kinetic energy, the energy of motion (FIGURE 2.12). The kinetic energy of moving water can be captured at a dam and transferred to a turbine and generator, and ultimately to the energy in electricity. Can you think of other common examples of kinetic energy? A car moving down the street, a flying honeybee, and a football travelling through the air all have kinetic energy. Sound also has kinetic energy because it travels in waves through the coordinated motion of atoms. Systems can contain potential energy, kinetic energy, or some of each.

**TABLE 2.1** Common units of energy and their conversion into joules

<table>
<thead>
<tr>
<th>Unit</th>
<th>Definition</th>
<th>Relationship to Joules</th>
<th>Common uses</th>
</tr>
</thead>
<tbody>
<tr>
<td>calorie</td>
<td>Amount of energy it takes to heat 1 gram of water 1°C</td>
<td>1 calorie = 4.184 J</td>
<td>Energy expenditure and transfer in ecosystems; human food consumption</td>
</tr>
<tr>
<td>Calorie</td>
<td>Food calorie; always shown with a capital C</td>
<td>1 Calorie = 1,000 calories = 1 kilocalorie (kcal)</td>
<td>Food labels; human food consumption</td>
</tr>
<tr>
<td>British thermal unit (BTU)</td>
<td>Amount of energy it takes to heat 1 pound of water 1°F</td>
<td>1 BTU = 1,055 J</td>
<td>Energy transfer in air conditioners and home and water heaters</td>
</tr>
<tr>
<td>kilowatt-hour (kWh)</td>
<td>Amount of energy expended by using 1 kilowatt of electricity for 1 hour</td>
<td>1 kWh = 3,600,000 J = 3.6 megajoules (MJ)</td>
<td>Energy use by electrical appliances, often given in kWh per year</td>
</tr>
</tbody>
</table>
Potential energy stored in chemical bonds is known as chemical energy. The energy in food is a familiar example. By breaking down the high-energy bonds in the pizza you had for lunch, your body obtains energy to power its activities and functions. Likewise, an automobile engine combusts gasoline and releases its chemical energy to propel the car.

**TEMPERATURE** All matter, even the frozen water in the world’s ice caps, contains some energy. When we say

---

**DO THE MATH**

**Calculating Energy Use and Converting Units**

Your electricity bill shows that you use 600 kWh of electricity each month. Your refrigerator, which is 15 years old, could be responsible for up to 25 percent of this electricity consumption. Newer refrigerators are more efficient, meaning that they use less energy to do the same amount of work. If you wish to conserve electrical energy and save money, should you replace your refrigerator? How can you compare the energy efficiency of your old refrigerator with that of the more efficient new models?

Your refrigerator uses 500 watts when the motor is running. The motor runs for about 30 minutes per hour (or a total of 12 hours per day).

1. How much energy does your refrigerator use?
   
   \[ \text{0.5 kW} \times \text{12 hours/day} = 6 \text{ kWh/day} \]
   
   \[ 6 \text{ kWh/day} \times 365 \text{ days/year} = 2,190 \text{ kWh/year} \]

2. How much more efficient is the best new refrigerator compared with your older model?
   
   The best new model uses 400 kWh per year. Your refrigerator uses 2,190 kWh per year.
   
   \[ 2,190 \text{ kWh/year} - 400 \text{ kWh/year} = 1,790 \text{ kWh/year} \]

3. Assume that you are paying, on average, $0.10 per kilowatt-hour for electricity. A new refrigerator would cost you $550. You will receive a rebate of $50 from your electric company for purchasing an energy-efficient refrigerator. If you replace your refrigerator, how long will it be before your energy savings compensate you for the cost of the new appliance?
   
   You will save
   
   \[ 1,790 \text{ kWh/year} \times \$0.10/\text{kWh} = \$179/\text{year} \]
   
   Dividing $500 by $179 indicates that in less than 3 years, you will recover the cost of the new appliance.

**Your Turn:** Environmental scientists must often convert energy units in order to compare various types of energy. For instance, you might want to compare the energy you would save by purchasing an energy-efficient refrigerator with the energy you would save by driving a more fuel-efficient car. Assume that for the amount you would spend on the new refrigerator ($500), you can make repairs to your car engine that would save you 20 gallons (76 liters) of gasoline per month (1 liter of gasoline contains the energy equivalent of about 10 kWh). Using this information and Table 2.1, convert the quantities of both gasoline and electricity into joules and compare the energy savings. Which decision would save the most energy?
it energy moves matter, we mean that it is moving the molecules within a substance. The measure of the average kinetic energy of a substance is its temperature. 

Changes in temperature—and, therefore, in energy—can convert matter from one state to another. At a certain temperature, the molecules in a solid substance start moving so fast that they begin to flow, and the substance melts into a liquid. At an even higher temperature, the molecules in the liquid move even faster, with increasing amounts of energy. Finally, the molecules move with such speed and energy that they overcome the forces holding them together and become gases.

