INVESTIGATION **2.A**

Target Skills

Analyzing data to determine water use by different sectors of society

Presenting the results of this analysis to fellow students

Stating conclusions based on this analysis

Societal Uses of Water

Issue

About 97.5 percent of the water that is consumed in Alberta comes from surface water, such as the water in lakes and rivers. The rest of the water that is consumed comes from ground water, which collects when rain or melted snow filters down through the ground and accumulates underground in large gaps in the rocks.

Gathering Data and Information

1. In a group, choose one of the categories of water use in Alberta that is shown in the pie graphs. Answer the following questions:
   - How much water (in L) is used for this purpose?
   - What are some ways (if any) to reduce the use of water for this purpose?
   - Is water quality affected? If so, what can be done to restore water quality?
   - What are the benefits of using water for this purpose?

Organizing Findings

2. As a group, make a brief presentation of your findings to the rest of the class.

Opinions and Recommendations

1. Which use of water in Alberta do you think should be decreased? Justify your response.

2. What are some possible ways to decrease water use in the category you chose in question 1?

3. Do you think water use is a basic human right that people should not have to pay for? Or do you think people should pay *more* for water than they do, in order to encourage water conservation?

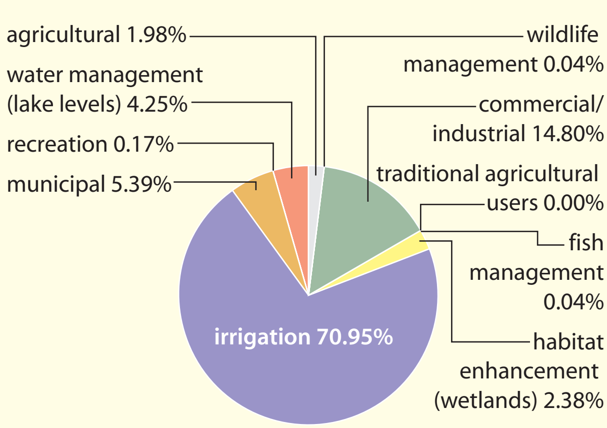
4. One solution to meeting the demand for irrigation in drier regions of Alberta is to use pipelines to divert water from other parts of the province. Evaluate the arguments for and against doing this:

Benefits:	Costs:
• The diversion would allow for the growth of economically important crops.	• The removal of large amounts of water from a particular source (bulk water removal) would be permanent.
• The diversion would allow for the growth of important food crops.	• Ecosystems that depend on the source of the diverted water could be negatively affected.
• Rural communities could use the diverted water in their homes and town buildings.	• Diversion could introduce species, such as parasites, from the water source into ecosystems in the other region.

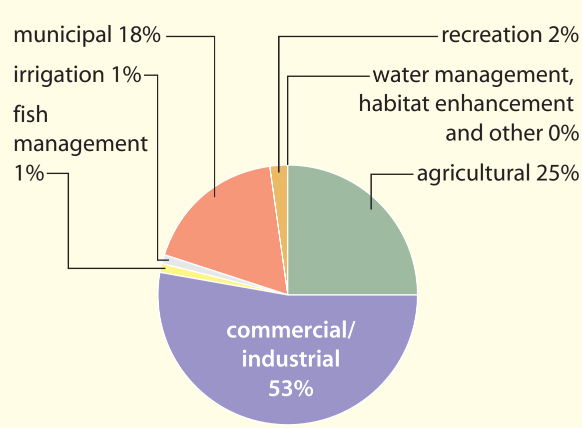
a) With your classmates, discuss whether the risks of diversion outweigh its benefits.

b) What questions would you pursue to evaluate, more thoroughly, the risks and benefits of a diversion strategy for a specific rural area?

Alberta's surface-water consumption uses



Alberta's ground-water consumption uses



SECTION 2.2

Biogeochemical Cycles

Section Outcomes

In this section, you will
- **summarize** the biogeochemical cycling of carbon, oxygen, nitrogen, sulfur, and phosphorus
- **relate** biogeochemical cycles to the reuse of all matter in the biosphere
- **design** an experiment to compare the production of carbon dioxide in plants and animals
- **measure** and **record** properties and chemical composition of water samples
- **identify** human activities that can affect cycles of matter
- **predict** the effect of human activities on various biogeochemical cycles

Key Terms

rapid cycling (of nutrients)
slow cycling (of nutrients)
acid deposition
nitrogen fixation
ammonification
denitrification
algal bloom

Figure 2.8 The pea plant on the right has been well watered and has received ample sunlight. Why does it look so unhealthy compared to the plant on the left?

Because autotrophs produce their own food, it might seem reasonable to think that they could live independently of heterotrophs. How are primary producers, such as plants, connected to heterotrophic organisms? Plants, like all organisms, require matter to build cell structures and provide energy. In order to survive and grow, organisms must obtain nutrients that serve as sources of energy or chemical building blocks, or both. For example, the pea plants in Figure 2.8 can only survive if they have access to nutrients, such as compounds that contain sulfur, nitrogen, and phosphorus. These compounds must be in forms that the pea plants can use. Heterotrophs convert many nutrients into forms that plants can access and use. Fertilizers provide another source of accessible plant nutrients (see Figure 2.9).

The recycling of matter through the biotic and abiotic parts of ecosystems allows all organisms, including plants, to obtain essential nutrients.

At each step in a biogeochemical cycle, substances are temporarily stored in nutrient reservoirs, such as organisms, soil, air, and water. All biogeochemical cycles involve some substances that are being stored in these reservoirs for various amounts of time and some substances that are moving through the environment, from reservoir to reservoir. Substances can cycle between nutrient reservoirs relatively quickly. When this happens, they are said to be part of the **rapid cycling** of nutrients. For example, carbon moves from producer to consumer to decomposer, and back to the atmosphere through rapid cycling.

Figure 2.9 Fertilizers contain essential nutrients required by plants.

Substances also accumulate and are stored for long periods of time in nutrient reservoirs. Fossil fuel deposits, such as coal and oil, are carbon reservoirs formed over millions of years as organic matter built up without fully decomposing. Deep underground, the organic matter was subjected to intense pressure. When substances accumulate and are unavailable to organisms they are said to be part of the **slow cycling** of nutrients. It can take millions of years for these substances to again become available as nutrients for living organisms. Figure 2.10 illustrates the connections between the rapid cycling of substances (on the left) and the slow cycling of substances (on the right).

Some elements, such as oxygen (O), carbon (C), nitrogen (N), and sulfur (S), form compounds that easily travel in both water and air. As a result, these elements can literally travel around the world. Other elements, such as iron (Fe) and phosphorus (P) are found in soil and water, but generally do not enter the atmosphere.

> **Q6** What is a nutrient reservoir?
>
> **Q7** Explain the connections between the slow cycling and rapid cycling of nutrients.

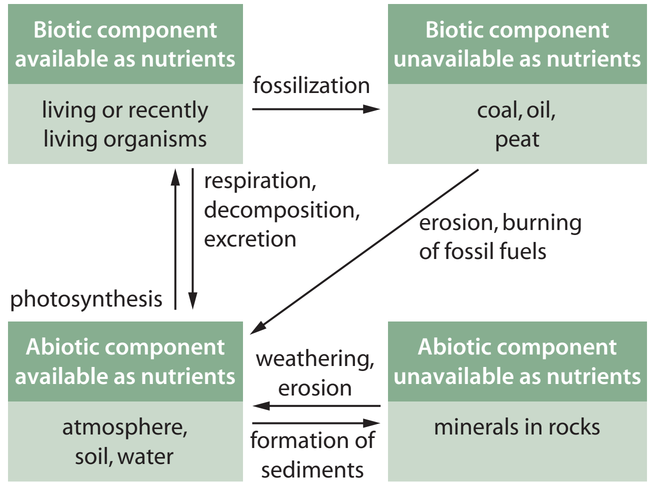
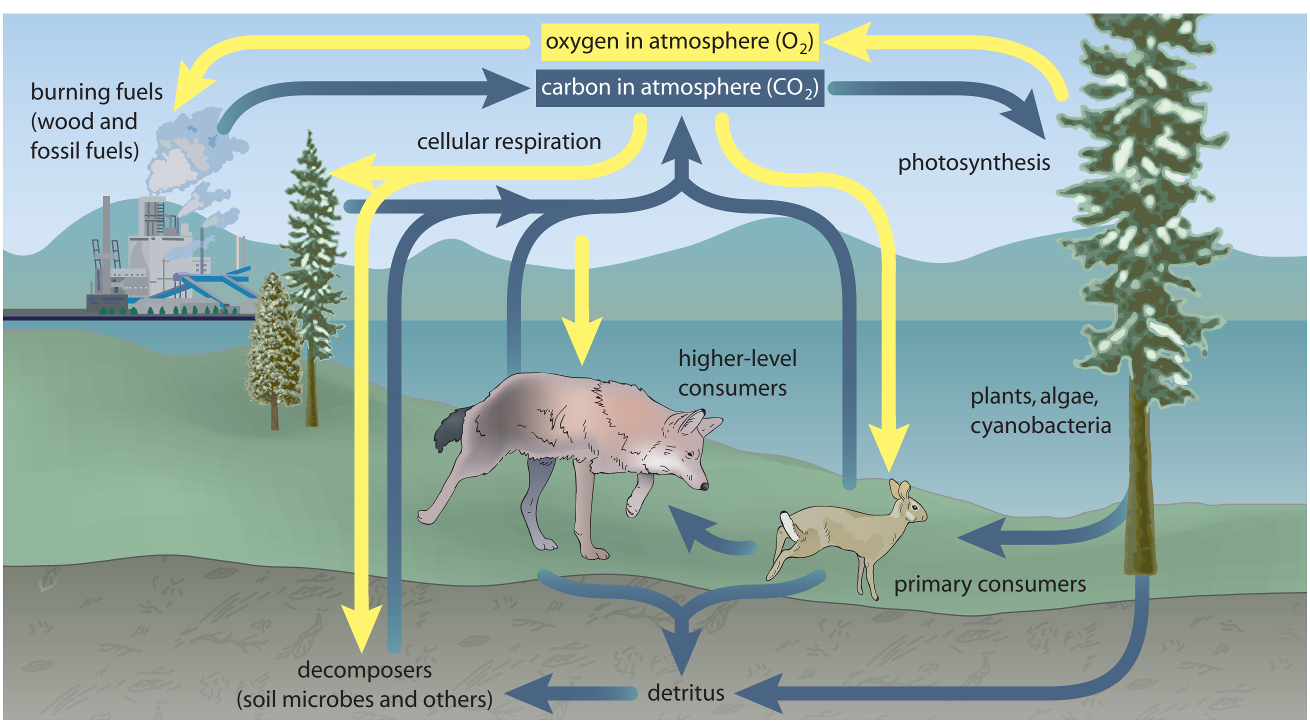


Figure 2.10 The four nutrient reservoirs are categorized with respect to whether they involve biotic or abiotic components of the ecosystem and whether the nutrients they contain are directly available to living things.

The Carbon and Oxygen Cycles

Plants consume billions of tonnes of carbon in the form of carbon dioxide (CO_2) each year—much more carbon than animals and plants release from cellular respiration. As Figure 2.11 shows, much of the carbon that is released back into the atmosphere as carbon dioxide comes from forest fires and the breakdown of organic matter, such as plant materials, by decomposers.

Figure 2.11 The carbon and oxygen cycles. How are these cycles interconnected?



Biology File

Web Link

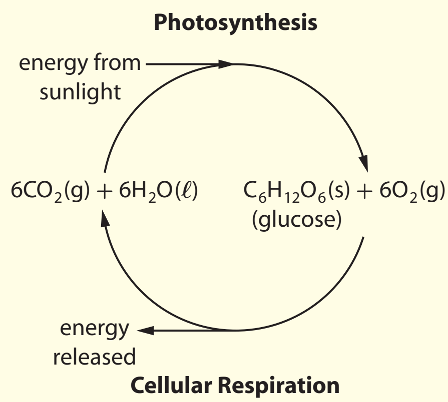
How much carbon dioxide do you and your family generate in your daily activities? Compare the results of at least two online carbon dioxide calculators.

www.albertabiology.ca

WWW

Thus, plants, animals, and decomposers play an important role in the rapid cycling of carbon.

Plants, animals, and decomposers also play an important role in the rapid cycling of oxygen. As the following diagram shows, photosynthesis produces oxygen gas (O_2), which is needed for cellular respiration.



Although the processes are very different, the overall equations for photosynthesis and cellular respiration are complementary. As well, both photosynthesis and cellular respiration contribute to the rapid cycling of carbon and oxygen.

Explore the connection between photosynthesis and respiration in the investigation that follows.

> **Q 8** How are (a) plants and (b) animals involved in the rapid cycling of carbon?

The Slow Cycling of Carbon

As you have learned, living organisms play an important role in the rapid cycling of carbon. Living organisms also play an important role in the slow cycling of carbon. Photosynthetic organisms remove carbon dioxide from the atmosphere and incorporate carbon into organic matter. The trees in forests act as carbon sinks (reservoirs that absorb more carbon than they emit to the environment). The trees store large amounts of carbon, most of which is only released when they die and decompose or are combusted by forest fires. Deforestation accounts for the return of about 2 gigatonnes (Gt) of carbon to the atmosphere per year. In addition, photosynthetic organisms in

INVESTIGATION 2.B

Carbon Dioxide Production in Plants and Animals

Target Skills

Designing an investigation to compare carbon dioxide production by a plant and an animal

Gathering data to measure the rate of carbon dioxide production by a plant

Stating a conclusion based on the analysis of collected and provided data

Plants and animals both use glucose as an energy source and as a source of carbon to build cell structures. Therefore, like animal cells, plant cells carry out cellular respiration. The amount of carbon dioxide that plants produce by cellular respiration is very small, however, compared with the amount of carbon dioxide that plants take in during photosynthesis. In this investigation, you will research and design a procedure to measure the rate of carbon dioxide production by a plant. You will then use the data you collected to compare carbon dioxide production by a plant with carbon dioxide production by an animal (data is provided for the latter).

