I

INTRODUCTION

1

WHY ECOLOGICAL ENGINEERING AND ECOSYSTEM RESTORATION?

We are now in a position to make a substantial contribution to the ‘‘greening’’ of the planet through ecological engineering and ecosystem restoration. We find ourselves in a retrospective period of human history, both politically and ecologically, where although not necessarily questioning all we have built and engineered to date, we are determining (1) whether to continue practices as usual (and whether we can afford to do so) and (2) what new approaches are available for restoring the ‘‘bodily functions’’ of nature, on which we depend. Signs all around us confirm that a paradigm shift is taking place, both within and outside the ecological and engineering professions, to accommodate ecological approaches to what was formerly done through rigid engineering and a general avoidance of any reliance on natural systems.

Engineers, ecologists, resource managers, and even politicians are now completely redesigning, at a cost of almost $8 billion, the plumbing in the southern Florida Everglades to provide a more ecologically integrated system (Figure 1.1). As part of the effort in the Florida Everglades, the Kissimmee River in Florida is being ‘‘restored’’—at an enormous cost—to something resembling its former self before it was canalized 30 years ago (Figure 1.2). Ecological approaches are being investigated to reduce nonpoint-source pollution from reaching the Baltic Sea, where extensive eutrophication is occurring. The Gulf of Mexico continues to have annual ‘‘dead zones’’ that now spread well over 20,000 km^2, approaching the size of the state of Massachusetts. Discussions are being held not on whether to restore the Mississippi River Basin to a more natural state by removing levees and restoring wetlands and riparian forests (Figure 1.3), but when and how that restoration will occur. In a related effort, the Louisiana delta and coastline are disappearing into the sea, and major efforts are under way to reduce land loss along that coastline.

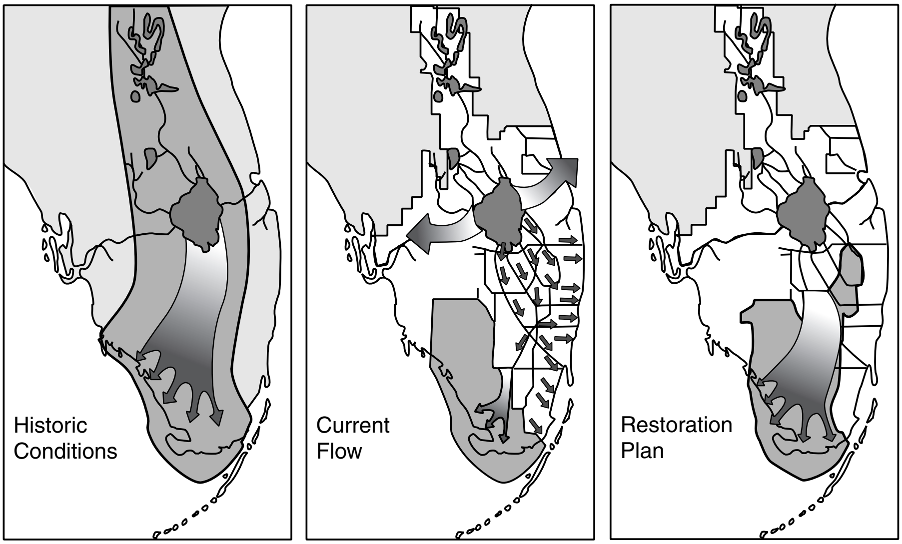


Figure 1.1 The largest ecological redesign ever attempted is the $8 billion, 20-year restoration of the Everglades in southern Florida. The historic flow of water as seasonal overflow from Lake Okeechobee through the Everglades has been altered dramatically by a system of drainage canals and pump stations built in the twentieth century that now divert a large amount of the water east and west to the Atlantic Ocean and Gulf of Mexico. The restoration plan is to restore historical hydrologic flow of water through the Everglades and to Florida Bay to the south. (Redrawn from U.S. Army Corps of Engineers.)

Figure 1.2 Part of the Everglades area restoration has involved the remeandering and restoration of the Kissimmee River that flows from central Florida to Lake Okeechobee. At approximately 10 times the cost of the stream straightening that occurred in the 1960s, the river is being partially restored by low-head dams and reattachment of backwaters and old meanders to the stream channel. (Courtesy of Lou Toth; photo by Paul Whalen, South Florida Water Management District, West Palm Beach, Florida; reprinted with permission.)

