the rest of the textbook will build. As you read through *Environmental Geology*, you will notice that these concepts are revisited throughout the text.

1. ***Human population growth***
2. ***Sustainability***
3. ***Earth as a system***
4. ***Hazardous Earth processes***
5. ***Scientific knowledge and values***

The five concepts presented here do not constitute a list of all concepts that are important to environmental geologists, and they are not meant to be memorized. However, a general understanding of each concept will help you comprehend and evaluate the material presented in the rest of the text.

Concept One: Human Population Growth

The number one environmental problem is the increase in human population.

The number one environmental problem is the ever-growing human population. For most of human history, our numbers were small, as was our input on Earth. With the advent of agriculture, sanitation, modern medicine, and, especially, inexpensive energy sources such as oil, we have proliferated to the point where our numbers are a problem. The total environmental impact from people is estimated by the impact per person times the total number of people. Therefore, as population increases, the total impact must also increase. As population increases, more resources are needed and, given our present technology, greater environmental disruption results. When local population density increases as a result of political upheaval and wars, famine may result (Figure 1.2).

FIGURE 1.2 Famine Korem Camp, Ethiopia, in 1984. Hungry people are forced to flee their homes as a result of political and military activity and gather in camps such as these. Surrounding lands may be devastated by overgrazing from stock animals, gathering of firewood, and just too many people in a confined area. The result may be famine. *(David Burnett/Contact Press Images, Inc.)*

Exponential Growth

What Is the Population Bomb? Overpopulation has been a problem in some areas of the world for at least several hundred years, but it is now apparent that it is a global problem. From 1830 to 1930, the world's population doubled from 1 to 2 billion people. By 1970 it had nearly doubled again, and, by the year 2000, there were about 6 billion people on Earth. The problem is sometimes called the population bomb, because the exponential growth of the human population results in the explosive increase in the number of people (Figure 1.3). **Exponential growth** of humans means that the

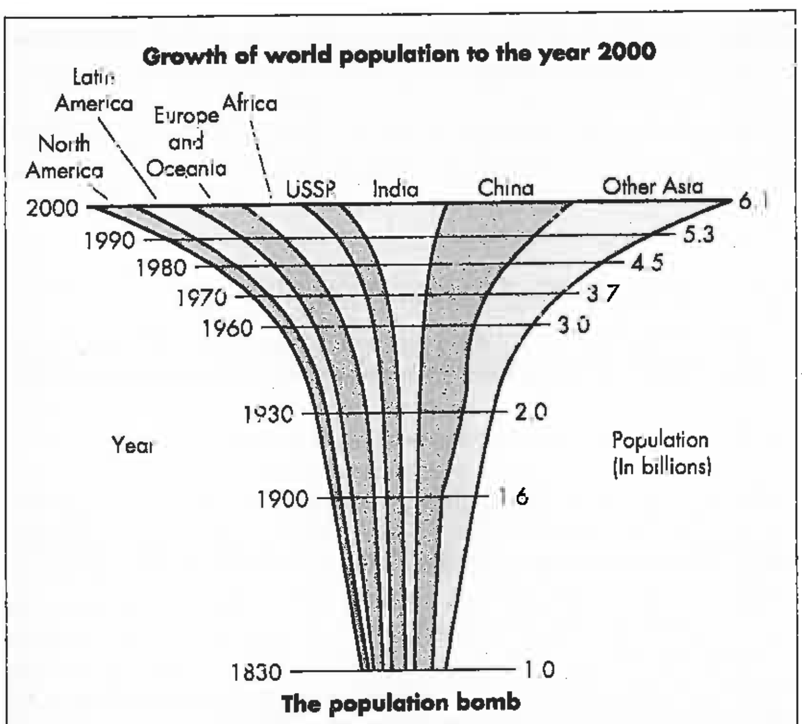

FIGURE 1.3 The population bomb The population in 2006 is 6.6 billion and growing. *(Modified after U.S. Department of State)*

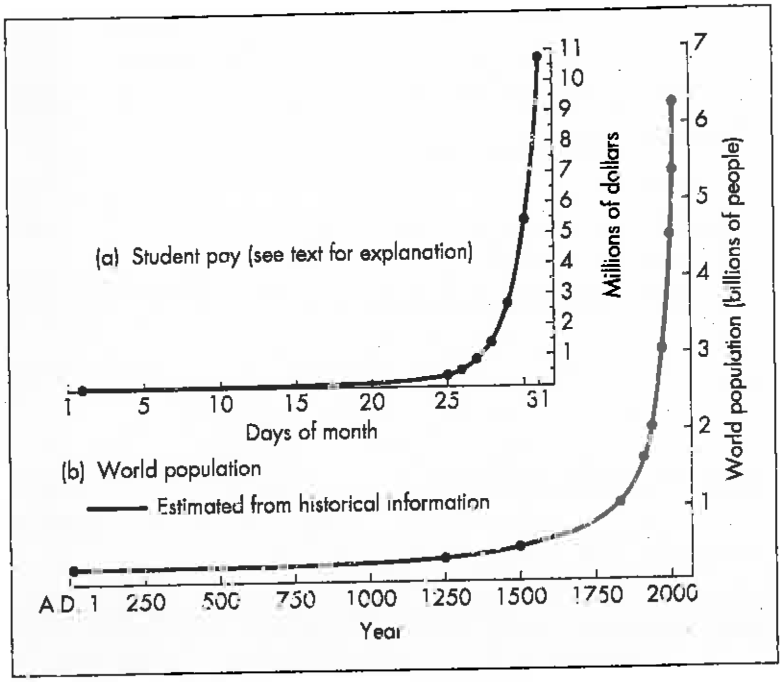

FIGURE 1.4 Exponential growth (a) Example of a student's pay, beginning at 1 cent for the first day of work and doubling daily for 31 days. (b) World population. Notice that both curves have the characteristic J shape, with a slow initial increase followed by a rapid increase. The actual shape of the curve depends on the scale at which the data are plotted. It often looks like the tip of a skateboard. *(Population data from U.S. Department of State)*

number of people added to the population each year is not constant; rather, a constant percentage of the current population is added each year. As an analogy, consider a high-yield savings account that pays interest of 7 percent per year. If you start with $100, at the end of the first year you have $107, and you earned $7 in interest. At the end of the second year, 7 percent of $107 is $7.49, and your balance is $107 plus $7.49, or $114.49. Interest in the third year is 7 percent of 114.49, or $8.01, and your account has $122.51. In 30 years you will have saved about $800.00. Read on to find out how I know this.

There are two important aspects of exponential growth:

- The **growth rate,** measured as a percentage
- The **doubling time,** or the time it takes for whatever is growing to double

Figure 1.4 illustrates two examples of exponential growth. In each case, the object being considered (student pay or world population) grows quite slowly at first, begins to increase more rapidly, and then continues at a very rapid rate. Even very modest rates of growth eventually produce very large increases in whatever is growing.

How Fast Does Population Double? A general rule is that doubling time (D) is roughly equal to 70 divided by the growth rate (G):

$$D = 70/G$$

Using this approximation, we find that a population with a 2 percent annual growth rate would double in about 35 years. If it were growing at 1 percent per year, it would double in about 70 years (see *Putting Some Numbers On: Exponential Growth*).

Many systems in nature display exponential growth some of the time, so it is important that we be able to recognize such growth because it can eventually yield incredibly large numbers. As an extreme example of exponential growth (Figure 1.4a), consider the student who, after taking a job for 1 month, requests from the employer a payment of 1 cent for the first day of work, 2 cents for the second day, 4 cents for the third day, and so on. In other words, the payment would double each day. What would be the total? It would take the student 8 days to earn a wage of more than $1 per day, and, by the eleventh day, his earnings would be more than $10 per day. Payment for the 16th day of the month would be more than $300, and, on the last day of the 31-day month, the student's earnings for that one day would be more than $10 million! This is an extreme case because the constant rate of increase is 100 percent per day, but it shows that exponential growth is a very dynamic process. The human population increases at a much lower rate—1.2 percent per year today—but even this slower exponential growth eventually results in a dramatic increase in numbers (Figure 1.4b). Exponential growth will be discussed further under Concept Three, when we consider systems and change.

Human Population through History

What Is Our History of Population Growth? The story of human population increase is put in historic perspective in Table 1.2. When we were hunter-gatherers, our numbers were very small, and growth rates were very low. With agriculture, growth rates in human population increased by several hundred times, owing to a stable food supply. During the early industrial period, (A.D. 1600 to 1800), growth rates increased again by about 10 times. With the Industrial Revolution, with modern sanitation and medicine, the growth rates increased another 10 times. Human population reached 6 billion in 2000. By 2013, it will be 7 billion, and, by 2050, it will be about 9 billion. That is 1 billion new people in only 13 years and 3 billion (about one-half of today's population)

PUTTING SOME NUMBERS ON

Exponential Growth

Exponential growth is a powerful process related to positive feedback, where the quantity of what is being evaluated (for example, human population increase, consumption of resources such as oil or minerals, or rate of land converted to urban purposes) grow at a fixed rate (a percentage) per year. Exponential growth of the human population is shown in Figure 1.4.

