Matter Cycles Through Ecosystems

Earth is an open system in terms of energy, as it gains energy from the sun. In contrast, Earth is a closed system in terms of matter. All of the matter on Earth has more or less been here for billions of years. Matter and energy cannot be created or destroyed, only transformed into other forms.

Predict Matter and energy move through ecosystems between different organisms. Where does this matter come from and how does it travel through an ecosystem or through Earth's spheres?

Energy and Matter in the Earth System

The Earth system includes all of the matter, energy, processes, and cycles within Earth's boundary with space. Energy from the sun drives the cycling of matter in Earth's spheres and in the many ecosystems within those spheres. Producers use only about one percent of the sun's energy that enters Earth's atmosphere.

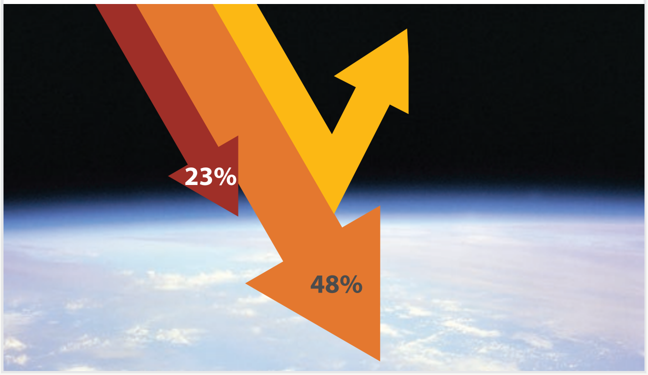
Math Connection

Solar Radiation

When solar radiation enters Earth's atmosphere, about 23 percent is absorbed in the atmosphere and about 48 percent is absorbed at the surface.

Collaborate With a partner discuss these questions: If energy is conserved, what percent of the solar energy should be reflected back into space? How do you think Earth's ecosystems would be different if more or less solar radiation was reflected by the atmosphere?

FIGURE 2: Earth's atmosphere absorbs and reflects energy.



Like energy, matter in the Earth system cycles within and among Earths' spheres: the atmosphere, geosphere, hydrosphere, and biosphere. A relatively small amount of matter is lost into space from the very top of the atmosphere, but scientists generally think of the Earth system as closed in terms of matter.

Matter also changes form as it cycles through the Earth system, but like energy, it cannot be destroyed. For example, organisms metabolize food using chemical reactions. These reactions break bonds and form new chemical bonds among the same atoms to make new substances. The organism can use these new substances for growth and cell processes. Some matter is excreted as waste, which is recycled in the environment. The total amount of matter in the system remains unchanged.

FIGURE 3: The Earth system is closed.

Using food webs and pyramid models, you can see matter cycles through different trophic levels in an ecosystem. As one organism consumes another, that matter is transferred into higher trophic levels. When organisms die, their matter is cycled back through lower trophic levels. In this way, no new matter is created, but matter continually moves through and between ecosystems, as illustrated in Figure 3.

