30

The Future of the Biosphere

Concept Outline

30.1 The world's human population is growing explosively.

A Growing Population. The world's population of 6 billion people is growing rapidly and at current rates will double in 39 years.

30.2 Improvements in agriculture are needed to feed a hungry world.

The Future of Agriculture. Much of the effort in searching for new sources of food has focused on improving the productivity of existing crops.

30.3 Human activity is placing the environment under increasing stress.

Nuclear Power. Nuclear power, a plentiful source of energy, is neither cheap nor safe.
Carbon Dioxide and Global Warming. The world's industrialization has led to a marked increase in the atmosphere's level of CO_2, with resulting warming of climates.
Pollution. Human industrial and agricultural activity introduces significant levels of many harmful chemicals into ecosystems.
Acid Precipitation. Burning of cheap high-sulfur coal has introduced sulfur to the upper atmosphere, where it combines with water to form sulfuric acid that falls back to earth, harming ecosystems.
The Ozone Hole. Industrial chemicals called CFCs are destroying the atmosphere's ozone layer, removing an essential shield from the sun's UV radiation.
Destruction of the Tropical Forests. Much of the world's tropical forest is being destroyed by human activity.

30.4 Solving environmental problems requires individual involvement.

Environmental Science. The commitment of one person often makes a key difference in solving environmental problems.
Preserving Nonreplaceable Resources. Three key nonreplaceable resources are topsoil, groundwater, and biodiversity.

FIGURE 30.1
New York City by satellite.

The view of New York City in figure 30.1 was photographed from a satellite in the spring of 1985. At the moment this picture was taken, millions of people within its view were talking, hundreds of thousands of cars were struggling through traffic, hearts were being broken, babies born, and dead people buried. Our futures and those of everyone on the planet are linked to the unseen millions in this photograph, for we share the earth with them. A lot of people consume a lot of food and water, use a great deal of energy and raw materials, and produce a great deal of waste. They also have the potential to solve the problems that arise in an increasingly crowded world. In this chapter, we will study how human life affects the environment and how the efforts being mounted can lessen the adverse impact and increase the potential benefits of our burgeoning population.

30.1 The world's human population is growing explosively.

A Growing Population

The current world population of 6 billion people is placing severe strains on the biosphere. How did it grow so large? For the past 300 years, the human birthrate (as a global average) has remained nearly constant, at about 30 births per year per 1000 people. Today it is about 25 births per year per 1000 people. However, at the same time, better sanitation and improved medical techniques have caused the death rate to fall steadily, from about 29 deaths per 1000 people per year to 13 per 1000 per year. Thus, while the birthrate has remained fairly constant and may have even decreased slightly, the tremendous fall in the death rate has produced today's enormous population. The difference between the birth and death rates amounts to an annual worldwide increase of approximately 1.4%. This rate of increase may seem relatively small, but it would double the world's population in only 39 years!

The *annual* increase in world population today is nearly 77 million people, about equal to the current population of Germany. 210,000 people are added to the world each day, or more than 140 every minute! The world population is expected to continue beyond its current level of 6 billion people, perhaps stabilizing at a figure anywhere between 8.5 billion and 20 billion during the next century.

The Future Situation

About 60% of the people in the world live in tropical or subtropical regions (figure 30.2). An additional 20% will be living in China, and the remaining 20% in the developed or industrialized countries: Europe, the successor states of the Soviet Union, Japan, United States, Canada, Australia, and New Zealand. Although populations of industrialized countries are growing at an annual rate of about 0.3%, those of the developing, mostly tropical countries (excluding China) are growing at an annual rate estimated in 1995 to be about 2.2%. For every person living in an industrialized country like the United States in 1950, there were two people living elsewhere; in 2020, just 70 years later, there will be five.

As you learned in chapter 24, the age structure of a population determines how fast the population will grow. To predict the future growth patterns of a population, it is essential to know what proportion of its individuals have not yet reached childbearing age. In industrialized countries such as the United States, about a fifth of the population is under 15 years of age; in developing countries such as Mexico, the proportion is typically about twice as high. Even if most tropical and subtropical countries consistently carry out the policies they have established to limit population growth, their populations will continue to grow well into the twenty-first century (figure 30.3), and industrialized countries will constitute a smaller and smaller proportion of the world's population. If India, with a 1995 population level of about 930 million people (36% under 15 years old), managed to reach a simple replacement reproductive rate by the year 2000, its population would still not stop growing until the middle of the twenty-first century. At present rates of growth, India will have a population of nearly 1.4 billion people by 2025 and will still be growing rapidly.

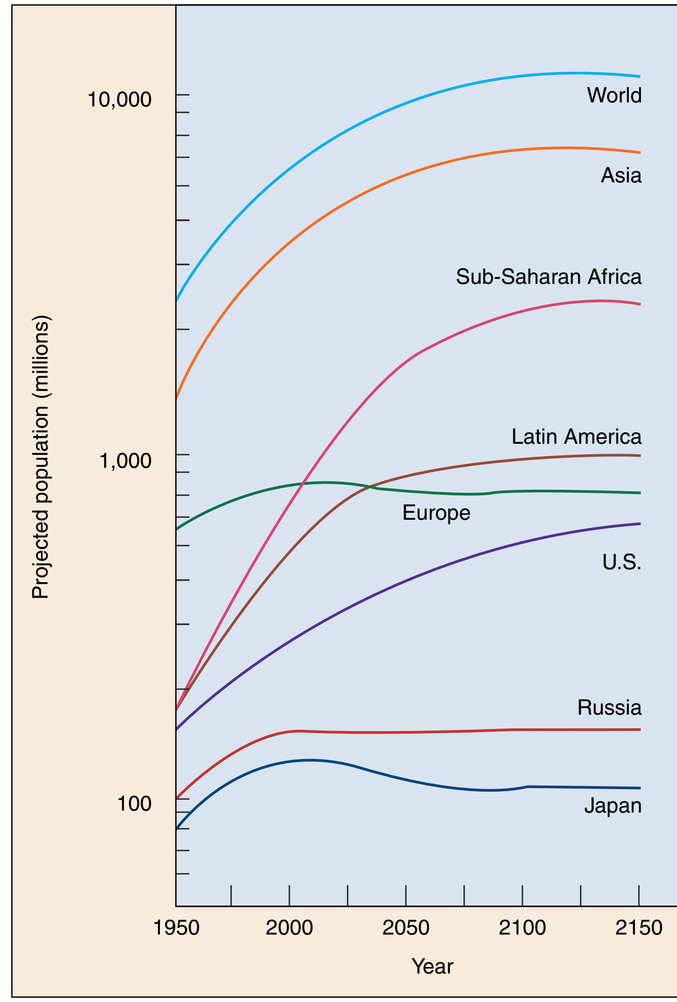


FIGURE 30.2
Anticipated growth of the global human population. Despite considerable progress in lowering birthrates, the human population will continue to grow for another century (data are presented above on a log scale). Much of the growth will center in sub-Saharan Africa, the poorest region on the globe, where the population could reach over 2 billion. Fertility rates there currently range from 3 to more than 5 children per woman, compared to fewer than 2.1 in Europe and the United States.

