LESSON 2

Systems in Environmental Science

Guiding Question: What types of systems play roles in environmental science?

Knowledge and Skills

- Describe two major ways that Earth's systems interact.
- Define Earth's geosphere, lithosphere, biosphere, atmosphere, and hydrosphere.

Reading Strategy and Vocabulary

Reading Strategy As you read the section on feedback loops, draw a cycle diagram showing the negative feedback loop involved in a thermostat's regulation of the heat in a house.

Vocabulary feedback loop, erosion, geosphere, lithosphere, biosphere, atmosphere, hydrosphere

A *SYSTEM* IS A NETWORK of relationships among parts, elements, or components that interact with and influence one another through the exchange of energy, matter, or information. Systems receive *inputs* of energy, matter, or information; process these inputs; and produce *outputs* of energy, matter, or information.

Earth's environment consists of complex, interlinked systems. Earth's systems include the complex webs of relationships among species and the interactions of living organisms with the nonliving objects around them. Earth's systems also include cycles that shape landscapes and guide the flow of chemical elements and compounds that support life and regulate climate.

Interacting Systems

An output of one of Earth's systems is often also an input to that or another system.

Systems seldom have well-defined boundaries, so deciding where one system ends and another begins can be difficult. Consider a desktop computer system. What are its boundaries? Is the system made up of just what arrives in the shipping box and sits on your desk? Or does it also include the network you connect it to? What about the energy grid you plug it into, with its distant power plants and transmission lines—is that part of the system, too? Does the system include the Internet?

Whenever we try to define a system, we run into connections to other systems. Systems may exchange energy, matter, and information with other systems, and they may contain or be contained within other systems. So the boundaries we draw for a system usually depend on our focus at the moment. In our discussions of Earth's systems then, you may infer connections to other systems that are not being discussed at the moment. Don't worry—we'll get to them.

FIGURE 11 Earth's Systems The shrimp caught by this shrimper are an output of the Gulf of Mexico system. The shrimp will become inputs for several human systems.

Earth's Systems Inputs into Earth's systems include energy, information, and matter. Energy inputs to Earth's environmental systems include solar energy as well as energy released by geothermal activity, the life processes of organisms, and human activities such as fossil fuel combustion. Information inputs can come in the form of sensory cues or genes. Inputs of matter occur when chemicals or physical materials move among systems, such as when seeds are dispersed long distances or when plants convert carbon in the air to living tissue via photosynthesis.

For example, as a system, the Gulf of Mexico receives inputs of fresh water, sediments, nutrients, and pollutants from the Mississippi and other rivers. Shrimpers and fishers harvest some of the Gulf system's output: matter and energy in the form of shrimp and fish **(Figure 11).** This output then becomes input to the global economic system and to the digestive systems of the many people who consume the shrimp and fish.

Feedback Loops Sometimes an event is both a cause, or input, and an effect, or output, in the same system, a cyclical process called a **feedback loop.** A feedback loop can be either negative or positive.

▶ ***Negative Feedback Loops*** In a *negative feedback loop* **(Figure 12),** the output of a system moving in one direction acts as input that causes the system to move in the other direction. Input and output respond to each other's effects, canceling them out and stabilizing the system.

A thermostat, for example, stabilizes a room's temperature by turning the furnace on when the room gets cold and shutting it off when the room gets hot. One environmental example of negative feedback is a system in which predator and prey populations—wolves and moose, for example—rise and fall in response to each other. Most systems in nature involve negative feedback loops. Negative feedback loops enhance stability, and in the long run, only stable systems persist.

Reading Checkpoint *What would you call a process in which an event is both an input and output of the same system?*

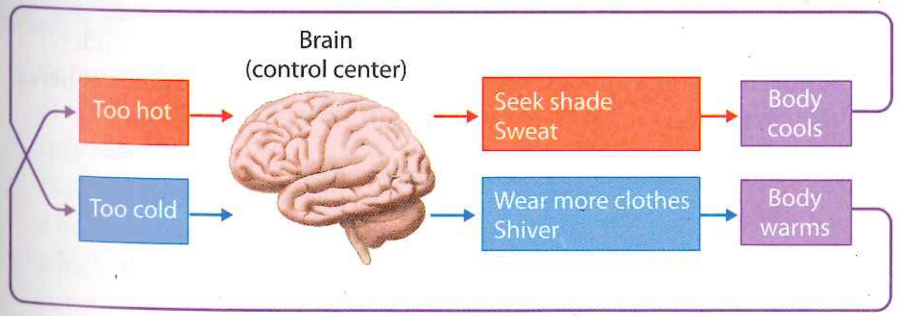


FIGURE 12 Negative Feedback Loop Negative feedback loops stabilize systems and are common in nature. The human body's responses to heat and cold involve a negative feedback loop.

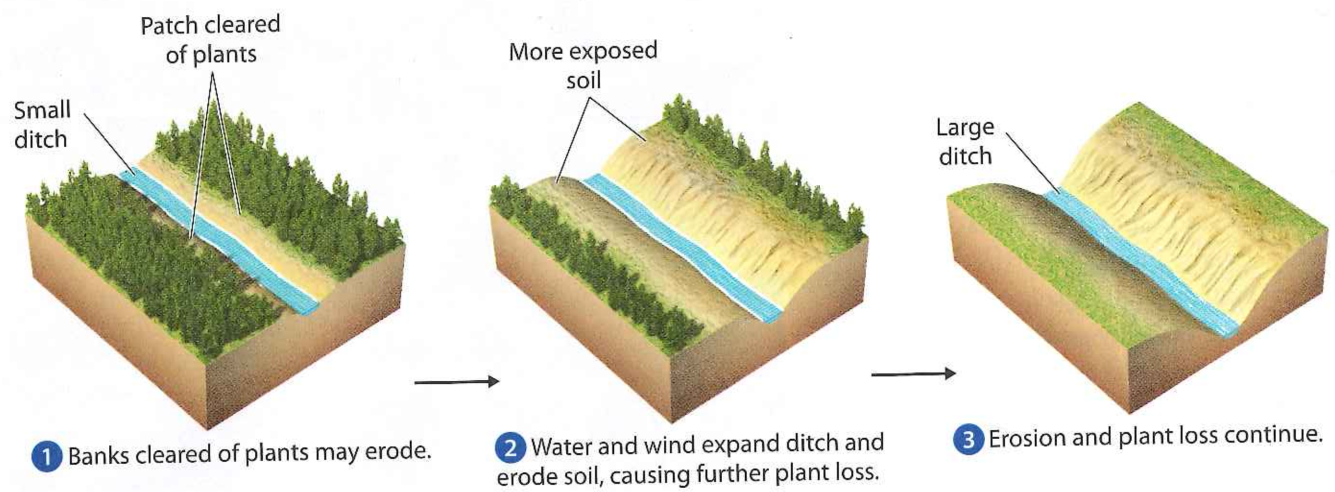


FIGURE 13 Positive Feedback Loop Positive feedback loops destabilize systems and push them toward extremes. For example, the clearing of plants from land can lead to uncontrolled soil erosion. Water flowing through an eroded ditch may expand it and lead to further erosion. Positive feedback loops are rare in natural systems, but common in systems altered by humans, such as on land that has been grazed too much by livestock.

▶ ***Positive Feedback Loops*** *Positive feedback loops* have the opposite effect of negative feedback loops. Rather than stabilizing a system, they drive it toward an extreme. **Erosion,** the removal of soil by water, wind, ice, or gravity, can lead to a positive feedback loop. Once plants have been cleared from an area and soil is exposed, erosion may increase if the effects of water or wind surpass the rate of plant regrowth **(Figure 13).** (You will learn more about erosion in a later chapter.) Because positive feedback destabilizes a system and drives it toward an extreme, it can alter a system drastically. This may be the reason that positive feedback loops are relatively rare in natural environmental systems. They are, however, common in environmental systems changed by people.

Earth's "Spheres"

Earth's geosphere, lithosphere, biosphere, atmosphere, and hydrosphere are defined according to their functions in Earth's systems.

Despite the challenges discussed earlier, categorizing Earth's environmental systems can help make Earth's complexity and environmental issues easier to understand. So scientists often divide Earth into spheres, some of which are described more by their makeup than by their location **(Figure 14).** Earth's **geosphere** is made of all the rock at and below Earth's surface. The **lithosphere** is the hard rock on and just below Earth's surface—the outermost layer of the geosphere. The **biosphere** consists of all the planet's living or once-living things and the nonliving parts of the environment with which they interact. The **atmosphere** consists of the layers of gases surrounding our planet. The **hydrosphere** encompasses all water—salt, fresh, liquid, ice, and vapor—on Earth's surface, underground, and in the atmosphere. You will learn more about Earth's spheres in the next lesson.