First Law of Thermodynamics: Energy Is Conserved

As matter cannot be created nor destroyed, energy is neither created nor destroyed. This principle is the first law of thermodynamics. Like matter, energy also changes from one form to another. So, when water is released from behind a dam, the potential energy of the impounded water becomes the kinetic energy of the water rushing through the gates of the dam.

The first law of thermodynamics dictates that you can’t get something for nothing. When an organism consumes, it must convert the energy from an energy source such as the Sun or food. The potential energy contained in firewood never goes away, but it is transformed into heat energy permeating a room when the wood is burned in a fireplace. Sometimes it may be difficult to identify where the energy is going, but it is always conserved.

Look at Figure 2.13, which uses a car to show the first law in action through a series of energy conversions. Think of the car, including its fuel tank, as a system. The potential energy of the fuel (gasoline) is converted into kinetic energy when the battery supplies a spark in the presence of gasoline and air. The gasoline combusts, and the resulting gas expands, pushing the pistons in the engine—converting the chemical energy in the gasoline into the kinetic energy of the moving pistons. Energy is transferred from the pistons to the drive train, and from there to the wheels, which propel the car. The combustion of gasoline also produces heat, which dissipates into the environment outside the system. The kinetic energy of the moving car is converted into heat and sound energy as the tires create friction with the road and the body of the automobile moves through the air. When the brakes are applied to stop the car, friction between brake parts releases heat energy. No energy is ever destroyed in this example, but chemical energy is converted into motion, heat, and sound. Notice that some of the energy stays within the system and some (such as the heat from burning gasoline) leaves the system.

Second Law of Thermodynamics

We have seen how the potential energy of gasoline is transformed into the kinetic energy of moving pistons in a car engine. But as Figure 2.13 shows, some of that energy is converted into a less usable form—in this case, heat. The heat that is created is called waste heat, meaning that it is not used to do any useful work. The second law of thermodynamics tells us that when energy is transformed, the quantity of energy remains the same, but its ability to do work diminishes.

Energy Efficiency To quantify this observation, we use the concept of energy efficiency. Energy efficiency is the ratio of the amount of work that is done to the total amount of energy that is introduced into the system in the first place. Two machines or engines that perform the same amount of work, but use different amounts of energy to do that work, have different energy efficiencies. Consider the difference between modern woodstoves and traditional open fireplaces. A woodstove that is 70 percent efficient might use 2 kg of wood to heat a room to a comfortable 20°C (68°F), whereas a fireplace that is 10 percent efficient would require 14 kg.

**Figure 2.13** Conservation of energy within a system. In a car, the potential energy of gasoline is converted into other forms of energy. Some of that energy leaves the system, but all of it is conserved.
to achieve the same temperature—a sevenfold greater energy input (FIGURE 2.14).

We can also calculate the energy efficiency of transforming one form of energy into other forms of energy. Let’s consider what happens when we convert the chemical energy of coal into the electricity that operates a reading lamp and the heat that the lamp releases. FIGURE 2.15 shows the process.

A modern coal-burning power plant can convert 1 metric ton of coal, containing 24,000 megajoules (MJ; 1 MJ = 1 million joules) of chemical energy into about 8,400 MJ of electricity. Since 8,400 is 35 percent of 24,000, this means that the process of turning coal into electricity is about 35 percent efficient. The rest of the energy from the coal—65 percent—is lost as waste heat.

In the electrical transmission lines between the power plant and the house, 10 percent of the electrical energy from the plant is lost as heat and sound, so the transport of energy away from the plant is about 90 percent efficient. We know that the conversion of electrical energy into light in an incandescent bulb is 5 percent efficient; again, the rest of the energy is lost as heat. From beginning to end, we can calculate the energy efficiency of converting coal into incandescent lighting by multiplying all the individual efficiencies:

\[
0.35 \times 0.90 \times 0.05 = 0.016
\]

(1.6% efficiency)

\[
\text{coal to electricity} \times \text{transport of electricity} \times \text{light bulb efficiency} = \text{overall efficiency}
\]

**FIGURE 2.15** The second law of thermodynamics. Whenever one form of energy is transformed into another, some of that energy is converted into a less usable form of energy, such as heat. In this example, we see that the conversion of coal into the light of an incandescent bulb is only 1.6 percent efficient.

**FIGURE 2.14** Energy efficiency. (a) The energy efficiency of a traditional fireplace is low because so much heated air can escape through the chimney. (b) A modern woodstove, which can heat a room using much less wood, is much more energy efficient.
ENERGY QUALITY  Related to energy efficiency is energy quality, the ease with which an energy source can be used for work. A high-quality energy source has a convenient, concentrated form so that it does not take too much energy to move it from one place to another. Gasoline, for example, is a high-quality energy source because its chemical energy is concentrated (about 44 MJ/kg), and because we have technology that can conveniently transport it from one location to another. In addition, it is relatively easy to convert gasoline energy into work and heat. Wood, on the other hand, is a lower-quality energy source. It has less than half the energy concentration of gasoline (about 20 MJ/kg) and is more difficult to use to do work. Imagine using wood to power an automobile. Clearly, gasoline is a higher-quality energy source than wood. Energy quality is one important factor humans must consider when they make energy choices.

