1 Philosophy and Fundamental Concepts

Statues at Easter Island. *(Tom Till/Tony Stone Images)*

Polynesian people first reached Easter Island approximately 1500 years ago. The small island is located several thousand kilometers west of South America and has a semi-arid climate. When the Polynesians first arrived, they were greeted by a green island covered with forest. By the sixteenth century, the 7000 people there had established a complex society spread among small villages that raised crops and chickens supplemented by fish from the ocean. The people carved massive 8-m-high statues from volcanic rock that were moved into place at various locations in the island using tree trunks as rollers. Europeans reached Easter Island in the seventeenth century, and the only symbols of the once-vibrant civilization were the statues.

The society evidently collapsed in just a few decades, probably the result of the degradation of the island's limited resource base. As the human population of the island increased, more and more land was cleared for agriculture while remaining trees were used for fuel and for moving the statues into place. The soils beneath the forest cover were protected and held water in the semi-arid environment, and soil nutrients were probably supplied from dust by thousands of miles away that reached the island with the winds. With the clearing of the forest, the soils eroded and the agricultural base of the society was diminished. Loss of the forest also resulted in loss of forest products necessary for building homes and boats, and, as a result, the people were forced to live in caves. They could no longer rely on fish as a source of protein. As population pressure increased, wars between villages became common, as did slavery and even cannibalism, in attempts to survive in an environment depleted of its resource base.

The story of Easter Island is a dark one that vividly points to what can happen when an isolated area is deprived of its resources through human activity. The lesson learned was that limited resources cannot support an ever-growing human population. There is fear today that our planet (an isolated island in space) may be reaching the same threshold that faced

LEARNING OBJECTIVES

In this chapter we discuss what environmental geology is and some aspects of culture and society that are particularly significant to environmental awareness. We also present some basic concepts of environmental science that provide the philosophical framework of this book. After reading this chapter you should be prepared to discuss:

- *What environmental geology is.*
- *What the scientific method is.*
- *The development of environmental ethics and, in particular, the emerging land ethic.*
- *Important factors contributing to the "environmental crisis."*
- *Why environmental problems transcend political and religious systems.*
- *Why the number-one environmental problem is increasing human population.*
- *The concept of sustainability, what a sustainable economy would look like and do, and why sustainability is the environmental objective of the future.*
- *Basic ideas of systems theory, including feedback, growth rates, and changes in systems.*
- *What earth system science is and how it is related to the Gaia hypothesis.*
- *The concept of uniformitarianism and why it is important to environmental geology.*
- *Why land- and water-use planning needs to balance economic considerations and less tangible variables such as aesthetics.*
- *How the cumulative impact of land use gives us a responsibility to future generations.*

Web Resources

Visit the "Environmental Geology" Web site at www.prenhall.com/keller to find additional resources for this chapter, including:

- Web Destinations
- On-line Quizzes
- On-line "Web Essay" Questions
- Search Engines
- Regional Updates

the people of Easter Island in the sixteenth century. As we move into the twenty-first century, we are facing limits of resources in a variety of areas, including soils, fresh water, forests, rangelands, and ocean fisheries. A big question from an environmental perspective and for the history of humans on earth is: Will we recognize limits of the earth's resources before it is too late to avoid the collapse of human society on a global scale? Today there are no more frontiers on the earth, and we have a nearly fully integrated global economy. The lesson from Easter Island is clear: develop a sustainable global economy that ensures the survival of our resource base and other living things on earth, or suffer the consequences.*

1.1 Introduction to Environmental Geology

Everything has a beginning and an end. Our earth began about 4.6 billion years ago when a cloud of interstellar gas known as a *solar nebula* collapsed, forming protostars and planetary systems. Life on earth began about 3 billion years ago, and since then multitudes of diverse organisms have emerged, prospered, and died out, leaving only their fossils to mark their place in earth's history. Just a few million years ago, our ancestors set the stage for the present dominance of the human species. As certainly as our sun will die, we too will eventually disappear. Viewed in terms of billions of years, our role in earth's history may be insignificant, but for us living now and for our children and theirs, our impact on the environment is significant indeed.

The place of humanity in the universe is well stated in the *Desiderata* (1): "You are a child of the universe, no less than the trees and the stars; you have a right to be here. And whether or not it is clear to you, no doubt the universe is unfolding as it should." Geologically speaking, we have been here for a very short time. Dinosaurs, for example, ruled the land for more than 100 million years. We do not know how long our own reign will be, but the fossil record suggests that all species eventually become extinct. How will the history of our own species unfold, and who will write it? We can hope that we will leave something more than some fossils marking a brief time in the record when *Homo sapiens* flourished. As we evolve, it is hoped that we will be more environmentally aware and find ways to live in harmony with our planet.

Environmental geology is applied geology. Specifically, it is the use of geologic information to help us solve conflicts in land use, to minimize environmental degradation, and to maximize the beneficial results of using our natural and modified environments. The application of geology to these problems includes the study of:

- *Natural hazards* (such as floods, landslides, earthquakes, and volcanic activity) in order to minimize loss of life and property.

*Source: Brown, L. R. and Flavin, C. 1999. A new economy for a new century. In *State of the world 1999*, ed. L. Stark, pp. 3–21. New York: W. W. Norton.

- *Landscapes* for site selection, land-use planning, and *environmental impact analysis*.
- *Earth materials* (such as minerals, rocks, and soils) to determine their potential use as resources or waste disposal sites and their effects on human health.
- *Hydrologic processes* of groundwater and surface water to evaluate water resources and water pollution problems.
- *Geologic processes* (such as deposition of sediment on the ocean floor, the formation of mountains, and the movement of water on and below the surface of the earth) to evaluate local, regional, and global change.

Considering the breadth of its applications, we can define environmental geology as the branch of earth science that studies the entire spectrum of human interactions with the physical environment.

The **environment** is the total set of circumstances that surround an individual or a community. It includes all of the physical conditions, such as air, water, gases, and landforms, that affect the growth and development of an individual or a community. It also includes the social and cultural conditions, such as ethics, economics, and aesthetics, that affect individual or communal behavior. Therefore, an introduction to environmental geology must consider not only the earth processes, resources, and structures described by earth scientists, but also the society and culture influencing how we perceive and react to our physical surroundings.

1.2 How Geologists Work: The Scientific Method

It's the thrill of discovery of something that was previously unknown about how the world works that excites geologists and drives them on in continued work. Most scientists are motivated by a basic curiosity of how things work. Creativity and insight that may result in scientific breakthroughs often start with asking the right question. Given that we know so little about how our world works, how do we go about studying it? Most studies start with identification of some problem of interest to the investigator. If little is known about the topic or process being studied, then the first step is to try to qualitatively understand what is going on. This involves making careful observations in the field or perhaps a laboratory. Based upon the observations, the scientist then may develop a question or series of questions about those observations. Next the investigator suggests an answer or several possible answers to the question or questions. These are hypotheses to be tested. The best **hypotheses** can be tested by designing an experiment that involves data collection, organization, and analysis. Following collection and analysis of the data it is interpreted and a conclusion may be drawn. 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. The above method is sometimes referred to as the **scientific method.** If a hypothesis withstands a sufficient number of experiments to test it, it may be accepted as a theory. A **theory** is a strong scientific statement that the hypothesis behind the theory is likely to be true but has not been conclusively proven. 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 develop better ones.

Geologists often begin their observations in the field or in the laboratory by taking careful notes about what they are observing. In field studies geologists may identify and describe the earth materials present and make maps to show how these materials are distributed at the surface of the earth.

The important variable that distinguishes geology from most of the other sciences is the consideration of time. Geologists are interested in earth history over time periods that are nearly incomprehensible to most people. The geologic time scale highlighting biological evolution is provided on the inside back cover of this book. Notice that humans evolved during the Pleistocene, in the last 1.65 million years, which is less than 0.05 percent of the age of the earth. In answering environmental geology questions we are often most interested in the latest Pleistocene (last 18,000 years) but most interested in the last few thousand or few hundred years of the Holocene, which started approximately 10,000 years ago. Thus in geologic study it is often the task of the geologist to design hypotheses to answer questions integrated through time. For example, we may wish to test the hypothesis that the burning of fossil fuels such as coal and oil is causing global warming. One way to test this would be to show that prior to the Industrial Revolution (when we started burning a lot of coal and later oil), the mean global temperature was significantly less. We might 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. In order to test the hypothesis that global warming is occurring, the investigator might examine prehistoric earth materials that might provide indicators of global temperature. This might involve studying glacial ice or sediments from the bottom of the ocean or lake. Properly completed, studies can provide information to test the hypothesis that global warming is occurring or to reject the hypothesis.

With our increased understanding of what environmental geology is and how geologists work, we will now consider some of the philosophical underpinnings of studying the environment and introduce fundamental concepts of environmental geology.