Reading Checkpoint *What are the components of the biosphere?*

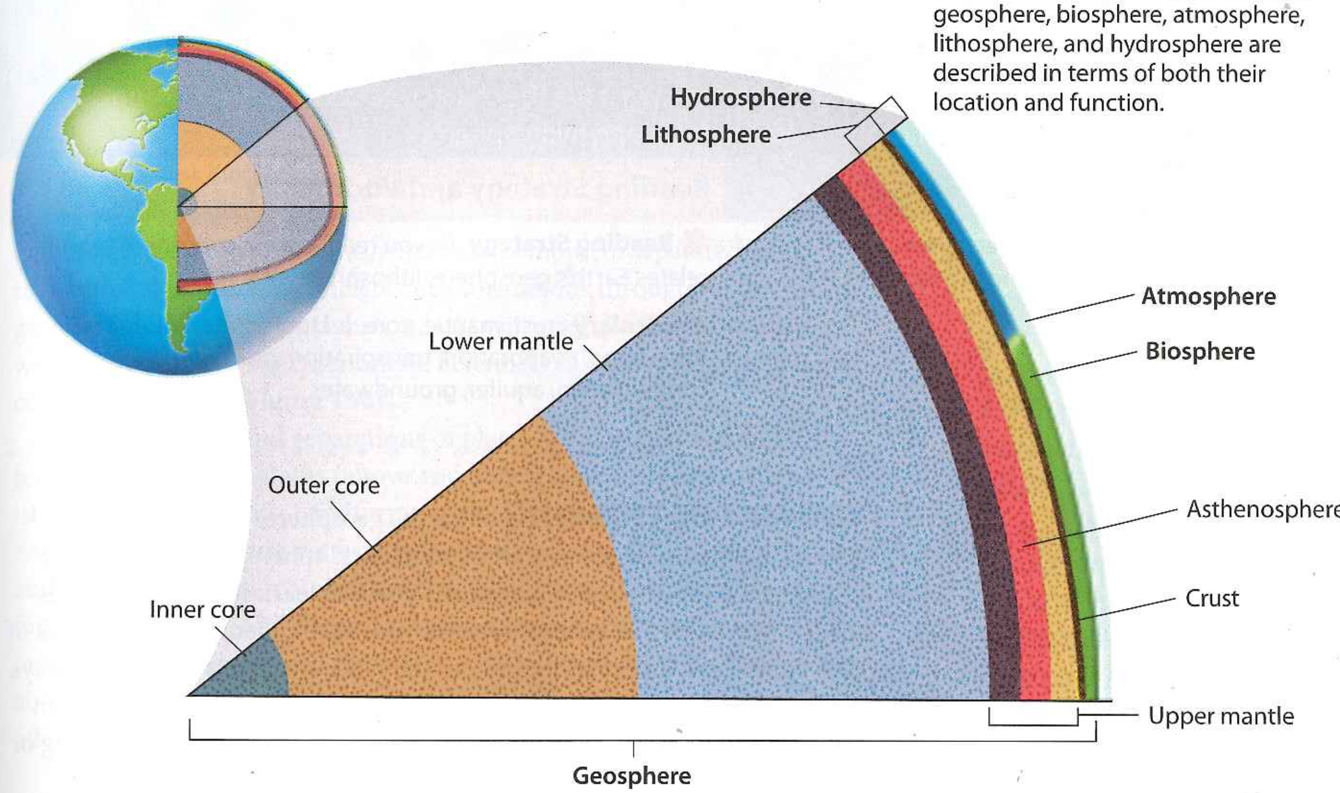


FIGURE 14 Earth's Spheres Earth's geosphere, biosphere, atmosphere, lithosphere, and hydrosphere are described in terms of both their location and function.

Although these spheres are useful models, keep in mind that they both overlap and interact. For example: Picture a robin plucking an earthworm from the ground after a rainstorm and then flying to a tree. You are witnessing the robin (an organism) eating the earthworm (another organism) that has been tunneling through the soil (the lithosphere)—all made possible because rain (from the hydrosphere) has dampened the ground. The robin might then fly through the air (the atmosphere) and land in a tree (another organism), in the process respiring (combining oxygen from the atmosphere with glucose from the organism, and adding water to the hydrosphere and carbon dioxide and heat to the atmosphere). Finally, the bird might release waste, adding nutrients to the soil (the lithosphere). And it all takes place in the biosphere. The study of the complex interactions in such apparently simple events is typical of environmental science.

LESSON 2 Assessment

1. **Compare and Contrast** What are the two types of feedback loops? How are they similar? How are they different?
2. **Classify** Suppose your lab partner were to empty a beaker of mud onto your lab table and ask you which of Earth's spheres it was part of. How would you answer? Explain.
3. **THINK IT *THROUGH*** As snow melts on a city street, it exposes some darker-colored pavement. Dark-colored surfaces absorb more sunlight and heat than light-colored surfaces. Would you expect a feedback process to result from this situation? If so, which type? Explain your answer.

LESSON 3

Earth's Spheres

Guiding Question: What are the characteristics of Earth's geosphere, biosphere, atmosphere, and hydrosphere?

Knowledge and Skills

- Describe the parts of Earth's geosphere.
- Describe Earth's biosphere and atmosphere.
- Discuss the water cycle.

Reading Strategy and Vocabulary

Reading Strategy As you read, draw a concept map that relates Earth's geosphere, lithosphere, mantle, and core.

Vocabulary crust, mantle, core, tectonic plate, landform, deposition, evaporation, transpiration, precipitation, condensation, aquifer, groundwater

YOU MAY BE THINKING of Earth's geosphere, biosphere, atmosphere, and hydrosphere as a set of concentric spheres or Russian dolls, fitting neatly together but separate. As you will learn in the next two lessons, however, Earth's spheres interact with each other. You could think of each sphere as a different highway in the same area. Cars on the highways can travel independently of one another. But at interchanges, there is an intricate dance between cars traveling on a highway and those entering or exiting it.

The Geosphere

Earth's geosphere consists of the crust, the mantle, and the core.

Earth's geosphere consists of the rock and minerals (including soil) on Earth's surface and below it. It includes the crust, the mantle, and the core. Tectonic plates that carry the continents move with the mantle, whose movement is fueled by heat from Earth's core.

Earth's Crust and Mantle Earth's **crust** is a thin layer of relatively cool rock that forms Earth's outer skin both on dry land and in the ocean. Below the crust is the **mantle,** a layer of very hot but mostly solid rock. The crust and the uppermost part of the mantle make up the lithosphere. The lithosphere is carried on a softer, hot layer of rock called the *asthenosphere.* The lower part of the lithosphere and the asthenosphere are included in the upper mantle. Below the upper mantle is the solid rock of the lower mantle.

The Core Beneath the lower mantle is Earth's **core.** Earth's outer core is made of molten metals such as iron and nickel that are almost as hot as the surface of the sun. Earth's inner core is a dense ball of solid metal. The heat from the outer core pushes the asthenosphere's soft rock upward (as it warms). The rock then sinks downward as it cools, like a gigantic conveyor belt. This process is called *convection.*

Plate Tectonics As the asthenosphere moves, it drags along large plates of lithosphere called **tectonic plates.** Earth's surface consists of about 15 major tectonic plates, most of which include some combination of ocean floor and continent **(Figure 15a).** Imagine peeling an orange and putting the pieces of peel back onto the fruit; the ragged pieces of peel are like the plates of Earth's crust. These plates move about 2 to 15 centimeters (1 to 6 inches) per year. This movement has influenced Earth's climate and life's evolution as the continents have combined, separated, and recombined. By studying ancient rock formations throughout the world, geologists have determined that, at least twice, all the world's continents were combined as a supercontinent. Scientists call the most recent supercontinent *Pangaea* **(Figure 15b).**

These collisions and separations of plates result in **landforms**—features such as mountains (above and beneath the ocean's surface), islands, and continents. Landforms created by tectonic processes influence climate by altering patterns of rainfall, wind, ocean currents, heating, and cooling. These climate characteristics, in turn, affect the rates of soil formation, erosion, and **deposition** (the depositing of eroded soil at a new location). And climate, soil formation, erosion, and deposition affect the ability of a given plant or animal to inhabit a region. Thus, plate tectonics affects the types of animals that can live in an area.

Map it

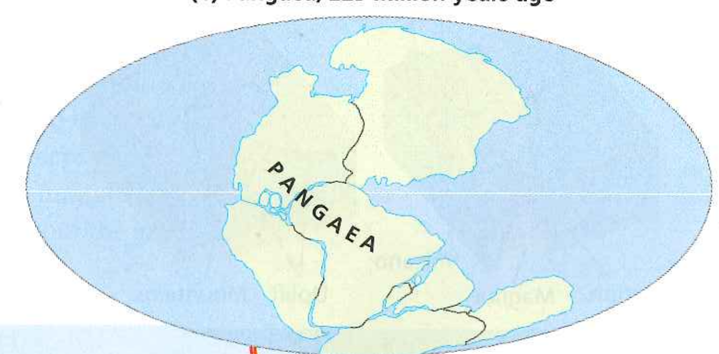
Pangaea

Trace Pangaea and the boundaries drawn on it in **Figure 15b.** Then refer to **Figure 15a** as you respond to the items below.

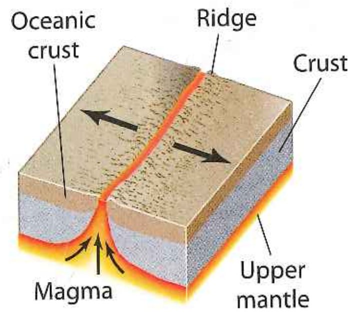
1. **Compare and Contrast** Compare the shapes drawn on Pangaea to the shapes of today's continents. Aside from Antarctica, can you match each of those shapes, to one of today's continents?
2. **Interpret Maps** On your tracing, label the shapes that correspond to modern North America, South America, Eurasia, Africa, India, and Australia.

FIGURE 15 Tectonic Plates Earth's crust consists of about 15 major plates **(a)** that move very slowly by the process of plate tectonics. Today's continents were joined in the supercontinent Pangaea **(b)** about 225 million years ago.

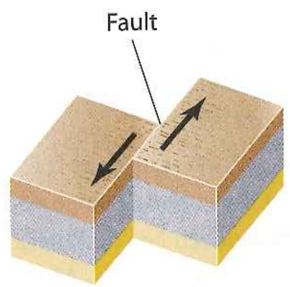
(b) Pangaea, 225 million years ago



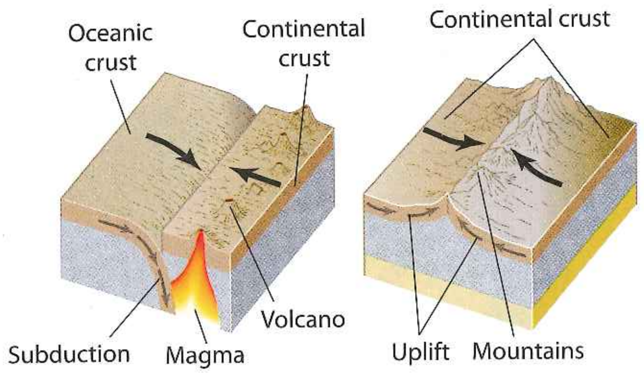
(a) Tectonic plates



(a) Divergent plate boundary



(b) Transform plate boundary



(c) Convergent plate boundaries

FIGURE 16 Plate Boundaries
Different types of boundaries between tectonic plates result in different geologic processes (above). At a divergent plate boundary **(a),** magma surges up through the crust, and the two plates move gradually away like conveyor belts. At a transform plate boundary **(b),** two plates slide alongside each other, producing friction that leads to earthquakes. At a convergent plate boundary **(c),** one plate may be subducted beneath another, leading to volcanoes, or both plates may be uplifted, resulting in mountain ranges, such as the Himalayas (right).

