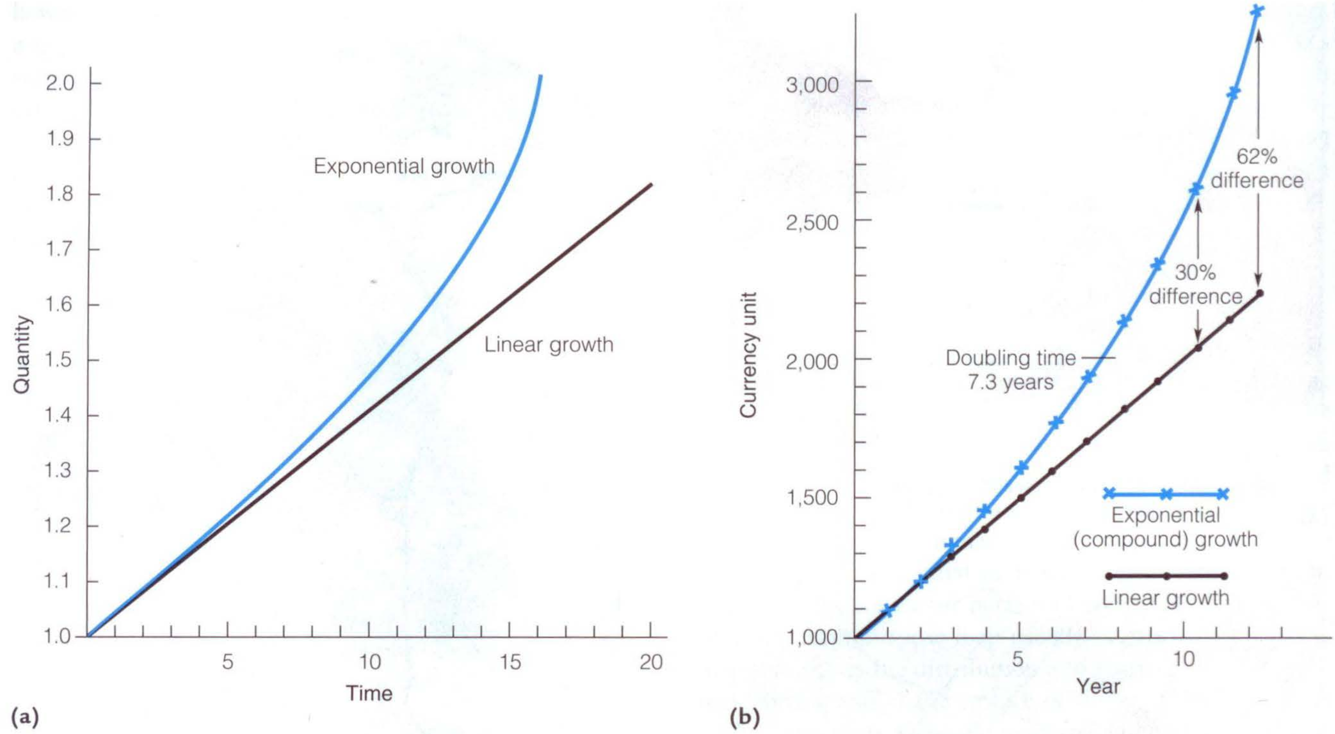


◆ FIGURE 1.7 Linear versus exponential growth. (a) The principle. (b) The growth of a savings account at 10 percent interest per year. Although the text example uses the dollar as the currency unit, the unit could be pounds, yen, or rupees—and the principle is the same for population growth. Note that the doubling time for exponential growth at a 10 percent annual rate is about 7 years. (USGS)

Page 6 to Page 12

…rground water and soils have been devel- … the laws (see Chapter 8). The deadline for … leaking tanks—which became known as …he environmental field—was the end of …ns that were not compliant by then were no … store or dispense gasoline.

…sposal is an ongoing major problem. It … geologically acceptable disposal sites, …ed to be safe for sequestering hazardous …pter 15).