1.3 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 social institutions—political, economic, ethical, religious, and aesthetic—affect the way we perceive and respond to our physical environment.

To solve environmental problems such as overpopulation, disposal of hazardous waste, global warming, and resource depletion, we must look to the future. If our social institutions are to contribute to the solutions, fundamental changes in how society works at both the personal and institutional level will be necessary. The magnitude of this adjustment may be comparable to that of the Industrial Revolution, which changed the relationship between people and the environment by producing ever-increasing demands on resources and releasing ever-increasing quantities of toxic waste into the surroundings.

Global environmental concerns are now serious political issues requiring cooperative efforts by both industrial and developing countries. For example, we cannot expect South American nations to better manage the rain forest if the United States and other industrial countries continue to place heavy economic pressure on South America to export tremendous quantities of resources. How can we expect poor, developing societies to respect the environment when wealthier industrial societies remain largely unwilling to do so? Fortunately, public concern for the environment appears to be increasing; if so, we should begin to see real progress in finding political solutions to environmental problems.

1.4 Environmental Ethics

When statesman and conservationist Stewart Udall published *The Quiet Crisis* in 1963 (2), most people were unaware that resource depletion and environmental degradation were problems. Today we are all acutely aware of what Udall called "a crisis of survival." Our emerging environmental consciousness is changing our lifestyles, our institutions, and our ethics.

An ethical approach to the environment is the most recent development in the long history of human ethical evolution, which has included changes in our concept of property rights. 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 modern idea that people cannot be property. Similarly, until very recently, few people in the industrialized world questioned the right of landowners to dispose of land as they saw fit. 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 involve 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, namely the larger community consisting of plants, animals, soil, atmosphere, and so forth. According to this ethic, we are the land's citizens and protectors, not its conquerors. This role change requires us to revere and love our land rather than allow economics to determine all land use (see *A Closer Look: The Land Ethic and the American Experience*).

A land ethic affirms the right of all resources, including plants, animals, and earth materials, to continued existence and, at least in certain locations, continued existence in a natural state. This statement is sometimes interpreted as granting to individual plants and animals the fundamental right to live. That is an unrealistic interpretation, however, for if we are part of the environment we must extract from it the energy necessary to survive. Therefore, although the land ethic assigns animals such as deer, cattle, or chickens the right to survive as species, it does not necessarily assign rights to an individual deer, cow, or chicken. The same argument may be given to justify the use of stream gravel for construction material, or the mining and use of other resources necessary for our well-being. However, unique landscapes with high aesthetic value, such as endangered species, are in need of protection within our ethical framework.

Although widespread ecological awareness is a recent phenomenon, these ideas about the land ethic were expressed by Aldo Leopold nearly 50 years ago (3). Stewart Udall restated our moral responsibility to the land as follows: "Each generation has its own rendezvous with the land, for despite our fee titles and claims of ownership, we are all brief tenants on this planet. By choice or by default, we will carve out a land for our heirs. We can misuse the land and diminish the usefulness of resources, or we can create a world in which physical affluence and spiritual affluence go hand in hand" (2). The resounding message is that humanity is an integral part of the environment. We have a moral obligation to ensure that those who follow us also experience the pleasure of belonging to and cooperating with the entire earth community.

Environmental knowledge is increasing rapidly, and we are more aware than ever of environmental problems at local, regional, and global levels. This makes the field of environmental ethics an emerging subject of intense interest. Important topics in this field include ethical grounds for decision making, environmental racism and social justice, the value of landscape, moral relations with nonhumans, the rights of inanimate objects, and our obligations to future generations (4). If our response to environmental problems is based both on scientific knowledge and on a new perception of our kinship with the earth, we can develop policies that have profound beneficial effects on ourselves and the rest of the natural world.

1.5 The Environmental Crisis

The demands made on diminishing resources by a growing human population, along with the ever-increasing production of human waste, has produced what is popularly referred to as the **environmental crisis.** This crisis in America and 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 (5). Today the raid on resources continues on a global scale:

A CLOSER LOOK The Land Ethic and the American Experience*

Arriving in late fall of 1620, after two months on the stormy North Atlantic, 73 men and 29 women from the Mayflower confronted what seemed to them a wild and savage land. The colonists feared the wilderness, and they lacked the skills and knowledge they needed to adapt quickly to their new environment. Nevertheless, they brought three things that assured their eventual success in the New World. First, they brought a new technology. The Pilgrims reportedly did not even have a saw when they landed, but they did have the Iron Age skills necessary to ensure relentless subjugation of the land and its inhabitants. In the long run, the ax, gun, and wheel asserted their supremacy. Second, the colonists carried with them the social blueprints for remaking the New World. They knew how to organize work, use work animals, and sell their surplus to overseas markets. Third, they brought with them a concept of land ownership completely different from that of the Native Americans, whose bonds to the land were religious and based on kinship with nature rather than exclusive possession. The colonists' idea of ownership involved an absolute title to land, regardless of who actually worked the land or how far away the owner was. After the Native Americans were displaced, land use or abuse depended entirely on the attitude of the owner (2).

Today, America, as in its early years, suffers greatly from the **myth of superabundance.** This myth assumes that the land and resources in America are inexhaustible and that management of resources is therefore unnecessary. Stewart Udall writes that the land myth was instrumental in environmental degradation ever since the birth of land policy in the eighteenth century. Even young Thomas Jefferson, who in later life was to become aware of the value of conservation, said there was such a great deal of farmland that it could be wasted as he pleased.

Potentially damaging resource utilization, sometimes called the "raid on resources," in the western United States probably began with the mountain men and their beaver trapping in the 1820s. This was only the beginning; there followed the invention of machines that were capable of large-scale removal of resources and landscape alteration. The inventions included the sawmills that precipitated the destruction of the American forests, and the "Little Giant" hose nozzle that could tear up an entire hillside in the search for California gold. Hydraulic mining was finally outlawed in 1884. However, the effects of these damaging land-use practices are still visible today.

The seeds of conservation were planted in the latter part of the nineteenth century by men such as Secretary of the Interior Carl Schurz and geologist and explorer John Wesley Powell. Their messages concerning conservation of resources and land-use planning, although largely ignored when first introduced, today stand as landmarks in perceptive and innovative conservation.

The historical roots of our landscape heritage are full of lessons. We have learned the hard way that our resources are not infinite and that land and water management is necessary for meaningful existence. This conclusion has become even more significant over the years, as American society continues to urbanize and consume resources at an ever-increasing rate (2).

*Summarized in part from Stewart Udall, *The Quiet Crisis*. New York: Avon Books, pp. 25–27.

- Deforestation and accompanying soil erosion and water and air pollution occur on many continents (Figure 1.1).
- Mining of resources such as metals, coal, and petroleum wherever they occur produces a variety of environmental problems (Figure 1.2).
- Development of both ground and surface water resources results in loss and damage to many environments on a global scale (see *Case History: Aral Sea*).

▲ **FIGURE 1.1** Clear-cut timber harvesting exposes soils, compacting them and generally contributing to an increase in soil erosion and other environmental problems. (*Edward A. Keller*)

On a positive note, we have learned a great deal from the environmental crisis. We know a lot about the relationship of environmental degradation to resource utilization; many innovative plans have been and are being developed to lessen or eliminate environmental problems; and we have made real progress, particularly in developed countries, in reducing many environmental problems such as water pollution and management of hazardous waste.

To consider solutions, we must understand the nature and origins of the crisis. Some writers have suggested that a particular religion or culture or a specific economic or political system is responsible for the way people treat the land. However, such proposals cannot be rigorously defended. It is well known that Communist China and the formerly Communist countries of Eastern Europe have severe environmental problems, as do the capitalist United States and Western Europe (Figure 1.3). Some argue that the Judeo-

▲ **FIGURE 1.2** Large open pit mines such as this one east of Silver City, New Mexico, are necessary if we are to obtain resources. However, they do cause disturbance to the surface of the land and reclamation may be difficult or nearly impossible in some instances. (*Michael Collier*)

Christian heritage, which views nature as having been created to serve humankind, is responsible for Western attitudes toward the environment (7). However, prehistoric people also exploited and disrupted their land, as have ancient and modern peoples of both Eastern and Western religions. Although the ideals of some cultures may suggest that land is sacred, there is a considerable gap between ethical ideals and actual land-use practices (5,8).

Because environmental degradation apparently transcends both political systems and religious beliefs, we must look further for the primary cause of our present condition. A more satisfactory explanation holds that environmental problems are the natural result of human inventiveness and that they began when people first used tools to better their chances for survival. Each innovation expanded the niche of *Homo sapiens* in a harsh world and assured that everyone who followed had an easier time. A pattern of development emerged in which innovation led to a larger population, which placed greater demands on resources and also demanded more innovation. This spiral has continued to the present, when there are signs that we are on a collision course with our environment.