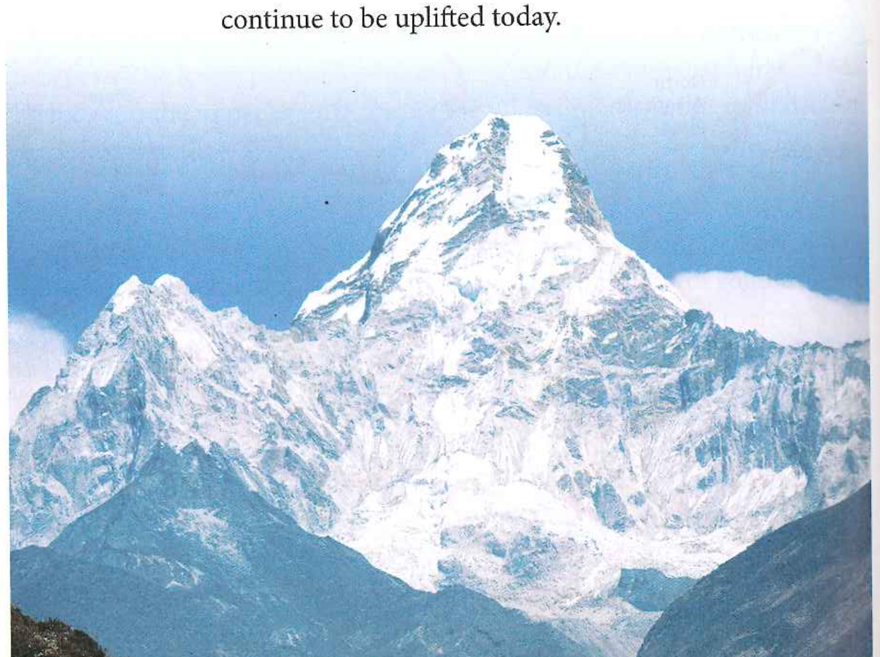
Types of Plate Boundaries Plates interact in different ways based on the type of boundary between them. The type of plate boundary also determines the type of landform that results from a collision. Plate boundaries are either divergent, transform, or convergent.

▶ ***Divergent Plate Boundaries*** At *divergent plate boundaries, magma,* or molten rock, surges upward to the surface and pushes plates apart, creating new crust as it cools **(Figure 16a).** A prime example is the Mid-Atlantic Ridge, part of a 74,000-kilometer (46,000-mile) system that cuts across the ocean floor. Plates expanding outward from divergent plate boundaries at mid-ocean ridges bump against other plates, forming transform or convergent plate boundaries.

▶ ***Transform Plate Boundaries*** When two plates meet, they may slip and grind alongside one another, forming a *transform plate boundary* **(Figure 16b).** The friction between plates at transform plate boundaries often spawns earthquakes. The Pacific Plate and the North American Plate, for example, rub against each other along California's San Andreas Fault, the origin of many of North America's most severe earthquakes.

▶ ***Convergent Plate Boundaries*** When plates collide at *convergent plate boundaries,* one of two events happens **(Figure 16c).** One plate of crust may slide beneath another in a process called *subduction.* The subducted crust is heated as it dives into the mantle, and it may send up magma that erupts through the surface in volcanoes. Mount Saint Helens in Washington, which erupted violently in 1980 and became active again in 2004, is fueled by magma from this process of subduction.

Alternately, the two plates may collide, slowly lifting material from both plates in a process called *mountain-building.* The Himalayas, the world's highest mountains, formed through mountain-building. They are the result of the Indian-Australian Plate's collision with the Eurasian Plate 40–50 million years ago. The Himalayas continue to be uplifted today.



The Biosphere and Atmosphere

Earth's biosphere and atmosphere are the living Earth and the ocean of gases that supports and protects it.

Like all of Earth's systems, Earth's biosphere and atmosphere interact. The gases used and expelled by organisms in the biosphere affect the composition of gases in the atmosphere. In turn, the gases in the atmosphere protect and support the organisms in the biosphere.

The Biosphere The part of Earth in which living things interact with nonliving things is Earth's biosphere, which you could call "the living Earth." You may think that all of Earth has living things, but remember that Earth is not an empty shell. It is filled with hot rock and metal—and scientists know of no organisms living in Earth's mantle or core.

The Atmosphere When you look at a photo of Earth from space, the atmosphere looks like a very thin blue line **(Figure 17).** But that thin blue line is an ocean of gases that support and protect the entire biosphere. The atmosphere contains the gases, such as oxygen, that organisms use for their life processes. It also contains *ozone,* a gas made up of oxygen molecules that each have three oxygen atoms. A layer of ozone protects the biosphere from the sun's radiation—it is a sort of global sunscreen.

The atmosphere also includes gases that keep Earth warm enough to support life, protecting the biosphere from the bitter cold of space. These gases, which include carbon dioxide and methane, are called greenhouse gases because the way they keep Earth warm is analogous to the way the sun's energy, enhanced by the windows of a greenhouse, keeps plants warm. The process is called the greenhouse effect. As you may already know, human activities can affect it. You will read more about the greenhouse effect in a later chapter.

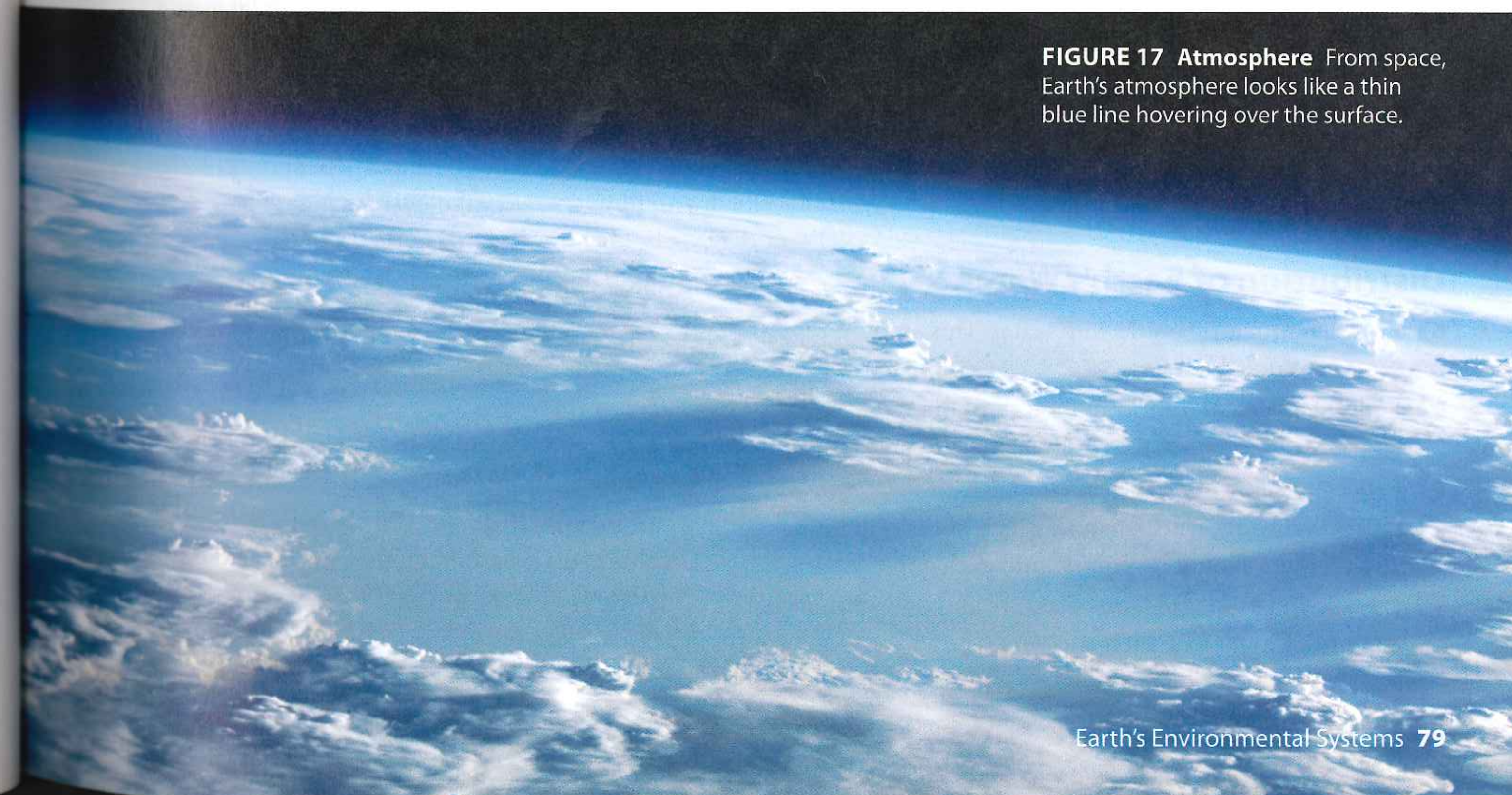
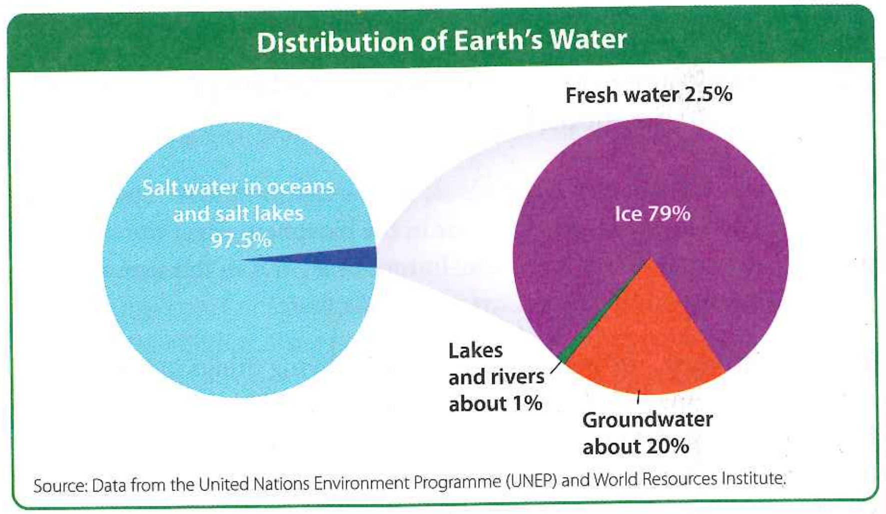


FIGURE 17 Atmosphere From space, Earth's atmosphere looks like a thin blue line hovering over the surface.

FIGURE 18 Distribution of Earth's Water Most of Earth's water is salt water, which cannot be used for drinking or for watering crops. Only 2.5 percent of Earth's water is fresh water, and 79 percent of that is frozen. A tiny percentage of Earth's water is vapor.



The Hydrosphere

Water cycles through the lithosphere, biosphere, and atmosphere endlessly.

Water is essential to life, but we frequently take it for granted. As a means of transport and as a solvent, water plays key roles in nearly every environmental system, including all the other cycles of matter and the life processes of every organism in the biosphere.