… from beneath the land surface for human …ss enough, but in Venice, Italy, this is causing … the city to subside. This sinking causes …th serious consequences for the residents …rce of revenue, tourism. Similarly, subsi- …on of underground water has altered the … and storm drains over large areas of the … Gulf Coast and the Great Valley of California.

At the core of these and many other environmental problems is the burgeoning world population. This growing population exists on a planet with limited air, land, water, and mineral resources.

Too Many People

The concept of **carrying capacity**—the idea that a given amount of land or other critical resource can support a limited number of people or animals—has intrigued scientists, economists, and philosophers for centuries. Thomas Malthus postulated in 1812 that populations grow geometrically, whereas food supplies increase only linearly, which leads to a gap between demand (population) and supply (food) that eventually results in famine. Human life is inextricably linked to resource utilization, environmental quality, and economic well-being. Thus, a good starting point for any environmental study is to learn how populations grow, a study referred to as **population dynamics.**

World population increased dramatically in the twentieth century. In 1900, the population of the earth was estimated at 1.6 billion people. By 2000 this figure had quadrupled, to 6 billion. Stated another way, it took about 10,000 generations for humankind to reach the first two billion in population, but only one generation to add the most recent two billion. Pogo, a popular comic strip character of the 1960s, once said, "Yep, son, we have met the enemy, and he is us," and this applies to the global population dilemma. Much of the recent dramatic increase in population can be explained by a reduction in the death rate due to overall better health globally.

Exponential Growth and the Population Explosion

Growth and increases are familiar processes to all of us; we see them in our national debt, taxes, rents, food costs, and so on. Increases that occur in nearly equal increments are described as *linear*. Examples include your electric bill variation with usage of electricity and growth of the grass in your lawn between weekly cuttings. Some other things grow by increments that become larger with time, and this kind of growth is described as *geometric* or *exponential.* Examples include the expansion of weeds in a neglected garden and historic increases in the national debt. The growth of a savings account also is exponential, assuming no withdrawals. A thousand dollars invested at 10 percent annual interest rate earns $100 the first year and becomes $1,100. During the second year $1,100 at 10 percent earns $110, and the value of the account grows to $1,210, and so on in each succeeding year. Thus, interest is earned on interest (compounded) so that at the end of ten years, for instance, the account balance is not just $1,000 *plus* 10 percent interest *times* 10 years, or $2,000, but $2,593.74.

It may seem incongruous that to our well-being and way of life the most important increases are not interest rates or the national debt, but the explosive growth of world population and natural-resource consumption. The graphs of ◆ Figure 1.7 contrast linear (straight) and exponential (**J**-shaped) growth curves. Although a population growth rate of 2 percent per year or a similar increase in the consumption of a particular natural resource may seem trivial, when we realize that this growth is exponential, our assessment changes. Valid concerns for the future of the human condition arise. As world population increases exponentially, natural resources are rapidly being depleted; even if geological exploration can double or triple known oil or mineral reserves, it will make little difference in the useful lifetime of those resources (see ○ Case Study 1.2 on page 13).

Population growth rate is determined by subtracting a population's death rate from its birthrate, with death and birth rates expressed as deaths and live births per 1,000 people per year, respectively. For example, a birthrate of 20 *minus* a death rate of 10 would yield a growth rate of 10 per 1,000 persons, or 1.0 percent. World growth rates were low in 1900 (about 0.8%), and they have fluctuated with time. They reached a high of about 2.06 percent during the 1960s and then have slowly declined to the year 2000. At first glance you might think that a growth rate of 1 percent would yield a population **doubling time** of 100 years (since 1% per year × 100 years = 100%). This is not the case, however. Populations grow like savings accounts with compounded interest. Just as you can earn interest on interest, the people that are added produce more people, resulting in a shorter doubling time. A very close approximation of doubling time can be obtained by the "rule of 70"; that is,

$$\text{Population doubling time} = 70 \div \text{growth rate (\%)}$$

Thus, the doubling time for a 1 percent growth rate would be 70 years; that for a 2 percent growth rate would be 35 years, and so forth. ✻ Table 1.1 provides some examples. The global population growth and the average annual growth rate for 1950 to 2000 are shown in ✻ Table 1.2. Although some progress has been made in slowing the growth rate, the number of people added each year continues to grow larger. The world population grew by almost a billion people in the decade 1990–2000, the largest increment ever for a single decade.