The situation we seem headed for may be analogous to what happens to deer when, through our artificial management, their numbers exceed the carrying capacity of the land. Deprived of their natural enemies, these "artificial deer" increase in numbers until they have eaten all available food, causing a serious shortage of winter feed and decreased reproduction of food plants for the following spring. Everything from wildflowers to trees is gradually impoverished, and the deer either become dwarfed from malnutrition or starve (3). Are we, with our increasingly artificial environment, doing to ourselves what we have sometimes done to the deer? It is important at this juncture to acknowledge that science must be part of the solution and not part of the problem. The explosion of deer populations occurred because environmental factors controlling population growth were not understood and therefore not applied to managing the herds. Solving environmental problems begins with understanding the science of the problem.

▲ **FIGURE 1.3** Foaming pollutants on a stream near Zabrze, Poland. Zabrze is one of the Polish towns that has experienced some of the worst industrial pollution in Eastern Europe. (*Simon Fraser/Science Photo Library/Photo Researchers, Inc.*)

1.6 Fundamental Concepts of Environmental Science

In the rest of this chapter we discuss some fundamental concepts of environmental science in general and environmental geology in particular. The eight concepts presented here do not constitute a list of everything that is important to environmental scientists, and they are not meant to be memorized. However, understanding the general thesis of each concept will help you to understand and evaluate the philosophical and technical material presented in the rest of the text.

CONCEPT ONE: Population Growth

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

The number-one environmental problem is the ever-growing human population. The well-known human ecologist Garrett Hardin has stated that the total environmental impact of

CASE HISTORY Aral Sea

Water diversion for agriculture in what was the southern USSR has nearly eliminated the Aral Sea in a period of only 30 years. A potential tourist vacation spot in 1960, it is now a dying sea surrounded by thousands of square kilometers (km^2) of salt flats, and the change is permanently damaging the economic base of the region.

The area of the Aral Sea in 1960 was about 67,000 km^2. Diversion of the two main rivers that fed the sea has resulted in a drop in surface elevation of more than 20 m and loss of about 28,000 km^2 of surface area (Figure 1.A). Towns that were once fishing centers on the shore of the sea are today about 30 km inland. Loss of the sea's moderating effect is changing the regional climate: The winters are now colder and the summers warmer. Windstorms pick up salty dust and spread it over a vast area, damaging the land and polluting the air.

The lesson of the Aral Sea is how quick regional change from environmental damage can be. Many worry that what people have done to the Aral region is symptomatic of what we are doing on many fronts on a global scale (6).

(a)

(b)

▲ **FIGURE 1.A** (a) The Aral Sea is a dying sea, surrounded by thousands of square kilometers of salt flats. (*Courtesy of Philip P. Micklin*) (b) Water diversion for agriculture has nearly eliminated the sea. The two ships shown here are stranded high and dry along the shoreline, which contains extensive salt flats formed as the Aral Sea has evaporated in recent years. (*David Turnley/Black Star*)

population is equal to the product of the impact per person times the population. 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 (Figure 1.4).

Overpopulation has been a problem in some areas for at least several hundred years, but it is now apparent that it is becoming a global problem. From 1830 to 1930, the world population doubled from 1 billion to 2 billion people. By 1970, it had nearly doubled again, and by the year 2000, it is expected that there will be about 6.2 billion people on earth. By the middle of the next century there will probably be 10 billion to 15 billion inhabitants on earth! The problem is sometimes called the *population bomb*, because the **exponential growth** of the human population results in the explosive increase shown in Figure 1.5. Exponential growth means that the number of people added to the population each year is not constant; rather, it is a constant percentage of the current population.

▲ **FIGURE 1.4** Korem Camp, Ethiopia, in 1984. Hungry people forced to flee their homes as a result of political/military activity 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*)

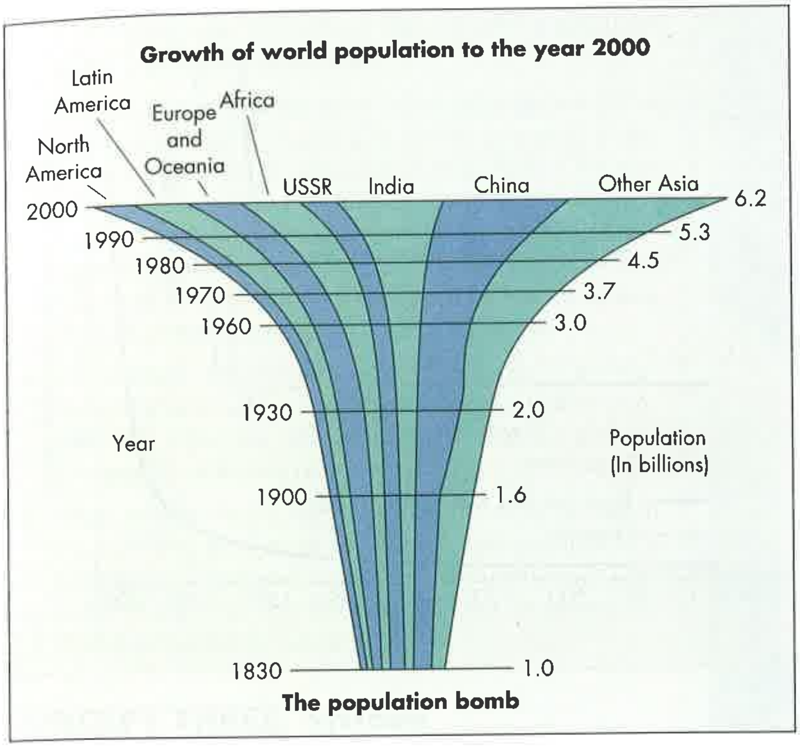


FIGURE 1.5 The population bomb. (*Modified after* U.S. *Department of State*)

As an extreme example of exponential growth (Figure 1.6a), consider the student who, upon taking a job for one 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 eight days to earn a wage of more than $1 per day, and by the eleventh day, earnings would be more than $10 per day. Payment for the sixteenth 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—1.4 percent annually today—but even this slower exponential growth eventually results in a dramatic increase in numbers (Figure 1.6b). Exponential growth will be discussed further under Concept Three, when we consider systems and change.

Because the world's population is increasing exponentially, many scientists are concerned that it will be impossible to supply resources and a high-quality environment for the billions of people who may be added to the global population in the twenty-first century. 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.

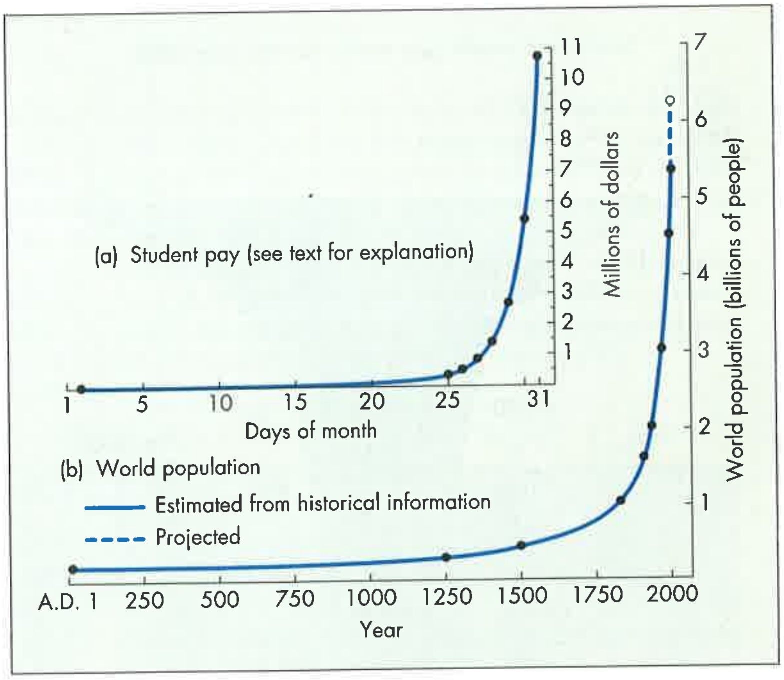
The population problem has no easy answer. In the future we may be able to mass produce enough food from a nearly landless agriculture to support our ever-growing numbers. However, this does not solve the problems of the space available to people and the quality of their lives. Some studies suggest that the present population is already over a comfortable carrying capacity for the planet (the maximum number of people the 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.

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. Pessimistic scientists believe that population growth will take care of itself through disease and other catastrophes, such as famine. Optimistic scientists hope 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.

CONCEPT TWO: Sustainability

Sustainability is the environmental objective.

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,



▶ **FIGURE 1.6** 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 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*)

oil, and groundwater without sufficient 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. **Sustainability** is something that we are still struggling to define. Some would define it as ensuring that future generations have equal opportunity to the resources that our planet offers. Others would argue that sustainability refers to types of development that are economically viable, do not harm the environment, and are socially just.