Population Growth Rate Starting to Decline

The United Nations has announced that the world population growth rate continues to decline, down from a high of 2.0% in the period 1965–1970 to 1.4% in 1998. Nonetheless, because of the larger population, this amounts to an increase of 77 million people per year to the world population, compared to 53 million per year in the 1960s.

The U.N. attributes the decline to increased family planning efforts and the increased economic power and social status of women. While the U.N. applauds the United States for leading the world in funding family planning programs abroad, some oppose spending money on international family planning. The opposition states that money is better spent on improving education and the economy in other countries, leading to an increased awareness and lowered fertility rates. The U.N. certainly supports the improvement of education programs in developing countries, but, interestingly, it has reported increased education levels *following* a decrease in family size as a result of family planning.

Most countries are devoting considerable attention to slowing the growth rate of their populations, and there are genuine signs of progress. If these efforts are maintained, the world population may stabilize sometime in the next century. No one knows how many people the planet can support, but we clearly already have more people than can be sustainably supported with current technologies.

However, population size is not the only factor that determines resource use; per capita consumption is also important. In this respect, we in the developing world need to pay more attention to lessening the impact each of us makes, because, even though the vast majority of the world's population is in developing countries, the vast majority of resource consumption occurs in the developed world. Indeed, the wealthiest 20% of the world's population accounts for 86% of the world's consumption of resources and produces 53% of the world's carbon dioxide emissions, whereas the poorest 20% of the world is responsible for only 1.3% of consumption and 3% of CO_2 emissions. Looked at another way, in terms of resource use, a child born today in the developed world will consume as many resources over the course of his or her life as 30 to 50 children born in the developing world.

Building a sustainable world is the most important task facing humanity's future. The quality of life available to our children in the next century will depend to a large extent on our success both in limiting population growth and the amount of per capita resource consumption.

In 1998, the global human population of 6 billion people was growing at a rate of approximately 1.4% annually. At that rate, the population would double in 39 years. Growth rates, however, are declining, but consumption per capita in the developing world is also a significant drain on resources.

FIGURE 30.3
Population growth is highest in tropical and subtropical countries. Mexico City, the world's largest city, has well over 20 million inhabitants.

The Future of Agriculture

One of the greatest and most immediate challenges facing today's world is producing enough food to feed our expanding population. This problem is often not appreciated by economists, who estimate that world food production has expanded 2.6 times since 1950, more rapidly than the human population. However, virtually all land that can be cultivated is already in use, and much of the world is populated by large numbers of hungry people who are rapidly destroying the sustainable productivity of the lands they inhabit. Well over 20% of the world's topsoil has been lost from agricultural lands since 1950. In the face of these massive problems, we need to consider what the prospects are for increased agricultural productivity in the future.

Finding New Food Plants

How many food plants do we use at present? Just three species—rice, wheat, and corn—supply more than half of all human energy requirements. Just over 100 kinds of plants supply over 90% of the calories we consume. Only about 5000 have ever been used for food. There may be tens of thousands of additional kinds of plants, among the 250,000 known species, that could be used for human food if their properties were fully explored and they were brought into cultivation (figure 30.4).

Agricultural scientists are attempting to identify such new crops, especially ones that will grow well in the tropics and subtropics, where the world's population is expanding most rapidly. Nearly all major crops now grown in the world have been cultivated for hundreds or even thousands of years. Only a few, including rubber and oil palms, have entered widespread cultivation since 1800.

One key feature for which nearly all of our important crops were first selected was ease of growth by relatively simple methods. Today, however, techniques of cultivation are far more sophisticated and are able to improve soil fertility and combat pests. This enables us to consider many more plants as potential crops. Agricultural scientists are searching systematically for new crops that fit the multiple needs of modern society, in ways that would not have been considered earlier.

Improving the Productivity of Today's Crops

Searching for new crops is not a quick process. While the search proceeds, the most promising strategy to quickly expand the world food supply is to improve the productivity of crops that are already being grown. Much of the im-

(a)

(b)

FIGURE 30.4
New food plants. (*a*) Grain amaranths (*Amaranthus* spp.) were important crops in the Latin American highlands during the days of the Incas and Aztecs. Grain amaranths are fast-growing plants that produce abundant grain rich in lysine, an amino acid rare in plant proteins but essential for animal nutrition. (*b*) The winged bean (*Psophocarpus tetragonolobus*) is a nitrogen-fixing tropical vine that produces highly nutritious leaves and tubers whose seeds produce large quantities of edible oil. First cultivated in New Guinea and Southeast Asia, the winged bean has spread since the 1970s throughout the tropics.

provement in food production must take place in the tropics and subtropics, where the rapidly growing majority of the world's population lives, including most of those enduring a life of extreme poverty. These people cannot be fed by exports from industrial nations, which contribute only about 8% of their total food at present and whose agricultural lands are already heavily exploited. During the 1950s and 1960s, the so-called Green Revolution introduced new, improved strains of wheat and rice. The production of wheat in Mexico increased nearly tenfold between 1950 and 1970, and Mexico temporarily became an exporter of wheat rather than an importer. During the same decades, food production in India was largely able to outstrip even a population growth of approximately 2.3% annually, and China became self-sufficient in food.

Despite the apparent success of the Green Revolution, improvements were limited. Raising the new agricultural strains of plants requires the expenditure of large amounts of energy and abundant supplies of fertilizers, pesticides, and herbicides, as well as adequate machinery. For example, in the United States it requires about 1000 times as much energy to produce the same amount of wheat produced from traditional farming methods in India.

Biologists are playing a crucial role in improving existing crops and in developing new ones by applying traditional methods of plant breeding and selection to many new, nontraditional crops in the tropics and subtropics (see figure 30.4).

Genetic Engineering to Improve Crops

Genetic engineering techniques (discussed in chapter 19) make it possible to produce plants resistant to specific herbicides. These herbicides can then control weeds much more effectively, without damaging crop plants. Genetic engineers are also developing new strains of plants that will grow successfully in areas where they previously could not grow. Desirable characteristics are being introduced into important crop plants. Genetically modified rice, for example, is no longer deficient in ascorbic acid and iron, providing a major improvement in human nutrition. Other modifications allow crops to tolerate irrigation with salt water, fix nitrogen, carry out C_4 photosynthesis, and produce substances that deter pests and diseases.

Genetically modified crops (so-called GM foods) have proven to be a highly controversial issue, one currently being debated in legislative bodies all over the globe. Critics fear loss of genetic diversity, escape of engineered varieties into the environment, harm to insects feeding near GM crops, undo influence of seed companies, and many other real or imagined potential problems. The issue of risk is assessed in chapter 19. While risks must be carefully considered, the ability to transfer genes between organisms, first accomplished in a laboratory in 1973, has tremendous potential for the improvement of crop plants as the twenty-first century opens.

