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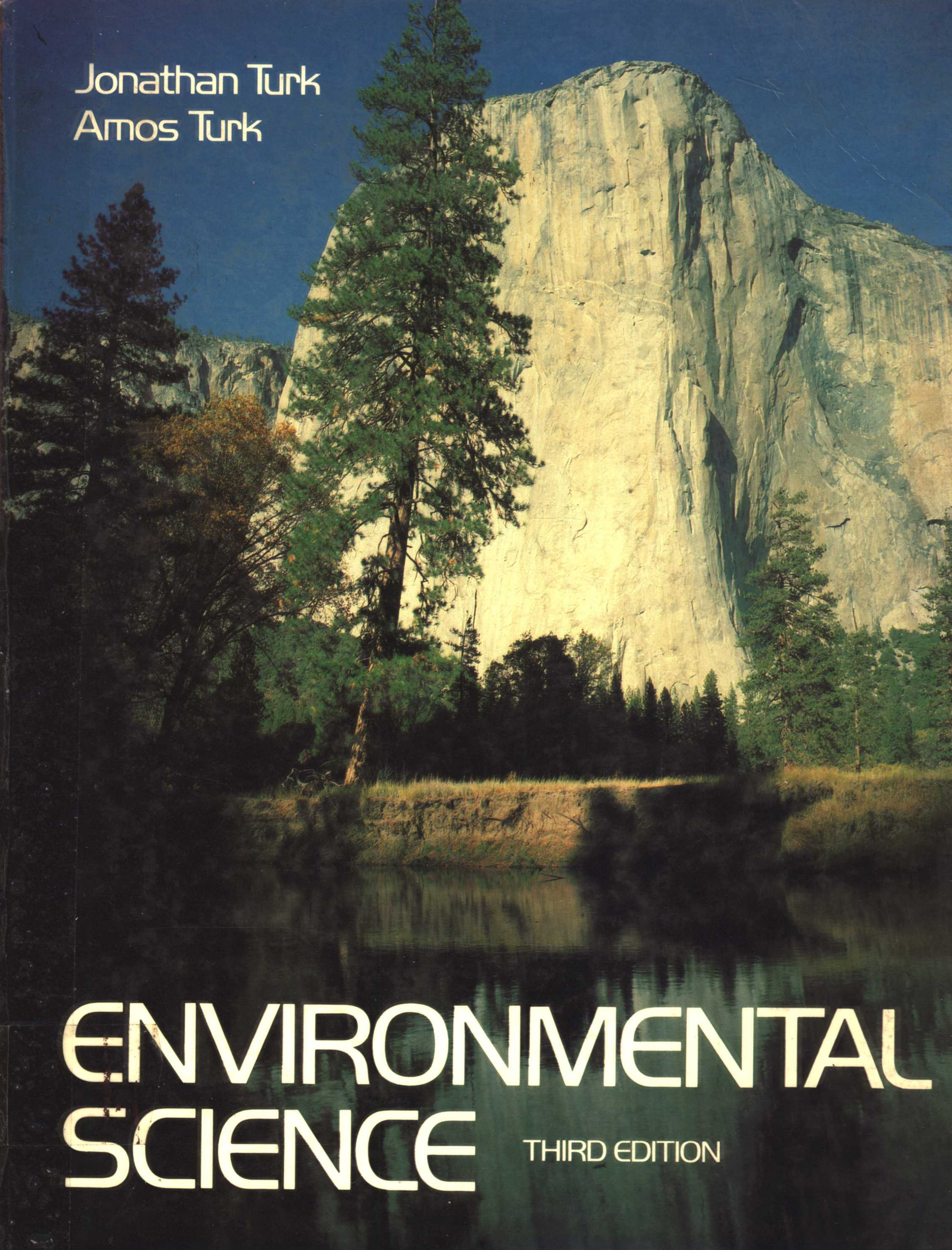

ENVIRONMENTAL SCIENCE

THIRD EDITION

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PREFACE

Environmental science is an integration of material from the disciplines of biology, the physical sciences, and the social sciences. A prime objective of this book is to emphasize this interdependence and to maintain a balanced presentation of environmental issues important to the student. To this end, we have developed a principles-oriented book that emphasizes concepts rather than the memorization of large amounts of raw data. This text is designed to explain how the underlying science, economics, and politics affect important environmental issues. Adequate facts are given to illustrate and support the principles developed, and, more importantly, facts and principles are integrated throughout the text.

