CK-12 Foundation

FIS Environmental Science

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- Compare ways in which energy is changed from one form to another.
- Discuss what happens when we burn a fuel.
- Describe the difference between renewable and nonrenewable resources, and classify different energy resources as renewable or nonrenewable.

Introduction

Did you know that everything you do takes energy? Even while you are sitting still, your body is using energy to breathe, to keep your blood circulating, and to control many different processes. But it's not just you. Everything that moves or changes in any way—from plants to animals to machines—needs energy. Have you ever wondered where all of this energy comes from?

The Need for Energy

Energy can be defined as the ability to move or change matter. Every living thing needs energy to live and grow. Your body gets its energy from food, but that is only a small part of the energy you use every day. Cooking your food takes energy, and so does keeping it cold in the refrigerator or the freezer. The same is true for heating or cooling your home. Whether you are turning on a light in the kitchen or riding in a car to school, you are using energy all day long. And because billions of people all around the world use energy, there is a huge need for resources to provide all of this energy. Why do we need so much energy? The main reason is that almost everything that happens on Earth involves energy. Most of the time when something happens, energy is changing forms.

Even though energy does change form, the total amount of energy always stays the same. The Law of Conservation of Energy says that energy cannot be created or destroyed. Scientists discovered this law by noticing that any time they observed energy changing from one form to another, they could measure that the overall amount of energy did not change.

For an example of how energy changes from one form to another, think about what goes on when you kick a soccer ball. Your body gets its energy from food. When your body breaks down the food you eat, it

Figure 1.1: Electrical transmission towers like the one shown in this picture help deliver the electricity that you use for energy every day.

stores the energy from the food in a form called **chemical energy**. But some of this stored energy has to be released to make your leg muscles move. When this happens, the energy that is released changes from chemical energy to another form, called **kinetic energy**. Kinetic energy is the energy of anything in motion. Your muscles move your leg, your foot kicks the ball, and the ball gains kinetic energy by being kicked. So you can think of the action of kicking the ball as a story of energy moving and changing forms. The same is true for anything that happens involving movement or change. **Potential energy** is energy that is stored. Potential energy has the potential to do work or the potential to be converted into other forms of energy. An example of potential energy might be the ball you kicked, if it ended up at the top of a hill.

Energy, Fuel, and Heat

As you have learned, energy is the ability to move or change matter. To put it another way, you could say that energy is the ability to do work. But what makes energy available whenever you need it? If you have ever accidentally unplugged a lamp while you were using it, you have seen that the lamp does not have a supply of energy to keep itself lit. When the lamp is plugged into an outlet, it has the source of energy it needs—electricity. The electricity comes from a power plant, and the power plant has to have energy to produce this electricity (**Figure** 1.1). The energy to make the electricity comes from a fuel, which stores the energy and releases it when it is needed. A fuel is any material that can release energy in a chemical change. The food you eat acts as a *fuel* for your body. You probably hear the word fuel most often when someone refers to its use in transportation. Gasoline and diesel fuel are two fuels that provide the energy for most cars, trucks, and buses. But many different kinds of fuel are used to meet the wide variety of needs for energy storage.

For a fuel to be useful, its energy must be released in a way that can be controlled. Controlling the release of the energy makes it possible for the energy to be used to do work. When a fuel is used for its energy, the fuel is usually burned, and most of the energy is released as heat. The heat can be used to do work. For an example of how the energy in a fuel is released mostly as heat, think about what happens when someone starts a fire in a fireplace. First, the person strikes a match and uses it to set some small twigs on fire. After the twigs have burned for a while, they get hot enough to make some larger sticks burn. The fire keeps getting hotter, and soon it is hot enough to burn whole logs.

You might think at first that the heat comes from starting the fire. After all, someone struck a match to start the fire, and then the fire just spread, right? But if you think about this fire in terms of energy, almost all of the heat comes from the energy that has been stored in the wood. In other words, the wood is the fuel for the fire. There is a reason why it is easy to be confused about the source of the fire's heat. The reason is that some energy has to be put into *starting* the fire before any energy can come out of the fire. At first, there is energy stored in the head of the match as chemical energy. When someone strikes a match, this chemical energy is released as heat.

The lit match gives off enough heat to set the twigs on fire. This heat is enough energy to start changing the chemical energy in the wood (and the oxygen in the air, which the wood needs in order to burn) into heat. What happens is that the heat from the match breaks chemical bonds in the twigs. When these bonds break, the atoms in the twigs are free to move around and form new bonds. When the atoms form new bonds, they release more heat. This heat causes more and more of the wood to change its stored chemical energy into heat. So, what started as a fairly small amount of heat from the match turns into a much, much larger amount of heat from the wood. The same thing is true for any fuel. We have to add some energy to the fuel to get it started. But once the fuel starts burning, it keeps changing its chemical energy into heat. As long as the conditions are right, the fuel will keep turning its energy into heat until the fuel is all gone.

Types of Energy Resources

Energy resources can be put into two categories—either renewable or nonrenewable. Resources that are *nonrenewable* are used faster than they can be replaced (**Figure** 1.2). Other resources that are called *renewable* will never run out. In most cases, these resources are replaced as quickly as they are used.

In a way, the difference between nonrenewable and renewable resources is like the difference between ordinary batteries and rechargeable ones. If you have a flashlight at home that uses ordinary batteries, and you accidentally leave the flashlight on all night long, you will need to buy new batteries once the ones in the flashlight have died. The energy in the ordinary batteries is nonrenewable. But if the flashlight has rechargeable batteries, you can put them in a battery charger and use them in the flashlight again. In this way, the energy in the rechargeable batteries is "renewable."

Fossil fuels are the most common example of nonrenewable energy resources. Renewable energy resources include solar, water, and wind power. If you traced the energy in all of these resources back to its origin, you would find that almost all energy resources—not just solar energy—come from the sun. Fossil fuels are made of the remains of plants and animals that stored the sun's energy millions of years ago. These plants and animals got all of their energy from the sun, either directly or indirectly. The sun heats some areas more than others, which causes wind. The sun's energy drives the water cycle, which moves water

Figure 1.2: Like other fossil fuels, this piece of anthracite coal is a nonrenewable energy resource.

over the surface of the Earth. Both wind and water power can be used as renewable resources.

Types of Nonrenewable Resources

Fossil fuels, which include coal, oil, and natural gas are nonrenewable resources. Millions of years ago, plants used energy from the sun to form sugars, carbohydrates, and other energy-rich carbon compounds that were later transformed into coal, oil, or natural gas. The solar energy stored in these fuels is a rich source of energy, but while fossil fuels took millions of years to form, we are using them up in a matter of decades and will soon run out. Fossil fuels are nonrenewable resources. The burning of fossil fuels also releases large amounts of the greenhouse gas carbon dioxide.

Types of Renewable Resources

Renewable energy resources include solar, water, wind, biomass, and geothermal power. These resources can usually be replaced at the same rate that we use them. Scientists know that the sun will continue to shine for billions of years and we can use the energy from the sun as long as we have a sun. Water flows from high places to lower ones and wind blows from areas of high pressure to areas of low pressure. We can use the flow of wind and water to generate power and we can count on wind and water to continue to flow. Some examples of biomass energy are burning something like wood or changing grains into biofuels. We can plant new trees or crops to replace the ones we use. Geothermal energy uses water in the rocks that has been heated by magma. The magma will heat more water in the rocks as we take hot water out.

Even renewable resources can come with problems, though. We could cut down too many trees or we might need grains to be used for food rather than biofuels. Some renewable resources have been too expensive to be widely used or cause some types of environmental problems. As the technology improves and more people use renewable energy, the prices may come down. And, as we use up fossil fuels, they will become more expensive. At some point, even if renewable energy is expensive, nonrenewable energy will be even more expensive. Ultimately, we will have to use renewable sources (and conserve).

Important Things to Consider About Energy Resources

With both renewable and nonrenewable resources, there are at least two important things to consider. One is that we have to have a practical way to turn the resource into a useful form of energy. The other is that we have to consider what happens when we turn the resource into energy.

For example, if we get much less energy from burning a fuel than we put into making it, then that fuel is probably not a practical energy resource. On the other hand, if another fuel gives us large amounts of energy but also creates large amounts of pollution, that fuel also may not be the best choice for an energy resource.

Lesson Summary

- According to the law of conservation of energy, energy is neither created or destroyed.
- Renewable resources can be replaced at the rate they are being used.
- Nonrenewable resources are available in limited amounts or are being used faster than they can be replaced.

Interdisciplinary Connection

Health: Read the nutrition labels on some food packages in your kitchen or at the grocery store. How is the energy in food measured? What are some foods that provide the most energy per serving? Are the foods that contain the most energy the most healthful foods?

Review Questions

1. What is needed by anything that moves or changes in any way
2. What is the original source of most of our energy?
3. When your body breaks down the food you eat, in what form does it store the energy from the food?
4. When we burn a fuel, what is released that allows work to be done?
5. For biomass, coal, natural gas, oil and geothermal energy, identify each energy resource as renewable or nonrenewable. Explain your reasoning.
6. What factors are important in judging how helpful an energy resource is to us?
7. Is a rechargeable battery a renewable source of energy? Explain.

Further Reading / Supplemental Links

- Kydes, Andy, ”Primary Energy.” Encyclopedia of Earth, 2006. Available on the Web at:
- `http://www.eoearth.org/article/Primary_energy`
- `http://www.earthportal.org/`

Vocabulary

chemical energy Energy that is stored in the connections between atoms in a chemical substance.

energy The ability to move or change matter.

fuel Material that can release energy in a chemical change.

kinetic energy The energy that an object in motion has because of its motion.

law of conservation of energy Law stating that energy cannot be created or destroyed.

potential energy Energy stored within a physical system.

Points to Consider

- How long do fossil fuels take to form?
- Are all fossil fuels nonrenewable resources?
- Do all fossil fuels affect the environment equally?

1.2 Nonrenewable Energy Resources

Lesson Objectives

- Describe the natural processes that formed different fossil fuels.
- Describe different fossil fuels, and understand why they are nonrenewable resources.
- Explain how fossil fuels are turned into useful forms of energy.
- Understand that when we burn a fossil fuel, most of its energy is released as heat.
- Describe how the use of fossil fuels affects the environment.
- Describe how a nuclear power plant produces energy.

Introduction

Have you ever seen dinosaur fossils at a museum? If so, you may have read about how the dinosaur bones turned into fossils. The same processes that formed these fossils also formed some of our most important energy resources. These resources are called fossil fuels. Fossil fuels provide a very high quality energy, but because of our demand for energy, we are using up these resources much faster than they formed.

Formation of Fossil Fuels

As you might guess from their name, fossil fuels are made from fossils. Fossil fuels come from materials that began forming about 500 million years ago. As plants and animals died, their remains settled on the ground and at the bottom of bodies of water. Over time, these remains formed layer after layer. Eventually, all of these layers were buried deep enough that they were under an enormous mass of earth. The weight of the earth pressing down on these layers created intense heat and pressure.

After millions of years of heat and pressure, the material in these layers turned into chemicals called *hydrocarbons,* which are compounds of carbon and hydrogen. The hydrocarbons in these layers are what we call fossil fuels. The hydrocarbons could be solid, liquid, or gaseous. The solid form is what we know as coal. The liquid form is petroleum, or crude oil. We call the gaseous hydrocarbons natural gas.

You may be surprised to learn that anything that used to be alive could change enough to become something so different, such as coal or oil. There is enough heat and pressure deep below the earth's surface even to create diamonds, which are the hardest natural material in the world.

Like fossil fuels, diamond is made of carbon. In fact, diamond is a type of pure carbon, so it does not contain the hydrogen that fossil fuels do. What determines whether the remains of living things deep in the earth turn into coal, oil, natural gas, diamond, or something else? All of these materials form under high heat and pressure, but the conditions are different for each material.

Coal

Coal is the solid fossil fuel that forms from dead plants that settled at the bottom of swamps millions of years ago. The water and mud in the swamps affected how the remains of plants broke down as they were compressed. The water and mud in the swamp keep oxygen away from the plant material. When plants are buried without oxygen, the organic material can be preserved or fossilized. Then, other material, such as sand and clay, settles on top of the decaying plants and squeezes out the water and some other substances. Over time, the pressure removes most of the material other than carbon, and the carbon-containing material forms a layer of rock that we know as coal.

Coal is black or brownish-black in appearance. Coal is a rock that burns easily. Most forms of coal are *sedimentary* rock. But the hardest type of coal, anthracite, is a *metamorphic* rock, because it is exposed to higher temperature and pressure as it forms. Coal is mostly carbon, but some other elements can be found in coal, including sulfur.

Around the world, coal is the largest source of energy for electricity. The United States is rich in coal, which is used for electricity. California once had a number of small coal mines but the state no longer produces coal.

A common way of turning coal into a useful form to make electricity starts with crushing the coal into powder. Then, a power plant burns the powder in a furnace that has a boiler. Like other fuels, coal releases most of its energy as heat when it burns. The heat that the burning coal releases in the furnace is enough to boil the water in the boiler, making steam. The power plant uses this steam to spin turbines, and the spinning turbines make generators turn to create electricity.

For people to use coal as an energy source, they need to get it out of the ground. The process of removing coal from the ground is known as coal mining. Coal mining can take place underground or at the surface. The process of coal mining, especially surface mining, affects the environment. Surface mining exposes minerals from underground to air and water from the surface. These minerals contain the chemical element sulfur, and sulfur mixes with air and water to make sulfuric acid, which is a highly corrosive chemical. The sulfuric acid gets into nearby streams and can kill fish, plants, and animals that live in or near the water. The process of burning coal causes other problems for the environment. A little later, we will look at these other pollution problems, when we explore problems with fossil fuels in general.

Oil

Figure 1.3: Refineries like this one separate crude oil into many useful fuels and other chemicals.

Oil is a thick liquid that is usually dark brown or black in appearance. It is found mostly in formations of porous rock in the upper layers of the Earth's crust. Oil is currently the single largest source of energy in the world. How does oil form? The process of making oil is similar in many ways to the process of making coal. The main difference is in the size of the living things—the organisms—whose remains turn into these fossil fuels. The organisms that die and became the material for making oil are much smaller than the plants that turned into coal. These organisms are called plankton and algae. When the plankton and algae die, their remains settle to the bottom of the sea. There, they were buried away from oxygen, just as the plants did in the process of becoming coal. As layers of sediment pile on top of these decaying organisms, heat and pressure increase. Over a period of millions of years, the heat and pressure turn the material into liquid oil.

The United States produces oil, although only about one-quarter as much as it uses. The main oil producing regions are the Gulf of Mexico, Texas, Alaska, and California. Most of California's oil fields are in the southern San Joaquin Valley. Compression from when the region was a convergent plate boundary produced a set of anticlines that are parallel to the San Andreas Fault. Oil collects in permeable sediments that are capped by an impermeable cap rock. Oil is also pumped on and off the southern California coast.

Oil as it comes out of the ground is called crude oil. Crude oil is a mixture of many different hydrocarbons. Oil refining is used to separate the compounds in this mixture from one another (**Figure** 1.3). We can separate crude oil into several useful fuels because each hydrocarbon compound in crude oil boils at a different temperature. An oil refinery heats the crude oil enough to boil the mixture of compounds. Special equipment in the refinery separates these compounds from one another as they boil.

Most of the compounds that come out of the refining process are fuels. The rest make up waxes, plastics, fertilizers, and other products. The fuels that come from crude oil, including gasoline, diesel, and heating oil, are rich sources of energy that can be easily transported. Because of this, fuels from oil provide about 90% of the energy used for transportation around the world.

We get gasoline from refining oil. Like oil, gasoline is most commonly used for transportation because it is a concentrated form of energy that is easily carried. Let's consider how gasoline powers a car. Like other fuels you have learned about, gasoline burns and releases most of its energy as heat. When it burns, the gasoline turns into carbon dioxide gas and water vapor. The heat makes these gases expand, like the heated air that fills a hot-air balloon. The expanding gases create enough force to move pistons inside an engine, and the engine makes enough power to move the car.

When a resource like gasoline is concentrated in energy; it contains a large amount of energy for its weight. This is important because the more an object weighs, the more energy it takes to move that object. If we could only get a little energy from a certain amount of gasoline, a car would have to carry more of it to be able to travel very far. But carrying more gasoline would make the car heavier, so moving the car would take even more energy. So a resource with highly concentrated energy is a practical fuel to power cars and other forms of transportation.

Unfortunately, using gasoline to power automobiles also affects the environment. The exhaust fumes from burning gasoline include gases that cause many different types of pollution, including smog and ground-level ozone. These forms of pollution cause air-quality problems for cities where large numbers of people drive every day. Burning gasoline also produces carbon dioxide, which is a cause of global warming.

Natural Gas

Natural gas is a fuel that is a mixture of methane and several other chemical compounds. It is often found along with coal or oil in underground deposits. The conditions that create natural gas are similar to those that create oil. In both cases, small organisms called plankton and algae die and settle to the bottom of the sea. In both cases, the remains of these organisms decay without oxygen being present. The difference is that natural gas forms at higher temperatures than oil does.

The largest natural gas reserves in the United States is found are in the Rocky Mountain states, Texas and the Gulf of Mexico region. California also has natural gas, mostly in the northern Sacramento Valley and the Sacramento Delta. In that region, a sediment filled trough formed aside an ancient convergent margin. Organic material buried in the sediments hardened to become a shale formation that is the source of the gas.

Because it is a mixture of different chemicals, natural gas must be processed before it can be used as a fuel. Some of the chemicals in unprocessed natural gas are poisonous to humans. Other parts, such as water, make the gas a less useful fuel. The processing removes almost everything but methane from natural gas. At this point, the gas is ready to be delivered and used.

Natural gas, often known simply as gas, is delivered to homes for uses such as cooking and heating. Many ranges and ovens use natural gas as a fuel, and gas-powered furnaces, boilers, water heaters, and clothes dryers are also common.

Natural gas is a major source of energy for powering gas turbines and steam turbines to make electricity. When it is used in this way, natural gas works similarly to the way coal does in producing energy for electricity. Like coal and other fuels, natural gas releases most of its energy as heat when it burns. The power plant is able to use this heat, either in the form of hot gases or steam from heated water, to spin turbines. The spinning turbines turn generators, and the generators create electricity.

Processing and using natural gas does have some harmful effects on the environment. Natural gas does burn cleaner than other fossil fuels, meaning that it causes less air pollution. It also produces less carbon dioxide than the other fossil fuels for the same amount of energy.

Problems with Fossil Fuels

Although they are rich sources of energy, fossil fuels do present many problems. Because these fuels are nonrenewable resources, their supplies will eventually run out. Safety can be a problem, too, because these fuels burn so easily. For example, a natural gas leak in a building or an underground pipe can lead to a deadly explosion.

Using fossil fuels affects the environment in a variety of ways. There are impacts to the environment when we extract these resources. There are problems that arise because we are running out of supplies of these resources. Burning these fuels can cause air pollution and burning them releases carbon dioxide, which is a major factor in global warming (**Figure** 1.4).

Many of the problems with fossil fuels are worse for coal than for oil or natural gas. Coal contains less energy for the amount of carbon it contains than oil or gas. As a result, burning coal releases more carbon

Figure 1.4: Coal power plants like this one release large amounts of steam and smoke into the air.

dioxide than burning either oil or gas (for the same energy). And yet coal is the most common fossil fuel and so we continue to burn large amounts of it. Coal is the biggest contributor to global warming.

Another problem with coal is that it usually contains sulfur. When coal burns, the sulfur goes into the air as sulfur dioxide. Sulfur dioxide is the main cause of acid rain, which can be deadly to plants, animals, and whole ecosystems. Burning coal also puts other polluting chemicals and a large number of small solid ”particulates” into the air. These particles are dangerous to people, especially those who have an illness, like asthma, that makes breathing hard for them.

Nuclear Energy

When scientists learned how to split the nucleus of an atom, they released a huge amount of energy. Scientists and engineers have learned to control this release of energy. The controlled release of this energy is called *nuclear energy*. Nuclear power plants use uranium that has been processed and concentrated in fuel rods (**Figure** 1.5). The uranium atoms are split apart when they are hit by other extremely tiny particles. These extremely tiny particles need to be controlled or they would cause a dangerous explosion.

Nuclear power plants use the energy they produce to heat water. Once the water is heated, the process is a lot like what happens in a coal power plant. The hot water or steam causes a turbine to spin. When the turbine spins, it makes a generator turn, which in turn produces electricity.

Many countries around the world use nuclear energy as a source of electricity. For example, France gets about 80% of its electricity from nuclear energy. In the United States, a little less than 20% of electricity comes from nuclear energy.

Nuclear energy does not pollute the air. In fact, a nuclear power plant releases nothing but steam into the air. But nuclear energy does create other environmental problems. The process of splitting atoms creates a dangerous by-product called radioactive waste. The radioactive wastes produced by nuclear power plants remain dangerous for thousands or hundreds of thousands of years. So far, concerns about this waste have kept nuclear energy from being a larger source of energy in this country. Scientists and engineers are looking for ways to keep this waste safely away from people.

Figure 1.5: Nuclear power plants like this one provide France with almost 80% of its electricity.

Lesson Summary

- Coal, oil and natural gas are all fossil fuels formed from the remains of once living organisms.
- Coal is our largest source of energy for producing electricity.
- Mining and using coal produce many environmental impacts, including carbon dioxide emissions and acid rain.
- Oil and natural gas are important sources of energy for many types of vehicles and uses in our homes and industry.
- Nuclear energy is produced by splitting atoms. It also produces radioactive wastes that are very dangerous for many years.
- Fossil fuels are nonrenewable sources of energy that produce environmental damage.

Interdisciplinary Connection

Social Studies: Find a map that shows the location of oil refineries in the United States. Which states have the most refineries?

Review Questions

1. How does a fossil fuel form?
2. The hardest type of coal is called anthracite. Why is anthracite harder than other kinds of coal?
3. What product of nuclear energy has caused concerns about the use of this resource?
4. What is one important fuel that comes out of the oil refining process?
5. Which chemical element exposed in surface coal mining can cause environmental problems in nearby bodies of water?
6. Waxes can be made from the processing of which fossil fuel?
7. Why does natural gas need to be processed before we can use it as a fuel?
8. What are some problems with using coal? but not for using gasoline?
9. What characteristic of gasoline is most important in making it a useful fuel for transportation? Explain.

10. Does nuclear energy cause air pollution? Explain.

Further Reading / Supplemental Links

- Perry, Mildred, "Coal." Encyclopedia of Earth, 2007. Available on the Web at
- `http://www.eoearth.org/article/Coal`
- `http://www.earthportal.org/`

Vocabulary

corrosive Able to cause chemical changes to a substance that weaken or destroy the substance.

hydrocarbon A chemical compound that contains only carbon and hydrogen.

metamorphic A type of rock that forms when existing rock is exposed to high temperature and pressure.

nuclear energy Energy that is released from the nucleus of an atom when it is changed into another atom.

sedimentary A type of rock that forms from layers of sediment under high pressure.

Points to Consider

1. How are renewable sources of energy different from nonrenewable sources of energy?
2. Are all renewable energy sources equally practical?
3. Are all renewable energy sources equally good for the environment?

1.3 Renewable Energy Resources

Lesson Objectives

- Describe different renewable resources, and understand why they are renewable.
- Understand that the sun is the source of most of Earth's energy.
- Describe how energy is carried from one place to another as heat and by moving objects.
- Understand how conduction, convection, and radiation transfer energy as heat when renewable energy sources are used.
- Understand that some renewable energy sources cost less than others and some cause less pollution than others.
- Explain how renewable energy resources are turned into useful forms of energy.
- Describe how the use of different renewable energy resources affects the environment.

Introduction

What if we could have all of the energy we needed and never run out of it? What if we could use this energy without polluting the air and water? In the future, renewable sources of energy may be able to provide all of the energy we need. Some of these resources can give us “clean” energy that causes little or no pollution.

Plenty of clean energy is available for us to use. The largest amount of energy to reach Earth’s surface is from solar radiation. Each year is 174 petawatts (1.74 x 1017 W) of energy from the sun enter the Earth’s atmosphere. Because the planet’s interior is hot, heat flows outward from the interior, providing about 23 terawatts (2.3 x 1013 W) of energy per year. By contrast, the total world power consumption is around 16 terawatts (1.6 x 1013W) per year. So solar or geothermal energy alone could provide all of the energy needed for people if it could be harnessed.

Solar Energy

Figure 1.6: Solar panels like these can turn the sun’s energy into electricity to provide power to homes.

When you think of the sun, you probably think of two things—light and heat. The sun is Earth’s main source of energy, and light and heat are two different kinds of energy that the sun makes. The sun makes this energy when one element, called hydrogen, changes into another element, called helium. Changing hydrogen into helium releases huge amounts of energy. The energy travels to the Earth mostly as visible light. The light carries the energy through the empty space between the sun and the Earth in a process called **radiation**. We can use this light from the sun as an energy resource called solar energy (**Figure** 1.6).

Solar energy is a resource that has been used on a small scale for hundreds of years. Its use on a larger scale is just starting to ramp up and people increase production of renewable energy sources. One focus of solar power development in the United States is the desert southwest. Solar power plants are in the works for southeastern California, near the California-Nevada border.

Solar energy is used to heat homes, to heat water, and to make electricity. Solar energy can be used to heat the water in your pool or to heat tile floors in your home. In recent years, scientists and engineers have found new ways to get more and more energy from this resource (Figure below). Because there are many different uses for solar energy, there are also many different ways of turning the sun’s energy into useful forms. One of the most common ways is by using solar cells. Solar cells are devices that can turn sunlight directly into electricity. You may have seen solar panels on roof tops. Lots of solar cells make up an individual solar panel.

Solar power plants turn sunlight into electricity using a large group of mirrors to focus sunlight on one place, called a receiver (**Figure** 1.8). When a liquid, such as oil or water flows through this receiver, the focused sunlight heats the liquid to a high temperature. Then, this heated liquid transfers its heat by **conduction**. In conduction, energy moves between two objects that are in contact with one another. The object that is at a higher temperature transfers energy as heat to the object that is at a lower temperature. For example, when you heat a pot of water on a stove top, conduction causes energy to move from the pot to its metal handle, and the handle gets very hot. In the case of the solar power plant, the energy conducted by the heated liquid is used to make electricity.

Solar energy has many benefits. It does not produce any pollution. Also, there is plenty of it available. In fact, the amount of energy that reaches Earth from the sun every day is many times more than all of the energy we use. For this reason, we consider solar energy a renewable form of energy. For as long as sunlight continues to warm the Earth, we will never run out of this resource. One problem with solar energy is that it cannot be used at night, unless a special battery stores extra energy during the day for use at night. The technology for most uses of solar energy is still expensive. Until this technology becomes more affordable, most people will prefer to get their energy from other sources. As you learned earlier, most of the Earth's energy comes from the sun. Other renewable resources also come from the sun originally. You will be learning about these resources later in this lesson.

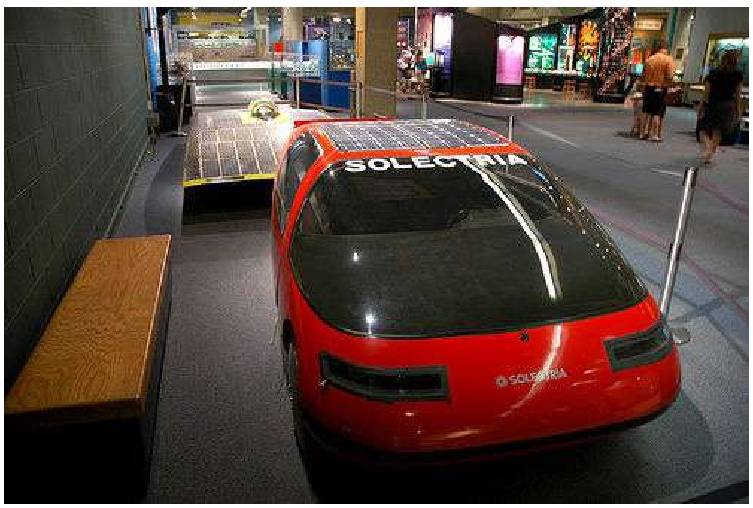

Figure 1.7: This experimental car is one example of the many uses that engineers have found for solar energy.

Figure 1.8: This solar power plant uses mirrors to focus sunlight on the tower in the center. The sunlight heats a liquid inside the tower to a very high temperature, producing energy to make electricity.

Water Power

Figure 1.9: Hydroelectric dams like this one use the power of moving water to create electricity.

Earlier in this lesson, you learned that energy can travel in the form of light and heat, just as it does when it travels from the sun to the Earth. Now, you will learn about one way in which energy can travel in the form of a moving object. In this case, the moving object is water (**Figure** 1.9). Water power uses the energy of water in motion to make electricity. It is the most widely used form of renewable energy in the world, and it provides almost one fifth of the world's electricity.

In most power plants that use water power, a dam holds water back from where it would normally flow. Instead, the water is allowed to flow into a large turbine. Because the water is moving, it has energy of motion, called kinetic energy. The energy of this moving water makes the turbine spin. The turbine is connected to a generator, which makes electricity.

Many of the streams in the United States where water flows down a slope have probably been developed for hydroelectric power. This is a major source of California's electricity, about 14.5 percent of the total. Most of California's nearly 400 hydropower plants are located in the eastern mountain ranges where large streams descend down a steep grade.

One big benefit of water power is that it does not burn a fuel. This benefit gives water power an advantage over most other energy resources in how it affects the environment. Because water power does not burn a fuel, it causes less pollution than many other kinds of energy. Another benefit of water power is that, like the other resources you are learning about in this lesson, it is a renewable resource. We use energy from the water's movement, but we are not using up the water itself. Water keeps flowing into our rivers and lakes, so wherever we can build plants to use it, water will be available as a source of energy. The energy of waves and tides can also be used to produce water power.

Water power does have its problems, though. When a large dam is built, this creates a reservoir, changing the ecosystem upstream. Large river ecosystems are inundated, killing all the plants and animals. The dams and turbines also change the downstream environment for fish and other living things. Dams also slow the release of silt, so that downstream deltas retreat and seaside cities become dangerously exposed to storms and rising sea levels. Tidal power stations may need to close off a narrow bay or estuary. Wave power applications have to be able to withstand coastal storms and the corrosion of seawater.

Wind Power

Figure 1.10: Wind turbines like the ones shown above turn wind into electricity without creating pollution.

As you learned earlier, the sun provides plenty of energy to the Earth. The energy from the sun also creates wind (**Figure** 1.10). Learning about what causes wind will help you understand that energy can move as heat, not just by radiation and conduction, but also by convection. Wind happens when the sun heats some parts of the Earth differently. For example, sunlight hits the equator much more directly than it hits the North and South Poles. Hot air rises and cooler air moves in, so when the air near the equator is heated much more than the air near the poles, the air begins to move carrying heat through the air in a process called **convection**. This movement of air is wind.

Wind power uses moving air as a source of energy. Some examples of wind power have been around for a long time. Windmills have been used to grind grain and pump water for hundreds of years. Ships with sails have depended on wind for even longer. Wind can be used to generate electricity, too. Like the moving water that creates water power, the moving air can make a turbine spin to make electricity.

To help you understand how moving air can be used to make electricity, you could think back to what you have learned about energy of motion, called kinetic energy. Any form of matter that is moving has kinetic energy. Even though you cannot see air, it is matter, because it takes up space and has mass. So, when wind makes the air move, this air has kinetic energy. When the moving air hits the blades of a turbine, it makes those blades move, and the turbine spins. The spinning of the turbine creates electricity.