The Water Cycle

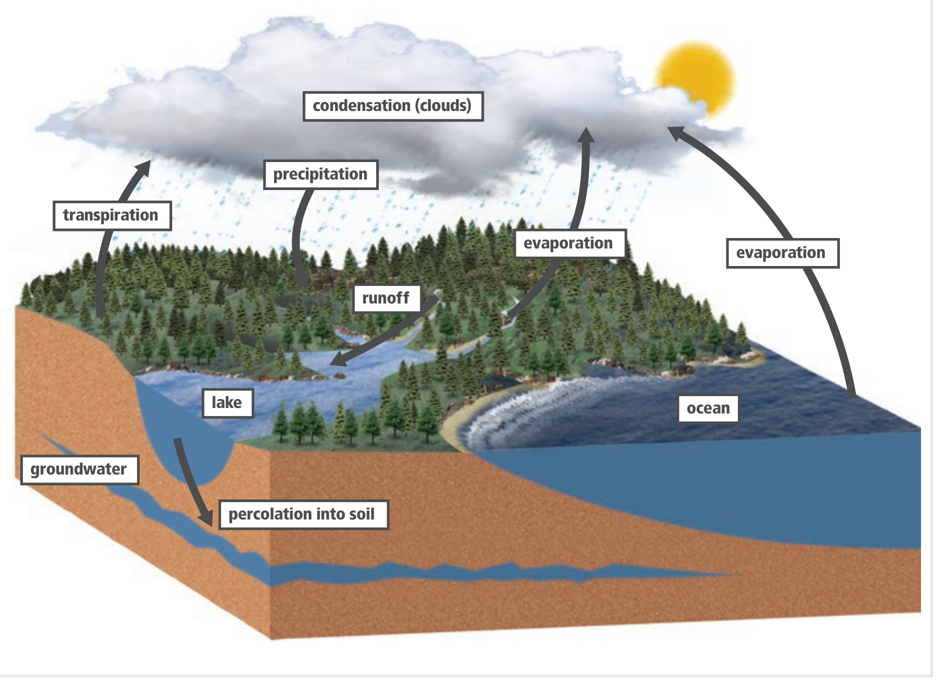
Scientists model specific chemical cycles in order to better understand the cycling of matter in the Earth system. The hydrologic cycle, also known as the water cycle, is the circular pathway of water on Earth from the atmosphere, to the surface, below ground, and back into the atmosphere.

As shown in Figure 4, within the hydrologic cycle, water moves by different processes between reservoirs, such as oceans or lakes. Reservoirs are any location where cycling matter is stored. Water molecules might be stored in a reservoir for a long period of time, such as in a glacier, or for shorter periods of time, such as in a cloud. Evaporation and precipitation are examples of processes that move water between reservoirs.

Analyze If the total amount of water on Earth does not change, why are there concerns about global shortages of fresh water?

FIGURE 4: The hydrologic cycle transfers water molecules between reservoirs.

Explore Online



In the hydrologic cycle, heat from the sun causes water to evaporate from reservoirs such as the ocean and to evaporate from plant leaves through transpiration. As water rises into the atmosphere it cools and condenses into clouds. Water then falls back to Earth in the form of precipitation, such as rain, snow, or hail. Precipitation seeps in the ground or flows into streams or rivers. Water ends up in a reservoir where it is stored until the process starts again.

Explain Choose two reservoirs in the diagram and, for each location, explain how water cycles through the system.

Biogeochemical Cycles

Many elements are essential for the functioning and growth of organisms. These elements include oxygen, hydrogen, carbon, nitrogen, and phosphorus. Just like water, these elements cycle through the Earth system, ecosystems, and organisms.

A biogeochemical cycle is the movement of a particular chemical through the biotic and abiotic components of an ecosystem. The sun and heat from within Earth provide energy that drives these cycles. Like the hydrologic cycle, the matter in biogeochemical cycles flows between reservoirs where it is stored for a period of time. In contrast to the water cycle, bonds are broken, and atoms are rearranged into new molecules in biogeochemical cycles. The main biogeochemical cycles are the oxygen cycle, the carbon cycle, the nitrogen cycle, and the phosphorus cycle.