New Approaches to Cultivation

Several new approaches may improve crop production. "No-till" agriculture, spreading widely in the United States and elsewhere in the 1990s, conserves topsoil and so is a desirable agricultural practice for many areas. On the other hand, **hydroponics,** the cultivation of plants in water containing an appropriate mixture of nutrients, holds less promise. It does not differ remarkably in its requirements and challenges from growing plants on land. It requires as much fertilizer and other chemicals, as well as the water itself.

The oceans were once regarded as an inexhaustible source of food, but overexploitation of their resources is limiting the world catch more each year, and these catches are costing more in terms of energy. Mismanagement of fisheries, mainly through overfishing, local pollution, and the destruction of fish breeding and feeding grounds, has lowered the catch of fish in the sea by about 20% from maximum levels. Many fishing areas that were until recently important sources of food have been depleted or closed. For example, the Grand Banks in the North Atlantic Ocean off Newfoundland, a major source of cod and other fish, are now nearly depleted. In 1994, the Canadian government prohibited all cod fishing there indefinitely, throwing 27,000 fishermen out of work, and the United States government banned all fishing on Georges Bank and other defined New England waters. Populations of Atlantic bluefin tuna have dropped 90% since 1975. The United Nations Food and Agriculture organization estimated in 1993 that 13 of 17 major ocean fisheries are in trouble, with the annual marine fish catch dropping from 86 million metric tons in 1986 to 82.5 million tons by 1992 and continuing to fall each year as the intensity of the fishing increases.

The development of new kinds of food, such as microorganisms cultured in nutrient solutions, should definitely be pursued. For example, the photosynthetic, nitrogen-fixing cyanobacterium *Spirulina* is being investigated in several countries as a possible commercial food source. It is a traditional food in Africa, Mexico, and other regions. *Spirulina* thrives in very alkaline water, and it has a higher protein content than soybeans. Ponds in which it grows are 10 times more productive than wheat fields. Such protein-rich concentrates of microorganisms could provide important nutritional supplements. However, psychological barriers must be overcome to persuade people to eat such foods, and the processing required tends to be energy-expensive.

Just over 100 kinds of plants, out of the roughly 250,000 known, supply more than 90% of all the calories we consume. Many more could be developed by a careful search for new crops.

30.3 Human activity is placing the environment under increasing stress.

The simplest way to gain a feeling for the dimensions of the global environmental problem we face is simply to scan the front pages of any newspaper or news magazine or to watch television. Although they are only a sampling, features selected by these media teach us a great deal about the scale and complexity of the challenge we face. We will discuss a few of the most important issues here.

Nuclear Power

At 1:24 A.M. on April 26, 1986, one of the four reactors of the Chernobyl nuclear power plant blew up. Located in Ukraine 100 kilometers north of Kiev, Chernobyl was one of the largest nuclear power plants in Europe, producing 1000 megawatts of electricity, enough to light a medium-sized city. Before dawn on April 26, workers at the plant hurried to complete a series of tests of how Reactor Number 4 performed during a power reduction and took a foolish short-cut: they shut off all the safety systems. Reactors at Chernobyl were graphite reactors designed with a series of emergency systems that shut the reactors down at low power, because the core is unstable then—and these are the emergency systems the workers turned off. A power surge occurred during the test, and there was nothing to dampen it. Power zoomed to hundreds of times the maximum, and a white-hot blast with the force of a ton of dynamite partially melted the fuel rods and heated a vast head of steam that blew the reactor apart.

The explosion and heat sent up a plume 5 kilometers high, carrying several tons of uranium dioxide fuel and fission products. The blast released over 100 megacuries of radioactivity, making it the largest nuclear accident ever reported; by comparison, the Three Mile Island accident in Pennsylvania in 1979 released 17 curies, millions of times less. This cloud traveled first northwest, then southeast, spreading the radioactivity in a band across central Europe from Scandinavia to Greece. Within a 30-kilometer radius of the reactor, at least one-fifth of the population, some 24,000 people, received serious radiation doses (greater than 45 rem). Thirty-one individuals died as a direct result of radiation poisoning, most of them firefighters who succeeded in preventing the fire from spreading to nearby reactors.

The rest of Europe received a much lower but still significant radiation dose. Data indicate that, because of the large numbers of people exposed, radiation outside of the immediate Chernobyl area can be expected to cause from 5000 to 75,000 cancer deaths.

The Promise of Nuclear Power

Our industrial society has grown for over 200 years on a diet of cheap energy. Until recently, much of this energy has been derived from burning wood and fossil fuels: coal, gas, and oil. However, as these sources of fuel become increasingly scarce and the cost of locating and extracting new deposits becomes more expensive, modern society is being forced to look elsewhere for energy. The great promise of nuclear power is that it provides an alternative source of plentiful energy. Although nuclear power is not cheap—power plants are expensive to build and operate—its raw material, uranium ore, is so common in the earth's crust that it is unlikely we will ever run out of it.

Burning coal and oil to obtain energy produces two undesirable chemical by-products: sulfur and carbon dioxide. The sulfur emitted from burning coal is a principal cause of acid rain, while the CO_2 produced from burning all fossil fuels is a major greenhouse gas (see the discussion of global warming in the next section). For these reasons, we need to find replacements for fossil fuels.

For all of its promise of plentiful energy, nuclear power presents several new problems that must be addressed before its full potential can be realized. First, safe operation of the world's approximately 390 nuclear reactors must be ensured. A second challenge is the need to safely dispose of the radioactive wastes produced by the plants and to safely decommission plants that have reached the end of their useful lives (about 25 years). In 1997, over 35 plants were more than 25 years old, and not one has been safely decommissioned, its nuclear wastes disposed of. A third challenge is the need to guard against terrorism and sabotage, because the technology of nuclear power generation is closely linked to that of nuclear weapons.

For these reasons, it is important to continue to investigate and develop other promising alternatives to fossil fuels, such as solar energy and wind energy. The generation of electricity by burning fossil fuels accounts for up to 15% of global warming gas emissions in the United States. As much as 75% of the electricity produced in the United States and Canada currently is wasted through the use of inefficient appliances, according to scientists at Lawrence Berkeley Laboratory. Using highly efficient motors, lights, heaters, air conditioners, refrigerators, and other technologies already available could save huge amounts of energy and greatly reduce global warming gas emission. For example, a new, compact fluorescent light bulb uses only 20% of the amount of electricity a conventional light bulb uses, provides equal or better lighting, lasts up to 13 times longer, and provides substantial cost savings.

Nuclear power offers plentiful energy for the world's future, but its use involves significant problems and dangers.