Earth's Water Most of Earth's water is salt water **(Figure 18).** The salt water in oceans and salt lakes makes up about 97.5 percent of Earth's water. So only 2.5 percent of Earth's water is fresh water. And more than three quarters of that fresh water is ice. (The ice-covered parts of Earth are sometimes called the *cryosphere.*) Only about 0.5 percent of Earth's water is unfrozen fresh water that might be used for drinking or watering crops. Most of that water is underground, in groundwater, and must be brought to the surface via pumps and/or wells. The rest is in lakes and rivers and must be transported to the areas that need it. Given water's importance and its limited accessibility, it is easy to see how shortages and conflicts over its use occur.

Quick Lab

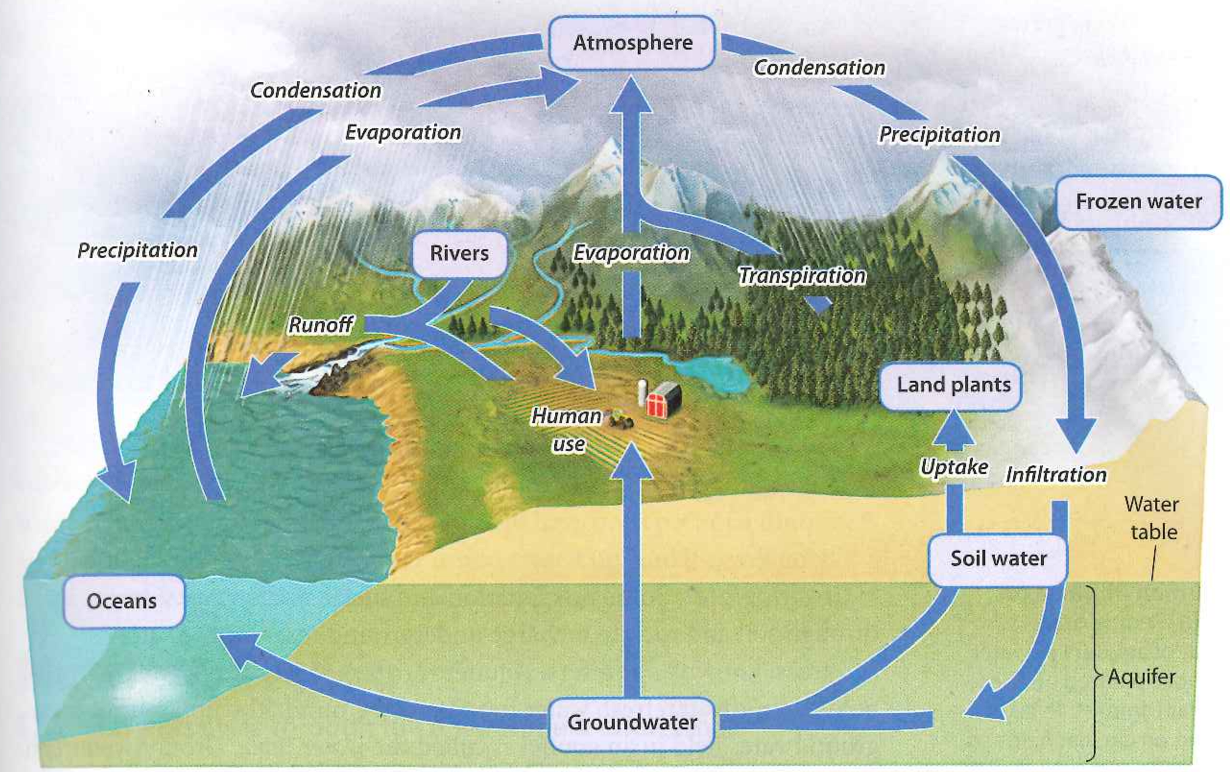
Distribution of Earth's Water

1. Fill a 1-liter plastic bottle with water. This amount represents all of Earth's water.
2. Pour 97.5 percent, or 975 milliliters, of the water into a large bowl. This amount represents Earth's salt water.
3. Label cups *Ice, Groundwater,* and *Lakes and Rivers.*
4. Using **Figure 18,** calculate how much of the remaining 25 milliliters should be poured into each cup.
5. Use a graduated cylinder to measure and pour the correct amount of water into each cup.

Analyze and Conclude

1. **Infer** Which cup(s) represent water that humans can easily use for drinking or watering crops?
2. **Calculate** Calculate the percentage of Earth's water that those cups represent, combined.
3. **Draw Conclusions** Some regions have water shortages even though they are located on ocean coasts. How could that be the case?

FIGURE 19 The Water Cycle The water cycle summarizes the many routes that water molecules take through Earth's spheres. In this diagram, labels in boxes refer to sources of water, and italic labels refer to processes of the water cycle.

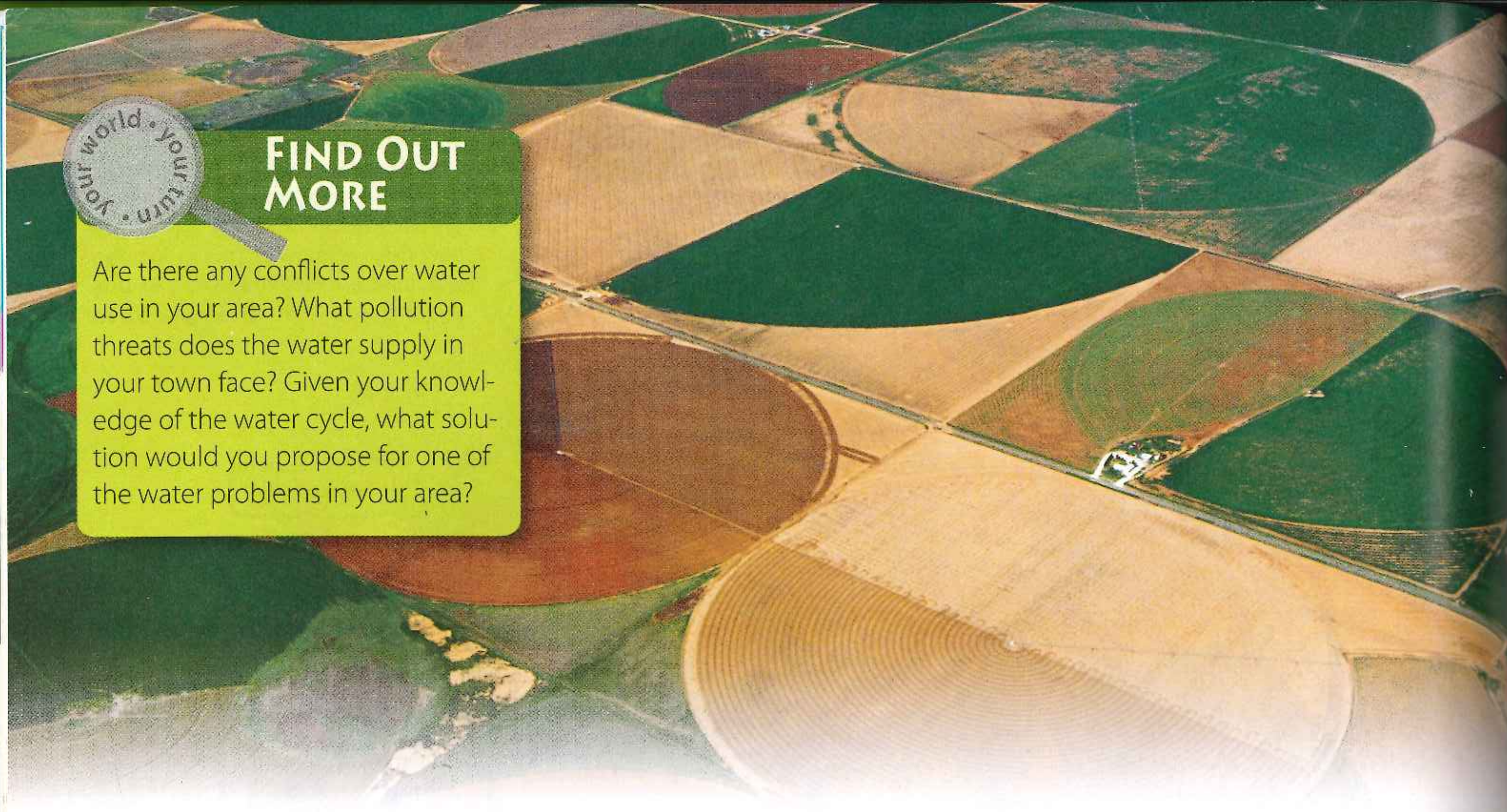


Adapted from Schlesinger, W.H. 1997. *Biogeochemistry: An analysis of global change, 2nd ed.* London: Academic Press

The Water Cycle The *water cycle,* or *hydrologic cycle* **(Figure 19),** summarizes the roles that water—liquid, gaseous, and solid—plays in our environment. Evaporation, transpiration, precipitation, and condensation are the major processes of the water cycle.

Evaporation and Transpiration Water moves from bodies of water and moist soil into the atmosphere by **evaporation,** the conversion of a substance from a liquid to a gas. Warm temperatures and strong winds speed evaporation. Exposed soil loses moisture very quickly—a logged area or an area converted to farms or buildings will lose moisture faster than a similar-sized area covered with natural vegetation. Water also enters the atmosphere by **transpiration,** the release of water vapor by plants through their leaves. Evaporation and transpiration distill water naturally, creating pure water by filtering out minerals and pollutants. Small amounts of water also enter the atmosphere as byproducts of cellular respiration and combustion.

Precipitation and Condensation Water returns from the atmosphere to Earth's surface as **precipitation** such as rain or snow. Precipitation occurs when water vapor undergoes **condensation,** a change in state from a gas to a liquid. Precipitation may be taken up by plants and used by animals, but much of it flows as *runoff* into bodies of surface water such as rivers, lakes, and oceans.



FIND OUT MORE

Are there any conflicts over water use in your area? What pollution threats does the water supply in your town face? Given your knowledge of the water cycle, what solution would you propose for one of the water problems in your area?

FIGURE 20 Human Impacts on the Water Cycle People draw groundwater out of aquifers to water crops, such as those planted on these circular fields near Dimmitt, Texas. Crops are planted on circular fields so that they can be efficiently watered by a sprayer pipe that extends across the radius of the circle.

▶ ***Groundwater*** Some precipitation and surface water soaks down through soil and rock to recharge underground reservoirs, or storage areas, known as **aquifers.** Aquifers are layers of rock and soil that hold **groundwater,** fresh water found underground. The upper limit of groundwater held in an aquifer is called the *water table.* Groundwater can take hundreds or even thousands of years to recharge fully after being depleted, if it *ever* recharges, so it is an extremely precious resource.