✻TABLE 1.1 How Populations Grow

Growth Rate, %	Doubling Time, Years*
1.0	70.0
2.0	35.0
3.0	23.3
4.0	17.5
5.0	14.0
6.0	11.7
7.0	10.0

*Calculated by using the formula 70 ÷ growth rate (%), which yields a close approximation up to a growth rate of 10%.

U.S. Population Growth and Immigration

In 2002 an estimated 289 million people were living in the United States. They generated 15.9 live births per thousand people and a death rate of 9.0 per 1,000, for a growth rate of 6.9 per 1,000, or 0.69 percent. At first glance these figures appear to be real progress toward **zero population growth,** a condition that exists when, on average, as many people die as are born each year. However, even at this low rate the population would double in 100 years, without accounting for immigration—which adds significantly to the U.S. population, particularly in Texas, Florida, and California. From the 1920s through the 1960s about 200,000 immigrants came to the United States each year. Since then this number has grown dramatically for a variety of political and economic reasons. By 1993 there were 810,000 legal immigrants *plus* an estimated

✻TABLE 1.2 World Population and Growth Rate, 1950–2002

Year	Population, Billions	Growth Rate, %*
1950	2.52	
1955	2.75	1.77
1960	3.03	1.95
1965	3.34	1.99
1970	3.77	1.90
1975	4.08	1.84
1980	4.45	1.81
1985	4.85	1.75
1990	5.30	1.70
1995	5.76	1.68
2002	6.26	1.56

*Average annual rate for the previous five-year period.
Sources: Estimates in United Nations, *Demographics Yearbooks* for 1985 and 1990, and in *World Resources, 1994–95* (New York: Oxford University Press).

200,000 illegal ones, for a total of about a million new persons—five times the annual immigration of 30 years earlier. From the year 2000 through the end of the twenty-first century, it is estimated that 90 percent of the population growth in the United States will be immigrants and their progeny.

World Population Growth, Resources, and the Environment

In 1900 the world population growth rate was 1 percent. It climbed to a historical high of 2.2 percent in 1964, and then gradually dropped to 1.4 percent in 1997—a good sign. If the 1964 growth rate had remained at that level instead of decreasing, the earth's population would now be over 8 billion people. Some experts expect this growth rate to remain fairly steady for at least two decades and then to drop. Other experts expect education and birth-control measures to lower the growth rate steadily. The world continues to grow by 75 million people each year, the equivalent of almost five New York cities, with all the increases in the least developed countries. Forty eight of these underdeveloped nations are expected to triple in population by 2050, and in many more the population could easily double. The most significant world trend is that death rates are falling in poor and rich countries alike, while birthrates remain high in most poor countries and low in most rich ones. Exceptions are the generally higher death rates of Africa and the high birthrates of the rich oil-producing countries.

Due to varying estimates of *growth rate momentum*, world population projections for 2050 range widely. The United Nations Population Division in 2002 projected a 2050 world population of 8.9 billion people, 2.6 billion higher than today's population but 400 million lower than its previous projection. About half of the decrease is due to deaths from the HIV/AIDS pandemic and the lower than expected birthrates. The U.N. report says that fertility levels in most developing countries have fallen from six children per woman in 1950 to three children per woman today. China provides a good example of population momentum. Utilizing education and incentives, the country cut its growth rate dramatically in a few decades to 1.1 percent from more than 2.0 percent. With a population in excess of 1.3 billion, however, 11–13 million people are added every year even with a low growth rate! Keep in mind that the population growth curve is the typical **J-curve** for exponential growth of anything—slow growth at first followed by compounding and very rapid growth (see Figure 1.1).