Wind power has many advantages. It is clean energy, meaning that it does not cause pollution or release carbon dioxide. Also, wind is plentiful almost everywhere. One problem with wind energy is that the wind does not blow all of the time. One solution is to find efficient ways to store energy for later use. Until then, another energy source needs to be available when the wind is not blowing. Lastly, windmills are expensive and wear out quickly. For the amount of energy they generate, windmills are more expensive than some other forms of renewable energy.

California was an early adopter of wind power. Windmills are found in mountain passes, especially where cooler Pacific ocean air is sucked across the passes and into the warmer inland valleys. Large fields of windmills can be seen at Altamont pass in the eastern San Francisco Bay Area, San Gorgonio Pass east of Los Angeles, and Tehachapi Pass at the southern end of the San Joaquin Valley.

Biomass

Another renewable source of energy is biomass. Biomass is the material that comes from plants and animals that were recently living. Biomass also includes the waste that plants and animals produce. People can use biomass directly for heating. For example, many people burn wood in fireplaces or in wood-burning stoves.

Besides burning biomass directly for heating, people can process biomass to make fuel. This processing makes what is called biofuel. Biofuel is a fairly new type of energy that is becoming more popular. People can use fuels from biomass in many of the same ways that they use fossil fuels. For example, some mechanics have made changes to car, truck, and bus engines to allow them to use a fuel called biodiesel. Other engines can run on pure vegetable oil or even recycled vegetable oil.

If we use fuels made from biomass, we can cut down on the amount of fossil fuel that we use. Because living plants take carbon dioxide out of the air, growing plants for biofuel can mean that we will put less of this gas into the air overall. This could help us do something about the problem of global warming.

Geothermal Energy

Geothermal energy is a source of energy that comes from heat deep below the surface of the Earth. This heat produces hot water and steam from rocks that are heated by magma. Power plants that use this type of energy get to the heat by drilling wells into these rocks. The hot water or steam comes up through these wells. Then, the hot water or steam makes a turbine spin to make electricity. Because the hot water or steam can be used directly to make a turbine spin, geothermal energy is a resource that can be used without processing. The fact that it does not need to be processed makes geothermal energy different from most other energy resources. Geothermal energy is clean and safe. It is renewable, too, because the power plant can pump the hot water back into the underground pool. There, the water can pick up heat to make more steam.

This source of energy is an excellent resource in some parts of the world. For example, Iceland is a country that gets about one fourth of its electricity from geothermal sources. In the United States, California leads all states in producing geothermal energy. Geothermal energy in California is concentrated in a few areas in the northern part of the state. The largest geothermal power plant in the state is in the Geysers Geothermal Resource Area in Napa and Sonoma Counties. The source of heat is thought to be a large magma chamber lying beneath the area, a part of the Pacific Ring of Fire. Many parts of the world do not have underground sources of heat that are close enough to the surface for building geothermal power plants.

Lesson Summary

- Solar energy, water power, wind power, biomass energy and geothermal energy are renewable energy sources.
- Solar energy can be used either by passively storing and holding the sun's heat, converting it to electricity or concentrating it.
- There are many ways to use the energy of moving water including hydroelectric dams.
- Wind power uses the energy of moving air to turn turbines.
- Biomass energy uses renewable materials like wood or grains to produce energy.
- Geothermal energy uses heat from deep within the earth to heat homes or produce steam that turns turbines.

Review Questions

1. If you turn on the burner on a gas stove under a pan of cold water, energy moves from the burner to the pan of water. What is this energy called? How does this energy move?
2. What are some ways that we can use solar power?
3. If you burn wood in a fireplace, which type of energy resource are you using?
4. Which form of energy is an important factor in making electricity from water power?
5. When the air moves around as wind, it carries heat from warmer areas to cooler areas. What is this movement of heat called?
6. Most of the energy that travels from the sun to the Earth arrives in the form of visible light. What is this movement of energy called?
7. Explain how mirrors can be useful in some solar energy plants.
8. Explain how wind power uses kinetic energy.

Further Reading / Supplemental Links

- Cleveland, Cutler, "Energy Transitions Past and Future." Encyclopedia of Earth, 2007. Available on the Web at:
- `http://www.eoearth.org/article/Energy_transitions_past_and_future`
- `http://www.earthportal.org/`

Vocabulary

conduction The process in which energy moves through matter as heat, moving from an area of higher temperature to an area of lower temperature.

convection The movement of heat in an air current from a warmer space to a cooler space.

radiation The movement of energy through empty space.

Points to Consider

- What areas do you think would be best for using solar energy?
- What causes the high temperatures deep inside the Earth that make geothermal energy possible?
- Do you think your town or city could use wind or water power?

Image Sources

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Chapter 2

Earth's Fresh Water

2.1 Water on Earth

Lesson Objectives

- Describe how water is distributed on Earth.
- Describe what powers the water cycle and how water moves through this cycle.

Introduction

Water is a simple compound, made of two atoms of hydrogen and one atom of oxygen bonded together. More than any other substance on the Earth, water is important to life and has remarkable properties. Without water, life could probably not even exist on Earth. When looking at Earth from space, the abundance of water on Earth becomes obvious — see **Figure** 2.1. On land, water is also common: it swirls and meanders through streams, falls from the sky, freezes into snow flakes, and even makes up most of you and me. In this chapter, we'll look at the distribution of water on Earth, and also examine some of its unique properties.

Distribution of Earth's Water

As **Figure** 2.1 makes clear, water is the most abundant substance on the Earth's surface. About 71% of the Earth's surface is covered with water, most of which is found in the oceans. In fact, 97% of Earth's water, nearly all of it, is in the Earth's oceans. This means that just 3% of Earth's water is **fresh water**, water with low concentrations of salts (**Figure** 2.2). Most freshwater is found as ice in the vast glaciers of Greenland and the immense ice sheets of Antarctica. That leaves just 0.6% of Earth's water that is freshwater that humans can easily use. Most liquid freshwater is found under the Earth's surface as groundwater, while the rest is found in lakes, rivers, and streams, and water vapor in the sky.

The Water Cycle

Water is a special substance. It is abundant on Earth and frequently appears as a gas, liquid, and solid. It is one of the few substances on Earth that is frequently found in all three phases of matter. Moreover, it can readily cycle through the globe: the same molecule can travel through many different regions on

Figure 2.1: Earth, the Blue Marble, can be seen in this photograph to be mostly covered with liquid water.

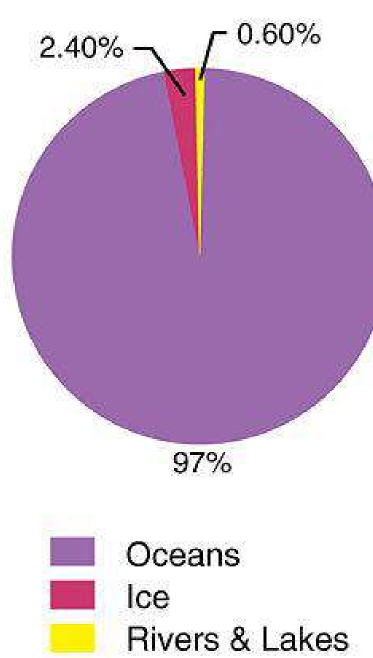


Figure 2.2: Earths water is mostly in the oceans. Fresh water is only 3% of all the Earths water, and most of that is in the form of ice.

Earth.

Three States of Water

Part of the reason that water is unique is because of its melting point and boiling point. Under normal atmospheric conditions, water freezes at 0°C (32°F) and boils at 100°C (212°F). Because of our Earth's position in the solar system, Earth's temperature varies from far below the melting point of water to well above that melting point. Even though water does not boil at normal temperatures, it often becomes gaseous **water vapor** by evaporating. All this means that we frequently see water in its three phases on Earth (See **Figures** 2.3, 2.4, and 2.5).

Figure 2.3: Solid ice floating amidst liquid water. This image shows what an iceberg might look like if you could see both above and below the surface.

Figure 2.4: Liquid water.

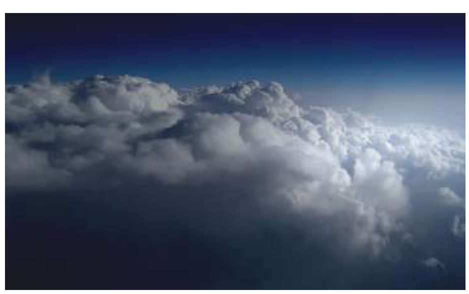


Figure 2.5: Water vapor is invisible to our eyes. However, we can see the clouds that form when water vapor condenses.

The Water Cycle

The water on Earth moves about the Earth in what is known as the **water cycle** (**Figure** 2.6). Because it is a cycle, there truly is no beginning and no end. The very same water molecule found in your glass of water today has probably been on the Earth for billions of years. It may have been in a glacier or far below the ground. It may have been high up in the atmosphere and deep in the belly of a dinosaur. Who knows where it will end up today, when you're done with it!

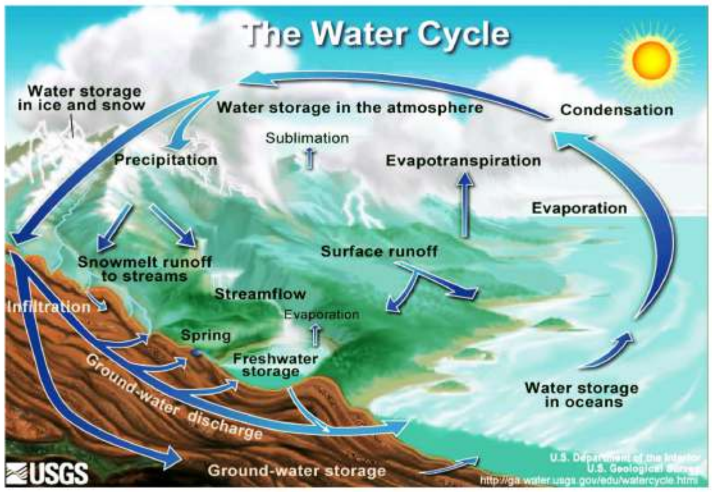


Figure 2.6: Water on Earth is constantly in motion.

Let's study **Figure** 2.6 for a moment. The Sun, many millions of kilometers away, provides the energy which drives the water cycle. Since the ocean holds most of the Earth's water, let's begin there. As you can see in the illustration, water in the ocean evaporates as water vapor into the air. The salt in the ocean does not evaporate with the water, however, so the water vapor is fresh. Some of the invisible water vapor in the air **condenses** to form liquid droplets in clouds. The clouds are blown about the globe by wind. As the water particles in the clouds collide and grow, they fall from the sky as **precipitation.** Precipitation can occur in forms such as rain, sleet, hail, and snow. Sometimes precipitation falls right back into the ocean. Other times, however, it falls onto the solid earth as freshwater.

That freshwater, now on the Earth, may be found in a solid form as snow or ice. Some of it goes directly back into the air to form water vapor and clouds again. However, most of this solid water sits atop mountains and slowly melts over time to provide a steady flow of freshwater to streams, rivers, and lakes below. Some of that water enters the Earth's **groundwater**, seeping below the surface through pores in the ground. This water can form **aquifers** that store freshwater for centuries. Alternatively, it may come to the surface through springs or find its way back to the oceans.

When water falls from the sky is rain it form streams and rivers that flow downward to oceans and lakes. People use these natural resources as their source of water. They also create canals, aqueducts, dams, and wells to direct water to living areas to meet their needs (**Figure** 2.7). Sometimes, our manipulation or pollution of water greatly affects other species. Many scientists are seeking better ways of using Earth's water in a sustainable and efficient way.

Obviously, people are not the only creatures that rely on water. Plants and animals also depend on this vital resource. Plants play an important role in the water cycle because they release large amounts of water vapor into the air from their leaves. This process of **transpiration** moves liquid water from plants into the air. You can see transpiration in action if you cover a few leaves on a plant with a plastic bag.

Within a few hours, water vapor released from the leaves will have condensed onto the surface of the bag.

Figure 2.7: Hoover Dam on the Colorado River.

Lesson Summary

- Earth's surface is mostly water covered. Most of that water is in our oceans, leaving only 3% freshwater.
- Water exists on Earth in all three phases: solid, liquid and gas.
- The water cycle moves water from the hydrosphere to the atmosphere to the land and back again.
- The major processes of the water cycle include evaporation and transpiration, condensation, precipitation and return to the oceans via runoff and groundwater supplies.

Review Questions

1. About what percent of the Earth's water is fresh water?
2. About what percent of all of Earth's water is found in groundwater, streams, lakes, and rivers?
3. Explain the following statement: The water on other planets is present in a different form than on Earth.
4. What powers the water cycle?
5. In what state would water be found at 130°C? What state would water be at -45°C?
6. Define the words condensation and evaporation.
7. Summarize the water cycle.
8. Why do you think the atmosphere is so important to the water cycle?
9. Suppose the sun grew much stronger in intensity. How would this affect the water cycle?

Further Reading / Supplemental Links

- `http://www.freshwaterlife.org/`http://www.freshwaterlife.org/
- `http://www.usgs.gov/`http://www.usgs.gov/

Vocabulary

aquifer A layer of rock, sand, or gravel that holds large amounts of groundwater. Humans often use aquifers as sources of freshwater.

condense To turn from a gas to a liquid.

freshwater Water with a low concentration of salts, which can be consumed and used by humans.

groundwater Water that is found beneath the Earth's surface, between soil or rock particles.

precipitation Water that falls to the Earth from the sky. Precipitation usually takes the form of rain, but can also occur as snow, sleet, or hail.

transpiration The release of water vapor into the air through the leaves of plants; sometimes called evapotranspiration.

water cycle The cycle through which water moves around the Earth, changing both its phase (between solid to liquid to gas) and its location (in the oceans, in clouds, in streams and lakes, and in groundwater).

water vapor Water in the form of a gas. Water vapor is invisible to humans; when we see clouds, we actually are seeing liquid water in the clouds.

Points to Consider

- How does precipitation affect the topography of the Earth?
- What natural disasters are caused by the water cycle?
- How might pollution affect creatures far from the source of the pollution?
- How might building dams disrupt the natural water cycle?
- If the temperature of the Earth increases through global warming, how might the water cycle be altered?

Chapter 3

Human Actions and Earth's Waters

3.1 Humans and the Water Supply

Learning Objectives

- Learn how humans use water.
- Discuss how much water is taken up by each water use.
- Explain the difference between consumptive and non-consumptive water uses.
- Discuss three of the most serious issues humans face today, including shortages of fresh water, lack of safe drinking water and water pollution.

- Discuss why humans are facing water shortages.
- Discuss how water shortages can lead to disputes and even battles between states and countries bordering on the same water source.
- Explain why one fifth of the human population does not have access to safe drinking water.
- Describe the relationship between disease and exposure to unsafe drinking water.
- What is the origin of California's fresh water supply?

Human Uses of Water

All forms of life need water to survive. As humans, we need water to drink or we need to get it from the foods we eat. We also use water for agriculture, industry, household uses, and recreation. Water is continually cycled and recycled through the environment.

Some ways that we use water consume a lot of water that then is lost to the ecosystem and some ways we use water put less demand on our water supplies. Understanding how water cycles and is replaced is important, especially when we look for ways to use less water. Currently, agricultural uses the most water. Considering different methods of irrigation and times of day to water crops can improve this situation. Farming, growing crops and raising livestock uses more than two thirds of the water used by humans globally.

When water is used but not recycled, the water use is called consumptive. That water is lost to the ecosystem. When excess water is captured or recycled, it is called non-consumptive. As we move to a more sustainable future, we want to be sure as much of our water use is non-consumptive as possible.

What is the most important thing for all life on Earth? Not gold or diamonds. It is water! From the smallest bacteria to the largest trees, all forms of life on Earth depend on water for survival. As humans, we could not survive for more than a few days without drinking water or getting water from the foods we eat.

In addition to our basic survival need for water to drink, people also use freshwater for agriculture, industry and household needs. Across the world, different communities also use water for many kinds of recreational and environmental activities.

Which human activity uses the most water? Not showers, baths, washing dishes or other household uses. On average, agriculture uses more than two thirds of the water that humans use across the world. Industry and household uses average 15% each. Recreational use and environmental uses average 1% each. (See **Figure** 3.1)

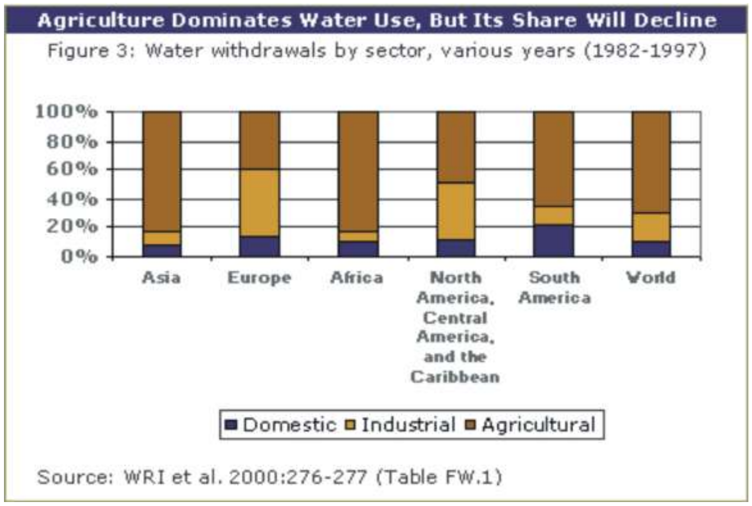


Figure 3.1: Proportion of water used for home, industrial, and agricultural purposes across the world.

Some ways that people use water do not use up the water. When you swim in a lake, you do not use up the water. The water is still in the lake when you climb out. In some cases, water can be recycled for reuse. For example, the water you use to brush your teeth or take a bath can be collected through your household pipes and the sewer system, purified and then redistributed for reuse. These are examples of **non-consumptive water use.** By recycling water, we ultimately reduce our overall water consumption.

Unlike the previous examples, water sprinklers are called **consumptive,** because much of the water is lost to the air as evaporation. None of the lost water can be captured and reused.

Agricultural Water Uses

Have you ever watched huge sprinklers watering large fields of crops (**Figure** 3.2)? If you have, try to imagine how much water it takes to water a field compared to taking a shower or bath. You may be surprised to learn that agriculture uses more than two thirds (69%) of the water humans use, globally. http://authors.ck12.org/wiki/index.php/File:Ear-2101-02.jpg

Two of the most popular irrigation methods are overhead sprinklers and trench irrigation. Trench irrigation systems are just that: trench canals that carry water from a water source to the fields. Farmers often chose these methods because they relatively inexpensive. Unfortunately, they are also wasteful of water. Roughly fifteen to thirty-six percent of the water never reaches the crops, because it evaporates into the air or is lost as runoff. When rain or irrigation water is not absorbed by the soil, often it washes valuable soil away.

Giving up irrigation is not a choice for most farmers. A farmer living in a dry region, such as a desert,

Figure 3.2: Agricultural Water Use: Overhead sprinklers need to use large quantities of water on crops because much of the water is lost to evaporation and runoff.

needs irrigation, just to grow crops. A farmer living in a wetter place would use irrigation to produce more crops or to grow more profitable crops. In some cases, farmers can choose to grow crops that match the amount of rain that falls in that region naturally.

Figure 3.3: Drip Irrigation uses a series of pipes and tubes to deliver water to the base of each plant. Because little water is lost to evaporation and runoff, this method uses less water than sprinklers and trenches.

Instead of giving up irrigation, farmers can use less water by choosing more efficient irrigation methods, such as **drip irrigation** (**Figure** 3.3). This irrigation system uses pipes and tubes to deliver small amounts of water directly to the soil at the roots of each plant or tree. It wastes less water than sprinklers and trenches, because almost all of the water goes directly to the soil and plant roots.

You might wonder why any farmer would not switch to efficient irrigation methods, since they would save so much water. There are two reasons. First, drip irrigation and other efficient irrigation methods cost more than trenches and sprinklers. Second, in some countries, such as the United States, the government pays for much of the cost of the water that is used for agriculture. Because, farmers do not have to pay the full price of the water they use, they do not have any financial reason or **incentive** to use less water.

Aquaculture

Aquaculture is the name for the type of farming you might do if you were raising fish, shellfish, algae or aquatic plants (**Figure** 3.4). This is a farming practice where plants and animals that live in water are raised. As the supplies of fish from lakes, rivers, and the oceans dwindle, people are getting more fish from aquaculture. Raising fish instead of hunting for them is a different way of increasing our food resources. The next time you pass the fish display in the grocery store, look for labels for ‘‘farm raised” fish. These fish would have been raised in an aquaculture setting.

Figure 3.4: Aquaculture: Workers at a fish farm harvest fish they will sell to stores.

Some of the most productive aquaculture farming takes place in wetland areas along coastlines. Rivers and streams carry nutrient-rich water into these wetlands, so fish and other animal life thrives. A good supply of nutrients is important when raising a large community of plants or animals. We need to be careful about the wastes that are added to our coastal waters when we increase plant and animal populations in these areas. Aquaculture can be considered a non-consumptive use of water, as long as we keep our coastal waters in good condition.

Industrial Water Use

Figure 3.5: Industrial water use: A power plant in Poland sits on the edge of a lake with easy access to water for cooling and other purposes.

However, industrial water use accounts for an estimated fifteen percent of worldwide water use. Industries include power plants that use water to cool their equipment, and oil refineries that use water for chemical processes (**Figure** 3.5). Industry also uses water in many manufacturing processes. Looking at water use in a completely different way, hydroelectric power plants are built along rivers and streams to generate energy. This is a very efficient way to use water that is also non-consumptive.

Household Use

Starting from when you wake up in the morning, count the ways you use water at home (**Figure** 3.6). You will need to count the water you drink, water used in cooking, bathing, flushing toilets, and even gardening. You will be surprised to notice how many times a day you use water. Have you ever had to go without water? The United States is a developed country. In developed countries, people use a lot of water each day. People living in lesser developed countries use far less water than people in the United States. Globally, household or personal water use is estimated to account for fifteen percent of world-wide water use.

Some household water uses are considered non-consumptive, because water is recaptured in sewer systems, treated and returned to surface water supplies for reuse. Watering lawns with sprinklers is an exception. Just like sprinkler irrigation on farms, yard sprinklers are consumptive and use large amounts of water.

We all have many ways to lower the amount of water we use at home. Hardware stores sell water-efficient home products, such as drip irrigation to water lawns and gardens, low flow shower heads and low flow toilets. What other ways can you use less water at home?

Figure 3.6: Domestic water use.

Figure 3.7: Recreational Water: Many recreational activities, such as swimming and fishing, are non-consumptive water activities; which wont deplete the water supply.

Recreational Use

Which sports use water? Swimming, fishing, and boating are easy examples to think about (**Figure** 3.7). Do you think playing golf requires water? Actually it does, because we irrigate the golf course in order to keep it nice and green! The amount of water that most recreational activities use is low: less than one percent of all the water we use.

Most recreational water uses are non-consumptive. That would include swimming, fishing, and boating. We can swim, fish, and boat without reducing the water supply. The same is not true for playing golf, which is the biggest recreational water consumer. Golf courses require large amounts of water. Water used for golf courses is generally consumptive, since most of it is lost to evaporation, soil, and runoff.

Environmental Use

Figure 3.8: Environmental Water Use: Wetlands and other environments depend on clean water to survive. Water shortages are a leading cause of global biodiversity loss.

Environmental uses include activities to create habitat for wildlife, such as building lakes and fish ladders to help fish spawn (**Figure** 3.8). Most environmental uses are non-consumptive; they account for even less water use than recreation.

Lesson Summary

- Human water use can be lumped into five categories. The uses are arranged in order of greatest to the least amounts of total water use on Earth:

- Agriculture (sixty-nine percent)
- Industry uses (fifteen percent of global water use)
- Home and Personal use (fifteen percent)
- Recreation uses (less than one percent)
- Environmental use (less than one percent)

Review Questions

1. Describe the three water uses that consume the most fresh water.
2. Explain why humans are limited to using less than one percent of all the water on Earth for our needs.
3. List two reasons why human water use has increased tremendously during the past century.
4. Describe four consequences of water shortages.
5. What does the phrase 'water is more valuable than gold' mean?
6. Describe why some water uses are called consumptive.
7. Describe drip irrigation and why it wastes less water than irrigating with sprinklers.
8. Describe why droughts are more serious in arid regions of the world than in wetter regions.

Vocabulary

consumptive Water use where water is 'lost' to evaporation.

drip irrigation Pipes & tubes that deliver small amounts of water directly to the soil at the roots.

incentive A financial benefit for taking a particular action.

non-consumptive Water use that does not 'use up' the water supply.

Points to Consider

- How could fresh water be more valuable than gold or a diamond?
- Which human activity uses more water than all other activities combined?
- Why don't all farmers use drip irrigation and other water efficient irrigation methods?

3.2 Problems with Water Distribution

Learning Objectives

- Explain why water shortages are increasingly frequent throughout the world.
- Discuss why 1.1 billion people (one fifth of the people on Earth) do not have access to safe drinking water.
- Explain why humans can use less than one percent of all water on Earth.
- Discuss the ways in which human water demands are unsustainable.

Introduction

Humans are facing a worldwide water crisis according to the United Nations. The crisis includes worldwide shortages of fresh water that humans can access, scarcity of safe drinking water supplies and water pollution.

World Water Supply and Distribution

Water is everywhere. More than 70% of the Earth's surface is covered by water. The Earth has a limited supply of water that we can use. There are supplies of freshwater in lakes, rivers, streams, swamps, reservoirs, and even underground water rich regions of soil and rock, called **aquifers.** Almost anywhere you stand, there is water somewhere beneath you. Sometimes that water is just several meters below you, sometimes it is deeper within the Earth.

Still, this supply of freshwater is less than 1% of all of the water on Earth. Why is so little water available for human use? Two reasons:

- For most of our needs, humans cannot use saltwater, which makes up 97-98% of all water on Earth.
- Humans cannot use most of the freshwater on Earth, because is frozen in glaciers and icebergs, mainly in Greenland and Antarctica (**Figure** 3.9).

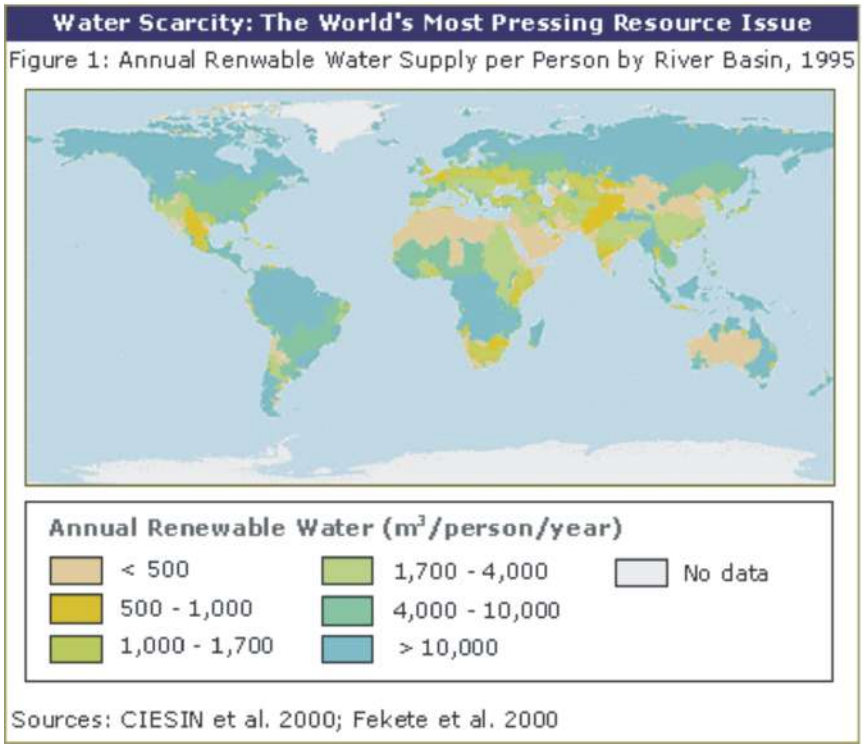
Figure 3.9: Most fresh water on Earth is in the form of frozen icebergs and glaciers.

A common misconception is that water shortages can be solved by desalination, removing salt from seawater. This is because the desalination process requires so much energy and is so costly, that it is not an economical way to increase freshwater resources.

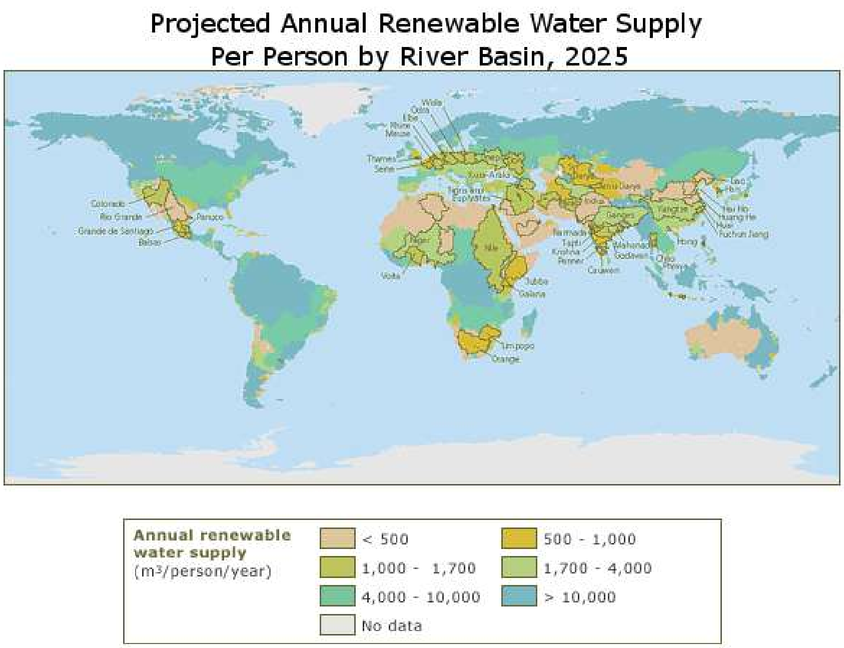
Water Distribution

Look closely at the climates of different regions around the Earth. Some places have water rich climates, while many others do not. Roughly 40% of the land on Earth is arid or semiarid, which means it receives little or almost no rainfall.

Water Distribution: Water is unevenly distributed across the world. The blue areas are the most water rich regions of the world. The salmon pink areas are desert areas. (Source: http://earthtrends.wri.org/maps_-spatial/maps_detail_static.php?map_select=264&theme=2. CC-BY-SA)



Projected Water Distribution in 2025: The blue areas are the most water rich regions of the world. The salmon pink areas are desert areas. (Source: http://earthtrends.wri.org/maps_spatial/maps_detail_-static.php?map_select=265&theme=2. CC-BY-SA)



Global warming affects patterns of rainfall and water distribution. As the Earth warms, regions that currently receive an adequate supply of rain may shift. Regions of Earth that normally are low pressure areas may become areas where high pressure dominates. That would completely change the types of plants and animals that can live successfully in that region.

In 1995, about 40% of the world's population faced water scarcity (**Figure** 3.10). Scientists believe that

Nearly Half the World Will Live With Water Scarcity by 2025

Figure 2: Global Renewable Water Supply per Person, 1995 and 2025 (projected)

Water Supply (m3/person /year)	1995 Population (millions)	1995 Percent of Total	2025 Population (millions)	2025 Percent of Total
<500	1,077	19.0	1,783	24.5
500-1,000	587	10.4	624	8.6
1,000-1,700	669	11.8	1,077	14.8
Subtotal	2,333	41.2	3,484	47.9
>1,700	3,091	54.6	3,494	48.0
Unallocated	241	4.2	296	4.0
Total	5,665	100.0	7,274	100.0

Source: WRI. The 2025 estimates are considered conservative because they are based on the United Nations' low-range projections for population growth, which has population peaking at 7.3 billion in 2025 (UNDP 1999:3). In addition, a slight mismatch between the water runoff and population data sets leaves 4 percent of the global population unaccounted in this analysis.