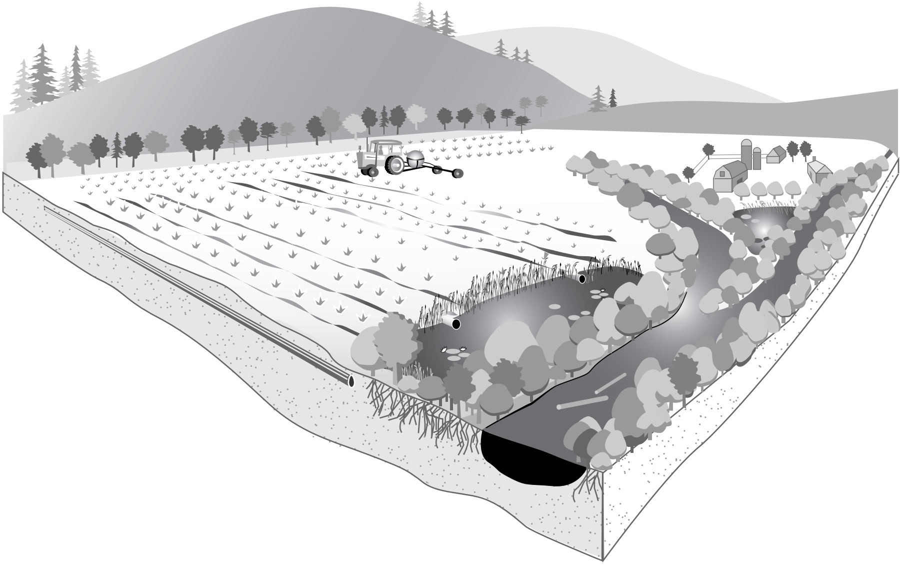


Figure 1.3 Creating and restoring wetlands and riparian ecosystems in an agricultural landscape are being proposed as means of controlling nonpoint-source pollution in Scandinavia to protect the Baltic Sea and in the United States to protect the Gulf of Mexico and the Chesapeake Bay. (From Mitsch and Gosselink, 2000; copyright 2000; reprinted with permission from John Wiley & Sons, Inc.)

Denmark is bringing back its largest river, the Skern River, to its old meandering course to prevent continued deterioration of coastal waters (Figure 1.4). Treating wastewater with constructed wetlands (Figure 1.5), an approach just begun with experiments in the 1960s and 1970s, is now an accepted approach for wastewater treatment throughout the world. Thousands of hectares of coastal marshes are being restored along the Delaware Bay in New Jersey from hay farms to a status they have not seen since the eighteenth century by removing dikes and carving tidal creeks (Figure 1.6).

The planners of the expensive and controversial Biosphere 2 enclosed ecosystems in Arizona (Figure 1.7) have perhaps unwittingly illustrated the great value of natural ecosystems. In an ecological engineering of the most extreme kind, a group of ecosystems were designed in a 1.25-ha glass-enclosed system to illustrate potential use of such enclosed systems for human support in future space colonies. But fans were used for air movement instead of natural air movement and pumps for water movement to replace the free water flow from the hydrologic cycle, illustrating exactly the point of this book: Ecosystems, running on the natural energies of sunlight, wind, and water, are our real support systems, providing a great variety of free public service functions that we do not realize are important until they are gone. Costanza et al.'s (1997) classic answer to the question ‘‘what is nature

Figure 1.4 A major river restoration project in Europe is being carried out on the Skern River in Jutland, Denmark, where Denmark's largest river is being restored to its former meandering course. When the restoration is complete, 2200 ha of meadows and wetlands—half of the area drained in the 1960s—will be restored. A reason for the restoration is coastal pollution in a fjord adjacent to the North Sea caused by the straightened river and pollution transport from agriculture. The Danish public funds earmarked for this project are 8.5 times the cost of the original river drainage project, most of which occurred in the mid-twentieth century. (Photo by W. J. Mitsch.)

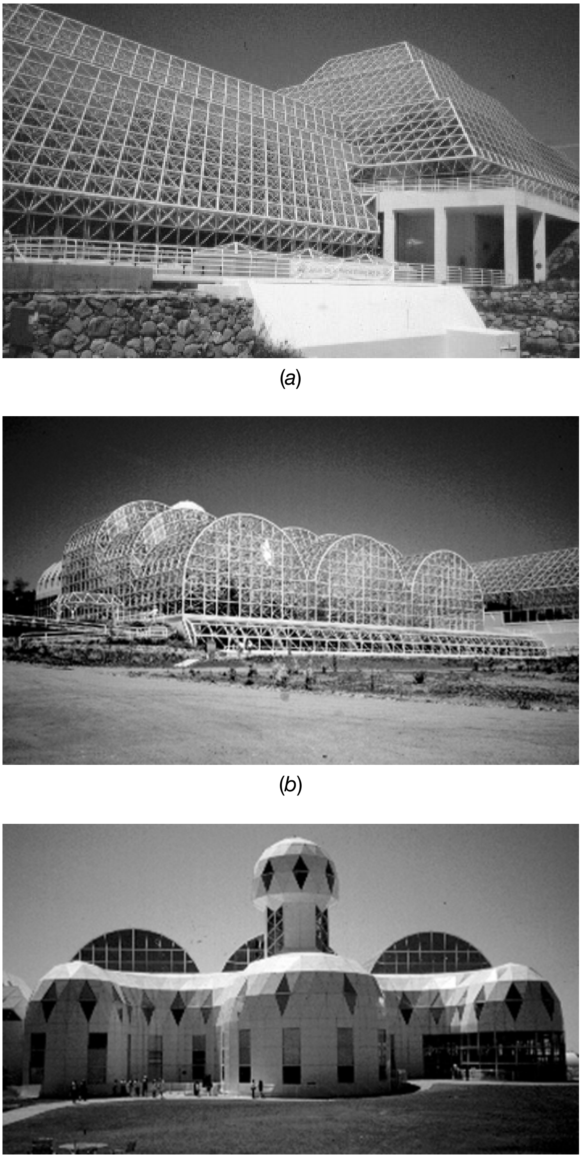
worth?" suggested that ecosystems are providing services equivalent to about \$64,000 per square kilometer per year. By using the cost of construction and maintenance of Biosphere 2 as an indicator of what it would take to produce ecosystems devoid of our climate, air, water, and winds, the value of an ecosystem escalates to about \$1 billion per square kilometer per year (Mitsch,

Figure 1.5 A 3-ha treatment wetland adjacent to a wastewater treatment plant in central Ohio. The treatment plant delivers secondarily treated wastewater to the wetland that has, as its main function, tertiary treatment of the wastewater to prevent nitrogen and phosphorus from reaching the adjacent north fork of the Licking River. (Courtesy of W. J. Mitsch.)