Calculating exponential growth is surprisingly easy and involves a rather simple equation:

$$N = N_0 e^{kt}$$

where N is the future value of whatever is being evaluated; N_0 is present value; e is a constant 2.71828; k is equal to the rate of increase (a decimal representing a percentage); and t is the number of years over which the growth is to be calculated. Growth rate R is defined as the percent change per unit of time: $K = R/100$. This equation may be solved utilizing a simple hand calculator, and a number of interesting environmental questions may be asked as a result. For example, assume that we wanted to know what the world population is going to be in the year 2020, given that the population in 2000 is 6.1 billion and the population is growing at a constant rate of 1.2 percent per year (0.012 as a decimal). Precise figures of human population and growth rates may be obtained from a variety of sources, including the U.S. Bureau of Census. Assuming that world population was 6.1 billion in the year 2000 and that the growth rate is 1.2 percent per year, we can estimate the world population for the year 2020 by applying the equation above:

$$N\,(\text{world population in 2020}) = (6.1 \times 10^9)(e^{(0.012 \times 20)})$$

$$N = (6.1 \times 10^9)(e^{0.24})$$

$$= (6.1 \times 10^9)(2.71828^{0.24})$$

$$N\,(\text{population projected to year 2020 based upon the above assumptions}) = 7.75 \times 10^9,$$

or 7.75 billion persons.

Our equation for exponential growth may also be rearranged to project the time in the future when the earth will reach a certain population. In this case, we must assume a beginning population, a population at some time in the future, and the growth rate. Thus, t may be solved by the following equation:

$$t = (1/k)\ln(N/N_0)$$

where all the terms have been defined and ln is the natural logarithm to the base 2.71828. If we use our previous example and pose the question that, if the population growth remains constant at 1.20 percent per year and the population in the year 2000 was 6.1 billion people, in what year will it reach 7.75 billion? By substituting in the above equation $t = (1/0.012)\,ln(7.75 \times 10^9/6.1 \times 10^9)$, we see that t is equal to 20 years.

A word of caution concerning the use of exponential growth—it is based upon the assumption of constant growth rate. In trying to put arguments concerning exponential growth in a critical thinking framework, it is important to recognize that assumptions we make are statements accepted as true without proof. Rates of growth represented as a percentage may, in fact, not be constant. As a result, the estimations we make when applying the exponential growth equation based upon a constant rate of increase need to be critically examined in terms of how realistic the constant growth rate is. The longer the period of time over which we apply constant rates of growth, the more unlikely it is that our predictions will be accurate. In spite of these shortcomings, analysis of exponential growth is one way to provide insight into predicting future change and the growth or decline of a number or quantity of particular material of interest. The equation used to predict the decline of a quantity, assuming a constant rate of reduction as a percentage, is:

$$N = N_0 e^{-kt}$$

where the terms are defined as above.

Assume a quantity of something is experiencing exponential growth. The time for it to double can be calculated by:

$$2N_0 = N_0 e^{kTd}$$

where Td is the doubling time. Take the natural logarithm of both sides of the equation:

$$ln\,2 = kTd, \text{ then}$$

$$Td = ln\,2/k$$

$$\text{Remember, } k = R/100$$

$$Td = 0.693/R/100$$

$$= 0.693(100)/R$$

$$= 69.3/R \text{ or } \sim 70/R$$

This equates to our general rule that the doubling time is approximately 70 ÷ the growth rate. For example, if $R = 5$ percent per year, then $Td = 14$ years.

in 50 years. By comparison, total human population had reached only 1 billion in about A.D. 1800, after over 40,000 years of human history! Less developed countries have death rates similar to those of more developed countries, but their birth rates are twice those of developed countries. India will likely have the greatest population of all countries by 2050, with about 18 percent of the total world population, followed by China with 15 percent. Together, these two countries will have about one-third of the total world population by 2050.[6]

TABLE 1.2 How we became 6 billion+

40,000–9,000 B.C.: Hunters and Gatherers

Population density about 1 person per 100 km^2 of habitable areas;* total population probably less than a few million; average annual growth rate less than 0.0001% (doubling time about 700,000 years)

9,000 B.C.–A.D. 1600: Preindustrial Agricultural

Population density about 1 person per 3 km^2 of habitable areas (about 300 times that of the hunter and gatherer period); total population about 500 million; average annual growth rate about 0.03% (doubling time about 2300 years)

A.D. 1600–1800: Early Industrial

Population density about 7 persons per 1 km^2 of habitable areas; total population by 1800 about 1 billion; annual growth rate about 0.1% (doubling time about 700 years)

A.D. 1800–2000: Modern

Population density about 40 persons per 1 km^2; total population in 2000 about 6.1 billion; annual growth rate at 2000 about 1.4% (doubling time about 50 years)

**Habitable area is assumed to be about 150 million square kilometers (58 million square miles). Modified after Botkin, D. B., and Keller, E. A., 2000. Environmental Science, 3rd ed., New York: John Wiley and Sons.*

Population Growth and the Future

How Many People Can Earth Comfortably Support?

Because Earth's population is increasing exponentially, many scientists are concerned that, in the twenty-first century, it will be impossible to supply resources and a high-quality environment for the billions of people who may be added to the world population. Three billion more people by 2050, with almost all of the growth in the developing countries, is cause for concern. Increasing population at local, regional, and global levels compounds nearly all environmental geology problems, including pollution of ground and surface waters; production and management of hazardous waste; and exposure of people and human structures to natural processes (hazards) such as floods, landslides, volcanic eruptions, and earthquakes.

There is no easy answer to the population problem. In the future, we may be able to mass-produce enough food from a nearly landless agriculture, or use artificial growing situations, to support our ever-growing numbers. However, the ability to feed people does not solve the problems of limited space available to people and maintenance or improvement of their quality of life. Some studies suggest that the present population is already above a comfortable **carrying capacity** for the planet. Carrying capacity is the maximum number of people Earth can hold without causing environmental degradation that reduces the ability of the planet to support the population. The role of education is paramount in the population problem. As people (particularly women) become more educated, the population growth rate tends to decrease. As the rate of literacy increases, population growth is reduced. Given the variety of cultures, values, and norms in the world today, it appears that our greatest hope for population control is, in fact, through education.[7]

The Earth Is Our Only Suitable Habitat The Earth is now and for the foreseeable future the only suitable habitat we have, and its resources are limited. Some resources, such as water, are renewable, but many, such as fuels and minerals, are not. Other planets in our solar system, such as Mars, cannot currently be considered a solution to our resource and population problems. We may eventually have a colony of people on Mars, but it would be a harsh environment, with people living in bubbles.

When resource and other environmental data are combined with population growth data, the conclusion is clear: It is impossible, in the long run, to support exponential population growth with a finite resource base. Therefore, one of the primary goals of environmental work is to ensure that we can defuse the population bomb. Some scientists believe that population growth will take care of itself through disease and other catastrophes, such as famine. Other scientists are optimistic that we will find better ways to control the population of the world within the limits of our available resources, space, and other environmental needs.

Good News on Human Population Growth It is not all bad news regarding human population growth; for the first time since the mid-1900s, the rate of increase in human population is decreasing. Figure 1.5 shows that the number of people added to the total population of Earth peaked in the late 1980s and has generally decreased since then. This is a milestone in human population growth, and it is encouraging.[8] From an optimistic point of view, it is possible that our global population of 6 billion persons in 2000 may not double again. Although population growth is difficult to estimate because of variables such as agriculture, sanitation, medicine, culture, and education, it is estimated that, by the year 2050, human population will be between 7.3 and 10.7 billion, with 8.9 billion

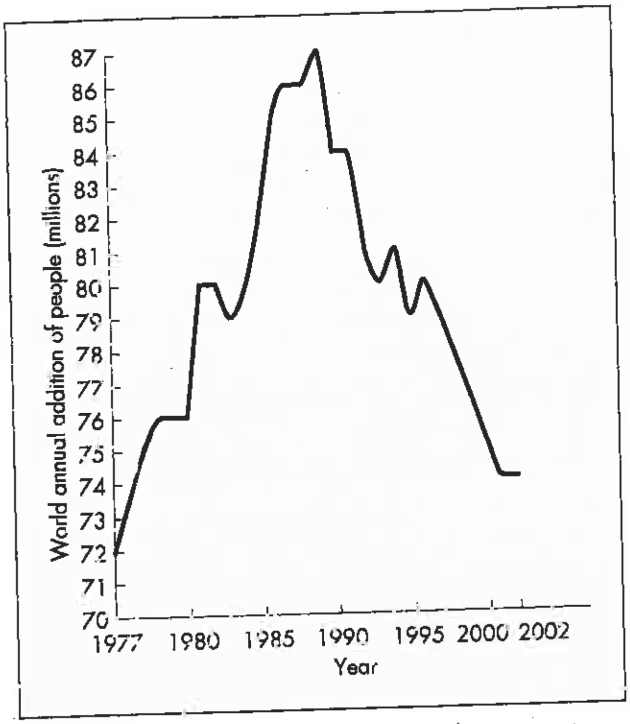

FIGURE 1.5 Good news on population growth World annual increase in population peaked in the late 1980s. Today it is at a level comparable to the late 1970s. This increase is like adding two Californias each year. *(Data from the U.S. Bureau of the Census and Worldwatch Institute)*

being most likely. Population reduction is most likely related to the education of women, the decision to marry later in life, and the availability of modern birth control methods. Until the growth rate is zero, however, population will continue to grow. About 20 countries, mostly in Western Europe but including China, have achieved a total fertility rate (number of children per woman) of less than 2.1, which is the level necessary for replacement.