Figure 3.10: Water Supply Compared to Population.

by the year 2025, nearly half of the world's people won't have enough water to meet their daily needs. Nearly one quarter of the people in the world will have less than 500 m^3 of water per person to use in an entire year. A cubic meter of water equals 1,000 liters. That means in certain areas of the world, many people will have less water available in a year than some people in the United States use in one day.

Water Shortages

Water Shortages Projections for 2025

As we continue to use our precious freshwater supplies, scientists expect that we will encounter several different types of problems. We currently irrigate our crops using supplies of groundwater in aquifers underground. When we have used up these groundwater supplies, we will not be able to grow as many different types of crops or we will have lower yields of the crops we grow. Using our freshwater often adds many different types of dissolved materials to the freshwater supply. This use may lead to pollution of our water resources and cause harm not only to humans but to many life forms, reducing our biodiversity. Most importantly, as our water supplies become scarce, there will be conflicts between individuals who have enough clean water and those who do not (**Figure** 3.11). As with any limited resource, this conflict could produce warfare.

Two of the most serious problems facing humans today are shortages of fresh water and the lack of safe drinking water.

Humans use six times as much water today as we did a hundred years ago. As the number of people on Earth continues to rise, our demand for water grows. Also, people living in developed countries use more water per person than individuals in lesser developed countries. This is because most of our activities today, such as farming, industry, building, and lawn care, are all water-intense practices, practices that require large amounts of water.

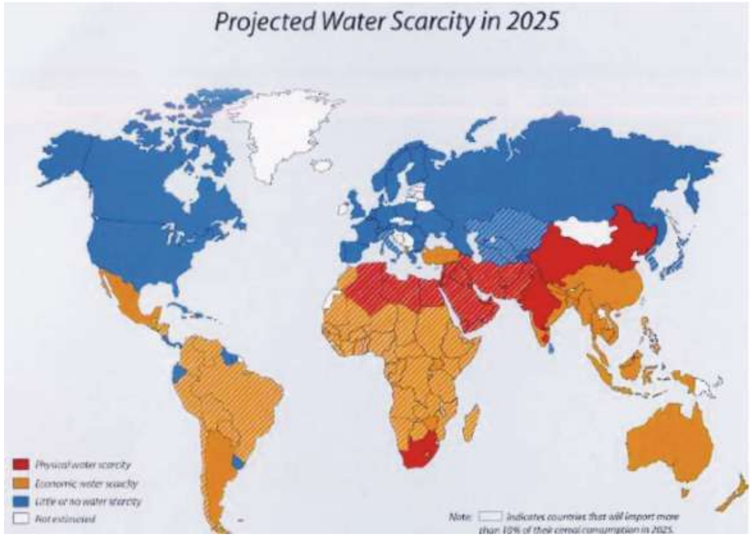


Figure 3.11: Water Scarcity Projections: If world-wide water use and population growth continues to grow at the current rate many people in the world will face serious water shortages.

Droughts occur when for months or years, a region experiences unusually low rainfall (**Figure** 3.12). Periods of drought naturally make water shortages worse. Human activities, such as deforestation, can contribute to how often droughts occur. Trees and other land plants add water back into the atmosphere through transpiration. When trees are cut down, we break this part of the water cycle. Some dry periods are normal and can happen anywhere in the world. Droughts are a longer term event and can have serious consequences for a region. Because it is difficult to predict when droughts will happen, it is difficult for countries to predict how serious water shortages will be each year.

Water shortages hurt human health, agriculture and the environment. What happens when water supplies run out? In undeveloped regions in the world, people are often forced to move to a place where there is water. This can result in serious conflicts, even wars, between groups of people competing for water.

Water disputes happen in developed countries as well. Water-thirsty regions may build aqueducts, large canals or pathways to import water from other locations. For example, several cities in **arid** regions of the United States import water from the Colorado River. So much water is taken from the river that it can end as just a trickle when it reaches Mexico. Years ago, Mexico could depend on the river supplying water for irrigation and other uses. Today that water resource is gone from importing water upstream.

Some of the biggest legal battles in the United States have been over water rights, including access to the Colorado River. Water disputes may have lead to some of the earliest wars known.

Problems with Water Quality

Scarcity of Safe Drinking Water

The next time you get water from your faucet, imagine life in a country that cannot afford the technology to treat and purify water. What would it be like if your only water came from a polluted river where sewage was dumped? Your only choice would be to drink polluted water. One fifth of all people in the world, more than 1.1 billion people, do not have access to safe water for drinking, personal cleanliness and domestic use. Unsafe drinking water can carry many disease-causing agents, such as infectious bacteria, toxic chemicals, radiological hazards, and parasites.

Figure 3.12: Extended periods with lower than normal rainfall cause droughts.

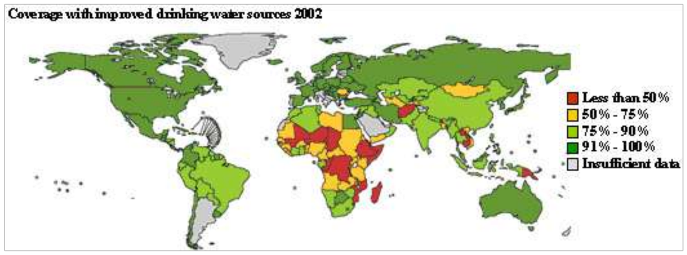


Figure 3.13: Access to improved drinking water and progress towards achieving the internationally agreed goals on water and sanitation.

One of the leading causes of death worldwide is waterborne disease, disease caused by unsafe drinking water. It is also the leading cause of death for children under the age of five. Many children die when they only have unsafe drinking water and lack of clean water for personal hygiene. About eighty-eight percent of all diseases are caused by drinking unsafe water. At any given time, half of the world's hospital beds are occupied by patients suffering from a waterborne disease. The water you get from a faucet is safe because it has gone through a series of treatment and purification processes to remove contaminants.

Economic Considerations

A glass of water may be free in a restaurant, but this does not reflect its value as a resource. Water is often regarded as more valuable than gold, because human survival depends on having steady access to it.

Water scarcity can have dire consequences for the people, the economy and the environment. Without adequate water:

- Crops and livestock dwindle and people go hungry.
- Industrial, construction and economic development is halted.
- The risk of regional conflicts over scarce water resources rises.
- Ultimately some people die from lack of water.

Finding safe drinking water poses further challenges. What does it take for a country to provide its people with access to safe drinking water? It takes sophisticated technology to purify water, which removes harmful substances and **pathogens,** disease-causing organisms. Most developing countries lack the finances and the technology needed to supply their people with purified drinking water.

Water resources are so valuable, that wars have been fought over water rights throughout history. In many cases, water disputes add to tensions between countries where differing national interests and withdrawal rights have been in conflict (**Figure** 3.14).

Some of today's greatest tensions are happening in places where water is scarce. Water disputes are happening along 260 different river systems that cross national boundaries including water disputes between:

- Iraq, Iran, and Syria

Figure 3.14: The states and Canadian Provinces surrounding the Great Lakes have created a pact to control water in the lakes, preventing other states from over-draining the lakes.

- Hungary and Czechoslovakia
- North and South Korea
- Iran and Syria
- Israel and Jordan
- Egypt and Ethiopia

International water laws, such as the Helsinki Rules, help interpret water rights among countries.

Lesson Summary

- Water is a renewable resource, but it is not unlimited. Humans are limited to less than one percent of the water on Earth. Also, water is not evenly distributed across the globe.

- Water is so valuable that countries have fought each other over water rights throughout history. Water shortages and water pollution have become so serious across the world, that some organizations call our water status a "water crisis." The crisis is blamed on overpopulation, overuse of water, pollution, and global warming.

- Undeveloped countries are rarely able to afford water treatment and purification facilities, unless other countries and international organizations help.

Review Questions

1. If most of the Earth is covered with water, how can there be water shortages?
2. Why are waterborne diseases more common in less developed countries than developed countries?
3. Why does the United Nations describe the current water status today as a crisis?

4. How do droughts affect water supplies?
5. Why do water disputes happen?
6. Give two reasons why water shortages are happening around the world today?

Vocabulary

aquifer Regions of soil or rock that are saturated with water.

arid Regions without enough water for things to grow.

drought A long period of lower than normal rainfall for a particular region.

pathogen Disease causing organisms.

Points to Consider

- What can we do to help the one fifth of the people on Earth who do not have access to safe drinking water?
- How can we reduce water shortages due to overuse, overpopulation, and drought?
- Water is so valuable that wars have been fought over it throughout history. Could conserving freshwater now help avoid future wars?

3.3 Water Pollution

Learning Objectives

- Discuss the risks that water pollution poses to human and environmental health.
- Explain where fresh and saltwater pollution come from.
- Discuss how pathogen born diseases are caused by water pollution.
- Describe why conserving water and protecting water quality is important to human health and the environment.
- Describe how water pollution reduces the amount of safe drinking water available.
- Discuss who is responsible for preventing and cleaning up water pollution.

Freshwater and ocean pollution are serious global problems that affect the availability of safe drinking water, human health and the environment. Waterborne diseases from water pollution kill millions of people in undeveloped countries every year.

Sources of Water Pollution

Water pollution can make our current water shortages even worse than they already are. Imagine that all of your drinking water came from a river polluted by industrial waste and sewage. In undeveloped countries throughout the world, raw sewage is dumped into the same water that undeveloped people drink and bathe in. Without the technology to collect, treat and distribute water, people do not have access to safe drinking water. Throughout the world, more than 14,000 people die every day from waterborne diseases, like cholera which is spread through polluted water.

Even in developed countries that can afford the technology to treat water, water pollution affects human and environmental health.

Water pollution includes any contaminant that gets into lakes, streams and oceans. The most widespread source of water contamination in undeveloped countries is raw sewage dumped into lakes, rivers and streams. In developed countries, the three main sources of water pollution are:

- Agriculture, including fertilizers, animal waste and other waste, pesticides, etc.
- Industry, including toxic and nontoxic chemicals
- Municipal uses, including yard and human waste

Types of Water Pollution

Municipal Pollution

Figure 3.15: Municipal and agricultural pollution.

Wastewater usually contains many different contaminants. This makes it difficult for the Environmental Protection Agency (EPA) to identify the main source when toxic chemicals are found in wastewater. The pollution coming from homes, stores and other businesses is called municipal pollution (**Figure** 3.15). Contaminants come from:

- Sewage disposal (some sewage is inadequately treated or untreated)
- Storm drains
- Septic tanks: sewage from homes
- Boats that dump sewage
- Yard runoff (See agriculture discussion of fertilizer waste)

Figure 3.16: Industrial Waste Water: Polluted water coming from a factory in Mexico. The different colors of foam indicate various chemicals in the water and industrial pollution.

Industrial Pollution

Many kinds of pollutants from factories and hospitals end up in our air and waterways (**Figure** 3.16). Some of the most hazardous industrial pollutants include:

- Radioactive substances from nuclear power plants, as well as medical and scientific uses.
- Other chemicals in industrial waste, such as heavy metals, organic toxins, oils, and solids.
- Chemical waste from burning high sulfur fossil fuels that cause acid rain.
- Inadequately treated or untreated sewage and solid wastes from inappropriate waste disposal.
- Oil and other petroleum products from supertanker spills and offshore drilling accidents.
- Heated water from industrial processes such as power stations.

Agricultural Pollution

Agriculture includes crops, livestock and poultry farming. Most agricultural contaminants are carried by runoff that carries fertilizers, pesticides, and animal waste into nearby waterways (**Figure** 3.17). Soil and silt erosion also contribute to surface water contamination.

Animal wastes expose humans and the environment to some of the most harmful disease causing organisms or pathogens. These include bacteria, viruses, protozoa, and parasites. Pathogens are especially harmful to humans, because they can cause many illnesses including typhoid and dysentery as well as minor respiratory and skin diseases.

You may be surprised to learn that even the fertilizers we use on our lawns and farm fields are extremely harmful to the environment. Fertilizers from lawns and farm fields wash into nearby rivers, lakes and the oceans. Fertilizers contain nitrates that promote tremendous plant growth in the water. Consequences of this accelerated plant growth include:

- Lakes, rivers and bays become clogged with a carpet of aquatic plants that block light from entering the water.

Figure 3.17: Many types of agriculture add pollutants to groundwater.

- Without light reaching plants in the water below, these organisms die.
- As the plants die, their decomposition uses up all the oxygen in the water. Without enough dissolved oxygen in the water, large numbers of plants, fish and bottom-dwelling animals die.

Every year you can see **dead zones**, hundreds of kilometers of ocean without fish or plant life (**Figure** 3.18). These dead zones occur in the Gulf of Mexico and other river delta areas due to water polluted with fertilizers. In 1999, a dead zone in the Gulf of Mexico reached over 7,700 square miles.

Ocean Water Pollution

Most (80 %) of ocean pollution comes as runoff from agriculture, industry, and domestic uses (**Figure** 3.19). These same kinds of runoff also pollute freshwater. The remaining 20% of water pollution comes from oil spills and people dumping sewage directly into the water.

Coastal pollution can make coastal water unsafe for humans and wildlife. After rainfall, there can be enough runoff pollution that beaches are closed to prevent the spread of disease from pollutants.

A large proportion of the fish stocks we rely on for food live in the coastal wetlands. Coastal runoff from farm waste often carries water-borne organisms that cause lesions that kill fish. Humans who come in contact with polluted waters and affected fish can also experience harmful symptoms. More than one-third of the shellfish-growing waters of the United States are adversely affected by coastal pollution.

Thermal Water Pollution

Thermal pollution is anything that causes water temperatures to rise or fall (**Figure** 3.20). For example, power plants and other industries often use water to cool equipment. Once the water absorbs heat from a power plant or industry, the heated water is returned to the natural environment at a higher temperature. Cold water pollution can be observed when very cold water is released from reservoirs.

Why would changing water temperature harm the environment? Fish and other aquatic organisms are often vulnerable to even small temperature changes. Heated water kills fish and other organisms by decreasing oxygen supply in the water. Frigid water has a severe effect on fish (particularly eggs and larvae), macro invertebrates and river productivity.

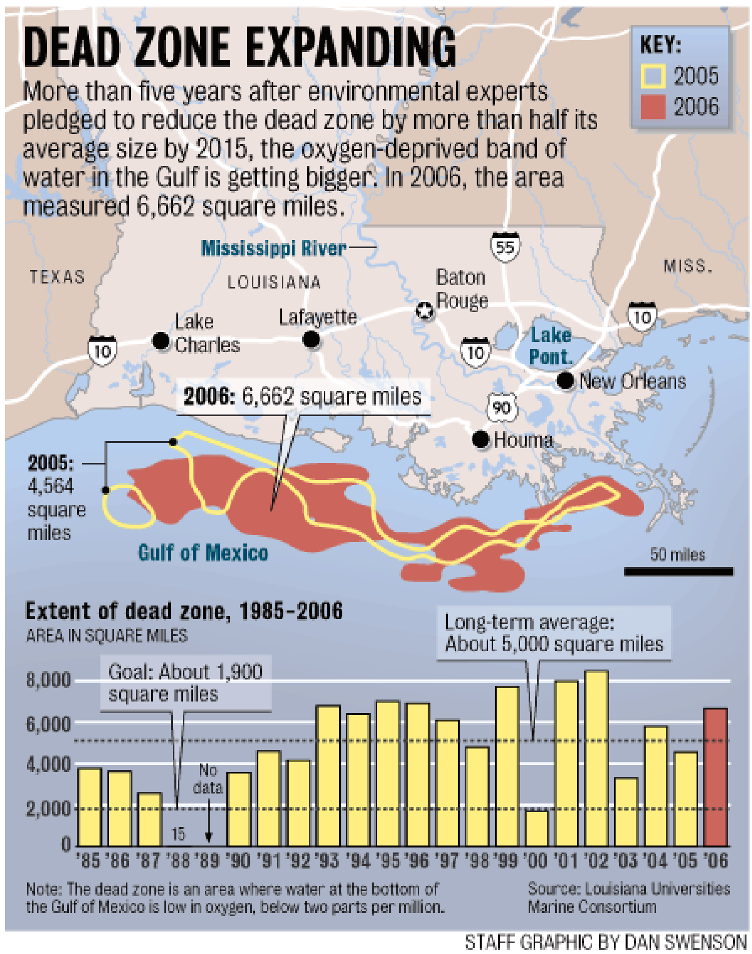


Figure 3.18: Agricultural Waste Water: A Dead Zone is a large area of water where fertilizer runoff pollutes farms and yards, ultimately killing off aquatic life. The size of the dead zone in the Gulf of Mexico varies at different times of the year.

Figure 3.19: In some areas of the world, ocean pollution is all too obvious.

Figure 3.20: The Macquarie perch is now extinct in most of its upland river habitats partially due to thermal pollution by dams.

Lesson Summary

- Industrial, agricultural, and municipal sources produce harmful water pollutants such as toxic chemicals, radiological agents, and animal wastes. Thousands of people die from waterborne diseases every year.

Review Questions

1. What do the initials 'EPA' stand for?
2. What is runoff and why is it a problem?
3. Who is responsible for reducing water pollution?
4. Explain what a dead zone is and where you might find one?
5. What is the leading cause of death for children around the world?

Vocabulary

dead zone A region hundreds of kilometers wide without fish or plant life due to lack of oxygen in the water.

thermal pollution Water pollution created by added heat to water.

Points to Consider

- Water pollution not only harms human health and the environment. Consider how this reduces the amount of water available to humans.
- Fifty percent of all infectious diseases are caused by water pollution. What can be done to reduce the number of pathogens that reach our freshwater supplies?
- Ocean pollution harms some of the most productive sources of marine life. How can we change our behaviors to protect marine life?

3.4 Protecting the Water Supply

Learning Objectives

- Describe several ways water can be conserved.
- Discuss how water is treated to eliminate harmful particles.
- State what governments and international organizations can do to reduce water pollution.

Water Treatment

The goal of water treatment is to make water suitable for such uses as drinking water, medicine, agriculture and industrial processes.

People living in developed countries suffer from few waterborne diseases and illness, because they have extensive water treatment systems to collect, treat, and redeliver clean water to their people. Many undeveloped nations have few or no water treatment facilities.

Figure 3.21: Wastewater Treatment: Most wastewater treatment facilities separate contaminants from water by passing wastewater through a series of settlement containers. At each step, solids and particles are separated from water. Chemical and biological agents are also used to remove any remaining impurities.

Water treatment is any process used to remove unwanted contaminants from water (**Figure** 3.21). Water treatment processes are designed to reduce harmful substances such as suspended solids, oxygen-demanding materials, dissolved inorganic compounds, and harmful bacteria. Ideally, water treatment produces both liquids and solid materials that are not harmful the natural environment.

Water can contain hundreds of contaminants. Not all treatment processes are able to remove all of these particles and not all treated water is pure enough to qualify as safe drinking water. **Sewage treatment** is any process that removes contaminants from sewage or wastewater. **Water purification** is any process used to produce drinking water for humans by removing contaminants from untreated water. Purification processes remove bacteria, algae, viruses, and fungi, unpleasant elements such as iron and sulphur, and man-made chemical pollutants.

The choice of treatment method used depends on the kind of wastewater being treated. Most wastewater is treated using a series of steps, increasingly purifying the water at each step. Treatment usually starts with separating solids from liquids. Water may then be filtered or treated with chlorine. With each subsequent step, the water has fewer contaminants and the effluent is increasingly pure.

Reducing Water Pollution

How can people reduce water pollution? And who is responsible for doing it?

People have two ways to reduce any kind of pollution: We can prevent people from polluting water. And, we can use science to clean contaminants from water that is already polluted.

Governments can:

- Pass laws to control pollution emissions from different sources, such as factories and agriculture.
- Pass laws that require polluters to clean up water they pollute.
- Provide money to build and run water treatment facilities (and fund research to improve water quality technology).
- Educate the public, teach them how to prevent and clean up water pollution.
- Enforce laws.

The United Nations and other international groups have established organizations to improve global water quality standards. Some international organizations provide developing nations with the technology and education to collect, treat, and distribute water. Another priority is educating the people in these countries about how they can help improve the quality of the water they use.

In the United States, legislators passed the Clean Water Act which gives the Environmental Protection Agency the authority to sets standards for water quality for industry, agriculture and domestic uses (**Figure** 3.22).

Figure 3.22: Scientists control water pollution by sampling the water and studying the pollutants are in the water.

One of the toughest problems is enforcement, catching anyone who is not following water regulations. Scientists are working to create methods to accurately track the source of water pollutants. Monitoring (tracking) methods allow the government to identify, catch and punish violators.

Who is responsible for reducing water pollution? Everyone who pollutes water is responsible for helping to clean it up. This includes individuals, communities, industries, and farmers. Just a few of the things you can do to protect water quality include:

- Find approved recycling or disposal facilities for motor oil and household chemicals so these substances do not end up in the water.
- Use lawn, garden, and farm chemicals sparingly and wisely.
- Repair automobile or boat engine leaks immediately.
- Keep litter, pet waste, leaves, and grass clippings out of gutters and storm drains.

Controlling Ocean Pollution

Controlling seawater pollution and fresh water pollution are similar, but not exactly the same. We can try to prevent polluters from further spoiling the ocean and we can require polluters to clean up any pollution they cause. Government and international agencies can pass laws, provide funding, and enforce laws to prevent and clean up ocean pollution (**Figure** 3.23).

Several national and international agencies monitor and control ocean pollution. The agencies include the National Oceanic and Atmospheric Administration (NOAA), the Environmental Protection Agency, the

Figure 3.23: Many forms of marine pollution can be controlled by regulation such as the pumping of ballast water from ships.

Department of Agriculture as well as other federal and state agencies.

When runoff pollution does cause problems, NOAA scientists help track down the exact causes and find solutions. This organization is also one of many organizations trying to educate the public on ways to prevent ocean pollution.

Conserving Water

Figure 3.24: Low flow showerheads reduce the amount water used during showers.

As human population growth continues, water conservation will become increasingly important globally (**Figure** 3.24). Yet, the methods to conserve water are likely to differ between developing nations and developed countries.

For example, some people in undeveloped countries use so little water, that they may not gain much water by reducing their personal use. Meanwhile, large quantities of water can be conserved in the United States by finding ways to stop overconsumption of water.

At Earth Summit 2002 many governments approved a Plan of Action to address the scarcity of water and safe drinking water in developing countries. One goal of this plan is to cut in half, the number of people without access to safe drinking water by 2015.

Developed countries have many options to reduce water consumption. A farmer can cut water consumption drastically by using more efficient irrigation methods. People also have many opportunities to reduce our personal and household water demand with such measures as low flow shower heads, toilets that use less water, and drip irrigation to water lawns.

During prolonged droughts and other water shortages, some communities ration water use and prohibit such water intensive uses as watering lawns during the day and hosing down sidewalks. Often legislation is needed to provide incentives for individuals to reduce their water consumption.

Lesson Summary

- Many technologies are available to conserve water as well as to prevent and treat water pollution. Yet, most undeveloped countries cannot afford the technology they need to collect, treat and distribute water to their people.

- Developing countries may be able to afford water treatment systems, but people still need incentives to use conservation steps.

Review Questions

1. What is the purpose of water treatment and purification?
2. How can governments and international organizations help to reduce water pollution?
3. Name three things that a person could do to reduce pollution? Use lawn, garden or farming chemicals sparingly or use short term, specific chemicals, rather than long term broad spectrum chemicals. Repair engine leaks immediately. Keep litter, pet waste, leaves and grass clippings out of storm drains. Use an approved recycling center to dispose of motor oil and household chemicals and batteries.
4. Name three ways that you could reduce your personal water use.

Further Reading / Supplemental Links

- The American Association for the Advancement of Science, *AAAS Atlas of Population and Environment.* University of California Press, 2000.
- www.globalchange.umich.edu/globalchange2/current/lectures/freshwater_supply/freshwater.html
- `http://www.sfgate.com/cgi-bin/article.cgi?f=/c/a/2007/12/09/IN2HTP07B.DTL`http://www.sfgate.com/cgi-bin/article.cgi?f=/c/a/2007/12/09/IN2HTP07B.DTL
- `http://www.wri.org/#`http://www.wri.org/#
- `http://www.who.int/en/`http://www.who.int/en/
- `http://www.worldbank.org/`http://www.worldbank.org/
- `http://www.epa.gov/r5water/cwa.htm`http://www.epa.gov/r5water/cwa.htm
- `http://www.epa.gov/lawsreg/laws/cwa.html`http://www.epa.gov/lawsreg/laws/cwa.html
- `http://en.wikibooks.org/wiki/Main_Page`http://en.wikibooks.org/wiki/Main_Page

Vocabulary

sewage treatment; Any process that removes contaminants from sewage or wastewater.

water purification Any process used to produce safe drinking water by removing contaminants.

Points to Consider

- Who is responsible for controlling water pollution?
- What can governments and international organizations do to control pollution?
- It is usually cheaper to dump polluted water without spending money to treat and purify the water. What incentives would convince industry to control water pollution?

Chapter 4

Earth's Atmosphere

4.1 The Atmosphere

Lesson Objectives

- Describe the importance of the atmosphere to our planet and its life.
- Outline the role of the atmosphere in the water cycle.
- List the major components of the atmosphere and know their functions.
- Describe how atmospheric pressure changes with altitude.

Introduction

Earth's atmosphere is a thin blanket of gases and tiny particles—together called air. Without air, the Earth would just be another lifeless rock orbiting the Sun. Although we are rarely aware of it, air surrounds us. We are most aware of air when it moves, creating wind. Like all gases, air takes up space. These gases that make up our air are packed closer together near the Earth's surface than at higher elevations.

All living things need some of the gases in air for life support. In particular, all organisms rely on oxygen for respiration — even plants require oxygen to stay alive at night or when the Sun is obscured. Plants also require carbon dioxide in the air for photosynthesis. All weather happens in the atmosphere. The atmosphere has many other important roles as well. These include moderating Earth's temperatures and protecting living things from the Sun's most harmful rays.

Significance of the Atmosphere

Without the atmosphere, planet Earth would be much more like the Moon than like the planet we live on today. The Earth's atmosphere, along with the abundant liquid water on the Earth's surface, are keys to our planet's unique place in the solar system. Much of what makes Earth exceptional depends on the atmosphere. Let's consider some of the many reasons we are lucky to have an atmosphere.

Atmospheric Gases Are Indispensable for Life on Earth

Without the atmosphere, Earth would be lifeless. Carbon dioxide (CO_2) and oxygen (O_2) are the most important gases for living organisms. CO_2 is vital for use by plants in **photosynthesis**, in which plants use CO_2 and water to convert the Sun's energy into food energy. This food energy is in the form of the sugar glucose ($C_6H_{12}O_6$). Plants also produce O_2. Photosynthesis is responsible for nearly all of the oxygen currently found in the atmosphere.

The chemical reaction for photosynthesis is:

$6CO_2 + 6H_2O$ + solar energy $\rightarrow C_6H_{12}O_6 + 6O_2$

By creating oxygen and food, plants have made an environment that is favorable for animals. In **respiration**, animals use oxygen to convert sugar into food energy they can use. Plants also go through respiration and consume some of the sugars they produce.

The chemical reaction for respiration is:

$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O$ + useable energy

Notice that respiration looks like photosynthesis in reverse. In photosynthesis, CO_2 is converted to O_2 and in respiration, O_2 is converted to CO_2.

The Atmosphere is a Crucial Part of the Water Cycle

Water moves from the atmosphere onto the land, into soil, through organisms, to the oceans and back into the atmosphere in any order. This movement of water is called the water cycle or **hydrologic cycle** (**Figure** 4.1).

Water changes from a liquid to a gas by **evaporation**. **Water vapor** is the name for water when it is a gas. When the Sun's energy evaporates water from the ocean surface or from lakes, streams, or puddles on land, it becomes water vapor. The water vapor remains in the atmosphere until it **condenses** to become tiny droplets of liquid. The tiny droplets may come together to create **precipitation**, like rain and snow. Snow may become part of the ice in a glacier, where it may remain for hundreds or thousands of years. Eventually, the snow or ice will melt to form liquid water. A water droplet that falls as rain, could become part of a stream or a lake, or it could sink into the ground and become part of **groundwater**. At the surface, the water will eventually undergo evaporation and reenter the atmosphere. If the water is taken up by a plant and then evaporates from the plant, the process is called **evapotranspiration**.

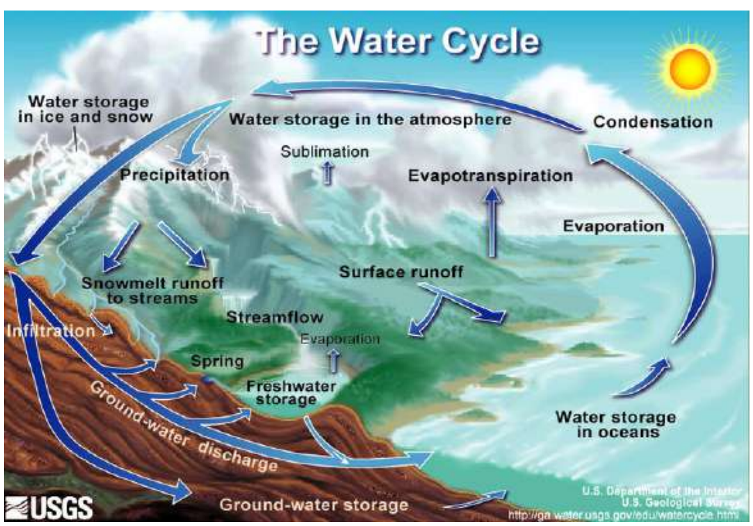


Figure 4.1: The Water Cycle.

All **weather** takes place in the atmosphere, virtually all of it in the lower atmosphere. Weather describes what the atmosphere is like at a specific time and place, and may include temperature, wind and precipitation. It is the changes we experience from day to day. **Climate** is the long-term average of weather in a particular spot. Although the weather for a particular winter day in Tucson, Arizona may include snow, the climate of Tucson is generally warm and dry.

The physical and chemical changes that happen on Earth's surface due to precipitation, wind and reactions with the gases in our atmosphere are called **weathering**. Weathering alters rocks and minerals and shapes landforms at the Earth's surface. Without weathering, Earth's surface would not change much at all. For example, the Moon has no atmosphere, water or winds, so it does not have weathering. The footprints that astronauts made on the Moon decades ago will remain there until someone (human or alien) smooths them out! You would only need to spend a few minutes at the beach to know that Earth's surface is changing all the time.

Ozone in the Upper Atmosphere Makes Life on Earth Possible

Ozone is a molecule composed of three oxygen atoms, (O_3). Ozone in the upper atmosphere absorbs high energy **ultraviolet radiation** (UV) coming from the Sun. This protects living things on Earth's surface from the Sun's most harmful rays. Without ozone for protection, only the simplest life forms would be able to live on Earth.

The Atmosphere Keeps Earth's Temperature Moderate

Our atmosphere keeps Earth's temperatures within an acceptable range; the difference between the very coldest places on Earth and the very hottest is about 150°C (270°F). Without our atmosphere, Earth's temperatures would be frigid at night and scorching during the day. Our daily temperatures would resemble those seen on the Moon, where the temperature range is 310°C (560°F) because there is no atmosphere. **Greenhouse gases** trap heat in the atmosphere. Important greenhouse gases include carbon dioxide, methane, water vapor and ozone.

Atmospheric Gases Provide the Substance for Waves to Travel Through

The atmosphere is made of gases, mostly nitrogen and oxygen. Even though you can't see them, gases take up space and can transmit energy. Sound waves are among the types of energy that can travel though the atmosphere. Without an atmosphere, we could not hear a single sound. Earth would be as silent as outer space. Of course, no insect, bird or airplane would be able to fly since there would be no atmosphere to hold it up!