(*a*)

(*b*)

Figure 1.6 One of the largest coastal wetland restoration projects in the eastern United States involves the restoration, enhancement, and preservation of 5000 ha of coastal salt marshes on Delaware Bay in New Jersey and Delaware. One part of that project involves reflooding salt hay farms by breeching coastal dikes and constructing "starter" tidal creeks to create a high percentage cover of desirable vegetation such as *Spartina alterniflora,* a relatively low percent of open water, and the absence of the invasive reed grass *Phragmites australis*. Tidal restoration construction work was completed at the 460-ha Maurice River site in New Jersey in early 1988. (*a*) Tidal creek construction activity in 1995; (*b*) vegetation recovery of the site by *Spartina alterniflora* by June 2001. Restoration of the site by *Spartina* and other desirable vegetation occurred on 71 percent of the site after four growing seasons [(*a*) Courtesy of Ken Strait, PSEG; reprinted with permission from PSEG, Salem, New Jersey; (*b*) photo by W. J. Mitsch.]



(*a*)

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Figure 1.7 Biosphere 2, a 1.25-ha glass-enclosed mesocosm created in the Arizona desert, an example of ecological engineering in its extreme: (*a*) savannah, ocean, wetland, and desert containment; (*b*) intensive agriculture containment; (*c*) human living quarters. A 10-MW power plant (not pictured) is necessary to provide sufficient power to create sufficient water flow and air movement for various ecosystems to flourish in this high-CO_2 environment. Based on this project, it was estimated that to create such artificial ecological systems in place of nature providing the same services free would cost $1 billion per square kilometer per year (Mitsch, 1999). (Photos by W. J. Mitsch.)

1999). This is the cost we would incur to create our natural Earth in space, forgetting the cost to get there. The message of these estimates is of course clear: We should protect and enhance our Biosphere 1, allowing it to provide the services it provides and, in some cases, enhancing its ability to provide more.

Ecologists are now refining the techniques of restoring function in degraded ecosystems, and countless ecologists now call themselves restoration ecologists. Agricultural engineers, known for the efficiency with which they drained the landscape, are changing their names and their actions in many locations by restoring ditches to stream channels and farmlands to wetlands. Civil engineers, the nation's top river straighteners, are busy removing dams and restoring river meanders. The U.S. Army Corps of Engineers is now "greening" its mission to specifically include ecological restoration; some in that organization see themselves not only as the nation's water resource managers, but also as the nation's ecological engineers. Restoration and creation of ecosystems is now an industry.

1.1 FORTY YEARS OF ENVIRONMENTAL PROTECTION AND RESTORATION

We are approaching an age of diminishing resources where the growth of the human population continues and we have not yet found the proper means to solve local, regional, and global pollution and shortage of renewable resources. The first green wave that appeared in the middle and late 1960s was thought to offer feasible ways to solve pollution problems completely. Visible problems were mostly limited to point sources of air and water pollution and a comprehensive "end-of-the-pipe technology" (i.e., environmental technology) was developed and refined in that time to solve pollution problems. It was even seriously forecast in the early 1970s that what was called *zero discharge* could be attained for water pollution. For example, the U.S. Congress declared in the Clean Water Act in 1972 that all waters of the nation should be fishable and swimmable by 1983. The year came and went, yet half the rivers in the country were not "fishable and swimmable" as the act had stipulated just because the politicians said it should be. There were complications far beyond controlling industrial and municipal wastewater.

It became clear that zero-discharge or similar policies would be too expensive and that we should also rely on the self-purification ability of ecosystems. That outlook called for the development of environmental and ecological models to assess the self-purification capacity of ecosystems and to set up emission standards reflecting the relationship between impacts and effects in the ecosystems (Figure 1.8). In this case, models were used to relate an emission to its effect on the ecosystem, and toxicological studies were used to determine the effects on its components (e.g., fish). Those relationships were then used to determine a good solution to the environmental prob-

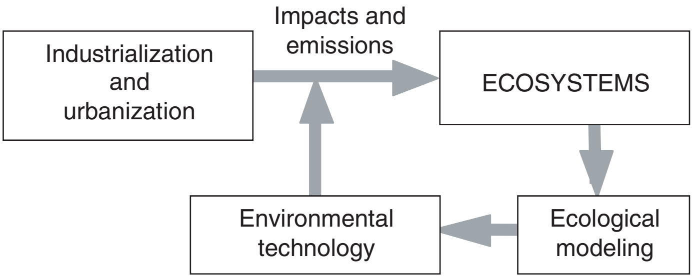

Figure 1.8 Strategy applied in environmental management in the early 1970s. An ecological model is used to relate an emission or discharge to its effect on the ecosystem and its components. The relationship is applied to the selection of a good solution to the environmental problems by application of environmental technology. (From Jørgensen and Bendoricchio, 2001; copyright 2001; reprinted with permission from Elsevier Science.)

lems by application of environmental technology (e.g., wastewater treatment systems).

Meanwhile, we have found that what we could call the environmental crisis is much more complex than thought. We could, for instance, remove heavy metals from wastewater, but where should we dispose the sludge containing the heavy metals? Resource management pointed toward recycling instead of removal. Nonpoint sources of toxic substances and nutrients, originating primarily from agriculture, emerged as new threatening environmental problems in the late 1970s. The focus on global environmental problems such as acid deposition, the greenhouse effect, and the decomposition of the ozone layer in the 1980s added to the complexity of the situation. It was revealed that we use as many as 100,000 chemicals that may threaten the environment, due to their more-or-less toxic effects on plants, animals, humans, and entire ecosystems. In most industrialized countries, comprehensive environmental legislation was introduced to regulate the wide spectrum of different pollution sources. Trillions of dollars have been invested in pollution abatement on a global scale, but it seems that two or more new problems emerge for each problem that we solve. Our society seems not to be geared to solving environmental problems, or is there perhaps another explanation?