▶ ***Human Impacts*** Human activity can affect every aspect of the water cycle. By clearing plants from Earth's surface, we increase runoff and erosion, increase evaporation, and reduce transpiration. By spreading water on farm fields, we can deplete surface water and groundwater and increase evaporation **(Figure 20).** And by releasing certain pollutants into the atmosphere, we cause precipitation to become more acidic. Perhaps most threatening to our future, we are depleting groundwater with unrestrained use by irrigation and industry. The depletion is so severe in some areas, such as South Asia, the Middle East, and the American West, that water shortages have given rise to political, or even armed, conflicts.

LESSON 3 Assessment

1. **Apply Concepts** What parts of the geosphere are involved in plate tectonics? What are their functions in that process?
2. **Use Analogies** Use an anology to describe one way that gases in Earth's atmosphere protect the biosphere.
3. **Relate Cause and Effect** Describe the two processes by which most water moves into the atmosphere.
4. Explore the **BIG**QUESTION How are the processes of the water cycle essential to an unpolluted biosphere?

Biogeochemical Cycles

LESSON 4

Guiding Question: How do nutrients cycle through the environment?

Knowledge and Skills

- Explain how the law of conservation of matter applies to the behavior of nutrients in the environment.
- Describe the carbon cycle.
- Describe the events of the phosphorus cycle.
- Explain the importance of bacteria to the nitrogen cycle.

Reading Strategy and Vocabulary

Reading Strategy Before you read, preview **Figure 21.** Make a list of questions you have about the carbon cycle. As you read, try to answer those questions.

Vocabulary law of conservation of matter, nutrient, biogeochemical cycle, primary producer, photosynthesis, consumer, decomposer, cellular respiration, eutrophication, nitrogen fixation

CONSIDER THIS: A carbon atom in your fingernail today might have helped make up the muscle of a cow a year ago, may have belonged to a blade of grass a month before that, and may have been part of a dinosaur's tooth 100 million years ago. Matter is never used up, and it never goes away. It just keeps cycling around and around.

Nutrient Cycling

Nutrients cycle through the environment endlessly.

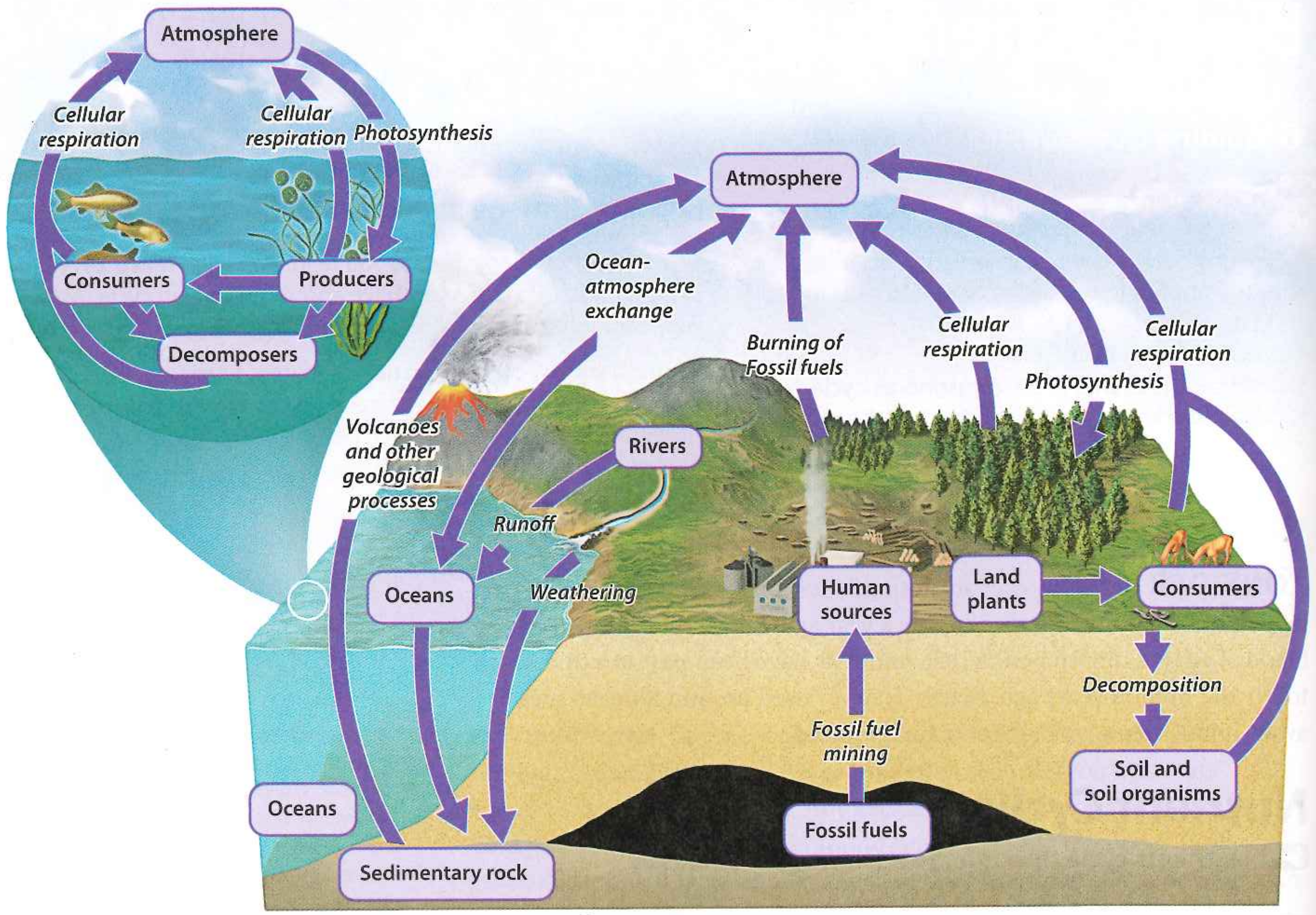
Why does matter, such as water, cycle through the environment, never getting used up? Here's the answer: Matter may be transformed from one type to another, but it cannot be created or destroyed. This principle is called the **law of conservation of matter.** It explains why the amount of matter in the environment stays the same as it flows through matter cycles, such as the water cycle.

Nutrients are matter that organisms require for their life processes. Organisms need several dozen nutrients. The nutrients required in relatively large amounts are called *macronutrients* and include nitrogen, carbon, and phosphorus. The nutrients needed in small amounts are called *micronutrients.* Nutrients circulate endlessly throughout the environment in complex cycles called **biogeochemical cycles,** or nutrient cycles. Carbon, oxygen, phosphorus, and nitrogen are nutrients that cycle through all of Earth's spheres and organisms. The water cycle plays parts in all the biogeochemical cycles.

The Carbon Cycle

Producers play vital roles in the cycling of carbon through the environment.

From fossil fuels to DNA, from plastics to medicines, carbon (C) atoms are everywhere. The *carbon cycle* describes the routes that carbon atoms take through the environment.



Adapted from Schlesinger, W.H. 1997. *Biogeochemistry: An analysis of global change, 2nd ed.* London: Academic Press

FIGURE 21 Carbon Cycle The carbon cycle describes the routes that carbon atoms take as they move through the environment. In this diagram, labels in boxes refer to reservoirs, or pools, of carbon, and italic labels refer to processes of the carbon cycle.

Producers Primary producers are organisms, including plants and algae, that produce their own food. Producers use the sun's energy or chemical energy along with carbon dioxide to produce carbohydrates. The carbohydrates are used as food by the producers.

Most producers make their own food by using the sun's energy in photosynthesis. In photosynthesis, producers pull carbon dioxide out of their environment and combine it with water in the presence of sunlight. The chemical bonds in carbon dioxide (CO_2) and water (H_2O) are then broken, producing oxygen (O_2) and carbohydrates (such as glucose, $C_6H_{12}O_6$). (The numbers in front of the chemical formulas below are numbers of molecules.)

$$6CO_2 + 6H_2O + \text{the sun's energy} \rightarrow C_6H_{12}O_6 \text{ (sugar)} + 6O_2$$

Consumers and Decomposers The carbon in a producer may be passed on to another organism, either a consumer that eats it or a decomposer that breaks down its wastes or remains. Consumers are organisms, mainly animals, that must eat other organisms to obtain nutrients. Decomposers are organisms such as bacteria and fungi that break down wastes and dead organisms.

Cellular Respiration Cellular respiration does *not* refer to *breathing*. Cellular respiration is the process by which organisms use oxygen to release the chemical energy of sugars and release CO_2 and water. In general terms, it is the chemical reverse of photosynthesis.

$$C_6H_{12}O_6 \text{ (sugar)} + 6O_2 \rightarrow 6CO_2 + 6H_2O + \text{energy}$$

Most organisms undergo cellular respiration constantly, releasing carbon back into the atmosphere and oceans. Organisms do not release all the carbon they take in, however. They use some of it for their life processes. In fact, the abundance of plants and the fact that they use so much carbon for photosynthesis and other processes makes them a major carbon *sink.* (A sink is a reservoir of a substance that accepts more of that substance than it releases.)

Carbon in Sediments When organisms die in water, their remains may settle in sediments. As new layers of sediment accumulate, pressure on earlier layers increases. These conditions can convert soft tissues into fossil fuels, and shells and skeletons into sedimentary rock such as limestone. Limestone and other sedimentary rock make up the largest reservoir of carbon. Sedimentary rock releases some of its carbon through erosion and volcanic eruptions. Fossil fuel deposits contain a great deal of carbon, which is released when we extract the fossil fuels.

Carbon in Oceans The world's oceans are the second-largest carbon reservoir **(Figure 22).** They absorb carbon compounds from the atmosphere, from runoff, from undersea volcanoes, and from the wastes and remains of organisms. The rates at which seawater absorbs and releases carbon depend on many factors, including the water temperature and the numbers of marine organisms living in it.

FIGURE 22 Carbon in the Oceans It's hard to believe that this beautiful blue-green wave is full of carbon. Oceans are Earth's second-largest carbon reservoir.

Human Impacts Humans shift carbon to the atmosphere in many ways. By extracting fossil fuels, we remove carbon from storage in the lithosphere. By then burning those fossil fuels, we move carbon dioxide into the atmosphere. The cutting of forests and burning of forests to plant farm fields also increase carbon in the atmosphere, both by releasing it from storage in plants and by reducing the plants available to use it. Producers cannot absorb enough carbon to keep up with human activities.