The environmental statement of the 1990s was "save our planet." Is earth's very survival really in danger? In the long view of planetary evolution, it seems highly likely that planet earth will survive us. Our sun is likely to last another several billion years at least, and if all humans became extinct in the next few years, life would still flourish on our planet. The changes we have made in the landscape, the atmosphere, and the waters might last for a few hundreds or thousands of years, but they would eventually be cleansed by natural processes. What we are concerned with, as environmentalists, is the quality of the *human* environment on earth.

As a result of thinking about the quality of the environment, we have begun to consider what is sometimes called the **sustainable global economy.** By *economy*, environmentalists mean the careful management and wise use of the planet and its resources, analogous to the management of money and goods considered by economists. By focusing on the concept of a sustainable global economy, we are assuming that under present conditions the global economy is *not* sustainable. In this view, increasing numbers of people have resulted in pollution of the land, air, and water to such an extent that the ecosystems upon which people depend are in danger of collapse.

How might we define a sustainable global economy? Such an economy might have the following attributes (9):

- Populations of humans and other organisms in harmony with the natural support systems such as air, water, and land (including ecosystems).
- An energy policy that does not pollute the atmosphere, cause climatic perturbations such as global warming, or present unacceptable risk (a political or social decision).
- A utilization plan for renewable resources such as water, forests, grasslands, agricultural lands, and fisheries that does not deplete the resources or destroy ecosystems.
- A resource utilization plan for nonrenewable resources that doesn't damage the global environment and provides for a share of our nonrenewable resources to be available to future generations.
- A social, legal, and political system dedicated to a sustainable and socially just global economy, with a democratic mandate to produce such an economy.

Recognizing the fact that population is the environmental problem, we should keep in mind that a sustainable global economy will not be constructed around a completely stable global population. Rather, such an economy requires a balance-of-nature approach, in which the size of the human population fluctuates (within some stable range) as necessary to maintain its desired relationship to other components of the environment.

To achieve a sustainable global economy, it is necessary that (9):

- We develop an effective population-control strategy. This will require considerable education of people in developing countries, since literacy and population growth are inversely related.

- We completely restructure our energy programs. It has been argued that a sustainable global economy is impossible if it is based upon use of fossil fuels. Our new energy plans will have to consider the concept of an integrated energy policy with a much greater emphasis upon renewable energy sources (such as solar and wind). Above all, conservation of energy must have a central place in our management of energy resources.
- We institute economic planning, including development of a tax structure that encourages population control and wise use of resources. Financial aid for developing countries is also necessary.
- We institute social, legal, political, and educational changes that have as their goal the maintenance of a quality local, regional, and global environment. This must be a serious commitment that the peoples of the world cooperate to achieve.

CONCEPT THREE: Systems

Understanding the earth's systems and their changes is critical to solving environmental problems. The earth itself is an open system with respect to energy, but essentially a closed system with respect to materials.

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 1.7). Most systems contain component parts that mutually adjust, so that changes in one part brings about changes in the others.

▲ **FIGURE 1.7** Landsat image showing the Amazon River (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 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 disturbances, such as roads or other human activity. (*Earth Satellite Corporation/Science Photo Library/Photo Researchers, Inc.*)

The Earth as a System The earth may be considered a system with four parts: the **atmosphere** (air); the **hydrosphere** (water); the **biosphere** (life); and the **lithosphere** (rock, soil). The mutual interaction of these parts is responsible for the surface features of the earth today. Any change in the magnitude or frequency of processes in one part causes changes in the other parts.

This propensity for coordinated change in the various parts of the environment is known as the **principle of environmental unity.** Put more simply, this principle says that everything affects everything else. For example, an increase in the magnitude of the processes that uplift mountains may affect the atmosphere by causing regional changes in precipitation patterns as a new rain shadow is produced. This in turn affects the local hydrosphere as more or less runoff reaches the ocean basins. Biospheric changes as a result of changes in the environment (such as change in types of plants and animals present) also can be expected. Eventually, the steeper slopes will also affect the lithosphere: Increased erosion will change the rate and types of sediments produced and thus the types of rocks created from the sediments.

These interactions among the variables in systems are not random. We can understand them by examining each variable to determine how it interacts with other variables and how it varies spatially over a site, area, or region. The spatial distribution of the oceans affects the amount of sunlight they receive, which affects the amount of evaporation that occurs in each region. These changes in the hydrosphere in turn affect atmospheric conditions by increasing or decreasing the amount of water in the atmosphere. We know that the earth is not static; rather, it is a dynamic, evolving system in which material and energy are constantly changing. Such dynamics suggest that the earth is an **open system,** that is, one that exchanges energy or material with its surroundings. This is certainly true with respect to energy, since the earth receives energy from the sun and radiates energy back into space.

There is also some exchange of matter between earth and its surroundings: Meteors fall to earth, and a small amount of earth material escapes into space as gas. However, most of the earth's material is continuously recycled within the system. When we consider natural cycles such as the water and rock cycles, we can best think of the earth as a **closed system** or, more accurately, a coalition of many closed systems (10). The rain that falls today will eventually return to the atmosphere, and the sediment deposited yesterday will be transformed into solid rock. We will discuss the water and rock cycles in Chapter 2.

Feedback **Feedback** is a system response in which output of the system (something happening) is an input (back into the system) causing change. There are two types of feedback in systems, called *negative* and *positive*. In **negative feedback,** the outcome moderates or decreases the process, inducing the system to approach a steady state. For example, imagine a river that maintains a certain width, volume, and velocity of flow. The river channel and banks are a type of open system called a *steady-state system*; that is, water flows through the system, but there is no net change. If the width, volume, and velocity of water increase (in response to increased regional rainfall or changes caused by urbanization), the increased flow may erode the river banks, causing the channel to widen. This widening allows the larger volume of water to flow more slowly again, so that a new steady state is established.

In **positive feedback,** often called the *vicious cycle*, the outcome of a change amplifies the initiating event, which in turn amplifies the outcome, and so on. For example, off-road vehicle use (Figure 1.8) may set a positive feedback cycle into motion by uprooting plants on a slope. Loss of the plants increases erosion, which causes still more plants to be lost, which further increases erosion. Eventually an area intensively used by off-road vehicles may be nearly denuded of all vegetation and have a very high erosion rate.

Growth Rates Because growth is an important change in many systems, we must understand something about growth rates. Exponential growth, described under Concept One, is particularly significant to the systems with which we are concerned. Consider again Figure 1.6, which illustrates two examples of exponential growth. In each case, the thing being considered (student pay or world population) increases quite slowly at first, then begins to increase more rapidly—and then very rapidly.

▲ **FIGURE 1.8** Off-road vehicle trails on this slope have caused extensive soil erosion. The site is a managed off-road vehicle park in the western Transverse Ranges of California. (Edward A. Keller)

There are two important measures of exponential growth:

- The **growth rate** measured as a percentage.
- The **doubling time.**

As already stated, exponential growth is characterized by a constant percent increase; for example, a population might be increasing at a rate of 2 percent per year, so that the number of individuals added annually is greater than the number added the year before. *Doubling time* is the time necessary for the quantity of whatever is being measured to double. A rule of thumb is that doubling time is roughly equal to 70 divided by the growth rate. Using this approximation, we find that a population with a 2 percent annual growth rate would double in about 35 years. Exponential growth assuming constant growth rate is not difficult to calculate and allows for important environmental questions to be addressed (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. In particular, we need to recognize exponential growth with positive feedback, for positive feedback cycles may be very difficult to stop. For example, we are having a very difficult time controlling (stopping) the growth of earth's human population.

Predicting Changes in Systems Some changes in natural systems are predictable, and anyone looking for solutions to environmental problems must be able to recognize systems in which predictable change takes place. Recognizing positive and negative feedback systems and calculating growth rates are important in making predictions concerning resource management. In addition, we need to understand how the input and output of a system affect the supply of a given resource and how all of these factors affect natural cyclical processes. In this discussion of changes in systems, we will begin with some of the methods used for analyzing simple systems or portions of systems, then examine the complex changes that take place on a larger scale.