The complexity and additional options of today's environmental management includes simultaneous application of environmental technology, cleaner technology, environmental legislation, ecological engineering, and ecosystem restoration (Figure 1.9). Traditional environmental technology offers a broad range of methods that are able to remove pollutants from water, air, and soil, and these methods are particularly applicable to cope with point sources. Cleaner technology explores the possibilities of recycling by-products or final waste products or attempts to change the entire production technology to obtain reduced emission. It attempts to answer the pertinent question: Couldn't we produce our product by a more environmentally friendly method?

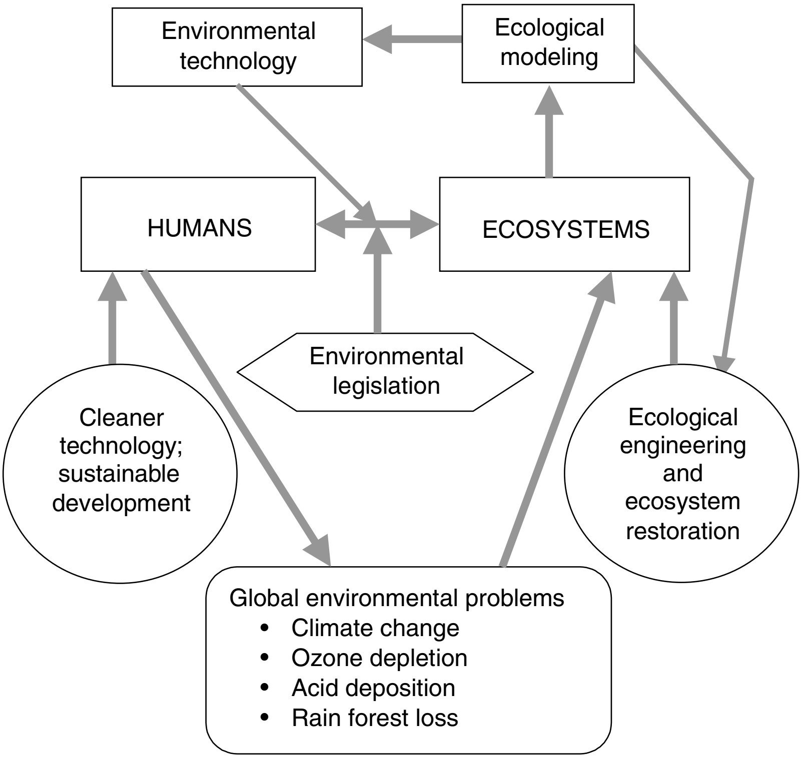

Figure 1.9 Environmental management in the twenty-first century is much more complex than the early approach shown in Figure 1.8. Models are still used in environmental management, but the management tools are more numerous and complex and include the approaches of environmental technology, cleaner technology and sustainable development (sometimes called *industrial ecology*), and ecological engineering / ecosystem restoration. Models can be used to select the best environmental management strategy. In addition, global environmental problems, which also require the use of models as synthesizing tools, have become important environmental issues with little solution except adaptation and pollution source reduction. (Redrawn from Jørgensen and Bendoricchio, 2001.)

To a great extent, the answer will be based on environmental risk assessment, life-cycle analysis, and environmental auditing. The ISO 14000 series and risk reduction techniques are among the most important tools in the application of cleaner technology. Environmental legislation and green taxes may be used in addition to the classes of technology. The fourth option—ecological engineering and ecosystem restoration combined—is the subject of this book.

Figure 1.10 shows the flows of material (and energy) in the history of a product, from raw materials to final disposal as waste. The exact number of products in modern technological society is not known, but it is probably on the order of 10^7 to 10^8. All these products emit pollutants to the environment