The tripling of the population in the twentieth century has placed extreme demands on soil, water, forest, energy, and mineral resources. As a population increases, marginal lands are tilled because of the need for more food, and thus, poor agricultural practices become exaggerated. In addition, between 1940 and 1990, atmospheric carbon dioxide (CO_2) levels increased 13 percent, which may have implications for global warming, and the protective stratospheric ozone layer decreased 2 percent worldwide (more than that over Antarctica; see Chapter 11). None of these problems is insurmountable, but human ingenuity will certainly be taxed to overcome the challenges they present.

Overpopulation Scenario One: The Sky Is Falling

This scenario is fairly simple. The earth has too many people and finite resources for sustaining them. The carrying capacity of the earth has either been reached or is fast approaching, and the basic resources for life—soil, water, energy, and clean air—are being taxed to their limit. Students of population dynamics, economics, and environmental science generally agree that the earth will be hard pressed to sustain the 9–10 billion people projected for 2050, based upon the *lowest* of the projected world growth rates. If nothing is done to stabilize population, future population reduction will occur by increased fatalities from natural disasters, mass starvation, epidemics, and ecological degradation.

Overpopulation Scenario Two: The Gaia Hypothesis

The name of Gaia, the Greek goddess of the earth, has been applied by James Lovelock and U.S. biologist Lynn Margulis to their hypothesis that the earth is a superorganism whose environment is controlled by the plants and animals that inhabit it, rather than vice-versa. According to this hypothesis, the planet is "self-adjusting," so to speak. The superorganism regulates its environment with a complex system of mechanisms and buffers, just as an animal adjusts to varying temperatures, chemistry, and other environmental factors. For example, carbon dioxide, CO_2, a gas that is required for photosynthesis and therefore all of life, also acts as an insulating blanket in that it holds the sun's heat close to the earth. Terrestrial and marine plants act as regulators that "pump out" excess CO_2 from the atmosphere when great amounts are added by volcanic activity, which, if it were to accumulate, would smother humans and other animals.

According to the Gaia hypothesis, the last ice age ended abruptly when atmospheric CO_2 doubled due to a sudden failure of the "pumps," not by the slow processes of geochemistry as invoked by conventional scientific theory.

The Gaia hypothesis is appealing to some people because it seems to offer an easy solution for our environmental problems. However, toward the end of the twenty-first century the amount of CO_2 in the atmosphere will be doubled, and even Lovelock admits that "it is near certain that the new state will be less favorable for humans than the one we enjoy now."

Toward a Sustainable Society

A **sustainable society** (see Case Study 1.2) is one that satisfies its needs without jeopardizing the needs of future generations. The current generation *should* strive to pass along its legacy of food, fuel, clean air and water, and mineral resources for material needs to the generations of the twenty-first century. We know what needs to be done to accomplish this, but knowing what to do and implementing a long-range plan for carrying it out are entirely different things. A promising development in

TABLE 1.3 Examples of Glaciers Wasting

Name	Described Loss
Greenland	Thinning at a rate of about a meter a year at its southern and eastern edges.
Glacier National Park	Since 1850, the number of glaciers has dropped from 150 to less than 50.
Alps	Glacial volume has shrunk by more than 50 percent since 1850.
Kilamanjaro (Tanzania)	Glacial ice has shrunk almost one-third since 1989.
Alaska (Glacier Bay)	Ice was at the entrance to the bay in 1794. Today, the Grand Pacific Glacier has retreated 105 km (65 mi) up the bay (see Chapter 11, Figure 11.4).

Various sources.