Question

How does carbon dioxide production compare in plants and animals?

Hypothesis

In your group, generate a hypothesis about the rate of carbon dioxide production in plants compared with that of animals.

Prediction

Make a prediction about the outcome of this investigation.

Safety Precaution

Your teacher will inform you about safety precautions appropriate to your experimental design.

Materials

As per your experimental design.

Experimental Plan

1. Research (using the Internet or library) and design a procedure to measure the rate of carbon dioxide production by a plant. The following questions can help guide your research and design decisions. ICT
   - What is a respirometer and how can you build one?
   - How could you use carbon dioxide sensors (if they are available) and an appropriate interface such as a computer, calculator, or handheld device?
   - How could you use pH?
2. In your experimental design, be sure to consider the following factors:
   - controlled, manipulated, and responding variables
   - materials (for example, germinating seeds could work well; they generate carbon dioxide through cellular respiration but do not yet absorb carbon dioxide through photosynthesis, a factor that will affect your results if you use mature plants.)
   - data collection (for example, what measurements will you take? How often will you take them? How will you record your data?)
   - safety

   Note: The rate of carbon dioxide production in mL/min from respiration is approximately equal to the rate of oxygen consumption in mL/min.
3. Review your procedure with your teacher.

Data and Observations

4. Record your data as per your experimental design. Be sure to note all observations you make.

Analysis

1. **a)** The rate of carbon dioxide production for a Chilean cricket, *Hophlosphyrum griseus*, at 27 °C is, on average, 2.856×10^{-6} mL/min. Calculate the amount of carbon dioxide that an average Chilean cricket would produce in 15 minutes.
   b) Would a larger cricket produce more or less carbon dioxide than the average cricket? Explain your reasoning.
   c) Would an active cricket or a resting cricket respire at a higher rate? Explain your reasoning.
2. **a)** At what rate did the plants in your experiment produce carbon dioxide?
   b) An average Chilean cricket has a mass of 36.2 mg. Calculate and compare the amount of carbon dioxide produced, per gram, for the plants you studied and the crickets.
3. **a)** Which variables did you control?
   b) Discuss how using controlled variables helps you interpret the results of this investigation.

Conclusions

4. Did your results support your hypothesis? Explain.
5. How could you demonstrate that photosynthesis and cellular respiration are complementary processes?
6. Up to a point, cellular reactions increase as temperature increases.
   a) Predict how increasing the temperature in this investigation would affect your results.
   b) Predict how increasing environmental temperatures might affect the rapid cycling of carbon.

Extension

7. Many other factors affect the rate at which plants respire. Choose two of the following factors and hypothesize how a change in each factor may influence the rate of carbon dioxide production:
   - light levels
   - maturation of tissues (i.e., germinating seed versus mature plant)
   - availability of nutrients
   - species of plant

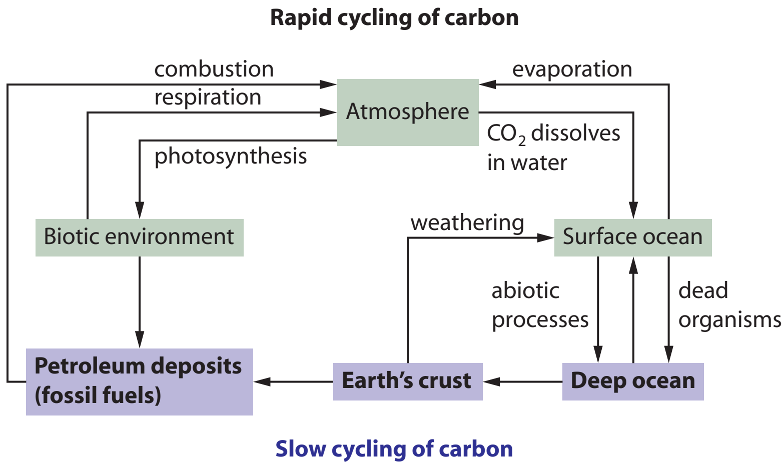


Figure 2.12 The rapid cycling of carbon is shown in green, and the slow cycling of carbon is shown in purple.

the ocean, such as phytoplankton and algae, reproduce rapidly, producing large amounts of biomass and incorporating carbon into their structures. Much of this biomass is consumed by zooplankton, fish, whales, and other heterotrophs. A small percentage of the biomass of autotrophs and heterotrophs drifts to the ocean floor. Over millions of years, organic matter that is not fully broken down by decomposers may become incorporated into rocks or contribute to petroleum (fossil fuel) deposits.

The ocean itself is the largest carbon sink. It contains 38 000 Gt of carbon in the form of dissolved carbon dioxide. Another 11 000 Gt of carbon lies on the ocean floor, trapped in methane hydrates, compounds that are complexes of methane (CH_4) and water. Figure 2.12 summarizes the rapid and slow cycling of carbon in the biosphere.

Natural processes that return carbon to rapid cycling can occur quickly (such as in forest fires) or extremely slowly (such as in weathering). Limestone rock contains carbon. It is formed from calcium carbonate ($CaCO_3$), which comes from the shells of aquatic organisms (Figure 2.13) or may precipitate from dissolved calcium carbonate in water. As limestone weathers over time, small amounts of carbon are released back into the soil, air, and water.

Human activities influence the slow cycling of carbon in a number of ways. In particular, the combustion of petroleum deposits quickly releases carbon back into the atmosphere. Since the industrial revolution (around the late eighteenth and early nineteenth centuries), levels of atmospheric carbon dioxide have increased by about 30 percent.

9 List the major carbon sinks on the Earth.

10 Explain how each of the following human activities can affect carbon cycling:

a) deforestation

b) burning of fossil fuels

c) agriculture

The Sulfur Cycle

All organisms require sulfur because it is an important part of proteins and vitamins. Plants and algae use sulfur in the form of sulfate (SO_4^{2-}), which dissolves readily in water. They incorporate the sulfur into their cells and tissues. When they die, decomposers quickly return much of the sulfur to the soil or atmosphere. The distinctive sulfurous smell, like the smell of rotten eggs, from a muddy pond or wetland is hydrogen sulfide (H_2S). It indicates that decomposers are hard at work. Figure 2.14 shows how sulfur is converted to different forms in the sulfur cycle.

Figure 2.13 Why are seashells a source of slow-cycling carbon?

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FYI

Human activities, such as deforestation and burning fossil fuels, add about 8 billion tonnes of carbon dioxide to the atmosphere each year. Only about 3.2 billion tonnes of this carbon dioxide remains in the atmosphere, however; 4.8 billion tonnes are unaccounted for. The missing carbon dioxide is called the *missing carbon sink*. Some scientists speculate that part of the missing carbon dioxide gets absorbed by the oceans. Other scientists speculate that terrestrial vegetation, somewhere in the northern hemisphere, is absorbing carbon dioxide at a higher rate than previously thought. Many scientists around the world are involved in trying to find the missing carbon sink.

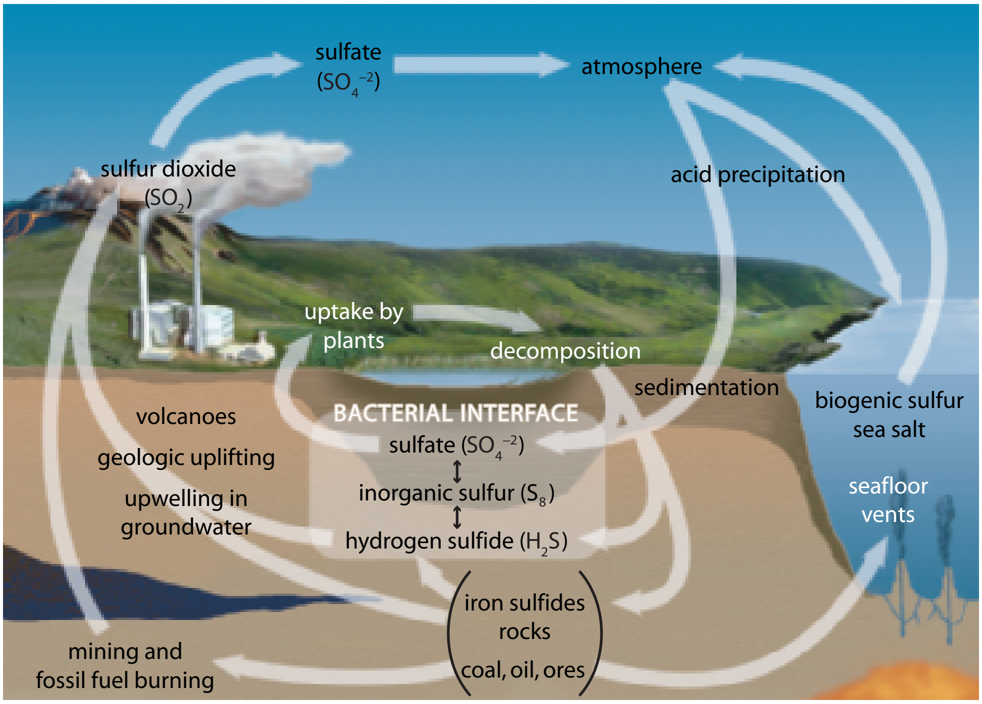

Figure 2.14 Sulfur compounds do not stay in the atmosphere long. When there is rain or snow, sulfur is returned to Earth's surface, where it is eventually used by plants, algae, and bacteria. The decomposition of organic matter, as well as volcanoes and human activities, distributes sulfur into air, soil, and water.

Various bacteria use sulfur-containing compounds in photosynthesis or in types of cellular respiration. In fact, bacteria are an essential part of the sulfur cycle. Different types of bacteria have different roles. Figure 2.15 shows a mini-ecosystem that contains different types of bacteria, each type capable of converting one form of sulfur to another. Sulfate reducers convert sulfate to sulfide, while sulfur oxidizers convert sulfide to elemental sulfur and sulfate. As the diagram below shows, the waste that is generated by one type of bacteria is a required material for a different type of bacteria.

Acid Deposition

Some sulfur is taken out of rapid cycling when bacteria convert the sulfur to forms that are layered down as sediments, eventually becoming part of rocks. Fossil fuel deposits, such as oil, coal, and natural gas, also contain sulfur. Coal that is mined in Alberta is considered to be high grade because it has a lower sulfur content than coal that is mined in other areas of the world. Weathering releases some of the sulfur that is trapped in rocks. Volcanic activity also releases some of the trapped sulfur into the atmosphere as sulfur dioxide (SO_2).

Sulfur dioxide reacts with oxygen and water vapour in the atmosphere to form sulfurous acid (H_2SO_3) and

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Web Link
The Winogradsky column is an artificial ecosystem that represents a natural pond-mud ecosystem. What accounts for the different layers in a Winogradsky column?

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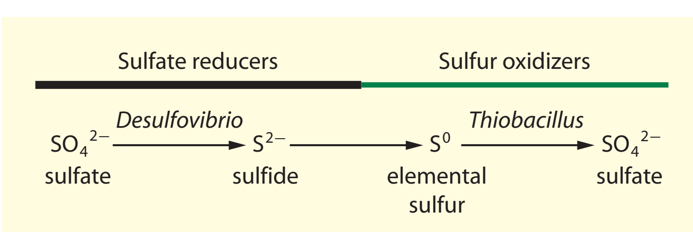


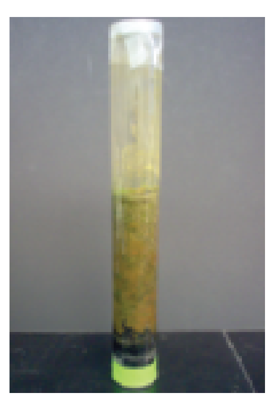


Figure 2.15 This mini-ecosystem, called a Winogradsky column after its inventor, Sergei Winogradsky, contains several types of bacteria. The black layer at the bottom is composed of iron sulfide, a by-product of bacteria using sulfate in their metabolism.

BiologyFile

FYI
In spring, melt water from snow often causes a high concentration of acid to enter a lake, resulting in sudden fish death. Powdered limestone may be added to a lake to counter this "acid shock." The alkaline soils that cover most of Alberta tend to neutralize the effects of acid deposition, as does the limestone in soils in central and southern Alberta.

sulfuric acid (H_2SO_4). These reactions result in **acid deposition** (such as acidified rain, snow, or sleet), which returns sulfur to the oceans and soils. Although acid deposition is a natural part of the sulfur cycle, large amounts of acid deposition can damage plants, acidify lakes, and leach nutrients from the soil.

When people burn fossil fuels such as oil, coal, and natural gas, sulfur (as sulfur dioxide) is released into the atmosphere. The production of sour gas (natural gas that contains hydrogen sulfide), such as that found in the foothills of the Rocky Mountains in Alberta, is another significant source of sulfur emissions. The amount of sulfur that is released to the atmosphere due to human activities is far greater than the amount that is released by natural processes.

Q 11 How can acid deposition affect ecosystems?