The publication of the third edition of ENVIRONMENTAL SCIENCE marks the 10th year in print of this title. In the past 10 years many environmental questions, once of interest mainly to scientists, have become serious issues of public policy and have sustained a steadily growing public awareness. Concern about the environment is now worldwide, and policies set in the United States can have far-reaching global effects.

It is with these and other changes in mind that we have revised ENVIRONMENTAL SCIENCE. To provide a better basis for the discussion of environmental problems, the biological and geological material in the third edition have been considerably improved. Karen Arms, noted author of biology textbooks (Arms and Camp, BIOLOGY, 2nd edition, Saunders College Publishing, 1982; Camp and Arms, EXPLORING BIOLOGY, 2nd edition, Saunders College Publishing, 1984), has strengthened greatly the chapters on the biology of natural ecosystems. There is increased emphasis on the technical and social issues regarding global resources—fuels, fiber, food, water, soil, and minerals. This greater international overview is evident in the number of examples of environmental problems and solutions cited from other countries. Contemporary areas of concern—energy use, land management, and pollution and waste control—have been expanded and updated.

In order to incorporate all the changes of the last decade, it was quickly discovered that a major restructuring was necessary. Thus, the organization has been revised so that environmental science is presented as a unified, integrated study. The stage for this study is set in the very first unit, in which both legal and technical limitations on environmental improvement are introduced.

Following is an annotated list of noteworthy features contained in the third edition.

(1) *Organization.* It has been our aim to offer logical, orderly sequences of presentation and to avoid awkward breaks in the continuity. At the same time, we recognize that the instructor requires flexibility and may choose to emphasize certain topics more than others. Therefore, the material has been arranged so that the presentation can be individualized to suit the particular course objectives. It is for this reason that the text is organized into units that are individually self-contained and need not be presented in the sequence in which they appear in the text. The units are as follows:

Unit 1. Environmental Science: An Overview
This unit introduces environmental science and its relation to the human con-

dition, discusses the classification of environmental problems, shows how environmental improvement is tied to economic and legal concerns, and discusses how the laws of nature limit our response to environmental challenges.

Unit 2. The Ecological Background
This unit provides a comprehensive look at the biology of natural ecosystems, populations, speciation, extinction and genetic resources, and an overview of the biosphere.

Unit 3. Human Impact on the Earth
This unit discusses the relationship of human beings and the environment, beginning with the origins of the human species and the growth of human populations and ending with discussions of the effects of chemical and hazardous wastes on human health.

Unit 4. Energy
This unit, extensively revised and expanded in this edition, discusses sources of energy; nuclear energy and its environmental effect; the search for and use of energy and its environmental, economic, and political consequences; and the need for both short-term and long-term planning.

Unit 5. Soil, Land, and Minerals
This unit deals with soil and agriculture; the control of pests and weeds and the debate over insecticides; food production, the Green Revolution, and the consequences of world hunger; land use and encroaching urbanization; and nonrenewable mineral resources.

Unit 6. Air, Water, and Wastes
This unit discusses water resources; water and air pollution and their environmental effects; the social, legal, and economic aspects of water and air pollution; and the disposal of solid wastes.

Epilogue. Planning for a Sustainable Society
This coda discusses some of the realistic options we do have and stresses the need for planning.

(2) *Enrichment Material.* Various case histories and special topics (which appear in boxes) are interspersed throughout the text. These are presented, for the most part, because they are interesting. Many offer a human outlook that is not necessarily conveyed in a purely didactic approach. However, they are not required for a reading or understanding of the chapter, nor are questions at the end of the chapter based on them.