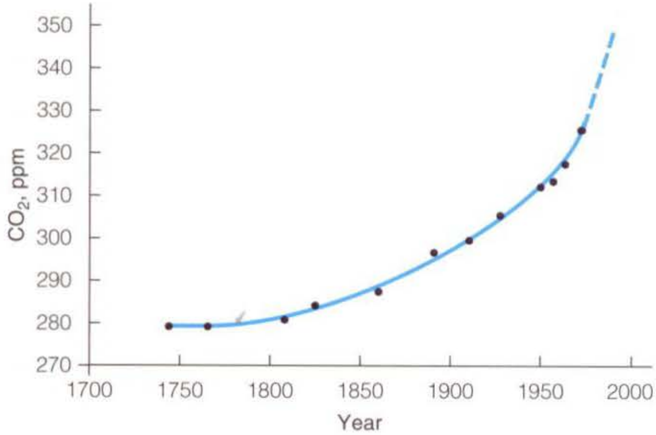


FIGURE 1.8 Estimated atmospheric carbon dioxide changes from 1700 to 1980 based on data from air bubbles trapped in Antarctic ice cores and on atmospheric measurements. (NOAA data)

industrialized nations is the growing respect for basing an economy on steady-state conditions, rather than on continual growth. The conceptual ideal is sometimes referred to as the *spaceship economy,* since all resources must be conserved, shared, and recycled in space travel. This, together with population control, could lead in time to a sustainable society.

Too Many People and Signs of a Stressed Earth

Global Warming and Energy

In August 2000, the *New York Times* reported that a cruise ship sailed to the North Pole in open water. The Arctic Ocean at the pole is usually frozen over, year round. It was the rule in the past that captains of adventure cruises allowed the passengers to disembark in order to be photographed on the ice near the pole—but not during the summer of 2000. Early explorers hiking over the ice that summer would have had to swim the last few miles to the North Pole. It is noteworthy that the 14 warmest years since 1866 occurred between 1980 and 2001.

Melting ice is one of the most visible results of warmer temperatures (see Case Study 1.3) on page 13). In late 1991 an intact 5,000-year-old man was discovered protruding from a glacier on the Austrian–Italian border. He became known as the "Ice Man" and was quite famous. In general, glaciers and sea ice worldwide are wasting and are a sensitive indicator of global warming. Selected examples are shown in Table 1.3, and the subject is covered in more detail in Chapter 11. Besides providing scenic beauty, glaciers store water in winter that is released in spring and summer to run power stations and provide fresh water. Switzerland, Scandinavia, and to some extent the United States depend on glaciers as a source of water.

Global warming is potentially the most serious long-term environmental problem facing humankind. It is closely associated with the increase in atmospheric carbon dioxide produced by the burning of coal, oil, and natural gas (Figure 1.8). Other greenhouse gases, such as methane, nitrous oxide, ozone, and chlorofluorocarbons (CFCs), are also increasing in the atmosphere, and this, too, is closely associated with population growth. It is estimated that these gases may contribute to about half of the global warming projected for the twenty-first century.

Carbon-dioxide concentrations in the atmosphere today (as measured atop Hawaii's Mauna Loa volcano; see Chapter 5) are at their highest levels of the past 160,000 years, as indicated also by CO_2 in air bubbles in Antarctic deep ice cores (Chapter 11). If the goal is to stabilize climate, calculations indicate that the CO_2 emissions must be lowered from their 1990 level of 22 billion tons per year to 8 billion tons per year. In developed countries this would require an 85 percent per capita reduction in fossil-fuel consumption, which is unrealistic in the short term. As a start, a 5.2 percent average reduction has been agreed to by 38 industrialized nations, and there is some doubt that even this can be accomplished. Industrial nations consume energy at a prodigious rate—2–4 times the global per capita mean and 10–20 times that of Africa and Australasia (Figure 1.9). In the early 1990s half a billion motor vehicles were registered in the world, and this figure is expected to double by 2025—each consuming an average of two gallons of gasoline per day. Thus, other means of powering those vehicles must be developed—perhaps fuel cells; liquid or gaseous fuels derived from coal, natural gas, or biomass (alcohol); or even solar energy (see Chapter 14).

As developing nations raise their standards of living, their energy consumption will also increase, and competition between the developed and the developing nations for energy supplies will increase. This competition will surely increase as the world's coal and oil reserves decrease. The developing nations were using 30 percent of the world's energy in the early 1990s, a usage that was predicted to double by 2015.