Q 12 What is the general role of bacteria in the sulfur cycle?

Explore another connection between the sulfur and carbon cycles in the next Thought Lab.

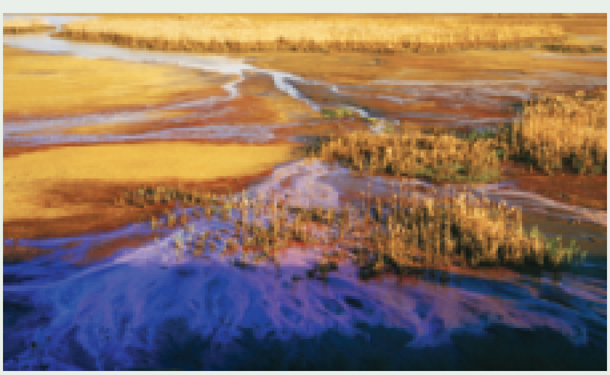
The Nitrogen Cycle

Nitrogen gas ($N_2(g)$) makes up 78.1 percent of Earth's atmosphere by volume. In contrast, oxygen makes up 20.9 percent of Earth's atmosphere, and carbon dioxide and other trace gases make up only one percent. Nitrogen is an essential part of the proteins found in organisms and the genetic material (DNA) found in cells. Most organisms, however, cannot use atmospheric nitrogen. Some bacteria can convert nitrogen gas into ammonium (NH_4^+) in a process called **nitrogen fixation** (Figure 2.16). The lumpy nodules on the roots of legume plants, such as clover, contain nitrogen-fixing bacteria that live in a mutually beneficial relationship with the plants (Figure 2.17). These bacteria fix (convert) nitrogen into ammonium, which is shared with the plants. The plants provide the bacteria with sugars produced in photosynthesis.

Thought Lab 2.2 Carbon, Sulfur, and Iron

Target Skills

Explaining how coal mining can damage the environment and disrupt biogeochemical cycles



Coal mining exposes otherwise buried deposits of sulfur compounds. Pyrite (iron sulfide, FeS) is known as "fool's gold" because of its shiny, golden appearance. Pyrite slowly breaks down once it is exposed to oxygen, converting the sulfide to sulfuric acid. This process is accelerated when *Thiobacillus* bacteria use the pyrite for energy.

Analysis

1. Abandoned coal mines are sometimes surrounded by areas in which all the trees and other plants have died. Hypothesize as to what might have caused this situation.
2. a) Much of Alberta's coal is now mined in large pit mines that have significant impact on the surrounding environment. What problems do you think these mines create?
   b) In what ways do you think your views about controlling these mines would be different, depending on whether you live nearby one of these mines?
3. Explain how mining might affect:
   a) the sulfur cycle
   b) the carbon cycle
4. Iron cycles between two ionic forms, Fe^{2+} and Fe^{3+}. In the presence of oxygen or by the action of bacteria, Fe^{2+} is changed to Fe^{3+}. Soils, sediments, and water contain both forms of iron, and organisms contain Fe^{3+} compounds. Pyrite contains Fe^{2+}. How might coal mining affect the iron cycle?

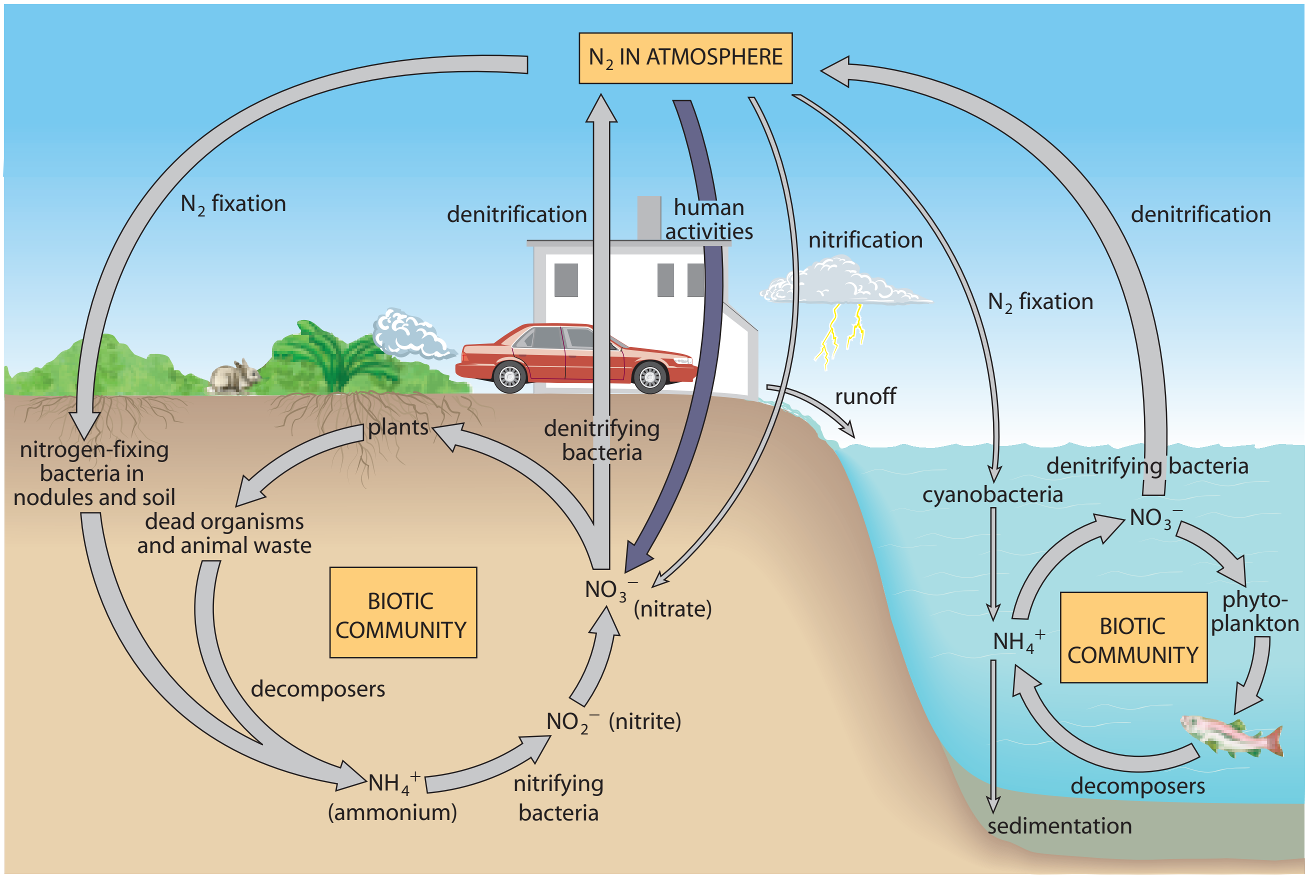


Figure 2.16 Bacterial communities in the soil and ocean play an important role in the nitrogen cycle. As well, lightning can convert atmospheric molecular nitrogen (N_2) to nitrate, a form of nitrogen that plants can use.

Ammonium is also produced when decomposers break down organic matter in a process is called **ammonification**. Some types of soil bacteria convert the ammonium into nitrite (NO_2^-) and then into nitrate (NO_3^-). Plants can use the nitrate as a nitrogen source.

Denitrifying bacteria complete the cycle by converting nitrite or nitrate back into nitrogen gas. As Figure 2.16 shows, this process, called **denitrification**, occurs in environments where there is very little oxygen.

The nutrient-deficient plant shown in Figure 2.8 on page 42 would have been healthier if it had been fertilized or grown with nitrogen-fixing bacteria. A common farming method is to grow legumes (such as alfalfa and clover) one growing season and crops (such as corn) the following season. This method, called crop rotation, helps to maintain a high nitrogen content in the soil.

Q 13 What are two sources of fixed nitrogen that plants can use?

Q 14 Draw a flow chart or diagram to illustrate the conversion of atmospheric nitrogen to nitrate, nitrite, and ammonium.

The Phosphorus Cycle

Phosphorus is an essential nutrient, but it is often available in only limited quantities in the environment. Phosphorus is concentrated in living organisms, however. Phosphorus is a part of cellular DNA and ATP (the energy carrier essential to all cells) and is a major component of bones and teeth.

Unlike carbon, nitrogen, and sulfur, phosphorus does not cycle through the atmosphere. Phosphorus is found in soil and water, and weathering gradually releases the phosphorus trapped in rocks. (See Figure 2.18 on the next page.)

Magnification: 88 ×

Figure 2.17 Nitrogen-fixing bacteria live in the round nodules on the roots of legume plants such as this one.

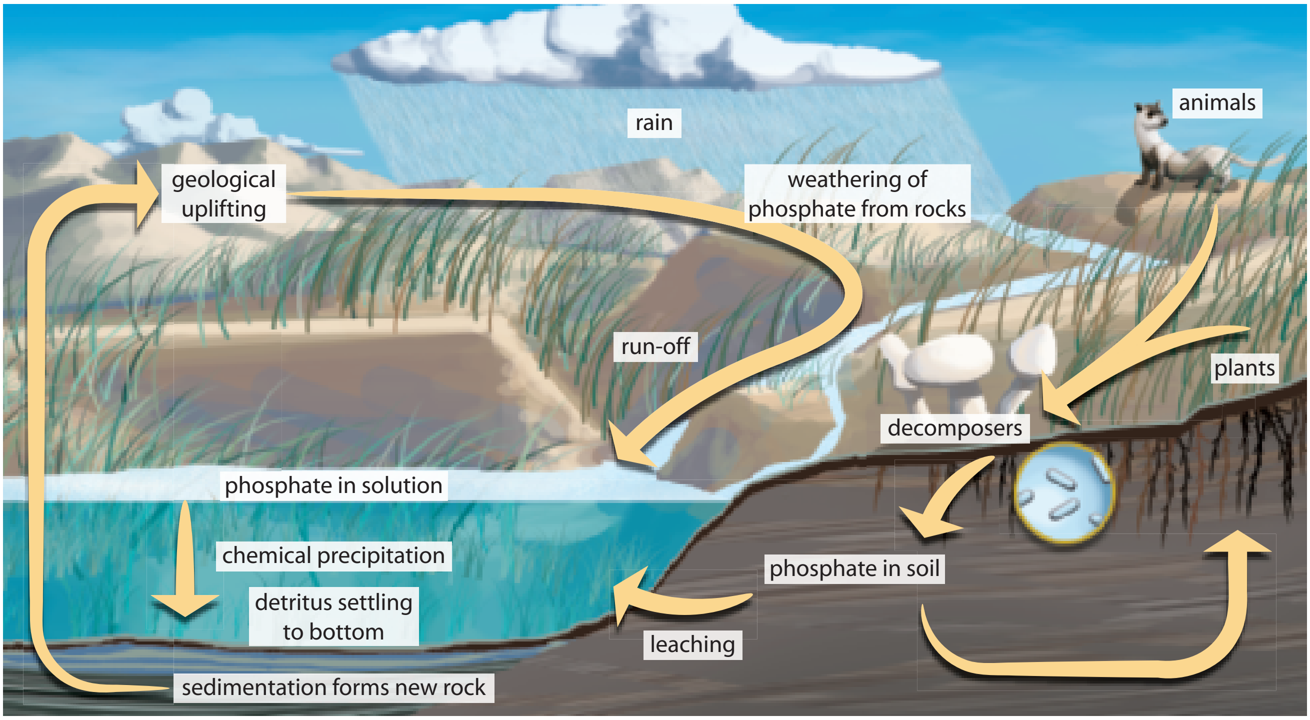


Figure 2.18 The phosphorus cycle

Animals obtain phosphorus by consuming foods such as milk, grain, and meat. Producers, such as plants and algae, can only use phosphorus if it is in the form of phosphate (PO_4^{3-}), which dissolves in water. The scarcity of phosphorus keeps the growth of producers in balance, but it can also limit the growth of crops. How might increased availability of phosphorus affect an aquatic ecosystem?

The growth of algae in aquatic ecosystems is limited by the amount of available nutrients. The overgrowth of algae, called an **algal bloom**, produces large amounts of organic matter. As decomposers break down the organic matter, they use up the oxygen in the water, resulting in the death of fish and other aquatic life.

In the 1970s, scientists debated whether algal blooms were caused by excess nitrogen or phosphorus. Figure 2.19 shows an experimental lake in Ontario, which was divided by a plastic barrier. Researchers added nitrogen to one side of the lake and nitrogen and phosphorus to the other side.

As a result of the research at the Experimental Lakes Area, Canadian scientists were able to convince the federal government to ban the use of phosphates in soaps and laundry detergents.

15. Why do organisms need phosphorus?
16. How is phosphorus transported through the biosphere?
17. What are the effects of increased amounts of phosphorus on aquatic environments?

Figure 2.19 Experimental Lake 226, near Kenora, Ontario, in 1973. One side of the lake is bright green due to an algal bloom due to excess phosphorus.

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FYI

The build-up of excess nutrients in aquatic systems is called eutrophication. If eutrophication occurs in an ecosystem, algal overgrowth can block sunlight so that plants below the surface can no longer photosynthesize. When these plants die, the decomposer population grows quickly, depleting oxygen levels in the water so organisms requiring oxygen can no longer survive.

INVESTIGATION 2.C

What's in the Water?

Target Skills

Measuring and **recording** data on pH and water quality parameters in local water samples

Comparing data from different sources to determine the impact of human activities on water quality

Stating a conclusion

Both human activities and natural processes affect water quality. Scientists monitor water quality by testing for chemical and biological contaminants and for pH (a measure of acidity or alkalinity).