Concept Two: Sustainability

Sustainability is the environmental objective.

What is sustainability? **Sustainability** is something that we are struggling to define. One definition is that sustainability is development that ensures that future generations will have equal access to the resources that our planet offers. Sustainability also refers to types of development that are economically viable, do not harm the environment, and are socially just.[7] Sustainability is a long-term concept, something that happens over decades or even over hundreds of years. It is important to acknowledge that sustainability, with respect to use of resources, is possible for renewable resources such as air and water. Sustainable development with respect to nonrenewable resources such as fossil fuels and minerals is possible by, first, extending their availability through conservation and recycling; and, second, rather than focusing on when a particular nonrenewable resource is depleted, focusing on how that resource is used and developing substitutes for those uses.

There is little doubt that we are using living environmental resources such as forests, fish, and wildlife faster than they can be naturally replenished. We have extracted minerals, oil, and groundwater without concern for their limits or for the need to recycle them. As a result, there are shortages of some resources. We must learn how to sustain our environmental resources so that they continue to provide benefits for people and other living things on the planet.

We stated in Concept One, with respect to humans and resources, that Earth is the only place to live that is now accessible to us and that our resources are limited. To meet future resource demands and to sustain our resources, we will need large-scale recycling of many materials. Most materials can theoretically be recycled. The challenge is to find ways to do it that do not harm the environment, that increase the quality of life, and that are economically viable. A large part of our solid and liquid waste disposal problems could be alleviated if these wastes were reused or recycled. In other words, many wastes that are now considered pollutants can be turned into resources. Land is also an important resource for people, plants, and animals, as well as for manufacturing, mining, and energy production; transportation; deposition of waste products; and aesthetics. Owing in part to human population increases that demand more land for urban and agricultural purposes, human-induced change to Earth is increasing at a rapid rate. A recent study of human activity and the ability to move soil and rock concluded that human activity (agriculture, mining, urbanization, and so on) moves as much or more soil and rock on an annual basis than any other Earth process (Figure 1.6), including mountain building or river transport of sediment. These activities and their associated visual changes to Earth (for example, leveling hills) suggest that human activity is the most significant process shaping the surface of Earth.[9] We will discuss land-use planning in Chapter 17.

FIGURE 1.6 Mining A giant excavating machine in this mine can move Earth materials at a rate that could bury one of the Egyptian Pyramids in a short time. *(Joseph J. Scherschel/NGS Image Collection)*

Are We in an Environmental Crisis? Demands made on diminishing resources by a growing human population and the ever-increasing production of human waste have produced what is popularly referred to as the **environmental crisis**. This crisis in the United States and throughout the world is a result of overpopulation, urbanization, and industrialization, combined with too little ethical regard for our land and inadequate institutions to cope with environmental stress.[10] The rapid use of resources continues to cause environmental problems on a global scale, including

- Climate change from burning fossil fuels resulting in global warming.
- Deforestation and accompanying soil erosion and water and air pollution occur on many continents (Figure 1.7).
- Mining of resources such as metals, coal, and petroleum wherever they occur produces a variety of environmental problems.
- Development of both groundwater and surface-water resources results in loss of and damage to many environments on a global scale. For example, the Aral Sea in Kazakhstan and Uzbekistan over a period of 30 years decreased in area from 67,000 km^2 (26,000 mi^2) to 28,000 km^2 (10,800 mi^2) due to diversion of two rivers that fed it. Loss of the sea is changing the regional weather, making winters cooler and summers warmer. An ambitious program to restore part of the sea through water conservation has been partly successful.[11]

On a positive note, we have learned a great deal from the environmental crisis, particularly concerning the relationship between environmental degradation and resource utilization. Innovative plans for sustainable development of resources, including water and energy, are being developed to lessen a wide variety of environmental problems associated with using resources.

Do We Need to Save Earth or Ourselves? The environmental slogan of the 1990s was "save our planet." Is Earth's very survival really in danger? In the long view of planetary evolution, Earth will outlive the human race. Our Sun is likely to last another several billion years at least, and, even if all humans became extinct in the next few years, life would still flourish on our planet. The environmental degradation we have imposed on the landscape, atmosphere, and waters might last for a few hundreds or thousands of years, but they would eventually be cleansed by natural processes. Therefore, our major concern is the quality of the human environment, which depends on sustaining our larger support systems, including air, water, soil, and other life.

FIGURE 1.7 Logging Clear-cut timber harvesting exposes soils, compacting them and generally contributing to an increase in soil erosion and other environmental problems. *(Edward A. Keller)*

Concept Three: Earth as a System

Understanding Earth's systems and their changes is critical to solving environmental problems.

A **system** is any defined part of the universe that we select for study. Examples of systems are a planet, a volcano, an ocean basin, or a river (Figure 1.8). Most systems contain several component parts that mutually adjust to function as a whole, with changes in one component bringing about changes in other components. For example, the components of our global system are water, land, atmosphere, and life. These components mutually adjust, helping to keep the entire Earth system operating.[12]

Input-Output Analysis

Input-output analysis is an important method for analyzing change in systems. Figure 1.9 identifies three types of change in a pool or stock of materials; in each case, the net change depends on the relative rates of the input and output. Where the input into the system is equal to the output (Figure 1.9a), a rough steady state is established and no net change occurs. The example shown is a university in which students enter as freshmen and graduate four years later at a constant rate. Thus, the pool of university students remains a constant size. At the global scale, our planet is a roughly steady-state system with respect to energy: Incoming solar radiation is roughly balanced by outgoing radiation from Earth. In the second type of change, the input into the system is less than the output (Figure 1.9b). Examples include the use of resources such as fossil fuels or groundwater and the harvest of certain plants or animals. If the input is much less than the output, then the fuel or water source may be completely used up or the plants or animals may become extinct. In a system in which input exceeds output (Figure 1.9c), the stock of whatever is being measured will increase. Examples include the buildup of heavy metals in lakes from industrial pollution or the pollution of soil and water.

How Can We Evaluate Change? By evaluating rates of change or the input and output of a system, we can derive an **average residence time** for a particular material, such as a resource. The average residence time is a measure of the time it takes for the total stock or supply of the material to be cycled through a system. To compute the average residence time (T; assuming constant size of the system and constant rate of

FIGURE 1.8 River as a system Image of part of the Amazon River system (blue) and its confluence with the Rio Negro (black). The blue water of the Amazon is heavily laden with sediment, whereas the water of the Rio Negro is nearly clear. Note that as the two large rivers join, the waters do not mix initially but remain separate for some distance past the confluence. The Rio Negro is in flood stage. The red is the Amazon rain forest, and the white lines are areas of human-caused disturbances such as roads. *(Earth Satellite Corporation/Science Photo Library/Photo Researchers, Inc.)*