Composition of Air

Air is made almost entirely of two gases. The most common gas is nitrogen, and the second most common gas is oxygen (O_2). Nitrogen and oxygen together make up 99% of the planet's atmosphere. All other gases together make up the remaining 1%. Although each of these trace gases are only found in tiny quantities, many such as ozone, serve important roles for the planet and its life. One very important minor gas is carbon dioxide, CO_2, which is essential for photosynthesis and is also a very important greenhouse gas (**Table** (4.1).

Table 4.1: (continued)

Gas	Symbol	Concentration (%)

Table 4.1: **Concentrations of Atmospheric Gases**

Gas	Symbol	Concentration (%)
Nitrogen	N_2	78.08
Oxygen	O_2	20.95
Argon	Ar	0.93
Neon	Ne	0.0018
Helium	He	0.0005
Hydrogen	H	0.00006
Xenon	Xe	0.000009
Water vapor	H_2O	0 to 4
Carbon dioxide	CO_2	0.038
Methane	CH_4	0.00017
Krypton	Kr	0.00011
Nitrous oxide	N_2O	0.00005
Ozone	O_3	0.000004
Particles (dust, soot)		0.000001
Chlorofluorocarbons (CFCs)		0.00000002

(*Source:* http://upload.wikimedia.org/wikipedia/commons/7/7a/Atmosphere_gas_proportions.svg, *License:* GNU-FDL)

In nature, air is never completely dry. Up to 4% of the volume of air can be water vapor. **Humidity** is the amount of water vapor in air. The humidity of the air varies from place to place and season to season. This fact is obvious if you compare a summer day in Atlanta,Georgia where humidity is very high, with a winter day in Phoenix, Arizona where humidity is very low. When the air is very humid, it feels heavy or sticky. Your hair might get really curly or frizzy when it is very humid outside. Most people feel more comfortable when the air is dry. The percentage of water vapor in our atmosphere is listed with a wide range of values in the table above because air can be both very humid or dry.

Argon, neon, helium, xenon, and krypton are **noble gases**. They are colorless, odorless, tasteless, and they do not become part of ordinary chemical reactions because they are chemically inert. The noble gases simply exist in the atmosphere.

Some of what is in the atmosphere is not a gas. Particles of dust, soil, fecal matter, metals, salt, smoke, ash and other solids make up a small percentage of the atmosphere. This percentage is variable, as anyone who has spent a windy day in the desert knows (**Figure** 4.2). Particles are important because they provide starting points (or nuclei) for water vapor to condense on, which then forms raindrops. Some particles are pollutants, which are discussed in the chapter on human actions and the atmosphere.

Lesson Summary

- Without its atmosphere, Earth would be a very different planet. Gases in the atmosphere allow plants to photosynthesize and animals and plants to engage in respiration.
- Water vapor, which is an atmospheric gas, is an essential part of the water cycle.
- All weather takes place in the atmosphere.

Figure 4.2: A dust storm in Al Asad, Iraq.

- While the amount of gases do not vary relative to each other in the atmosphere, there is one exception: the ozone layer. Ozone in the upper atmosphere protects life from the Sun's high energy ultraviolet radiation.

Review Questions

1. What gas is used and what gas is created during photosynthesis? What gas is used and what gas is created during respiration?
2. Describe two reasons why photosynthesis is important.
3. Briefly describe the movement of water through the water cycle.
4. What is evapotranspiration?
5. What will happen if the humidity of the atmosphere increases?
6. Is weathering more effective in a humid or a dry climate?
7. On an unusual February day in Portland, Oregon, the temperature is 18°C (65°F) and it is dry and sunny. The winter climate in Portland is usually chilly and rainy. How could you explain a warm, dry day in Portland in winter?
8. What important role do greenhouse gases play in the atmosphere?

Vocabulary

air pressure The force of air pressing on a given area.

altitude Distance above sea level.

climate The long-term average of weather.

condenses Changes state from a gas to a liquid; in the case of water, from water vapor to liquid water.

evaporation The change in state of a substance from a liquid to a gas; in the case of water, from liquid water to water vapor.

evapotranspiration Water loss by plants to the atmosphere.

greenhouse gases Gases that trap heat in the atmosphere; these include water vapor, carbon dioxide, methane and ozone.

groundwater Fresh water found beneath the ground surface.

humidity The amount of water vapor held in the air; usually refers to relative humidity, meaning the amount of water the air holds relative to the total amount it could hold.

noble gases Gases that usually do not react chemically and have no color, taste, or odor; these are helium, neon, argon, xenon and krypton.

ozone A molecule made of three oxygen atoms; ozone in the lower atmosphere is a pollutant, but in the upper atmosphere it filters out the sun's most harmful ultraviolet radiation.

photosynthesis The process in which plants produce simple sugars (food energy) from solar energy; the process of photosynthesis changes carbon dioxide to oxygen.

precipitation Condensed moisture including rain, sleet, hail, snow, frost or dew.

respiration The process in which animals and plants use oxygen and produce carbon dioxide; in respiration, organisms convert sugar into food energy they can use.

water vapor The gas form of water.

weather The temporary state of the atmosphere in a region; the weather in a location depends on the air temperature, humidity, precipitation, wind and other features of the atmosphere.

Points to Consider

- How would Earth be different if it did not have an atmosphere?
- What are the most important components of the atmosphere?
- How does the atmosphere vary with altitude?

4.2 Atmospheric Layers

Lesson Objectives

- List the major layers of the atmosphere and their temperatures.
- Discuss why all weather takes place in the troposphere.
- Discuss how the ozone layer protects the surface from harmful radiation.

Introduction

The atmosphere is layered, and these layers correspond with how the atmosphere's temperature changes with altitude. By understanding the way temperature changes with altitude, we can learn a lot about how the atmosphere works. For example, the reason that weather takes place in the lowest layer is that the Earth's surface is the atmosphere's primary heat source. Heating the lowest part of the atmosphere places warm air beneath colder air, an unstable situation that can produce violent weather. Interesting things happen higher in the atmosphere, like the beautiful aurora, which light up the sky with brilliant flashes, streaks and rolls of white or colored light.

Air Temperature

Warm air rises: that's a saying just about everyone has heard. But maybe not everyone knows why this is true. Gas molecules are free to move around, and the molecules can take up as much space as they need. When the molecules are cool, they are sluggish and do not move as much, so they do not take up as much space. When the molecules are warm, they move vigorously and take up more space. With the same number of molecules in this larger volume, the air is less dense and air pressure is lower. This warmer, lighter air is more buoyant than the cooler air above it, so it rises. The cooler air then sinks down, since it is more dense than the air beneath it. The rising of warmer air and sinking of cooler air is a very important concept for understanding the atmosphere.

As you learned in the previous section, the composition of gases is mostly the same throughout the first 100 km of our atmosphere. This means if we measure the percentages of different gases throughout the atmosphere, it will stay basically the same. However the density of the gases and the air pressure do change with altitude; they basically decrease with increasing altitude. The property that changes most strikingly with altitude is air temperature. Unlike the change in pressure and density, changes in air temperature are not regular. A change in temperature with distance is called a **temperature gradient**.

The atmosphere is divided into layers based on how the temperature in that layer changes with altitude, the layer's temperature gradient (**Figure** 4.3). The temperature gradient of each layer is different. In some layers, temperature increases with altitude and in others it decreases. The temperature gradient in each layer is determined by the heat source of the layer. The different temperature gradients in each of the four main layers create the thermal structure of the atmosphere.

There are several layers of the atmosphere. The first layer is the **troposphere**. It is the closest to the ground and is sometimes referred to as the lower atmosphere. The second layer is the **stratosphere**, and is sometimes referred to as the upper atmosphere. Most of the important processes of the atmosphere take place in one of these two layers.

Troposphere

About three-fourths of the gases of the atmosphere are found in the troposphere because gravity pulls most of the gases close to the Earth's surface. As with the rest of the atmosphere, 99% of the gases are nitrogen and oxygen.

The thickness of the troposphere varies around the planet. Near the equator, the troposphere is thicker than at the poles, since the spinning of the Earth tends to shift air towards the equator. The thickness of the troposphere also varies with season. The troposphere is thicker in the summer and thinner in the winter all around the planet. At the poles in winter, the atmosphere is uniformly very cold and the troposphere cannot be distinguished from other layers. The importance of this feature of the atmosphere will become clear when we learn about ozone depletion.

Figure 4.3: The layers of the atmosphere with altitude.

Earth's surface is a major source of heat for the troposphere. Where does the heat come from? Nearly all the heat comes from the sun, either directly or indirectly. Some incoming sunlight warms the gases in the atmosphere directly. But more sunlight strikes the Earth's rock, soil, and water, which radiate it back into the atmosphere as heat, further warming the troposphere. The temperature of the troposphere is highest near the surface of the Earth and declines with altitude. On average, the temperature gradient of the troposphere is 6.5°C per 1,000 m (3.6°F per 1,000 feet) of altitude.

Notice that in the troposphere, warm air is beneath cold air. Since warm air is less dense and tries to rise, this condition is unstable. So the warm air at the base of the troposphere rises and cool air higher in the troposphere sinks. For this reason, air in the troposphere does a lot of mixing. This mixing causes the temperature gradient to vary with time and place. For reasons that will be discussed in the next section, rising air cannot rise above the top of the troposphere. The rising and sinking of air in the troposphere means that all of the planet's weather takes place in the troposphere.

When there is a temperature **inversion**, air temperature in the troposphere *increases* with altitude and warm air sits over cold air. This is called an inversion because the usual situation is reversed or inverted. Inversions are very stable and they often last for several days or even weeks. Inversions commonly form over land at night or in winter. At these times, the ground is cold because there is little solar energy reaching it. At night, the Sun isn't out and in winter, the Sun is at a low angle, so little solar radiation reaches the ground. This cold ground cools the air that sits above it, making this low layer of air denser than the air above it. An inversion also forms on the coast where cold seawater cools the air above it. When that denser air moves inland, it slides beneath the warmer air over the land. Since temperature inversions are stable, they often trap pollutants and produce unhealthy air conditions in cities (**Figure** 4.4).

At the top of the troposphere is a thin layer called the **tropopause**. Temperature in the tropopause does not change with height. This means that the cooler, denser air of the troposphere is trapped beneath

Figure 4.4: Smoke makes a temperature inversion visible. The smoke is trapped in cold dense air that lies beneath a cap of warmer air.

the warmer, less dense air of the stratosphere. So the tropopause is a barrier that keeps air from moving from the troposphere to the stratosphere. Sometimes breaks are found in the tropopause and air from the troposphere and stratosphere can mix.

Stratosphere

The **stratosphere** rises above the tropopause. When a volcano erupts dust and gas that makes its way into the stratosphere, it remains suspended there for many years. This is because there is so little mixing between the stratosphere and troposphere. Pilots like to fly in the lower portions of the stratosphere because there is little air turbulence.

In the stratosphere, temperature increases with altitude. The reason is that the direct heat source for the stratosphere is the Sun. A layer of ozone molecules absorbs solar radiation, which heats the stratosphere. Unlike in the troposphere, air in the stratosphere is stable because warmer, less dense air sits over cooler, denser air. As a result, there is little mixing of air within the layer.

The stratosphere has the same composition of gases as the rest of the atmosphere, with the exception of the **ozone layer**. The ozone layer is found within the stratosphere at between 15 to 30 km (9 to 19 miles) altitude. The thickness of the ozone layer varies by the season and also by the latitude. The amount of ozone present in the ozone layer is tiny, only a few molecules per million air molecules. Still, the concentration of ozone is much greater than in the rest of the atmosphere. The ozone layer is extremely important because ozone gas in the stratosphere absorbs most of the Sun's harmful ultraviolet (UV) radiation.

How does ozone do this? High energy ultraviolet light, traveling through the ozone layer, breaks apart the ozone molecule, O_3 into one oxygen molecule (O_2) and one oxygen atom (O). This process absorbs the Sun's most harmful UV rays. Ozone is also reformed in the ozone layer: Oxygen atoms bond with O_2 molecules to make O_3. Under natural circumstances, the same amount of ozone is continually being created and destroyed and so the amount of ozone in the ozone layer remains the same.

The ozone layer is so effective that the highest energy ultraviolet, the UVC, does not reach the planet's surface at all. Some of the second highest energy ultraviolet, UVB, is stopped as well. The lowest energy ultraviolet, UVA, travels through the atmosphere to the ground. In this way, the ozone layer protects life on Earth. High energy ultraviolet light penetrates cells and damages DNA, leading to cell death (which we know as a bad sunburn). Organisms on Earth are not adapted to heavy UV exposure, which kills or damages them. Without the ozone layer to reflect UVC and UVB, most complex life on Earth would not survive long.

Above the stratosphere is the thin **stratopause**, which is the boundary between the stratosphere below and the mesosphere above. The stratopause is at about 50 km above the Earth's surface.

Mesosphere

Temperatures in the **mesosphere** decrease with altitude. Since there are very few gas molecules in the mesosphere to absorb the Sun's radiation, the heat source here is the stratosphere below. The mesosphere is extremely cold, especially at its top, about -90°C (-130°F).

The air in the mesosphere is extremely thin: 99.9% of the mass of the atmosphere is below the mesosphere. As a result, air pressure is very low. Although the amount of oxygen relative to other gases is the same as at sea level, there is very little gas and so very little oxygen. A person traveling through the mesosphere would experience severe burns from ultraviolet light since the ozone layer which provides UV protection is in the stratosphere below them. And there would be almost no oxygen for breathing! Stranger yet, an unprotected traveler's blood would boil at normal body temperature because the pressure is so low.

Despite the thin air, the mesosphere has enough gas that meteors burn as they enter the atmosphere (**Figure** 4.5). The gas causes friction with the descending meteor, producing its tail. Some people call them "shooting stars." Above the mesosphere is the **mesopause**. Astronauts are the only people who travel through the mesopause.

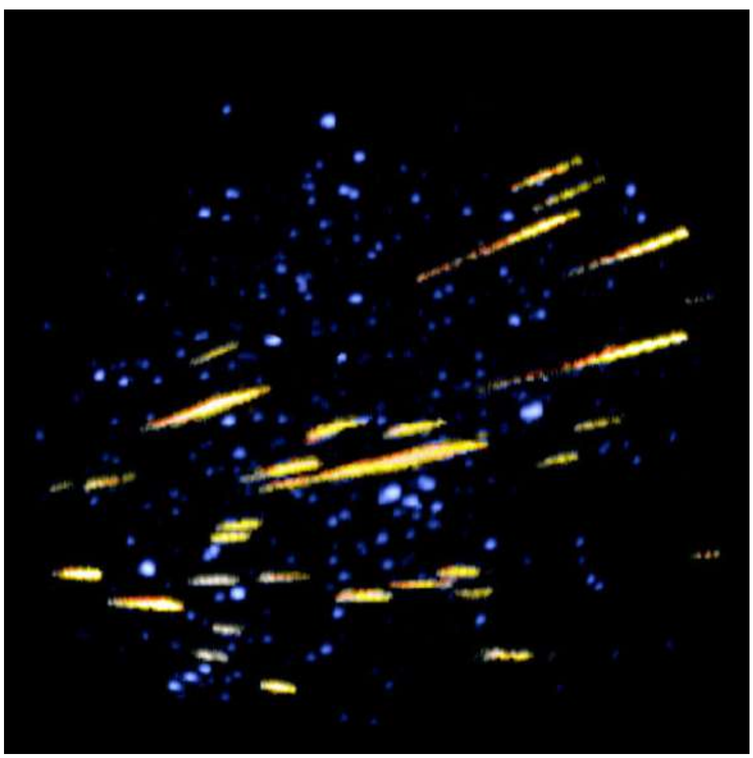


Figure 4.5: Meteors burn up as they hit the mesosphere.

Thermosphere and Beyond

The **thermosphere** rises from the mesopause. The International Space Station (ISS) orbits within the upper part of the thermosphere, at about 320 to 380 km above the Earth (**Figure** 4.6).

Figure 4.6: The International Space Station.

What does an astronaut experience in the thermosphere? Temperatures in the thermosphere can exceed 1000°C (1800°F) because oxygen molecules in the layer absorb short wavelength solar energy. Yet despite these high temperatures, the atmosphere outside the ISS feels cold. This is because gas molecules are so few and far between that they very rarely collide with other atoms and so little energy is transferred. The density of molecules is so low that one gas molecule can go about 1 km before it collides with another molecule.

Within the thermosphere is the **ionosphere**. The ionosphere gets its name because nitrogen and oxygen molecules are ionized by solar radiation. In the process of ionization, the neutrally-charged molecules absorb high-energy, short-wavelength energy from the Sun. This causes the molecules to lose one or more electrons and become positively-charged ions. The freed electrons travel within the ionosphere as electric currents. Because of the free ions, the ionosphere has many interesting characteristics.

Have you ever been out on an open road and found a radio station on the AM dial that is transmitted from hundreds of kilometers away? The reason radio waves can travel so far at night involves the ionosphere. During the day, the lower part of the ionosphere absorbs some of the energy from the radio waves and reflects some back to Earth. But at night the waves bounce off of the ionosphere, go back down to the ground, and then bounce back up again. This does not happen during the day due to ionization in the ionosphere. This bouncing up and down allows radio waves to travel long distances.

The most spectacular feature of the ionosphere is the nighttime **aurora**. Spectacular light displays with streamers, arcs, or foglike glows are visible on many nights in the polar regions. The lights can be white, green, blue, red or purple. The display is called the *aurora borealis* or northern lights in the Northern Hemisphere (**Figure** 4.7). It is called the *aurora australis* or southern lights in the Southern Hemisphere.

The aurora is caused by massive storms on the Sun that release great quantities of protons and electrons. These electrically charged particles fly through space and spiral in along lines of Earth's magnetic field. Earth's magnetic field guides the charged particles toward the poles, which explains why the auroras are seen primarily in the polar regions. When the protons and electrons enter the ionosphere, they energize oxygen and nitrogen gas molecules and cause them to light up. Each gas emits a particular color of light.

Figure 4.7: The Northern Lights above Bear Lake, Alaska.

Depending on where they are in the atmosphere, oxygen shines green or red and nitrogen shines red or blue. The frequency and intensity of the aurora increases when the Sun has more magnetic storms.

The outermost layer of the atmosphere is the **exosphere**. There is no real outer limit to the exosphere. If you continued traveling farther out from the Earth, the gas molecules would finally become so scarce that you would be in outer space. There is so little gravity holding gas molecules in the exosphere that they sometimes escape into outer space. Beyond the atmosphere is the **solar wind**. The solar wind is made of high-speed particles, mostly protons and electrons, traveling rapidly outward from the Sun.

Lesson Summary

- Different temperature gradients create different layers within the atmosphere. The lowest layer is the troposphere, where most of the atmospheric gases and all of the planet's weather are located.
- The troposphere gets its heat from the ground, and so temperature decreases with altitude. Warm air rises and cool air sinks and so the troposphere is unstable.
- In the stratosphere, temperature increases with altitude. The stratosphere contains the ozone layer, which protects the planet from the Sun's harmful UV. The higher layers contain few gas molecules and are very cold.

Review Questions

1. Why does warm air rise?
2. Why doesn't air temperature increase or decrease uniformly with altitude, just like air pressure decreases uniformly with altitude? Give examples of the different possible scenarios.
3. Where and when in the atmosphere is there no real layering at all? Why is this phenomenon important?
4. Describe how the ground acts as the heat source for the troposphere. What is the source of energy and what happens to that energy?
5. How stable is an inversion and why? How does an inversion form?
6. Why doesn't air from the troposphere and the stratosphere mix freely?
7. Where does the heat from the stratosphere come from and what is needed for that heat to be absorbed?

8. Describe the process of ozone creation and loss in the ozone layer. Under normal circumstances, does one occur more than the other?
9. How and where are 'shooting stars' created?
10. Why would an unprotected traveler's blood boil at normal body temperature in the mesosphere?

Further Reading / Supplemental Links

- http://www.youtube.com/watch?v=PaSFAbATPvk&feature=relatedhttp://www.youtube.com/watch?v=

Vocabulary

aurora A spectacular light display that occurs in the ionosphere near the poles; called the aurora borealis or northern lights in the Northern Hemisphere, and the aurora australis or southern lights in the Southern Hemisphere.

exosphere The outermost layer of the atmosphere, where gas molecules are extremely far apart and some occasionally escape earth's gravity and fly off into outer space.

inversion A situation in the troposhere in which warm air lies above cold air.

ionosphere An ionized layer contained within the thermosphere; the second to the last layer of the atmosphere.

mesopause The thin transition layer in the atmosphere, the boundary between the mesosphere and the thermosphere.

mesosphere The layer of the atmosphere between the stratosphere and the thermosphere; temperature decreases with altitude.

ozone layer A layer of the stratosphere where ozone gas is more highly concentrated.

solar wind High-speed protons and electrons that fly through the solar system from the Sun.

stratopause The thin transitional layer of the atmosphere between the stratosphere and the mesosphere.

stratosphere The second layer of the atmosphere, where temperature increases with altitude due the presence of ozone.

temperature gradient The change in temperature with distance.

thermosphere The second to the last layer of the atmosphere where gases are extremely thinly distributed.

tropopause The thin transitional layer of the atmosphere between the troposphere and the stratosphere.

troposphere The lowermost layer of the atmosphere.

ultraviolet radiationn High energy radiation that comes from the Sun; there are three types of UV radiation, UVA, UVB and UVC. The shortest wavelength, and therefore the most dangerous, is UVC.

Points to Consider

- How does solar energy create the atmosphere's layers?
- How does solar energy create the weather?
- What would be the situation for life on Earth if there was less ozone in the ozone layer?

The Greenhouse Effect

The remaining factor in the Earth's heat budget s the role of greenhouse gases. Greenhouse gases warm the atmosphere by trapping heat. Sunlight strikes the ground, is converted to heat, and radiates back into the lower atmosphere. Some of the heat is trapped by greenhouse gases in the troposphere, and cannot exit into space. Like a blanket on a sleeping person, greenhouse gases act as **insulation** for the planet. The warming of the atmosphere due to insulation by greenhouse gases is called the **greenhouse effect** (**Figure** 4.8).

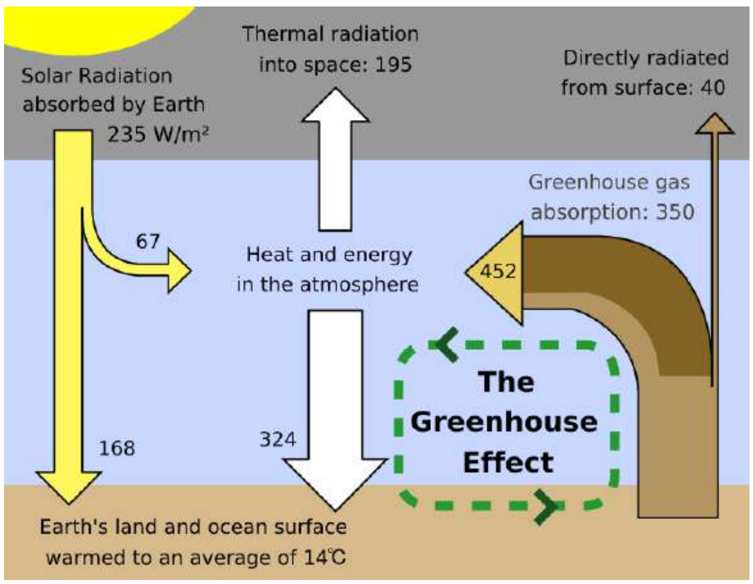


Figure 4.8: The Earths heat budget, showing the amount of energy coming into and going out of the Earth system and the importance of the greenhouse effect. The numbers are the amount of energy that is found in one square meter of that location.

The greenhouse effect is very important, since without it the average temperature of the atmosphere would be about -18°C (0°F). With the greenhouse effect, the average temperature of the atmosphere is a pleasant 15°C (59°F). Without insulation, daytime temperatures would be very high and nighttime temperatures would be extremely low. This is the situation on all of the planets and moons that have no atmosphere. If the Earth did not have insulation, temperatures would likely be too cold and too variable for complex life forms.

There are many important greenhouse gases in the atmosphere including CO_2, H_2O, methane, O_3, nitrous oxides (NO and NO_2), and chlorofluorocarbons (CFCs). All of these gases are a normal part of the atmosphere except CFCs, which are human-made. However, human activity has significantly raised the levels of many of these gases; for example, methane levels are about 2 1/2 times higher as a result of human activity. **Table** 4.2 shows how each greenhouse gas naturally enters the atmosphere.

Different greenhouse gases have different abilities to trap heat. For example, one methane molecule can trap 23 times as much heat as one CO_2 molecule. One CFC-12 molecule (a type of CFC) can trap 10,600 times as much heat as one CO_2. Still, CO_2 is a very important greenhouse gas because it is much more abundant in the atmosphere than the others.

Table 4.2:

Greenhouse Gas	Where It Comes From
Carbon dioxide	Respiration, volcanic eruptions, decomposition of plant material; burning of fossil fuels
Methane	Decomposition of plant material under some conditions, biochemical reactions in stomachs
Nitrous oxides	Produced by bacteria
Ozone	Atmospheric processes
Chlorofluorocarbons	Not naturally occurring; made by humans

The greenhouse effect is very important for another reason. If greenhouse gases in the atmosphere increase, they trap more heat and warm the atmosphere. If greenhouse gases in the atmosphere decrease, less heat is trapped and the atmosphere cools. The increase or decrease of greenhouse gases in the atmosphere affect climate and weather the world over.

Review Questions

1. What is the difference between temperature and heat?
2. Give an example of the saying ‘‘energy can't be created or destroyed.
3. What is the difference between conduction and convection?
4. Why is carbon dioxide the most important greenhouse gas?
5. How does the amount of greenhouse gases in the atmosphere affect the atmosphere's temperature?

Vocabulary

conduction Heat transfer between molecules in motion.

convection Heat transfer by the movement of currents.

convection cell A heat transfer unit in which warm material rises, cold material sinks, and material moves between the two to create a cell.

energy The ability to work; energy is not created or destroyed but can be transferred from one form to another.

greenhouse effect The trapping of heat that is radiated out from the planet's surface by greenhouse gases in the atmosphere and moderates a planet's temperatures.

latent heat The energy taken in or released as a substance changes state from solid to liquid or liquid to gas.

radiation The movement of energy through a material or through space, as carried by electromagnetic waves.

Points to Consider

- How does the difference in solar radiation that reaches the lower and upper latitudes explain the way the atmosphere circulates?
- How does the atmosphere protect life on Earth from harmful radiation and from extreme temperatures?
- What would the consequences be if the Earth's overall heat budget were not balanced?

Chapter 5

Human Actions and the Atmosphere

5.1 Air Pollution

Lesson Objectives

- Describe the different types of air pollutants.
- Discuss what conditions lead some cities to become more polluted than others.
- Describe the sources of air pollutants.

Introduction

Earth's atmosphere supports life by providing the necessary gases for photosynthesis and respiration. The ozone layer protects life on Earth from the Sun's ultraviolet radiation. People also use the atmosphere as a dump for waste gases and particles. Pollutants include materials that are naturally-occurring but present in larger quantities than normal. In addition, pollutants consist of human-made compounds that have never before been found in the atmosphere. Pollutants dirty the air, change natural processes in the atmosphere, and harm living things. Excess greenhouse gases raise global temperatures.

Air Quality

Air pollution problems began centuries ago when fossil fuels began to be burned for heat and power. The problem grew into a crisis in the developed nations in the mid-20th century. Coal smoke and auto exhaust combined to create toxic smog that in some places caused lung damage and sometimes death. In Donora, Pennsylvania in October 1948, 20 people died and 4,000 became ill when coal smoke was trapped by an inversion. Even worse, in London in December 1952, the "Big Smoke" killed 4,000 people over five days, and it is likely that thousands more died of health complications from the event in the next several months (**Figure** 5.1).

A different type of air pollution became a problem in Southern California after World War II. Although there was no coal smoke, cars and abundant sunshine produced **photochemical smog**. This smog is the result of a chemical reaction between some of the molecules in auto exhaust or oil refinery emissions, and sunshine. Photochemical smog consists of more than 100 compounds, most importantly ozone.

In the United States, these events led to the passage of the Clean Air Act in 1970. The act now regulates 189 pollutants. The six most important pollutants are ozone, particulate matter, sulfur dioxide, nitro-

Figure 5.1: A film crew recreates London smog in the Victorian Era.

gen dioxide, carbon monoxide, and the heavy metal lead. Other important regulated pollutants include benzene, perchloroethylene, methylene chloride, dioxin, asbestos, toluene, and metals such as cadmium, mercury, chromium, and lead compounds. Some of these will be discussed in the following section.

Besides human-caused emissions, air quality is affected by environmental factors. A mountain range can trap pollutants on its leeward side. Winds can move pollutants into or out of a region. Pollutants can become trapped in an air mass as a temperature inversion traps cool air beneath warm air. If the inversion lasts long enough, pollution can reach dangerous levels. Pollutants remain over a region until they are transported out of the area by wind, diluted by air blown in from another region, transformed into other compounds, or carried to the ground when mixed with rain or snow.

As a result of the Clean Air Act, air in the United States is much cleaner. Visibility is better and people are no longer incapacitated by industrial smog. Still, in the United States, industry, power plants and vehicles put 160 million tons of pollutants into the air each year. Some of this smog is invisible and some contributes to the orange or blue haze that affects many cities (**Figure** 5.2).

Table 5.1 lists the smoggiest cities in 2007: six of the 10 are in California. The state has the right conditions for collecting pollutants including mountain ranges that trap smoggy air, arid and sometimes windless conditions, and lots and lots of cars.

Figure 5.2: Smog over Los Angeles as viewed from the Hollywood Hills.

Table 5.1: **Smoggiest Cities, 2007**

Rank	City, State
1	Los Angeles, California
2	Bakersfield, California
3	Visalia-Porterville, California
4	Fresno, California
5	Houston, Texas
6	Merced, California
7	Dallas-Fort Worth, Texas
8	Sacramento, California
9	New York, New York
10	Philadelphia, Pennsylvania

(*Source:* American Lung Association)

Types of Air Pollution

Most air pollutants enter the atmosphere directly; these are primary pollutants. Secondary pollutants become pollutants only after undergoing a chemical reaction. Primary pollutants include toxic gases, particulates, compounds that react with water vapor to form acids, heavy metals, ozone, and greenhouse gases. Ozone is one of the major secondary pollutants. It is created by a chemical reaction that takes place in exhaust and in the presence of sunlight.

Primary Pollutants

Some primary pollutants are natural, such as dust and volcanic ash, but most are caused by human activities. Primary pollutants are direct emissions from vehicles and smokestacks. Some of the most harmful pollutants that go directly into the atmosphere from human activities include:

- **Carbon oxides** include carbon monoxide (CO) and carbon dioxide (CO_2). Both are colorless, odorless gases. CO is toxic to both plants and animals. CO and CO_2 are both greenhouse gases.
- **Nitrogen oxides** are produced when nitrogen and oxygen from the atmosphere come together at high temperatures. This occurs in hot exhaust gas from vehicles, power plants or factories. Nitrogen oxide (NO) and nitrogen dioxide (NO_2) are greenhouse gases. Nitrogen oxides contribute to acid rain.
- **Sulfur oxides** include sulfur dioxide (SO_2) and sulfur trioxide (SO_3). These form when sulfur from burning coal reaches the air. Sulfur oxides are components of acid rain.
- **Particulates** are solid particles, such as ash, dust and fecal matter. They are commonly formed from combustion of fossil fuels, and can produce smog. In addition, particulate matter can contribute to asthma, heart disease, and some types of cancers.
- **Lead** was once widely used in automobile fuels, paint, and pipes. This heavy metal causes can cause brain damage or blood poisoning.
- **Volatile organic compounds** (VOCs) are mostly hydrocarbons, compounds made of hydrogen and carbon. Important VOCs include methane (a naturally occurring greenhouse gas that is increasing due to human activities), chlorofluorocarbons (human-made compounds that are being phased out because of their effect on the ozone layer), and dioxin (a byproduct of chemical production that serves no useful purpose, but is harmful to humans and other organisms).