ENTROPY The second law of thermodynamics also tells us that all systems move toward randomness rather than toward order. This randomness, called entropy, is always increasing in a system, unless new energy from outside the system is added to create order.

Think of your bedroom as a system. At the start of the week, your books may be in the bookcase, your clothes may be in the dresser, and your shoes may be lined up in a row in the closet. But what happens if, as the week goes on, you don’t expend energy to put your things away (FIGURE 2.16)? Unfortunately, your books will not spontaneously line up in the bookcase, your clothes will not fall folded into the dresser, and your shoes will not pair up and arrange themselves in the closet. Unless you bring energy into the system to put things in order, your room will slowly become more and more disorganized.

The energy you use to pick up your room comes from the energy stored in food. Food is a relatively high-quality energy source because the human body easily converts it into usable energy. The molecules of food are ordered rather than random. In other words, food is a low-entropy energy source. Only a small portion of the energy in your digested food is converted into work, however; the rest becomes body heat, which may or may not be needed. This waste heat has a high degree of entropy because heat is the random movement of molecules. Thus, in using food energy to power your body to organize your room, you are decreasing the entropy of the room, but increasing the entropy in the universe by producing waste body heat.

Another example of the second law can be found in the observation that energy always flows from hot to cold. A pot of water will never boil without an input of energy, but hot water left alone will gradually cool as its energy dissipates into the surrounding air. This application of the second law is important in many of the global circulation patterns that are powered by the energy of the Sun.

CHECKPOINT
✓ What is the difference between power and energy? Why is it important to know the difference?
✓ How do potential energy and kinetic energy differ? What is chemical energy?
✓ What are the first and second laws of thermodynamics?
Energy conversions underlie all ecological processes

Life requires order. If organisms were not made up of molecules organized into structures such as proteins and cells, they could not grow—in fact, they could never develop in the first place. All living things work against entropy by using energy to maintain order.

Individual organisms rely on a continuous input of energy in order to survive, grow, and reproduce. But interactions at levels beyond the organism can also be seen as a process of converting energy into organization. Consider a forest ecosystem. Trees absorb water through their roots and carbon dioxide through their leaves. By combining these compounds in the presence of sunlight, they convert water and carbon dioxide into sugars that will provide them with the energy they need. Trees fight entropy by keeping their atoms and molecules together in tree form, rather than having them dispersed randomly throughout the universe. But then a deer grazes on tree leaves, and later a mountain lion eats the deer. At each step, energy is converted by organisms into work.

The form and amount of energy available in an environment determines what kinds of organisms can live there. Plants thrive in tropical rainforests where there is plenty of sunlight as well as water. Many food crops, not surprisingly, can be planted and grown in temperate climates that have a moderate amount of sunlight. Life is much more sparse at high latitudes, toward the North and South Poles, where less solar energy is available to organisms. The landscape is populated mainly by small plants and shrubs, insects, and migrating animals. Plants cannot live at all on the deep ocean floor, where no solar energy penetrates. The animals that live there, such as eels, anglerfish, and squid, get their energy by feeding on dead organisms that sink from above. Chemical

**FIGURE 2.17** The amount of available energy determines which organisms can live in a natural system. (a) A tropical rainforest has abundant energy available from the Sun and enough moisture for plants to make use of that energy. (b) The Arctic tundra has much less energy available, so plants grow more slowly there and do not reach large sizes. (c) Organisms, such as this squid, living at the bottom of the ocean must rely on dead biological matter falling from above. (d) The energy supporting this deep-ocean vent community comes from chemicals emitted from the vent. Bacteria convert the chemicals into forms of energy that other organisms, such as tube worms, can use.
nergy, in the form of sulfides emitted from deep-ocean vents (underwater geysers), supports a plandless ecosystem that includes sea spiders, 2.4 meter (8-foot) tube worms, and bacteria (FIGURE 2.17).

CHECKPOINT

✓ Provide an example of how organisms convert energy from one form into another.

✓ How does energy determine the suitability of an environment for growing food?

Systems analysis shows how matter and energy flow in the environment

Why is it important for environmental scientists to study whole systems rather than focusing on the individual plants, animals, or substances within a system? Imagine taking apart your cell phone and trying to understand how it works simply by focusing on the microphone. You wouldn't get very far. Similarly, it is important for environmental scientists to look at the whole picture, not just the individual parts of a system, in order to understand how that system works.

Studying systems allows scientists to think about how matter and energy flow in the environment. In this way, researchers can learn about the complex relationships between organisms and the environment, but more importantly, they can predict how changes to any part of the system—for example, changes in the water level at Mono Lake—will change the entire system.