(3) *Pedagogy.* Several pedagogical elements are incorporated into the text.

a. Chapter summaries. These summaries highlight the principles of each chapter and the key words that the student should know.

b. Questions. End-of-chapter questions function in two ways. First, they help students review important points covered in the chapter. Second, they present real-world situations that challenge students to apply what they have learned as they develop solutions for environmental problems. The questions are usually grouped by major subtopic.

c. Suggested readings. The references at the end of the each chapter are selected to include classic sources, readings at both introductory and more advanced levels, and the most recent contributions to the field. They are not intended to be exhaustive in scope.

d. Appendix. The appendix is a reference section on units, various physical concepts, chemical formulas, and calculations of growth rates and of decibel levels.

e. Glossary. An extensive glossary of terms used in the text is provided at the end of the book.

f. Use of the metric system. Metric units are given first, with the United States Customary or British units sometimes following. Measures of heat are shown in calories. The confusion between the different kinds of tons is avoided by using only the designation **tonne,** which means metric ton and is intermediate between the customary long and short tons. All needed conversions are provided in the Appendix.

(4) *"Take-Home" Experiments.* The various "take-home" experiments that appeared in previous editions, as well as new ones, have been gathered into one supplementary laboratory section at the end of the book. These experiments require no more, or very little more, equipment and supplies than are commonly available in a grocery, hobby, or hardware store. Some of the experiments can be used as classroom projects or can serve as springboards for class discussion. They should all be interesting and informative and serve to reinforce the principles of environmental science.

(5) *Supplements.* Three supplementary items are available to adopters of ENVIRONMENTAL SCIENCE. An Instructor's Manual provides teaching suggestions and other useful information. A set of 100 Overhead Transparencies containing about 100 illustrations from the text is also available. An environmental simulation entitled "WORLD: The Fate of Civilization" is available on disk for microcomputers and is accompanied by a manual explaining the use of the software.

Since ENVIRONMENTAL SCIENCE is an introductory text, only a minimal science background is required by the student. Also, no mathematics is needed to comprehend the concepts presented. Even though the text offers a broad-spectrum view of environmental science, we have written a book that tries to explain the true complexity of environmental issues without over-simplifying or providing simplistic solutions that really don't work. We have always attempted to be realistic in discussing the true complexity of the world in which we live; yet we have, at the same time, strived to convey a picture of humans in their environment that is understandable and relevant to scientists and nonscientists alike.

CONTENTS

UNIT

1

Environmental Science: An Overview

This view of the head of Yellowstone Falls shows the fresh water, clear skies, and lush vegetation that a protected natural environment can provide. (Photo courtesy of Richard L. Moore.)

1

Studying the Environment

During the 1960s and 1970s people began to listen seriously to predictions that human existence would be threatened unless humans adjusted their relationship with their environment. Scientists said that the earth was becoming polluted and that soil, mineral, and fuel resources were being used faster than they were being replaced. Demographers said that the world's human population was growing faster than its food supply. Economists pointed out that the gap between the rich and the poor was growing wider. These concerns were the incentive for the development of the discipline of environmental science—the study of the relationship between human beings and their environment.

The human environment is the Earth we live on. It includes all the physical parts of the Earth such as air, soil, minerals, rocks, and water, and all its biological inhabitants such as animals, including human beings, bacteria, fungi, and plants. Environmental science provides an approach toward understanding the human environment and the impact of human life upon that environment. It is also a search for solutions to the environmental problems that confront us.

This chapter provides an overall look at the topics that will be covered in more depth in succeeding chapters. This overview includes consideration of the worldwide problems that initiated the study of environmental science and of how those problems are related to each other.

1.1 The Human Condition

Consider the state of humankind on Earth, the planet we call home. In the past, life was hard and short for most people. Then, at the beginning of the twentieth century, rapid progress in medicine, agriculture, and industrial techniques seemed to promise that everyone might soon be able to enjoy long life, decent food, satisfying employment, and adequate housing. This promise has not been realized. In 1982 there were about 5 billion people on Earth. One quarter of them had a greater life expectancy and lived in greater luxury than anyone a hundred years ago would have believed possible. But at the same time three quarters of all people had inadequate or unsatisfactory water and shelter, and more than one third suffered from malnutrition and hunger (Fig. 1–1). More

Figure 1–1 A malnourished mother and her children in India. Millions of people starve to death every year and many more are permanently crippled by malnourishment. (Photo courtesy of Henri Bureau-Sygma.)

people starved to death in 1982 than in any year since the beginning of time.