Photochemical Smog

Any city can have photochemical smog, but it is most common in arid locations. A rise in the number of vehicles in cities worldwide has increased photochemical smog. This smog forms when car exhaust is exposed to sunlight. Nitrogen oxides are created in car combustion chambers. If there is sunshine, the NO_2 splits and releases an oxygen atom (O). The oxygen ion then combines with an oxygen molecule (O_2) to form ozone (O_3). This reaction can also go in reverse: Nitric oxide (NO) removes an oxygen atom from ozone to make it O_2. The direction the reaction proceeds depends on how much NO_2 and NO there is. If NO_2 is three times more abundant than NO, ozone will be produced. If nitrous oxide levels are high, ozone will not be created.

Ozone is an acrid-smelling, whitish gas. Warm, dry cities surrounded by mountains, such as Los Angeles, Phoenix, and Denver, are especially prone to photochemical smog (**Figure** 5.3). Photochemical smog peaks at midday on the hottest days of summer. Other compounds in addition to ozone are found in photochemical smog. Ozone is also a greenhouse gas.

Causes of Air Pollution

Most air pollutants come from burning fossil fuels or plant material. Some are the result of evaporation from human-made materials. Nearly half (49%) of air pollution comes from transportation, 28% from factories and power plants, and the remaining pollution from a variety of other sources.

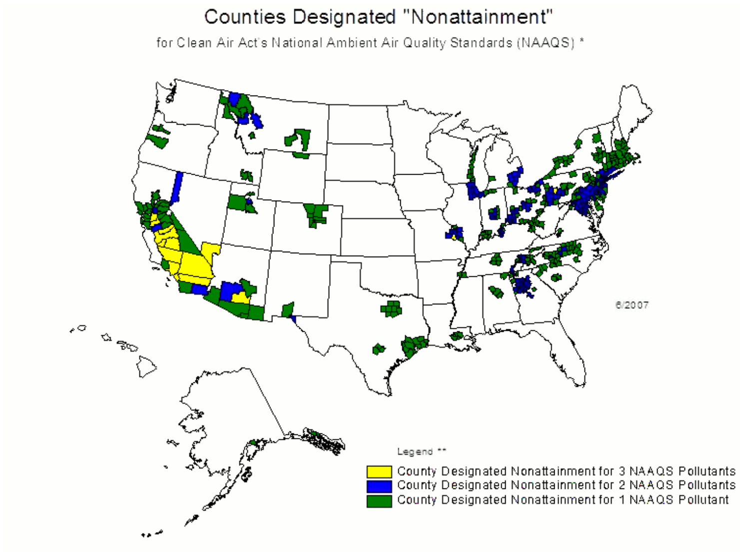


Figure 5.3: Counties with such high ozone levels that they do not attain federal air quality standards.

Fossil Fuels

Fossil fuels are burned in most motor vehicles and power plants (**Figure** 5.4). They fuel manufacturing and other industries. Pure coal and petroleum can theoretically burn cleanly, emitting only carbon dioxide and water, which are both greenhouse gases. But most of the time, these fossil fuels do not completely burn, so these incomplete chemical reactions produce pollutants. In addition, few fossil fuels are pure and so other pollutants are usually released. These pollutants include carbon monoxide, nitrogen dioxide, sulfur dioxide and hydrocarbons.

Figure 5.4: A power plant and its emissions before emission control equipment was added.

In large car-dependent cities such as Los Angeles and Mexico City, 80% to 85% of air pollution is from motor vehicles. Auto emissions are the most common source of ozone. Carbon monoxide is toxic in enclosed spaces like tunnels. Nitrous oxides come from the exhaust from a vehicle or a factory. Lead was once put in gasoline to improve engine knock, but is now banned in the United States. Still, enormous quantities of lead are released into the air every year from other sources.

A few pollutants come primarily from power plants or industrial plants. They pour out of smokestacks that burn coal or oil. Sulfur dioxide (SO_2) is a major component of industrial air pollution. It is released whenever coal and petroleum are burned. SO_2 mixes with H_2O in the air to produce sulfuric acid (H_2SO_4). The heavy metal mercury is released when coal and some types of wastes are burned. Mercury is emitted as a gas, but as it cools, it becomes a droplet. Mercury droplets eventually fall to the ground. If they fall into sediments, bacteria convert them to the most dangerous form of mercury: methyl mercury. Highly toxic, methyl mercury is one of the metal's organic forms.

Biomass Burning

Fossil fuels are ancient plants and animals that have been converted into usable hydrocarbons. Burning plant and animal material directly also produces pollutants. **Biomass** is the total amount of living material found in an environment. The biomass of a rainforest is the amount of living material found in that rainforest.

The primary way biomass is burned is by **slash-and-burn agriculture** (**Figure** 5.5). The rainforest is slashed down and then the waste is burned to clear the land for farming. Biomass from other biomes, like savannah, is also burned to clear farmland. The pollutants are much the same as from burning fossil fuels: CO_2, carbon monoxide, methane, particulates, nitrous oxide, hydrocarbons, and organic and elemental carbon. Burning forests increase greenhouse gases in the atmosphere by releasing the CO_2 stored in the biomass and also by removing the forest so that it cannot store CO_2 in the future. As with all forms of air pollution, the smoke from biomass burning often spreads far and pollutants can plague neighboring states or countries.

Figure 5.5: A forest that has been slash-and-burned to make new farmland.

Particulates result when anything is burned. About 40% of the particulates that enter the atmosphere above the United States are from industry and about 17% are from vehicles. Particulates also occur naturally from volcanic eruptions or windblown dust. Like other pollutants, they travel all around the world on atmospheric currents.

Evaporation

Volatile organic compounds (VOCs) enter the atmosphere by evaporation. VOCs evaporate from human-made substances, such as paint thinners, dry cleaning solvents, petroleum, wood preservatives, and other liquids. Naturally occurring VOCs evaporate off of pine and citrus trees. The atmosphere contains tens of thousands of different VOCs, nearly 100 of which are monitored. The most common is methane, a greenhouse gas. Methane occurs naturally, but human agriculture is increasing the amount of methane in the atmosphere.

Lesson Summary

- Industrial pollution causes health problems and even death, though the Clean Air Act has decreased these health problems in the United States by forcing industry to clean their emissions.
- The increase in motor vehicles in arid cities has increased ozone and other secondary pollutants in these regions.
- Burning fossil fuels is the greatest source of air pollution.
- Biomass burning is also a large source, especially in places where slash-and-burn agriculture is practiced.

Review Questions

1. What is the difference between the type of smog experienced by cities in the eastern United States and that found in Southern California?
2. London has suffered from terrible air pollution for at least seven centuries. Why is the city so prone to its famous "London fog?" What did London do to get rid of its air pollution?
3. Imagine two cities of the same size with the same amount of industrialization and the same number of motor vehicles. City A is incredibly smoggy most of the time and City B usually has very little air pollution. What factors are important for creating these two different situations?
4. What might be a reason why the city of San Francisco and its metropolitan area not on the list of smoggiest cities for 2007?
5. Why are naturally-occurring substances, like particulates or carbon dioxide, sometimes considered pollutants?
6. How does ozone form from vehicle exhaust?
7. What are the necessary ingredients for ozone creation, excluding those that are readily available in the atmosphere? Why could there be a city with a lot of cars but relatively little ozone pollution?
8. Some people say that we need to phase out fossil fuel use and replace it with clean energy. Why is fossil fuel use becoming undesirable?
9. Mercury is not particularly toxic as a metal but it is very dangerous in its organic form. How does mercury convert from the metal to the organic form?
10. In what two ways does deforestation contribute to air pollution?

Vocabulary

lead A heavy metal found in a large number of products. Exposure to too much lead causes lead poisoning, which harms people's brain and blood.

mercury A heavy metal that enters the atmosphere primarily from coal-burning power plants. Mercury that has been converted to an organic form (methylmercury) is highly toxic.

ozone Three oxygen atoms bonded together in an O_3 molecule. Ozone in the lower atmosphere is a pollutant but in the upper atmosphere protects life from ultraviolet radiation.

particulates Particles like ash, dust and fecal matter in the air. Particulates may be caused by natural processes, such as volcanic eruptions or dust storms, or they may be caused by human activities, like burning fossil fuels or biomass.

photochemical smog This type of air pollution results from a chemical reaction between pollutants in the presence of sunshine.

slash-and-burn agriculture In the tropics, rainforest plants are slashed down and then burned to clear the land for agriculture.

volatile organic compounds (VOCs) Pollutants that evaporate into the atmosphere from solvents and other humanmade compounds. Some VOCs occur naturally.

Points to Consider

- Despite the Clean Air Act, the air over many regions in the United States is still not clean. Why?
- How do pollutants damage human health?
- In what ways does air pollution harm the environment?

5.2 Effects of Air Pollution

Lesson Objectives

- Describe the damage that is being done by smog.
- Discuss how acid rain is formed and the damage it does.
- Discus how chlorofluorocarbons destroy the ozone layer.

Introduction

People in developing countries often do not have laws to protect the air that they breathe. The World Health Organization estimates that 22 million people die each year from complications due to air pollution. Even in the United States, more than 120 million Americans live in areas where the air is considered unhealthy. This lesson looks at the human health and environmental problems caused by different types of air pollution.

Smog

All air pollutants cause some damage to living creatures and the environment. Different types of pollutants cause different types of harm. Particulates reduce visibility. For example, in the western United States, people can now ordinarily see only about 100 to 150 kilometers (60 to 90 miles), which is one-half to two-thirds the natural (pre-pollution) range on a clear day. In the East, visibility is worse. People can only see about 40 to 60 kilometers (25-35 miles), which is one-fifth the distance they could see without any air pollution.

Particulates reduce the amount of sunshine that reaches the ground. Since plants also receive less sunlight, there may be less photosynthesis. Particulates also form the nucleus for raindrops, snowflakes or other forms of precipitation. An increase in particles in the air seems to increase the number of raindrops, but often decreases their size. By reducing sunshine, particulates can also alter air temperature. In the three days after the terrorists attacks on September 11, 2001, jet airplanes did not fly over the United States. Without the gases from jet contrails blocking sunlight, air temperature increased 1°C (1.8°F) across the U.S (**Figure** 5.6). Imagine how much all of the sources of particulates combine to reduce temperatures.

Figure 5.6: Jet contrails block sunlight.

Ozone damages some plants. Since ozone effects accumulate, plants that live a long time show the most damage. Some species of trees appear to be the most susceptible. If a forest contains ozone-sensitive trees, they may die out and be replaced by species that are not as easily harmed. This can change an entire ecosystem, since animals and plants may not be able to survive without the habitats created by the native trees.

Some crop plants show ozone damage. When exposed to ozone, spinach leaves become spotted. Soybeans and other crops have reduced productivity. In developing nations, where getting every last bit of food energy out of the agricultural system is critical, any loss is keenly felt. Many of these nations, like China and India, also have heavy air pollution. Some pollutants have a positive effect on plant growth. Increased CO_2 seems to lessen ozone damage to some plants and it may promote growth. Unfortunately, CO_2 and other greenhouse gases cause other problems that harm the ecosystem and reduce growth of some plants.

Other air pollutants damage the environment (**Figure** 5.7). NO_2 is a toxic, orange-brown colored gas that gives air a distinctive orange color and an unpleasant odor. Nitrogen and sulfur-oxides in the atmosphere create acids that fall as acid rain. Human health suffers in locations with high levels of air pollution. Lead is the most common toxic material for humans and is responsible for lead poisoning. Carbon monoxide is a toxic gas and can kill people in poorly ventilated spaces, like tunnels. Nitrogen and sulfur-oxides cause lung disease and increase rates of asthma, emphysema, and viral infections like flu. Ozone also damages the human respiratory system, causing lung disease. High ozone levels are also associated with increased heart disease and cancer. Particulates enter the lungs and cause heart or lung disease. When particulate levels are high, asthma attacks are more common. By some estimates, 30,000 deaths a year in the United States are caused by fine particle pollution.

Although not all cases of asthma can be linked to air pollution, many can. During the 1996 Olympic Games, Atlanta, Georgia closed off their downtown to private vehicles. As a result, ozone levels decreased by 28%. At the same time, there were 40% fewer hospital visits for asthma.

Figure 5.7: Smog in New York City.

Lung cancer among non-smokers is also increasing. One study showed that the risk of being afflicted with lung cancer increases directly with a person's exposure to air pollution. The study concluded that no level of air pollution should be considered safe. Exposure to smog also increased the risk of dying from any cause, including heart disease.

Children are more vulnerable to problems from breathing dirty air than adults because their lungs are still growing and developing. Children take in 50% more air for their body weight than adults. Children spend more time outside in unfiltered air and are more likely to breathe hard from playing or exercising. One study found that in the United States, children develop asthma at more than twice the rate of two decades ago and at four times the rate in Canada. Adults also suffer from air pollution-related illnesses that include lung disease, heart disease, lung cancer, and weakened immune systems. The asthma rate worldwide is rising 20% to 50% every decade.

Especially dangerous are pollutants that remain in an organism throughout its life, called **bioaccumulation**. In this process, an organism accumulates the entire amount of a toxic compound that it consumes over its lifetime. Not all substances bioaccumulate. A person who takes a daily dose of aspirin only has that day's worth of aspirin in her system, because aspirin does not stay within her system. When a compound bioaccumulates, the person has all of that compound she's ever eaten in her system. Compounds that bioaccumulate are usually stored in the organism's fat.

Mercury is a good example of a substance that bioaccumulates. Bacteria and plankton store all of the mercury from all of the seawater they ingest. A small fish that eats bacteria and plankton accumulates all of the mercury from all of the tiny creatures it eats over its lifetime. A big fish accumulates all of the mercury from all of the small fish it eats over its lifetime. The organisms that accumulate the most mercury are the large predators that eat high on the food chain. Tuna pose a health hazard to anything that eats them because their bodies are so high in mercury. This is why the government recommends limits on the amount of tuna that people eat. These limits are especially important for children and pregnant women, since mercury particularly affects young people. If the mercury just stayed in fat, it would not be harmful, but that fat is used when a woman is pregnant or nursing a baby, or when she burns the fat while losing weight. Methyl mercury poisoning can cause nervous system or brain damage, especially in infants and children. Children may experience brain damage or developmental delays. Like mercury, other metals and VOCS can bioaccumulate, causing harm to animals and people high on the food chain.

Acid Rain

Acid rain is caused by sulfur and nitrogen oxides. These pollutants are emitted into the atmosphere from power plants or metal refineries. The oxides come out of smokestacks that have been built tall so that pollutants don't sit over cities. The high smokestacks allow the emissions to rise high into the atmosphere and travel up to 1000 km (600 miles) downwind. As they move, these pollutants combine with water vapor to form sulfuric and nitric acids. The acid droplets form acid fog, rain, snow, or they may be deposited dry. Most typical is **acid rain** (**Figure** 5.8).

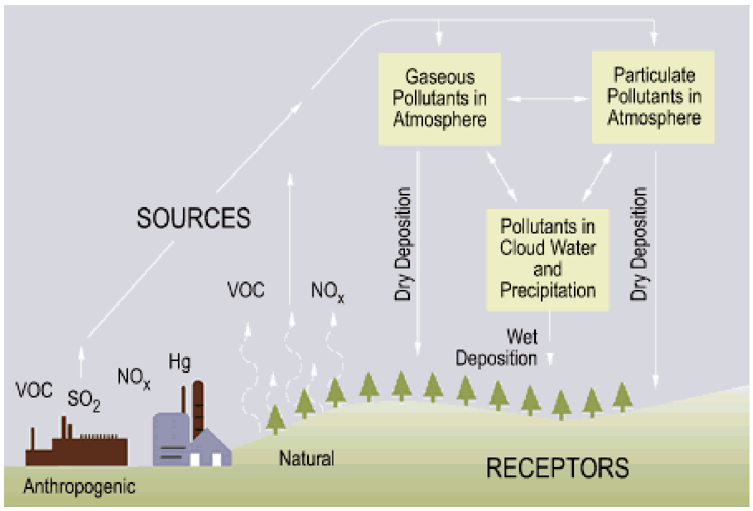


Figure 5.8: How acid rain is formed. Anthropogenic pollutants are those that are human-made. Deposition of a pollutant occurs when it is placed on a surface. Rain can bring wet deposition or a pollutant can be blown onto the ground for dry deposition.

Acid rain water is more acidic than normal rain water. To be called acid rain, it must have a pH of less than 5.0. Acidity is measured on the **pH scale**, which goes from 1 to 14. A value of 7 is neutral. Lower numbers are more acidic and higher numbers are less acidic (also called more **alkaline**). The strongest acids are at the low end of the scale and the strongest bases are at the high end. Natural rain is somewhat acidic with a pH of 5.6. The acid comes from carbonic acid that forms when CO_2 combines with water in the atmosphere. A small change in pH represents a large change in acidity: rain with a pH of 4.6 is 10 times more acidic than normal rain (with a pH of 5.6). Rain with a pH of 3.6 is 100 times more acidic.

Regions that have a lot of coal-burning power plants have the most acidic rain. The acidity of average rainwater in the northeastern United States has fallen to between 4.0 and 4.6. Acid fog has even lower pH with an average of around 3.4. One fog in Southern California in 1986 had a pH of 1.7, equal to toilet bowl cleaner. In arid climates, like in Southern California, acids deposit on the ground dry. Acid precipitation ends up on the land surface and in water bodies. Some forest soils in the northeast are 5 to 10 times more acidic than they were two or three decades ago. Acid droplets move down through acidic soils to lower the pH of streams and lakes even more. Acids strip soil of metals and nutrients, which collect in streams and lakes. As a result, stripped soils may no longer provide the nutrients that native plants need.

Acid rain takes a toll on ecosystems (**Figure** 5.9). Plants that are exposed to acids become weak and are more likely to be damaged by bad weather, insect pests, or disease. Snails die in acid soils, so songbirds do not have as much food to eat. Young birds and mammals do not build bones as well and may not be as strong. Eggshells may also be weak and break more easily.

The nitrates found in acid rain cause some plants to grow better. These nitrate-lovers can drive out other plants, which may cause the ecosystem to change. Nitrates also fertilize the oceans, which makes more

Figure 5.9: Acid rain has killed trees in this forest in the Czech Republic.

algae grow. The algae use up all the oxygen in the water, which can bring about disastrous ecological changes, including the deaths of many fish. As lakes become acidic, organisms die off. If the pH drops below 4.5, all the fish die. Organic material cannot decay, and mosses take over the lake. Wildlife that depend on the lake for drinking water suffer population declines. Crops are damaged by acid rain. This is most noticeable in poor nations where people can't afford to fix the problems with fertilizers or other technology. Buildings and monuments are damaged by acid precipitation (**Figure** 5.10). These include the U.S. Capital and many buildings in Europe, such as Westminster Abbey.

Figure 5.10: Acid rain damages cultural monuments like buildings and statues.

Carbonate rocks can neutralize acids and so some regions do not suffer the effects of acid rain nearly as much. The Midwestern United States is protected by the limestone rocks throughout the area, which are made up of calcium carbonate. One reason that the northeastern United States is so vulnerable to acid rain damage is that the rocks are not carbonates.

Because pollutants can travel so far, much of the acid rain that falls hurts states or nations other than ones where the pollutants were released. All the rain that falls in Sweden is acidic and fish in lakes all over the country are dying. The pollutants come from the United Kingdom and Western Europe, which are now working to decrease their emissions. Canada also suffers from acid rain that originates in the United States, a problem that is also improving. Southeast Asia is experiencing more acid rain between nations as the region industrializes.

Ozone Depletion

At this point you might be asking yourself, "Is ozone bad or is ozone good?" There is no simple answer to that question: It depends on where the ozone is located. In the troposphere, ozone is a pollutant. Higher up, in the stratosphere, ozone screens out high energy ultraviolet radiation and thus makes Earth habitable. This protective ozone is found in the ozone layer.

The ozone layer is being attacked by human-made chemicals that break ozone molecules apart in the stratosphere. The most common of these chemicals are chlorofluorocarbons (CFCs), but includes others such as halons, methyl bromide, carbon tetrachloride, and methyl chloroform. CFCs were once widely used because they are cheap, nontoxic, nonflammable, and non-reactive. They were used as spray-can propellants, refrigerants, and in many other products.

Once they are released into the air, CFCs float up to the stratosphere. Air currents move them toward the poles. In the winter, they freeze onto nitric acid molecules in polar stratospheric clouds (PSC). PSCs form only where the stratosphere is coldest, and are most common above Antarctica in the wintertime. In the spring, the sun's warmth starts the air moving, and ultraviolet light breaks the CFCs apart. The chlorine atom floats away and attaches to one of the oxygen atoms on an ozone molecule. The chlorine pulls the oxygen atom away, leaving behind an O_2 molecule, which provides no UV protection. The chlorine then releases the oxygen atom and moves on to destroy another ozone molecule. One CFC molecule can destroy as many as 100,000 ozone molecules.

Ozone destruction creates the **ozone hole** where the layer is dangerously thin (**Figure** 5.11). As air circulates over Antarctica in the spring, the ozone hole expands northward over the southern continents, including Australia, New Zealand, southern South America, and southern Africa. UV levels may rise as much as 20% beneath the ozone hole. The hole was first measured in 1981 when it was 2 million square km (900,000 square miles)). The 2006 hole was the largest ever observed at 28 million square km (11.4 million square miles). It had the lowest ozone levels ever recorded and also lasted the longest. The difference in the size of the ozone hole each year depends on many factors, including whether conditions are right for the formation of polar stratospheric clouds.

Ozone loss also occurs over the north polar region, but it is not enough for scientists to call it a hole. The region of low ozone levels is small because the atmosphere is not as cold and PSCs do not form as readily. Still, springtime ozone levels are relatively low. This low moves south over some of the world's most populated areas in Europe, North America, and Asia. At 40°N, the latitude of New York City, UV-B has increased about 4% per decade since 1978. At 55°N, the approximate latitude of Moscow and Copenhagen, the increase has been 6.8% per decade since 1978.

Ozone losses in population centers increase sunburns, cataracts (clouding of the lens of the eye), and skin cancers. A loss of ozone of only 1% is estimated to increase skin cancer cases by 5 to 6%. People may also suffer from decreases in their immune system's ability to fight off infectious diseases. Ozone loss may reduce crop yields, since many plants are sensitive to ultraviolet light. Excess UV appears to be decreasing the productivity of plankton in the oceans. A decrease of 6 to 12% has been measured around Antarctica, which may be at least partly related to the ozone hole. The effects of excess UV on other organisms is not known. When the problem with ozone depletion was recognized, world leaders took action. CFCs were banned in spray cans in some nations in 1978. The greatest production of CFCs was in 1986, but has declined since then. This will be discussed more in the next lesson.

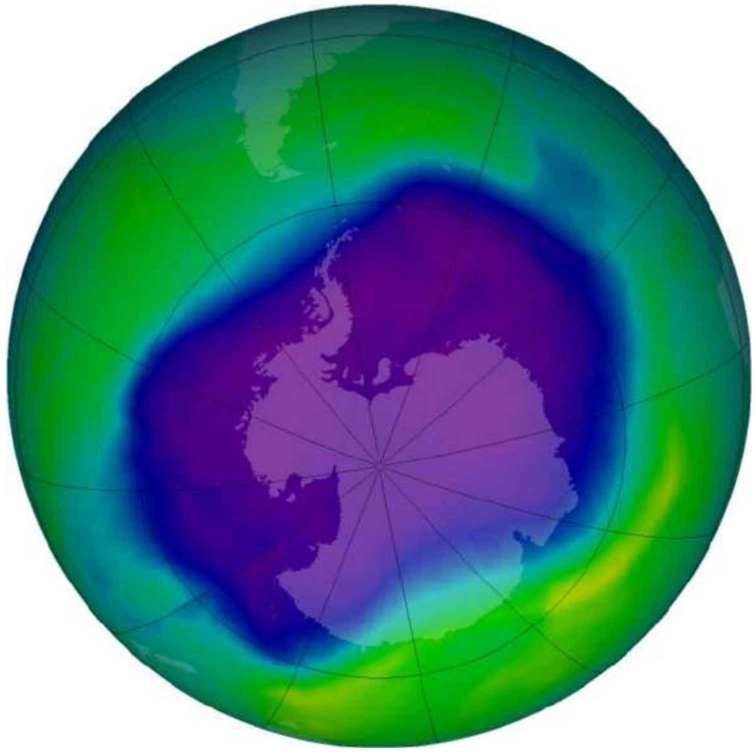


Figure 5.11: The September 2006 ozone hole, the largest ever observed. Blue and purple colors show particularly low levels of ozone.

Lesson Summary

- Air pollutants damage human health and the environment. Particulates reduce visibility, alter the weather, and cause lung problems like asthma attacks.
- Ozone damages plants and can also cause lung disease. Acid rain damages forests, crops, buildings and statues.
- The ozone hole, caused by ozone-destroying chemicals, allows more UV radiation to strike the Earth.
- This can cause plankton populations to decline and skin cancers in humans to increase, along with other effects.

Review Questions

1. Why is visibility so reduced in the United States?
2. Why do health recommendations suggest that people limit the amount of tuna they eat?
3. Why might ozone pollution or acid rain change an entire ecosystem?
4. Why does air pollution cause problems in developing nations more than in developed ones?
5. Why are children more vulnerable to the effects of air pollutants than adults?
6. Describe bioaccumulation.
7. How does pollution indirectly kill or harm plants?
8. What do you think the effect is of jet airplanes on global warming?
9. Why is air pollution a local, regional and global problem?
10. How do CFCs deplete the ozone layer?

Vocabulary

acid rain Rain that has a pH of less than 5.0.

alkaline Also called basic. Substances that have a pH of greater than 7.0.

bioaccumulation The accumulation of toxic substances within organisms so that the concentrations increase up the food web.

ozone hole A region around Antarctica in which ozone levels are reduced in springtime, due to the action of ozone-destroying chemicals.

pH scale A scale that measures the acidity of a solution. A pH of 7 is neutral. Smaller numbers are more acidic and larger numbers are more alkaline.

polar stratospheric clouds (PSC) Clouds that form in the stratosphere when it is especially cold; PSCs are necessary for the breakup of CFCs.

Points to Consider

- Since mercury bioaccumulates and coal-fired power plants continue to emit mercury into the atmosphere, what will be the consequence for people who like to eat tuna and other large predatory fish?
- What are the possible causes of rising asthma rates in children?
- A ban has been imposed on CFCs and some other ozone-depleting substances. How will the ozone hole change in response to this ban?

5.3 Reducing Air Pollution

Lesson Objectives

- Describe the major ways that energy use can be reduced.
- Discuss new technologies that are being developed to reduce air pollutants, including greenhouse gases.
- Describe the difference between placing caps on emissions and reducing emissions.

Introduction

The Clean Air Act of 1970 and the amendments since then have done a great job in requiring people to clean up the air over the United States. Emissions of the six major pollutants regulated by the Clean Air Act, carbon monoxide, lead, nitrous oxides, ozone, sulfur dioxide, and particulates, have decreased by more than 50%. Cars, power plants, and factories individually release less pollution than they did in the mid-20th century. But there are many more cars, power plants and factories. Many pollutants are still being released and some substances have been found to be pollutants that were not known to be pollutants in the past. There is still much work to be done to continue to clean up the air.

Ways to Reduce Air Pollution

Air pollution can be reduced in a number of ways. Using less fossil fuel is one way to lessen pollution. People use less fuel by engaging in conservation, which means not using a resource or using less of it. For example, riding a bike or walking instead of driving doesn't use any fossil fuel. Taking a bus uses less than driving or riding by yourself in a car, as does carpooling. If you need to drive, buying a car that has greater fuel efficiency is important. You can conserve electricity (and thus fossil fuels) at home by turning off light bulbs and appliances when they are not in use, using energy efficient light bulbs and appliances, and even buying less stuff. All these actions reduce the amount of energy that power plants need to produce.

There are many reasons for people in North America and Europe to try to reduce their use of fossil fuels. As you have already seen, air pollution has tremendous health and environmental costs. There are other reasons as well. Much of the oil we use comes from the Middle East, which is a politically unstable region of the world. Also, fossil fuels are running out, although some will run out sooner than others. The most easily accessible fossil fuels are mostly already gone and harder to use or recover fuels are now being used. There are other types of fossil fuels that can eventually replace coal and petroleum, such as tar sands and oil shale. But these have even more environmental problems than traditional fossil fuels have: mining them from the ground causes severe environmental damage and burning them releases pollutants, including greenhouse gases.

Alternative energy sources are important. They currently are not a large part of the energy supply, but they will increase rapidly over the coming years and decades. Several sources of alternative energy, including solar and wind are not currently being used much because the technologies are not well enough developed. Converting sunlight into usable solar power, for example, is still very expensive relative to using fossil fuels. For solar to be used more widely, technology will need to advance so that the price falls. Also, solar power is not practiced in all parts of the United States because some areas get low amounts of sunlight. These locations will need to develop different power sources. While the desert Southwest will need to develop solar, the Great Plains can use wind energy as its energy source. Perhaps some locations will rely on nuclear power plants, although current nuclear power plants have major problems like safety and waste disposal.

Some pollutants can be filtered out of the exhaust stream before they are released into the atmosphere. Other pollutants can be broken down into non-toxic compounds before they are released. Some of these technologies will be described in the following sections.

Reducing Air Pollution from Vehicles

Reducing air pollution from vehicles can be done in a number of ways. Pollutants can be broken down before they are released into the atmosphere. The vehicles can be more fuel efficient. New technologies can be developed so that they do not rely on fossil fuels at all.

Motor vehicles emit less pollution than they once did due to **catalytic converters** (**Figure** 5.12). Catalytic converters are placed on modern cars in the United States. These devices reduce emissions of nitrous oxides, carbon monoxide and VOCs. A **catalyst** speeds up chemical reactions without being used up in the reaction itself. For nitrous oxides, the catalyst breaks the nitrogen and oxygen atoms apart. The nitrogen then combines with another nitrogen ion to form nitrogen gas (N_2) and the oxygen forms O_2. VOCs and CO are similarly broken apart into the greenhouse gases H_2O and CO_2. Catalytic converters only work when they are hot, so a lot of exhaust escapes as the car is warming up.

There are several simple ways to make a vehicle more fuel efficient. Lighter vehicles need less energy to move. Streamlined vehicles experience less resistance from the wind. So, small, lightweight, streamlined cars get much better gas mileage than chunky, heavy SUVs. **Hybrid vehicles** are among the most efficient

Figure 5.12: A large catalytic converter on an SUV.

vehicles that are now widely available. Hybrids have a small internal combustion engine that works like an ordinary car. They also have an electric motor and a rechargeable battery. During braking, a normal car loses the energy it has because it is in motion. In a hybrid, that energy is instead funneled into charging the battery. When the car accelerates again, it uses the power stored in the battery. The internal combustion engine only takes over when power in the battery has run out. Hybrids get excellent gas mileage in cities where the vehicle frequently stops and starts. Hybrid vehicles also have catalytic converters: the battery preheats the converter so that it begins to work much sooner after the car is turned on. Hybrids can reduce auto emissions by 90% or more. Unfortunately, in many hybrid vehicles the hybrid technology is used to improve acceleration more than gas mileage.