Systems can be either open or closed. In an open system, exchanges of matter or energy occur across system boundaries. Most systems are open. Even at remote Mono Lake, water flows in, and birds fly to and from the lake. The ocean is also an open system. Energy from the Sun enters the ocean, warming the waters and providing energy to plants and algae. Energy and matter are transferred from the ocean to the atmosphere as energy from the Sun evaporates water, giving rise to meteorological events such as tropical storms, in which clouds form and send rain back to the ocean surface. Matter, such as sediment and nutrients, enters the ocean from rivers and streams and leaves it through the geologic cycles and other processes.

In a closed system, matter and energy exchanges across system boundaries do not occur. Closed systems are less common than open systems. Some underground cave systems are nearly completely closed systems.

As FIGURE 2.18 shows, Earth is an open system with respect to energy. Solar radiation enters Earth's atmosphere, and heat and reflected light leave it. But because of its gravitational field, Earth is essentially a closed system with respect to matter. Only an insignificant amount of material enters or leaves the Earth system. All important material exchanges occur within the system.

Inputs and Outputs

By now you have seen numerous examples of both inputs, or additions to a given system, and outputs, or losses from the system. People who study systems often conduct a systems analysis, in which they determine inputs, outputs, and changes in the system under various conditions. For instance, researchers studying Mono Lake might quantify the inputs to that system—such as water and salts—and the outputs—such as water that evaporates from the lake and brine shrimp removed by migratory birds. Because no water flows out of the lake, salts are not removed, and even without the aqueduct, Mono Lake, like other terminal lakes, would slowly

![Energy](image)

**Input:** Solar radiation

**Output:** Heat, reflected light

**Matter**

**Input:** Nutrients, energy

**Output:** Food, waste

*FIGURE 2.18* Open and closed systems. (a) Earth is an open system with respect to energy. Solar radiation enters the Earth system, and energy leaves it in the form of heat and reflected light. (b) However, Earth is essentially a closed system with respect to matter because very little matter enters or leaves the Earth system. The white arrows indicate the cycling of energy and matter.
DO THE MATH

The Mystery of the Missing Salt

Before the Los Angeles Aqueduct was built, about 120 billion liters of stream water (31 billion gallons) flowed into Mono Lake in an average year. As a terminal lake, it had no outflow streams. The water level did not rise or fall in an average year. Therefore, the water in the lake had to be going somewhere to balance the water coming in; if the system size was not changing, then inputs must equal outputs. In this case, roughly the same amount of water that entered the lake must have evaporated. The salt content of the stream water flowing into Mono Lake varied, but a typical liter of stream water averaged 50 mg of salt.

1. How much salt entered Mono Lake annually?

To calculate the total amount of salt that entered Mono Lake each year, we can multiply the amount of salt (50 mg) per liter of water by the number of liters of water flowing into the lake (120 billion per year):

$$\frac{50\text{ mg/L}}{120\text{ billion L/year}} = 6\text{ trillion mg/year} = 6\text{ million kg/year}$$

2. The lake today contains about 285 billion kilograms of dissolved salt. At the rate of salt input we have just calculated, how long would it take to accumulate that much salt, starting with zero salt in the lake?

We have just determined that the salt concentration of Mono Lake increases by 6 million kilograms per year. Mono Lake contains approximately 285 billion kilograms of dissolved salts today, so at the rate of stream flow before the diversion, it would have taken about 47,500 years to accumulate that much salt:

$$285\text{ billion kg} + 6\text{ million kg/year} = 47,500\text{ years}$$

3. No water has flowed out of the Mono Lake basin since it was formed about 120,000 years ago. Assume that Earth’s climate hasn’t changed much over that time. At today’s input rate, how much salt should be in the water of Mono Lake today?

$$6\text{ million kg/year} \times 120,000\text{ years} = 720\text{ billion kg}$$

4. The salt loads in questions 2 and 3 do not agree. How can we explain the discrepancy?

The lake’s towering tufa formations hold the answer: many of the salts (including calcium and sodium) have precipitated—that is, separated—out of the water to form the tufa rock. In this way, the salts have been removed from the water, but not from the Mono Lake system as a whole. Our analysis is complete when we account for the salts removed from the lake as tufa. FIGURE 2.19 summarizes these inputs to and outputs from the Mono Lake system.

Steady States

At Mono Lake, in any given period, the same amount of water that enters the lake eventually evaporates. In many cases, the most important aspect of conducting a systems analysis is determining whether your system is in steady state—that is, whether inputs equal outputs, so that the system is not changing over time. This information is particularly useful in the study of environmental science. For example, it allows us to know whether the amount of a valuable resource or harmful pollutant is increasing, decreasing, or staying the same.

The first step in determining whether a system is in steady state is to measure the amount of matter and energy within it. If the scale of the system allows, we can perform these measurements directly. Consider the leaky bucket shown in FIGURE 2.20. We can measure the amount of water going into the bucket and the amount of water flowing out through the holes. However, some properties of systems, such as the volume of a lake or the size of an insect population, are difficult to measure directly, so we must calculate or estimate the amount of energy or matter stored in the system. We can then use this information to determine the inputs to and outputs from the system to determine whether it is in steady state.