The Missing Carbon Sink Our understanding of the carbon cycle is not complete. Scientists have long been baffled by a missing carbon sink. Of the carbon dioxide humans release, scientists have measured how much is returned to the atmosphere and oceans, and more than 1–2 billion metric tons (1.1–2.2 billion tons) are unaccounted for. Many researchers think it must be taken up by the northern forests. But they'd like to know for sure.

MAKE A DIFFERENCE

your world · your turn

Many household detergents contain phosphates (phosphorus compounds). Phosphates in runoff can cause or worsen eutrophication. Check the packages of dishwasher and laundry detergents in your home to see if they contain phosphates. With your family, consider switching to a brand with less phosphate.

The Phosphorus Cycle

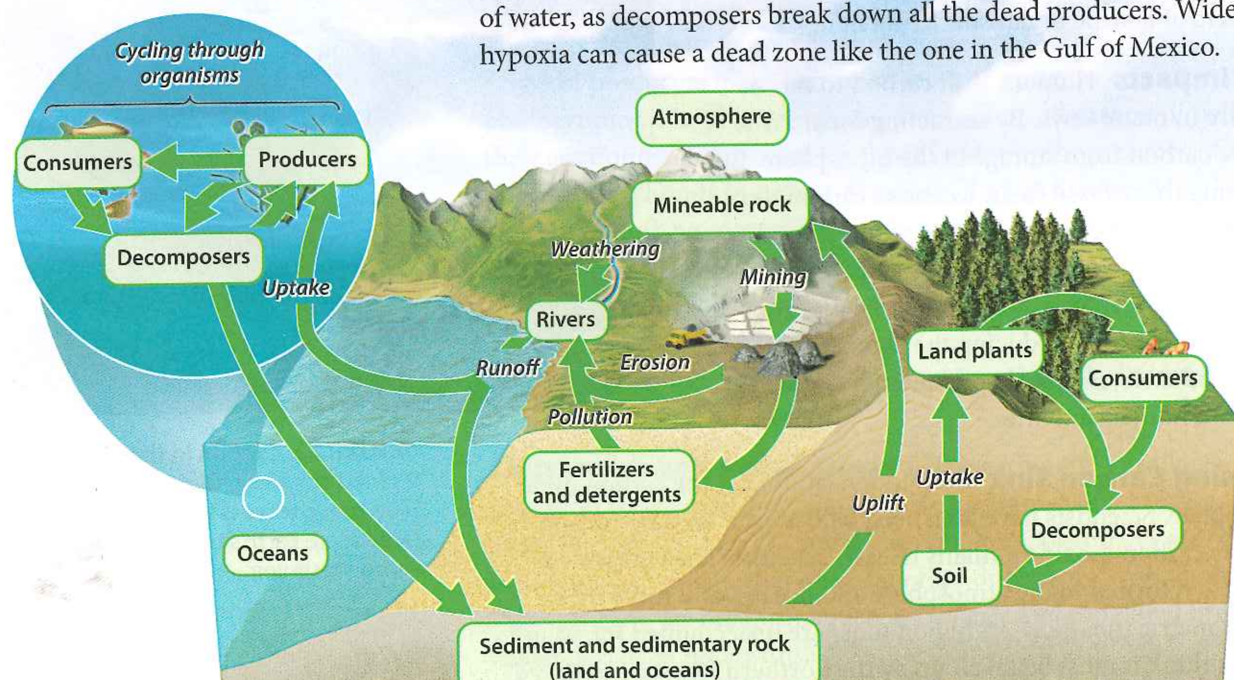
The phosphorus cycle keeps phosphorus availability naturally low.

The *phosphorus cycle* (**Figure 23**) involves mainly the lithosphere and the oceans. Phosphorus is a key component of cell membranes and of several molecules essential to life, including DNA and RNA. Although phosphorus is essential to life, the amount of phosphorus in organisms is dwarfed by the vast amounts in rocks, soil, sediments, and the oceans. Phosphorus is released naturally only when rocks are worn down by water or wind. Because most phosphorus is bound up in rock, the phosphorus available to organisms at any time tends to be very low. This scarcity, along with the need that organisms have for phosphorus, explains why plant and algae growth often jumps dramatically when phosphorus is added to their environments.

Organisms in the Phosphorus Cycle Plants can take up phosphorus through their roots only when it is dissolved in water. Consumers acquire phosphorus from the water they drink and the organisms they eat. The waste of consumers contains phosphorus that decomposers return to the soil.

Human Impacts People influence the phosphorus cycle in several ways. We mine phosphorus to use as fertilizer. People also release phosphorus-rich wastewater from their houses and businesses. (Phosphorus compounds are added to many detergents to improve their cleaning power.) Wastewater containing fertilizers and detergents that runs off or leaches into waterways adds phosphorus to them. The addition of phosphorus to bodies of water can lead to an overgrowth of producers (usually algae) in a process called **eutrophication.** In extreme cases, eutrophication can lead to *hypoxia,* or extremely low levels of oxygen in a body of water, as decomposers break down all the dead producers. Widespread hypoxia can cause a dead zone like the one in the Gulf of Mexico.

FIGURE 23 Phosphorus Cycle The phosphorus cycle describes the routes that phosphorus atoms take through the environment. In this diagram, labels in boxes refer to reservoirs of phosphorus, and italic labels refer to processes of the phosphorus cycle.



Adapted from Schlesinger, W.H. 1997. *Biogeochemistry: An analysis of global change, 2nd ed.* London: Academic Press

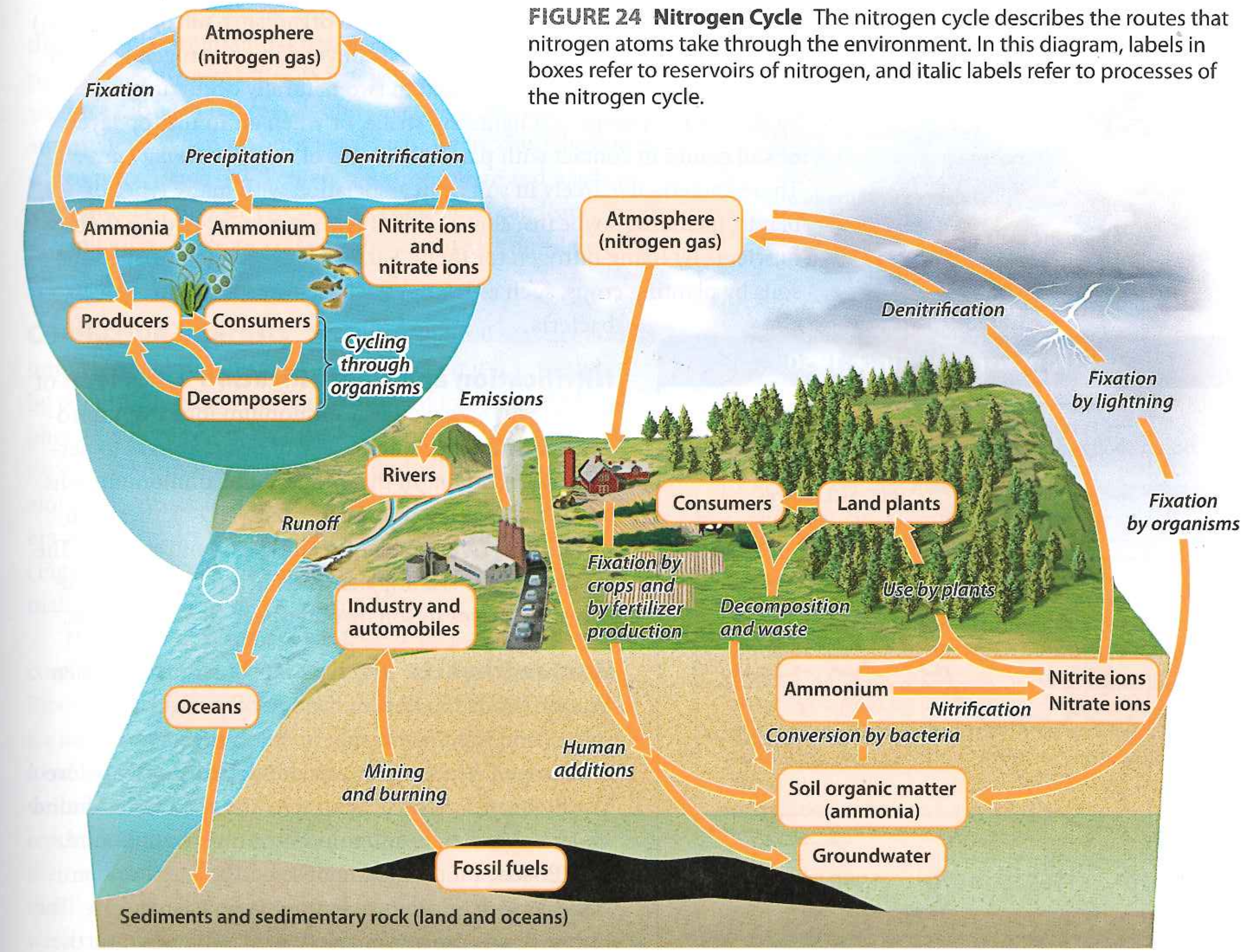


FIGURE 24 Nitrogen Cycle The nitrogen cycle describes the routes that nitrogen atoms take through the environment. In this diagram, labels in boxes refer to reservoirs of nitrogen, and italic labels refer to processes of the nitrogen cycle.

Adapted from Schlesinger, W.H. 1997. *Biogeochemistry: An analysis of global change, 2nd ed.* London: Academic Press

The Nitrogen Cycle

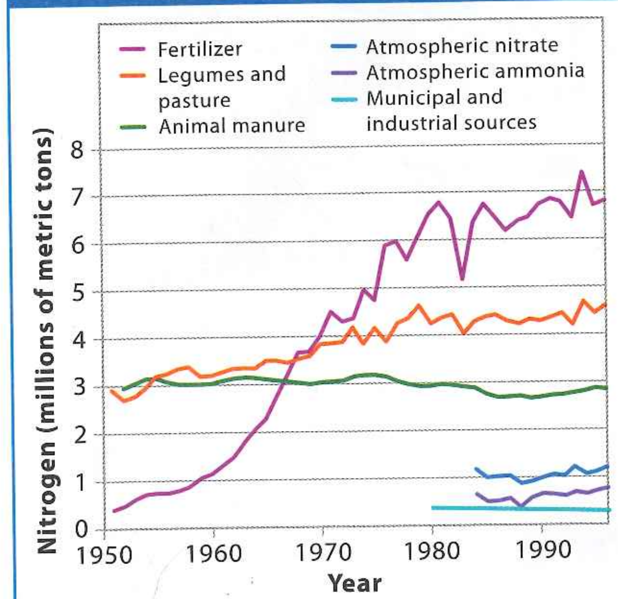
The nitrogen cycle relies on bacteria that make nitrogen useful to organisms and bacteria that can return it to the atmosphere.