Explore Online

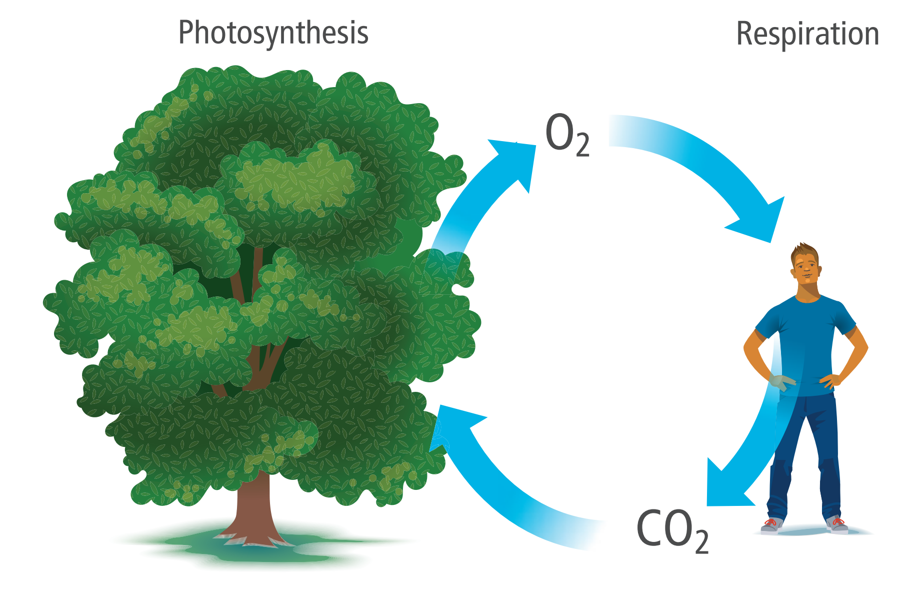
Hands-On Activity

Winter Water Chemistry Model summer and winter lake conditions to determine how surface ice affects the water chemistry of a lake.

The Oxygen Cycle

Oxygen (O_2) is released into the atmosphere as a product of photosynthesis. The atmosphere serves as a reservoir for oxygen until it is taken in by an organism for use in cellular respiration. Humans, and other organisms, also take in oxygen as part of respiration, or breathing.

FIGURE 5: The oxygen cycle is driven by photosynthesis and cellular respiration.



Collaborate With a partner, discuss how a drought caused by a decrease in precipitation might affect the oxygen cycle. Use evidence from previous lessons to support your answer.

Some of the oxygen is incorporated into compounds that remain in the organism. Thus the organism becomes a reservoir for the oxygen. Carbon dioxide (CO_2) is released back into the atmosphere as a byproduct of cellular respiration. Carbon dioxide is then taken up by plants and used for photosynthesis, and oxygen is released back into the atmosphere. Each cycle on Earth interacts with other cycles. For example, the water cycle interacts with the oxygen cycle, because water is necessary for photosynthesis.

Gather Evidence In the Biosphere 2 project, oxygen concentration decreased over time and carbon dioxide reached dangerous levels. Describe a possible solution to this problem, and explain how it relates to processes in the oxygen cycle.