The only options for large-scale power production sufficient to drive economic growth and human requirements in the near future are solar-energy conversion and nuclear energy, including both fission and fusion. Solar-derived electricity at present costs one-third less than electricity from a nuclear power plant and it lacks the hazards associated with radioactive substances. On the negative side, with present technology, solar-energy conversion requires vast areas of land and an effective storage system (see Chapter 14).

Rising Sea Level

A sensitive indicator of global warming is the rising sea level. It is affected by melt water from land-based glaciers, thermal expansion of seawater, and to a lesser extent the volume of the container. During the twentieth century sea level rose 10–20 centimeters (4–8 in) and it could rise as much as 1 meter during the twenty-first century. The consequences are loss of land, salt-water contamination of coastal underground fresh water (see Chapter 8), and beach erosion as waves break further inland (see Chapter 10). We must add to this the loss of agricultural productivity. For instance, Bangladesh would lose half its rice production by a 1-meter rise of sea level. It is not hard to visualize the economic and social consequences of millions of climate refugees.

The Land

The amount of cultivatable soil limits the number of humans the earth can support, because soil determines grain production and therefore food supplies. Arable soils worldwide suffered slight to severe degradation between 1945 and 1990 due to poor agricultural practices, natural erosion, and erosion accelerated by deforestation (* Table 1.4). The world's farmers lost an estimated 500 million tons of topsoil in the 1970s and 80s, an amount equal to the tillable area of India and France combined. Waterlogging and salt-contamination of soils are reducing the productivity of at least a fourth of the world's cropland, and human-generated smog (ozone) and acid rain also are taking their toll on crops. It is the lack of soil, sometimes combined with drought, that is the cause of famine, not soil infertility. (Soils are discussed in detail in Chapter 6.)

***TABLE 1.4 Estimated World Soil Degradation, 1945–1990**

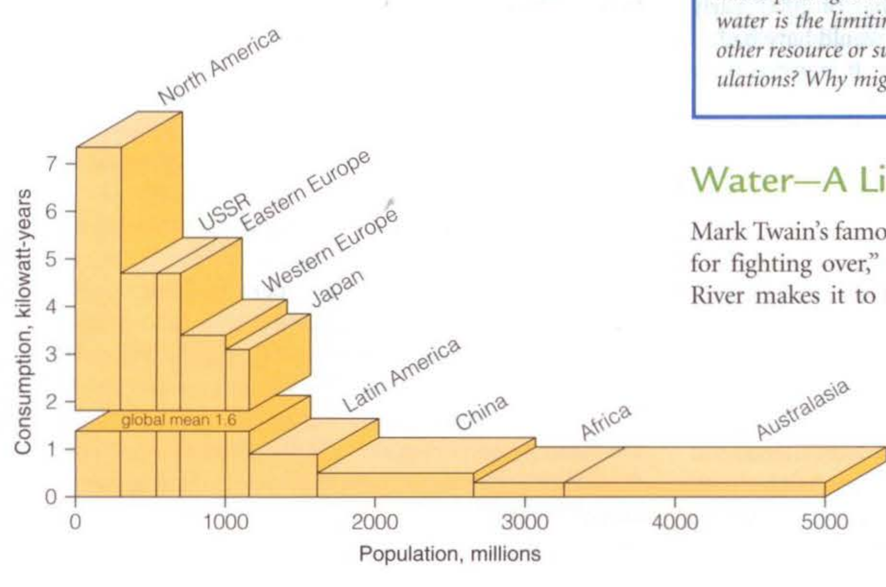
Region	Degraded Land Area as a Percentage of Vegetated Land		
	Total	*Light Erosion**	*Moderate to Extreme Erosion***
World	17	7	10
Asia	20	7	13
South America	14	6	8
Europe	23	6	17
Africa	22	8	14
North America (U.S., Canada)	5	1	4
Central America, Mexico	25	1	24

**Light:* crop yields reduced less than 10 percent.
***Moderate:* crop yields reduced 10–50 percent. *Severe:* crop yields reduced more than 50 percent. *Extreme:* no crop growth possible. About 9 million hectares worldwide exhibit extreme erosion, less than 0.5 percent of all degraded lands.
Source: Various sources compiled by World Resources Institute and the United Nations, *World Resources 1992–93* (New York: Oxford University Press, 1992).