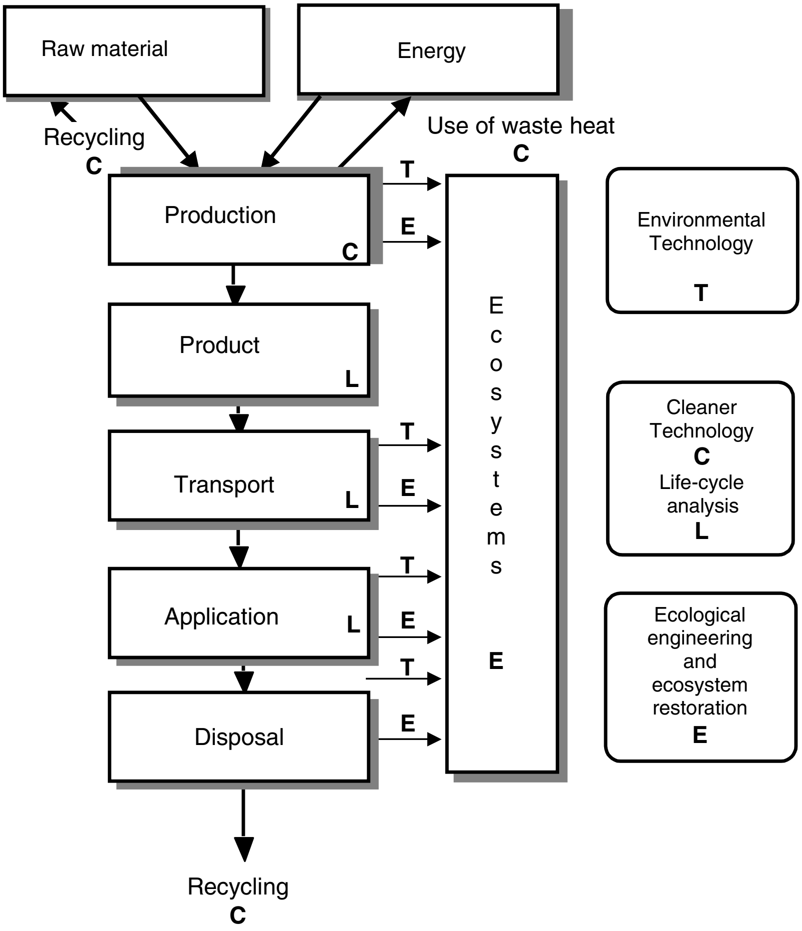

Figure 1.10 Pollution flow and possible approaches to its control. The large arrows cover mass flows and the thin arrows symbolize control possibilities. Production includes both industrial and agricultural production, the latter being mostly responsible for nonpoint pollution. Environmental technology (T) is applied on point pollution, while ecological engineering and ecosystem restoration (E) are needed for the solution of many ecological and environmental problems. Clean technology (C) explores the possibilities of changing the present production methods to obtain a reduction in pollution, either through recycling by-products and waste products or by a more-or-less radical change in the production technology. Life-cycle analyses (L) are used to determine where in the history of a product the pollution actually takes place, with the view to change the product, its transport, and/or its application. (Redrawn from Jørgensen, 2000.)

during their production, transportation from producer to use, application, and final disposal as waste. The core problems in environmental management are how to control pollutants properly and how to manage our ecological systems in this less-than-perfect world. The answer is that we must have a wide spectrum of methods. Notice that Figure 1.10 is based on the principles of conservation of matter and energy and on our wider use of ecosystem properties in environmental management. Environmental legislation and green taxes are not included in Figure 1.10, as they may in principle be used as regulating instruments in every step of the flow from raw materials and energy to final waste disposal of the product used.

From this short introduction to environmental management and the wide spectrum of methods that can be implemented to solve environmental problems, we can conclude that environmental management is a very complex issue. A local environmental problem may be solved by selection of another raw material or energy source, by a partial or complete change in the method of production, by increased use of recycling, by selection of the proper combination of technological methods taken from any of the four aforementioned classes of technologies, by a slight change in the properties of the product, by a combination of environmental technology with recovery of the ecosystem affected, and so on. The number of possible solutions is enormous, yet the environmental management strategy should attempt to find the optimum solution from an economic–ecological point of view.

Two major forces can lead to apathy: naive technological optimism—the idea that some technological wonder will always save us regardless of what we do, and gloom and doom pessimism—the idea that nothing will work and our destruction is assured. Ecological and environmental problems are very complex and difficult to solve. The best starting point to solving the complex and difficult problems must be an understanding of the nature of the problems. Ecological principles and ecological methods can then be employed to solve some of them.

1.2 WHY ECOLOGICAL ENGINEERING AND RESTORATION ARE NEEDED

The state of our environment, combined with a dwindling in nonrenewable natural resources available to solve environmental problems, suggests that the time has come for a new paradigm that involves ecosystem- and landscape-scale questions and solutions. There are a great number of environmental and resource problems that need an ecosystem approach, not just a standard technological solution. We have finally recognized that we cannot achieve complete elimination of pollutants, owing to a number of factors, and that we need new approaches better attuned to our natural ecosystems. In our attempts to control our own environment, we have also seen that we have tried to control nature too much at times, with disastrous consequences such as enormous floods, invasive species, air and water pollution being transported hundreds and thousands of kilometers instead of a few kilometers, and the production of massive quantities of solid wastes that need disposal or use somewhere. But why now, and why do we suggest this new field, especially to include engineers, whom many blame for the difficult situation in which we now find ourselves?

Limited Resources

There is a finite quantity of resources to address to the problems of pollution control and natural resource disappearance. This is particularly true for developing countries that wish to have the standard of living and technology of developed countries but currently must deal with pollution problems often more serious than those in the developed world. The limited resources and the high and increasing human population force us to find a trade-off between the two extremes of pollution and totally unaffected ecosystems. We cannot and must not accept a situation of no environmental control, but neither can we afford zero-discharge policies, knowing that we do not provide one-third of the world's population with sufficient food and housing.

Three pronounced developments have caused the environmental crisis that we are now facing: the growth in population, industrialization, and urbanization. Figure 1.11 illustrates world population growth, past and projected. From the graph it can be seen that population growth has experienced decreasing doubling time, which implies that growth is more than exponential (exponential growth corresponds to a constant doubling time). The growth of population from 1 billion to 2 billion people took about 100 years, whereas the next doubling in population took only 45 years. The net birth rate at present is about 370,000 people per day, while the death rate is 150,000 per day. The population growth is determined by the differences between the two: population increase = birth rate − death rate. The present growth rate implies that the world's population is increasing by more than 200,000 people per day, or about 1.5 million per week, corresponding to more than 80 million per year.