Many aspects of natural systems, such as the water vapor in the global atmosphere, have been in steady state.
for at least as long as we have been studying them. The amount of water that enters the atmosphere by evaporation from oceans, rivers, and lakes is roughly equal to the amount that falls from the atmosphere as precipitation. Until recently, the oceans have also been in steady state: the amount of water that enters from rivers and streams has been roughly equal to the amount that evaporates into the air. One concern about the effects of global climate change is that some global systems, such as the system that includes water balance in the oceans and atmosphere, may no longer be in steady state.

It's interesting to note that one part of a system can be in steady state while another part is not. Before the Los Angeles Aqueduct was built, the Mono Lake system was in steady state with respect to water (the inflow of water equaled the rate of water evaporation), but not with respect to salt: salt was slowly accumulating, as it does in all terminal lakes.

**Feedbacks**

Most natural systems are in steady state. Why? A natural system can respond to changes in its inputs and outputs. For example, during a period of drought, evaporation from a lake will be greater than precipitation and stream water flowing into the lake. Therefore, the lake will begin to dry up. Soon there will be less surface water available for evaporation, and the evaporation rate will continue to fall until it matches the new, lower precipitation rate. When this happens, the system returns to steady state, and the lake stops shrinking.

Of course, the opposite is also true. In very wet periods, the size of the lake will grow, and evaporation from the expanded surface area will continue to increase until the system returns to a steady state at which inputs and outputs are equal.

Adjustments in input or output rates caused by changes to a system are called feedbacks. The term feedback means that the results of a process feed back into the system to change the rate of that process. Feedbacks, which can be diagrammed as loops or cycles, are found throughout the environment.

There are two kinds of feedback, negative and positive. In natural systems, scientists most often observe negative feedback loops, in which a system responds to a change by returning to its original state, or at least by decreasing the rate at which the change is occurring. Figure 2.21 shows a negative feedback loop for Mono Lake: when

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**Figure 2.20** A system in steady state. In this leaky bucket, inputs equal outputs. As a result, there is no change in the total amount of water in the bucket: the system is in steady state.

**Figure 2.21** Negative and positive feedback loops. (a) A negative feedback loop occurs at Mono Lake: when the water level drops, the lake surface area is reduced, and evaporation decreases. As a result of the decrease in evaporation, the lake level rises again. (b) Population growth is an example of positive feedback. As members of a species reproduce, they create more offspring that will be able to reproduce in turn, creating a cycle that increases the population size. The green arrow indicates the starting point of each cycle.
Natural systems change across space and over time

The decline in the water level of Mono Lake was caused by people: humans diverted water from the lake for their own use. Anthropogenic change in an environmental system is often very visible. We see anthropogenic change in rivers that have been dammed, air that has been polluted by automobile emissions, and cities that have encroached on once wild areas.

Differences in environmental conditions affect what grows or lives in an area, creating geographic variation among natural systems. Variations in temperature, precipitation, or soil composition across a landscape can lead to vastly different numbers and types of organisms. In Texas, for example, sycamore trees grow in river valleys where there is plenty of water available, whereas pine trees dominate mountain slopes because they can tolerate the cold, dry conditions there. Paying close attention to these natural variations may help us predict the effects of any change in an environment. So we know that if the rivers that support the sycamores in Texas dry up, the trees will probably die.

Natural systems are also affected by the passage of time. Thousands of years ago, when the climate of the Sahara was much wetter than it is today, it supported large populations of Nubian farmers and herders. Small changes in Earth's orbit relative to the Sun, along with a series of other factors, led to the disappearance of monsoon rains in northern Africa. As a result, the Sahara—now a desert nearly the size of the continental United States—became one of Earth's driest regions. Other, more dramatic changes have occurred on the planet. In the last few million years, Earth has moved in and out of several ice ages; 70 million years ago, central North America was covered by a sea; 240 million years ago, Antarctica was warm enough for 6-foot-long salamander-like amphibians to roam its swamps. Natural systems respond to such changes in the global environment with migrations and extinctions of species as well as the evolution of new species.

Throughout Earth's history, small natural changes have had large effects on complex systems, but human activities have increased both the pace and the intensity of these natural environmental changes, as they did at Mono Lake. Studying variations in natural systems over space and time can help scientists learn more about what to expect from the alterations humans are making to the world today.

CHECKPOINT

✓ Give some examples of environmental conditions that might vary among natural systems.
✓ Why is it important to study variation in natural systems over space and time?
WORKING TOWARD SUSTAINABILITY

South Florida's vast Everglades ecosystem extends over 50,000 km² (12,500,000 acres) (FIGURE 2.22). The region, which includes the Everglades and Biscayne Bay national parks, is home to many threatened and endangered bird, mammal, reptile, and plant species, including the Florida panther (Puma concolor coryi) and the Florida manatee (Trichechus manatus latirostris). The 4,000 km² (988,000-acre) subtropical wetland area for which the region is best known has been called a "river of grass" because a thin sheet of water flows constantly through it, allowing tall water-tolerant grasses to grow (FIGURE 2.23).