A new technology that is in development is a plug-in hybrid. The vehicle is plugged into an electricity source when it is not in use, perhaps in a garage. The car uses the power stored in that battery when it is next used. Plug-in hybrids are less polluting than regular hybrids, since they can run for a longer time on electricity. Automakers expect that plug-in hybrids will become available around 2010.

Fuel cells are another technology that is in development (**Figure** 5.13). Hydrogen fuel cells harness the energy released when hydrogen and oxygen come together to create water. Fuel cells are extremely efficient and they produce no pollutants. But developing fuel cell technology has its problems. The oxygen the fuel cell uses comes from the atmosphere, but there is no easy source of hydrogen. Natural gas is a source, but converting it into usable hydrogen decreases the efficiency of the fuel cells and increases pollution, including greenhouse gases. Natural gas also has other important uses. A few fuel cell cars are now being produced as models. Right now these cars are extremely expensive and fueling stations are rare. Some automakers say that for fuel cell vehicles to become widespread the cost of production must decrease to 1% of its current price.

Figure 5.13: A hydrogen fuel cell car looks like a gasoline-powered car.

Reducing Industrial Air Pollution

Pollutants are removed from the exhaust streams of power plants and industrial plants before they enter the atmosphere. Particulates can be filtered out, while sulfur and nitric oxides are broken down by catalysts. Removing these oxides reduces the pollutants that cause acid rain.

Particles are relatively easy to remove from emissions. Baghouses work like a giant vacuum cleaner bag, filtering dust as it streams past. Baghouses collect about 98% of dry particulates. Cyclones are air streams that rotate quickly through a container shaped like a cylinder or a cone. Large particles are forced toward the edges of the air stream. When they hit the outside wall of the container, they fall to the bottom and are swept up. Smaller particles can be picked up as the radius of the cyclone is reduced. Particles can also be collected and removed by static electricity. These electrostatic precipitators are useful for removing materials from very hot gases.

Scrubbers remove particles and waste gases from exhaust (**Figure** 5.14). Wet scrubbers use a liquid solution to scrub pollutants. Dry scrubbers use alkali or other materials to neutralize acid gas pollutants. Other techniques are used to eliminate other toxic gases. Nitrogen oxides, for example, can be broken down at very high temperatures.

Gasification is a developing technology. This method removes some of the toxins present in coal before they are released into the atmosphere. In gasification, coal is heated to extremely high temperatures. The gas that is produced is filtered and the energy goes on to drive a generator. About 80% less pollution is released over regular coal plants, and greenhouse gases are also lower. Clean coal plants do not need scrubbers or other pollution control devices. Although the technology is ready, clean coal plants are more expensive to construct and operate and so they are seldom built. Also, heating the coal to high enough temperatures uses a great deal of energy, so the technology not very energy efficient. In addition, large amounts of the greenhouse gas CO_2 are still released even with clean coal technology.

Reducing Ozone Destruction

One success story in reducing pollutants that harm the atmosphere concerns ozone-destroying chemicals. In 1973, scientists calculated that CFCs could reach the stratosphere and break apart. This would release chlorine atoms, which would then destroy ozone. Based only on their calculations, the United States and most Scandinavian countries banned CFCs in spray cans in 1978.

More confirmation that CFCs break down ozone was needed before more was done to reduce production of ozone-destroying chemicals. In 1985, members of the British Antarctic Survey reported that a 50% reduction in the ozone layer had been found over Antarctica in the previous three springs. Two years later,

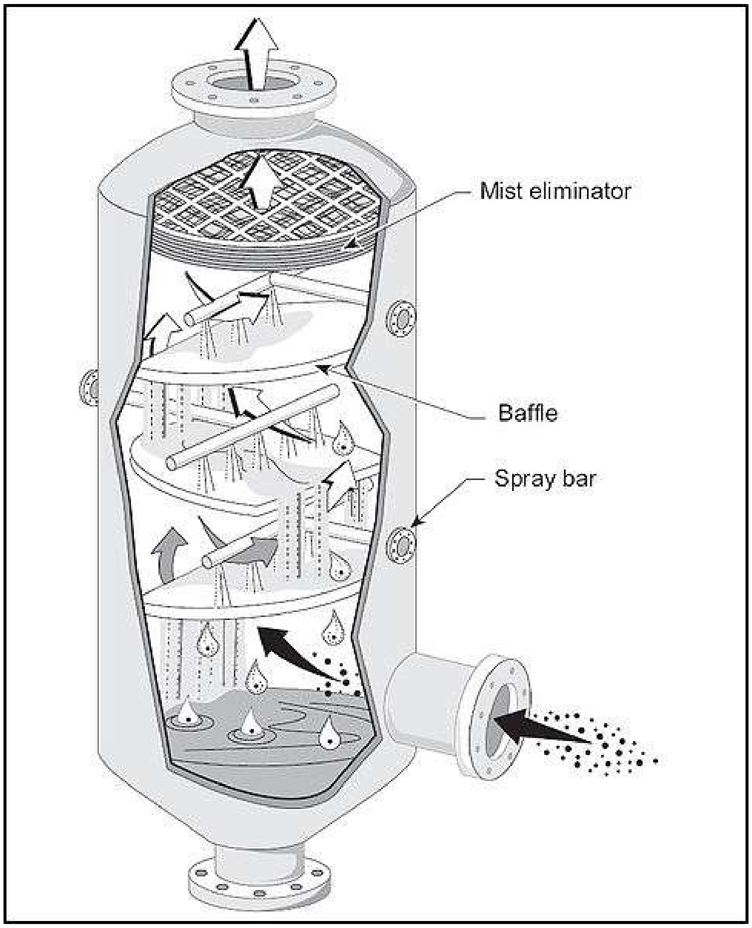


Figure 5.14: Diagram of one type of scrubber.

the 'Montreal Protocol on Substances that Deplete the Ozone Layer' was ratified by nations all over the world.

The Montreal Protocol controls the production and consumption of 96 chemicals that damage the ozone layer. Hazardous substances are phased out first by developed nations and one decade later by developing nations. More hazardous substances are phased out more quickly. CFCs have been mostly phased out since 1995, although some will be used in developing nations until 2010. The Protocol also requires that wealthier nations donate money to develop technologies that will replace these chemicals.

If CFCs were not being phased out, by 2050 they would have been probably been 10 times more abundant than they were in 1980. The result would have been about 20 million more cases of skin cancer in the United States and 130 million cases globally. Even though governments have acted to reduce CFC's, they take many years to reach the stratosphere and they can survive there a long time before they break down. So the ozone hole will probably continue to grow for some time before it begins to shrink. The ozone layer will reach the same levels it had before 1980 in around 2068 and 1950 levels in one or two centuries.

Reducing Greenhouse Gases

Reducing greenhouse gas emissions is related to air pollution control. Unlike many other air pollutants, climate change is a global problem. Climate scientists agree that all nations must come together to reduce greenhouse gas emissions. So far, this has not occurred.

The first attempt to cap greenhouse gas emissions was the Kyoto Protocol. The Kyoto Protocol limits greenhouse gas emissions for developed nations to below 1990 levels. Kyoto has not achieved the success of the Montreal Protocol for several reasons. The largest emitter of greenhouse gases, the United States, did not sign and was not bound by the agreement. Developing nations, most notably China, signed the treaty but are not obligated to make changes in their greenhouse gas emissions. Of the nations that agreed to reduce their emissions, few are on track to achieve their target. More importantly, several years have passed since this process was begun and climate scientists agree that the Protocol does not reduce emissions nearly enough. Some say that reductions 40 times those required by Kyoto are needed to avoid dangerous climate change. Plans are now being made to replace the Kyoto Protocol with a more effective treaty in 2012.

The Kyoto Protocol set up a cap-and-trade system. Each participating nation was given a cap on greenhouse gas emissions that it should not go over. If a nation is likely to go over its cap, it can buy credits from a nation that will emit less greenhouses gases than allowed by the cap. Cap-and-trade provides a monetary incentive for nations to develop technologies that will reduce emissions and to conserve energy. Some states and cities within the United States have begun their own cap-and-trade systems, since they believe that the federal government is not doing enough to address the problem of climate change.

However it is done, climate scientists and many others agree that greenhouse gas emissions must be lowered. The easiest and quickest way is to increase energy efficiency. A carbon tax can be placed on CO_2 emissions to encourage conservation. The tax would be placed on gasoline, carbon dioxide emitted by factories, and home energy bills to encourage conservation. For example, when people make a purchase of a new car, they will be more likely to purchase an energy efficient model. The money from the carbon tax can then be used for research into alternative energy sources. All plans for a carbon tax allow a tax credit for people who cannot afford to pay more for energy, so that they do not suffer unfairly.

More energy efficient vehicles and appliances can be developed. Some, like hybrid cars are currently available. Agricultural practices that lessen the amount of methane produced can be used.

Beyond increasing efficiency, new technologies can be developed. Alternative energy sources, like solar and wind can be developed and expanded. **Biofuels** can replace gasoline in vehicles, but they must be developed sensibly (**Figure** 5.15). So far much of the biofuel is produced from crops like corn. But when food crops are used for fuel, the price of food goes up. Also modern agriculture is extremely reliant on fossil fuels for pesticides, fertilizers and the work of farming. This means that not much energy is gained from using a biofuel over using the fossil fuels directly. More promising crops for biofuels are now being researched. Surprisingly, algae is being investigated as a source of fuel! The algae can be grown in areas that are not useful for agriculture, and it also contains much more useable oil than crops like corn.

Figure 5.15: A bus that runs on soybean oil shows the potential of biofuels.

Greenhouse gases can also be removed from the atmosphere after they are emitted. **Carbon sequestration** occurs when carbon dioxide is removed from the atmosphere. Carbon is sequestered naturally in forests, but unfortunately, more forest land is currently being lost than gained. Another idea is to artificially sequester carbon. For example, carbon can be captured from the emissions from gasification plants. That carbon is then stored underground in salt layers or coal seams, which keeps it out of the atmosphere. While some small sequestration projects are underway, no large-scale sequestration has yet been attempted. While it is a promising new technology, carbon sequestration is also untested and may not prove to be significant in fighting global warming.

Just as individuals can diminish other types of air pollution, people can fight global warming by conserving energy. Also, people can become involved in local, regional and national efforts to make sound choices on energy policy.

Lesson Summary

- Air pollutants can be reduced in many ways. The best method is to not use the energy that produces the pollutants by conservation or increasing energy efficiency.
- Alternative energy sources are another good way to reduce pollution. Most of these alternate energy technologies are still being refined (solar, wind) and some have other problems associated with them (nuclear, biofuels).
- Pollutants can be removed from an exhaust stream by being filtered out or broken down. Some pollutants are best not released at all like CFCs.

Review Questions

1. Since the Clean Air Act was passed in 1970, why is the air still not clean?

2. What are some ways that you can conserve energy?
3. How does reducing air pollutants, as described in the Clean Air Act of 1970, affect greenhouse gas emissions?
4. What has to be done before alternative energy sources can replace fossil fuels?
5. What are catalytic converters?
6. Why are hybrid vehicles more energy efficient than regular vehicles powered by internal combustion engines?
7. Why aren't fuel cell vehicles widely available yet?
8. How does a cyclone reduce particulate pollution?
9. How can coal power be made so that it has nearly zero carbon contribution to the atmosphere?
10. Why is it that the ozone hole will not be healed for several decades?
11. Many people think that biofuels are the solution to a lot of the problem of climate change, but others disagree. What requirements would biofuels have to meet if they were to be really effective at replacing gasoline in motor vehicles?

Vocabulary

biofuel A fuel made from living materials, usually crop plants.

carbon sequestration Removal of carbon dioxide from the atmosphere, so that it does not act as a greenhouse gas in the atmosphere.

catalyst A substance that increases (or decreases) the rate of a chemical reaction but is not used up in the reaction.

catalytic converter Found on modern motor vehicles, these devices use a catalyst to break apart pollutants.

fuel cell An energy cell in which chemical energy is converted into electrical energy.

gasification A technology that cleans coal before it is burned, which increases efficiency and reduces emissions.

hybrid vehicle A very efficient vehicle that is powered by an internal combustion engine, an electric motor and a rechargeable battery.

Points to Consider

- Why is it important to reduce air pollution?
- What can you do in your own life to reduce your impact on the atmosphere?
- Why is a worldwide effort needed to reduce the threat of global climate change?

Image Sources

(1) *Smog in New York City.*. Public Domain.

(2) `http://en.wikipedia.org/wiki/Image:DodgeCatCon.jpg`. Public Domain.

(3) http://en.wikipedia.org/wiki/Image:Pollution_-_Damaged_by_acid_rain.jpg. GNU-FDL.

(4) EPA. http://en.wikipedia.org/wiki/Image:Origins.gif. Public Domain.

(5) EPA. http://en.wikipedia.org/wiki/Image:US-overall-nonattainment-2007-06.png. Public Domain.

(6) David Iliff. http://en.wikipedia.org/wiki/Image:Los_Angeles_Pollution.jpg. CC-BY-SA 3.0.

(7) Jami Dwyer. http://en.wikipedia.org/wiki/Image:Lacanja_burn.JPG. Public Domain.

(8) *Jet contrails block sunlight.*. GNU-FDL.

(9) NPS. http://en.wikipedia.org/wiki/Image:Air_.pollution_1.jpg. Public Domain.

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(13) DOE. http://en.wikipedia.org/wiki/Image:Soybus.jpg. Public Domain.

(14) http://en.wikipedia.org/wiki/File:Acid_rain_woods1.JPG. CC-BY-SA.

(15) NASA. http://en.wikipedia.org/wiki/Image:160658main2_OZONE_large_350.png. Public Domain.

Chapter 6

Ecosystem Dynamics

6.1 Flow of Energy

Lesson Objectives

- Explain where all the energy in an ecosystem ultimately comes from.
- Classify organisms on the basis of how they obtain energy (producers, consumers, and decomposers) and describe examples of each.

Check Your Understanding

- What is photosynthesis?
- What are some examples of organisms that can photosynthesize?

Introduction

Energy is defined as the ability to do work. In organisms, this work can involve not only physical work like walking or jumping, but also carrying out the essential chemical reactions of our bodies. Therefore, all organisms need a supply of energy to stay alive. Some organisms can capture the energy of the sun, while others obtain energy from the bodies of other organisms. Through predator-prey relationships, the energy of one organism is passed on to another. Therefore, energy is constantly flowing through a community. Understanding how this energy moves through the ecosystem is an important part of the study of ecology.

Energy and Producers

With just a few exceptions, all life on Earth depends on the sun's energy for survival. The energy of the sun is first captured by **producers** (**Figure** 6.1), organisms that can make their own food. Many producers make their own food through the process of photosynthesis. Producers make or "produce" food for the rest of the ecosystem. In addition, there are bacteria that use chemical processes to produce food, getting their energy from sources other than the sun, and these are also considered producers.

There are many types of photosynthetic organisms that produce food for ecosystems. On land, plants are the dominant photosynthetic organisms. Algae are common producers in aquatic ecosystems. Single celled algae and tiny multicellular algae that float near the surface of water and that photosynthesize are called phytoplankton.

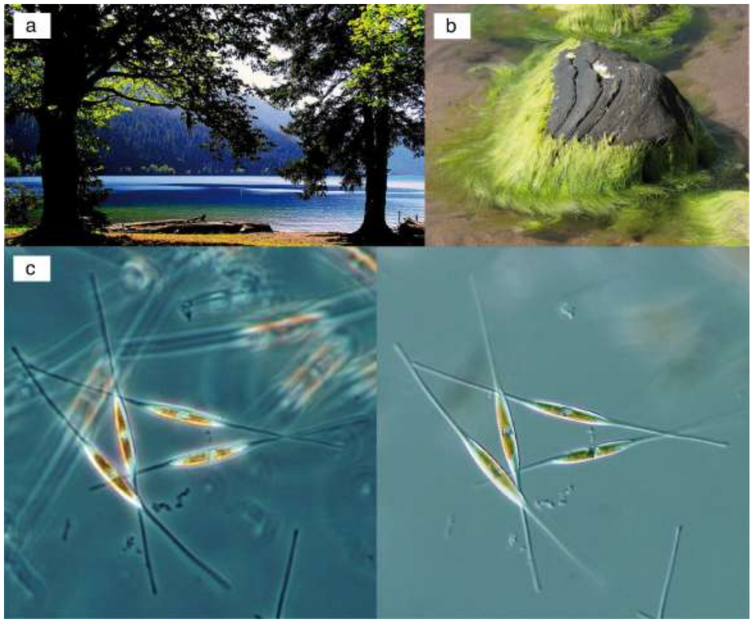

Figure 6.1: Producers include plants (a), algae (b), and diatoms, which are unicellular algae(c).

Although producers might look quite different from one another, they are similar in that they make food containing complex organic compounds, such as fats or carbohydrates, from simple inorganic ingredients. Recall that the only required ingredients needed for photosynthesis are sunlight, carbon dioxide (CO_2), and water (H_2O). From these simple inorganic building blocks, photosynthetic organisms can produce glucose ($C_6H_{12}O_6$) and other complex organic compounds.

Consumers and Decomposers

Many types of organisms are not producers and cannot make their own food from sunlight, air, and water. The animals that must consume other organisms to get food for energy are called **consumers**. The consumers can be placed into several groups. **Herbivores** are animals that eat photosynthetic organisms to obtain energy. For example, rabbits and deer are herbivores that eat plants. The caterpillar in **Figure** 6.2 is a herbivore. Animals that eat phytoplankton in aquatic environments are also herbivores. **Carnivores** feed on animals, either the herbivores or other carnivores. Snakes that eat mice are carnivores, and hawks that eat the snakes are also carnivores. **Omnivores** eat both producers and consumers. Most people are omnivores since they eat fruits, vegetables, and grains from plants and also meat and dairy products from animals. Dogs, bears, and raccoons are also omnivores.

Decomposers (**Figure** 6.3) obtain nutrients and energy by breaking down dead organisms and animal wastes. Through this process, decomposers release nutrients, such as carbon and nitrogen, back into the ecosystem so that the producers can use them. Through this process these essential nutrients are recycled, an essential role for the survival of every ecosystem. Examples of decomposers include mushrooms on a decaying log and bacteria in the soil. Decomposers are essential for the survival of every ecosystem. Imagine what would happen if there were no decomposers. Wastes and the remains of dead organisms would pile up and the nutrients within the waste and dead organisms would never be released back into the ecosystem!

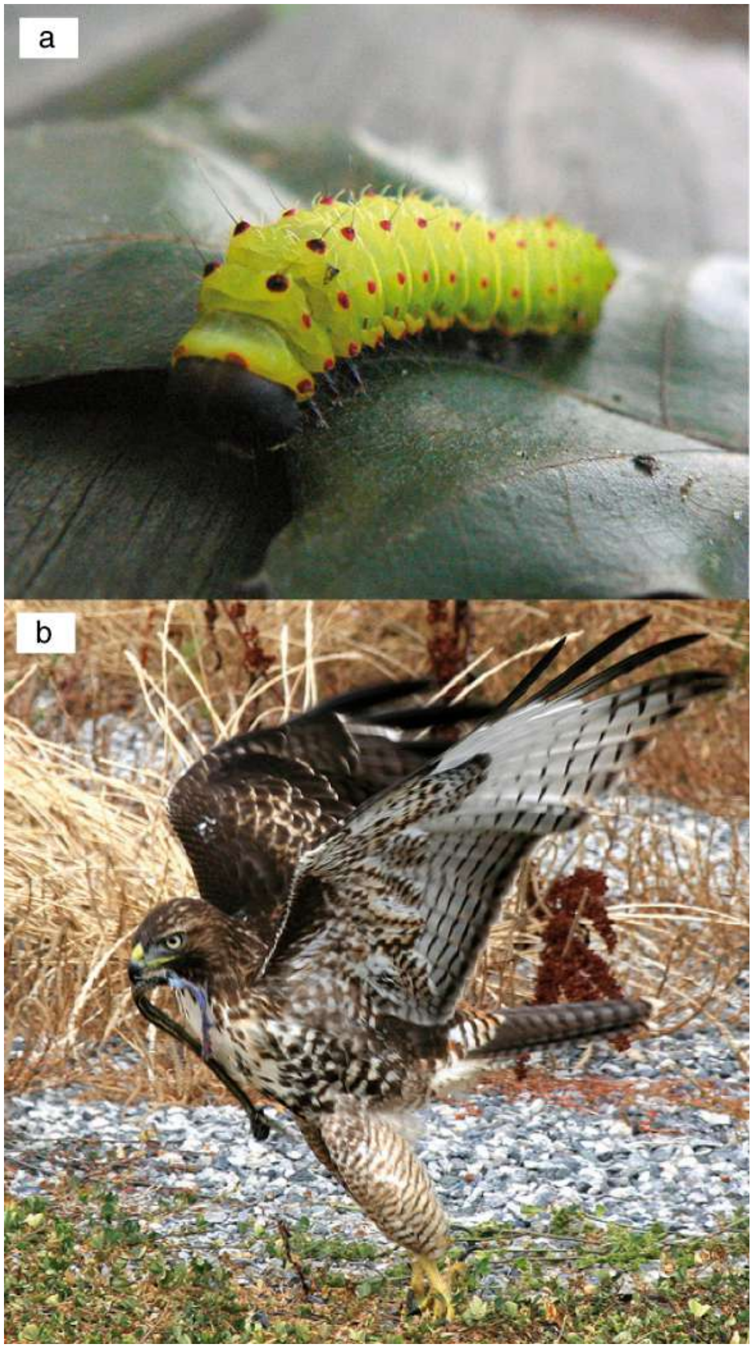

Figure 6.2: Examples of consumers are caterpillars (herbivores) and hawks (carnivore).

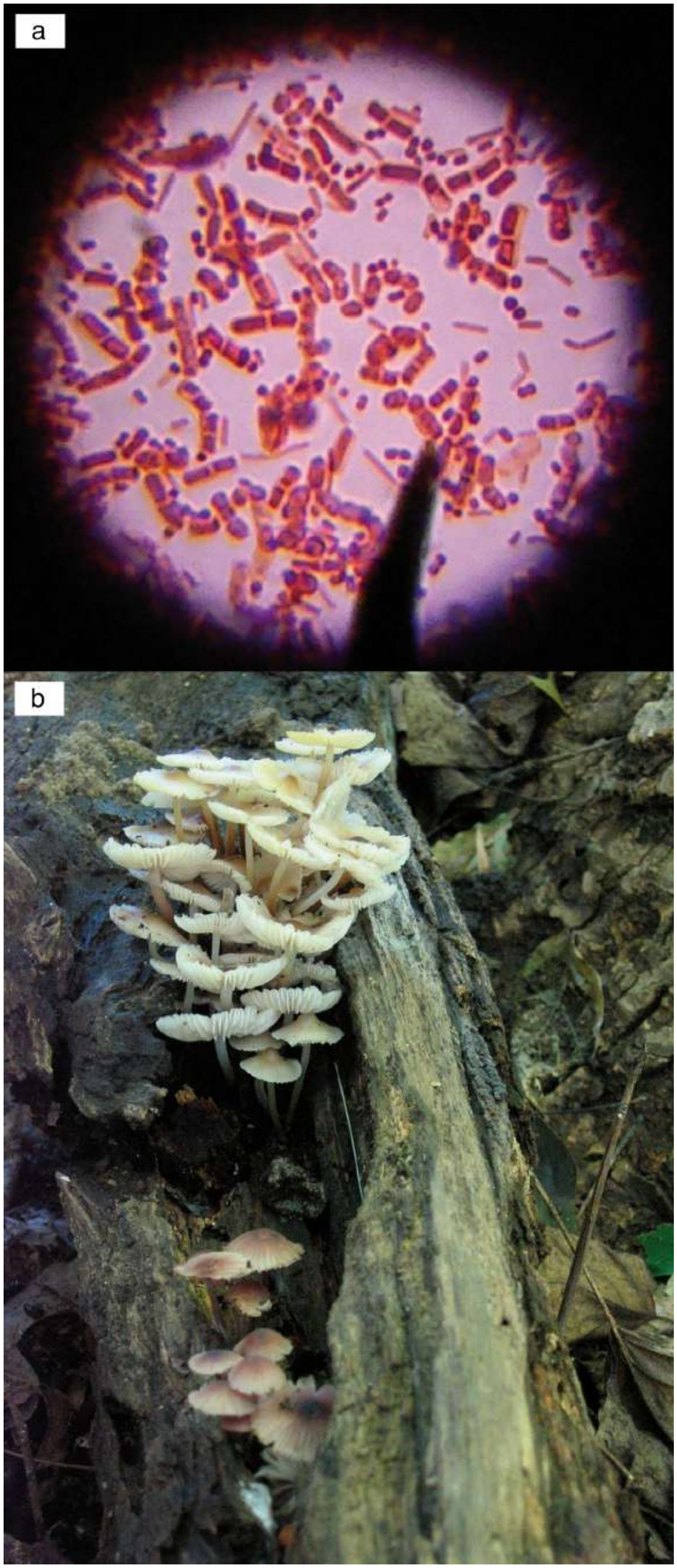

Figure 6.3: Examples of decomposers are bacteria (a) and fungi (b).

Lesson Summary

- Producers, which include photosynthetic organisms like plants and algae, can make their own food from simple inorganic compounds.
- Consumers must obtain their nutrients and energy by eating other organisms, while decomposers break down animal remains and wastes to obtain energy.

Further Reading / Supplemental Links

- `http://www.eelsinc.org/id43.html`http://www.eelsinc.org/id43.html
- `http://science-class.net/Ecology/energy_transfer.htm`http://science-class.net/Ecology/energy__-transfer.htm
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- `http://science-class.net/Ecology/energy_transfer.htm`http://science-class.net/Ecology/energy__-transfer.htm
- `http://en.wikipedia.org/wiki/Food_chain`http://en.wikipedia.org/wiki/Food__chain

Vocabulary

biomass The total dry weight of all the individuals of one type of organism.
carnivore An organism that eats other animals.
consumer An organism that must eat other organisms to obtain energy and nutrients.
decomposer An organism that breaks down animal remains or wastes to gain energy and nutrients.
herbivore A consumer of producers in a community; often organisms that eat plants.
omnivore A consumer in a community that eat both producers and consumers; usually eaters of both plants and animals.
producer An organism that can absorb the energy of the sun and convert it into food through the process of photosynthesis; i.e. plants and algae.

Points to Consider

- Animals are carbon-based organisms. When animals decompose, what happens to the carbon? Discuss this with your class.
- We need nitrogen to make our DNA. Where does it come from? Where does it go? What would happen to nitrogen released from decaying organisms?
- Water is essential for photosynthesis. Water moves through both the living and non-living parts of an ecosystem. How does water move through the living parts of an ecosystem?

6.2 Cycles of Matter

Lesson Objectives

- Describe the key features of the water cycle.
- Describe the key features of the nitrogen cycle.
- Describe the key features of the carbon cycle.

Check Your Understanding

- What types of organisms break down animal remains and wastes to release nutrients?
- What are the main chemical elements that are essential for life?

Introduction

What happens to all the plants and animals that die? Do they pile up and litter ecosystems with dead remains? Or do they decompose? The role of decomposers in the environment often goes unnoticed, but these organisms are absolutely crucial for every ecosystem. Imagine if the decomposers were somehow taken out of an ecosystem. The nutrients, such as carbon and nitrogen, in animal wastes and dead organisms would remain locked in these forms if there was nothing to decompose them. Overtime, almost all the nutrients in the ecosystem would be used up. However, these elements are essential to build the organic compounds necessary for life and so they must be recycled. The decomposition of animal wastes and dead organisms allows these nutrients to be recycled and re-enter the ecosystem, where they can be used by living organisms.

The pathways by which chemicals are recycled in an ecosystem are **biogeochemical cycles**. This recycling process involves both the living parts of the ecosystem and the non-living parts of the ecosystem, such as the atmosphere, soil, or water. The same chemicals are constantly being passed through living organisms to non-living matter and back again, over and over. Through biogeochemical cycles, inorganic nutrients that are essential for life are continually recycled and made available again to living organisms. These recycled nutrients contain the elements carbon and nitrogen, and also include water.

The Carbon Cycle

Carbon is one of the most abundant elements found in living organisms. Carbon chains form the backbones of carbohydrates, proteins, and fats. Carbon is constantly cycling between living things and the atmosphere (**Figure** 6.4).

In the atmosphere, water is in the form of carbon dioxide. Producers capture this carbon dioxide and convert it to food through the process of photosynthesis (discussed in the chapter titled *Cells and Their Structures*). As consumers eat producers or other consumers, they gain the carbon from that organism. Some of this carbon is lost, however, through the process of cellular respiration. When our cells burn food for energy, carbon dioxide is released. We exhale this carbon dioxide and it returns to the atmosphere. Also, carbon dioxide is released to the atmosphere as an organism dies and decomposes.

Millions of years ago there was so much organic matter that it could not be completely decomposed before it was buried. As this buried organic matter was under pressure for millions of years, it formed into **fossil fuels** such as coal, oil, and natural gas. When humans excavate and use fossil fuels, we have an impact on the carbon cycle (**Figure** 6.5). The burning of fossil fuels releases more carbon dioxide into the atmosphere than is used by photosynthesis. Therefore the net amount of carbon dioxide in the atmosphere is rising. Carbon dioxide is known as a greenhouse gas since it lets in light energy but does not let heat escape, much like the panes of a greenhouse. The increase of greenhouse gasses in the atmosphere is contributing to a global rise in Earth's temperature, known as **global warming** (see the *Environmental Problems* chapter for additional information).

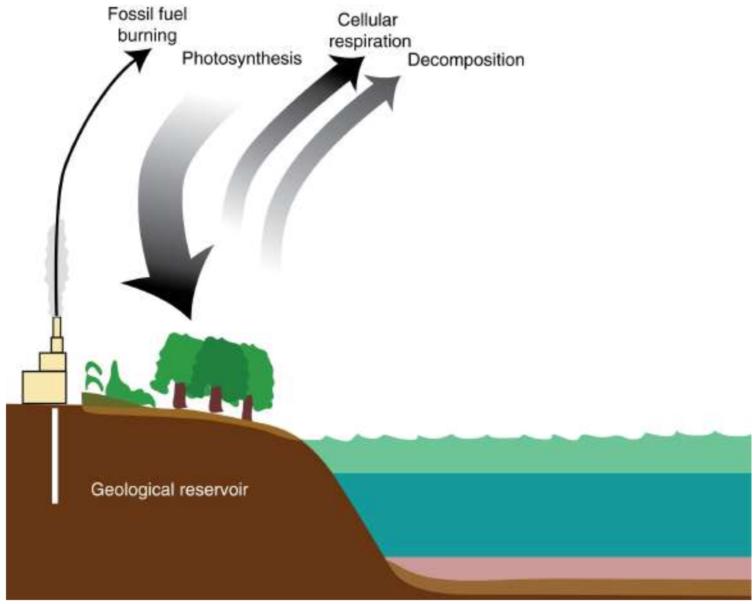

Figure 6.4: The carbon cycle.

Figure 6.5: Human activities like burning gasoline in cars are contributing to a global change in our climate.

The Nitrogen Cycle

Nitrogen is also one of the most abundant elements in living things. It's important for constructing both proteins and nucleic acids like DNA. The great irony of the nitrogen cycle is that nitrogen gas (N_2) comprises the majority of the air we breathe, and yet is not accessible to us or plants in the gaseous form (**Figure** 6.6). In fact, plants often suffer from nitrogen deficiency even through they are surrounded by plenty of nitrogen gas!

In order for plants to make use of nitrogen, it must be converted into compounds with other elements. This can be accomplished several different ways. First, Nitrogen gas can be converted to nitrate (NO_3^-) through lightning strikes. Alternatively, special nitrogen-fixing bacteria can also convert nitrogen gas into useful forms, a process called **nitrogen fixation.** These bacteria live in nodules on the roots of plants in the pea family. In aquatic environments, bacteria in the water can fix nitrogen gas into ammonium (NH_4^+), which can be used by aquatic plants as a source of nitrogen.