Most of the people who starve to death live in poverty-stricken developing nations. But now, at the end of the twentieth century, the wealthy nations are in trouble too. According to most estimates, the average standard of living in North America and Western Europe peaked in about 1967. Even the wealthiest nations are running out of fuel, hardwoods, and some minerals. As a result, necessities such as housing, food, and fuel are demanding more and more of the family budget, leaving less available for luxuries. Pollutants (Fig. 1–2) contaminate cities, towns, and even rural environments. Sewage or poisonous pesticides in waterways, smog-laden air, and garbage in streets or parks lower the standard of living of everyone, no matter how wealthy.

Our vast and swiftly growing population consumes the Earth's resources of agricultural land, minerals, water, and fuel faster than natural processes can replace them. This is a serious problem in itself. But global conditions are further endangered because these resources are not distributed evenly. One quarter of the population, those that live in the developed nations, use nearly 80 percent of the resources consumed by humankind in any one year. People in the United States alone, although they comprise only 5 percent of the Earth's population, use about 35 percent of all raw materials. The other three quarters of the population consume only about 20 percent of the resources used in a year. The gap between the haves and the have-nots is growing wider. Today, when transistor radios are to be found even in the most remote African villages, the world's poor know how underprivileged they are. This knowledge produces political instability. Years ago, political upheaval in one nation meant little to the rest of the world. But times have changed, because modern technology ensures that nearly all nations possess weapons that can wreak havoc far beyond their own borders. As a result, no nation can afford to ignore the problems of another.

For many years most people forgot that the Earth is largely a closed system, with only finite supplies of resources and a limited ability to absorb wastes. Because only a thoughtful few re-

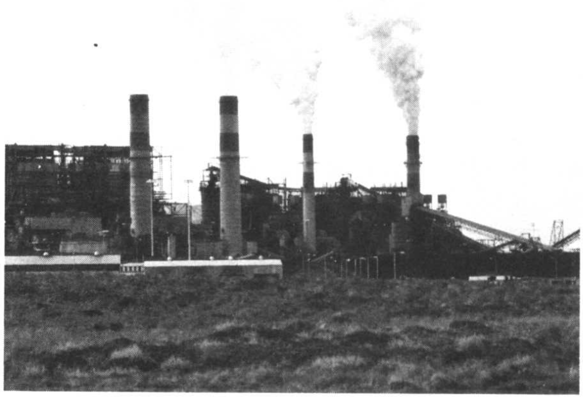

Figure 1–2 Air pollutants from electrical generating stations. (Courtesy of EPA.)

alized what was happening, little was done about the problems, and the situation continued to deteriorate. Some experts now think that everyone on Earth can have enough to eat and a reasonable standard of living only if the human population is reduced considerably. Some even think that our time on Earth is nearly done. These pessimists believe that the disparity between the rich and the poor and the destruction of the environment will lead to social unrest that can end only in a nuclear war that will destroy us all. Others think that the human plight is serious but not desperate. They believe that technology can be used to solve environmental problems as it has solved so many others, and that the developed nations will see the wisdom of spending more of their wealth on improving the human condition. But surely everyone must agree that a better understanding of the relationship between humankind and the environment is one positive step forward. To this end, the rest of this book is a beginning.

1.2 Classifying Environmental Problems

Environmental problems are always interrelated. Sometimes a solution to one problem actually creates another problem. For example, when people are sick and dying from disease, it is natural to want to improve human health. When health is improved and infant mortality is reduced, a population explosion may result. To feed this growing population, natural habitats are often destroyed by turning them into farmland. As natural habitats are destroyed, the wild plants, predatory animals, and parasites that once lived there are killed as well. Because of the lack of predators and parasites, outbreaks of insect pests become more common. Farmers use pesticides to control the pests and protect the crops, but in the process the environment becomes polluted. The development of this entire cycle in itself consumes fossil fuel supplies that are becoming scarce. In addition, when fuels are burned, air pollutants are generated.