Carbon Dioxide and Global Warming

By studying earth's history and making comparisons with other planets, scientists have determined that concentrations of gases in the atmosphere, particularly carbon dioxide, maintain the average temperature on earth about 25°C higher than it would be if these gases were absent. Carbon dioxide and other gases trap the longer wavelengths of infrared light, or heat, radiating from the surface of the earth, creating what is known as a **greenhouse effect** (figure 30.5). The atmosphere acts like the glass of a gigantic greenhouse surrounding the earth.

Roughly seven times as much carbon dioxide is locked up in fossil fuels as exists in the atmosphere today. Before industrialization, the concentration of carbon dioxide in the atmosphere was approximately 260 to 280 parts per million (ppm). Since the extensive use of fossil fuels, the amount of carbon dioxide in the atmosphere has been increasing rapidly. During the 25-year period starting in 1958, the concentration of carbon dioxide increased from 315 ppm to more than 340 ppm and continues to rise. Climatologists have calculated that the actual mean global temperature has increased about 1°C since 1900, a change known as **global warming.**

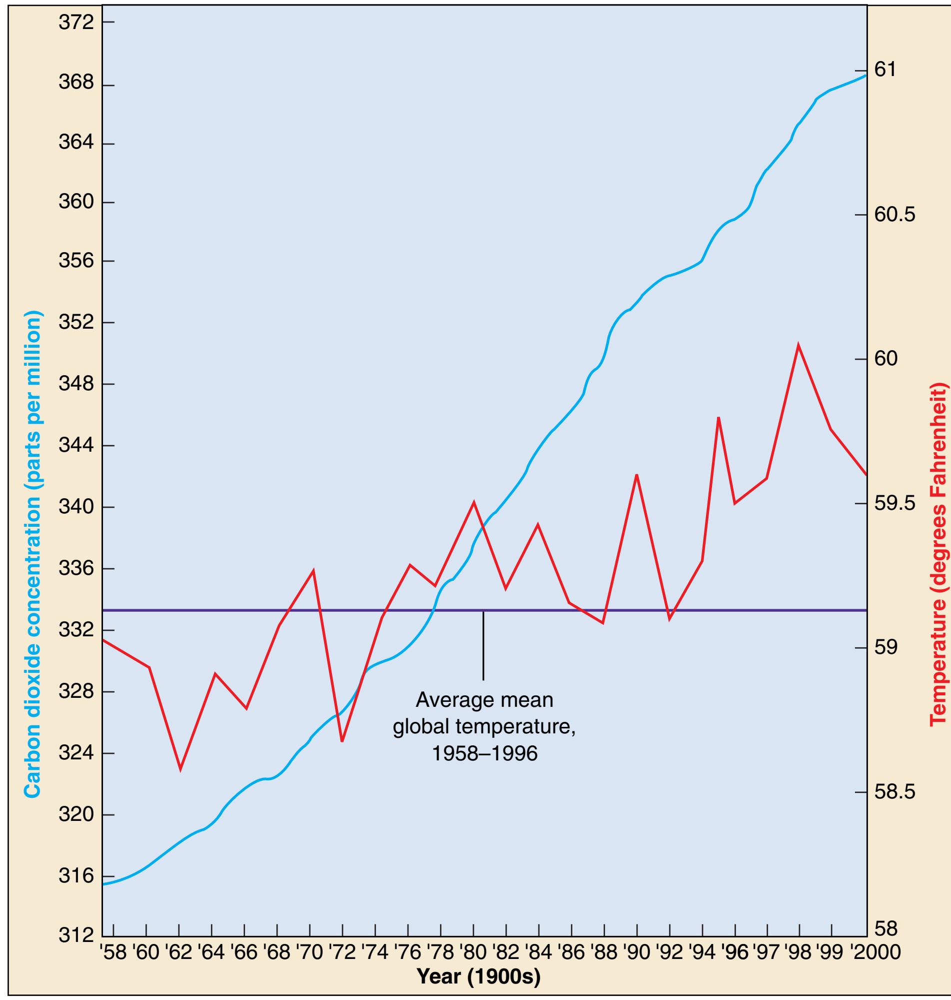


FIGURE 30.5
The greenhouse effect. The concentration of carbon dioxide in the atmosphere has steadily increased since the 1950s (*blue line*). The red line shows the general increase in average global temperature for the same period of time.
Source: Data from Geophysical Monograph, American Geophysical Union, National Academy of Sciences, and National Center for Atmospheric Research.

In a recent study, the U.S. National Research Council estimated that the concentration of carbon dioxide in the atmosphere would pass 600 ppm (roughly double the current level) by the third quarter of the next century, and might exceed that level as soon as 2035. These concentrations of carbon dioxide, if actually reached, would warm global surface air by between 1.5° and 4.5°C. The actual increase might be considerably greater, however, because a number of trace gases, such as nitrous oxide, methane, ozone, and chlorofluorocarbons, are also increasing rapidly in the atmosphere as a result of human activities. These gases have warming, or "greenhouse," effects similar to those of carbon dioxide. One, methane, increased from 1.14 ppm in the atmosphere in 1951 to 1.68 ppm in 1986—nearly a 50% increase.

Major problems associated with climatic warming include rising sea levels. Sea levels may have already risen 2 to 5 centimeters from global warming. If the climate becomes so warm that the polar ice caps melt, sea levels would rise by more than 150 meters, flooding the entire Atlantic coast of North America for an average distance of several hundred kilometers inland.

Changes in the distribution of precipitation are difficult to model. Certainly, changing climatic patterns are likely to make some of the best farmlands much drier than they are at present. If the climate warms as rapidly as many scientists project, the next 50 years may see greatly altered weather patterns, a rising sea level, and major shifts of deserts and fertile regions.

As the global concentration of carbon dioxide increases, the world's temperature is rising, with great potential impact on the world's climate.

Pollution

The River Rhine is a broad ribbon of water that runs through the heart of Europe. From high in the Alps that separate Italy and Switzerland, the Rhine flows north across the industrial regions of Germany before reaching Holland and the sea. Where it crosses the mountains between Mainz and Coblenz, Germany, the Rhine is one of the most beautiful rivers on earth. On the first day of November 1986, the Rhine almost died.

The blow that struck at the life of the Rhine did not at first seem deadly. Firefighters were battling a blaze that morning in Basel, Switzerland. The fire was gutting a huge warehouse, into which firefighters shot streams of water to dampen the flames. The warehouse belonged to Sandoz, a giant chemical company. In the rush to contain the fire, no one thought to ask what chemicals were stored in the warehouse. By the time the fire was out, streams of water had washed 30 tons of mercury and pesticides into the Rhine.

Flowing downriver, the deadly wall of poison killed everything it passed. For hundreds of kilometers, dead fish blanketed the surface of the river. Many cities that use the water of the Rhine for drinking had little time to make other arrangements. Even the plants in the river began to die. All across Germany, from Switzerland to the sea, the river reeked of rotting fish, and not one drop of water was safe to drink.