Input-output analysis is an important method for analyzing change in open systems—that is, in systems with an input and output of materials or energy. 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 are brought in as freshmen and graduated four years later at a constant rate. Thus, the pool of university students remains a constant size. Our planet is a roughly steady-state system with respect to energy: Incoming solar radiation is roughly balanced by outgoing radiation from the 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, or the harvest of certain plants or animals. If the input is much less

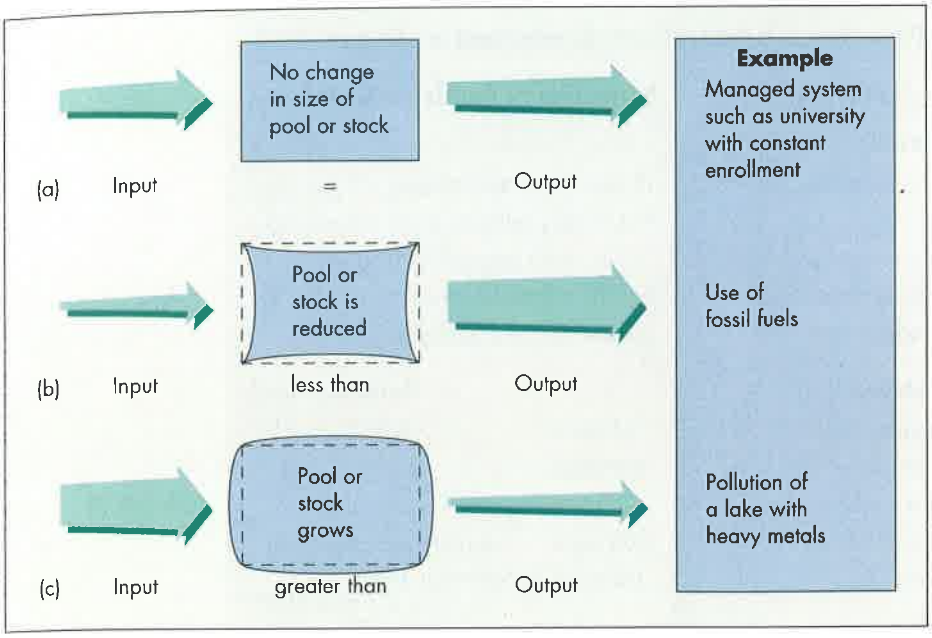


FIGURE 1.9 Major ways in which a pool or stock of some material may change. (*Modified after* P. R. Ehrlich, A. H. Ehrlich, *and* J. P. Holdren. 1977. Ecoscience: Population, Resources, Environment, *3rd ed.* W. H. Freeman)

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 where input exceeds output (Figure 1.9c), the stock of whatever is being measured will increase. Examples are the buildup of heavy metals in lakes or the pollution of soil and water.

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 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 (assuming constant size of the system and constant rate of transfer), we simply take the total size of the stock and divide it by the average rate of transfer through the system. For example, if a reservoir holds 100 million cubic meters (m^3) of water and both the average input from streams entering the reservoir and the average output over the spillway are 1 m^3/sec, then the average residence time for a cubic meter of water in the reservoir is 100 million seconds, or about 3.2 years. 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, knowing this, apply the information to developing sound management principles.

Rates of change and input-output analysis help us follow materials through their natural cycles. As more and more demands are made on the earth and its limited resources, it becomes increasingly important for us to understand the magnitude and frequency of the processes that maintain these cycles. For instance, if we hope to manage the water resources of a region, we must know the nature and extent to which natural processes will supply groundwater and surface water. Or, if we are concerned with getting rid of dangerous chemicals in a disposal well, we must know how the procedure will interact with natural cycles to ensure that we or our heirs will not be exposed to hazardous chemicals. This becomes especially critical in dealing with radioactive wastes, which must be contained for periods ranging from several centuries to as long as a quarter of a million years. Therefore, it is exceedingly important to recognize earth cycles and determine the length of time involved in various parts of specific cycles. Table 1.1 lists the residence times of selected earth materials, and Table 1.2 gives the rates of some natural processes.

Complex Systems and Earth System Science So far we have dealt with ways of analyzing small portions of the environment, but ecologists also deal with larger natural systems, including the earth itself. The common expression **"balance of nature"** describes an early model for change in natural systems. According to this model, natural systems untampered with by human activity tend toward some sort of equilibrium. We gave an example of this tendency earlier when we talked about a river channel adapting to an increased volume of water. Although many parts of the environment do tend toward an equilibrium due to negative feedback, it is worthwhile to ask how accurate and how widely applicable the equilibrium model really is. As we look at natural systems for longer periods and in greater detail, we find that equilibrium is seldom obtained or maintained for a very long time. Instead, changes in systems are best described in terms of **complex response, thresholds,** and **disturbance.**

Consider a river system that periodically experiences floods. A large flood can be viewed as a disturbance within the river system that can cause considerable change to both the physical and biological environment. Usually, however, a flood must be of a certain magnitude before change occurs. For example, the banks of a river are often composed of sand, gravel, silt, and clay, bound together by the frictional and cohesive forces of these materials as well as by roots of

Table 1.1 Residence times of some selected materials

Earth Materials	Some Typical Residence Times
Atmosphere circulation	
Water vapor	10 days (lower atmosphere)
Carbon dioxide	5 to 10 days (with the sea)
Aerosol particles	
Stratosphere (upper atmosphere)	Several months to several years
Troposphere (lower atmosphere)	One week to several weeks
Hydrosphere circulation	
Atlantic surface water	10 years
Atlantic deep water	600 years
Pacific surface water	25 years
Pacific deep water	1300 years
Terrestrial groundwater	150 years (above 760 m depth)
Biosphere circulation[a]	
Water	2,000,000 years
Oxygen	2000 years
Carbon dioxide	300 years
Seawater constituents[a]	
Water	44,000 years
All salts	22,000,000 years
Calcium ion	1,200,000 years
Sulfate ion	11,000,000 years
Sodium ion	260,000,000 years
Chloride ion	Infinite

[a]Average time it takes these materials to recycle within the atmosphere and hydrosphere.

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the plants growing on the banks. Erosion of the banks will not occur unless the power of the moving floodwaters exceeds the resistance of the banks.

We may look upon the resistance of the banks as a threshold that, if crossed, will result in change—in this case, bank erosion. Suppose that a high-magnitude storm occurs in the headwater portions of a large river system. The threshold of bank erosion is crossed and erosion occurs, carrying materials from the slopes and river banks to the lower part of the river system. If the lower part of the river is unable to carry all of the sediment delivered, deposition occurs. Thus, in the upper part of the drainage system erosion is the predominant process, whereas deposition predominates downstream. Because of these differences, the eroded channel upstream behaves differently in later storms from the downstream area where deposition occurred. This is an example of complex response, which is characterized by changes in a system brought about by internal processes in the system itself.

Thus, changes in systems are not necessarily related to maintaining a balance or equilibrium. Rather, they are often complex, depending upon disturbance and crossing of thresholds. The lesson to be learned is that disturbance in natural systems is common and probably necessary for the systems to function and provide diversity in the physical and biological environments. That is, a flood may change the shape of a river channel (scouring pools, for example) that produces more physical diversity in habitat for fish and other aquatic life. The more-diverse physical habitat encourages a larger diversity in the plants and animals living in the river. Furthermore, human activity is only one type of disturbance. Events such as hurricanes, floods, wildfire (Figure 1.10), volcanic eruptions, and earthquakes also cause natural systems to change in complex ways as thresholds of change are exceeded.

Earth system science is an emerging field of study that attempts to understand the entire planet in terms of its systems. It asks how components such as the atmosphere,

Table 1.2 Rates of some natural processes

Earth Processes	Some Typical Rates
Erosion	
Average U.S. erosion rate[a]	6.1 cm per 1000 years
Colorado River drainage area	16.5 cm per 1000 years
Mississippi River drainage area	5.1 cm per 1000 years
N. Atlantic drainage area	4.8 cm per 1000 years
Pacific slope (California)	9.1 cm per 1000 years
Sedimentation[b]	
Colorado River	281 million metric tons per year
Mississippi River	431 million metric tons per year
N. Atlantic coast of U.S.	48 million metric tons per year
Pacific slope (California)	76 million metric tons per year
Tectonism	
Seafloor spreading	
N. Atlantic	2.5 cm per year
E. Pacific	7 to 10 cm per year
Faulting	
San Andreas (California)	1 to 5 cm per year
Mountain uplift	
Cajon Pass, San Bernardino Mts. (California)	1 cm per year

[a]Thickness of the layer of surface of the continental United States eroded per 1000 years.
[b]Includes solid particles and dissolved salts.

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(a)

(b)

▲ **FIGURE 1.10** (a) Aerial view of burned forest land from the 1988 Yellowstone National Park fire along the Firehole River. The steam is from geysers and hot springs. Note the sharp line between the burned, brown forest and the unburned, green forest. (*Michael Collier*) (b) Carpets of wildflowers that emerged following the Yellowstone fire are part of the natural recovery. (*Jack W. Dykinga*)

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 human population is shown on Figure 1.6.