Question

How do human activities affect local water quality?

Hypothesis

With your lab partner, write a hypothesis about water quality in two similar but contrasting areas, such as:

- upstream of a city vs. downstream of the city
- upstream of an animal farm vs. downstream of the animal farm
- run-off from a freshly watered plant vs. run-off from a freshly watered and fertilized plant

Prediction

Based on your hypothesis, predict how water samples from the two areas will differ with respect to pH and concentrations of sulfate (or iron), nitrate, and phosphate.

Materials

- water sample from each area
- Probeware or colourimetric assay kit for sulfate (or iron), nitrate, phosphate, and pH
- 8 to 10 test tubes (10 mL)
- pipette bulb
- 2 pipettes (2 mL)
- 2 sample jars and lids
- metal scoopula

Safety Precautions

Read and follow the safety instructions that come with the assay kit. Wear gloves and wash your hands after completing the investigation.

Procedure

1. Make a data table in which to record your results.
2. Obtain water samples from the two contrasting areas.
3. If you and your lab partner are using a colourimetric assay kit, first label each set of test tubes with the field site and the test (for example, nitrate). Use the pipette bulb and a pipette to dispense water from each water sample into the labelled test tubes. Use the colourimetric assay kit to test the samples in the test tubes, and record the data.
4. If you are using Probeware, test the samples directly from the sample jars and record the data.

Analysis

1. Draw a bar graph to compare the results of each test for the two water samples.
2. Explain any differences between the two samples.
3. Compare your results with the amounts of sulfate (or iron), nitrate, phosphate, and pH in Calgary tap water, given below.

Calgary Tap Water Parameters

Water quality parameter	Units	Calgary tap water
sulfate	mg/L	30.4–43.6
iron	mg/L	< 0.1
nitrate (as total nitrogen)	mg/L	0.052–0.124
phosphate	mg/L	0.001–0.004
pH		6.98–8.18

Conclusions

4. Based on your results, suggest how human activities are affecting local water quality.
5. How might problems with local water quality affect the natural environment?

Extension

6. In August 2005, a train derailment caused 730 000 L of fuel oil and wood preservative to empty into Wabamun Lake, west of Edmonton. Since then, the Paul Band has been active in the cleanup effort of what is, to them, a sacred resource. Which chemicals contaminated the lake? Where were the immediate effects? What is the status of the lake now?

The Flow of Matter and Transfer of Energy are Linked

Each biogeochemical cycle is unique. Carbon, oxygen, sulfur, nitrogen, and phosphorus each take a different path through the biosphere. All of these cycles, however, and the hydrologic cycle are similar and interrelated. All six cycles involve both the abiotic and biotic environment. When living organisms take nutrients from their surroundings, for example, the nutrients become, at least temporarily, a part of the biotic environment. Therefore, effects on the transfer of energy from producer to consumer to decomposer also affect the biogeochemical cycling of matter. As Section 2.3 describes, natural processes and human activities can influence the transfer of energy and matter through the biosphere in various ways.

Section 2.2 Summary

- Carbon, oxygen, sulfur, and nitrogen are found in living organisms and in the land, atmosphere, and water.
- Phosphorus is found in living organisms and in the land and water.
- All of these nutrients are recycled through biotic and abiotic processes. They are stored in nutrient reservoirs for short to longer periods of time. They cycle among these reservoirs at different rates.
- Biogeochemical cycles are similar and interrelated. Disruptions in one biogeochemical cycle can affect another biogeochemical cycle. Human activities impact the biogeochemical cycles.

Section 2.2 Review

1. a) Explain why carbon moving from producer to consumer to decomposer and back to the atmosphere is an example of the rapid cycling of matter.

b) Explain why the formation of a fossil fuel such as coal is an example of the slow cycling of matter.

2. Describe the essential differences between the biogeochemical cycles for elements such as nitrogen or oxygen and for elements such as phosphorus and calcium.

3. Describe the role(s) of bacteria in:

a) the sulfur cycle

b) the nitrogen cycle

4. Identify three features that biogeochemical cycles have in common.

5. Explain why green plants need:

a) nitrogen

b) sulfur

c) phosphorus

6. a) Use word processing or graphics software to create a flow chart or other graphic organizer illustrating the nitrogen cycle. ICT

b) Describe the role of nitrogen fixation in supplying essential nutrients to the species found at higher levels in a food chain.

7. a) Use word processing or graphics software to create a flow chart or other graphic organizer illustrating the sulfur cycle. ICT

b) Explain the role that the burning of fossil fuels plays in the sulfur cycle and, in particular, acid deposition.

8. a) Use word processing or graphics software to create a flow chart or other graphic organizer illustrating the phosphorus cycle. ICT

b) In terms of the phosphorus cycle and environmental damage, explain why laundry detergents today are no longer made with phosphates.

SECTION 2.3

The Balance of the Matter and Energy Exchange

Section Outcomes

In this section, you will
- **explain** how energy, matter, and the productivity of ecosystems are interrelated
- **explain** the influence on atmospheric composition of the equilibrium between the exchange of oxygen and carbon dioxide in photosynthesis and cellular respiration
- **describe** evidence and scientific explanations for changes in the composition of Earth's atmosphere from past to present, and **describe** the significance of these to current states of equilibrium in the biosphere
- **outline**, **explain**, and **evaluate** the influence of human activities on the biosphere
- **design** and **evaluate** a model of a closed biological system

Key Terms

productivity
stromatolites

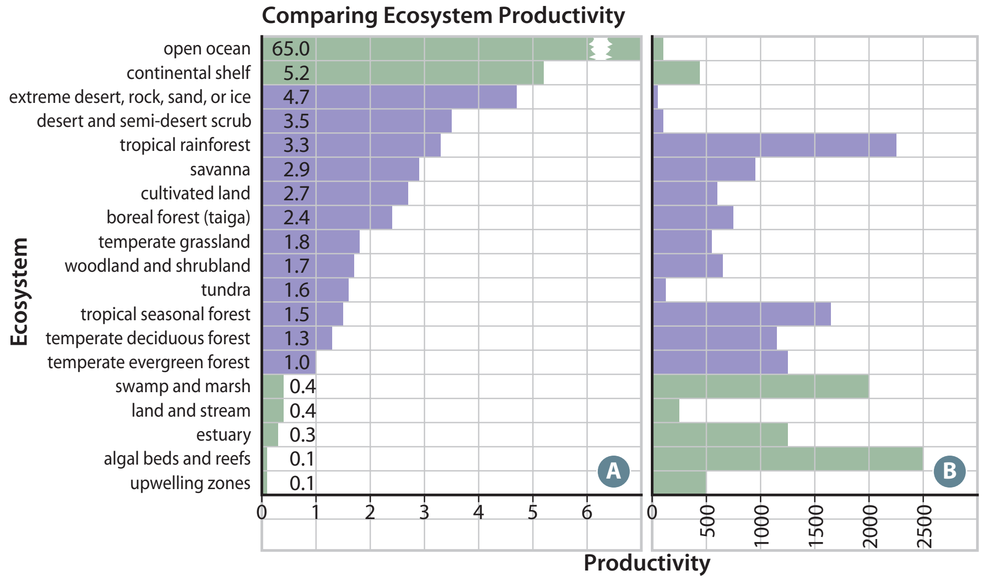


Figure 2.20 Comparing productivity of ecosystems in terms of **(A)** the percentage of Earth's surface and **(B)** average net productivity. Net productivity here is the total amount of radiant energy that is transformed to chemical energy by producers, minus the amount used by the producers during cellular respiration.

The biosphere is not a closed system. Although the biosphere does not exchange significant amounts of matter with its surroundings (outer space), there is a constant input of energy into the biosphere from the Sun and a constant output of radiant energy (heat) to space. The amount of sunlight that is received by an ecosystem affects the amount and type of productivity in the ecosystem. **Productivity** is the rate at which an ecosystem's producers capture and store energy within organic compounds over a certain length of time. It is commonly measured in terms of energy per area, per year (J/m^2/a). It can also be expressed in terms of biomass of vegetation added to an ecosystem per area, per year (g/m^2/a).

Productivity is the rate at which organisms produce new biomass. (In other words, productivity does not refer to the total mass of all producers in an area at any one time.) For example, a forest has a very large biomass. The mass of its vegetation is greater than that of a grassland of equal size. But productivity of a grassland ecosystem may actually be higher during the growing season, because animals are constantly eating the plants and new ones are constantly being produced. Thus, new mass accumulates in a grassland ecosystem at a higher rate than in the forest.

Figure 2.20 shows that productivity varies among ecosystems. The rate of productivity depends on many variables. These include the number of producers present in the ecosystem, the amount of light and heat available, and the amount of rainfall the system receives.

Productivity in the ocean is determined by the available nutrients and sunlight. The ocean receives nutrients at the mouths of large rivers and at upwelling zones on the west side of continents. As well, nutrients are released during the seasonal melting of ice. Nutrients promote the growth of algae.

In general, the amount of solar radiation limits a region's productivity. Can too much solar radiation affect productivity? Explore this question in the following Thought Lab.

Thought Lab 2.3 Too Much of a Good Thing

Target Skills

Analyzing information to investigate the impact of increasing ultraviolet radiation on organisms

Stating conclusions based on the analysis of information

Approximately six percent of the sunlight that reaches Earth's surface is ultraviolet radiation (UVR). UVR transfers much more energy than visible light. As a result, UVR can inhibit photosynthesis and harm cells by damaging their DNA. DNA damage, in turn, can lead to cancer.

Organisms that live in sunny regions are adapted to resist the harmful effects of UVR. As well, environmental factors can protect organisms. For example, the alpine lakes of the Canadian Rockies are at a high elevation, but studies show that dissolved organic matter in these alpine lakes can shield aquatic organisms from UVR.

Atmospheric gases also shield the biosphere from some incoming UVR. Ozone (O_3) in the lower atmosphere (troposphere) pollutes the air, but ozone in the upper atmosphere (stratosphere) absorbs UVR. The stratospheric ozone layer is thinning, however. From the 1950s through the 1990s, chlorofluorocarbons (CFCs) were used as propellants in spray cans and coolants in refrigerators. They were also used in the manufacture of plastics. In the 1970s, scientists discovered that CFCs, decomposed by UVR, were destroying the ozone layer. In 1985, a springtime depletion of stratospheric ozone was discovered over the South Pole. (This is often referred to as the Antarctic ozone hole.)

In 1987, 27 countries signed a global environmental agreement called the Montréal Protocol to Reduce Substances that Deplete the Ozone Layer. Its London Amendment (1990) called for the production of CFCs to end by 2000. The production of CFCs has been banned in many countries. There are other human-generated chemicals that are contributing to ozone thinning, however. For example, hydrochlorofluorocarbons (HCFCs) are one alternative to CFCs and are considered to be less harmful to the ozone layer. The Copenhagen Amendment (1992) to the Montréal Protocol calls for a ban on the production of HCFCs by 2030.

Procedure

Working in a group, use the information presented below to answer the Analysis questions.

Analysis

1. What might be the effects of increasing amounts of UVR on productivity?
2. What direct effects does increasing UVR have on animals?
3. What indirect effects might increasing UVR have on animals?
4. Suggest an approach to counteract increased levels of UVR in ecosystems. What would you need to find out to ensure that your approach is a wise one?

Effects of UVR on Different Organisms

Type of organism	Overall effect of increasing amounts of UVR	Adaptations for protection against UVR	Environmental features that protect against UVR
algae or phytoplankton	• can inhibit photosynthesis	• UVR-absorbing compounds	• dissolved material in water can act as a shield
plants	• in general, inhibits photosynthesis • reduces leaf size and decreases growth of many plants	• pigmentation • UVR-absorbing compounds • DNA repair processes	• shade can protect plants
bacteria	• depending on species, may be killed or highly resistant	• DNA repair processes	• amount of Sun exposure is limited
protozoa	• varies; damages cells in some species	• DNA repair processes in some protozoa	• protozoa living in deeper waters are shielded from UVR
zooplankton	• can be damaging or kill depending on age and other factors	• pigmentation • UVR-absorbing compounds • DNA repair	• zooplankton are shielded from UVR when they swim to deeper waters
fish	• damaging • can kill fish	• pigmentation • DNA repair in fish eggs	• deeper, cooler waters protect developing fish
amphibians	• causes developmental damage • can kill some amphibians • possibly reduces amphibians' ability to fight disease	• pigmentation • DNA repair processes	• dissolved materials in water can act as a shield • some amphibians are nocturnal
humans	• causes skin deterioration, skin cancer, and eye problems (cataracts)	• pigmentation (melanin in skin) • DNA repair processes	• shade, clothing, and sunscreen can protect against UVR

Productivity Depends on Available Moisture

The deserts and tropical forests of Africa both receive considerable sunlight but, as Figure 2.21 shows, deserts are too dry for most of the year to support very much productivity. Likewise, the tundra receives less than 25 cm of precipitation per year, and water is mostly trapped in snow and permafrost.

Q 18 Explain how increased amounts of sunlight can have both positive and negative effects on productivity.

Q 19 What are two major factors (other than available nutrients) that limit productivity?

The Biosphere in Balance

To live, an organism must maintain its internal conditions within certain limits in spite of changing external conditions. In a grizzly bear's body, for example, the pH and the levels of sugars and ions in the blood fluctuate on a daily basis but remain within narrow limits. Maintaining a state of balance, or *equilibrium*, is called homeostasis. To help maintain homeostasis, the cells of a grizzly bear's body must convert ingested food into usable energy and rid the body of wastes.