How does a person begin to study such a network of interlocking problems? To make the task a bit more manageable, we will divide environmental disruptions into five main types.

(a) Overpopulation. Overpopulation may be defined as the presence in a given area of more people than can be supported adequately by the resources available in that area. Many people argue that the population explosion that has taken place in the twentieth century is now the most important problem we face (Fig. 1–3). It is important first because overpopulation is a major cause of all other environmental problems: Fewer people would use less oil, chop down fewer trees, and pour less sewage into rivers. Second, overpopulation and the starvation that accompanies it are generally higher on our list of priorities than other environmental concerns. It is hard to argue that an area should be set aside as parkland to preserve a vanishing forest or savanna when that land might be used to raise crops that would prevent fellow human beings from starving to death.

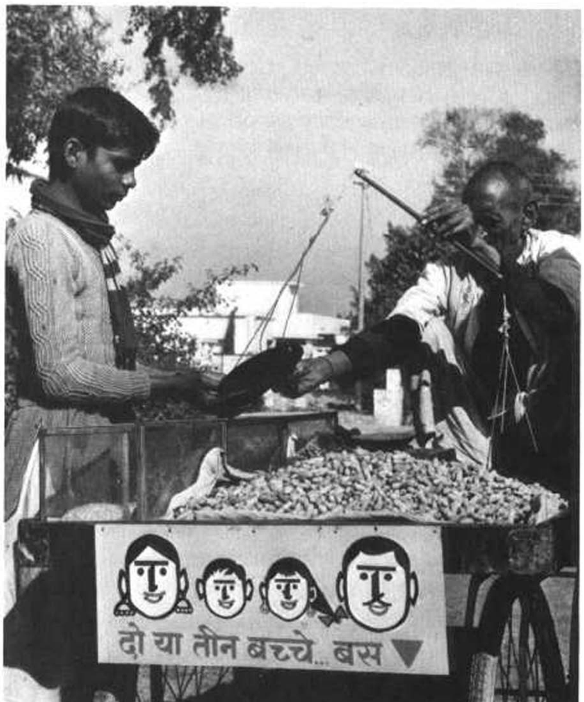

Figure 1–3 Some densely populated nations view overpopulation as one of their most devastating problems and encourage small families. Here a vendor displays the Family Planning publicity on his cart.

BOX 1.1 POLLUTION

For many years, the word pollute has meant "to impair the purity of," either morally* or physically.† The terms "air pollution" and "water pollution" refer to the impairment of the normal compositions of air and water by the addition of foreign matter, such as sulfuric acid. Within the past few years two new expressions, "thermal pollution" and "noise pollution," have become common. Neither of these refers to the impairment of purity by the addition of foreign matter. Thermal pollution is the impairment of the quality of environmental air or water by raising its temperature. The relative intensity of thermal pollution cannot be assessed with a thermometer, because what is pleasantly warm water for a man can be death to a trout. Thermal pollution must therefore be appraised by observing the effect of a rise in temperature. Similarly, noise pollution has nothing to do with purity: foul air can be quiet, and pure air can be noisy. Noise pollution (to be discussed in Chapter 10) is the impairment of the environmental quality of air by noise.

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*(1857.) Buckle, *Civilization.* I., viii, p. 526: "The clergy . . . urging him to exterminate the heretics, whose presence they thought polluted France."

†(1585.) T. Washington. trans. *Nicholay's Voyage,* IV, ii; p. 115: "No drop of the bloud should fall into the water, least the same should thereby be polluted."

(b) Pollution. Pollution is a reduction in the quality of the environment by the introduction of impurities (Box 1.1). Smoke pollutes the air; sewage pollutes the waters; junk cars pollute the land. We know that such contamination exists; it can be seen, smelled, or even tasted. The effects of pollution on human welfare or on the economy, however, may be matters of considerable disagreement (Fig. 1–4).

There are two distinctly different types of pollution.