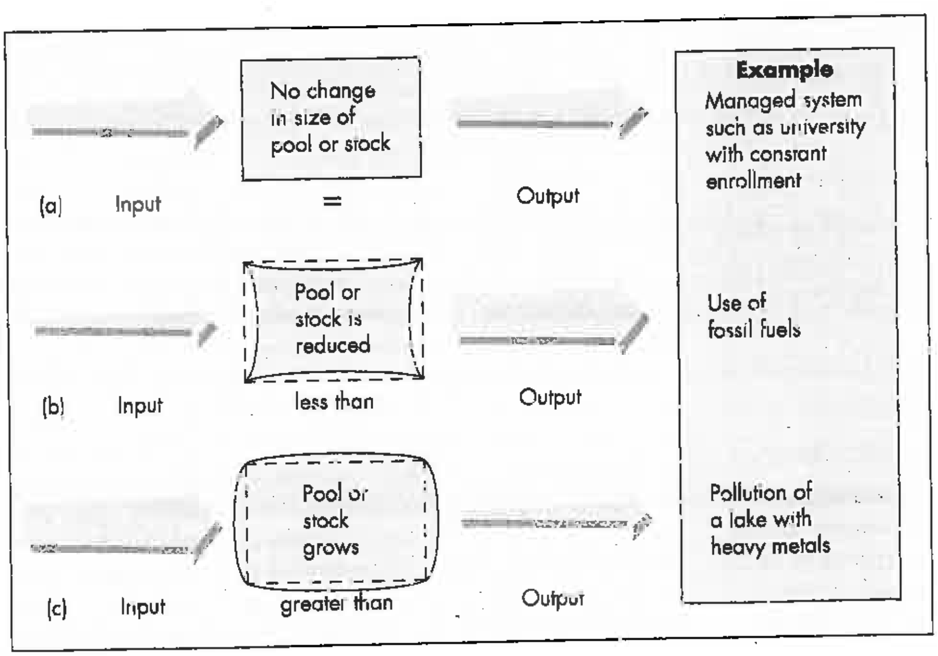

FIGURE 1.9 Change in systems Major ways in which a pool or stock of some material may change. *(Modified after Ehrlich, P. R., Ehrlich, A. H., and Holdren, J. P. 1977.* Ecoscience: Population, Resources, Environment. *3rd ed. San Francisco: W. H. Freeman)*

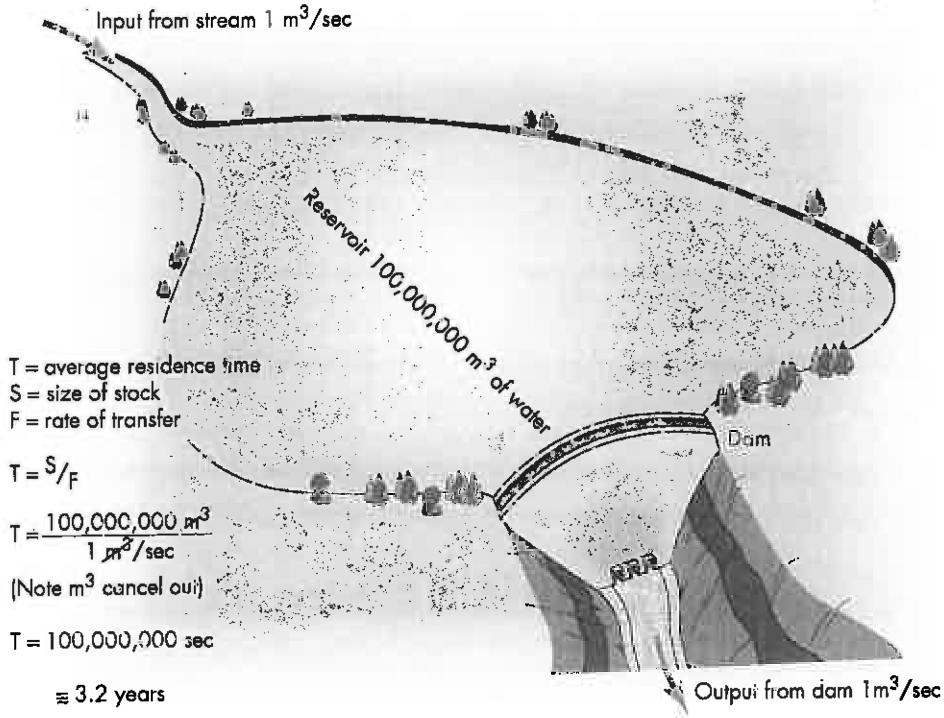

FIGURE 1.10 Average residence time Calculation of the average residence time for a cubic meter of water in a reservoir where input = output = 1 m^3 per second, and the size of the reservoir is constant at 100,000,000 m^3 of water.

transfer), we take the total size of the stock (S) and divide it by the average rate of transfer (F) through the system:

$$T = S/F$$

For example, if a reservoir holds 100 million cubic meters of water, and both the average input from streams entering the reservoir and the average output over the spillway are 1 cubic meter per second, then the average residence time for a cubic meter of water in the reservoir is 100 million seconds, or about 3.2 years (Figure 1.10). We can also calculate average residence time for systems that vary in size and rates of transfer, but the mathematics is more difficult. It is often possible to compute a residence time for a particular resource and then to apply the information to help understand and solve environmental problems. For example, the average residence time of water in rivers is about 2 weeks, compared with hundreds to thousands of years for some groundwater. Thus, strategies to treat a one-time pollution event of oil spilled in a river will be much different from those for removing oil floating on groundwater that resulted from a rupture of an underground pipeline. The oil in the river is a relatively accessible, straightforward, short-term problem, whereas polluted groundwater is a more difficult problem because it moves slowly and has a long average residence time. Because it may take from several hundreds of years for pollution of groundwater to be naturally removed, groundwater pollution is difficult to treat.

Predicting Changes in the Earth System The idea that "the present is the key to the past," called **uniformitarianism**, was popularized in 1785 by James Hutton (referred to by some scholars as the father of geology) is heralded today as a fundamental concept of Earth sciences. As the name suggests, uniformitarianism holds that processes we observe today also operated in the past (flow of water in rivers, formation and movement of glaciers, landslides, waves on beaches, uplift of the land from earthquakes, and so on). Uniformitarianism does not demand or even suggest that the magnitude (amount of energy expended) and frequency (how often a particular process occurs) of natural processes remain constant with time. We can infer that, for as long as Earth has had an atmosphere, oceans, and continents similar to those of today, the present processes were operating.

Present Human Activity Is Part of the Key to Understanding the Future In making inferences about geologic events, we must consider the effects of human activity on the Earth system and what effect these changes to the system as a whole may have on natural Earth processes. For example, small streams with drainage areas of a few to several 10s of km^2 flood regardless of human activities, but human activities, such as paving the ground in cities, increase runoff and the magnitude and frequency of flooding. That is, after the paving, floods of a particular size are more frequent, and a particular rainstorm can produce a larger flood than before the paving. Therefore, to predict the long-range effects of flooding, we must be able to determine how future human activities will change the size and frequency of floods. In this case, *the present is the key to the future*. For example, when environmental geologists examine recent landslide deposits Figure 1.11 in an area designated to become a housing development, they must use uniformitarianism to infer where there will be future landslides, as well as to predict what effects urbanization will have on the magnitude and frequency of future landslides. We will now consider linkages between processes.

FIGURE 1.11 Urban development The presence of a landslide on this slope suggests that the slope is not stable and further movement may occur in the future. This is a "red flag" for future development in the area. *(Edward A. Keller)*

Environmental Unity The principle of **environmental unity**, which states that one action causes others in a chain of actions, is an important principle in the prediction of changes in the Earth system. For example, if we constructed a dam on a river, a number of changes would occur. Sediment that moved down the river to the ocean before construction of the dam would be trapped in the reservoir. Consequently, beaches would be deprived of the sediment from the river, and the result of that deprivation may be increased coastal erosion. There being less sediment on the beach may also affect coastal animals such as sand crabs and clams that use the sand. Thus, building the dam would set off a chain or series of effects that would change the coastal environment and what lived there. The dam would also change the hydrology of the river and would block fish from migrating upstream. We will now consider global linkages.

Earth Systems Science **Earth systems science** is the study of the entire planet as a system in terms of its components (see *A Closer Look: The Gaia Hypothesis*). It asks how component systems (subsystems of the Earth system), such as the atmosphere (air), hydrosphere (water), biosphere (life), and lithosphere (rocks), are linked and have formed, evolved, and been maintained. It also explores how these components function, and how they will continue to evolve over periods ranging from a decade to a century and longer.[14] Because these systems are linked, it is also important to understand and be able to predict the impacts of a change in one component on the others.

The challenge is to learn to predict changes likely to be important to society and then to develop management strategies to minimize adverse environmental impacts. For example, the study of atmospheric chemistry suggests that our atmosphere has changed over millennia. Trace gases, such as carbon dioxide, have increased by about 100 percent since 1850. Chlorofluorocarbons (CFCs), used as refrigerants and aerosol-can propellants and released at the surface, have migrated to the stratosphere, where they react with energy from the Sun, causing destruction of the ozone layer that protects Earth from harmful ultraviolet radiation. The important topics of global change and Earth systems science will be discussed in Chapter 16, following topics such as Earth materials, natural hazards, and energy resources.

Concept Four: Hazardous Earth Processes

There have always been Earth processes that are hazardous to people. These natural hazards must be recognized and avoided when possible, and their threat to human life and property must be minimized.

We humans, like all animals, have to contend with natural processes such as storms, floods, earthquakes, landslides, and volcanic eruptions that periodically damage property and kill us. During the past 20 years, natural hazards on Earth have killed several million people. The annual loss was about 150,000 people, and annual financial damages were about $20 billion.