Figure 2.21 Satellite image of the amount of vegetation in Africa. Regions that are closer to the equator and coast are more humid and have the most vegetation.

In 1979, ecologist James Lovelock proposed the Gaia Hypothesis, which considers homeostasis on a global level. According to the Gaia Hypothesis, the biosphere acts like an organism that regulates itself, maintaining environmental conditions within certain limits. The biosphere needs a constant input of energy and the cycling of nutrients to maintain its internal balance.

Life itself plays a role in maintaining the conditions of the biosphere that allow organisms to survive. Scientists speculate that if life had never existed on Earth, atmospheric levels of carbon dioxide and oxygen would be very different (see Table 2.1).

Table 2.1 Composition of Earth's Atmosphere and Oceans

	Substance	Percent current composition	Percent hypothetical composition, with no life
Atmosphere	carbon dioxide	0.03	98
	nitrogen	78	1
	oxygen	21	0
	argon	1	1
Oceans	water	96	85
	salt	3.5	13

Source: James Lovelock, *Gaia, A New Look at Life on Earth*, 2000.

Deposits of ancient micro-organisms hold clues about the composition of Earth's atmosphere and oceans from 3.8 to 2.5 billion years ago. In the ancient past, the atmosphere lacked free oxygen (it was anoxic) and bacteria and bacteria-like organisms grew, forming thick mounds in shallow seas, lagoons, and lakes. As the micro-organisms died, the cells piled up, trapping or precipitating sediments and eventually forming sedimentary rocks, called **stromatolites** (Figure 2.22). Some stromatolites show bands of iron oxides, which formed when iron ions combined with dissolved oxygen in the oceans. Most stromatolites with these distinctive black iron bands are an estimated 2.5 billion years old or more. They suggest that, around this time, the level of oxygen in the oceans had started to increase.

BiologyFile

Web Link

Not all scientists agree with Lovelock, that Earth acts like an organism. How is the Gaia Hypothesis accepted in the scientific community?

www.albertabiology.ca
WWW

BiologyFile

FYI

When tropical rainforests are clear-cut, all vegetation is removed and available nutrients diminish. Areas once shaded by trees become too sunny and hot for transpiration to occur, rain washes away any remaining soil, and water evaporates more quickly into the atmosphere. Eventually, rainfall decreases over the clear-cut area and drought may occur. This disruption of the water cycle can cause climate change.

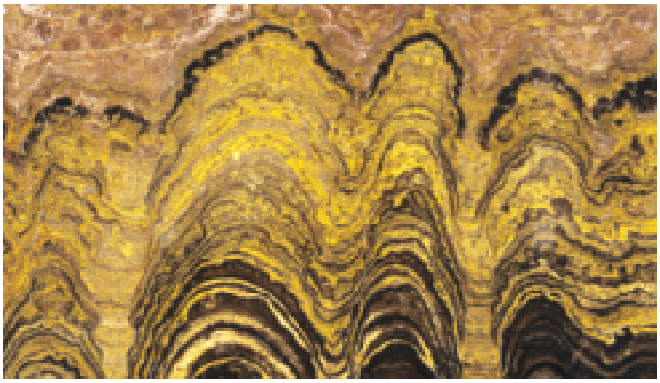


Figure 2.22 The iron banding pattern in this stromatolite formation developed when there was dissolved oxygen in the oceans, but little or no oxygen in the atmosphere.

The Concentration of Atmospheric Gases over Time

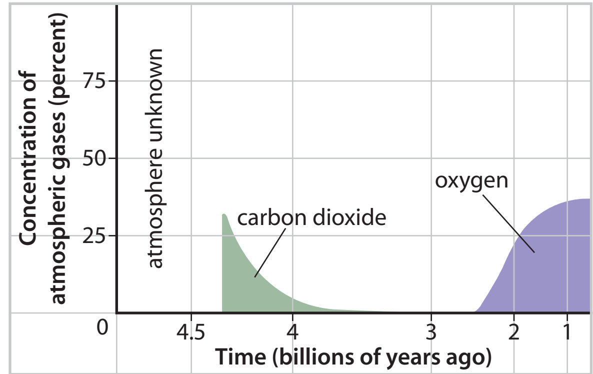


Figure 2.23 Atmospheric oxygen concentrations in the biosphere over time

Stromatolites that are less than 1.8 billion years old do not have black bands of iron oxides. Scientists speculate that, at this time, most of the iron ions in the oceans were already bound in iron oxides. With the ocean's store of iron ions used up, the oxygen produced by photosynthesis was free to build up as oxygen gas and eventually to escape into Earth's atmosphere.

Scientists think that the sudden increase in atmospheric oxygen about 2.5 billion years ago was mostly due to the activity of photosynthetic micro-organisms, such as cyanobacteria (see Figure 2.23). Over time, species that were well-adapted to life in the oxygen-rich biosphere evolved. Today, most life on Earth could not survive without oxygen. The interchange between photosynthetic organisms and consumers maintains levels of oxygen that are suitable for life as we know it.

Figure 2.24 Inside Biosphere 2, a research facility designed to be a closed system for 100 years. The system was never completely closed for more than two years. However, the facility is still used for ecosystems research.

Replicating Earth's Biosphere

Scientists have tried to replicate the self-regulating conditions of the biosphere in artificial environments. Biosphere 2 was a large-scale biosphere experiment in which engineers constructed a closed system, much like a massive domed greenhouse, in Arizona, United States (Figure 2.24). Plants in the system provided a source of oxygen and food, and human and animal wastes were filtered to recycle water. Researchers were able to live continuously and virtually independently in Biosphere 2 for several months, until oxygen levels dropped and carbon dioxide levels rose to unsafe levels.

The difficulties that Biosphere 2 researchers faced showed that the balance of energy and matter exchange in Earth's biosphere depends on an extremely complex system. Nevertheless, in order to support space colonies someday, scientists continue to investigate designs for a self-regulating closed system.

NASA has designed a program called the Advanced Life Support (ALS) program to research how plants may be grown in a space colony for food and oxygen regeneration. ALS also enables scientists to investigate how chemical and biological methods can be used to convert waste into usable resources. NASA has also conducted several experiments where humans have spent several months in self-sustaining environments at the Johnson Space Centre to test their research. In addition, the space agency also sponsors an international field project on Devon Island in the Canadian Arctic that models a hypothetical colony on Mars. The NASA Haughton-Mars Project is situated in the Arctic because the geology and biology of this region mirrors the Martian lithosphere better than anywhere else on Earth. New technologies are being tested in this Mars-like environment, providing useful information for future Mars colonists. The colony includes living and research facilities, as well as a fully enclosed greenhouse.

INVESTIGATION 2.D

Target Skills

Designing an investigation to evaluate carbon dioxide, water, and oxygen exchange in a closed biological system

Gathering and **recording** data on ecosystem variables to observe and learn how ecosystems function

Biosphere in a Bottle

What are the essential abiotic components of an ecosystem? What are the essential biotic components of an ecosystem? In this investigation, you will design a model biosphere in a bottle.

Question

How can you design a model ecosystem that can survive as a self-regulating system?

Materials

- 2 L (or larger) clear bottle with lid
- bottom sediment
- pond or river water
- thermometer (alcohol or digital)
- Parafilm™ or sealing wax
- 10 mL test tube
- small aquatic plants (such as floating duckweed and various submerged plants)
- small aquatic invertebrates (such as snails, flatworms, shrimps, and insects)

Procedure

1. With your group, design a model biosphere using the suggested materials. Your model biosphere must be completely sealed, using the Parafilm™ or sealing wax. It will require an outside light source, however, and a method for monitoring temperature. Record initial and any subsequent changes in water level, and note any condensation on the inside of the bottle.

   Note: Consider the ethical treatment of animals in your design.

2. Create a table to use to record, over time, observations such as temperature, water level, species present, changes to species composition or abundance, clarity of the water, and other variables that you feel may be important.
3. Set up your model biosphere, and make initial observations.
4. Make daily observations of your model biosphere for two weeks or longer.

Analysis

1. Identify the producers, consumers, and decomposers in your model biosphere.
2. Which biogeochemical cycles were represented in your model biosphere?
3. Why did you use a clear bottle, rather than an opaque bottle, for your model biosphere?
4. How did the temperature in the model biosphere change over the trial period?
5. How did you recognize the cycling of water in your model biosphere?
6. How well did your model biosphere function as a self-regulating system?
7. Compare your model biosphere with another group's model biosphere. Are there any differences? If so, what may have caused these differences?

Conclusions

8. Predict the effect of decreasing the amount of light available to the model biosphere.
9. Predict the effect of a significant reduction in productivity in Earth's biosphere on levels of:
   a) atmospheric oxygen
   b) atmospheric carbon dioxide

Figure 2.25 This satellite image reveals the path of nutrient-rich sediments from Ontario and the United States into Lake Erie. The excess nutrients cause algal blooms, which have created a dead zone in the lake.

Human Activities and the Natural Balance

Dead zones are regions of lakes or oceans in which aquatic life has suffocated due to algal blooms. There are approximately 150 dead zones in the oceans, ranging in area from 2.6 km^2 to more than 100 000 km^2. Algal blooms can occur seasonally in response to the turnover of nutrient-rich waters in warmer temperatures. As you learned in Section 2.2, however, various types of pollution can also contribute to algal blooms:

- Nutrients in the soil exposed by deforestation can be washed into rivers by rain.
- Sewage (particularly if inadequately treated) that is discharged into bodies of water carries significant amounts of phosphate and nitrate, which promote the growth of algae.
- Surface run-off and snowmelt carrying manure from livestock operations can add phosphate and nitrate to streams and rivers.
- Run-off from fertilized agricultural fields and lawns can enter rivers and oceans.

Figure 2.25 shows the path of nutrient-rich run-off into Lake Erie, which sits on the Ontario, Canada-United States border. Scientists are concerned about a dead zone in the central basin of Lake Erie during the late summer and early fall. Dead zones are just one example of how human activities can affect the balance of matter and energy exchange in the biosphere.

Solutions to environmental problems are often discovered in the biosphere itself. Wetlands, such as bogs, marshes, and swamps, are environments where soil is permanently saturated with water, either from ground water or surface

Thought Lab 2.4 Evaluating Water Treatments

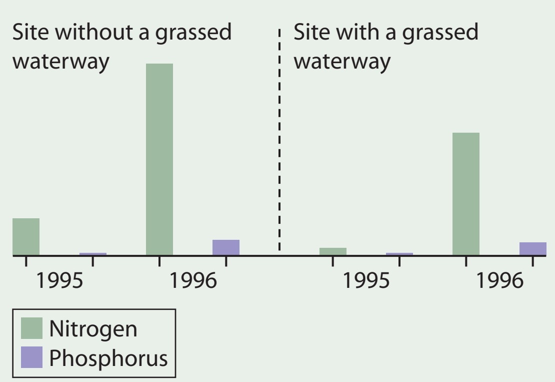
Target Skills

Analyzing data on water quality to evaluate the effectiveness of using grasses to treat agricultural run-off

Haynes Creek is a tributary of the Red Deer River, located east of Lacombe, Alberta. Haynes Creek runs through agricultural areas with heavy pesticide and fertilizer use, and through cattle farms. In the past, water from Haynes Creek has not met drinking water quality guidelines or standards for the preservation of aquatic life.

Scientists hypothesized that one way to improve water quality in Haynes Creek, and to slow erosion from the creek bed, would be to plant grass in drainage ditches around the creek. They did this, and then tested the creek water upstream and downstream of the grass "filter." Their results are shown in this graph.

Nitrogen & phosphorus losses from cultivated fields



Analysis

1. What effect did the grass "filter" in the creek have on the creek's water quality?
2. How could the findings of this experiment be applied to prevent farmland run-off from negatively affecting the water quality in nearby streams?

Figure 2.26 Many plants, animals, and other organisms inhabit wetlands. About 20 percent of Alberta, by area, is made up of wetlands. Most of these wetlands are located in northern Alberta. Animals such as the great blue heron and the endangered whooping crane depend on wetlands for survival. Some of the numerous ecosystem services that are provided by wetlands include water purification, water storage, biodiversity preservation, and flood control.

water (Figure 2.26). As a result, they act as large water filters. Unfortunately, many wetlands around the world have been drained in order to make room for agricultural land or urban growth.

The people of Calcutta, India have built a vast network of canals and wetlands to treat sewage coming out of the city. Calcutta is one of the most populated cities in the world, and it produces tonnes of sewage every day. Algae and bacteria in the wetlands feed on the organic material. Fish have been added to feed on the algae, in order to prevent algal blooms. Many people have been able to support themselves by growing vegetables or fishing in the wetlands, and selling the produce and fish.

Preserving the Natural Balance

Many communities have chosen to change the way they meet their food, water, and energy needs to preserve the natural working order of the biosphere. For example, the Piikani First Nation of southern Alberta (a member of the Blackfoot Confederacy) operates a wind turbine, called Weather Dancer 1, to generate electricity (Figure 2.27). The turbine generates energy for 450 homes and produces no carbon dioxide emissions. Powering the same number of homes by burning fossil fuels would release approximately 2500 tonnes of carbon dioxide gas per year, as well as other pollutants. Technologies such as Weather Dancer 1 are helping to preserve fossil fuel reservoirs and do not contribute to excessive carbon dioxide generation and carbon release in the

Figure 2.27 "Green power" produced by the Weather Dancer 1 wind turbine is distributed to homes on Alberta's electricity grid system.