Nitrogen makes up 78 percent of our atmosphere by mass, and is the sixth most abundant element. It is an essential ingredient in the proteins, DNA, and RNA that build our bodies. Like phosphorus, nitrogen is an essential nutrient for plant growth. Thus the *nitrogen cycle* (**Figure 24**) is of vital importance to us and to all other organisms. Despite its abundance, nitrogen gas cannot cycle out of the atmosphere and into organisms. For this reason, nitrogen is relatively scarce in the lithosphere, hydrosphere, and in organisms. However, once nitrogen undergoes the right kind of chemical change—assisted by lightning, specialized bacteria, or human technology—it becomes usable to the organisms that need it. Those nitrogen compounds can act as potent fertilizers in the biosphere.

Reading Checkpoint *Why is nitrogen scarce in the biosphere?*

Nitrogen Fixation To become usable to organisms, nitrogen gas (N_2) must be "fixed." **Nitrogen fixation** is the conversion of nitrogen gas into ammonia. This can be accomplished in two naturally occurring ways: by the intense energy of a lightning strike, or when air in the top layer of soil comes in contact with particular types of *nitrogen-fixing bacteria.* These bacteria live freely in soil or in association with many types of plants, including soybeans, clover, and other legumes, providing them nutrients by fixing nitrogen for them. Farmers have long nourished their soils by planting crops, such as legumes, whose roots host nitrogen-fixing bacteria.

Nitrogen Inputs Since 1950



Data from the National Oceanic and Atmospheric Administration *The causes of hypoxia in the Northern Gulf of Mexico.*

Nitrification and Denitrification Other types of bacteria living in soil use ammonium ions from nitrogen fixation or from the waste of decomposers to perform *nitrification.* In this process, the ammonium ions are first converted into nitrite ions (NO_2^-), then into nitrate ions (NO_3^-). Plants can take up nitrate ions. The nitrogen cycle is complete when *denitrifying bacteria* convert nitrates in soil or water back to nitrogen gas.

Human Impacts The slow rate of natural nitrogen fixation limits the flow of nitrogen out of the atmosphere and into the biosphere. But humans can also fix nitrogen. The process was developed shortly before World War I, when German scientist Fritz Haber found a way to synthesize ammonia, a nitrogen compound. Carl Bosch, another German scientist, later built on Haber's work to produce ammonia on a large scale. The Haber-Bosch process enabled people to overcome the limits on plant productivity imposed by the natural scarcity of nitrogen. Today, humans fix at least as much nitrogen artificially as is fixed naturally.

Connect to the Central Case

FIGURE 25 Nitrogen in the Mississippi River The graph shows the sources of nitrogen added to the Mississippi River basin (photo) since 1950. **Interpret Graphs** What has been the largest source of added nitrogen in the Mississippi River basin since 1970?

Reading Checkpoint *What are two ways in which nitrogen fixation can occur naturally?*

By fixing atmospheric nitrogen, we increase its flow out of the atmosphere and into other reservoirs. We also affect other parts of the nitrogen cycle. When we burn forests and fields, we force nitrogen out of soils and vegetation and into the atmosphere. When we burn fossil fuels, we increase the rate at which nitric oxide (NO) enters the atmosphere and reacts to form nitrogen dioxide (NO_2). This compound can lead to acid precipitation. These and other human activities unbalance the nitrogen cycle.

Conflicting Interests Nitrogen's natural scarcity and its importance to organisms mean that when it is introduced by people, problems similar to those of introduced phosphorus, such as eutrophication, can occur. The impacts of excess nitrogen from agriculture and other human activities along the Mississippi River are painfully evident to shrimpers and scientists with an interest in the Gulf of Mexico (**Figure 25**). Yet, farmers upstream also need to continue making a living, so there is a conflict.

The federal government has tried to help resolve that conflict. In 1998, the U.S. Congress passed the Harmful Algal Bloom and Hypoxia Research and Control Act. This law called for an "integrated assessment" of hypoxia in the northern Gulf to address the extent, nature, and causes of the dead zone, as well as its ecological and economic impacts. The assessment report published two years later outlined potential solutions and their estimated social and economic costs. The report proposed that the federal government work with Gulf Coast and Midwestern communities to carry out several proposals, which you can see in **Figure 26.** In 2004, Congress reauthorized the Act. Several expansions of the plan were under consideration in 2010.

Proposals for Reducing Gulf of Mexico Dead Zone

- Reduce nitrogen fertilizer use on Midwestern farms.
- Change the timing of fertilizer use to minimize runoff during the rainy season.
- Plant alternative crops.
- Manage nitrogen-rich livestock manure more effectively.
- Restore nitrogen-absorbing wetlands in the Mississippi River basin.
- Construct artificial wetlands to filter farm runoff.
- Improve sewage treatment.
- Restore frequently flooded lands to reduce runoff.
- Restore wetlands near the Mississippi River's mouth to improve nitrogen-absorbing ability.

Connect to the Central Case

FIGURE 26 Potential Solutions to the Dead Zone A 2000 assessment of hypoxia in the Gulf of Mexico led to these proposals. Congress continues to work on refining laws concerning the addition of nutrients to the Mississippi River basin in efforts to reduce the dead zone. **Infer** According to these proposals, what group will bear much of the responsibility for reducing the dead zone?

LESSON 4 Assessment

1. **Review** Describe the law of conservation of matter.
2. **Infer** Why is it said that photosynthesis and cellular respiration are reverse chemical processes?
3. **Sequence** Describe the roles of organisms in the phosphorus cycle.
4. **Classify** A classmate describes a bacterium to you as living on the roots of clover and providing nutrients to the plant. Would you classify this bacterium as nitrogen-fixing, nitrifying, or denitrifying? Explain.
5. **THINK IT *THROUGH*** You've been noticing that a local pond has developed a green scum that is getting thicker and thicker. When you look into the water, you see fewer fish and other animals than you used to, and you see fewer birds around the pond. Based on what you learned in this chapter, what is this process called? What are two possible causes?

A CLOSER LOOK

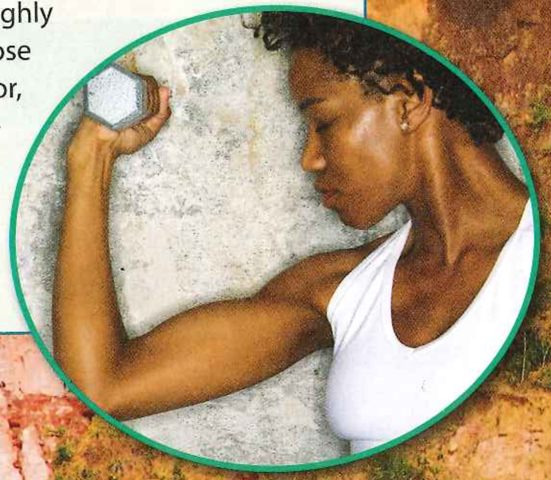
Nutrients

Carbon, nitrogen, and phosphorus are the most abundant nutrients in the biosphere, but there are many secondary nutrients that are also vital for life. Plants, for example, require 13 nutrients to grow; humans and animals require several more. Some of these are *macronutrients,* which are nutrients required in large quantities. Others are *micronutrients,* which are required only in small quantities. Potassium, calcium, and iron are three important nutrients that are required by almost every organism on Earth for survival.

Tropical soils are often leached of potassium.

POTASSIUM

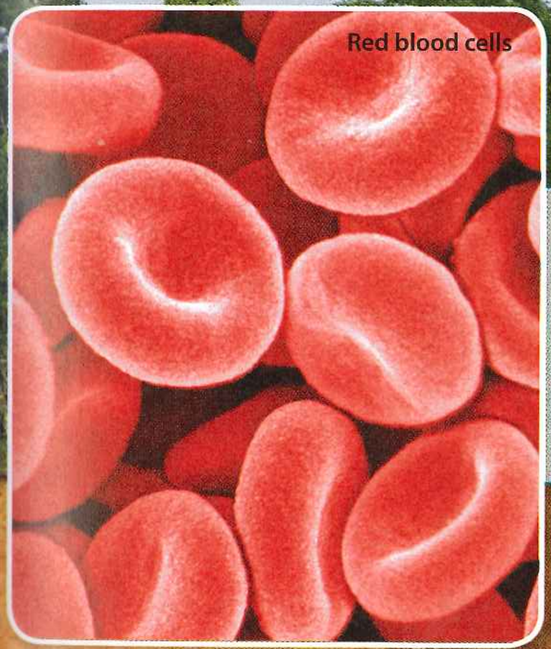
Potassium comes from weathered mineral salts in the Earth's crust. Plants need large amounts of potassium for the transport of water and nutrients through their stems—some plant species need even more potassium than nitrogen. Old, highly weathered acidic soils, however, such as those in rain forests and savannas near the equator, tend to be low in potassium, making potassium fertilizer necessary for agriculture in these regions. For animals, potassium is a micronutrient, that is needed to keep animal muscles and brains functioning.



CALCIUM

Calcium is best known as the mineral that strengthens bones in humans and other vertebrates, but plants need calcium, too. In fact, calcium can be just as important as nitrogen and phosphorus for plants. This is particularly true for plants growing in acidic soils where levels of calcium tend to be low. For these plants, calcium is often in short supply, which can limit growth. Calcium is also important for ocean creatures such as corals, snails, and tiny microscopic organisms that build shells or plates out of calcium carbonate ($CaCO_3$).

Calcium carbonate is the major component of clam shells and corals.



Red blood cells

IRON

Iron is a micronutrient, necessary only in small quantities, but nearly every organism on Earth depends on it for survival. In animals, iron is needed for transporting oxygen in the blood. In plants and bacteria, iron is necessary for photosynthesis.

21st Century Skills **Creativity and Innovation**

Pick one of the nutrients discussed in this feature. Use Internet or library resources to find out the following information: the source of the nutrient (type of foods it's found in), what happens if we don't get enough of the nutrient, and why it's needed in the body. Compile the information into a pamphlet that can be displayed in the classroom.

CHAPTER 3

Study Guide

BIGQUESTION

How do the nonliving parts of Earth's systems provide the basic materials to support life?

Lesson 1 What properties of matter are most important to environmental systems?

Lesson 2 What types of systems play roles in environmental science?

Lesson 3 What are the characteristics of Earth's geosphere, biosphere, atmosphere, and hydrosphere?