Natural Hazards That Produce Disasters Are Becoming Superdisasters Called Catastrophes

Early in human history, our struggle with natural Earth processes was mostly a day-to-day experience. Our numbers were neither great nor concentrated, so losses from hazardous Earth processes were not significant. As people learned to produce and maintain a larger and, in most

A CLOSER LOOK

The Gaia Hypothesis

Is Earth Analogous to an Organism? In 1785, at a meeting of the prestigious Royal Society of Edinburgh, James Hutton, the father of geology, said he believed that planet Earth is a superorganism (Figure 1.B). He compared the circulation of Earth's water, with its contained sediments and nutrients, to the circulation of blood in an animal. In Hutton's metaphor, the oceans are the heart of Earth's global system, and the forests are the lungs.[13] Two hundred years later, British scientist and professor James Lovelock introduced the **Gaia hypothesis**, reviving the idea of a living Earth. The hypothesis is named for Gaia, the Greek goddess Mother Earth.

FIGURE 1.B Home Image of Earth centering on the North Atlantic Ocean, North America, and the polar ice sheets. Given this perspective of our planet, it is not difficult to conceive of it as a single large system. *(Leonello Calvetti/Stocktrek Images/Getty Images)*

The Gaia hypothesis is best stated as a series of hypotheses:

- ***Life significantly affects the planetary environment.*** Very few scientists would disagree with this concept.
- ***Life affects the environment for the betterment of life.*** This hypothesis is supported by some studies showing that life on Earth plays an important role in regulating planetary climate so that it is neither too hot nor too cold for life to survive. For example, it is believed that single-cell plants floating near the surface of the ocean partially control the carbon dioxide content of the atmosphere and, thereby, the global climate.[13]
- ***Life deliberately or consciously controls the global environment.*** There are very few scientists who accept this third hypothesis. Interactions and the linking of processes that operate in the atmosphere, on the surface of Earth, and in the oceans are probably sufficient to explain most of the mechanisms by which life affects the environment. In contrast, humans are beginning to make decisions concerning the global environment, so the idea that humans can consciously influence the future of Earth is not an extreme view. Some people have interpreted this idea as support for the broader Gaia hypothesis.

Gaia Thinking Fosters Interdisciplinary Thinking. The real value of the Gaia hypothesis is that it has stimulated a lot of interdisciplinary research to understand how our planet works. As interpreted by most scientists, the hypothesis does not suggest foresight or planning on the part of life but, rather, that natural processes are operating.

years, more abundant food supply, the population increased and became more concentrated locally. The concentration of population and resources also increased the impact that periodic earthquakes, floods, and other natural disasters had on humans. This trend has continued, so that many people today live in areas likely to be damaged by hazardous Earth processes or susceptible to the adverse impact of such processes in adjacent areas. An emerging principle concerning natural hazards is that, as a result of human activity (population increase and changing the land through agriculture, logging, mining, and urbanization), what were formerly disasters are becoming catastrophes. For example,

- Human population increase has forced more people to live in hazardous areas such as floodplains, steep slopes (where landslides are more likely), and near volcanoes.
- Land use transformations, including urbanization and deforestation, increase runoff and flood hazard and may weaken slopes, making landslides more likely.
- Burning vast amounts of oil, gas, and coal has increased the concentration of carbon dioxide in the atmosphere, contributing to warming the atmosphere and oceans. As a result, more energy is fed into hurricanes. The number of hurricanes has not increased, but the intensity and size of the storms have increased.

We can recognize many natural processes and predict their effects by considering climatic, biological, and geologic conditions. After Earth scientists have identified potentially hazardous processes, they have the obligation to make the information available to planners and decision makers who can then consider ways of avoiding or minimizing the threat to human life or property. Put concisely, this process consists of assessing the risk of a certain hazard in a given area and basing planning decisions on that risk assessment. Public perception of hazards also plays a role in the determination of risk from a hazard. For example, although they probably understand that the earthquake hazard in southern California is real, the residents who have never experienced an earthquake firsthand may have less appreciation for the seriousness of the risk of loss of property and life than do persons who have experienced an earthquake.

Concept Five: Scientific Knowledge and Values

The use of scientific inquiry to solve a particular environmental problem often provides a series of potential solutions consistent with the scientific findings. The chosen solution is a reflection of our value system.

What Is Science? To understand our discussion of scientific knowledge and values, let us first gain an appreciation for the conventions of scientific inquiry. Most scientists are motivated by a basic curiosity about how things work. Geologists are excited by the thrill of discovering something previously unknown about how the world works. These discoveries drive them to continue their work. Given that we know little about internal and external processes that form and maintain our world, how do we go about studying it? The creativity and insight that may result from scientific breakthroughs often begin with asking the right question pertinent to some problem of interest to the investigators. If little is known about the topic or process being studied, they will first try to conceptually understand what is going on by making careful observations in the field or, perhaps, in a laboratory. On the basis of his or her observations, the scientist may then develop a question or a series of questions about those observations. Next, the investigator will suggest an answer or several possible answers to the question. The possible answer is a **hypothesis** to be tested. The best hypotheses can be tested by designing an experiment that involves data collection, organization, and analysis. After collection and analysis of the data, the scientist interprets the data and draws a conclusion. The conclusion is then compared with the hypothesis, and the hypothesis may be rejected or tentatively accepted. Often, a series of questions or multiple hypotheses are developed and tested. If all hypotheses suggested to answer a particular question are rejected, then a new set of hypotheses must be developed. This method is sometimes referred to as the **scientific method**. The steps of the scientific method are shown in Figure 1.12. The first step of the scientific method is the formation of a question—in this case, "Where does beach sand come from?" In order to explore this question, the scientist spends some time at the beach. The scientist notices some small streams that flow into the ocean; he/she knows that the streams originate in the nearby mountains. The scientist then refines the question to ask specifically, "Does beach sand come from the mountains to the beach by way of streams?" This question is the basis for the scientist's hypothesis: Beach sand originates in the mountains. To test this hypothesis, the scientist collects some sand from the beach and from the streams and some rock samples from the mountains. He/she then compares their mineral content. The scientist finds that the mineral content of all three is roughly the same. He/she draws a conclusion that the beach sand does come from the mountains, and so accepts the hypothesis. If the hypothesis had proved to be wrong, the scientist would have had to formulate a new hypothesis. In complex geologic problems, multiple hypotheses may be formulated and each tested. This is the method of multiple working hypotheses. If a hypothesis withstands the testing of a sufficient number of experiments, it may be accepted as a **theory**. A theory is a strong scientific statement that the hypothesis supporting the theory is likely to be true but has not been proved conclusively. New evidence often disproves existing hypotheses or scientific theory; absolute proof of scientific theory is not possible. Thus, much of the work of science is to develop and test hypotheses, striving to reject current hypotheses and to develop better ones.

Laboratory studies and fieldwork are commonly used in partnership to test hypotheses, and geologists often begin their observations in the field or in the laboratory by taking careful notes. For example, a geologist in the field may create a *geologic map*, carefully noting and describing the distribution of different Earth materials. The map can be completed in the laboratory, where the collected material can be analyzed.

The important variable that distinguishes geology from most of the other sciences is the consideration of time (see the Geologic Time Scale, Table 1.1). Geologists' interest in Earth history over time periods that are nearly incomprehensible to most people naturally leads to some interesting questions:

- How fast are mountains uplifted and formed?
- How fast do processes of erosion reduce the average elevation of the land?
- How fast do rivers erode canyons to produce scenic valleys, such as Yosemite Valley and the Grand Canyon (Figure 1.13)?
- How fast do floodwaters, glaciers, and lava flows move?

As shown in Table 1.3 rates of geologic processes vary from a fraction of a millimeter per year to several kilometers per second. The fastest rates are more than a trillion times more than those of the slowest. The most rapid rates, a few kilometers per second, are for events with durations of a few seconds. For example, uplift of 1 m (3.3 ft.) during an earthquake may seem like a lot, but, when averaged over 1,000 years (the time between earthquakes), it is a long-term rate of 1 mm per year (0.039 in. per year), a typical uplift rate in forming mountains. Of particular importance to environmental geology is that human activities may accelerate the rates of some processes. For example, timber harvesting and urban construction remove vegetation, exposing soils and increasing the rate of erosion. Conversely, the practice of sound soil conservation may reduce rates.