1. *Concentration of Organic Wastes.* All living organisms produce waste products; wastes are associated with the act of living. Upon death, the entire organism becomes a waste product. Before modern civilization, most organic wastes did not accumulate in the environment because they were consumed by other organisms and thereby recycled. In modern times, the natural decomposition of organic wastes does not always operate efficiently. For example, a city may house several million people in a small area of land. Organic wastes from such a city are not spread evenly about the countryside but instead are concentrated in a few locations. Sewage that is dumped into a river decays naturally, but the process takes time. If the volume or the concentration of sewage is high, the water may not be purified by the time it reaches the next site downstream where pure water is needed. If several cities line the river and each city discharges its wastes, then the river cannot cleanse itself. Many plants and animals that depend on the river and are beneficial to people die. Organisms that take their place are often less useful to humans or may even carry disease.

2. *Introduction of Synthetic Chemicals into the Environment.* Everything is made of chemicals—people, eagles, trees, lakes, plastic—everything. Although many natural chemical compounds have existed for billions of years, people have recently learned to make new chemical compounds, called **synthetic chemicals.** The quantity and variety of new synthetic chemicals are staggering. They are present in paints, dyes, food additives, drugs, pesticides, fertilizers, fire retardants, building materials, clothes, cleaning supplies, cosmetics, plastics, and so on. In 1980, some 70,000 different synthetic chemicals were produced in quantity for common use. About 2000 new compounds enter the environment every year. Just before the beginning of World

Figure 1–4 The effect and ultimate cost of pollution are often hard to assess. This is Copper Basin at Copperhill, Tennessee, where a luxuriant forest flourished until all vegetation was killed by the fumes from copper smelters. In such cases the rate and degree of recovery cannot be accurately predicted. (U.S. Forest Service. From Odum: *Fundamentals of Ecology.* 3rd ed. Philadelphia, W. B. Saunders Co., 1971.)

War II, production of synthetic chemicals in the United States totalled less than ½ billion kg per year. By 1980, that total had jumped to some 80 billion kg per year.

Synthetic chemicals are noted for the variety of their properties. Some of them are drugs that save millions of lives every year, and others are poisons. But because most of them are new to the environment, the traditional patterns of decay and recycling do not necessarily apply. Some synthetic chemicals break down rapidly in the environment by the action of sunlight, air, water, or soil, and some are eaten by living organisms. Such processes may take place over a span of minutes, hours, or days. A material that decomposes in the environment as a result of biological action is said to be **biodegradable.**

Many compounds, however, do not disappear so readily. Synthetic plastics, for example, remain in the environment for a long time because organisms that feed on them and break them down are rare. (Scientists have bred bacteria that do decompose a few plastics.) Plastic shampoo bottles may produce unsightly litter, but they are not biologically active. Many other synthetic chemicals, however, are harmful. For example, DDT was developed as an insecticide, but experience with it has shown that it has undesirable environmental effects as well. It kills nontarget insects and interferes with the life cycle of birds, by making their egg shells so thin that they break easily, causing many of the young to die prematurely. DDT decomposes so slowly that appreciable quantities remain in the soil 15 years after a single spray application (see Chapter 15).

Natural chemicals can also cause environmental problems. For example, arsenic is found in minerals that occur naturally in small concentrations in many rocks and soils. Arsenic compounds are poisonous, but when small amounts are chemically bound into rock formations they do not present a serious hazard to human health. Now, enter a mining operation. Rocks are dug up, crushed, and treated chemically to separate valuable minerals such as gold from the less valuable ones. In the process, arsenic is inadvertently concentrated. In many cases, the semiconcentrated arsenic is thrown away. In its new form it enters the environment as a real hazard to health.

(c) Depletion of Resources. A **resource** is any source of raw materials. Fuels, minerals, water, soil, and timber are all resources. A material is depleted, or used up, as it becomes less available for its intended function. Material resources can become depleted in three different ways. First, a substance can be *destroyed,* that is, converted into something else. Fuels are destroyed when they are used: Coal is converted to ashes and gas; uranium is converted to radioactive waste products. The ashes or waste products are no longer fuels.