CONSIDER THIS *A limiting resource is one that controls a population's growth and stability; for instance, the abundance of nitrates and phosphates in the oceans limits plant growth. Many earth scientists and biologists believe water is the limiting resource for humans. Can you think of any other resource or substance that might be limiting to human populations? Why might it be?*

Water—A Limiting Resource

Mark Twain's famous quote, "Whiskey is for drinking; water is for fighting over," was prophetic. Little water from the Nile River makes it to the Mediterranean, the Ganges River is a



◆ FIGURE 1.9 Per capita energy consumption in kilowatt-years (kwy). Note that the industrialized nations consumed 2–4 times the global per capita mean. The data are for 1987 but had not changed much by 2003 except for China, which has greatly increased industrial production. (Blue Planet Group) trickle in the dry season, and the Colorado River is a joke when it crosses the international border with Mexico. With the populations of Egypt and her neighbors projected to double between 2000 and 2050, and as the inevitable growth of India and Bangladesh occurs, there is bound to be competition for the use of water on the Nile and the Ganges. Two-thirds of the world's irrigated lands lie in Asia, where populations and water needs also are greatest. The Yellow River ran dry in 1972 for the first time in China's 3,000-year history, and water tables fell on every continent in the early 2000s. Water withdrawals exceed water recharge in the southern Great Plains and the entire southwestern United States (see Chapter 8).

Seventy percent of water that is diverted from rivers or pumped from underground is used for irrigating crops upon which entire cultures depend. It is said that India is on a temporary "free ride," expanding irrigation at the expense of stored underground water. Underground water needs to be managed, as it is not a limitless resource. When this fact strikes home, India's grain production could fall as much as 25 percent. For a country that adds 16 million people every year, the consequences could be disastrous.

CONSIDER THIS *Few people doubt the existence of ozone holes in our atmosphere and the increased flux of ultraviolet radiation to the earth's surface due to ozone depletion by CFCs in the stratosphere. Global warming and its cause, however, are subjects of heated (no joke intended) debate. The earth is getting warmer, and the big question is whether the cause is anthropogenic (humans' production of greenhouse gases), or just part of a natural climatic rhythm of warming and cooling. Think hard about the long-term impact of global warming on the hydrosphere, atmosphere, biosphere, and on humans, and then answer the question, Is it wise to wait, perhaps several decades, to know for certain whether the warming is natural or anthropogenic before reducing greenhouse-gas emissions?*

Forests

Deforestation continues to be one of the environmental issues of the day. Forests cover 30 percent of the earth's land surface, or 3.9 billion hectares (abbreviated ha; each ha is about 2.5 acres) and each year forests are diminished by man or by fires. According to the Food and Agricultural Organization (FAO) of the United Nations, between 1990 and 2000 there was a loss of 94 million hectares (235 million acres). The emerging nations lost 130 million hectares (325 million acres), and the industrial countries gained 36 million hectares (90 million acres), mostly by conversion of agricultural land. Simply put, every 3 years the developing countries lose 2 percent of their forestland. Deforestation leads to loss of habitat and decreased biodiversity, contributes to climate change by adding CO_2 to the atmosphere, and often results in soil degradation.

One reason for clearing forests is to convert land to agricultural use. More than half of the tropical-forest lands destroyed each year are in Brazil. It should be noted, however, that Brazil plans to set aside 1.6 million square kilometers (618,000 mi^2), about 20 percent of its land area, as public reserves and parks. The Indonesian government, in a full-page advertisement in a U.S. magazine in 1989, explained that the aspirations of its 170 million people were the same as those of citizens in developed nations, and that in order to better their lives, 20 percent of Indonesian forests were to be converted to plantations of teak, rubber, rice, and coffee. A poor African farmer, on the other hand, has little choice but to clear land to grow crops just for subsistence. How a country uses its land is a complex political and sociological issue, and there are no simple ways to reconcile the conflicting human needs that the issue involves.