A hundred years of rapid human population growth, and the resulting need for water and farmland, have had a dramatic impact on the region. Flood control, dams, irrigation, and the need to provide fresh water to Floridians have led to a 30 percent decline in water flow through the Everglades. Much of the water that does flow through the region is polluted by phosphorus-rich fertilizer and waste from farms and other sources upstream. Cattails thrive on the input of phosphorus, choking out other native plants. The reduction in water flow and water quality is, by most accounts, destroying the Everglades. Can we save this natural system while still providing water to the people who need it?

The response of scientists and policy makers has been to treat the Everglades as a set of interacting systems and manage the inputs and outputs of water and pollutants to those systems. The Comprehensive Everglades Restoration Plan of 2000 is a systems-based approach to the region's problems. It covers 16 counties and 46,600 km² (11,500,000 acres) of South Florida. The plan is based on three key steps: increasing water flow into the Everglades, reducing pollutants coming in, and developing strategies for dealing with future problems.

The first step—increasing water flow—will counteract some of the effects of decades of drainage by local communities. Its goal is to provide enough water to support the Everglades' aquatic and marsh organisms. The plan calls for restoring natural water flow as well as natural hydroperiods (seasonal increases and decreases in water flow). Its strategies include removal of over 390 km (240 miles) of inland levees, canals, and water control structures that have blocked this natural water movement.

FIGURE 2.22 The Florida Everglades Ecosystem. This map shows the locations of the Florida Everglades, Lake Okeechobee, and the broader Everglades ecosystem, which includes Everglades and Biscayne Bay National Parks and Big Cypress National Preserve.

FIGURE 2.23 River of grass. The subtropical wetland portion of the Florida Everglades has been described as a river of grass because of the tall water-tolerant grasses that cover its surface.
Water conservation will also be a crucial part of reaching this goal. New water storage facilities and restored wetlands will capture and store water during rainy seasons for use during dry seasons, redirecting much of the 6.4 billion liters (1.7 billion gallons) of fresh water that currently flow to the ocean every day. About 80 percent of this fresh water will be redistributed back into the ecosystem via wetlands and aquifers. The remaining water will be used by cities and farms. The federal and state governments also hope to purchase nearby irrigated cropland and return it to a more natural state. In 2009, for example, the state of Florida purchased 29,000 ha (71,700 acres) of land from the United States Sugar Corporation, the first of a number of actions that will allow engineers to restore the natural flow of water from Lake Okeechobee into the Everglades. Florida is currently negotiating to purchase even more land from United States Sugar.

To achieve the second goal—reducing water pollution—local authorities will improve waste treatment facilities and place restrictions on the use of agricultural chemicals. Marshlands are particularly effective at absorbing nutrients and breaking down toxins. Landscape engineers have designed and built more than 21,000 ha (52,000 acres) of artificial marshes upstream of the Everglades to help clean water before it reaches Everglades National Park. Although not all of the region has seen water quality improvements, phosphorus concentrations in runoff from farms south of Lake Okeechobee are lower, meaning that fewer pollutants are reaching the Everglades.

The third goal—to plan for the possibility of future problems—requires an adaptive management plan: a strategy that provides flexibility so that managers can modify it as future changes occur. Adaptive management is an answer to scientific uncertainty. In a highly complex system such as the Everglades, any changes, however well intentioned, may have unexpected consequences. Management strategies must adapt to the actual results of the restoration plan as they occur. In addition, an adaptive management plan can be changed to meet new challenges as they come. One such challenge is global warming. As the climate warms, glaciers melt, and sea levels rise, much of the Everglades could be inundated by seawater, which would destroy freshwater habitat. Adaptive management essentially means paying attention to what works and adjusting your methods accordingly. The Everglades restoration plan will be adjusted along the way to take the results of ongoing observations into account, and it has put formal mechanisms in place to ensure that this will occur.

The Everglades plan has its critics. Some people are concerned that control of water flow and pollution will restrict the use of private property and affect economic development, possibly even harming the local economy. Yet other critics fear that the restoration project is underfunded or moving too slowly, and that current farming practices in the region are inconsistent with the goal of restoration.

In spite of its critics, the Everglades restoration plan is, historically speaking, a milestone project, not least because it is based on the concept that the environment is made up of interacting systems.

Reference

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**Key Ideas Revisited**

- **Define systems** within the context of environmental science.
  Environmental systems are sets of interacting components connected in such a way that changes in one part of the system affect the other parts. Systems exist at multiple scales, and a large system may contain smaller systems within it. Earth itself is a single interconnected system.

- Explain the components and states of matter.
  Matter is composed of atoms, which are made up of protons, neutrons, and electrons. Atoms and molecules can interact in chemical reactions in which the bonds between particular atoms may change. Matter cannot be created or destroyed, but its form can be changed.

- Distinguish between various forms of energy and discuss the first and second laws of thermodynamics.
  Energy can take various forms, including energy that is stored (potential energy) and the energy of motion (kinetic energy). According to the first law of thermodynamics, energy cannot be created or destroyed, but it can be converted from one form into another. According to the second law of thermodynamics, in any conversion of energy, some energy is converted into unusable waste energy, and the entropy of the universe is increased.