Nitrogen also is released to the environment through decaying organisms or decaying wastes. These wastes often take on the form of ammonium. Ammonium in the soil can be converted to nitrate by a two-step process completed by two different types of bacteria. In the form of nitrate, it can be used by plants through a process called **assimilation**.

The conversion of nitrate back into nitrogen gas happens through the work of denitrifying bacteria. These bacteria often live in swamps and lakes. The release of nitrogen gas would equal the amount of nitrogen gas taken into living things if human activities did not influence the nitrogen cycle. These human activities include the burning of fossil fuels, which releases nitrogen oxide gasses into the atmosphere, leading to problems like acid rain.

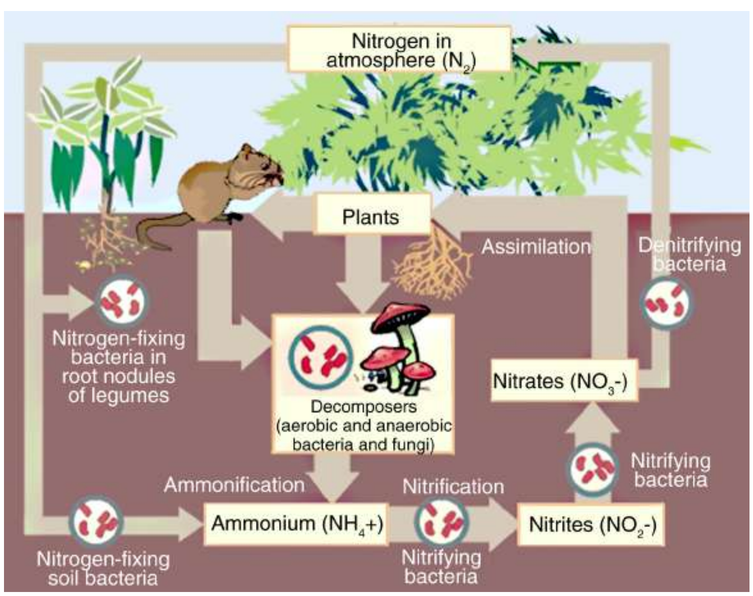

Figure 6.6: The nitrogen cycle includes assimilation, or uptake of nitrogen by plants; nitrogen-fixing bacteria that make the nitrogen available to plants in the form of nitrates; decomposers that convert nitrogen in dead organisms into ammonium; nitrifying bacteria that convert ammonium to nitrates; and denitrifying bacteria that convert help convert nitrates to gaseous nitrogen.

Lesson Summary

- During the water cycle, water enters the atmosphere through evaporation, and water returns to land through precipitation.
- During the carbon cycle, animals add carbon dioxide to the atmosphere through respiration and plants remove carbon dioxide through photosynthesis.
- During the nitrogen cycle, gaseous nitrogen is converted into water-soluble forms that can be used by plants, while denitrifying bacteria convert nitrate back to gaseous nitrogen.

Review Questions

1. What human activities have thrown the carbon cycle off balance?
2. What biological process ‘‘fixes” carbon, removing it from the atmosphere?
3. What is the significance of nitrogen-fixing bacteria?
4. What is the term for the remains of organisms that are burned for energy?
5. How does water in the atmosphere return to the ground?
6. What biological process releases carbon back into the atmosphere?
7. What are some examples of fossil fuels?
8. Why is carbon dioxide referred to as a ‘‘greenhouse gas”?
9. What must happen for plants to use nitrogen in the atmosphere?
10. What is the significance of denitrifying bacteria?

Further Reading / Supplemental Links

- `http://earthobservatory.nasa.gov/Library/CarbonCycle`http://earthobservatory.nasa.gov/Library/Carbo
- `http://www.cosee-ne.net/resources/documents/OceanLiteracyWorkshopIReport.pdf`http://www.cosee-ne.net/resources/documents/OceanLiteracyWorkshopIReport.pdf
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- `http://en.wikipedia.org/wiki`http://en.wikipedia.org/wiki

Vocabulary

assimilation The uptake of nitrogen by plants.

aquifers Layers of porous rock that can hold water underground.

biogeochemical cycles The pathway of elements like carbon and nitrogen through the non-living and living parts of the ecosystem.

denitrifying bacteria Bacteria that convert nitrates or nitrites back to nitrogen in the gaseous form.

fossil fuels Fuels made from partially decomposed organic matter that has been compressed underground for millions of years; examples are: coal, natural gas, and oil.

global warming Global increase in the Earth’s temperature due to human activities that release greenhouse gasses into the atmosphere.

groundwater Underground water reserves.

nitrogen fixation Process by which gaseous nitrogen is converted in chemical forms that can be used by plants.

precipitation Water that falls to the earth in the form of rain, snow, sleet, hail.

runoff Water that is not absorbed by the soil that eventually returns to streams and rivers.

transpiration Process by which water leaves a plant by evaporating from the leaves.

Chapter 7

Human Actions and the Land

7.1 Loss of Soils

Lesson Objectives

- Explain how human actions accelerate soil erosion.
- Describe ways that we can prevent soil erosion.

Introduction

Have you ever seen muddy rain or snow falling from the sky? Can you imagine what it might be like if the water that came down as rain and snow was muddy and brown? In May 1934, a huge wind storm picked up and blew away massive amounts of **topsoil** from the Central United States (**Figure** 7.1). The wind carried the soil eastward to Chicago. Some of the soil then fell down to the ground like a snowstorm made of mud. The rest of it continued blowing eastward, and reached all the way to New York and Washington, D.C. That winter, states like New York and Vermont actually had red snow because of all the dusty soil in the air.

A little less than one year later, in April 1935, another such storm happened (**Figure** 7.2). It was called a Black Blizzard. It made the day turn dark as night; people could not see right in front of them because of all the soil blown up by the wind storm. The storm caused tremendous damage and led to many people leaving the central United States to find other places to live. Many people became sick from breathing the soil in the air.

These storms are sometimes called the Dust Bowl storms. They continued on and off until about 1940. They are extreme examples of soil erosion, which is the process of moving soil from one place to another. Soil erosion is a serious problem because it takes away a valuable resource that we need to grow food. Several factors contributed to the Dust Bowl storms. First, farmers in the Central United States had plowed grasslands there to grow food crops. They left the crop fields bare in the winter months. This left the soil exposed to wind. Secondly, a long drought in the 1930's left the exposed soil especially dry. When the spring winds began blowing, the dry exposed soil was easily picked up and blown away.

We learned many lessons from the Dust Bowl storms. Today, we encourage farming practices that keep the soil covered even during the winter, so that it is not exposed and vulnerable to erosion. We have also learned of ways to prevent erosion in cities and towns as well as on farmlands. In this lesson, you will learn about some human activities that lead to erosion. You will then learn some of the specific ways we can

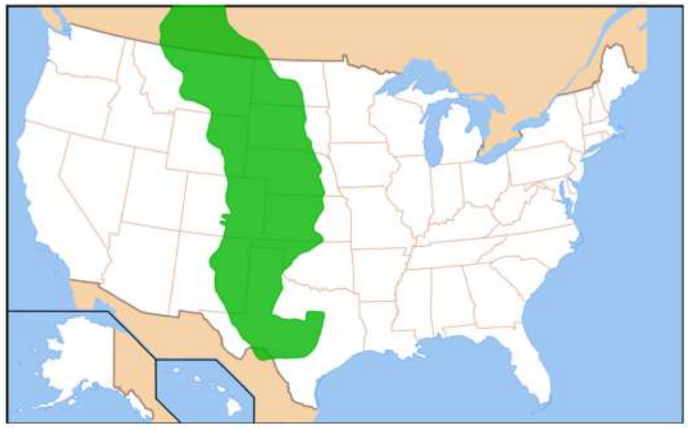

Figure 7.1: Soil loss from the dust storms of 1934 and 1935 came mostly from the states shown here in green in the Central United States. The soil blew all the way to the east coast of the United States.

Figure 7.2: This wind storm blew huge amounts of soil into the air in Texas on April 14, 1935.

prevent soil erosion.

Causes of Soil Erosion

Soil erosion occurs when water, wind, ice or gravity moves soil from one place to another. Running water is the leading cause of erosion, since it can easily take soil with it as the water flows downhill or moves across the land. Wind is the next leading cause of erosion. Just as in the Dust Bowl storms of the 1930's, wind can blow soil many hundreds of kilometers away. Soil is especially vulnerable to erosion if it is bare or exposed. Plants therefore serve a tremendous role in preventing soil erosion. If the soil is covered with plants, erosion is slowed down. But when soil is bare, the rate of erosion speeds up tremendously. What are some human activities that leave the soil exposed and speed up erosion? We speed up erosion through the following actions:

- Agriculture
- Grazing animals
- Logging and mining
- Construction
- Recreational activities, like driving vehicles off-road or hiking

Agriculture, is probably the most significant human action that accelerates, or speeds up, erosion (**Figure** 7.3). We first plow the land to plant fields of crops. This takes away the natural vegetative cover of an area and replaces it with rows of crop plants mixed with bare areas. It also creates an area where there may not be anything growing in the winter, because in most areas, food crops only grow in the spring and summer. The bare areas of a field are very susceptible to erosion. Without anything growing on them, the soil is easily picked up and carried away. The fields also experience more erosion in the winter if no plants are growing on them and they are just left as bare soil. In addition, farmers sometimes make deep grooves in the land with their tractor tires. These grooves act like small channels that give running water a path. This speeds up erosion from water.

Some parts of the world use an agricultural practice called slash and burn. This involves cutting and burning forests to create fields and **pastures**. It is one of the worldwide leading causes of excessive soil erosion. It is most commonly practiced in developing countries in tropical areas of the world, as people create more land for agriculture.

Grazing animals are animals that live on large areas of grassland (**Figure** 7.4). They wander over the area and eat grasses and shrubs. They can remove large amounts of the plant cover for an area. If too many animals graze the same land area, once the tips of grasses and shrubs have been eaten, they will use their hooves to pull plants out by their roots.

When an area is logged, large areas of trees are cut down and removed for human use (**Figure** 7.5). When the trees are taken away, the land is left exposed to erosion. Even more importantly, logging results in the loss of **leaf litter**, or dead leaves, bark, and branches on the forest floor. Leaf litter decreases because no trees are left to drop leaves or other plant parts to the ground. The leaf litter plays an important role in protecting forest soils from erosion.

Mining is another activity that speeds up erosion (**Figure** 7.6). When we mine we are digging in the Earth for mineral resources, like copper or silver. The huge holes dug by mining operations leave large amounts of ground exposed. In addition, most of the rock removed when mining is not actually the precious mineral, but **tailings**, or unwanted rock that is left next to the mine after the valuable minerals are removed. These tailings are usually piled up next to a mine, and are easily eroded downhill.

Constructing human buildings and roads also causes much soil erosion. This **development** involves changing forest and grassland into cities, buildings, roads, neighborhoods, and other human-made features.

Figure 7.3: The bare areas of farmland are especially vulnerable to erosion.

Figure 7.4: Grazing animals can cause erosion if they are allowed to overgraze and remove too much or all of the vegetation in a pasture.

Figure 7.5: Logging exposes large areas of land to erosion.

Figure 7.6: This large coal mining pit in Germany, and other mines like it, are major causes of erosion.

Any time we remove natural vegetation, we make the soil more susceptible to erosion. In addition, features like roads, sidewalks, and parking lots do not let water run through them into the ground because they are hard and **impermeable** (**Figure** 7.7). Since the water cannot enter the ground, it then runs over the ground faster than usual. This can speed up water erosion.

Figure 7.7: Urban areas and parking lots result in less water entering the ground. Therefore, more water runs over the land and quickly forms channels that can speed up erosion.

Humans also cause erosion through recreational activities, like hiking and riding off-road vehicles. An even greater amount of erosion occurs when people drive off-road vehicles over an area. The area eventually develops bare spots where no plants can grow. Erosion becomes a serious problem in these areas.

Human-caused Erosion

Some erosion is a natural process and has always happened on Earth. However, human activities like those discussed above, have accelerated soil erosion, which may occur about 10 times faster than its natural rate. As the human population grows, we increase our impact on soil erosion. In order to support Earth's human population, we need to create more and more farmland, we develop more areas and build more cities, and we use much more of the land for recreation. Human population growth can lead to degradation of the natural environment.

Human impact on erosion differs throughout the world. In developed countries like the United States, we have learned good agricultural practices that greatly slow down agriculture's impact on erosion. However, we still experience much erosion from the development of urban areas and construction of new cities. In developing countries, many people are very poor and just want to be able to grow food and make a simple living. They carry out slash and burn agriculture because it quickly gives them land to grow food crops on. Poverty is a big contributing factor to environmental problems like soil erosion in developing countries.

Preventing Soil Erosion

Soil is a renewable, natural resource necessary for growing food. However, it renews itself slowly: it can take hundreds or thousands of years to replenish lost soil. When we lose valuable soil, we also lose an important natural resource. Many of the farmers affected by the Dust Bowl storms of the 1930's lost their homes because they could no longer grow crops and earn money to live, once their topsoil had all blown away. While agriculture can cause erosion, it is also necessary for human life. We have learned many good agricultural practices that reduce erosion, instead of speeding it up.

Table 7.1 shows some seps that we can take to prevent erosion. Which of these things can you do in your own personal life? Can you think of any other steps we can take to slow down erosion? Notice that many of the things listed here involve ways that we use the land. Land use always requires humans to make choices.

Table 7.1:

Source of Erosion	Strategies for Prevention
Agriculture	• Leave leaf litter on the ground in the winter • Grow **cover crops**, special crops grown in the winter to cover the soil • Plant tall trees around fields to buffer the effects of wind • Drive tractors as little as possible • Use drip irrigation that puts small amounts of water in the ground frequently • Avoid watering crops with sprinklers that make big water drops on the ground • Keep fields as flat as possible to avoid soil eroding down hill
Grazing Animals	• Move animals throughout the year, so they don't consume all the vegetation in one spot • Keep animals away from stream banks, where hills are especially prone to erosion
Logging and Mining	• Reduce the amount of land that we log and mine • Reduce the number of roads that are built to access logging areas • Avoid logging and mining on steep lands • Cut only small areas at one time and quickly replant logged areas with new seedlings

Table 7.1: (continued)

Source of Erosion	Strategies for Prevention
Development	• Reduce the amount of land that we turn into cities, urban areas, parking lots, etc. • Keep as much "green space" in cities as possible, such as strips of trees where plants can grow • Invest in and use new technologies for parking lots that make them permeable to water in order to reduce runoff of water
Recreational Activities	• Avoid using off-road vehicles on hilly lands • Stay on designated trails
Building Construction	• Avoid building on steep hills • Grade surrounding land to distribute water rather than collecting it in one place • Where water collects, drain to creeks and rivers • Landscape with plants that minimize erosion

Lesson Summary

- Soil erosion is a natural process, but human activities have greatly accelerated soil erosion.
- We accelerate erosion through agriculture, grazing, logging and mining, development, and recreation.
- Soil is an important natural resource necessary for plant growth and should be kept safe from erosion as much as possible.
- There are many ways that we can slow down or prevent erosion, but practicing these involves making decisions about how we use land resources. It also requires striking a balance between economic needs and the needs of the environment.

Review Questions

1. Many farmers harvest their crops in the fall and then let the leftover plant material stay on the ground over winter. How does this help prevent erosion?
2. List five ways human activity has accelerated soil erosion.
3. How do urban areas contribute to soil erosion?
4. What is the connection between poverty and soil erosion in developing countries?
5. What is one way you can prevent soil erosion when you are hiking?
6. You often see stone barriers or cage-like materials set up along coastal shores and river banks. How do you think these serve to prevent erosion? Why are areas like this prone to erosion?

7. How can your own activities affect the environment, especially soil erosion?
8. What can we do to help solve environmental problems in developing countries? What responsibility do you have to help solve this problem?

Further Reading / Supplemental Links

- People who lived during the Dust Bowl talk about their experiences, the Ganzel Group `http://www.livinghistoryfarm.org/farminginthe30s/water_02.html`

- Video of the Dust Bowl `http://www.weru.ksu.edu/vids/dust002.mpg`

Vocabulary

cover crop A special crop grown by a farmer in the wintertime to reduce soil erosion. Cover crops often also add nitrogen to the soil.

development The construction of new buildings, roads, and other human-made features in a previously natural place.

impermeable Not allowing water to flow through it.

leaf litter Dead leaves, branches, bark, and other plant parts that accumulate on the floor of a forest.

pasture Land that is used for grazing animals.

topsoil The very important top few inches of soil, where much of the nutrients are found necessary for plant growth; Part of the A horizon

Points to Consider

- Is soil a renewable resource or a nonrenewable resource? Explain the ways it could be either.
- Could humans live without soil?
- What could you do to help to conserve soil?

7.2 Pollution of the Land

Lesson Objectives

- Define hazardous waste and describe its sources.
- Describe some of the impacts of hazardous waste on human health and on the environment.
- Detail some ways that we can control hazardous wastes.

Introduction

Sometimes human activities lower the quality or **degrade** the land by putting hazardous substance in the soil and water. A well-known example of this is the story of Love Canal in New York. The story began in the 1950's, when a local chemical company put dangerous chemicals in steel drum containers. They buried the containers in Love Canal, an abandoned waterway near Niagara Falls, New York (**Figure** 7.8). They then covered the containers with soil and sold the land to the local school system.

Figure 7.8: Steel barrels like these were used to contain the hazardous chemicals at Love Canal. After several years, they began to leak the chemicals into the soil and groundwater, which caused many people to become sick.

The school system built a school on the land. The city of Niagara Falls also built more than 800 homes near Love Canal. Several years later, people who lived there began to notice bad chemical smells in their homes. Children developed burns after playing in the soil, and they were often sick. A woman living in the area, named Lois Gibbs, organized a group of citizens called the 'Love Canal Homeowners Association' to try to find out why their children kept getting sick (**Figure** 7.9). They discovered that their homes and school were sitting on top of the site where the dangerous chemicals had been buried. They believed that the old steel drums used to contain the dangerous chemicals were leaking and making them and their children sick. They demanded that the government take action to clean up the area and remove the chemicals.

By 1979, the United States government fully realized that the old drums were indeed leaking dangerous chemicals into the soil and water where the people lived and went to school. The government gave money to many of the people to move somewhere safer and began cleaning up the site. The work of Lois Gibbs was important in bringing the problem of hazardous chemical pollution to peoples' attention. After the Love Canal problem, the U. S. government created a law called the **Superfund Act**. This law requires companies to be responsible for hazardous chemicals that they put into the environment. It also requires them to pay the money needed to clean up polluted sites, which can often be hundreds of millions of dollars. As a result, companies today are more careful about how they deal with hazardous substances.

This lesson describes some of the sources of hazardous wastes throughout the world. It then discusses the effects these wastes have on human health and the environment. Finally, this lesson covers ways that we can control hazardous wastes.

What is Hazardous Waste?

Hazardous waste is any waste material that is dangerous to human health or that degrades the environment. Hazardous waste materials include substances that are:

Figure 7.9: A resident of Love Canal protests the hazardous waste contamination in her neighborhood.

1. Toxic: something that causes serious harm, death or is poisonous.
2. Chemically active: something that causes dangerous or unwanted chemical reactions, like dangerous explosions.
3. Corrosive: something that destroys other things by chemical reactions.
4. Flammable: something that easily catches fire and may send dangerous smoke into the air.

Hazardous waste may be solid or liquid. It comes from many sources, and you may be surprised to learn that you probably have some sources of hazardous waste right in your own home. Several cleaning and gardening chemicals are hazardous if not used properly. These include chemicals like drain cleaners and **pesticides** that are toxic to humans and many other creatures. When we use, store, and dispose of them, we have to be careful. We have to protect our bodies from exposure to them and make sure they do not enter the environment (**Figure** 7.10). If they are thrown away or disposed of improperly, they become hazardous to the environment. Others sources of hazardous waste are shown in **Table** 7.2.

Figure 7.10: This farm worker wears special clothes for protection from the hazardous pesticide in the container.

Table 7.2:

Type of Hazardous Waste	Example	Why it is Hazardous
Chemicals from the automobile industry	Gasoline, used motor oil, battery acid, brake fluid	Toxic to humans and other organisms; often chemically active; often flammable
Batteries	Car batteries, household batteries	Contain toxic chemicals; are often corrosive
Medical wastes	Surgical gloves, wastes contaminated with body fluids such as blood, x-ray equipment	Toxic to humans and other organisms; may be chemically active
Paints	Paints, paint thinners, paint strippers, wood stains	Toxic; flammable
Dry cleaning chemicals	Many various chemicals	Toxic; many cause cancer in humans
Agricultural chemicals	Pesticides, herbicides, fertilizers	Toxic to humans; can harm other organism; pollute soils and water

Impacts of Hazardous Waste

Many hazardous waste materials have serious impacts on human health. They often cause cancer and can also cause birth defects. They can make people sick for very long times. Breathing the air or drinking the water that is contaminated with hazardous waste is a major health threat.

Two chemicals that are especially toxic in the environment are lead and mercury. Lead harms people by damaging their brain and nervous system. Lead is especially harmful in children under the age of six; about 200 children die every year from lead poisoning. Lead was once a common ingredient in gasoline and paint (**Figure** 7.11). In the 1970's and 1980's, the United States government passed laws completely banning lead in gasoline and paint. This has prevented the lead poisoning of millions of children in the United States. However, several other countries still use gasoline with lead in it. Also, homes built before the 1970's may contain paint that has lead in it. These still pose a threat to human health.

Figure 7.11: In the United States, automotive gasoline must now be unleaded, or free from lead.

Mercury is a pollutant affecting the whole world (**Figure** 7.12). Mercury enters the environment from volcanic eruptions, burning coal and from waste products like old batteries and electronic switches. It is also found in old discarded electronic appliances like television sets. Like lead, mercury also damages the brain and impairs nervous system function. Mercury often accumulates in fish, so people and other animals that eat the fish then are in danger of getting the mercury in their own bodies.

Preventing Hazardous Waste Pollution

The United States is currently the world's largest producer of hazardous wastes. However, as China becomes more industrialized, it may take over the number one spot. Countries with more industry produce more hazardous waste than those with little industry. Hazardous wastes can enter the air when we burn things like batteries containing mercury or old tires. Hazardous waste can enter the water when chemicals are dumped on the ground, or are buried and then leak. Substances buried in the ground often leak from their containers after a number of years. The chemicals then move through the soil until they reach groundwater. Hazardous chemicals are especially dangerous once they reach our groundwater resources. Sites like the one at Love Canal are now referred to as **Superfund sites**. They are found throughout the country. Many of them have been identified and cleaned up. We now have strict laws to prevent new sites like the Love Canal site from ever forming in the first place.

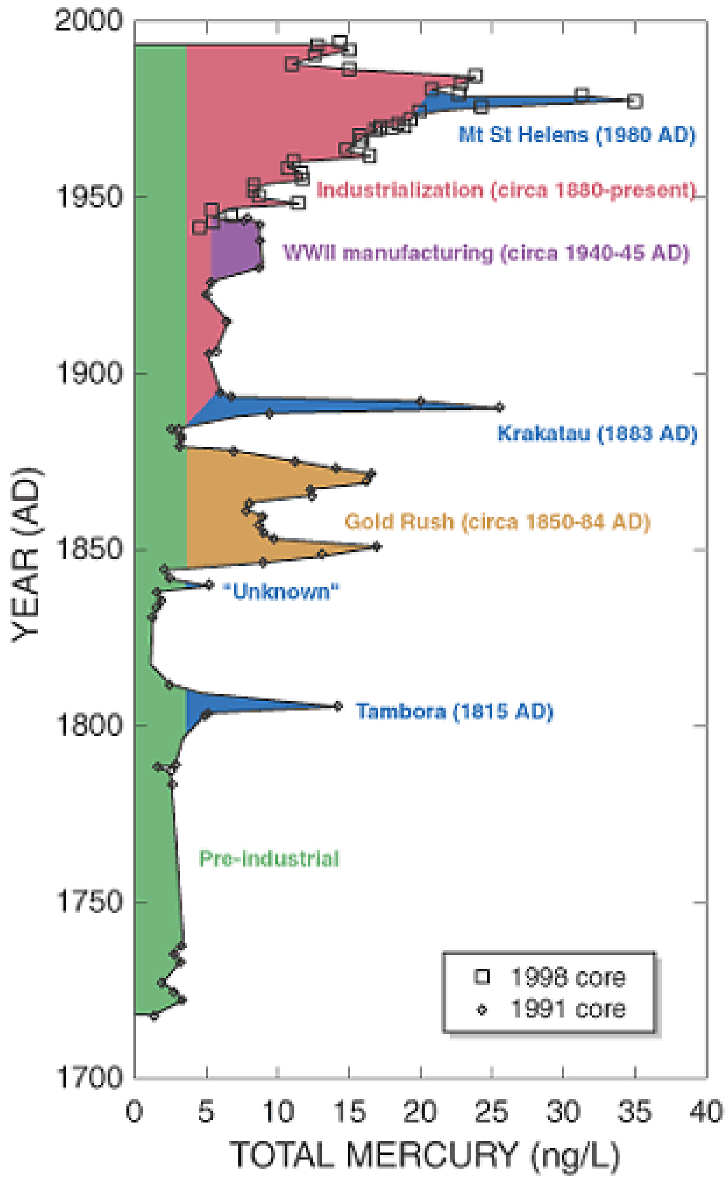

Figure 7.12: This graph shows historic increases of mercury in the atmosphere. Events in blue are volcanic eruptions. Events in brown, purple and pink are human-caused. Notice the effect of industrialization on mercury levels in the atmosphere (the red region of the graph).

In the United States, we have several laws that help control hazardous waste. The Resource Conservation and Recovery Act requires any company that produces hazardous materials to keep careful track of what happens to it. The government has passed special rules for how these materials can be disposed of. Companies must ensure that hazardous waste is not allowed to enter the environment in dangerous amounts. They have to protect their workers from the hazards of the materials. They must keep a record of how they dispose of hazardous wastes, and show the government that they did so in a safe way.

Individual people can also do much to control hazardous wastes. We can choose to use materials that are not hazardous in the first place. We can make sure that we dispose of materials properly. We can control the amount of pesticides that we use. We can make sure to not pour toxic chemicals over the land, or down the drain or toilet, or even into the trashcan. We can also use hazardous materials less often. We can find safer alternatives for many of the chemicals we use. For example, we can use vinegar and water to clean windows instead of the usual glass-cleaning chemicals.

Lesson Summary

- Hazardous wastes are dangerous to human health and the environment. They come from many sources, such as household chemicals, gasoline, paints, old batteries, discarded appliances, and industrial chemicals.
- Once in the air or buried on land, they can cause human health problems or even death and degrade the environment for other organisms.
- Developed countries like the United States produce most of the world's hazardous waste.
- We have passed laws that require careful disposal of hazardous materials and that make their producers financially responsible for them if they pollute the environment.

Review Questions

1. How does the United States Superfund Act help control hazardous wastes?
2. What is the difference between corrosive and flammable?
3. Organic farming is a method of growing food crops with natural alternatives to chemical pesticides. How does organic farming help control hazardous wastes?
4. What is one disadvantage of storing hazardous wastes in barrels buried deep in the ground?
5. Scientists who work with hazardous wastes often wear special clothing like gloves and masks. Why do you think they wear these items?
6. Which do you think is easiest and hardest to keep track of: hazardous waste that is present as a gas, liquid, or solid? Why?

Further Information / Supplemental Links

- Love Canal Pathfinder, Nathan Tallman `http://www.nathantallman.org/pathfinders/lovecanal.html`
- Superfund Sites Where You Live `http://www.epa.gov/superfund/sites/index.htm`

Vocabulary

degrade To lower the quality of something.

pesticides Chemicals used to kill or harm unwanted pests such as insects that damage food crops.

superfund act A law passed by the US Congress in 1980 that held companies responsible for any hazardous chemicals that they might create.

superfund site A site where hazardous waste has been spilled. Under the Superfund act, the company that created the hazardous waste is responsible for cleaning up the waste.

Points to Consider

- What are the best ways to either prevent or safely dispose of hazardous materials?
- If humans are the ones who mostly create hazardous materials, whose responsibility is it to clean them up?
- Is it important for each generation to leave the world a safe place? If one generation doesn't do this, who pays the price?

Image Sources

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Chapter 8

Environmental Problems

8.1 Lesson 25.1: Air Pollution

Lesson Objectives

- Discuss the types of outdoor pollution and what causes them.
- Describe the effects of outdoor pollution on the environment.
- Discuss where indoor air pollutants come from and what they are.
- Describe the health hazards of both indoor and outdoor pollutants.
- Discuss how you can protect yourself from air pollution.

Check your Understanding

- Describe the chemical composition of the atmosphere.
- Explain the significance of the atmosphere.

Introduction

Air is all around us and is everywhere and its mix of gases is essential for life. Despite the atmosphere's vastness, human activities, like the emission of chemical substances, particulate matter (smoke and dust), and even biological materials, cause air pollution. This pollution affects entire ecosystems, worldwide. Pollution is also a big problem indoors. Pollution, both the outdoor and indoor varieties, cause many health problems as well as deaths. In spite of all the dangers to human health from pollutants, there are ways for you to protect yourself.

Pollution of Outdoor Air

Air is so easy to take for granted. In its unpolluted state, it cannot be seen, smelled, tasted, felt, or heard, except when it blows or during cloud formation. Yet its gases are very important for life: nitrogen helps build proteins and nucleic acids, oxygen helps to power life, carbon dioxide provides the carbon to build bodies, and water has many unique properties which most forms of life depend on.

Outdoor air pollution consists of either chemical, physical (e.g. particulate matter), or biological agents that modify the natural characteristics of the atmosphere and cause unwanted changes to the environment and to human health. **Primary pollutants** are added directly to the atmosphere by such processes as fires (**Figure** 8.1) or combustion of fossil fuels (**Figure** 8.2), such as oil, coal, or natural gas (**Figure** 8.3). **Secondary pollutants** are formed when primary pollutants interact with sunlight, air, or each other. Both types are equally damaging.

Figure 8.1: Wildfires, either natural- or human-caused, release particulate matter into the air, one of the many causes of air pollution.

Figure 8.2: A major source of air pollution is the burning of fossil fuels from factories, power plants, and motor vehicles. Photo was taken prior to installation of emission controls equipment for removal of sulfur dioxide and particulate matter.

Most air pollutants can be traced to the burning of fossil fuels. These include the burning of fuels in power plants to generate electricity, in factories to make machinery run, in stoves and furnaces for heating, in various modes of transportation, and in waste facilities to burn waste. Even before the use of fossil fuels since the Industrial Revolution, wood was burned for heat and cooking in fireplaces and campfires, and vegetation was burned for agriculture and land management.

In addition to the burning of fossil fuels, other sources of human-caused (**anthropogenic**) air pollution are agriculture, such as cattle ranching, fertilizers, herbicides and pesticides, and erosion; industry, such as production of solvents, plastics, refrigerants, and aerosols; nuclear power and defense; landfills; mining; and biological warfare.

Figure 8.3: The majority of air pollutants can be found in the burning of fossil fuels for heat, electricity, industry, waste disposal, and transportation, the latter seen here on a busy highway.

Environmental Effects of Outdoor Air Pollution

Many outdoor air pollutants may impair the health of plants and animals (including humans). There are many specific problems caused by the burning of fossil fuels. For example, sulfur oxides from coal-fired power plants and nitrogen oxides from motor vehicle exhaust cause **acid rain** (**Figure** 8.4) (precipitation or deposits with a low pH). This has adverse effects on forests, freshwater habitats, and soils, killing insects and aquatic life.