Lesson 4 How do nutrients cycle through the environment?

LESSON 1 Matter and the Environment

- Atoms and elements are the basic building blocks of chemistry.
- Proteins, nucleic acids, carbohydrates, and lipids are the building blocks of life.
- Water is a unique compound with several unusual properties that make it essential to life.

matter (64)
atom (64)
element (64)
nucleus (65)
molecule (66)
compound (66)
hydrocarbon (66)
solution (67)
macromolecule (67)
protein (67)
nucleic acid (68)
carbohydrate (68)
lipid (69)
pH (71)

LESSON 2 Systems in Environmental Science

- An output of one of Earth's systems is often also an input to that or another system.
- Earth's geosphere, lithosphere, biosphere, atmosphere, and hydrosphere are defined according to their functions in Earth's systems.

feedback loop (73)
erosion (74)
geosphere (74)
lithosphere (74)
biosphere (74)
atmosphere (74)
hydrosphere (74)

LESSON 3 Earth's Spheres

- Earth's geosphere consists of the crust, the mantle, and the core.
- Earth's biosphere and atmosphere are the living Earth and the ocean of gases that supports and protects it.
- Water cycles through the lithosphere, biosphere, and atmosphere endlessly.

crust (76)
mantle (76)
core (76)
tectonic plate (77)
landform (77)
deposition (77)
evaporation (81)
transpiration (81)
precipitation (81)
condensation (81)
aquifer (82)
groundwater (82)

LESSON 4 Biogeochemical Cycles

- Nutrients cycle through the environment endlessly.
- Producers play vital roles in the cycling of carbon.
- Phosphorus availability is naturally low.
- The nitrogen cycle relies on bacteria that make nitrogen available to organisms and bacteria that can return it to the atmosphere.

law of conservation of matter (83)
nutrient (83)
biogeochemical cycle (83)
primary producer (84)
photosynthesis (84)
consumer (84)
decomposer (84)
cellular respiration (85)
eutrophication (86)
nitrogen fixation (88)

MyEnvironmentalScience.com

INQUIRY LABS AND ACTIVITIES

- **Age the Islands**
  Use position, shape, and size of the volcanic Galápagos Islands to infer which are older or younger.
- **Effects of CO_2 on Plants**
  Do plants thrive or decline when atmospheric CO_2 levels increase? Graph a sample dataset to find out.

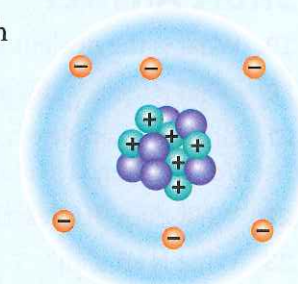
Chapter Assessment

Make Your Case

The Central Case in this chapter introduced the dead zone in the Gulf of Mexico. Scientists have evidence that farming practices and other human activities along the Mississippi River contribute to the dead zone. Based on what you have learned, how can the dead zone be reduced without hurting the livelihoods of the farmers upstream? Use examples from the Central Case and the lessons to support your opinion.

Review Concepts and Terms

1. Which of the following are the basic units of matter?
   a. compounds
   b. solutions
   c. atoms
   d. macromolecules
2. The particles labeled with negative signs in the diagram at the right are
   a. elements.
   b. electrons.
   c. protons.
   d. neutrons.



3. Which of Earth's spheres encompasses all of Earth's water?
   a. the hydrosphere
   b. the atmosphere
   c. the asthenosphere
   d. the geosphere
4. The crust, mantle, asthenosphere, and core are all parts of Earth's
   a. atmosphere.
   b. biosphere.
   c. hydrosphere.
   d. geosphere.
5. Landforms include
   a. aquifers.
   b. tectonic plates.
   c. mountains.
   d. all of the above.
6. Matter that organisms require for their life processes are
   a. biogeochemical cycles.
   b. producers.
   c. nutrients.
   d. decomposers.
7. An organism that must get nutrients by eating other organisms is called a
   a. producer.
   b. consumer.
   c. decomposer.
   d. nitrifying bacterium.
8. The phosphorus cycle involves mainly the
   a. atmosphere and biosphere.
   b. lithosphere and hydrosphere.
   c. geosphere and biosphere.
   d. asthenosphere and hydrosphere.
9. Eutrophication of a body of water is often caused by the addition of
   a. carbon and/or proteins.
   b. lipids and/or hydrocarbons.
   c. carbon and/or phosphorus.
   d. phosphorus and/or nitrogen.
10. Nitrogen fixation can be accomplished naturally either by a lightning strike or by
    a. nitrogen-fixing bacteria.
    b. denitrifying bacteria.
    c. the Haber-Bosch process.
    d. burning fossil fuels.

CHAPTER 3

Chapter Assessment

Modified True/False

Write true if the statement is true. If it is false, change the underlined word or words to make the statement true.

11. All material that has mass and occupies space is called <u>matter</u>.

12. Proteins, nucleic acids, carbohydrates, and lipids are all <u>macromolecules</u>.

13. The ever-worsening erosion of a patch of overgrazed land is an example of a <u>negative</u> feedback loop.

14. Most <u>decomposers</u> make their own food by photosynthesis.

15. Photosynthesis and <u>cellular respiration</u> can be considered the chemical reverse of each other.

Reading Comprehension

Read the following selection and answer the questions that follow.

Global climate change is occurring. Almost all environmental scientists agree that emissions of certain gases could be contributing to it. Carbon dioxide, methane, nitrous oxide, ozone, hydrochlorofluorocarbons, and water vapor are the main culprits. These "greenhouse gases" have increased dramatically in our atmosphere in the last 300 years. Human activities, especially the mining and burning of fossil fuels for transportation and industry, increase greenhouse gases in the atmosphere. And increasing industrial activity in developing nations will likely lead to rising emissions of those gases. If unchecked, carbon dioxide levels in the atmosphere could reach twice preindustrial levels by 2050 and double again by 2100. Computer models show that this rise in greenhouse gases could raise Earth's temperatures by as much as 10 degrees Fahrenheit.

16. Which of the following gases are considered greenhouse gases?
a. methane
b. carbon dioxide
c. ozone
d. all of the above

17. The primary human source of greenhouse gases in Earth's atmosphere is
a. photosynthesis.
b. the mining and burning of fossil fuels.
c. the use of aerosol sprays.
d. the removal of fossils.

18. How could an increase in industrial activity in developing nations contribute to global climate change?
a. Burning fossil fuels in industry increases greenhouse gases in the atmosphere.
b. Burning fossil fuels destroys the ozone layer.
c. Heat from industrial machines warms up the atmosphere.
d. Burning fossil fuels removes water vapor from the atmosphere.

Short Answer

19. What is the nucleus of an atom?

20. What particles are in the nucleus of an atom?

21. Give an example of each of three unusual properties of water.

22. What does pH describe?

23. What is erosion?

24. Briefly describe five of Earth's spheres.

25. Describe two ways in which Earth's biosphere and atmosphere interact.

26. What is the law of conservation of matter?

Critical Thinking

27. Classify Is pure water a solution? Explain.

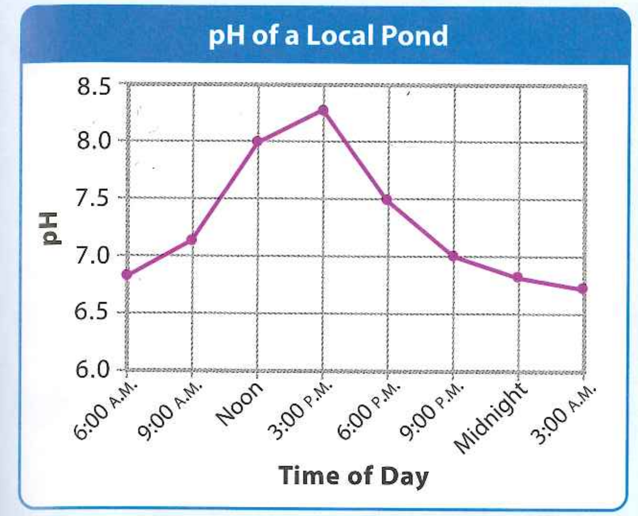
28. Infer Describe how the process of convection is responsible for the movement of Earth's tectonic plates.

29. Sequence Briefly describe the water cycle using the terms *evaporation, transpiration, condensation,* and *precipitation.*

30. Explain How is understanding the law of conservation of matter important to understanding the biogeochemical cycles?

Analyze Data

A student took water samples from a small pond every three hours and measured their pH. The results are plotted on the graph. Use the graph to answer the questions.



31. Interpret Graphs At which times of day is the pond most acidic?

32. Analyze Data How does the pH change from noon to 9:00 P.M.? How many times more acidic is the water at 9:00 P.M. than at noon?

33. Form a Hypothesis Form a hypothesis that could explain the data in the graph.

Write About It

34. Explanation Write a script for a one-minute announcement alerting people to the dangers of polluting groundwater.

35. Explanation Write a half-page explanation of the ways humans shift carbon to the atmosphere. Be sure to use the terms *atmosphere, lithosphere,* and *biosphere.*

36. Apply the BIG QUESTION Suppose that you are a wildlife biologist. You have discovered many species of fish dying in a lake next to a large golf course. You have also observed that the lake looks greener than lakes farther away from the golf course. You suspect eutrophication. What are three questions you would ask the golf course manager as you try to find the cause of the problem?

Ecological Footprints

Read the information below. Copy the table into your notebook, and record your calculations. Then, answer the questions that follow.

In the United States, many homeowners aim for a green, weed-free lawn surrounding their house. As a result, there are about 60 million lawns in the nation. That adds up to about 20 million acres of lawn grass in the United States!

Fertilizer application	Number of lawns	Pounds of nitrogen
Your 1/3-acre lawn	1	15
The lawns of your classmates		
All the lawns in your town		
All the lawns in your state		
All the lawns in the United States	60,000,000	

1. Given what you have learned about nitrogen fixation, where do you think the nitrogen for large quantities of fertilizer comes from?

2. Calculate the number of lawns for your classmates, town, and state, and enter your results in the second column of the table. (*Hint:* For your town and state, assume that each household in your state has a lawn and that each household has three people.)

3. Using the completed row of the table as a model, calculate the total amount of nitrogen applied to lawns by each group in the table. Enter your results in the third column.

4. According to your calculations, how many pounds of nitrogen are used on lawns in the United States? What effects might the addition of this many pounds of fixed nitrogen have on the environment?

5. What two recommendations would you make to a homeowner who was concerned about her lawn fertilizer adding nitrogen to the environment?