- Describe the ways in which ecological systems depend on energy inputs.
  Individual organisms rely on a continuous input of energy in order to survive, grow, and reproduce. More organisms can live where more energy is available.
Explain how scientists keep track of inputs, outputs, and changes to complex systems.

Systems can be open or closed to exchanges of matter, energy, or both. A systems analysis determines what goes into, what comes out of, and what has changed within a given system. Environmental scientists use systems analysis to calculate inputs to and outputs from a system and its rate of change. If there is no overall change, the system is in steady state. Changes in one input or output can affect the entire system.

Describe how natural systems change over time and space.

Variation in environmental conditions, such as temperature or precipitation, can affect the types and numbers of organisms present. Short-term and long-term changes in Earth's climate also affect species distributions.

PREPARING FOR THE AP EXAM

MULTIPLE-CHOICE QUESTIONS

1. Which of the following statements about atoms and molecules is correct?
(a) The mass number of an element is always less than its atomic number.
(b) Isotopes are the result of varying numbers of neutrons in atoms of the same element.
(c) Ionic bonds involve electrons while covalent bonds involve protons.
(d) Inorganic compounds never contain the element carbon.
(e) Protons and electrons have roughly the same mass.

2. Which of the following does not demonstrate the law of conservation of matter?
(a) CH₄ + 2 O₂ → CO₂ + 2 H₂O
(b) NaOH + HCl → NaCl + H₂O
(c) 2 HNO₃ + H₂O → HNO₄ + HNO₂
(d) PbO + C → 2 Pb + CO₂
(e) C₆H₁₂O₆ + 6 O₂ → 6 CO₂ + 6 H₂O

3. Pure water has a pH of 7 because
(a) its surface tension equally attracts acids and bases.
(b) its polarity results in a molecule with a positive and a negative end.
(c) its ability to dissolve carbon dioxide adjusts its natural pH.
(d) its capillary action attracts it to the surfaces of solid substances.
(e) its H⁺ concentration is equal to its OH⁻ concentration.

4. Which of the following is not a type of organic biological molecule?
(a) Lipids
(b) Carbohydrates
(c) Salts
(d) Nucleic acids
(e) Proteins

5. A wooden log that weighs 1.00 kg is placed in a fireplace. Once lit, it is allowed to burn until there are only traces of ash, weighing 0.04 kg, left. Which of the following best describes the flow of energy?
(a) The potential energy of the wooden log was converted into the kinetic energy of heat and light.
(b) The kinetic energy of the wooden log was converted into 0.04 kg of ash.
(c) The potential energy of the wooden log was converted into 1.00 J of heat.
(d) Since the ash weighs less than the wooden log, matter was converted directly into energy.
(e) The burning of the 1.00 kg wooden log produced 0.96 kg of gases and 0.04 kg of ash.

6. Consider a power plant that uses natural gas as a fuel to generate electricity. If there are 10,000 J of chemical energy contained in a specified amount of natural gas, then the amount of electricity that could be produced would be
(a) greater than 10,000 J because electricity has a higher energy quality than natural gas.
(b) something less than 10,000 J, depending on the efficiency of the generator.
(c) greater than 10,000 J when energy demands are highest; less than 10,000 J when energy demands are lowest.
(d) greater than 10,000 J because of the positive feedback loop of waste heat.
(e) equal to 10,000 J because energy cannot be created or destroyed.

7. A lake that has been affected by acid rain has a pH of 4. How many more times acidic is the lake water than seawater? (See Figure 2.8 on page 34.)
(a) 4
(b) 10
(c) 100
(d) 1,000
(e) 10,000
8. An automobile with an internal combustion engine converts the potential energy of gasoline (44 MJ/kg) into the kinetic energy of the moving pistons. If the average internal combustion engine is 10 percent efficient and 1 kg of gasoline is combusted, how much potential energy is converted into energy to run the pistons?
(a) 39.6 MJ
(b) 20.0 MJ
(c) 4.4 MJ
(d) Depends on the capacity of the gas tank
(e) Depends on the size of the engine

9. If the average adult woman consumes approximately 2,000 kcal per day, how long would she need to run in order to utilize 25 percent of her caloric intake, given that the energy requirement for running is 42,000 J per minute?
(a) 200 minutes
(b) 50 minutes
(c) 5 minutes
(d) 0.05 minutes
(e) 0.012 minutes

10. The National Hurricane Center studies the origins and intensities of hurricanes over the Atlantic and Pacific oceans and attempts to forecast their tracks, predict where they will make landfall, and assess what damage will result. Its systems analysis involves
(a) changes within a closed system.
(b) inputs and outputs within a closed system.
(c) outputs only within an open system.
(d) inputs from a closed system and outputs in an open system.
(e) inputs, outputs, and changes within an open system.