Six months later, Swiss and German environmental scientists monitoring the effects of the accident were able to report that the blow to the Rhine was not mortal. Enough small aquatic invertebrates and plants had survived to provide a basis for the eventual return of fish and other water life, and the river was rapidly washing out the remaining residues from the spill. A lesson difficult to ignore, the spill on the Rhine has caused the governments of Germany and Switzerland to intensify efforts to protect the river from future industrial accidents and to regulate the growth of chemical and industrial plants on its shores.

The Threat of Pollution

The pollution of the Rhine is a story that can be told countless times in different places in the industrial world, from Love Canal in New York to the James River in Virginia to the town of Times Beach in Missouri. Nor are all pollutants that threaten the sustainability of life immediately toxic. Many forms of pollution arise as by-products of industry. For example, the polymers known as plastics, which we produce in abundance, break down slowly in nature. Much is burned or otherwise degraded to smaller vinyl chloride units. Virtually all of the plastic that has ever been produced is still with us, in one form or another. Collectively, it constitutes a new form of pollution.

Widespread agriculture, carried out increasingly by modern methods, introduces large amounts of many new kinds of chemicals into the global ecosystem, including pesticides, herbicides, and fertilizers. Industrialized countries like the United States now attempt to carefully monitor side effects of these chemicals. Unfortunately, large quantities of many toxic chemicals no longer manufactured still circulate in the ecosystem.

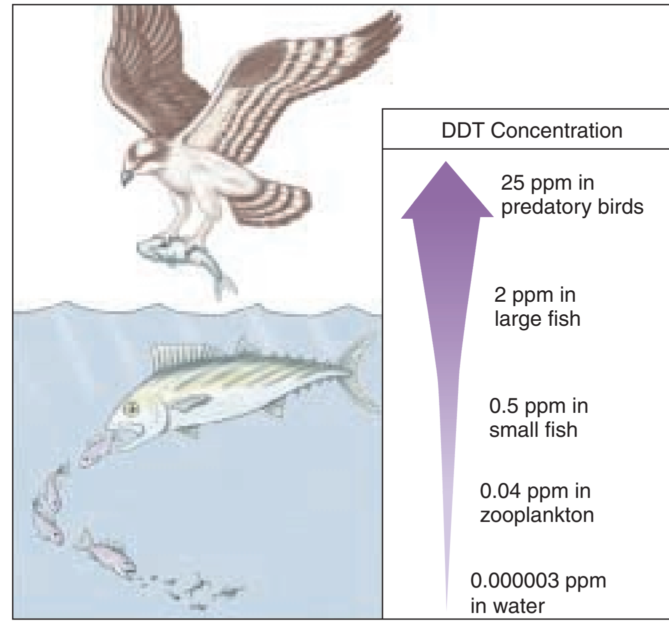


FIGURE 30.6
Biological magnification of DDT. Because DDT accumulates in animal fat, the compound becomes increasingly concentrated in higher levels of the food chain. Before DDT was banned in the United States, predatory bird populations drastically declined because DDT made their eggshells thin and fragile enough to break during incubation.

For example, the chlorinated hydrocarbons, a class of compounds that includes DDT, chlordane, lindane, and dieldrin, have all been banned for normal use in the United States, where they were once widely used. They are still manufactured in the United States, however, and exported to other countries, where their use continues. Chlorinated hydrocarbon molecules break down slowly and accumulate in animal fat. Furthermore, as they pass through a food chain, they become increasingly concentrated in a process called **biological magnification** (figure 30.6). DDT caused serious problems by leading to the production of thin, fragile eggshells in many predatory bird species in the United States and elsewhere until the late 1960s, when it was banned in time to save the birds from extinction. Chlorinated compounds have other undesirable side effects and exhibit hormonelike activities in the bodies of animals, disrupting normal hormonal cycles with sometimes potentially serious consequences.

Chemical pollution is causing ecosystems to accumulate many harmful substances, as the result of spills and runoff from agricultural or urban use.

Acid Precipitation

The Four Corners power plant in New Mexico burns coal, sending smoke up high into the atmosphere through its smokestacks, each over 65 meters tall. The smoke the stacks belch out contains high concentrations of sulfur dioxide and other sulfates, which produce acid when they combine with water vapor in the air. The intent of those who designed the plant was to release the sulfur-rich smoke high in the atmosphere, where winds would disperse and dilute it, carrying the acids far away.

Environmental effects of this acidity are serious. Sulfur introduced into the upper atmosphere combines with water vapor to produce sulfuric acid, and when the water later falls as rain or snow, the precipitation is acid. Natural rainwater rarely has a pH lower than 5.6; in the northeastern United States, however, rain and snow now have a pH of about 3.8, roughly 100 times as acid (figure 30.7).

Acid precipitation destroys life. Thousands of lakes in southern Sweden and Norway no longer support fish; these lakes are now eerily clear. In the northeastern United States and eastern Canada, tens of thousands of lakes are dying biologically as a result of acid precipitation. At pH levels below 5.0, many fish species and other aquatic animals die, unable to reproduce. In southern Sweden and elsewhere, groundwater now has a pH between 4.0 and 6.0, as acid precipitation slowly filters down into the underground reservoirs.

There has been enormous forest damage in the Black Forest in Germany and in the forests of the eastern United States and Canada. It has been estimated that at least 3.5 million hectares of forest in the northern hemisphere are being affected by acid precipitation (figure 30.8), and the problem is clearly growing.

Its solution at first seems obvious: capture and remove the emissions instead of releasing them into the atmosphere. However, there are serious difficulties in executing this solution. First, it is expensive. The costs of installing and maintaining the necessary "scrubbers" in the United States are estimated to be 4 to 5 billion dollars per year. An additional difficulty is that the polluter and the recipient of the pollution are far from each other, and neither wants to pay for what they view as someone else's problem. The Clean Air Act revisions of 1990 addressed this problem in the United States significantly for the first time, and substantial worldwide progress has been made in implementing a solution.

Industrial pollutants such as nitric and sulfuric acids, introduced into the upper atmosphere by factory smokestacks, are spread over wide areas by the prevailing winds and fall to earth with precipitation called "acid rain," lowering the pH of water on the ground and killing life.

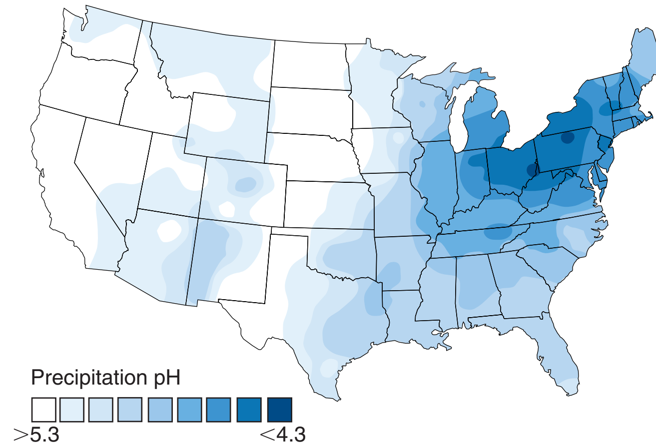


FIGURE 30.7
pH values of rainwater in the United States. Precipitation in the United States, especially in the Northeast, is more acidic than that of natural rainwater, which has a pH of about 5.6.