BiologyFile

FYI

Like nutrients, many human-made contaminants cycle through the environment. Other contaminants, such as the pesticide dichlorodiphenyltrichloroethane (DDT) and polychlorinated biphenyls (PCBs; used in electrical equipment and other specialized uses), can also biomagnify. Such contaminants, known as persistent organic pollutants (POPs), can also travel thousands, or tens of thousands, of kilometres in the atmosphere and be deposited in the Arctic. POPs have been found in Arctic wildlife and Aboriginal people who traditionally hunt and eat these animals. For example, scientists have found high levels of PCBs in nursing Inuit mothers in Nunavut.

rapid cycling of carbon. This reduces the production of a greenhouse gas. Also, since fossil fuels are not used, this eliminates a source of sulfur and the resulting acid deposition.

Like many First Nations peoples, the Piikani traditionally see themselves as part of the natural environment. They consider harm done to the natural environment as harm done to themselves. For the Piikani, using a non-polluting and renewable energy system makes sense in terms of their cultural beliefs.

Communities everywhere are facing the challenge of meeting their needs while preserving the integrity, or natural balance, of the biosphere. Fortunately, humans have developed many tools that can help us preserve the natural balance.

Far-Reaching Consequences

Ecologists are discovering that biogeochemical cycles are linked in unexpected ways. Similarly, the transfer of matter through the biosphere is closely linked to the transfer of energy through the biosphere. Local tap water may contain water molecules that were once transpired by a tree in a tropical rainforest. Fertilizers applied to a local

Thought Lab 2.5 Design a Self-Sustaining Mars Colony

Target Skills

Evaluating the technological requirements for a self-sustaining, Earth-like system

Evaluating the potential benefits to humanity and the possible environmental consequences of implementing such technology

If humans were to colonize another planet, such as Mars, they would have to find a way to create an ecosystem that can sustain itself in a manner similar to Earth's biosphere. Except for energy, such a colony would recycle and re-use all its components. In this Thought Lab, you will consider the requirements for a self-sustaining colony on Mars. (Contact with Earth is impractical due to the amount of time it takes to travel between the two planets using current technology.)

Procedure

1. In a group, design a self-sustaining Mars colony. Begin by brainstorming the requirements of such a colony. How would water, oxygen, and carbon dioxide be exchanged? How would nutrients be recycled? How would you address the issue of food production and waste disposal? How would energy be generated?
2. Make a list of what colonists would need to survive on Mars. Create a table of "inputs" the colony would require in order to obtain these things, and "outputs" that could be recycled to obtain them. What cycles would exist as a result of this recycling? How might the colony be affected if one of these cycles were to become disrupted?

Analysis

1. On Mars, large quantities of water are frozen in the polar ice caps and under the planet's surface. How could these resources be incorporated into a self-sustaining ecosystem?
2. Scientists have suggested that, like the International Space Station, a Mars colony could be powered by collecting the Sun's energy with solar panels. However, because of its distance form the Sun, Mars only receives half of the solar radiation that Earth does. Extensive atmospheric dust also reflects incoming sunlight. Suggest ways in which a self-sustaining Mars colony could address these issues. Do you think solar panels are a viable means of supplying power to a Mars colony? Why or why not? Can you provide a feasible alternative?
3. Mars has only a third of Earth's gravity. What sorts of problems might this present to a Mars colony and how would you address them?
4. The soil on Mars is very corrosive. Colonists may be able to grow crops in greenhouses using hydroponics (using nutrient-rich water instead of soil). Suggest a way that nutrients required for plant growth (such as nitrogen and phosphorus) might be recycled within the greenhouse.
5. The thin Martian atmosphere is about 95 percent carbon dioxide. However, Mars experiences only a very slight greenhouse effect. As part of the plans for colonizing Mars, some scientists have suggested the need to create a greenhouse effect for Mars—called a "runaway greenhouse effect." What do you think might be necessary to engineer this effect? What are some possible consequences of doing so?
6. Some people find the idea of terra-forming another planet or moon (making it Earth-like for human habitation) disagreeable. They point to the current condition of Earth as evidence that we have not yet learned how to live in balance with our home planet. On the other hand, some people find the idea of terra-forming inspiring—an opportunity to have a fresh start, to "get things right" based on the knowledge we have developed about the biosphere and its interconnected systems. What is your opinion? Provide reasons to support it.

green space may find their way into distant waterways, resulting in aquatic dead zones.

The effects that disruptions in one part of the biosphere may have on other parts of the biosphere can be difficult to predict. Satellite data and computer modelling are helping scientists understand the interactions between different biogeochemical cycles and the transfer of energy in the biosphere. By studying the steps in the biogeochemical cycles, and by standing back and looking at the biosphere as a whole, scientists can better understand what keeps the transfer of energy and the cycles of matter in balance, and what keeps the biosphere hospitable to life.

Section 2.3 Summary

- Biotic and abiotic processes maintain the balance of matter and energy exchange in the biosphere. Productivity is influenced by environmental factors such as sunlight and nutrient (including water) availability.
- Natural processes and human activities can affect the transfer of energy and the cycling of matter through the biosphere.
- Nutrient run-off can cause algal blooms and dead zones.
- Wetlands can clean polluted water and provide other ecosystem services.

Section 2.3 Review

1. Explain why the biosphere is considered to be an open system.
2. Define the term "productivity."
3. Explain why, during the summer, the productivity of a grassland ecosystem may be greater than the productivity in a forest.
4. Identify four variables that determine the productivity in a terrestrial ecosystem and explain how each affects production of new biomass.
5. Identify the two variables that determine the productivity in the oceans.
6. Briefly describe the Gaia Hypothesis.
7. Explain how scientists have used stromatolites to predict the oxygen levels in the atmosphere early in Earth's history.

Use the following information to answer the next question.

Algal Blooms

Algae are the producers in most aquatic ecosystem and are vital to the survival of other organisms in this environment. Algal blooms, however, can result in dead zones in lakes.

8. **a)** Describe why algal blooms occur and identify four human activities that can lead to their formation.

   b) Explain why algal blooms create dead zones in many lakes during the late summer and early fall.

Use the following information to answer the next question.

Hydrogen Sulfide

Hydrogen sulfide ($H_2S(g)$) is a colourless, flammable gas that can be deadly when inhaled. It can form when bacteria in swamps or even sewers break down organic matter in the absence of oxygen. It produces a foul odour that is described as the smell produced by rotting eggs. In the summer, when the temperature is warmer, bacteria in wetlands, mud, and soil are more active and produce more hydrogen sulfide gas than they do in cooler weather.

9. Suppose that global climate change had a similar effect and the annual emissions of hydrogen sulfide increased. Explain how this might affect:

   a) the sulfur cycle

   b) the productivity of temperate deciduous forest ecosystems

Phytoremediation

Petrochemical spills release toxic hydrocarbons into the environment. Some of these hydrocarbons can make their way into underground or surface waters and end up contaminating drinking water. One approach to treating hydrocarbon pollution is phytoremediation, which makes use of the natural ability of plants and micro-organisms to degrade or remove contaminants from soil and water. Researchers have found that prairie ecosystems have an important role to play in this approach.

It Takes Teamwork

Together, plants and micro-organisms can remove toxic hydrocarbons from soil and water, and even convert some of these contaminants into less harmful compounds. As in the nitrogen cycle, different types of bacteria either work independently or in an integrated manner to convert one form of hydrocarbon to another. Some bacteria produce non-toxic compounds, such as carbon dioxide and methane.

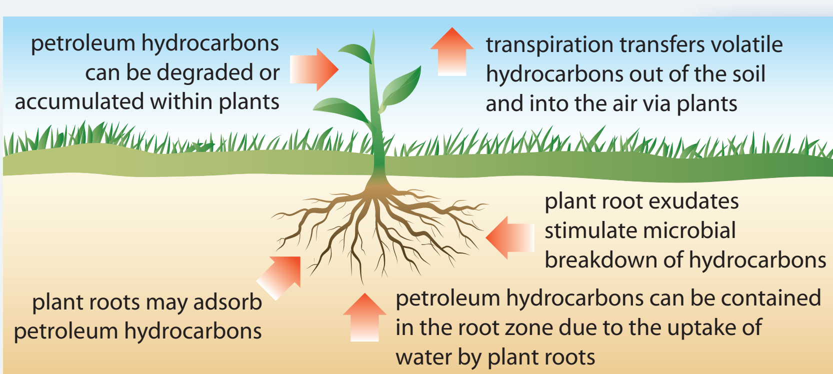
Plants produce compounds (root exudates) that stimulate bacterial metabolism. So, a combination of plants and bacteria can work well to clean up hydrocarbons. As shown in the diagram below, plants with fibrous roots, such as prairie grasses, are very good at adsorbing (attracting to their surface) hydrocarbons. Plants take up contaminated water when they take up hydrocarbons. This keeps the hydrocarbons out of the ground water and may allow the contaminants to collect in plant tissues. Plants can break down some of the hydrocarbons, and transpiration gradually transfers volatile hydrocarbons from the ground to the atmosphere.

The Right Solution to Pollution

Petrochemicals are widely used in manufacturing and as fuel, and accidental spills can occur during extraction, transportation, or use. Some clean-up methods are more effective than others, depending on the amount and type of petrochemicals spilled and the condition of the contaminated environment. Scientists need to consider whether the contamination poses an immediate risk to people or wildlife. One option is to treat the contamination on site (*in situ*), as in phytoremediation. Another option is to remove the contaminated soil or water to clean it using chemical or biological methods (*ex situ*).

• • •

1. Where might you look for plants that could be useful in phytoremediation?
2. Sometimes, bacteria convert hydrocarbons into more toxic products. Because of this risk, should phytoremediation be abandoned as a solution to hydrocarbon pollution? Explain.
3. Why might scientists be concerned about animals feeding on plants that are being used for phytoremediation?
4. Suppose that there is a large petrochemical spill that could quickly contaminate ground water. Would phytoremediation be an appropriate choice to deal with the spill? Explain your reasoning.
5. What makes phytoremediation a relatively economical solution for treating hydrocarbon contamination?
6. How would a phytoremediation method for treating heavy metal contamination be different from a phytoremediation method for treating hydrocarbon contamination?



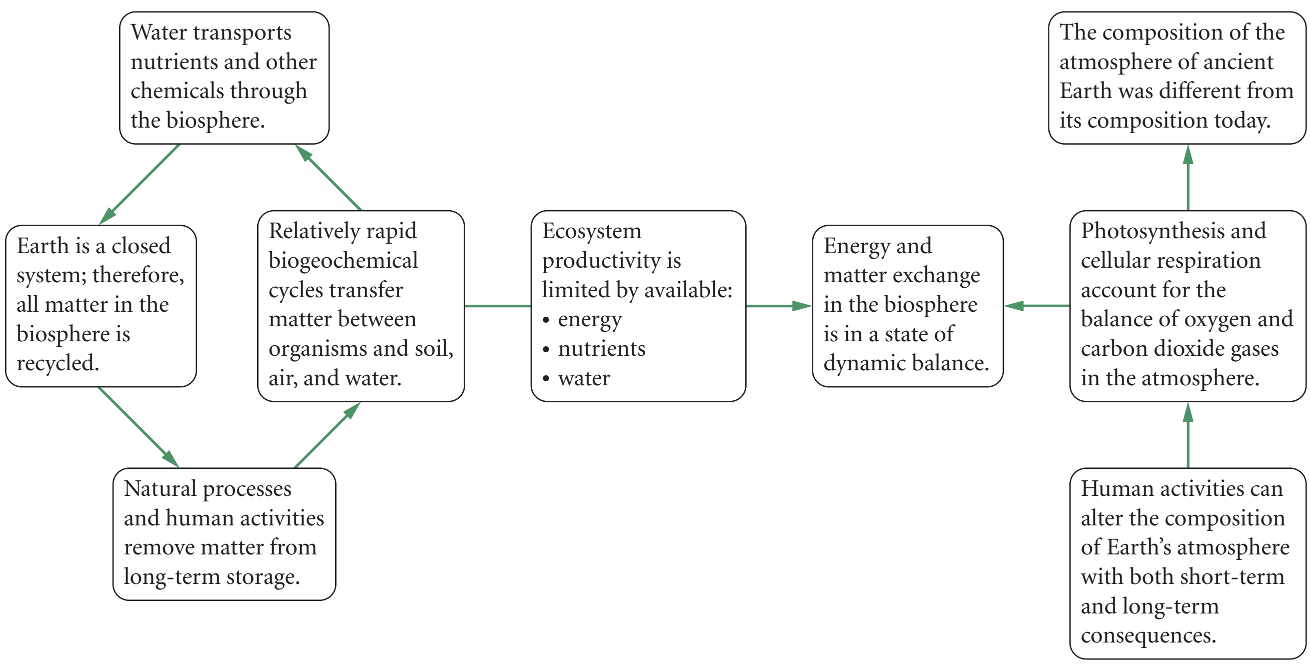
Chapter 2 SUMMARY

There is a limited (finite) amount of water in the biosphere. It is re-used, however, in the hydrologic cycle. Water is able to dissolve a wide variety of substances. Hydrogen bonding plays a key role in determining the properties and uses of water, such as its ability to dissolve and transport materials. Water provides an essential service for humans and ecosystems. Drought and poor water quality can affect water availability and impact humans and the environment.