11. Based on the graph below, which of the following is the best interpretation of the data?

(a) The atmospheric carbon dioxide concentration is in steady state.
(b) The output of carbon dioxide from the atmosphere is greater than the input into the atmosphere.
(c) The atmospheric carbon dioxide concentration appears to be decreasing.
(d) The input of carbon dioxide into the atmosphere is greater than the output from the atmosphere.
(e) The atmospheric carbon dioxide concentration will level off due to the annual cycle.

12. The diagram below represents which of the following concepts?

(a) A negative feedback loop, because melting of permafrost has a negative effect on the environment by increasing the amounts of carbon dioxide and methane in the atmosphere.
(b) A closed system, because only the concentrations of carbon dioxide and methane in the atmosphere contribute to the permafrost thaw.
(c) A positive feedback loop, because more carbon dioxide and methane in the atmosphere result in greater permafrost thaw, which releases more carbon dioxide and methane into the atmosphere.
(d) An open system that resists change and regulates global temperatures.
(e) Steady state, because inputs and outputs are equal.

13. Which of the following statements about the Comprehensive Everglades Restoration Plan is not correct?
(a) Human and natural systems interact because feedback loops lead to adaptations and changes in both systems.
(b) Water conservation will alter land uses and restore populations of aquatic and marsh organisms.
(c) Improvements in waste treatment facilities and restrictions on agricultural chemicals will reduce the nutrients and toxins in the water that reaches the Everglades.
(d) Adaptive management will allow for the modification of strategies as changes occur in this complex system.
(e) The Florida Everglades is a closed system that includes positive and negative feedback loops and is regulated as such.

14. Which of the following would represent a system in steady state?
I. The birth rate of chameleons on the island of Madagascar equals their death rate.
II. Evaporation from a lake is greater than precipitation and runoff flowing into the lake.
III. The steady flow of the Colorado River results in more erosion than deposition of rock particles.
(a) I only
(b) II only
(c) III only
(d) I and II
(e) I and III
FREE-RESPONSE QUESTIONS

1. The atomic number of uranium-235 is 92, its half-life is 704 million years, and the radioactive decay of 1 kg of $^{235}\text{U}$ releases $6.7 \times 10^{13}$ J. Radioactive material must be stored in a safe container or buried deep underground until its radiation output drops to a safe level. Generally, it is considered "safe" after 10 half-lives.
   (a) Assume that a nuclear power plant can convert energy from $^{235}\text{U}$ into electricity with an efficiency of 35 percent, the electrical transmission lines operate at 90 percent efficiency, and fluorescent lights operate at 22 percent efficiency.
      (i) What is the overall efficiency of converting the energy of $^{235}\text{U}$ into fluorescent light? (2 points)
      (ii) How much energy from 1 kg of $^{235}\text{U}$ is converted into fluorescent light? (2 points)
      (iii) Name one way in which you could improve the overall efficiency of this system. Explain how your suggestion would improve efficiency. (2 points)
   (b) What are the first and second laws of thermodynamics? (2 points)
   (c) How long would it take for the radiation from a sample of $^{235}\text{U}$ to reach a safe level? (2 points)

2. U.S. wheat farmers produce, on average, 3,000 kg of wheat per hectare. Farmers who plant wheat year after year on the same fields must add fertilizers to replace the nutrients removed by the harvested wheat. Consider a wheat farm as an open system.
   (a) Identify two inputs and two outputs of this system. (4 points)
   (b) Using one input to and one output from (a), diagram and explain one positive feedback loop. (2 points)
   (c) Identify two adaptive management strategies that could be employed if a drought occurred. (2 points)
   (d) Wheat contains about 2.5 kcal per gram, and the average U.S. male consumes 2,500 kcal per day. How many hectares of wheat are needed to support one average U.S. male for a year, assuming that 30 percent of his caloric intake is from wheat? (2 points)

MEASURING YOUR IMPACT

Bottled Water versus Tap Water  A 2007 study traced the energy input required to produce bottled water in the United States. In addition to the energy required to make plastic bottles from PET (polyethylene terephthalate), energy from 58 million barrels of oil was required to clean, fill, seal, and label the water bottles. This is 2,000 times more than the amount of energy required to produce tap water.

In 2007, the population of the United States was 300 million people, and on average, each of those people consumed 114 L (30 gallons) of bottled water. The average 0.6 L (20-ounce) bottle of water cost $1.00. The average charge for municipal tap water was about $0.0004 per liter.

   (a) Complete the following table for the year 2007. Show all calculations.

<table>
<thead>
<tr>
<th>Liters of bottled water consumed in 2007</th>
<th>Liters of bottled water produced per barrel of oil</th>
</tr>
</thead>
</table>

(b) How much energy (in barrels of oil) would be required to produce the amount of tap water equivalent to the amount of bottled water consumed in 2007? How many liters of tap water could be produced per barrel of oil?
(c) Compare the cost of bottled water versus tap water per capita per year.
(d) Identify and explain one output of the bottled water production and consumption system that could have a negative effect on the environment.
(e) List two reasons for using tap water rather than bottled water.

EXPLORING THE LITERATURE