Logging is another cause of deforestation, but it has been demonstrated that selective logging in tropical forests is sustainable if the logged lands are allowed to rejuvenate. In 1988 Thailand was inundated with 40 inches of rain in five days. Thousands of logs left on hillsides to dry floated off in mud and water that engulfed entire villages, killing 350 people. The Thai government banned logging, and was caught between the companies that wanted compensation for lost business and the landless poor who were given farms in the previously logged areas.

A third cause of deforestation is the demand for wood fuel and forest products. Many of the forests in India and the Sahel of West Africa have been decimated for use as domestic fuel and in light industry.

Deforestation is second only to the burning of fossil fuels as a source of atmospheric CO_2. Forests store 450 billion metric tons of carbon. When cleared, they can no longer sequester the carbon, and it is released rapidly to the atmosphere when trees are burned, or slowly if they are left to decay.

Other Resources

Our throw-away society, though certainly a convenient one, has become a recycling society as natural resources dwindle and waste-disposal sites become scarce and expensive to operate. Most of what we used to discard after one use—paper, plastic, glass, aluminum, and even steel—is now recycled. Trash disposal has become so expensive, at least in urban settings where most trash is generated, that recycling is close to being cost-effective. Unless alternative energy sources are maximally utilized, oil reserves will be exhausted in your lifetime or in your children's. United States coal reserves are estimated at a 400-year reserve, but such pollution considerations as smog, acid rain, and global warming will continue to limit coal's use. World reserves of metallic and nonmetallic resources, many of which are in abundant supply at present, can certainly be extended by recycling. The geological and environmental consequences of mining and energy consumption and the problems associated with waste disposal are considered in Chapters 13 through 15.

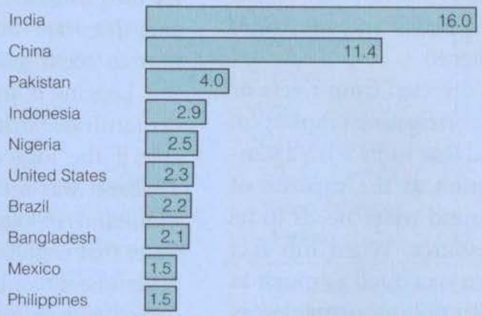
CONSIDER THIS *Name some of the things that earth's inhabitants could do now to develop a sustainable society for future generations.*

CASE STUDY 1.1

The Road to Seven Billion

Sometime during October 1999, the United Nations announced that the world population had reached 6 billion, only 12 years after the population reached the 5 billion mark. According to the U.N.'s Population Division projections, the 7 billionth person could be born as early as 2011 or as late as 2015, depending upon birth-rate trends in India or China. What is more disturbing, to us at least, is the trend toward urbanization. In the 1950s there were only 16 cities with more than a million people. London was the leader with 7 million, and only 7 percent of the population could be described as urban. The earth's population has doubled in the past 40 years, but city populations have increased five-fold. According to the U.N., in the next five years over half the population of the globe will be living in cities, with inadequate infrastructures and too few jobs (see the figure). Megacities are heat sinks that promote smog, trigger thunderstorms, and reduce the productivity of the land. At the same time, rise in sea levels due to global warming will threaten coastal areas and river deltas where most large cities are located. How can megacities exist with the need to protect the environment? This is one of the big questions debated at the Johannesburg Summit Meeting (see Case Study 1.2). However, with good planning and an eye for aesthetics, city dwelling of the future need not be bleak. The good news is that there is a trend for women to have one or two children in those nations with over 80 percent of the population.

Top 10 Countries in Population Growth
Net annual additions, in millions, 1995–2000



Largest Urban Areas, 2002
Population in millions