What about Geologic Time? Humans evolved during the Pleistocene epoch (the last 1.65 million years), which is a very small percentage of the age of Earth (see Table 1.1). To help you conceptualize the geologic time scale, Figure 1.14 illustrates all of geologic time as analogous to yards on a football field. Think back to your high school days, when your

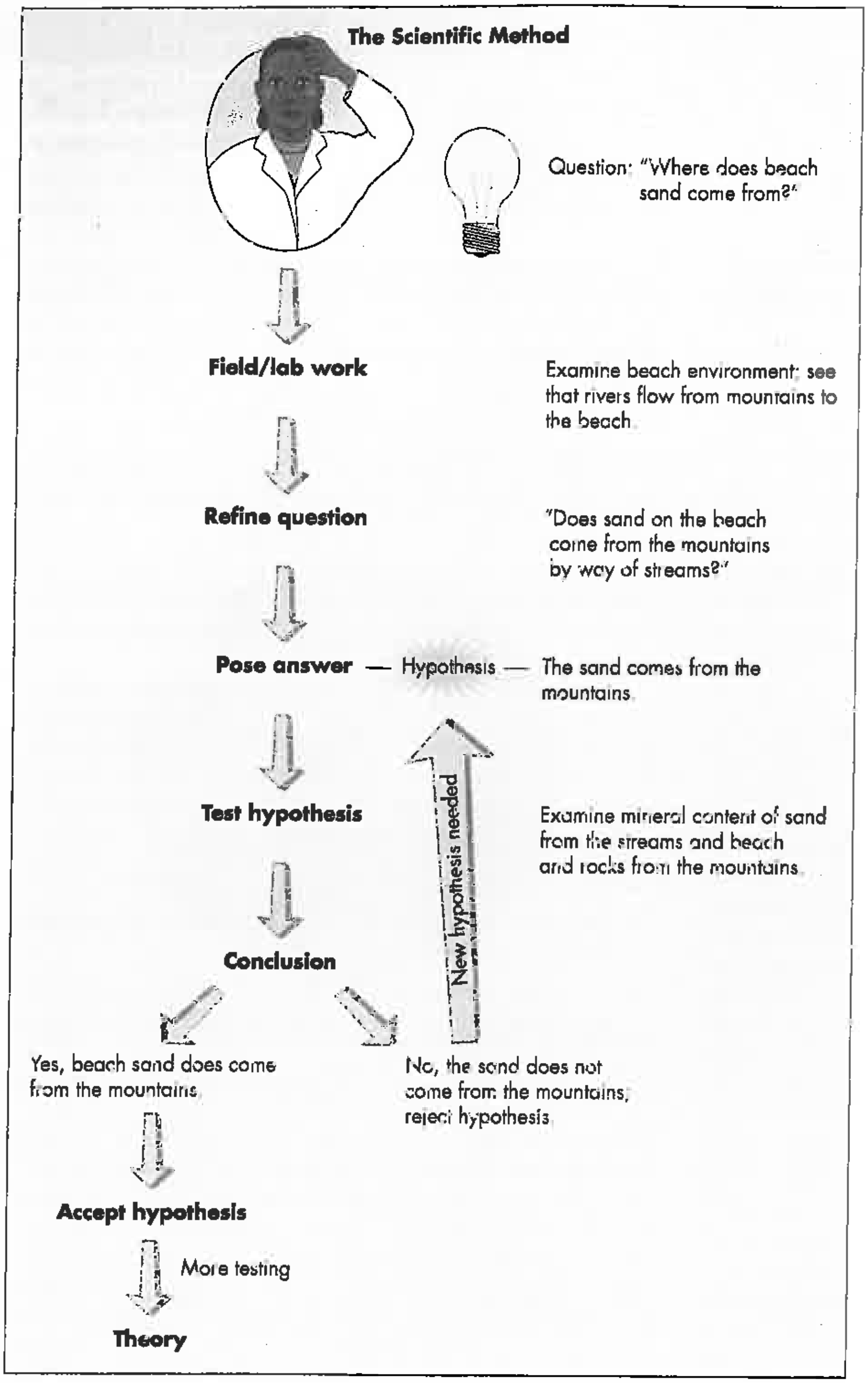

FIGURE 1.12 Science The steps in the scientific method.

star kick-off return player took it deep into your end zone. Assume that the 100 yard field represents the age of Earth (4.6 billion years), making each yard equal to 45 million years. As your star zigs and zags and reaches the 50-yard line, the crowd cheers. But, in Earth history, he has traveled only 2,250 million years and is still in a primitive oxygen-deficient environment. At the opponent's 45-yard line, free oxygen in the atmosphere begins to support life. As our runner crosses the 12-yard line, the Precambrian period comes to an end and life becomes much more diversified. At less than half a yard from the goal line, our star runner reaches the beginning of the Pleistocene, the most recent 1.65 million years of Earth history, when humans evolved. As he leaps over the 1-inch line and in for the touchdown, the corresponding period in Earth history is 100,000 years ago, and modern humans were living in Europe. Another way to visualize geologic time is to imagine that one calendar year is equal to the age of Earth, 4.6 billion years. In this case, Earth formed on January 1; the first oxygen in the atmosphere did not occur until July;

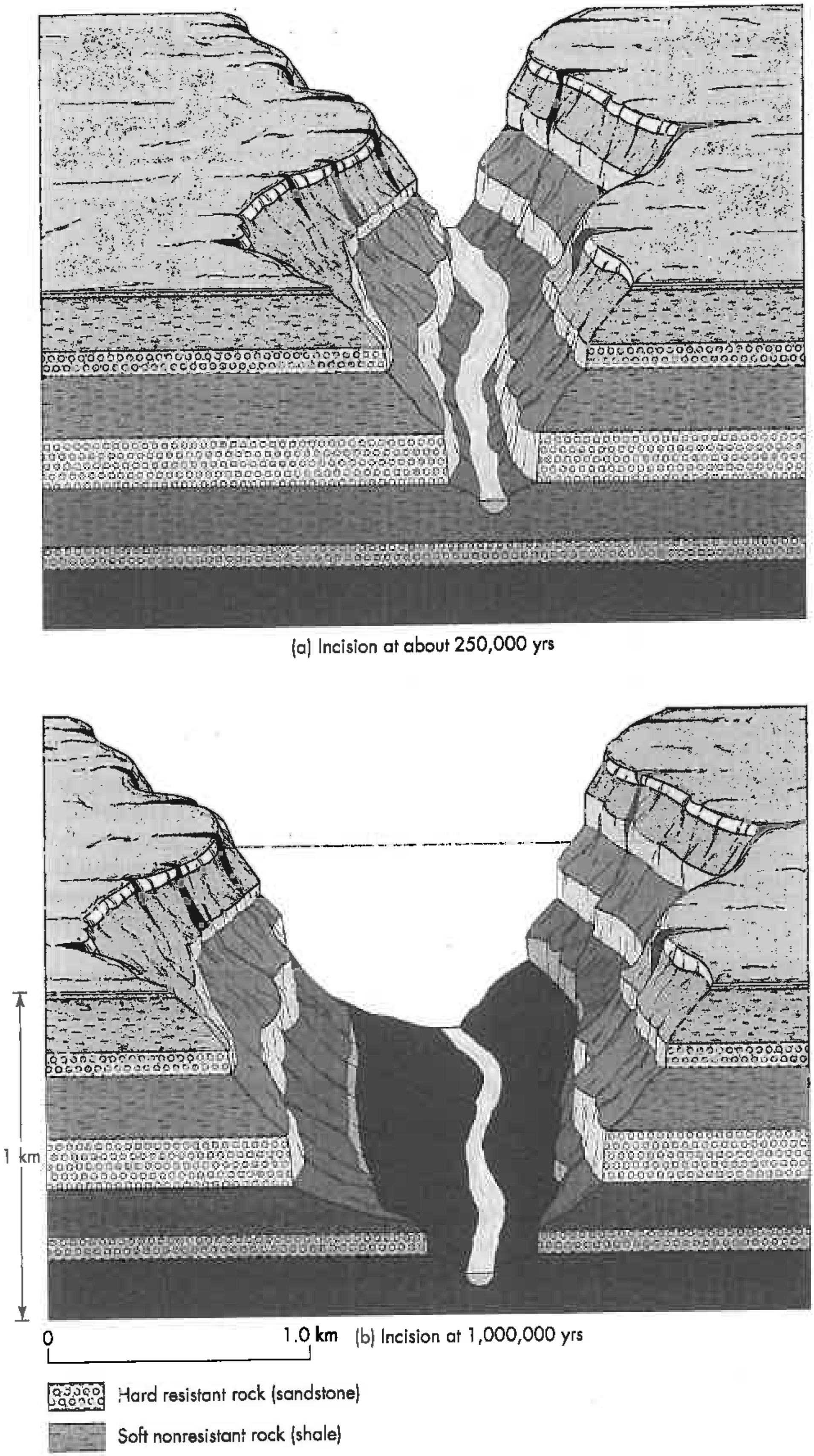

FIGURE 1.13 Eroding a valley Idealized diagram of progressive incision of a river into a sequence of horizontal rocks. The side slope is steep where rocks are hard and resistant to incision, and the rate of incision is generally less than about 0.01 mm per year (about 0.0004 in. per year). For softer rocks, where the side slope is gentle, the rate of incision may exceed 1 mm per year (0.039 in. per year). If the canyon incised about 1 km (0.62 mi) in 1 million years, the average rate is 1 mm per year (0.039 in. per year). *(Modified after King, P. B., and Schumm, S. A., 1980.* The Physical Geography of William Morris Davis. *Norwich, England: Geo Books)*