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

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

where N is the future value of whatever is being evaluated; N_o 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. This equation may be solved utilizing a simple hand calculator, and a number of interesting environmental questions may be asked. 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 6.2 billion and the population is growing at a constant rate of 1.36 percent per year (0.0136 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 is 6.2 billion in the year 2000 and that the growth rate is 1.36 percent per year, then we can estimate the world population for the year 2020 by applying the equation above:

N (world population in 2020) = $(6.2\times10^9)(e^{(0.0136 \times 20)})$

$N = (6.2\times10^9)(e^{0.272}) = (6.2\times10^9)(2.71828^{0.272})$

N (population projected to year 2020 based upon the above assumptions) = 8.14×10^9, or 8.14 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:

$$t = (1/k)\, ln(N/N_o)$$

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 state the question that if the population growth remains constant at 1.36 percent per year and the population in the year 2000 is 6.2 billion people, in what year will it reach 8.14 billion? Substituting in the above equation $t = (1/0.0136)\, ln\, (8.14\times10^9/6.2\times10^9)$. Solving this 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 (11). 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 period of time over which we apply constant rates of growth, the more unlikely our predictions are likely to be. In spite of these shortcomings, analysis of exponential growth is one way to provide insight into predicting future change, and growth or decline of a number or quantity of particular material of interest. The equation to predict decline of a quantity assuming constant rate of reduction as a percentage is:

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

where terms are defined as above.

hydrosphere, biosphere, and lithosphere have formed, evolved, and been maintained; how these components interact with each other and function; and how they will continue to evolve over periods ranging from a decade to a century (12) (see *A Closer Look: The Gaia Hypothesis*). 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, study of atmospheric chemistry suggests that our atmosphere has changed. Trace gases such as carbon dioxide have increased by about 100 percent since 1850. Chlorofluorocarbons (CFCs) released at the surface have migrated to the stratosphere, where they react with energy from the sun, causing ozone depletion. The important topics of global change and earth system science will be discussed in Chapter 16 of this book, following topics such as natural hazards, energy resources, and waste management.

CONCEPT FOUR: Limitation of Resources

The earth is the only suitable habitat we have, and its resources are limited.

Concept Four includes two fundamental truths: First, that earth is indeed the only place to live that is now accessible to us; and second, that our resources are limited, and while some resources are renewable, many are not. Therefore, we eventually will need large-scale recycling of many materials, and a large part of our solid and liquid waste-disposal problems could be alleviated if these wastes were recycled. In other words, many things that are now considered pollutants could be considered resources out of place (see Chapter 12).

There are two major views on natural resources. One school holds that finding resources is not so much a problem as is finding ways to use them. In other words, the entire earth, including the ocean and atmosphere, has raw materials that can be made useful if we can develop the necessary ingenuity and skill (13). The basic assumption is that as long as there is freedom to think and innovate, we will be able to produce sufficient energy and locate sufficient resources to meet our needs. Evidence supports this line of reasoning: First, efficient and intelligent use of materials has historically been a successful venture; second, we know more about extracting minerals and fuel than we did in the past and so can find new resources faster and mine lower-grade mineral deposits; and third, recycling of resources can help us meet the needs of the future.

The second school holds that "cornucopian premises" such as the one outlined above are fallacious, because a finite resource base cannot support an exponential increase of people forever. Furthermore, Preston Cloud claims that we are in a resource crisis for a number of reasons (14): first, improvements in medical technology contributing to overpopulation; second, an unrealistic view of the necessity of an ever-increasing gross national product based on obsolescence and waste; third, the finite nature of the earth's accessible minerals; and fourth, increased risk of irreversible damage to the environment as a result of overpopulation, waste, deforestation, burning of fossil fuels, and overuse of many resources including water, energy, soil, minerals, animals and forests (14).

CONCEPT FIVE: Uniformitarianism

The physical processes modifying our landscape today have operated throughout much of geologic time. However, the magnitude and frequency of these processes are subject to natural and artificially induced change.

Understanding the natural processes that are now forming and modifying our landscapes helps us make inferences about a landscape's geologic history. The idea that "the present is the key to the past," called **uniformitarianism**, was first suggested by James Hutton (remember him as the father of geology and the Gaia hypothesis, discussed on page 18) in 1785 and is heralded today as a fundamental concept of the earth sciences. As the name suggests, uniformitarianism holds that the processes we observe today also operated in the past.

Uniformitarianism does not demand or even suggest that the magnitude and frequency of natural processes remain constant with time. Furthermore, we now know that the principle cannot be extended back to include all of geologic time: Processes operating in the oxygen-free environment of the earth's first 2 billion years were quite different from those operating today. However, for as long as the earth has had an atmosphere, oceans, and continents similar to those of today, we can infer that the present processes were operating.

For example, if we know the characteristic landforms associated with today's alpine glaciers, we can infer that valleys with similar landforms were once glaciated even if no glacial ice is present today. Similarly, if we find ancient gravel deposits with all the characteristics of stream gravel on the top of a mountain, uniformitarianism suggests that a stream must have flowed there at one time. We can conclude that what was originally a stream valley has been changed by differential erosion and/or uplift to a mountaintop, a phenomenon known as *inversion of topography*. This and many other geologic phenomena would be difficult to infer without the principle of uniformitarianism.

In making inferences about geologic events, we must consider the effects of human activity on natural earth processes. For example, rivers flood regardless of human activities, but such activities can greatly increase or decrease the magnitude and frequency of flooding. Therefore, to predict the long-range effects of a natural process, we must be able to determine how our future activities will change its magnitude and rate. In this case, the present is the key to the future. We can assume that the same processes will operate but that their magnitudes and rates will vary as the environment adjusts to human activity. We recognize that ephemeral landforms such as beaches and lakes will continue to appear and disappear in response to natural processes and that human influence may be small in comparison.

Effects of human activity may be very pronounced in a local area. One year of erosion at a construction site or human-constructed slope such as grass embankments to a highway bridge (Figure 1.11) may exceed many years of erosion from an equivalent tract of woodland or even agricultural land (16). This erosion results from exposure of the soil following the removal of vegetation. Therefore, to maximize the value of geologic knowledge in land-use planning we must be able to use our understanding of natural earth processes in both a historical and a predictive mode.

▲ **FIGURE 1.11** Photo of soil erosion from human-constructed slop
(Edward A. Keller)

A CLOSER LOOK The Gaia Hypothesis

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 super organism (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. With Hutton's metaphor, the oceans are the heart of the earth and the forest the lungs (15). Two hundred years later James Lovelock (a British scientist and professor) introduced the **Gaia hypothesis,** reviving the idea of a living earth. The hypothesis is named for Gaia, the Greek goddess Mother Earth.

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 has some support from 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 carbon dioxide content of the atmosphere and thereby global climate (15).
- Life deliberately (consciously) controls the global environment. Very few scientists accept this third hypothesis. Systems of positive and negative feedback that operate in the atmosphere, on the surface of the earth, and in the oceans are probably sufficient to explain most of the mechanisms by which life affects the environment. On the other hand, 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.

▲ **FIGURE 1.B** Satellite 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 it as a single large system. (*Earth Imaging/Tony Stone Images*)

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 automatic processes of some sort are operating. From a geologic perspective this means that throughout much of earth history life has affected the physical and chemical systems of the earth, just as these systems affect life.

For instance, when environmental geologists examine recent mudflow deposits in an area designated to become a housing development, they must use uniformitarianism to infer where there will be future mudflows, as well as to predict what effects urbanization will have on the magnitude and frequency of future flows.

CONCEPT SIX: Hazardous Earth Processes

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

Because the geologic processes we know today were operating long before humans made their appearance, we have always been obligated to contend with processes that make our lives more difficult. Interestingly, *Homo sapiens* appear to be a product of the Ice Age, one of the harshest of all environments.

Early in the history of our species, our struggle with natural earth processes was probably a day-to-day experience. However, our numbers were neither great nor concentrated, so losses from hazardous earth processes were not very significant. As people learned to produce and maintain a constant food supply, the population increased and became more concentrated locally. The concentration of population and resources also increased the impact of periodic earthquakes, floods, and other natural disasters. 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.

Earth processes that often cause loss of life or property damage include flooding, earthquakes, volcanic activity, landslides, and mudflows. The magnitude and frequency of these processes depend on such factors as a region's climate, geology, and vegetation. For example, the effects of running water as an erosional or depositional process depend on the intensity of rainfall, the frequency of storms, how much and how fast the rainwater is able to infiltrate rock or soil, the rate of evaporation and transpiration of water back into the atmosphere, the nature and extent of the vegetation, and topography.

We can recognize many natural processes and predict their effects by considering climatic, biologic, 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.

CONCEPT SEVEN: Geology as a Basic Environmental Science

The fundamental component of every person's environment is the geologic component, and understanding our environment requires a broad-based comprehension and appreciation of the earth sciences and related disciplines.