Figure 8.4: A forest in the Jizera Mountains of the Czech Republic shows effects attributed to acid rain. At higher altitudes, effects of acid rain on soils combines with increased precipitation and fog to directly affect foliage.

Global warming (an increase in the earth's temperature) is thought to be caused mostly by the increase of **greenhouse gases** (water vapor, carbon dioxide, methane, ozone, chlorofluorocarbons (CFCs), nitrous oxide, hydrofluorocarbons, and perfluorocarbons) via the **greenhouse effect** (the atmosphere's trapping of heat energy radiated from the Earth's surface).

Water vapor causes about 36-70% of the greenhouse effect and carbon dioxide causes 9-26%. Fossil fuel burning has produced approximately three-quarters of the carbon dioxide from human activity over the past 20 years, while most of the rest is due to land-use change, particularly deforestation (**Figure** 8.5). Methane causes 4-9% of the greenhouse effect and ozone causes 3-7%. Some other naturally occurring gases contribute very little to the greenhouse effect; one of these, nitrous oxide, is increasing in concentration due to an increase in such human activities as agriculture.

Figure 8.5: Deforestation, shown here as a result of burning for agriculture in southern Mexico, has produced significant carbon dioxide production over the past 20 years.

The effect of global warming is to increase the average temperature of the Earth's near-surface air and oceans. This increase in global temperature will cause the sea level to rise and is expected to cause an increase in intensity of extreme weather events and to change the amount and pattern of precipitation. Other effects of global warming include changes in agricultural yields, trade routes, glacier retreat, and species extinctions.

Other environmental problems caused by human-caused air pollution include **global dimming** (a reduction in the amount of radiation reaching the Earth's surface) and **ozone depletion** (the latter being two related declines in stratospheric ozone). Particulate matter from the burning of wood and coal and **aerosols** (airborne solid particles or liquid droplets) cause global dimming, by absorbing solar energy and reflecting sunlight back into space. Environmental effects of global dimming include less photosynthesis, resulting in less food for all trophic levels; less energy to drive evaporation and the hydrologic cycle; and cooler ocean temperatures, which may lead to changes in rainfall and drought.

Ozone is both a benefit and detriment. As a component of the upper atmosphere, it has shielded all life from as much as 97-99% of the lethal solar ultraviolet (UV) radiation. However, as a ground-level product of the interaction between pollutants and sunlight, ozone itself is considered a pollutant which is toxic to animals' respiratory systems.

Ozone depletion consists of both losses in the total amount of ozone in the Earth's stratosphere – about 4% per year from 1980 to 2001, and the much larger loss, the **ozone hole,** a seasonal decline over Antarctica. A secondary effect of ozone depletion is a decline in stratospheric temperatures. The pollutants that are responsible for ozone depletion are CFCs, from the use of aerosol sprays, refrigerants (Freon), cleaning solvents, and fire extinguishers.

Ozone depletion and the resulting increase in levels of UV radiation reaching Earth could result in the reduced abundance of UV-sensitive nitrogen-fixing bacteria, which cause a disruption of nitrogen cycles, and a loss of plankton, causing a disruption of ocean food chains.

Pollution of Indoor Air

Lack of indoor ventilation and circulation concentrates air pollution in places where people often spend a majority of their time, and allows them to accumulate more than they would otherwise occur in nature. Some of these indoor pollutants include radon gas, released from the Earth in certain locations and then trapped inside buildings; formaldehyde gas, emitted from building materials, such as carpeting and plywood; volatile organic compounds (VOCs) are given off by paint and solvents as they dry; and lead paint, which can degenerate into dust.

Other air pollutants are caused by the use of air fresheners, incense, and other scented items. Wood fires in stoves and fireplaces can produce significant amounts of smoke particulates into the air. Use of pesticides and other chemical sprays indoors, without proper ventilation, can be another source of indoor pollution.

Carbon monoxide (CO) is often released by faulty vents and chimneys, poorly adjusted pilot lights, or by the burning of charcoal indoors. Flaws (non-functioning built-in traps) in domestic plumbing can result in emission of sewer gas and hydrogen sulfide. Dry cleaning fluids, such as tetrachloroethylene, can be emitted from clothing, days after dry cleaning. The extensive use of asbestos in industrial and domestic environments in the past has left a potentially very dangerous material in many localities (**Figure** 8.6).

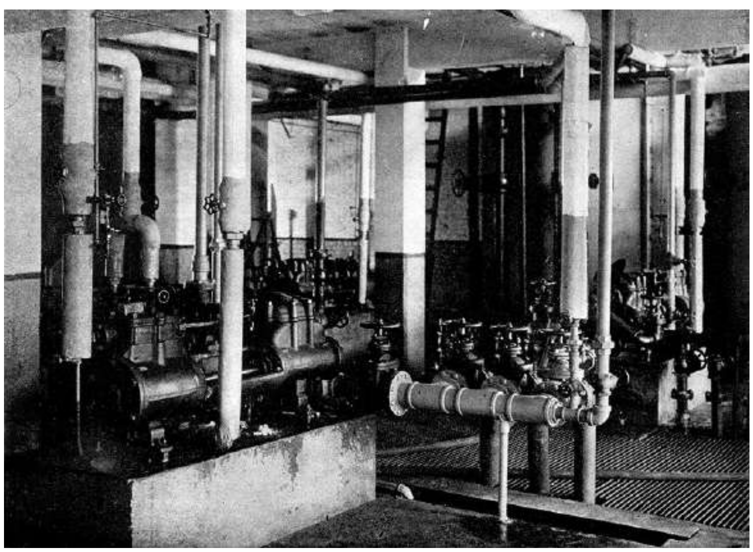

Figure 8.6: The extensive use of asbestos in industrial (as pictured here, asbestos-covered pipes in an oil-refining plant) and domestic environments in the past has left a potentially very dangerous material in many localities.

Biological sources of air pollution, such as gases and airborne particulates, are also found indoors. These are produced from pet dander; dust from minute skin flakes and decomposed hair; dust mites (which produce enzymes and micrometer-sized fecal droppings) from bedding, carpeting, and furniture; methane from the inhabitants; mold (which generates mycotoxins and spores) from walls, ceilings, and other structures; air conditioning systems, can incubate certain bacteria and mold; and pollen, dust, and mold from houseplants, soil, and surrounding gardens.

Health Hazards of Air Pollution

The World Health Organization (WHO) states that 2.4 million people die each year from causes directly related to air pollution, and 1.5 million of these deaths caused by indoor sources. One study has shown a strong correlation between pneumonia-related deaths and air pollution caused by motor vehicles. Worldwide, there are more deaths linked to air pollution per year than to car accidents. Research by WHO also shows that the greatest concentration of particulate matter particles exists in countries with high poverty and population rates, such as Egypt, Sudan, Mongolia, and Indonesia.

Direct causes of air-pollution related deaths include aggravated asthma, bronchitis, emphysema, lung and heart diseases, and respiratory allergies. The U.S. Environmental Protection Agency (EPA) estimates that a set of proposed changes in technology of diesel engines could result each year in the U.S. in 12,000 fewer mortalities, 15,000 fewer heart attacks, 6,000 fewer visits to the emergency room by children with asthma, and 8,900 fewer respiratory-related admissions to the hospital.

Health effects caused by air pollution may range from subtle physiological and biochemical changes to difficulties in breathing, wheezing, coughing, and aggravation of existing cardiac and respiratory conditions. These conditions can result in increased use of medications, visits to the doctor or emergency room, more admissions to the hospital, and premature deaths. Individual reactions to air pollution depends on the type of pollutant, the degree of exposure, and the individual's medical condition.

Certain respiratory conditions can be made worse in people who live closer or in large metropolitan areas. In one study, it was found that such patients had higher levels of pollutants found in their system because of more emissions in the larger cities. In patients with the disease of cystic fibrosis, patients already born with decreased lung function, had worse lung function as a result of such pollutants as smoke emissions from automobiles, tobacco smoke, and improper use of indoor heating devices. Some studies have shown that patients in urban areas suffer lower levels of lung function and more self diagnosis of chronic bronchitis and emphysema.

Because children are outdoors more they are more susceptible to the dangers of air pollution. Children living within cities with high exposure to air pollutants are at risk to develop asthma, pneumonia and other lower respiratory infections.

In addition to respiratory and heart-related ailments, air pollution can also cause an increase in cancer, eye problems, and other conditions. For example, use of certain agricultural herbicides and pesticides, such as DDT (an organic pesticide) and PCBs (poly-chlorinated biphenyls), use of some industrial solvents and plastics, radioactive waste, use of some indoor materials like asbestos, and ozone depletion can all cause cancer.

Smog, caused by coal burning, and ground-level ozone produced by motor vehicle exhaust can cause eye irritation, as well as respiratory problems, and ozone depletion can cause an increased incidence of cataracts. Carbon monoxide from motor vehicle exhaust and from faulty vents and chimneys and charcoal burning indoors can cause poisoning and fatalities. Mercury released from coal-fired power plants and from medical waste can cause neurotoxicity (poisoning to nerve tissue).

Protecting Yourself from Air Pollution

After reading the above sections, you may be confused as to where the air is healthier, outdoors or indoors? While it is not always possible to know what exact steps you should take under any situation, common sense often plays a role. For example, if you hear in the news that the outdoor air quality is particularly bad, then it might make sense to either wear masks outdoors or to stay indoors as much as possible at such times, especially if you already have such respiratory conditions as asthma, for example. Because you have more control over your indoor air quality than the outdoor air quality, there are some simple steps you can take indoors to make sure the air quality is less polluted.

Perhaps you could review the section, ''Pollution of Indoor Air" above, and come up with some ideas for how you could reduce indoor air pollution. For example, make sure your house is well ventilated and there is circulation of air. Try to avoid use of toxic substances in the home; always read labels to see what warnings about toxic ingredients are listed. If you are not sure about a particular product, use either outdoors or in a well-ventilated room and avoid direct inhalation. Use of medical supply masks is also helpful to protect yourself further.

Make sure that vents, chimneys, and vents are working properly and never burn charcoal indoors. Carbon monoxide detectors can be placed in the home, if carbon monoxide emission is of concern. In addition, keeping your home as clean as possible from pet dander, dust, dist mites, and mold, and making sure air conditioning systems are working properly can minimize effects on asthma and other respiratory problems. Are there any other ways you can think of to protect yourself from air pollution?

Lesson Summary

- Outdoor air pollution consists of either chemical, physical, or biological agents that modify the natural characteristics of the atmosphere and cause unwanted changes to the environment and to human health.
- There are two kinds of pollutants: primary and secondary pollutants.
- There are many sources of human-caused air pollution, the most common being the burning of fossil fuels.
- Outdoor air pollutants cause many environmental effects, among them global warming, global dimming, and ozone depletion.
- Indoor air pollutants are either chemical or biological in nature.
- Both outdoor and indoor pollutants cause many health problems, ranging from respiratory and cardiac to cancer, eye problems, and poisoning.
- While it is not always possible to protect yourself from poor air quality outdoors, there are a number of measures you can take to protect yourself from poor indoor air quality.

Review Questions

1. Define outdoor air pollution.
2. Most air pollutants can be traced to the burning of fossil fuels. What were the sources of such pollutants before the Industrial Revolution?
3. Why does deforestation contribute to an increase in global warming?
4. Explain why one of the environmental effects of global dimming may result in less food at all trophic levels.
5. Name two environmental effects of ozone depletion.
6. There is no direct evidence linking ozone depletion to a higher incidence of skin cancer in human beings. Give an explanation for this.

Further Reading / Supplemental Links

- Unabridged Dictionary, Second Edition, Random House, New York, 1998.
- http://www.epa.gov/region5/students/air.htmhttp://www.epa.gov/region5/students/air.htm
- http://www.epa.gov/acidrain/education/site_students/http://www.epa.gov/acidrain/education/site_-students/

- http://www.koshlandscience.org/exhibitgcc/index.jsphttp://www.koshlandscience.org/exhibitgcc/index.jsp

en.wikipedia.org/wiki

Vocabulary

acid rain Precipitation or deposits with a low (acidic) pH.

aerosols Airborne solid particles or liquid droplets.

air The mixture of gases present in the atmosphere.

anthropogenic Human-based causes.

atmosphere A layer of gases that surrounds the planet; composed of five layers.

global dimming A reduction in the amount of radiation reaching the Earth's surface.

global warming The recent increase in the Earth's temperature.

greenhouse effect The atmosphere's trapping of heat energy radiated from the Earth's surface.

greenhouse gases The cause of global warming by certain gases via the greenhouse effect.

outdoor air pollution Chemical, physical, or biological agents that modify the natural characteristics of the atmosphere and cause unwanted changes to the environment and to human health.

ozone depletion Reduction in the stratospheric concentration of ozone.

ozone hole A seasonal decline of ozone over Antarctica.

primary pollutants Substances released directly into the atmosphere by processes such as fire or combustion of fossil fuels.

secondary pollutants Substances formed when primary pollutants interact with sunlight, air, or each other.

Points to Consider

- One of the effects of outdoor air pollution is to cause global warming. Global warming, in turn, has an effect on both land and sea. Think about how the effects of global warming on the amount and pattern of precipitation will have an effect on water pollution.
- Environmental effects of global dimming include less energy to drive evaporation and the hydrologic cycle, and cooler ocean temperatures, which may lead to changes in rainfall and drought. Will such changes affect water pollution?
- Some outdoor air pollutants have a direct effect on aquatic habitats. For example, acid rain can adversely affect freshwater habitats.

8.2 Lesson 25.2: Water Pollution and Waste

Lesson Objectives

- Describe water pollution sources.
- Explain how water pollution affects living organisms.
- Discuss how to prevent water pollution.
- Discuss ways you can save water.

Check your Understanding

Water pollution obviously has to do with water.

- What are water resources?
- What is the demand for water?
- What are the sources of fresh water?

Answers

- Surface water is water found in rivers, lakes, or freshwater wetlands. It is naturally replenished by precipitation and naturally lost through discharge to evaporation, discharge to the oceans, and sub-surface (groundwater) seepage.
- Groundwater is the water flowing within **aquifers** (a geological formation that contains or conducts groundwater, especially for supplying water for wells, etc.). The natural input to groundwater is seepage from surface water and the natural outputs are to springs and seepage to bodies of water.
- Desalination is an artificial process by which saline water (usually sea water) is converted to fresh water. Only a very small amount of total water use is supplied by desalination.
- Frozen water found in icebergs has not been found to be a reliable water source. Glacier runoff is a source for surface water.

Introduction

While water may seem limitless and everywhere – after all, you can turn your faucet and out it comes, without appearing to dry up – in fact, in the United States it is a limited resource, and in many parts of the world, even scarce. Add to this the necessity of having water without pollution and you can see that unpolluted water is even harder to find (**Figure** 8.7).

Water pollution is the contamination of water bodies by contaminants, mostly anthropogenic, and causing a harmful effect on living organisms. As you explore in this lesson how water pollution affects living things, you will see the urgency in preventing water pollution and discover ways to save water. Perhaps you will be inspired to think of how your household, community, and even world can be a model to others to not take clean water for granted!

Sources of Water Pollution

Although natural phenomena such as storms, algal blooms, volcanoes, and earthquakes can cause major changes in water quality, human-caused contaminants have a much greater impact on the quality of the

Figure 8.7: Water pollution can cause harmful effects to ecology and human health.

water supply. Water is considered polluted either when it does not support a human use (like clean drinking water) or undergoes a major change in its ability to support the ecological communities it serves.

The primary sources of water pollution can be grouped into two categories, depending on the point of origin:

A. **Point source pollution** refers to contaminants that enter a waterway or water body through a single site. Examples of this includes discharge (also called effluent) of either untreated sewage or wastewater from a sewage treatment plant, industrial effluent, leaking underground tanks, or any other discrete sources of nutrients, toxins, or waste.
B. **Nonpoint source pollution** refers to contamination that does not originate from a single point source, but is often a cumulative effect of small amounts of contaminants (such as nutrients, toxins, or wastes) gathered from a large area. Examples of this include runoff in rainwater of soil, fertilizers (nutrients) or pesticides from an agricultural field, soil from forested areas that have been logged, toxins or waste from construction or mining sites, and even fertilizers or pesticides from your own backyard!

Specific contaminants causing water pollution include a wide variety of chemicals, and pathogens (disease-causing substances). While many of the chemicals and substances that are regulated may be occurring naturally (iron, manganese, etc.) it is often the concentration of the substance that determines what is a natural component of water and what is a contaminant.

In addition to toxic substances and disease-causing ones, alteration of water's physical chemistry, including acidity, electrical conductivity, and temperature, can also have an effect.

Effects of Water Pollution on Living Things

Water pollutants can have an effect on both the ecology of aquatic ecosystems as well as on human health. Let's examine several types of pollution problems **Table** (8.1) and how they affect both the ecology and human health.

Table 8.1:

Type of Problem Pollution	Cause	Effect on Ecology	Effect on Human Health and Well-Being
Eutrophication, an increase in chemical nutrients, specifically compounds containing nitrogen or phosphorus, in an ecosystem (**Figure** 8.8)	Frequently a result of nutrient pollution such as the release of sewage effluent and run-off from lawn fertilizers into natural waters, such as rivers or coastal waters	Excessive growth of aquatic vegetation or phytoplankton (or **algal bloom** and decay, and a lack of oxygen, the latter causing severe reductions in water quality, fish, and shellfish (**Figure** 8.9)	1. Decreases the resource value of rivers, lakes, and estuaries to adversely affect recreation, fishing, hunting, and aesthetic enjoyment. 2. If nitrogen is leached into groundwater, drinking water can be affected because nitrogen concentrations are not filtered out 3. Biotoxins created during algal blooms are taken up by shellfish, such as mussels or oysters; if humans eat these shellfish, then shellfish poisoning can occur and you can become extremely sick, including paralysis and other neurological conditions

Table 8.1: (continued)

Type of Problem Pollution	Cause	Effect on Ecology	Effect on Human Health and Well-Being
Ocean acidification, a process whereby the oceans' uptake of anthropogenic carbon dioxide from the atmosphere causes an ongoing decrease in pH of the oceans (see "Points to Consider," Lesson 25.1: Air Pollution, showing a possible link of air pollutants to water pollution)	Human actions such as land-use changes and the combustion of fossil fuels can lead to an increase in carbon dioxide into the atmosphere, some of which is then absorbed by the oceans	Decrease in pH primarily affects oceanic calcifying organisms, such as corals and shellfish; may also directly affect reproduction or other physiology of marine organisms or indirectly cause negative impacts through their food resources	No likely effects
Transformation of many chemicals, including chlorinated hydrocarbons (carcinogens), especially over long periods of time in groundwater	Used in industrial metal degreasing and electronics manufacturing	As they undergo change in groundwater, can lead to new hazardous chemicals	Such contaminated groundwater can poison drinking water and lead to various human health problems, including cancer
Aquatic debris (trash)	Shipping accidents. landfill erosion, dumping of trash	Aquatic wildlife swallowing plastic bags, strangulation by plastic six-pack rings, entanglement of wildlife in nets (**Figure** 8.10)	Adversely affects recreation and aesthetic enjoyment

Figure 8.8: Lake Valencia, Venezuela, showing vivid green algal blooms, resulting from continued influx of untreated wastewater from surrounding urban, agricultural, and industrial land uses. This contributes to ongoing eutrophication, contamination, and salinization of the lake This pollution impacts the lakes use as a reservoir for the surrounding urban centers and limits opportunities for tourism and recreational uses as well.

Let's close this section and look at a few other effects of water pollution on human health. According to the World Health Organization (WHO), diarrheal disease is responsible for the deaths of 1.8 million people

Figure 8.9: Marine debris can adversely impact all sorts of aquatic life. Pictured here is a marine turtle entangled in a net.

Figure 8.10: Intercepting nonpoint pollution between the source and waterway has been found to be successful. Pictured here, a bioretention cell, or rain garden, in the U.S, is designed to treat polluted storm water runoff from an adjacent parking lot.

every year. It was estimated that 88% of that burden is attributed to unsafe water supply, sanitation, and hygiene, and is mostly concentrated in the children of developing countries.

Such **waterborne diseases** can be caused by protozoa, viruses, bacteria, and intestinal parasites. Protozoal infections can be caused by sewage, non-treated drinking water, animal manure, poor disinfection, and groundwater contamination; some viruses and bacteria are water-borne and can be found in drinking water, sewage, contaminated seafood, or unsanitary recreational water; and parasitic infections are usually caused by contaminated drinking water.

Preventing Water Pollution

In the U.S., concern over water pollution resulted in the enactment of state anti-pollution laws in the latter half of the 1800s, and federal legislation in 1899, which prohibited the disposal of any refuse matter into the nation's navigable rivers, lakes, streams, and other bodies of water, unless a person first had a permit. In 1948, the Water Pollution Control Act was passed and gave authority to the Surgeon General to reduce water pollution.

Growing public awareness and concern for controlling water pollutants led to enactment of the Federal Water Pollution Control Act Amendments of 1972, later amended in 1977, to become commonly known as the Clean Water Act. This Act established the basics for regulating discharge of contaminants and established the authority for the U.S. Environmental Protection Agency (EPA) to implement standards for wastewater discharge by industry. The Clean Water Act also continued requirements to set water quality standards for all surface water contaminants.

More specifically, control of point sources of phosphorus through policy changes have resulted in rapid control of eutrophication. Nonpoint sources, on the other hand, are more difficult to regulate and usually vary with season, precipitation, and other irregular events. Nonpoint sources are especially troublesome because of soil retention, runoff to surface water and leaching to groundwater, and the effect of acid rain (See the Air Pollution lesson).

On the hopeful side, though, cleanup measures have been somewhat successful. For example, Finnish removal of phosphorus started in the mid-1970s has targeted rivers and lakes polluted by industrial and municipal discharges. These efforts have had a 90% efficiency in removal. And with nonpoint sources, some efforts, like intercepting pollutants between the source and water, are successful (**Figure** 8.11). Also, creating buffer zones near farms and roads is another possible way to prevent nutrients from traveling into waterways.

In addition, laws regulating the discharge and treatment of sewage have led to dramatic nutrient reductions to aquatic ecosystems, but a policy regulating agricultural use of fertilizer and animal waste must also be imposed. One technique (Soil Nitrogen Testing, or N-Testing) helps farmers optimize the amount of fertilizer applied to crops and at the same time decreases fertilizer application costs, decreases the nitrogen lost to surrounding water resources, and sometimes decreases both.

Actions aimed at lessening eutrophication and algal blooms are usually desirable. However, the focus should not necessarily be aimed at eliminating blooms, but towards creating a sustainable balance that maintains or improves ecosystem health. As you will see in the next lesson (25.3): Natural Resources, sustainable use is a useful concept for the use of resources as well. Can you think of some reasons why?

Ways to Save Water

While we will deal further with this topic in the next Lesson (25.3) on Natural Resources, we will examine here how saving water can also contribute to maximizing clean water for future use. In addition, preventing

Figure 8.11: A water purification system at Bret Lake, Switzerland. Contaminants are removed and clean new water is created.

water pollution is one way of preserving precious water resources.

One way to make sure that water is kept clean and conserved is the use of wastewater reuse or cycling systems, including the recycling of wastewater to be purified at a water treatment plant. By that means, many of the waterborne diseases, caused by sewage and non-treated drinking water, can be prevented.

There are also various means of water purification, whereby contaminants are removed from a raw water source and at the same time create clean new water. Atmospheric water generation is one technology that can provide high quality drinking water by extracting water from the air by cooling the air and thus condensing the water vapor.

Figure 8.12: Sand processing Mill, near Provodin, Czech Republic. Water is used to wash mined sand, then is drained into tanks, filtered, and recycled.

Reclaimed water, or recycled water (**Figure** 8.12) that is treated and allowed to recharge the aquifer, is used for non-drinking purposes, so that potable water is used for drinking. This helps to conserve high quality water.

Another way to reduce water pollution and at the same time conserve water is via **catchment management.** This is used to recharge groundwater supplies, helps in the formation of groundwater wells, and eventually reduces soil erosion, one cause of pollution, due to running water.

In addition, both developed and developing countries can increase protection of ecosystems, especially wetlands and riparian zones (areas located on the bank of a waterway, like a river, or sometimes along a lake or tidewater). Not only do these measures conserve biota, but they can also make more effective the natural water cycle flushing and transport that make water systems more healthy for humans. What are some ways you can save water in your own house or community in order to increase the resource of clean water, to be made available to everyone?

Lesson Summary

- There are two primary sources of water pollution, point source and nonpoint sources.
- Specific contaminants causing water pollution include chemicals, pathogens, and physical or sensory changes.
- Water pollution can affect both ecology and human health.
- One effect of water pollution is eutrophication, which can cause detrimental effects on aquatic ecosystems as well as on human life, including health.
- Water pollution also causes ocean acidification, which impacts oceanic calcifying organisms.
- Contaminated groundwater can lead to poisoned drinking water and various health problems, including cancer.
- A variety of water pollutants can cause waterborne diseases.
- Various legislation has regulated discharge of contaminants into water resources and led to dramatic nutrient reductions, but more can be done, especially in areas such as the agricultural use of fertilizer and animal waste.
- Different ways of saving water can also have an impact on our clean water supply.

Review Questions

1. When is water considered polluted?
2. Name some sources of nonpoint source pollution.
3. Lakes often become polluted as a result of point source pollution release of phosphorus from sewage plants. By what process would the release of phosphorus affect a lake's vegetation growth and how would this in turn affect reductions in water quality and fish and shellfish populations?
4. Name some sources of pollutants that can cause waterborne diseases.
5. Why are nonpoint sources of pollution so difficult to regulate?
6. Why might floating plastic debris be a problem for marine life?

Further Reading / Supplemental Links

- Unabridged Dictionary, Second Edition, Random House, New York, 1998.
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- http://www.cdli.ca/CITE/water.htmhttp://www.cdli.ca/CITE/water.htm
- http://www.epa.gov/region5/students/waste.htmhttp://www.epa.gov/region5/students/waste.htm
- http://en.wikipedia.orghttp://en.wikipedia.org

Vocabulary

algal bloom Excessive growth of aquatic vegetation or phytoplankton as a result of eutrophication.

aquifers Geological formations that contain or conduct groundwater.

catchment management Method used to recharge groundwater supplies, help in the formation of groundwater wells, and reduce soil erosion.

desalination An artificial process by which saline water is converted to fresh water.

eutrophication An increase in nutrients, specifically compounds containing nitrogen or phosphorus, in an ecosystem.

frozen water Found in icebergs and glaciers.

nonpoint source pollution Contaminants resulting from a cumulative effect of small amounts of contaminants gathered from a large area.

ocean acidification Process whereby the oceans' uptake of anthropogenic carbon dioxide from the atmosphere causes an ongoing decrease in ocean pH.

point source pollution Contaminants that enter a waterway or water body through a single site.

surface water Water found in rivers, lakes, or freshwater wetlands.

waterborne diseases Diseases caused by organisms transmitted via contaminated water.

water pollution The contamination of water bodies by substances, mostly anthropogenic, which cause a harmful effect on living organisms.

Reduce, Reuse, and Recycle

When we think of **reducing,** we're talking about reducing our output of waste. That could also mean cutting down on use of natural resources. Reusing and recycling are other ways we can cut down on use of resources.

Minimizing of waste may be difficult to achieve for individuals and households, but here are some starting points that you can include in your daily routine:

- When you go shopping for items, buy quantities you know you will use without waste; sometimes buying larger may be a better deal, cost-wise, but make sure you will really finish what you buy
- To minimize usage of electricity, turn lights off when not using and replace burned out bulbs with ones that are more ecologically efficient
- Reduce water use by turning off faucets when not using water; use low-flow shower heads, which save on water and use less energy, since less water is being heated; use low-flush and composting toilets
- Purchase water-efficient crops, which require little or no irrigation
- Put kitchen and garden waste into a compost pile

- In the summer, change filters on your air conditioner and keep your thermostat at a temperature as warm as you can tolerate; in winter, make sure your furnace is working properly, keep the temperature as cold as you can tolerate, and make sure there is enough insulation on windows and doors
- Mend broken or worn items, when feasible
- Walk or bicycle to destinations, when possible, rather than using an automobile, in order to save on fuel costs and to cut down on emissions
- When buying a new vehicle, check into hybrid and semi-hybrid brands (many new ones are coming rapidly onto the market) to cut down on gas mileage
- Consider which makes more sense – to spend valuable gas to go further to recycle, for example, or to sometimes use the trash instead of recycling

Let's now look at what we can **reuse**. Reusing includes using the same item again for the same function and also using an item again for a new function. Reuse can have both economic and environmental benefits. New packaging regulations are helping society to move towards these goals.

Some ways of reusing resources (think about ways these might be incorporated into your home) include:

- Use of gray water – water which has been used for laundry or washing, for example, can be used to water the garden or flush toilets * At the town level, sewage water can be used for fountains, watering public parks or golf courses, fire fighting, and irrigating crops that will be peeled or boiled before use
- Catching of runoff, which will also slow nonpoint source pollution and erosion – rain barrels next to buildings, recharge pits to re-fill aquifers

Perhaps you can think of some other ways to reuse resources!

Now we move on to **recycling.** Sometimes it may be difficult to understand the differences between reuse and recycling. Recycling differs in that it breaks down the item into raw materials, which are then used to make new items, whereas reusing uses the same item again. Even though recycling requires extra energy, it does often make use of items which are broken, worn out, or otherwise unsuitable for reuse.

The things that are commonly recycled include aggregates and concrete, batteries, biodegradable waste, electronics, iron and steel, aluminum, glass, paper, plastic, textiles, timber, industrial breaking of ships, and tires. Each type of recyclable requires a different technique. Perhaps you or your school could arrange for a trip to a recycling plant!

Here are some things you can do to recycle in your home, school, or community:

- If you have recycling in your community, make sure you separate out your plastics, glass, and paper, according to your local guidelines; have containers set up for easy placement
- See if your school recycles; if not perhaps you and some friends could start a recycling, or ecology, club, or organize efforts to better recycling goals

In order to judge the environmental and economic benefits of recycling, the cost of this process must be compared to the costs of extracting the original resource. In order for recycling to make economical sense, there usually must be a steady supply of recyclables and constant demand for the reprocessed products. Government legislation can stimulate both of these. As with all environmental issues, individuals can communicate with their representatives to make sure their wishes are heard.

The amount that an individual wastes is small in proportion to all waste produced by society. Yet all small contributions, when added up, can make a difference. In addition, influence on policy can be exerted in other areas. Awareness by you and your family, for example, of the impact and power of certain purchasing and recycling decisions can influence manufacturers and distributors to avoid buying products that do not have eco-labeling, are currently not mandatory, or that minimize the use of packaging.

Lesson Summary

- Reducing waste and the reusing and recycling of resources can help save natural resources as well as help us reach our goals for energy production.
- There are many things you can do in your household and community towards the goals of reducing, reusing, and recycling; individual efforts can also add up to make a difference nationally, and even internationally.
- Awareness of wise resource use at the consumer level can influence decisions at the manufacturing and distributing levels.
- Government legislation is also important to enforce these changes; it is up to individuals to communicate to their representatives the carrying out of wise use of natural resources, and to vote for those leaders who stand for sound ecological practices.

Natural Resources

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Vocabulary

natural resources Naturally occurring substances necessary for the support of life.

nonrenewable resource A natural resource that exists in fixed amounts and can be consumed or used up faster than it can be made by nature.

recycling The breaking down of an item into raw materials to make new items.

reducing Minimizing the use of resources.

renewable resources Resources that are replenished by natural processes at about the same rate at which they are used.

sustainable A rate which meets the needs of the present without impairing future generations from meeting their needs.