TABLE 1.3 Some Typical Rates of Geologic Processes

Slow Rates	■ Uplift that produces mountains. Generally, 0.5 to 2 mm per year (about 0.02 to 0.08 in. per year). Can be as great as 10 mm per year (about 0.39 in. per year). It takes (with no erosion) 1.5 million to 6 million years to produce mountains with elevations of 3 km (around 1.9 mi).
	■ Erosion of the land. Generally, 0.01 to 1 mm per year (about 0.004 to 0.039 in. per year). It takes (with no uplift) 3 million to 300 million years to erode a landscape by 3 km (about 1.9 mi). Erosion rates may be significantly increased by human activity such as timber harvesting or agricultural activities that increase the amount of water that runs off the land, causing erosion. Rates of uplift generally exceed rates of erosion, explaining why land above sea level persists.
	■ Incision of rivers into bedrock, producing canyons such as the Grand Canyon in Arizona. Incision is different from erosion, which is the material removed over a region. Rates are generally 0.005 to 10 mm per year (about 0.0002 to 0.39 in. per year). Therefore, to produce a canyon 3 km (around 1.9 mi) deep would take 300 thousand to 600 million years. The rate of incision may be increased several times by human activities such as building dams, because increased downcutting of the river channel occurs directly below a dam.
Intermediate Rates	■ Movement of soil and rock downslope by creeping in response to the pull of gravity. Rate is generally 0.5 to 1.2 mm per year (about 0.02 to 0.05 in. per year).
	■ Coastal erosion by waves. Generally, 0.25 to 1.0 m per year (0.82 to 3.28 ft per year). Thus, to provide 100 years' protection from erosion, a structure should be built about 25 to 100 m (about 82 to 328 ft) back from the cliff edge.
Fast Rates	■ Glacier movement. Generally, a few meters per year to a few meters per day.
	■ Lava flows. Depends on type of lava and slope. Generally, from a few meters per day to several meters per second.
	■ River flow in floods. Generally, a few meters per second.
	■ Debris avalanche, or flow of saturated earth, soil, and rocks downslope. Can be greater than 100 km (62 mi) per hour.
	■ Earthquake rupture. Several kilometers per second.

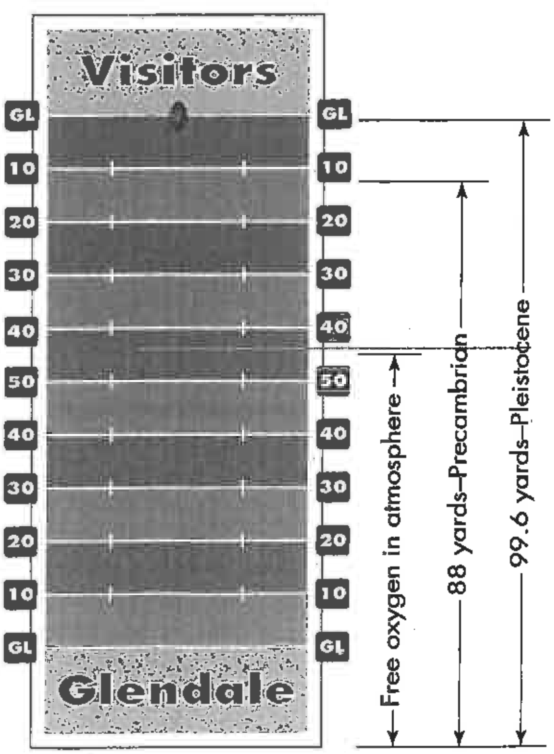

FIGURE 1.14 Time Geologic time as represented by a football field. See the text for further explanation.

and mammals did not make their appearance until December 18. The first human being arrived on the scene on December 31 at 6 P.M., and recorded history began only 48 seconds before midnight on December 31!

In answering environmental geology questions, we are often interested in the latest Pleistocene (the last 18,000 years), but we are most interested in the last few thousand or few hundred years of the Holocene epoch, which started approximately 10,000 years ago (see Appendix D, How Geologists Determine Time). Thus, in geologic study, geologists often design hypotheses to answer questions integrated through time. For example, we may wish to test the hypothesis that burning fossil fuels such as coal and oil, which we know releases carbon dioxide into the atmosphere, is causing global warming by trapping heat in the lower atmosphere. We term this phenomenon the greenhouse effect, which is discussed in detail in Chapter 16. One way to test this hypothesis would be to show that before the Industrial Revolution, when we started burning a lot of coal and, later, oil to power the new machinery of the time period, the mean global temperature was significantly lower than it is now. We would be particularly interested in the last few hundred to few thousand years, before temperature measurements were recorded at various spots around the planet as they are today. To test the hypothesis that global warming is occurring, the investigator could examine prehistoric Earth materials that might provide indicators of global temperature. This examination might involve studying glacial ice or sediments from the bottoms of the oceans or lakes to estimate past levels of carbon dioxide in the atmosphere. Properly completed, studies can provide conclusions that enable us to accept or reject the hypothesis that global warming is occurring.

Our discussion about what science is emphasizes that science is a process. As such, it is a way of knowing that constitutes a current set of beliefs based on the application of the scientific method and critical thinking. Science is not the only way a set of beliefs are established. Some beliefs are based on faith, but these, while valid, should not be confused with science. The famous Roman philosopher Cicero once concluded that divine providence, or, as we call it now, *intelligent design*, was responsible for the organization of nature and harmony that maintained the environment for all people. As modern science emerged and the process of science developed, other explanations emerged. These included explanations for biological evolution by biologists, the understanding of space and time by physicists, and the explanation that continents and ocean basins form through plate tectonics by geologists.

What is Critical Thinking? When we talk about the process of **critical thinking** in science we naturally consider the application of **intellectual standards** to our thinking process. A list of selected intellectual standards is shown on Table 1.4. The first standard is clarity. If you are not clear in what you write and talk about, you may not be understood or your ideas may be misinterpreted. Putting your argument in the correct time frame is particularly important for geological statements about topics such as the frequency of natural hazards or the development and use of energy and other resources (sustainability), which often have a variable time framework from geologic time 1000s to a few 100s thousands of years and longer, to prehistoric time, usually a few thousand to a few100s of years, to historic time, when the written record began, and, finally, to very recent time, a few decades or less. What assumptions did you make? Are the assumptions consistent with each other? Did you carefully check the calculations that you used to support your statement or argument? Did you gather your own data and come to your own conclusion? The latter is very important in the research you do. If you gather your own data and come to your own conclusions, you will be better prepared to defend your argument. Finally, did you use reliable sources for your information and cite sources of information correctly? Applying intellectual standards to any scientific problem and discussion will improve your thinking skills.

Culture and Environmental Awareness

Environmental awareness involves the entire way of life that we have transmitted from one generation to another. To uncover the roots of our present condition, we must look to the past to see how our culture and our political, economic, ethical, religious, and aesthetic institutions affect the way we perceive and respond to our physical environment.

An ethical approach to maintaining the environment is the most recent development in the long history of human ethical evolution. A change in the concept of property rights has provided a fundamental transformation in our ethical evolution. In earlier times, human beings were often held as property, and their masters had the unquestioned right to dispose of them as they pleased. Slaveholding societies certainly had codes of ethics, but these codes did not include the idea that people cannot be property. Similarly, until very

TABLE 1.4 Selected intellectual standards

- Clarity: If a statement is not clear, you can't judge whether it is relevant or accurate, and you may be misunderstood and your argument ignored.
- Assumptions: What assumptions are you making?
- Accuracy: Is a statement true? Can the statement be checked? How well does a measurement agree with the accepted value?
- Precision: Refers to degree of exactness to which something is measured. Can a statement or measurement be more specific, detailed, or exact?
- Relevance: Is a statement connected to the problem at hand?
- Depth: Did you adequately consider the complexities of a question?
- Breadth: Did you evaluate other points of view or examine it from a different perspective?
- Logic: Does a conclusion make sense and logically follow from the evidence?
- Significance: Is the problem an important one? Why? Why not?
- Timing: Did you present your statement or argument in the appropriate time framework (geologic, prehistoric, very recent, today)?
- Calculations: Did you check all the math?
- References: Did you use reliable sources?
- Conclusions: Did you gather your own data and come to your own conclusions?
- Fairness: Are there vested interests in the statement or argument and have other points of view been considered?