All geology can be considered environmental. An understanding of our complex environment requires considerable knowledge of such disciplines as **geomorphology,** the study of landforms and surface processes; **petrology,** the study of rocks and minerals; **sedimentology,** the study of environments of deposition of sediments; **tectonics,** the study of processes that produce continents, ocean basins, mountains, and other large structural features; **hydrogeology,** the study of surface and subsurface water; **pedology,** the study of soils; **economic geology,** the application of geology to locating and evaluating mineral materials; and **engineering geology,** the application of geologic information to engineering problems. Beyond this, the serious earth scientist should also be aware of the contributions to environmental research from such areas as biology, conservation, atmospheric science, chemistry, environmental law, architecture, and engineering, as well as physical, cultural, economic, and urban geography.

Environmental geology, then, is the domain of the generalist with a strong interdisciplinary interest. This in no way denies the significant contributions of specialists in various aspects of environmental studies, or the importance of focusing on specific problems or areas of research. It merely suggests that, although our research interests may be specialized, we should always be aware of other disciplines and their contribution to environmental geology. Also, many projects may be studied best by an interdisciplinary team of scientists.

The importance of the interdisciplinary nature of environmental geology becomes apparent when we explore the nature of environmental problems (see *A Closer Look: Geology and Ecosystems*). Most projects are complex, involving many facets that may be generalized into three categories: physical, biological, and of human use and interest. These are essentially the same categories used by Luna B. Leopold (a famous geomorphologist and son of Aldo Leopold, who introduced the concept of the land ethic discussed earlier) to evaluate river valleys, and their extension to other areas of environmental research seems appropriate (17). *Physical factors* include physical geography, geologic processes, hydrologic processes, rock and soil types, and climatology. *Biologic factors* include the nature of plant and animal activity, changes in biologic conditions or processes, and spatial analysis of biologic information. *Human use and interest factors* include land use, economics, aesthetics, interaction between human activity and the physical and biological realms, and environmental law.

Obviously, no one project or research interest will involve all possible factors in each of the three categories, and there is considerable interaction between the categories. Projects such as waste-disposal operations, highway construction, mass transit systems, urban land-use planning, and mining of resources may be concerned with all of the categories. For example, the planning, construction, and operation of a sanitary landfill site (a place where we dispose of urban waste) is concerned with physical factors such as physical location, topography, soil type, and hydrologic conditions; biologic processes such as decay of the organic refuse and contamination of the surrounding biologic realm; and human interests such as good engineering practice and compliance with laws and regulations.

CONCEPT EIGHT: Our Obligation to the Future

The effects of land use tend to be cumulative, and therefore we have an obligation to those who follow us.

Several million years ago, when early hominids roamed the grasslands, marshy deltas, and adjacent forests of ancient Lake Rudolf along the Great Rift Valley system of East Africa, these prehistoric people were completely dependent upon their immediate environment. Their effect on that environment was probably insignificant as they hunted game and were in turn hunted by predators. This relationship between people and the environment probably existed until about 800,000 years ago, when our ancestors developed skill in the use of fire.

Human use of fire brought with it new environmental effects. First, fire was capable of affecting large areas of forest or grasslands. Second, it was a repetitive process capable of damaging the same area at rather frequent intervals. Third, it was a rather selective process, in that certain species were locally exterminated, whereas species that exhibited a resistance to or rapid recovery from fire were favored. Early use of fire for protection and hunting probably had a significant effect on the environment, and as people became more and more dependent on an increasing variety of resources for clothing, lodging, and hunting, they also increased their capacity to observe and test the environment. This early experimentation probably led to planting and primitive agriculture about 7000 B.C.

Emergence of agriculture was the first instance of an artificial land use capable of modifying the natural environment. It also set the stage for the development of a more or less continuously occupied site or cluster of sites that introduced further modification of the environment, such as shelter for living space, primitive latrines, and protective barriers against predators and other people. These early sites probably became the first areas to experience pollution resulting from waste disposal and soil erosion resulting from removal of indigenous vegetation (18). By increasing

A CLOSER LOOK Geology and Ecosystems

An ecosystem is a community of organisms and its nonliving environment in which matter cycles and energy flows. More importantly, sustained life on our planet is a characteristic of ecosystems rather than individual organisms or populations of a single species.

Understanding ecosystems requires us to consider physical, biological, and hydrological processes. For example, if we are interested in studying the forest ecosystem that supports a salmon fishery in the Pacific Northwest (Figure 1.C), we must consider interactions among variables such as:

- Large organic debris (large stems and pieces of woody debris) that produces fish habitat in the stream.
- Supply and transport of stream gravel necessary for fish to spawn.
- Cycling of nutrients within the stream system that provides the food base for the aquatic system.
- Land use in the surrounding forest that may cause changes in supply of water and sediment to the stream system.
- The role of disturbance such as wildfire or high-magnitude storms in maintaining the ecosystem.

Such considerations tend to transcend disciplines such as biology, geology, and hydrologic sciences. Understanding the entire ecosystem requires understanding how each of these components interacts with the others. One of the most fruitful areas for future ecological research may be the interactions of physical and biological processes operating at the ecosystem level.

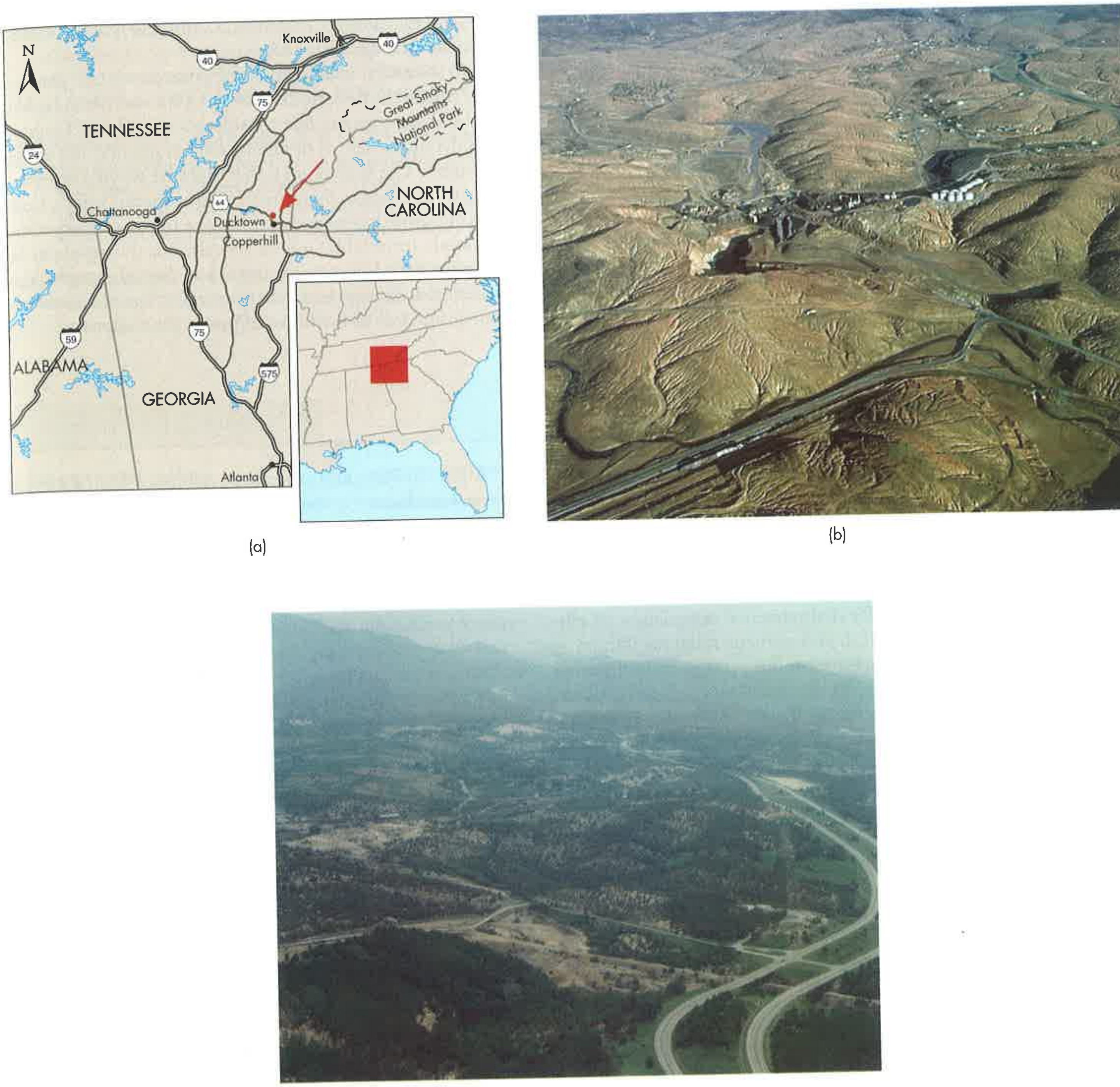
▲ **FIGURE 1.C** Large redwood stem in Prairie Creek shown here is responsible for the development of a scour pool important in providing fish habitat for the stream ecosystem. Such large debris may reside in the stream channel for centuries. (*Charles A. Mauzy/Tony Stone Images*)

the food supply, agriculture allowed population growth, which in turn necessitated the clearing of additional land (this is an example of positive feedback). This activity certainly influenced an area's ecological balance as some species were domesticated or cultivated and others were removed as pests. It is not surprising that the increase in human population has been paralleled by an increase in the number of extinctions among birds and mammals.