Renewable resources are those that can maintain themselves or be replenished continuously if managed wisely. Food crops, animals, wildlife, air, water, forest, and so on, belong to this class. Land and open space can also be considered renewable, but they shrink as the population increases. Although we cannot run out of these resources, we can use them faster than they can be regenerated, or by using them unwisely, we can affect the environment. Other resources, such as fossil fuels and minerals, are nonrenewable resources, whose finite supplies can be depleted. Theoretically, some of these resources are renewable, but only over hundreds of millions of years, whereas the time scale of concern to humans is only hundreds of years. When we talk about finite supplies of resources, we should qualify this by discussing finite supplies of substances presently considered to be resources. Often, our most

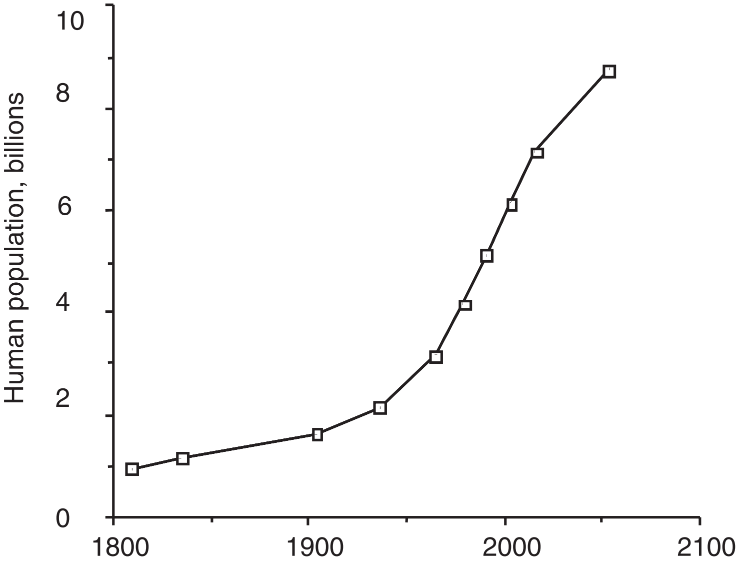

Figure 1.11 Human population through the nineteenth and twentieth centuries and projection to the year 2050. An optimistic prognosis is applied which predicts that population growth rate will begin to decrease after the year 2015. In the period 1805–1975, population growth was more than exponential. Even with a slowing growth rate in the first half of the twenty-first century, human population is expected to almost double from its level in 2000 to 9 billion by the year 2050.

important consideration is whether the pollution costs of extraction and use of a resource outweigh its benefits as population or per capita consumption increases.

The Shell Game

When we control pollution through technological means, we are often playing a shell game with the pollution. There are many examples of how traditional environmental technology removes pollutants from one medium and sends them to another. Toxic substances present in municipal wastewater cannot be biodegraded in a mechanical–biological wastewater treatment plant but will depend on the water solubility found either in the treated water or in the sludge. If the sludge is used as a soil conditioner in agriculture, the toxic substance will contaminate the soil. If the sludge is incinerated, it may cause air pollution or be found in the ash.

We use scrubbers to prevent sulfur emissions from power plants and are then faced with enormous solid waste storage problems from the sludge left behind. We build solid waste facilities and water pollution control systems, and the result can be atmospheric emissions of the greenhouse gas methane. We use industrial wastewater treatment methods to remove heavy metals from a factory and are left with a metal-rich sludge. We burn sludge and solid wastes and create air pollution problems. We are moving materials around in a shell game—if they are not under one shell, they are under another.

Climate Change and the Secondary Pollution Effect

During the last few decades we have observed a distinct increase in different types of pollution. The concentrations of carbon dioxide and other greenhouse gases in the atmosphere have increased uniformly and throughout the world in the past century. Concentrations of many toxic substances have increased in soil and water, and the ecological balance has been changed in our ecosystems. In many major river systems, oxygen depletion has been recorded more often, and many recreational lakes and coastlines are suffering from eutrophication as a result of high concentrations of nutrients—mainly nitrogen and phosphorus.

We are now confronted with the fact that seemingly inert carbon dioxide (CO_2)—the principal gas emitted by our own respiratory system—has increased by 20 percent in the twentieth century, due primarily to the increased use of fossil fuels (Figure 1.12). This continuing increase is now considered to be the chief cause of change in our climate. International efforts such as the Kyoto Treaty are now attempting to limit the burning of fossil fuels to minimize future climate effects, although many fear that climate changes are already inevitable, even with drastic fuel use reductions. Environmental technology is often fossil fuel–based. When expensive environmental technology is used to solve a pollution problem, we are solving a problem of one type and may be contributing to another through an increase in the global emissions of CO_2. Often, we have used a great amount of fossil fuel in the economy to develop that technology. The amount of energy used is generally proportional to the cost of the technology, and the CO_2 emission is proportional to the amount of fossil fuel used. The use of alternative "nature-based" technologies and low-cost technologies is therefore vital in overall pollution abatement.

Figure 1.12 also illustrates a more dramatic change in our environment that is slowly leading to eutrophication of the planet. Bioavailable nitrogen essentially doubled in the twentieth century, due to nitrogen fertilizer production and use, increased nitrogen fixing in cultured plants, and release of nitrogen from long-term soil storage because of land drainage. Humans are essentially eutrophying the planet, causing dramatic shifts in the ecology of both natural ecosystems such as estuaries and restored systems such as grasslands, forests, and wetlands. Restoration of ecosystems to systems remembered from publications and maps from the nineteenth century may be impossible because of this change; restoration that includes adapting to this change is a better approach.