FIGURE 30.8
Damage to trees at Clingman's Dome, Tennessee. Acid precipitation weakens trees and makes them more susceptible to pests and predators.

The Ozone Hole

The swirling colors of the satellite photos in figure 30.9 represent different concentrations of **ozone** (O_3), a different form of oxygen gas than O_2. As you can see, over Antarctica there is an "ozone hole" three times the size of the United States, an area within which the ozone concentration is much less than elsewhere. The ozone thinning appeared for the first time in 1975. The hole is not a permanent feature, but rather becomes evident each year for a few months during Antarctic winter. Every September from 1975 onward, the ozone "hole" has reappeared. Each year the layer of ozone is thinner and the hole is larger.

The major cause of the ozone depletion had already been suggested in 1974 by Sherwood Roland and Mario Molina, who were awarded the Nobel Prize for their work in 1995. They proposed that chlorofluorocarbons (CFCs), relatively inert chemicals used in cooling systems, fire extinguishers, and Styrofoam containers, were percolating up through the atmosphere and reducing O_3 molecules to O_2. One chlorine atom from a CFC molecule could destroy 100,000 ozone molecules in the following mechanism:

UV radiation causes CFCs to release Cl atoms:

$$CCl_3F \xrightarrow{UV} Cl + CCl_2F$$

UV creates oxygen free radicals:

$$O_2 \longrightarrow 2O$$

Cl atoms and O free radicals interact with ozone:

$$2Cl + 2O_3 \longrightarrow 2ClO + 2O_2$$

$$2ClO + 2O \longrightarrow 2Cl + 2O_2$$

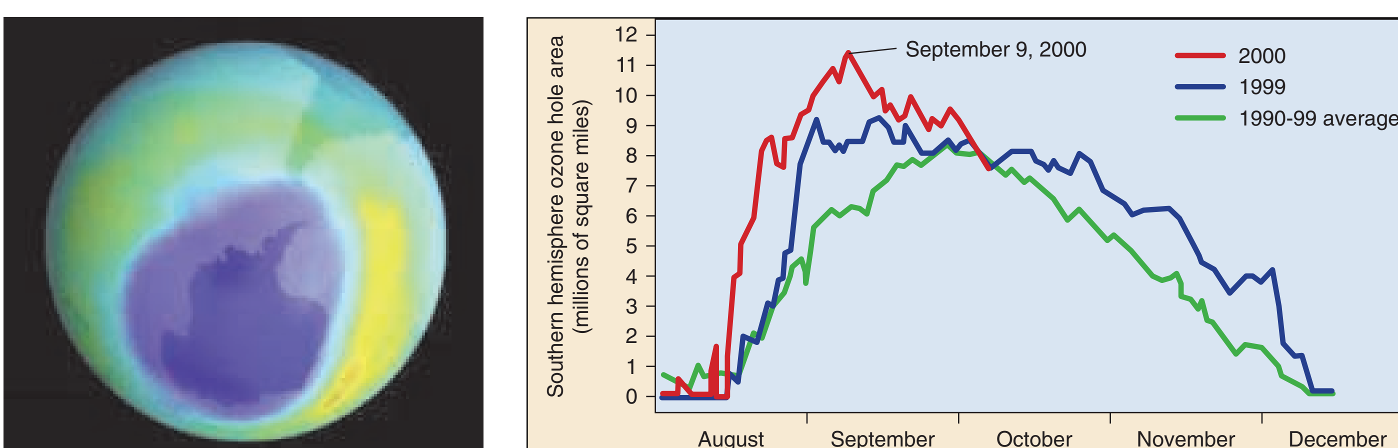
Net reaction: $2O_3 \longrightarrow 3O_2$

Although other factors have also been implicated in ozone depletion, the role of CFCs is so predominant that worldwide agreements have been signed to phase out their production. The United States banned the production of CFCs and other ozone-destroying chemicals after 1995. Nonetheless, the CFCs that were manufactured earlier are moving slowly upward through the atmosphere. The ozone layer will be further depleted before it begins to form again.

Thinning of the ozone layer in the stratosphere, 25 to 40 kilometers above the surface of the earth, is a matter of serious concern. This layer protects life from the harmful ultraviolet rays that bombard the earth continuously from the sun. Life appeared on land only after the oxygen layer was sufficiently thick to generate enough ozone to shield the surface of the earth from these destructive rays.

Ultraviolet radiation is a serious human health concern. Every 1% drop in atmospheric ozone is estimated to lead to a 6% increase in the incidence of skin cancers. At middle latitudes, the approximately 3% drop that has already occurred worldwide is estimated to have increased skin cancers by as much as 20%. A type of skin cancer (melanoma) is one of the more lethal human diseases.

Industrial CFCs released into the atmosphere react at very cold temperatures with ozone, converting it to oxygen gas. This has the effect of destroying the earth's ozone shield and exposing the earth's surface to increased levels of harmful UV radiation.



(a) (b)

FIGURE 30.9
The ozone hole over Antarctica is still growing. For decades NASA satellites have tracked the extent of ozone depletion over Antarctica. Every year since 1979 an ozone "hole" has appeared in August when sunlight triggers chemical reactions in cold air trapped over the South Pole during Antarctic winter. The hole intensifies during September before tailing off as temperatures rise in November-December. In 2000, the 11.4 million square-mile hole (dark blue in the satellite image) covered an area larger than the United States, Canada, and Mexico combined, the largest hole ever recorded. In September 2000, the hole extended over Punta Arenas, a city of about 120,000 people southern Chile, exposing residents to very high levels of UV radiation.

Destruction of the Tropical Forests

More than half of the world's human population lives in the tropics, and this percentage is increasing rapidly. For global stability, and for the sustainable management of the world ecosystem, it will be necessary to solve the problems of food production and regional stability in these areas. World trade, political and economic stability, and the future of most species of plants, animals, fungi, and microorganisms depend on our addressing these problems.

Rain Forests Are Rapidly Disappearing

Tropical rain forests are biologically the richest of the world's biomes. Most other kinds of tropical forest, such as seasonally dry forests and savanna forests, have already been largely destroyed—because they tend to grow on more fertile soils, they were exploited by humans a long time ago. Now the rain forests, which grow on poor soils, are being destroyed. In the mid-1990s, it is estimated that only about 5.5 million square kilometers of tropical rain forest still exist in a relatively undisturbed form. This area, about two-thirds of the size of the United States (excluding Alaska), represents about half of the original extent of the rain forest. From it, about 160,000 square kilometers are being clear-cut every year, with perhaps an equivalent amount severely disturbed by shifting cultivation, firewood gathering, and the clearing of land for cattle ranching. The total area of tropical rain forest destroyed—and therefore permanently removed from the world total—amounts to an area greater than the size of Indiana each year. At this rate, all of the tropical rain forest in the world will be gone in about 30 years; but in many regions, the rate of destruction is much more rapid. As a result of this overexploitation, experts predict there will be little undisturbed tropical forest left anywhere in the world by early in the next century. Many areas now occupied by dense, species-rich forests may still be tree-covered, but the stands will be sparse and species-poor.