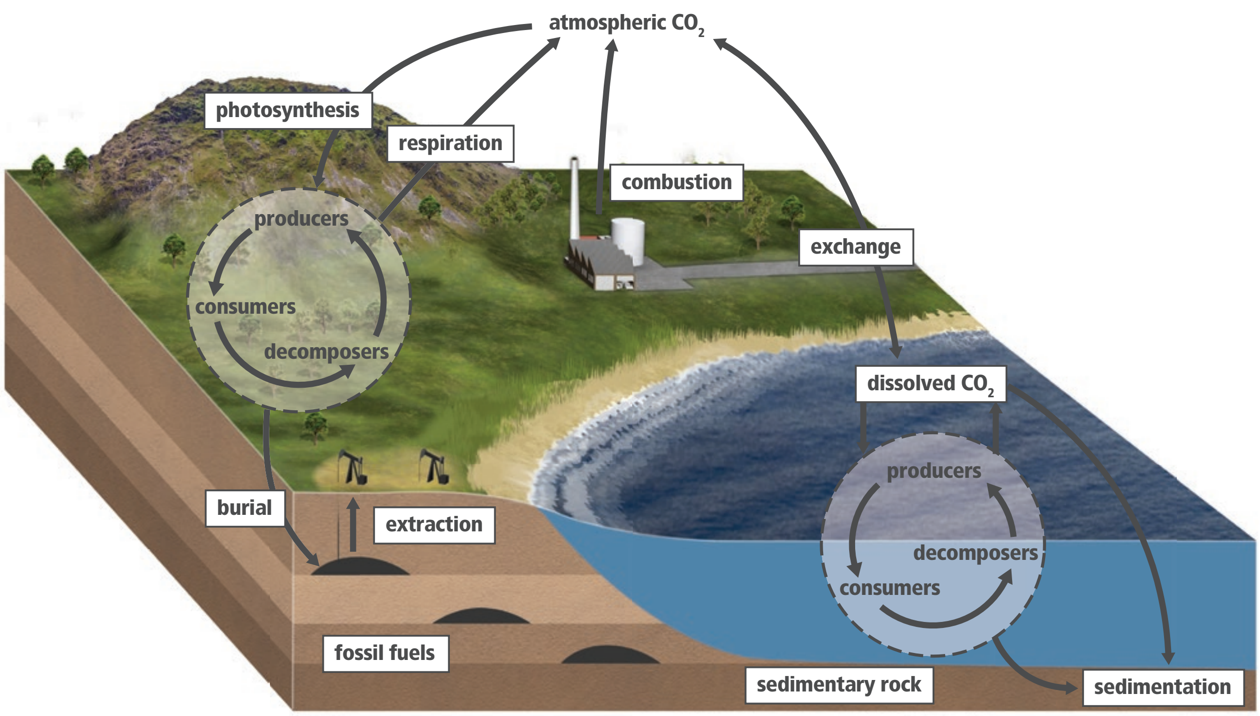
The Carbon Cycle

Gather Evidence Without humans, could carbon in these reservoirs be accessed?

Carbon is present in most chemical compounds that make up living things. Carbon is also stored in abiotic components of the Earth system. For example, CO_2 in the atmosphere, fossil fuels such as oil and coal, dead matter in the soil, and chemical compounds in rocks are carbon reservoirs.

FIGURE 6: Processes such as photosynthesis and combustion drive the cycling of carbon.

Explore Online



Producers remove CO_2 from the atmosphere through photosynthesis. Photosynthetic organisms incorporate the carbon into carbohydrates to store in their tissues. When consumers eat producers, they obtain the carbon, storing some of it in their tissues and releasing some back into the atmosphere through cellular respiration. When the consumers die, decomposers break down the organic matter and release carbon back into the atmosphere through cellular respiration. Carbon is also released into the soil.

Some of the carbon in the organic matter may become fossilized. Under certain conditions, the burial process stores that carbon in Earth's crust where, over millions of years, it becomes fossil fuel. Since the 1800s, humans have extracted this carbon and combusted it, releasing large amounts of carbon back into the atmosphere.

Carbon dioxide diffuses into the ocean from the atmosphere. Oceans are carbon sinks that absorb and hold large amounts of carbon. Carbon enters the aquatic biotic cycle when algae and phytoplankton convert it during photosynthesis. Some dissolved CO_2 is used in the processes of sedimentation and burial to form different types of sedimentary rock. These processes are very slow, taking millions of years, but they form extremely large carbon reservoirs.

Explore Online

Hands-On Activity

Lungs of the Planet
Why are rain forests called the "Lungs of the Planet"? Investigate with Dr. Mike and Dr. Oberbauer to determine if this claim is valid by measuring rates of photosynthesis of rain forest plant life.