What has caused this sudden increase in pollution? The answer is not simple, but the growth in population is obviously one factor that influences

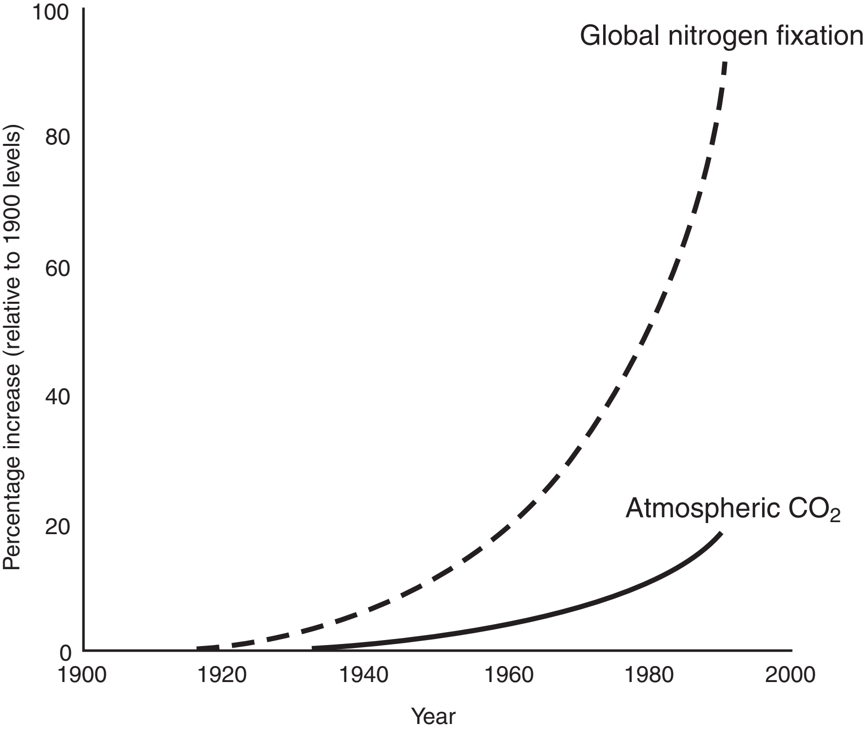

Figure 1.12 Pattern of atmospheric carbon dioxide and bioavailable nitrogen in the twentieth century. (Redrawn from Vitousek et al., 1997.)

our environment. Other factors include our rate of consumption, the type and amount of waste we produce, and the fact that consumption of resources in the production of environmental technology leads to an even greater production of secondary pollution. The economy that supports this technology is consuming fossil fuels while producing CO_2 and emitting nitrogen to the biosphere.

A Sustainable Society

Since we cannot solve all our environmental problems through high-technology solutions alone, and since our energy future appears quite clouded, we must investigate alternative means of cleaning the environment. Ecotechnology and ecological engineering will play a significant role in a sustainable society. *Sustainability* has become one of the buzzwords of our time, used again and again in the environmental debate—sometimes in the wrong context. It is therefore important to provide a clear definition here to avoid misunderstandings later in the book. The Brundtland report (World Commission on Environment and Development, 1987) produced the following definition:

Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs. Note that this definition includes no reference to environmental quality, biological integrity, ecosystem health, or biodiversity. Klostermann and Tukker (1998) discuss sustainability as based on product innovation and introduce the concept of *ecoefficiency,* the reciprocal of the weighted sum of the environmental claims, including ecological impacts and draws on renewable and nonrenewable resources.

Conservation philosophy has been divided into two schools: *resourcism* and *preservationism*. These are understood, respectively, as seeking maximum sustained yield of renewable resources, and excluding human inhabitation and economic exploitation from remaining areas of an undeveloped nature. These two philosophies of conservation are mutually incompatible. They are both reductive and ignore nonresources, and seem not to answer the core issue: how to achieve sustainable development, although preservationism has been retooled and adapted to conservation biology.

Lemons et al. (1998) gave a more down-to-earth solution by formulating the following rules:

1. *Output rule.* Waste emission from a project should be within the assimilative capacity of the local environment to absorb without unacceptable degradation of its future waste absorptive capacity or other important services.
2. *Input rule.* Harvest rates of renewable resources inputs should be within the regenerative capacity of the natural system that generates them, and depletion rates of nonrenewable resource inputs should be equal to the rate at which renewable substitutes are developed by human invention and investment.

An Overdue Alliance

Engineering and ecology are ripe for integration into one field, rather than following separate approaches, which are often adversarial. Ecology as a science is not routinely integrated in engineering curricula, even in environmental engineering programs. Engineers thus miss the one science that could help them most in environmental matters. Similarly, environmental scientists and managers are lacking an important element in their profession—problem solving. Although tremendously competent in describing problems and perhaps even in managing ecosystems one species at a time, ecologists are not well versed in prescribing solutions to problems. The basic science of ecological engineering is ecology, a field that has now matured to the point where it needs to have a prescriptive—rather than just a descriptive—aspect.

Nature Needs Help, Too

Most of the discussion above is on solving human problems, with little discussion of the impact on nature of what we do. We solve human problems and create problems for nature. That has been the history of humankind, at least in the Western world. We need to adopt approaches to solving environmental problems not only for our human well-being but also to protect streams, river, lakes, wetlands, forests, and savannahs. We need to work symbiotically with nature where we use her public service functions, but recognize the need to conserve nature as well. The idea of nature conservation is so important that it needs to become a goal of engineering, not just one of its possible outcomes. We must seek additional approaches to reducing the adverse effects of pollution while preserving our natural ecosystems and conserving our nonrenewable energy resources. Ecotechnology and ecological engineering offer such additional means for coping with some pollution problems, by recognizing of the self-designing properties of natural ecosystems. The prototype machines for ecological engineers are the ecosystems of the world.