Modified after Paul, R., and L. Elder. 2003. Critical thinking. Dillon Beach, CA: The Foundation for Critical Thinking.

recently, few people in the industrialized world questioned the right of landowners to dispose of land as they please. Only within this century has the relationship between civilization and its physical environment begun to emerge as a relationship involving ethical considerations.

Environmental (including ecological and land) ethics involves limitations on social as well as individual freedom of action in the struggle for existence in our stressed environment. A **land ethic** assumes that we are responsible not only to other individuals and society, but also to the total environment, the larger community consisting of plants, animals, soil, rocks, atmosphere, and water. According to this ethic, we are the land's citizens and protectors, not its conquerors. This role change requires us to revere, love, and protect our land rather than allow economics to determine land use.[15] The creation of national parks and forests is an example of protective action based on a land ethic. Yellowstone National Park, in Wyoming and Montana, was the first national park in the United States, established in March 1872. Yellowstone led to the creation of other national parks, monuments, and forests, preserving some of the country's most valued aesthetic resources. Trees, plants, animals, and rocks are protected within the bounds of a national park or forest. In addition, rivers flow free and clean, lakes are not overfished or polluted, and mineral resources are protected. The ethic that led to the protection of such lands allows us the privilege of enjoying these natural areas and ensures that future generations will have the same opportunity. We will now change focus to discuss why solving environmental problems tends to be difficult and to introduce the emerging environmental policy tool known as the precautionary principle.

Why Is Solving Environmental Problems So Difficult?

Many environmental problems tend to be complex and multifaceted. They may involve issues related to physical, biological, and human processes. Some of the problems are highly charged from an emotional standpoint, and potential solutions are often vigorously debated.

There are four main reasons that solving environmental problems may be difficult:

- Expediential growth is often encountered. Expediential growth means that the amount of change may be happening quickly, whether we are talking about an increase or decrease.
- There are often lag times between when a change occurs and when it is recognized as a problem. If the lag time is long, it may be very difficult to even recognize a particular problem.
- An environmental problem involves the possibility of irreversible change. If a species becomes extinct, it is gone forever.
- The principle of environmental unity is almost always involved. It may be difficult to identify a chain of events in a problem solution.

Environmental policy links to environmental economics are in their infancy. That is, the policy framework to solve environmental problems is a relatively new arena. We are developing policies such as the precautionary principle and finding ways to evaluate the economics of gains and losses from environmental change. For example, how do you put a dollar amount on the aesthetics of living in a quality environment? What the analysis often comes down to is an exercise in values clarification. Science can provide a number of potential solutions to problems, but which solution we pick will depend upon our values.

Precautionary Principle

What Is the Precautionary Principle? Science has the role of trying to understand physical and biological processes associated with environmental problems such as global warming, exposure to toxic materials, and depletion of resources, among others. However, all science is preliminary, and it is difficult to prove relationships between physical and biological processes and link them to human processes. Partly for this reason, in 1992, the Rio Earth Summit on sustainable development supported the **precautionary principle**. The idea behind the principle is that when a potentially serious environmental problem exists, scientific certainty is not required in order to take a precautionary approach. That is, better safe than sorry. The precautionary principle thus contributes to the critical thinking on a variety of environmental concerns, such as, for example, the manufacture and use of toxic chemicals or burning huge amounts of coal as oil becomes scarcer. It is considered one of the most influential ideas for obtaining an environmentally just policy framework for environmental problems.[16]

The precautionary principle recognizes that scientific proof is not possible in most instances, and that management practices are needed to reduce or eliminate environmental problems which are believed to result from human activities. In other words, in spite of the fact that full scientific certainty is not available, we should still take cost-effective action to solve environmental problems.

The Precautionary Principle May Be Difficult to Apply One of the difficulties in applying the precautionary principle is the decision concerning how much scientific evidence is needed before action on a particular problem should be taken. This is a significant and often controversial question. An issue being considered has to have some preliminary data and conclusions but awaits more scientific data and analysis. For example, when considering environmental health issues related to burning coal, there may be an abundance of scientific data about air, water, and land pollution, but with gaps, inconsistencies, and other scientific uncertainties. Those in favor of continuing or increasing the use of coal may argue that there is not sufficient proof to warrant restricting its use. Others would argue that absolute proof of safety is necessary before a big increase in burning of coal is allowed. The precautionary principle, applied to this case, would be that lack of full scientific certainty concerning the use of coal should not be used as a reason for not taking, or postponing, cost-effective measures to reduce or prevent environmental degradation or heath problems. This raises the question of what constitutes a cost-effective measure. Determination of the benefits and costs of burning more coal compared to burning less, or treating coal more in order to clean up the fuel, should be done, but other economic analyses may also be appropriate.[16,17]

There will be arguments over what is sufficient scientific knowledge for decision making. The precautionary principle may be difficult to apply, but it is becoming a common part of the process of environmental analysis and policy when applied to environmental protection and environmental health issues. The European Union has been applying the principle for over a decade, and the City and County of San Francisco, in 2003, became the first government in the United States to make the precautionary principle the basis for its environmental policy.

Applying the precautionary principle requires us to use the principle of environmental unity and predict potential consequences of activities before they occur. Therefore, the precautionary principle has the potential to become a proactive, rather than reactive, tool in reducing or eliminating environmental degradation resulting from human activity. The principle moves the burden of proof of no harm from the public to those proposing a particular action. Those who develop new chemicals or actions are often, but not always, against the precautionary principle. The opponents often argue that applying the principle is too expensive and will stall progress. It seems unlikely that the principle will be applied across the board to potential environmental problems in the United States any time soon. Nevertheless, it will likely be invoked more often in the future. When the precautionary principle is applied, it must be in the context of an honest debate between all informed and potentially affected parties. The entire range of alternative actions should be considered, including taking no action.

Science and Values

We Are Creatures of the Pleistocene There is no arguing that we are a very successful species that, until recently, has lived in harmony with both our planet and other forms of life for over 100 thousand years. We think of ourselves as modern people, and certainly our grasp of science and technology has grown tremendously in the past several hundred years. However, we cannot forget that our genetic roots are in the Pleistocene. In reality, our deepest beliefs and values are probably not far distant from those of our ancestors who sustained themselves in small communities, moving from location to location and hunting and gathering what they needed. At first, this statement seems inconceivable and not possible to substantiate, considering the differences between our current way of life and that of our Pleistocene ancestors. But it has been argued that studying our Pleistocene ancestors, with whom we share nearly identical genetic information, may help us understand ourselves better.[18] That is, much of our human nature and, in fact, our very humanity may be found in the lives of the early hunters and gatherers and may explain some of our current attitudes toward the natural world. We are more comfortable with natural sounds and smells, such as the movement of grass where game is moving or the smell of ripe fruit, than with the shrill noise of horns and jackhammers and the smell of air pollution in the city. Many of us enjoy sitting around a campfire roasting marshmallows and telling stories about bears and rattlesnakes. We may find a campfire comforting, even if smoke stings our eyes, because our Pleistocene ancestors knew fire protected them from predators such as bears, wolves, and lions. If you want to liven up a campfire talk, start telling grizzly bear stories! We speculate that women may like their hand and shoulder bags and find them comforting in part because the gathering instinct is still with us. On the other hand, hunting and fishing are activities that men are more likely to participate in.

Children and people that are not connected to nature may suffer more from attention deficit and depression. Those who exercise outside in a natural setting, such as a forest, along a stream or lake, in the mountains or desert, on a beach, or in a city park are more relaxed and less anxious or angry than people who exercise only inside. In hospital, we tend to heal faster and spend a shorter time there when we can look out on a natural setting. Children regularly exposed to nature (local parks or even a group of trees) may be more self-confident, less anxious, do better in science, and interact (cooperate) with others in play or work in more positive ways.[19]

The solutions we choose to solve environmental problems depend upon how we value people and the environment. For example, if we believe that human population growth is a problem, then conscious decisions to reduce human population growth reflects a value decision that we as a society choose to endorse and implement. As another example, consider flooding of small urban streams (a stream is a small river, a subjective decision). Flooding is a hazard experienced by many communities. Studies of rivers and their natural processes leads to a number of potential solutions for a given flood hazard. We may choose to place the stream in a concrete box—a remedy that can significantly reduce the flood hazard. Alternatively, we may choose to restore our urban streams and their floodplains, the flat land adjacent to the river that periodically floods, as greenbelts. This choice will reduce damage from flooding, while providing habitat for a variety of animals including raccoons, foxes, beavers, and muskrats that use the stream environment; resident and migratory birds that nest, feed, and rest close to a river; and a variety of fish that live in the river system. We will also be more comfortable when interacting with the river. That is why river parks are so popular.

The coastal environment, where the coastline and associated erosional processes come into conflict with development, provides another example of the relation between science and values. Solutions to coastal erosion may involve defending the coast, along with its urban development, at all cost by constructing "hard structures" such as seawalls. Science tells us that the consequences from the hard solution