(a) (b)

FIGURE 30.10
Destroying the tropical forests. (*a*) When tropical forests are cleared, the ecological consequences can be disastrous. These fires are destroying rain forest in Brazil and clearing it for cattle pasture. (*b*) The consequences of deforestation can be seen on these middle-elevation slopes in Ecuador, which now support only low-grade pastures and permit topsoil to erode into the rivers (note the color of the water, stained brown by high levels of soil erosion). These areas used to support highly productive forest, which protected the watersheds of the area, in the 1970s.

A Serious Matter

Not only does the disappearance of tropical forests represent a tragic loss of largely unknown biodiversity, but the loss of the forests themselves is ecologically a serious matter. Tropical forests are complex, productive ecosystems that function well in the areas where they have evolved. When people cut a forest or open a prairie in the north temperate zone, they provide farmland that we know can be worked for generations. In most areas of the tropics, people are unable to engage in continuous agriculture. When they clear a tropical forest, they engage in a one-time consumption of natural resources that will never be available again (figure 30.10). The complex ecosystems built up over millions of years are now being dismantled, in almost complete ignorance, by humans.

What biologists must do is to learn more about the construction of sustainable agricultural ecosystems that will meet human needs in tropical and subtropical regions. The ecological concepts we have been reviewing in the last three chapters are universal principles. The undisturbed tropical rain forest has one of the highest rates of net primary productivity of any plant community on earth, and it is therefore imperative to develop ways that it can be harvested for human purposes in a sustainable, intelligent way.

More than half of the tropical rain forests have been destroyed by human activity, and the rate of loss is accelerating.

30.4 Solving environmental problems requires individual involvement.

Environmental Science

Environmental scientists attempt to find solutions to environmental problems, considering them in a broad context. Unlike biology or ecology, sciences that seek to learn general principles about how life functions, environmental science is an applied science dedicated to solving practical problems. Its basic tools are derived from ecology, geology, meteorology, social sciences, and many other areas of knowledge that bear on the functioning of the environment and our management of it. Environmental science addresses the problems created by rapid human population growth: an increasing need for energy, a depletion of resources, and a growing level of pollution.

Solving Environmental Problems

The problems our severely stressed planet faces are not insurmountable. A combination of scientific investigation and public action, when brought to bear effectively, can solve environmental problems that seem intractable. Viewed simply, there are five components to solving any environmental problem:

1. **Assessment.** The first stage in addressing any environmental problem is scientific analysis, the gathering of information. Data must be collected and experiments performed to construct a model that describes the situation. This model can be used to make predictions about the future course of events.
2. **Risk analysis.** Using the results of scientific analysis as a tool, it is possible to analyze what could be expected to happen if a particular course of action were followed. It is necessary to evaluate not only the potential for solving the environmental problem, but also any adverse effects a plan of action might create.
3. **Public education.** When a clear choice can be made among alternative courses of action, the public must be informed. This involves explaining the problem in terms the public can understand, presenting the alternatives available, and explaining the probable costs and results of the different choices.
4. **Political action.** The public, through its elected officials selects a course of action and implements it. Choices are particularly difficult to implement when environmental problems transcend national boundaries.
5. **Follow-through.** The results of any action should be carefully monitored to see whether the environmental problem is being solved as well as to evaluate and improve the initial modeling of the problem. Every environmental intervention is an experiment, and we need the knowledge gained from each one to better address future problems.

Individuals Can Make the Difference

The development of appropriate solutions to the world's environmental problems must rest partly on the shoulders of politicians, economists, bankers, engineers—many kinds of public and commercial activity will be required. However, it is important not to lose sight of the key role often played by informed individuals in solving environmental problems. Often one person has made the difference; two examples serve to illustrate the point.

The Nashua River. Running through the heart of New England, the Nashua River was severely polluted by mills established in Massachusetts in the early 1900s. By the 1960s, the river was clogged with pollution and declared ecologically dead. When Marion Stoddart moved to a town along the river in 1962, she was appalled. She approached the state about setting aside a "greenway" (trees running the length of the river on both sides), but the state wasn't interested in buying land along a filthy river. So Stoddart organized the Nashua River Cleanup Committee and began a campaign to ban the dumping of chemicals and wastes into the river. The committee presented bottles of dirty river water to politicians, spoke at town meetings, recruited businesspeople to help finance a waste treatment plant, and began to clean garbage from the Nashua's banks. This citizen's campaign, coordinated by Stoddart, greatly aided passage of the Massachusetts Clean Water Act of 1966. Industrial dumping into the river is now banned, and the river has largely recovered.

Lake Washington. A large, 86 km^2 freshwater lake east of Seattle, Lake Washington became surrounded by Seattle suburbs in the building boom following the Second World War. Between 1940 and 1953, a ring of 10 municipal sewage plants discharged their treated effluent into the lake. Safe enough to drink, the effluent was believed "harmless." By the mid-1950s a great deal of effluent had been dumped into the lake (try multiplying 80 million liters/day $\times$ 365 days/year $\times$ 10 years). In 1954, an ecology professor at the University of Washington in Seattle, W. T. Edmondson, noted that his research students were reporting filamentous blue-green algae growing in the lake. Such algae require plentiful nutrients, which deep freshwater lakes usually lack—the sewage had been fertilizing the lake! Edmondson, alarmed, began a campaign in 1956 to educate public officials to the danger: bacteria decomposing dead algae would soon so deplete the lake's oxygen that the lake would die. After five years, joint municipal taxes financed the building of a sewer to carry the effluent out to sea. The lake is now clean.

In solving environmental problems, the commitment of one person can make a critical difference.

Preserving Nonreplaceable Resources

Among the many ways ecosystems are suffering damage, one class of problem stands out as more serious than the rest: consuming or destroying resources that we cannot replace in the future. While a polluted stream can be cleaned up, no one can restore an extinct species. In the United States, we are consuming three nonreplaceable resources at alarming rates: topsoil, groundwater, and biodiversity. We will briefly discuss the first two of these in this chapter, with a more detailed discussion of biodiversity in the following chapter.

Topsoil

The United States is one of the most productive agricultural countries on earth, largely because much of it is covered with particularly fertile soils. Our midwestern farm belt sits astride what was once a great prairie. The **topsoil** of that ecosystem accumulated bit by bit from countless generations of animals and plants until, by the time humans began to plow it, the rich soil extended down several feet.