Ecological Engineering Is Already Happening Anyhow

Ecological engineering is now, in effect, being practiced by many professions under a great variety of names, including *ecotechnology, ecosystem restoration, artificial ecology, biomanipulation, ecosystem rehabilitation, nature engineering* (in the Netherlands), *hydroecology* (in eastern Europe), and *bioengineering*. But little theory backs these practices. Engineers are building wetlands, lakes, and rivers with little understanding of the long-term biological integrity of these systems. Ecologists and landscape architects now design ecosystems with homespun methodologies that must be relearned each time. Engineers and ecologists who design and construct ecosystems use cookbooks that do not always work and often do not publish their successes and failures in the open literature. Theory has not yet connected with the practice.

Some of the ecotechnological methods presented in the book are not new; some have in fact, been practiced for centuries. In earlier times these methods were considered good empirical approaches. Today, ecology has developed sufficiently to understand the scientific background of ecological engineering, to formalize use of these approaches, and to develop new ones. We must understand not only how we can influence the processes in the ecosystem and how the ecosystem components are linked together, but also how changes in one ecosystem can produce changes in neighboring ecosystems.

1.3 APPROPRIATE TIMING FOR ECOLOGICAL ENGINEERING

We must acknowledge that there are now 2 billion more people on Earth than there were 20 years ago, and that the nonrenewable resources are more limited. We therefore need to find new ways to approach environmental concerns. We have attempted to solve problems through the use of available technology. Unfortunately, those attempts have partially failed. Therefore, we must think more ecologically and consider additional means. If applied properly, ecological engineering and ecosystem restoration are based on ecological considerations and attempt to optimize ecosystems (including limited resources) and human-made systems for the benefit of both. It should therefore afford additional opportunities for solving the crisis. We have had several energy crises during the past 30 years, and we know that new crises will appear in the future. Therefore, we have to rely more on solar-based ecosystems, which are the bases for ecological engineering.

In the short term, ecological engineering could bring immediate attention to the importance of "designing, building, and restoring ecosystems" as a logical extension of the field of ecology as it applies directly to solving environmental problems. In the long term, it will provide the basic and applied scientific results needed by environmental regulators and managers to control some types of pollution while reconstructing the landscape in an ecologically sound way. Formalization of the idea that natural ecosystems have values for humans other than directly commercial ones is also a benefit of ecotechnology and will go a long way toward enhancing even further a global ecological conservation ethic.

1.4 ECOLOGICAL ENGINEERING AND OUR EDUCATIONAL SYSTEM

Environmental problems are by definition multidisciplinary, but our educational systems are not. There is a need in environmental management for integration of disciplines, particularly between ecology and engineering, as emphasized in this book. Ecological training in schools and universities—at least at the ecosystem scale needed for solving many of our ecological problems—is often out of date and not taught well in biology-dominated programs. Ecology is considered by many to be a subset of biology, but the opposite is true; it is often taught far better in environmental science or similar programs. Aside from a recent frenzy in restoration ecology that is still not focused, it is unlikely that one can get a proper education in restoring and creating ecosystems in traditional biology programs. Similarly, engineers have not taken the demands and value of ecosystems into consideration in their development of technologies and their planning of production. Biology and ecology have scarcely been mentioned in undergraduate engineering education, partially because most engineers view ecology as what is portrayed in the popular press rather than as a substantially quantifiable science. An improperly trained engineer is a danger in ecological restoration.

A far better integration of disciplines is urgently needed for repairing the planet. Our higher educational system has for many years encouraged specialization. Plaudits have been given to scientists or experts who fully mastered a very narrow problem or topic, and analyses have been more appreciated than syntheses. But this system has created isolation from other problems and topics and has paralyzed interaction among disciplines. The result has been that ecologists have often not understood the need for quantifying ecosystems and dealing with applications of ecology in a technological framework. Therefore, we have been slowed by our educational system in solving environmental problems properly. Engineers want to quantify everything and lose appreciation for the many ecological pathways and feedbacks that need to be considered. A much more integrated education is urgently needed in the future if we are to find the right environmental solutions, asking the relevant questions and considering human society and ecosystems as an entity.

This does not imply that we should develop educational systems and curricula that give all students a little knowledge about everything. That type of “cafeteria” educational approach has been discredited in many circles, and we concur. Rather, we need to educate fundamentally sound generalists as well as specialists. Specialists must be taught to work together on multidisciplinary projects. Such collaboration will force specialists to understand other languages, it will prevent isolation, and it will encourage cooperation and coordination. Future students must devote some time to learning what other disciplines can offer.

The science of ecology is expected to continue its progress, and owing to the rapid growth of computer technology, we shall be able to describe and solve more and more complex ecological problems. However, a better general ecological understanding is needed by our politicians and the entire population, too, if we are to use ecological engineering successfully in the future. Such understanding will not come with a more complex technology if our educational system lags behind. Therefore, better ecological education with multidisciplinary aspects is needed urgently. Ecology should be introduced as a basic and compulsory subject at all school levels, including the elementary. It should be as required in our basic college education together with the humanities, social sciences, and chemistry.

1.5 FUTURE OF ECOLOGICAL ENGINEERING

Our experience with the formal fields of ecological engineering and ecosystem restoration is limited, but our experience is growing exponentially. We have had one decade of formal peer-reviewed experience in the journals *Ecological Engineering* and *Restoration Ecology*, two professional societies, and a few academic settings in the world where the fields are beginning to be taught. Although current results look very promising, we need to integrate the application of ecological engineering and ecosystem restoration much more in our pollution control and environmental planning in the future. Thus, continuous development of systems ecology, applied ecology, ecological modeling, and ecological engineering is much needed to complement the basic science of ecology. Ecological engineering and ecosystem restoration offer us a very useful tool for better planning in the future. It will be a challenge to humankind to use properly the tools that develop in this field. If we do, the twenty-first century can be an ecological century to which we can very much look forward.