The most significant lesson of this developmental history is that as cities and farms increase, demand for diversification of land use increases, and the effects tend to be cumulative. If this is so, then from an ethical and moral standpoint we need to examine the effects of land use in a historical framework, if only to ensure that our children and their children can survive in the environment they inherit. This is especially critical because it has been determined that at least since cities arose 6000 years ago, and perhaps as far back as 15,000 years ago, the entire surface of the earth has been altered by human activity. In other words, little if any land can be considered original or untouched (10). Furthermore, owing in part to human population increase that demands more land for urban and agricultural purposes, human-induced change to the earth is increasing at a rapid rate. A recent study of human activity and ability to move soil and rock concluded that human activity (agriculture, urbanization, etc.) moves as much or more soil and rock on an annual basis—40 to 45 Gt per year (1 gigaton [Gt] is one billion or 10^9 tons)—than any other earth process, including mountain building (34 Gt/year), river transport of sediment (24 Gt/year), and Pleistocene glaciers (10 Gt/year). This combined with the visual changes to the earth (leveling hills, etc.) suggests that human activity is the most significant process shaping the surface of the planet (19).

The lessons in land use are explicit. Where sound conservation practices were used, there were successful adjustments of population, but where wasteful exploitation of resources was practiced, the results varied from gullied fields to silted-up irrigation reservoirs and canals to the ruin of prosperous cities. Histories of long-populated areas show that soil erosion has frequently destroyed productive land and retarded the progress of civilization. Conservation of our soils must remain a national priority, for as stated by W. C. Lowdermilk, "One generation of people replaces another, but productive soils destroyed by erosion are seldom restorable and never replaceable" (20,21).

The misuse of land has continued in modern times. For an American example, consider Ducktown, Tennessee (22). The land surrounding Ducktown looks more like the Painted Desert of Arizona than the lush vegetation of the Blue Ridge Mountains of the southeastern United States (Figure 1.12). The story starts in 1843 with what was thought to be a gold rush that turned out to be a rush for copper. By 1855, some 30 companies were transporting copper ore by mule over the mountains to a site called "Copper Basin"



▲ **FIGURE 1.12** The lasting effects of land abuse. (a) Location of Ducktown, Tennessee. (b) The human-made desert resulting from mining activities around Ducktown more than 100 years ago. Extensive soil erosion and loss of vegetation has occurred and complete recovery will probably take more than 100 years. (*Kristoff, Emory/NGS Image Sales*) (c) Ducktown area in recent years showing the process of recovery. (*Tennessee Valley Authority*)

and to Ducktown. Huge ovens—open pits 200 m long and 30 m deep—were constructed to separate the copper from zinc, iron, and sulfur. The local hardwood forest was cut to fuel these ovens, and the tree stumps were pulled to be turned into charcoal. Eventually every tree over an area of about 130 km^2 was removed. The ovens produced great clouds of noxious gas that was reportedly so thick that mules wore bells to keep from colliding with people and with each other. The sulfur dioxide gas and particulates produced acid rain and acid dust that killed what vegetation remained. Loss of vegetation led to extensive soil erosion, leaving behind a hard mineralized rock cover resembling a desert. The scarred landscape is so large that it is one of the few human landmarks visible from space.

The devastation resulting from the Ducktown mining activity produced adverse economic and social change. Nevertheless, people in Ducktown in the 1980s remained optimistic. A sign at the entry to the town states "Copper made us famous. Our people made us great." Revegetation started in the 1930s, and by 1970 approximately two-thirds of the area had become covered with some vegetation. However, it will probably take hundreds of years for the land to recover. What is being learned concerning restoration of Copper Basin will provide useful information for other areas in the world where human-made deserts occur, such as the area around the smelters in Sudbury, Ontario. Finally, there is worry for mining areas, particularly in developing countries, where landscape destruction similar to that at Copper Basin is still happening (22).

In summary, meeting our obligations to future generations will not be easy. Both land- and water-use planning will need to balance economic considerations with less tangible considerations such as sustaining our land, water, and scenic resources. The basic point is that there are varying environmental values just as there are varying economic values. Logging old-growth redwood trees may be the most short-term, economic (profitable) use of a forest, but this needs to be balanced with longer-term landscape degradation such as soil erosion, damage to stream ecosystems, loss of a scenic resource, and loss of the forest to future generations.

SUMMARY

Environmental geology is the use of geologic information to better understand and manage our environment. It is applied geology. The important variable that distinguishes geology from the other sciences is the consideration of time. The work of geologists utilizes the testing of hypotheses and the scientific method.

The cultural bases for environmental degradation are ethical, economic, political, and perhaps religious, but environmental problems are not confined to any one political or social system. Our ethical framework appears to be slowly expanding and may eventually include the total environment in a land ethic. This ethic affirms the right of all resources, including plants, animals, and earth materials, to continued existence and, at least in certain locations, continued existence in a natural state. The immediate causes of the environmental crisis are overpopulation, urbanization, and industrialization, which have occurred with too little ethical regard for our land and inadequate institutions to cope with environmental stress. Solving them involves both scientific understanding and the fostering of social, economic, and ethical behavior that allows solutions to be implemented.

Eight fundamental concepts establish a philosophical framework for our investigation of environmental geology: (1) The increasing world population is the number-one environmental problem. (2) Sustainability is the environmental objective. (3) The earth is essentially a closed system with respect to materials, and an understanding of feedback and rates of change in such systems is critical to solving environmental problems. (4) The earth is the only suitable habitat we have, and its resources are limited. (5) Today's physical processes are modifying our landscape and have operated throughout much of geologic time, but the magnitude and frequency of these processes are subject to natural and artificially induced change. (6) Earth processes that are hazardous to people have always existed. These natural hazards must be recognized and avoided where possible, and their threat to human life and property must be minimized. (7) The fundamental component of every person's environment is the geologic one, and understanding our environment requires an understanding of the earth sciences and related disciplines. (8) The effects of land use tend to be cumulative, and we therefore have an obligation to those who follow us.

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KEY TERMS

environmental geology (p. 3)
hypothesis (p. 4)
scientific method (p. 4)
land ethic (p. 5)
environmental crisis (p. 5)
myth of superabundance (p. 6)
exponential growth (p. 8)
sustainability (p. 10)
sustainable global economy (p. 10)
system (p. 11)
principle of environmental unity (p. 11)
feedback (p. 12)
input-output analysis (p. 12)
average residence time (p. 13)
earth system science (p. 14)
uniformitarianism (p. 17)
Gaia hypothesis (p. 18)

SOME QUESTIONS TO THINK ABOUT

1. We state in the text that the evolution of ethics is an important environmental trend. Can this statement be rigorously defended? Present an argument that it is good for the environment to have an expanded view of ethics.
2. Stewart Udall writes about the "myth of superabundance" and "the raid on resources." What do you think we have learned in the United States today from our history of how we have treated the environment? Do we still think like the young Thomas Jefferson or have fundamental changes occurred in the relationship between people and the environment?
3. Assuming that there is an environmental crisis today, what possible solutions are available to alleviate the crisis? How will solutions in developing countries differ from those in highly industrialized societies? Will religion or political systems have a bearing on potential solutions? If so, how?
4. It has been argued that we must control human population because otherwise we won't be able to feed everyone. Assuming that we could feed 10 billion to 15 billion people, would we still want to have a smaller population than that? Why?
5. We state that sustainability is the environmental objective. Construct an argument to support this statement. Is the idea of sustainability and building a sustainable economy different in developing and poor countries from those that are affluent with a high standard of living? How and why?
6. The so-called Gaia hypothesis actually consists of three hypotheses. What would need to be done to test each of them? Many scientists would say that one of the hypotheses is fringe science and cannot be tested. Do you agree or disagree, and why? Perhaps the Gaia hypotheses are best considered as only a metaphor. Do you agree?
7. The concept of environmental unity is an important one today. Consider some major development being planned for your region and outline how the principle of environmental unity could help in determining potential environmental impact. In other words, consider a development and then a series of resultant consequences. Some of the impacts may be positive and some may be negative in your estimation.
8. Why is it important in land- and water-use planning to strive for a balance between economic considerations and less tangible variables such as aesthetics? In answering, consider what you have learned about both environmental ethics and sustainability.