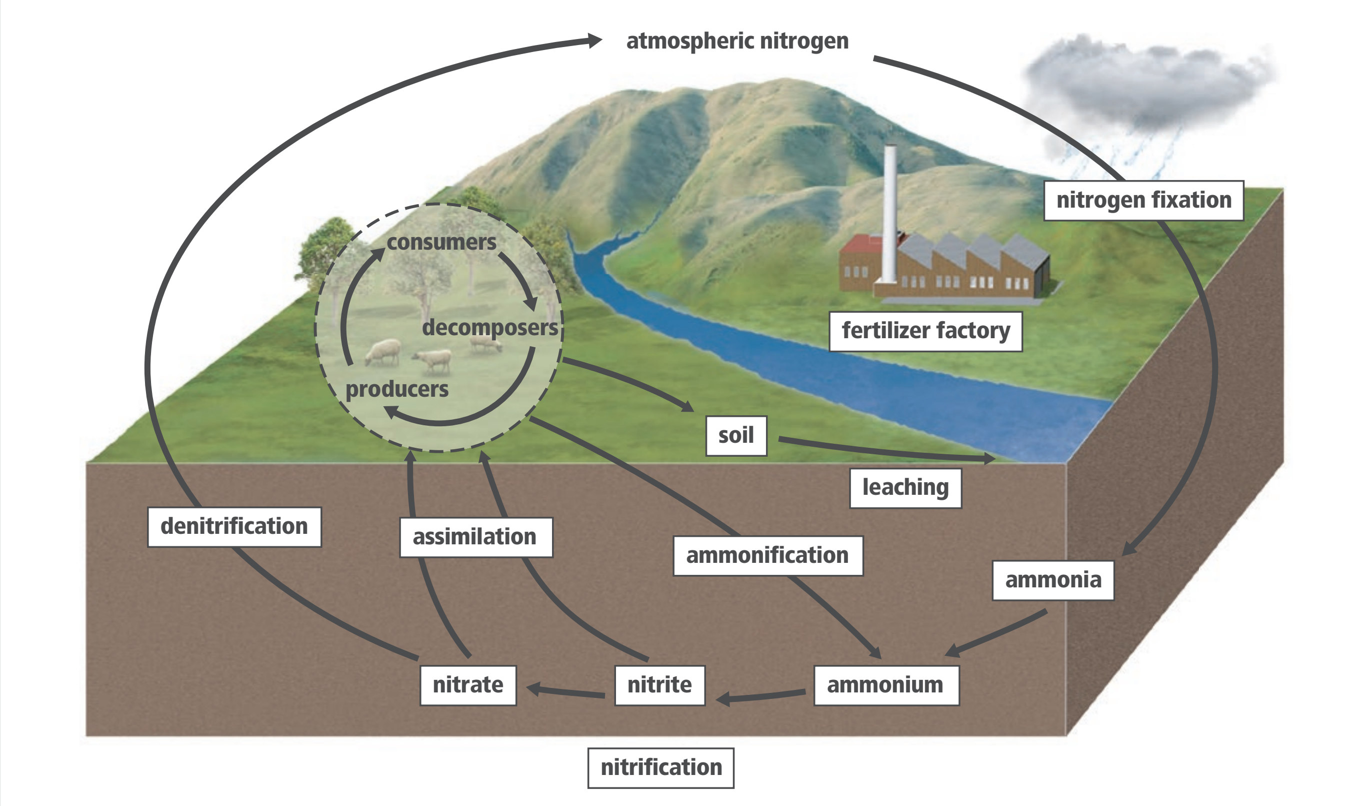
Model Make a model illustrating the roles of photosynthesis and cellular respiration in the cycling of carbon among Earth's spheres. Be sure to include the inputs and outputs for both processes in your model.

The Nitrogen Cycle

About 78% of Earth's atmosphere is composed of nitrogen gas (N_2). However, most organisms are not able to use nitrogen in this form to build organic molecules. The nitrogen must be fixed, or incorporated into other molecules that organisms can use. Bacteria, which are involved in many steps of the nitrogen cycle, fix nitrogen into ammonia, nitrite, nitrate, and other chemicals that organisms can use. As shown in Figure 7, much of the nitrogen cycle takes place below ground.

FIGURE 7: The nitrogen cycle is made up of many processes that move nitrogen from the atmosphere to the biosphere and back again.

Explore Online



Certain types of bacteria convert gaseous nitrogen into ammonia (NH_3) through a process called nitrogen fixation. Some of these bacteria are aerobic, which means they use oxygen. Other bacteria are anaerobic, which means they do not use oxygen. In aquatic ecosystems, this task is performed by a few types of cyanobacteria. Some nitrogen-fixing bacteria on land live in small outgrowths, called nodules, on the roots of plants such as beans and peas. Other nitrogen-fixing bacteria live freely in the soil. The ammonia released by these bacteria is transformed into ammonium (NH_4^+) by the addition of hydrogen ions found in acidic soil. Some ammonium is taken up by plants, but most is used by nitrifying bacteria as an energy source. These bacteria change ammonium into nitrate (NO_3^-) through a process called nitrification.

Nitrates released by soil bacteria are taken up by plants through assimilation, which converts them into organic compounds such as amino acids and proteins. Nitrogen continues along the cycle as animals eat plant or animal matter. When decomposers break down animal excretions or dead animal and plant matter, nitrogen is returned to the soil as ammonium, in a process called ammonification. Denitrifying bacteria use nitrate as an oxygen source, releasing nitrogen gas back into the atmosphere as a waste product via denitrification.

Scale, Proportion, and Quantity

Bacteria are microscopic organisms, but they are essential to life on Earth. Using evidence from the nitrogen cycle, explain how the microscopic fixation of nitrogen can have such a large impact on life.