Carbon, oxygen, sulfur, and nitrogen are some of the main nutrients (chemical elements) found in living organisms and in the land, atmosphere, and water. Phosphorus is found in living organisms and in the land and water, but is rarely found in the atmosphere. Biogeochemical (nutrient) cycles make these chemical elements available continuously. Nutrients are recycled through biotic and abiotic processes in the environment. They are stored in nutrient reservoirs for short to longer periods of time, and they cycle among these reservoirs at different rates.

Natural processes and human activities can affect the transfer of energy and the cycling of matter through the biosphere. Disruptions in one biogeochemical cycle can affect another cycle. For example, excess sulfur and nitrogen in the environment can result in acid deposition, which can harm both terrestrial and aquatic ecosystems. Excess nitrogen and phosphorus can run off into aquatic ecosystems where it can cause eutrophication and algal blooms.

Chapter 2 Graphic Organizer



Chapter 2 REVIEW

Understanding Concepts

1. Use word processing or graphics software to illustrate the relationship between the carbon and oxygen cycles. ICT

2. Identify the properties of water that make it an excellent transporter of dissolved materials, and briefly describe each.

3. Describe the role of plants and animals in:
   a) the rapid cycling of carbon
   b) the slow cycling of carbon

4. Explain how animals lose and replace water from their bodies.

5. Explain, with reference to the molecular structure of water:
   a) why ice floats
   b) why water is called the universal solvent
   c) why water has special adhesive and cohesive properties

6. Explain why each of the following is a reservoir for nitrogen:
   a) living organisms
   b) soil
   c) water
   d) atmosphere

7. Identify which of the following elements cycle through Earth's atmosphere: carbon, phosphorus, sulfur, oxygen, and nitrogen.

8. Explain how excess phosphate can affect aquatic ecosystems.

9. a) Identify the process that led to the increase in the amount of oxygen in Earth's atmosphere to current levels.
   b) Describe one way scientists have been able to assess the historical composition of Earth's atmosphere.

10. Describe the reason why farmers apply fertilizers to many of their crops.

11. a) Identify the useable form(s) of nitrogen that are available for green plants in a terrestrial ecosystem.
    b) Explain the role of bacteria in supplying these usable forms of nitrogen to plants.
    c) Describe how other bacteria actually remove these useable forms of nitrogen from the soil.

12. a) Describe acid deposition and explain how human activities have contributed to increased levels of acid deposition in eastern Canada.
    b) Name two biogeochemical cycles that are involved in acid deposition.

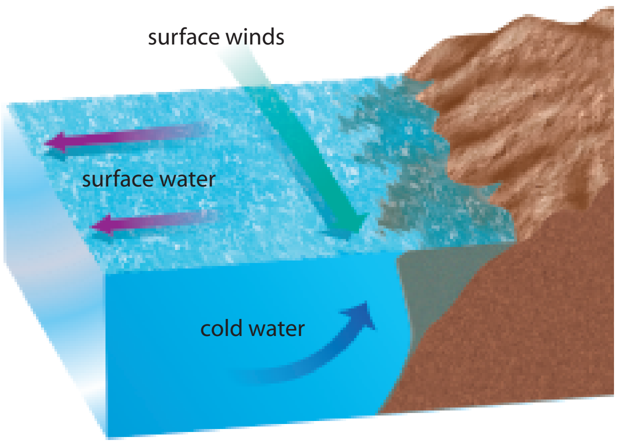
13. Compare and contrast the phosphorus and nitrogen cycles in terms of the role that the lithosphere plays in each cycle.

14. Define, using an example, the meaning of "ecosystem services."

Use the following information to answer the next question.

Nutrient Upwelling

As shown in this illustration, nutrient-rich water rises from deeper levels to replace the surface water that has drifted away. These nutrients are responsible for supporting the large fish populations commonly found in these areas.



15. Explain why, in general, there is less productivity deep in the oceans, compared with productivity of water closer to coastal areas.

16. Explain the importance of wetlands.

17. Use word processing and/or graphics software to illustrate the main stages in the nitrogen cycle in a terrestrial ecosystem. ICT

18. Summarize how the properties of water are essential for life as we know it.

Applying Concepts

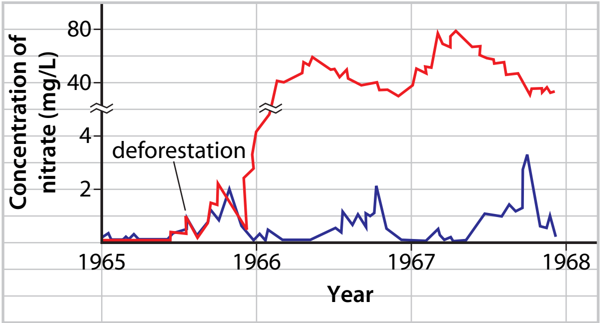
19. A researcher hypothesizes that increasing global temperatures will make it harder for algae to resist damage due to ultraviolet radiation (UVR). Another researcher suspects the opposite. Outline an experimental procedure that could be used to test this hypothesis in laboratory conditions.

Use the following information to answer the next question.

Deforestation

In order to study the effects of deforestation on biogeochemical cycles, scientists cut down an area of forest in the Hubbard Brook Experimental Forest in a mountainous region of New Hampshire, United States. Pesticides were used to prevent any vegetation from regrowing in this part of the valley. Following deforestation, the amount of water flowing out of the area increased by 40 percent. Scientists also measured the amount of nitrate in stream water in the forested and deforested areas. Their results are shown in the following graph.

The Concentration of Nitrate in Streams Leaving Forested and Deforested Areas over Time



The Hubbard Brook Experiment. The red line indicates the amount of nitrate in streams leaving deforested area. The blue line indicates the amount of nitrate in streams leaving intact nearby forests.

20. a) Explain how the results of this experiment might be used to explain flooding in areas downstream of a forest that has been cleared of trees.

b) Predict how large-scale deforestation around the world might affect the hydrologic cycle.

c) Describe the results of the graph. Explain the impact of deforestation on the amount of nitrate retained in the soil.

d) Explain, in general terms, how deforestation affects the nitrogen cycle.

e) Assuming no pesticides were being used, identify two other factors that might limit the growth of new vegetation in a previously deforested area.

21. Ground water comes from precipitation that has filtered down through soil and spaces between rocks. Explain how the careless dumping of pesticides into a land fill could impair ground-water quality.

Use the following information to answer the next question.

Walkerton, Ontario

In Walkerton, Ontario, seven people died and thousands became ill after pathogenic bacteria (*E. coli* 0157:H7) contaminated the town's water supply in 2000. Although the town's water supply was chlorinated, there was insufficient chlorine in the water to kill the bacteria. The source of the bacteria was later traced to an area near one of the town wells, a farmer's field that had recently been spread with manure. Prior to the *E. coli* outbreak, the region had received heavy rains.

22. a) Describe, in terms of the hydrologic cycle, how Walkerton's water supply might have become contaminated.

b) Suggest two actions that a municipality could take in order to safeguard the quality of drinking water supplies.

Making Connections

23. Use word processing and/or graphics software to show the relationship between the hydrologic and phosphorus cycles. ICT

24. Do wild animals produce garbage and/or pollution? Explain your answer.

Use the following information to answer the next question.

Acid Deposition

Some of the molecules that are released by burning fossil fuels include sulfur dioxide and nitrogen oxides. These molecules react with oxygen and water vapour in the air to produce acid deposition, which can damage plants and leach nutrients from the soil.

25. a) Use word processing and/or graphics software to illustrate the formation of acid deposition as the result of driving a car that burns gasoline. ICT

b) Explain how driving a car in Alberta can affect an ecosystem elsewhere in the country.

Career Focus: Ask a Sustainability Expert

There is no job description for what Professor Tang Lee does, but everything he does relates to sustaining the health of the planet and its inhabitants. He is an architect and a Professor of Environmental Design at the University of Calgary, where he teaches and conducts research into topics such as indoor air quality and sustainable building design. He is often called on to give expert testimony in court and to be interviewed on radio and television. As well, he is also a co-owner and operator of a tilapia (*Oreochromis niloticus*) fish farm, which supplies fish to stores in Calgary and Edmonton.

Q What is sustainability?

It can be as simple as conducting our lives so that we don't adversely affect future generations. There are many different definitions. You can sustain health, energy resources, food. To my mind, it is all of the above.

Q Why do you run a fish farm?

I look at the oceans being over-fished, and it's destroying water ecosystems. And there's so much pollution being dumped into the ocean—heavy metals, like mercury, cadmium, and lead. … I worry about the health of my children and grandchildren. To make a long story short, I decided to raise fish in a way that does not deplete the oceans—in a way that does not use chemicals, and hormones, and antibiotics, which of course go up the food chain.

Q How do you operate your fish farm?

Lots of fish farms have what's called a flow-through system, which means they take water out of the river and put it through the tank. Waste from the fish and uneaten fish food gets discharged (untreated) into the river. We don't do that. We have a greenhouse, and so the wastewater is put in a hydroponics system as well as soil culture. To make the soil culture we grind up any dead fish and mix this into the soil. We have beautiful compost that we donate to the garden clubs!

We only bring in about 10 percent of the water we use to replace water lost to evaporation, spillage, and so forth. And because of this, we don't discharge large amounts of nutrients downstream. We have equipment and the hydroponics system to filter the water. We also have a constructed wetland on our site, which does the final polishing. After the water goes through the wetland, it's completely clear. Nature is incredible in terms of how it can purify, as long as we don't overload the system.

Q You also design solar-powered buildings. What motivates you to do this?

We live in a privileged period of civilization in which we have fossil fuels to consume. The future is going to be different. … We're not going to be able to use, in the same way, fossil fuels for heating, cooling, and powering our buildings, or for transportation.

Q What keeps you in a positive frame of mind?

I'm hopeful because there are people who are working toward renewable energies, like solar and wind, different types of planning systems, and new types of vehicles. … We see a lot of what we call *ecovillages* springing up, in which communities are trying to be as self-sufficient as possible.

Q How else does architecture relate to sustainability?

It's more than just designing a building that's very energy efficient. We have to rethink what beautiful is. For example, do we really need imported marble in our homes? There's other beauty, such as Rocky Mountain stone, that we have right here in Alberta. We have to challenge the assumptions of our ways.

Other Careers Related to Sustainability

Environmental Technologist Environmental consulting firms, petrochemical companies, government agencies, and research centres employ technicians to collect and analyze environmental samples. Environmental technologists need a solid understanding of environmental regulations. Either a two-year technical diploma or a Bachelor of Science degree is required for an entry-level position.

Horticulturalist Trained gardeners maintain green spaces and cultivate crops for human consumption. A Bachelor of Applied Science degree, or a two-year college diploma combined with an apprenticeship, prepares gardeners to work in greenhouses, nurseries, and production fields. Horticulturalists can also specialize in agribusiness, or golf or landscape management.

Environmental Planner City or regional planners work with architects, land developers, transportation specialists, and others to plan how urban centres should grow. Environmental planners need to consider environmental, economic, and social aspects of city life. An undergraduate degree in planning or environmental studies is needed to start working in this field.

Professor of Environmental Design Environmental design is a broad field of study that looks at how human intervention impacts the environment in positive and negative ways. Professors with doctorate degrees or equivalent experience conduct and lead research on environmental design issues, teach at universities, and may consult for government or private companies.

Environmental Communications Specialist Freelance journalists and staff reporters cover environmental stories for media outlets. Public relations specialists help universities, governments, and companies communicate with the general public through brochures, newsletters, and advertisements. A communications specialist may have a college diploma or an undergraduate degree in communications, journalism, or science, combined with a work-practicum or relevant volunteer experience.

Environmental Lawyer Certified lawyers with additional expertise in environmental science mediate or represent clients in legal disputes, such as cases of illegal waste disposal. Environmental lawyers also advise industrial and real-estate companies of their rights and responsibilities according to environmental regulations.

Go Further…

1. Indoor environments affect outdoor environments, and vice versa. Research one aspect of building construction or interior design that affects the outside environment.
2. It is important for buildings to be designed to bring in fresh air. When carbon dioxide levels are too high, buildings get stuffy and people get headaches and feel sleepy. How do outdoor carbon dioxide levels affect the amount of fresh air that people need to bring into buildings?
3. In what ways are food quality and food safety global issues?

UNIT 1 REVIEW

Understanding Concepts

1. Explain how energy is transferred in a terrestrial environment.

2. At one time fungi, such as mushrooms, were classified in the same kingdom as green plants. Explain, in terms of their trophic level, why fungi are no longer placed in the same kingdom as green plants.