We can never replace this rich topsoil, the capital upon which our country's greatness is built, yet we are allowing it to be lost at a rate of centimeters every decade. By repeatedly tilling (turning the soil over) to eliminate weeds, we permit rain to wash more and more of the topsoil away, into rivers, and eventually out to sea. Our country has lost one-quarter of its topsoil since 1950! New approaches are desperately needed to lessen our reliance on intensive cultivation. Some possible solutions include using genetic engineering to make crops resistant to weed-killing herbicides and terracing to recapture lost topsoil.

Groundwater

A second resource we cannot replace is **groundwater,** water trapped beneath the soil within porous rock reservoirs called aquifers (figure 30.11). This water seeped into its underground reservoir very slowly during the last ice age over 12,000 years ago. We should not waste this treasure, for we cannot replace it.

In most areas of the United States, local governments exert relatively little control over the use of groundwater. As a result, a large portion is wasted watering lawns, washing cars, and running fountains. A great deal more is inadvertently polluted by poor disposal of chemical wastes—and once pollution enters the groundwater, there is no effective means of removing it.

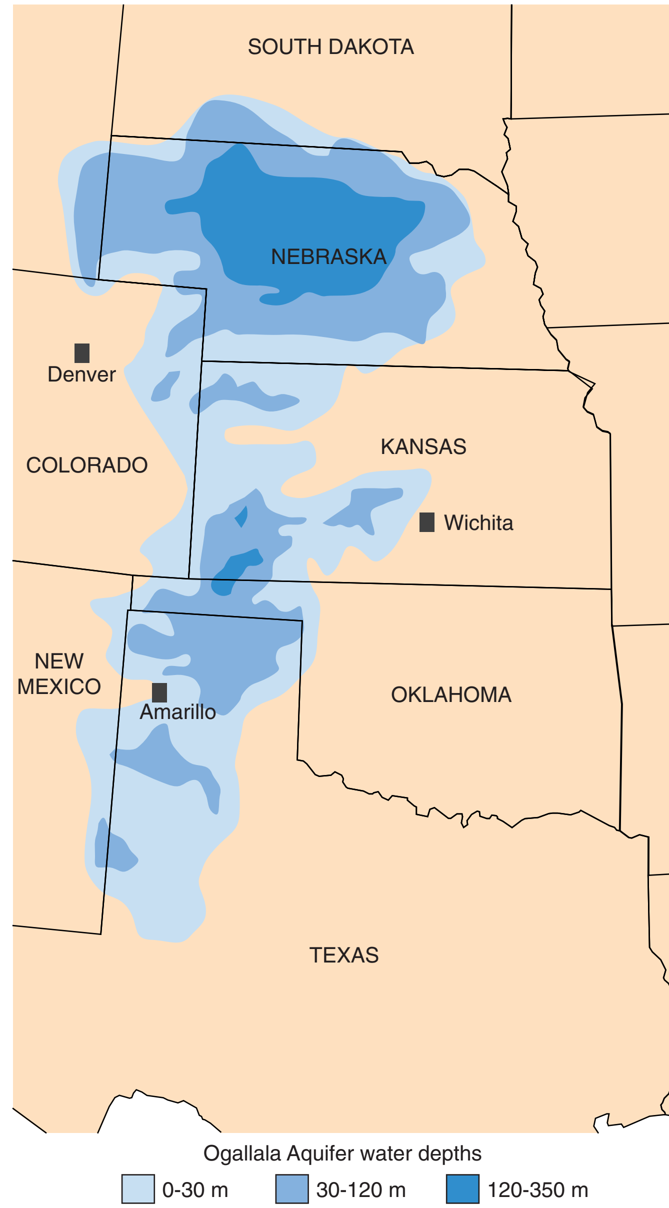


FIGURE 30.11
The Ogallala Aquifer. This massive deposit of groundwater lies under eight states, mainly Texas, Kansas, and Nebraska. Excessive pumping of this water for irrigation and other uses has caused the water level to drop 30 meters in some places. Continued excessive use of this kind endangers the survival of the Ogallala Aquifer, as it takes hundreds or even thousands of years for aquifers to recharge.

Topsoil and groundwater are essential for agriculture and other human activities. Replenishment of these resources occurs at a very slow rate. Current levels of consumption are not sustainable and will cause serious problems in the near future.

Chapter 30

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Summary | **Questions** | **Media Resources**

30.1 The world's human population is growing explosively.

Summary

- Population growth rates are declining throughout much of the world, but still the human population increases by 77 million people per year. At this rate, the global population will double in 39 years.
- An explosively growing human population is placing considerable stress on the environment. People in the developed world consume resources at a vastly higher rate than those in the nondeveloped world. Such high levels of consumption are not sustainable and are as important a problem as global overpopulation.

Questions

1. What biological event fostered the rapid growth of human populations? How did this event affect the location in which humans lived? What major cultural event eventually took place?

2. Why, in some respects, is the population size of the developed world more of a consideration in discussing resource use than the population of the nondeveloped world?

Media Resources

- History of Human Population

30.2 Improvements in agriculture are needed to feed a hungry world.

Summary

- Much current effort is focused on improving the productivity of existing crops, although the search for new crops continues.

Questions

3. What three species supply more than half of the human energy requirements on earth? How many plants supply over 90%?

Media Resources

- Food Needs
- Food Production
- Future Agricultural Prospects
- Land Degradation
- Agriculture-Related Problems

30.3 Human activity is placing the environment under increasing stress.

Summary

- Human activities present many challenges to the environment, including the release of harmful materials into the environment.
- Burning fossil fuels releases carbon dioxide, which may increase the world's temperature and alter weather and ocean levels.
- Release of pollutants into rivers may make the water unfit for aquatic life and human consumption.
- Release of industrial smoke into the upper atmosphere leads to acid precipitation that kills forests and lakes.
- Release of chemicals such as chlorofluorocarbons may destroy the atmosphere's ozone and expose the world to dangerous levels of ultraviolet radiation.
- Cutting and burning the tropical rain forests of the world to make pasture and cropland is producing a massive wave of extinction.

Questions

4. What problems must we master before nuclear power's full potential can be realized?

5. Why were chlorinated hydrocarbons banned in the United States? Why can you still find them as contaminants on fruits and vegetables?

6. How does acid precipitation form? Why has it been difficult to implement solutions to this problem?

7. What is the ozone layer? How is it formed? What are the harmful effects of decreasing the earth's ozone layer? What may be the primary cause of this damage?

Media Resources

- Global Warming
- Bioaccumulation
- Acid Rain
- Ozone Layer Depletion

- Student Research: Plants and Global Warming
- On Science Article: Shrinking Sea Ice

30.4 Solving environmental problems requires individual involvement.

Summary

- All of these challenges to our future can and must be addressed. Today, environmental scientists and concerned citizens are actively searching for constructive solutions to these problems.

Questions

8. What sort of action might you take that would make a significant contribution to solving the world's environmental problems?

Media Resources

- Scientists on Science: History of Life
- On Science Article: Do-It-Yourself Environmentalism