Explore Online

Hands-On Lab

Nitrogen Fixation Investigate the role of nitrogen-fixing bacteria by observing prepared slides of legume root nodules.

Nitrogen fixation can occur through biological processes carried out by special types of bacteria, but it can also occur through industrial processes such as the production of fertilizer. Some nitrogen also enters the soil as a result of atmospheric fixation by lightning. Energy from lightning breaks apart nitrogen molecules in the atmosphere. Nitrogen recombines with oxygen in the air, forming nitrogen monoxide. The combination of nitrogen monoxide with rainwater forms nitrates, which are absorbed by the soil. Nitrates in the soil may be moved by water, eventually settling at the bottom of lakes, swamps, and oceans in a process called leaching.

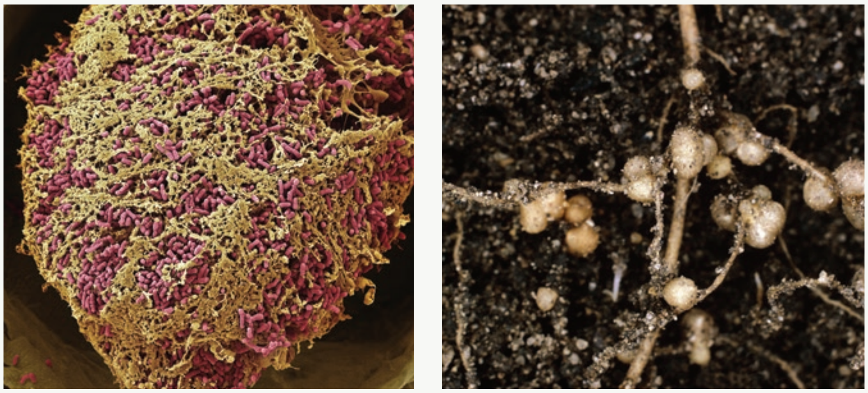
Analyze Organisms in a fish tank can become unhealthy if too much ammonium from their waste builds up in the water. Explain why it is beneficial to add bacteria and plants to a fish tank. Use evidence from the nitrogen cycle model to support your claim.

Energy and Matter

Rhizobia Bacteria

Gather Evidence Legumes are often planted and harvested as crops. When this happens, the plants are not left to decompose into the soil. How does removing the legumes from the ecosystem affect the nitrogen cycle?

FIGURE 8: Nitrogen-fixing bacteria live in a pea plant nodule.



a Rhizobia bacteria (colored SEM)