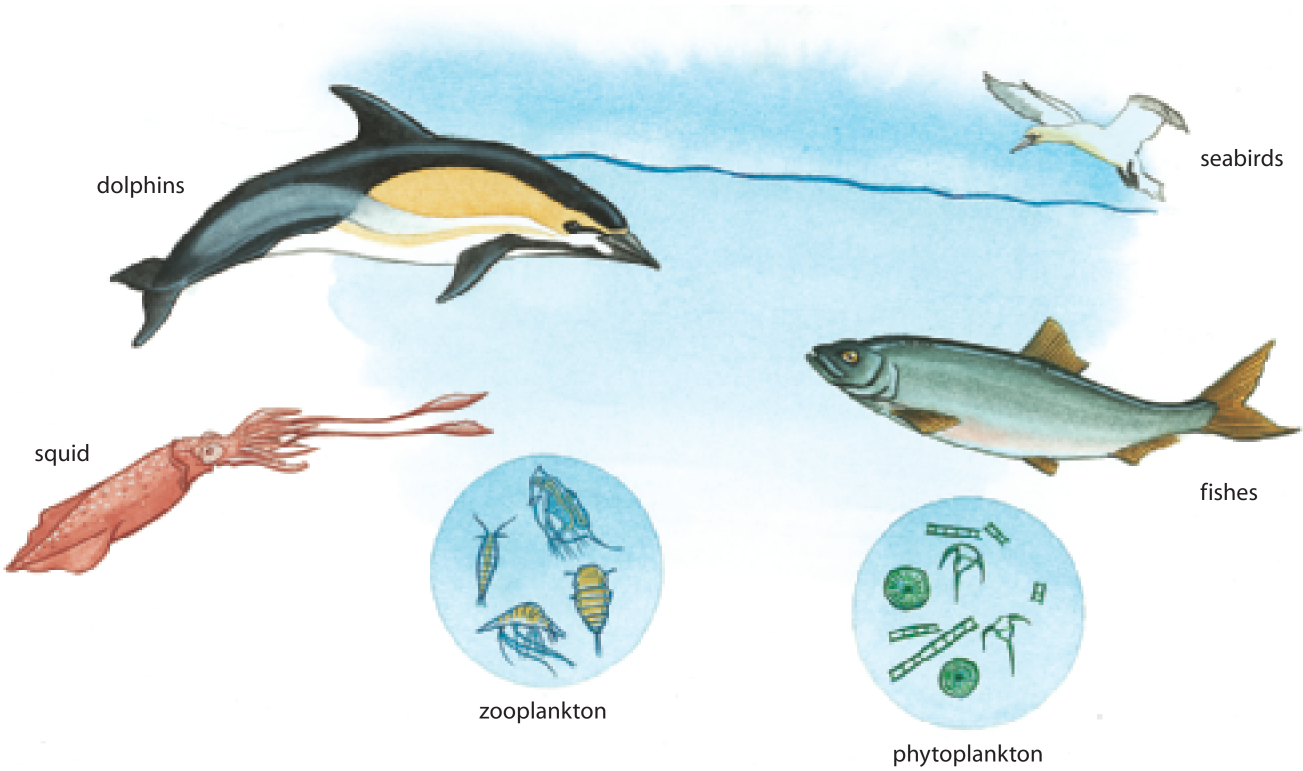
3. Explain how energy is transferred in a thermal vent community.

4. Use word processing or graphics software to construct a flow chart that illustrates the conversion of animal wastes to a form of nitrogen that green plants can use. ICT

5. Describe how phosphorus is utilized in plants and animals.

6. Predict what would happen to the levels of carbon dioxide and oxygen in the atmosphere if global productivity decreased.

Use the following illustration to answer the next question.

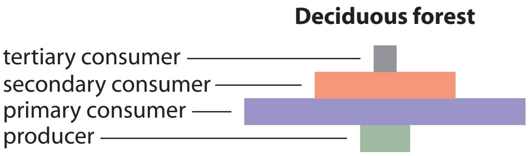


7. **a)** Identify the population(s) that would likely increase if the squid population increased.
   b) Use word processing and/or graphics software to illustrate a food chain in which sea birds are the top predators. Identify the producers, primary consumer, secondary consumer, and tertiary consumer in your food chain. ICT
   c) Assume that only 10 percent of the energy available at one tropic level is passed on to the next trophic level. If the phytoplankton provided 25 000 kJ of energy to the zooplankton, calculate the amount of energy available to the fish.

Use the following information to answer the next question.

Pyramid of Numbers

The following is a pyramid of numbers for a deciduous forest ecosystem.



8. Use word processing or graphics software to illustrate a pyramid of biomass for this same ecosystem. ICT

9. From the energy that a potato beetle gains from its food, the beetle uses 17 percent for growth and loses 33 percent by cellular respiration and 50 percent through feces (wastes). If the potato beetle consumes 750 J of energy, calculate how much of this energy is available to the next trophic level.

10. Identify four properties of water that make it vital to living organisms.

11. a) Identify the biogeochemical cycles that are involved in acid deposition, and explain how it forms.
    b) Describe the impact of acid deposition on a deciduous forest ecosystem.

12. Compare and contrast the relative amount of productivity in:
    a) the Arctic and a tropical rainforest;
    b) the coastal waters of British Columbia and a geologically inactive region of the sea floor; and
    c) a geologically inactive region of the sea floor and a region of the sea floor near a deep sea vent.

13. Explain how the current composition of the atmosphere compares with the composition of the atmosphere three billion years ago.

14. Explain the term metabolic water.

15. Compare the rapid cycling of carbon to the slow cycling of carbon.

16. Living cells capture a tiny amount of available solar radiation. This small amount is enough to support almost all life on Earth.
    a) Predict the consequences if photosynthetic organisms were able to capture twice as much solar energy. Explain.
    b) Predict the consequences if photosynthetic organisms were only able to capture half as much solar energy. Explain.

17. a) Describe dead zones in aquatic ecosystems.
    b) Explain, in terms of the phosphorus cycle, how human activities contribute to the formation of dead zones in lakes.

18. Antarctic krill (*Euphausia superba*) are shrimp-like animals that are abundant in the Southern Ocean. Krill are used as a feed supplement in the aquaculture industry. Some people suggest that krill be harvested for direct human use. What effects might increased krill farming have on Antarctic ecosystems?

19. a) Identify the roles that Alberta's wetlands play in the environment.
    b) Explain how wetlands can help to protect water quality.

Applying Concepts

Use the following information to answer the next question.

Exploring Distant Planets

Suppose that space scientists launch a robotic explorer to a distant planet that is similar to Earth 3.5 billion years ago. The robot reveals that there is liquid water on this planet, and water vapour in the atmosphere surrounding it, but no oxygen. There are many underwater volcanoes, which emit hydrogen gas and hydrogen sulfide gas. Using a special microscope, the robotic explorer also finds communities of bacteria coated with a black precipitate, which are thriving in the warm mineral-rich water.

20. a) As a scientist on the research team, describe how you think the newly discovered bacteria survive.
    b) Do you think this planet could support other forms of life? Explain.

21. Using the rule of 10 as a guide, calculate how much of 2500 J captured by 1.25 kg of a plant shrub would be passed on to a cougar that ate 1.00 kg of deer meat. (Assume that the deer ate 1.25 kg of the shrub.)

22. Summarize one major line of evidence suggesting that Earth's atmosphere was once free of oxygen.

Use the following information to answer the next question.

Space Station

Suppose that you have been asked to help design a space station in which astronauts will live for several years. The astronauts will have no access to outside food and will not be able to remove any waste from the space station during the mission. Water is a limited and expensive resource on board the space station. The reason for this is that there is limited storage space for water and there is no continuous water supply. However, some water can be produced when the fuel cells on board the space station combine oxygen and hydrogen to make electricity. Water may also be recovered from urine and feces from the astronauts.

23. Identify the key features you will include in the space station, and justify your choices.

Use the following information to answer the next question.

Algae and Cyanobacteria

Algae and cyanobacteria use photosynthesis to produce large quantities of oxygen. Both algae and cyanobacteria occur naturally in surface waters. Although their individual size is usually microscopic, when conditions are ideal, both can undergo a phenomenon known as a "bloom." This results when the algae reproduce rapidly and the individuals form clumps visible to the naked eye. It is difficult to predict when a bloom will occur. However, all blooms require light, nutrients, and oxygen. Some species bloom only in spring, others more frequently in the fall. These organisms can bloom in flowing or standing water. Blooms may even occur under ice in the middle of winter. Large, nuisance blooms commonly form following periods of hot, calm weather when the water is warm. They are also more likely to occur when water nutrient levels, and in particular phosphorus, are high.

Most algae do not produce substances that are toxic to humans or animals. In contrast, some cyanobacteria produce substances that are extremely toxic, and are capable of causing serious illness or even death if consumed. These substances are called cyanotoxins.

[Source: Agriculture and Agri-Food Canada; *Algae, Cyanobacteria and Water Quality*; March 2002]

24. a) Explain why it is a problem when algae and cyanobacteria reproduce in large numbers. Why are cyanobacterial blooms even more dangerous than algal blooms?

b) Identify the nutrient that causes them to reproduce in large numbers.

c) Although algal and cyanobacterial blooms occur naturally, many human activities contribute to this problem. Describe three human activities that contribute to blooms in aquatic ecosystems.

25. Use word processing and/or graphics software to illustrate a pyramid of biomass using the following population data from a coral reef: producers, 700 g/m^2; primary consumers, 132 g/m^2; secondary consumers, 11 g/m^2. ICT

26. Some scientists compare the biosphere to a living organism (Gaia Hypothesis). Explain this hypothesis and discuss the transfer of energy and matter through the biosphere.

27. Use word processing or graphics software to construct a flow chart that illustrates the slow cycling of carbon through the biosphere. ICT

28. a) Identify two biogeochemical cycles that are significantly influenced by human activities.

b) Identify the biogeochemical cycles in which bacteria play an important role.

c) Use word processing or graphics software to illustrate one of the biogeochemical cycles identified in "b" above. ICT

Use the following information to answer the next question.

Landfills

Landfill is the major method for waste disposal. Landfills are holes in the ground where the waste is placed, perhaps the site of a disused quarry or pit, or they may be purposefully excavated. Almost everyone uses and discards batteries into the waste stream. Although waste batteries are a small amount of the solid waste stream, they are a concentrated source of some types of heavy metals. The main constituents of concern for human health and the environment include cadmium, lead, and mercury.

29. Explain, in terms of biogeochemical cycles, what might happen to the chemicals in batteries that are put in landfills.

30. On Earth, matter cycles and energy "flows."

a) To make this statement clearer, explain how the concept of matter is different from that of energy in matter and energy exchange in the biosphere.

b) Use graphics software to draw a diagram to illustrate the given statement. ICT

31. Hydrogen sulfide gas reacts with metals, resulting in the precipitation of metal sulfides. Which organisms might you consider using to help clean up aquatic environments contaminated with heavy metals, such as mercury? Explain.

32. Use graphics software to draw a diagram showing how photosynthesis and cellular respiration form a cycle of connected reactions. ICT

Making Connections

Use the following information to answer the next question.

The Real Dirt on No-Till Soil
Jill Clapperton

Soils are formed from a stew of geological ingredients or parent materials (rocks and minerals), water, and billions of organisms. The interactions between climate, parent material, organisms, landscape, and time affect all major ecosystem processes which lead to the development of soil properties that are unique to that soil type and climate. The activities of, and chemicals produced by, soil micro-organisms, and the chemicals leached from plant residues and roots can further influence the weathering of parent materials changing the mineral nutrient content and structure of soil. Thus, farm management practices such as crop rotations, tillage, fallow, irrigation, and nutrient inputs can all affect the population and diversity of soil organisms, and in turn, soil quality.

There are three soil properties that define soil quality: chemical, physical and biological. The chemical properties of a soil are usually related to soil fertility such as available nitrogen (N), phosphorus (P), potassium (K), micronutrient uptake of Cu, Zn, Mn, and etc, as well as [soil] organic matter content (SOM) and pH. Soil structural characteristics such as aggregate formation and stability, tilth, and texture are physical properties. The biological properties of a soil unite the soil physical and chemical properties. For instance, fungi and bacteria recycle all the carbon, nitrogen, phosphorus, sulphur and other nutrients in SOM, including animal residues, into the mineral forms that can be used by plants. By breaking down the complex carbon compounds that make up SOM into simpler compounds, soil organisms acquire their energy.

[Source: Jill Clapperton, "Managing the Soil as a Habitat," *FarmTech* 2004, pp. 38–42]

Note: A soil with good tilth has large pore spaces for adequate air infiltration and water movement. Roots only grow where the soil tilth allows for adequate soil oxygen levels. It also holds a reasonable supply of water and nutrients.

33. a) Explain, in terms of biogeochemical cycles, how the overapplication of insecticides and herbicides could have an impact on the soil structural characteristics.

b) Explain why many farmers apply synthetic fertilizers containing nitrogen and phosphorus to their land before planting their crops in the spring.

Use the following information to answer the next question.

Snow Geese

Since the 1960s, the number of snow geese in Canada has increased from an estimated half a million to three million. For much of the year, the snow geese have easy access to croplands in the United States. In the late spring, the snow geese migrate to their breeding grounds in the Arctic. Some people consider these birds to be a nuisance and a threat to the tundra ecosystem, and feel that the snow geese population should be reduced by culling (killing a portion of the population).

34. Do you think culling the snow geese would help protect the tundra ecosystem? Explain.

Use the following information to answer the next question.

Human activities around the world can affect you here in Canada. Toxic chemicals that are dumped in an ocean might end up in fish you eat for dinner. If you are an Aboriginal hunter in the Arctic, you might ingest traces of the pesticide DDT, sprayed in 2003 by a local health official in Morocco to kill malaria-carrying mosquitoes.

35. Infer how human activities in other countries might affect the environment in Canada, and vice versa.

Use the following information to answer the next question.

Alberta Floods

In June 2005, many regions in Alberta experienced heavy rainfall and floods. During this period, Albertans were asked to restrict their use of water.

36. a) Explain why communities would need to restrict water use during a flood.

b) Given the heavy rains in 2005, explain why many scientists are concerned about water shortages in the future in Alberta.

37. Assuming that ecosystems are self-sustaining and self-regulating, explain why each of the following should or should not be considered an ecosystem:

a) a pond
b) a fish aquarium
c) a wheat farm
d) the city of Edmonton
e) Earth