Second, a substance can be lost by being *diluted,* or by being *displaced* to some location from which it cannot easily be recovered. If you open a helium-filled balloon, the gas escapes to the atmosphere. Not one atom of helium is destroyed, but nevertheless the gas is lost because it would be impossible, as a practical matter, to recover it. The same concept of loss by dilution applies to minerals. An **ore** is considered to be a rock mixture that contains enough valuable minerals to be mined profitably with currently available technology. Today, iron is profitable to mine when the ore contains about 40 percent iron. However, iron is also widely dispersed in the soil, in many rocks, and even in the ocean, where its concentration is about one millionth of 1 percent. These sources of iron are useless to humans as minerals because it would take far too much energy and equipment to recover them. When products containing iron, such as automobiles or paper clips, are thrown away, the metal rusts. The rust is iron oxide, which could be reprocessed to produce iron again. However, many of the old auto hulks (and all of the paper clips) are scattered so widely over the countryside that it is uneconomical to find and collect them. It is in this way that our reserves of iron are being depleted.

Third, a substance can be rendered unfit for use by being *polluted.* In this way pollution and depletion are related to each other. If industrial or agricultural wastes are discharged into a stream, or if they percolate down through soil and porous rock to reach a supply of groundwater, then these water resources become less fit for drinking or, in the case of the stream, for recreation or for the support of aquatic life.

Depletion of resources can be slowed by conservation, recycling, and substitution. Fuels,

Figure 1–5 Electric cars use energy that can be generated at a plant that burns coal, which will still be available after petroleum reserves are depleted. (United Press International photo.)

however, can be saved only by conservation (using less) and substitution (using other energy sources, see Fig. 1–5). Fuels cannot be recycled. Political decisions about depletion of resources, and especially about policies of conservation, are often difficult because there is generally little agreement on the amount of resources available, on future rates of consumption, or on alternative sources of energy and materials. It would be unrealistic, for example, to expect agreement on energy policy between one group who expects oil to run out by the end of the century, coal to last for only a few hundred years, and nuclear energy to be unavailable, and another group who believes that most fossil fuel reserves have not yet been discovered and that nuclear energy will be plentiful for thousands of years.

Finally, conservation is often seen as a measure whose benefits will be realized later, perhaps only by our children or grandchildren, and not all makers of policy are equally concerned about future generations.

(d) Changes in the Global Condition. Scientists have begun only recently to wonder whether human activities might affect the global environment. Aerosol sprays and aircraft exhaust may be destroying the ozone layer in the atmosphere that filters out ultraviolet radiation. Burning fossil fuels releases carbon dioxide that could affect planetary weather patterns. Pollution of the oceans destroys plant life that produces oxygen, and such pollution might eventually reduce the oxygen content of the air we breathe. Throughout much of the world, forests, jungles, shrublands, and other natural systems are being converted to farmland. In many areas, this process is depleting the fertility of the soil, altering the climate, and causing the extinction of literally thousands of species of plants and animals. Except in emotional terms, people often do not know precisely what has been lost when a species becomes extinct. Scientists are convinced that many endangered species of plants or animals should be saved because they may be essential in breeding valuable crops or domestic animals.

(e) War. In many ways, war is a combination of all environmental problems rather than a separate category. From time immemorial, overpopulation and want have led human groups into wars over food, land, or some other coveted resource. In modern times war and the preparation for war have led to pollution and depletion of resources that are far more extreme than any single peacetime activity. War reduces population, although the effect is trivial: more people were born in 6 months in 1982 than were killed throughout the first and second world wars. Finally, a nuclear war places the global systems of the Earth, human civilization, and even the human species itself at risk.

1.3 The Tragedy of the Commons

Some people were aware of environmental problems a long time ago. In 1789 Thomas Robert Malthus, an English clergyman and economist, published an *Essay on the Principle of Population*. In this essay he argued that human populations must invariably outgrow their food supplies and will then be reduced by starvation, disease, and war. The English poet William Wordsworth was well aware of air pollution. In his poem "On Westminster Bridge" he celebrated one of the rare days in the nineteenth