b Pea plant nodules

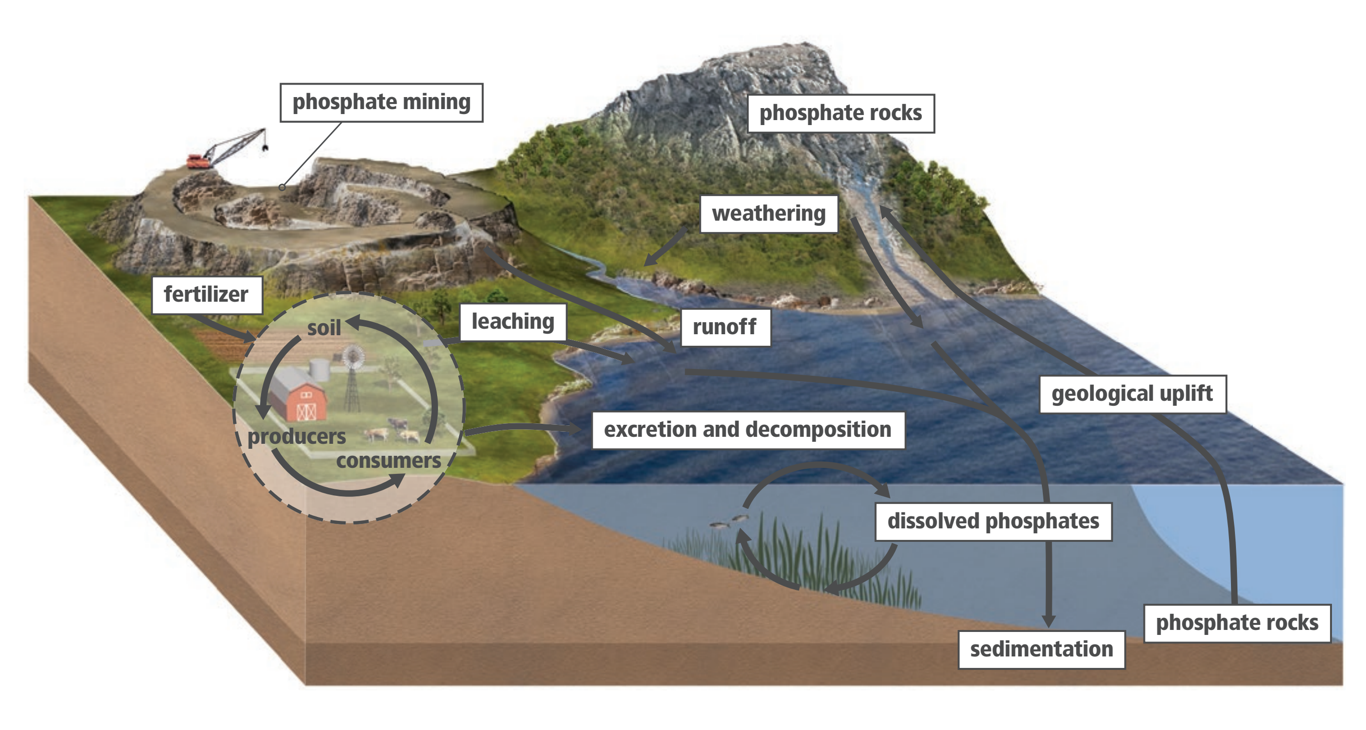
Nitrogen-fixing bacteria live symbiotically, or in close relationship, with certain types of plants, particularly those in the legume family. Rhizobia bacteria live in the nodules on the roots of legumes, as shown in Figure 8. The plant provides essential nutrients to the bacteria and, in return, the bacteria fix nitrogen into ammonia, which the plant absorbs. Most of the ammonia made by the bacteria is kept by the plant and very little is released into the soil until the plant dies. Then, decomposers convert the ammonia molecules into other nitrogen compounds and release some of that nitrogen back into the atmosphere as nitrogen gas.

The Phosphorus Cycle

Phosphorus is an important element for living things. It is a component of phosphate groups in ATP, DNA, and phospholipids in cell membranes. Phosphorus occurs in the form of phosphate salts found in ocean sediments and rocks. Geologic processes expose these rocks, and water and wind break them down, making them available to plants and animals.

FIGURE 9: The phosphorus cycle interacts with the rock cycle through processes such as geologic uplift and weathering.

Explore Online



Analyze Which of Earth's spheres is not part of the phosphorus cycle?

As shown in Figure 9, weathering of phosphate rocks by rain releases phosphate compounds in soil and water. On land, plants can take up phosphate compounds from the soil and consumers gain phosphorus by eating the producers. Decomposers then return phosphorus to the soil and water when they break down the organic matter and wastes of the producers and consumers.

Water can transport phosphorus to aquatic ecosystems through runoff and leaching. Phosphorus compounds dissolve into phosphates where they can be taken up by algae and then consumed by other aquatic organisms. Some dissolved phosphates settle at the bottom of oceans in a process called sedimentation, becoming phosphate rocks over millions of years.

Certain geologic processes expose the phosphate rocks at the bottom of the ocean to the atmosphere. The rocks then undergo weathering, releasing phosphate compounds back into the ecosystem, and continuing the phosphorus cycle. Humans also introduce phosphates into the ecosystem by mining them to make fertilizers and cleaners. Excess phosphates from human activities can enter aquatic ecosystems through runoff and leaching. Very little phosphate is naturally available in most bodies of water and any increases can lead to significant changes in the ecosystem.

Collaborate Discuss this question with a partner: When the water at Biosphere 2 became polluted with too many nutrients, researchers treated the water by running it over mats of algae. Why did they do this, and how does this action relate to the nitrogen and phosphorus cycles?

Explain How do the hydrologic cycle and the different biogeochemical cycles relate to one another? How can a change in one cycle affect all of the other cycles?