

DORK SAHAGIAN

# A USER'S GUIDE FOR PLANET EARTH

FUNDAMENTALS OF ENVIRONMENTAL SCIENCE



NEWLY REVISED SECOND EDITION

# A User's Guide for Planet Earth

Fundamentals of Environmental Science

*Newly Revised Second Edition*

Dork Sahagian

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# Preface

**T**HERE ARE MANY well-written and comprehensive books available from numerous authors and publishers on the subject of Environmental Science. However, there are two major issues outstanding for which this book was written. The first is that most introductory Environmental Science textbooks, while beautifully produced, include so many case studies, examples, horror stories, and human interest anecdotes, that the main scientific points can become lost or at least diluted in large volumes of text and pretty pictures. For this reason, this book focuses on the science involved, in an attempt to make the main points clearer to the student (and professor) in a one-semester introductory course. As such, this book is by no means comprehensive. This book was conceived in days of virtually unlimited free information access, when any topic can be searched on-line and facts and figures, along with a multitude of photographs, can be found for any environmental event, regulation, or technology (with the usual precautions about web searches, “alternative facts,” etc.). As such, no attempt is made to repeat all that in this textbook. Rather, we focus on helping the student understand the processes that control the physical, chemical, biological, and human components of the environment, and how they interact to drive the behavior of the Earth System. “How does the greenhouse effect work?” “What do air conditioners have to do with skin cancer?” These are the kinds of questions the student will be able to answer after reading this book, rather than “How big was the last oil spill?”

The second reason for writing this somewhat unusual Environmental Science textbook is the more mundane question of money. Environmental Science textbooks have reached astronomical prices, a situation poorly suited for a field that is changing so rapidly that books become outdated by mid-semester. Without a used book market in which students can engage, these expensive books end up on dusty shelves, or worse yet are tossed (hopefully recycled) after the class is done. This is no way for Environmental Science to be conducted. With this less rotund and much less expensive volume, the intent is that course material can be presented clearly and concisely, and should it be rendered out of date in the coming months by analysis of another coastal storm, photovoltaic discovery, or satellite observation, for instance, that refines our understanding of the environment, it is less of a loss to the student, school library, or college professor. It will be readily updated.

Both these reasons bring to mind the landmark book and subsequent documentary film by former Vice President Al Gore, *An Inconvenient Truth*. Learning the facts and concepts involved in environmental science should not be inconvenient or expensive. As such, one might consider this book a more “convenient truth” that is accessible to students and the general public alike. With this in mind, we will explore the various topics that help us understand not only the specific details of environmental problems, but also the way these interact to control the behavior of the Earth System.

Like the first edition, this second edition of the book is organized in such a way that provides the student with an exploration of several key background issues that lay the foundation for understanding the processes and drivers that control the behavior of the environment. It then delves into the main environmental systems of ecosystems, biogeochemical cycles, water, agriculture, oceans, human health, energy, and climate, culminating in a discussion of the Earth System. Definitions of key bolded terms are found in the margins of the same page, as are a few worked problems as examples for the student. Journal articles from the primary literature are included at the end of each chapter for references and research.

This book was written with college freshmen in mind. It assumes no prior courses in environmental science, Earth science, or related disciplines.

# What Is the Environment, How Do We Study It, and Why Does Anyone Care?

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*What is the environment? Why should we care?  
Conditions are changing—we'd better beware.  
Let's take a good look  
As we read through this book  
Some ways to preserve our food, water, and air!*

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**S**IMPLY PUT, THE environment is the physical and biological surroundings in which life on the planet is sustained. This includes climate, ecosystems, water, and all the interactions between these systems and energy from the sun that supports the functioning of the Earth System. The physical environment would persist in the absence of life, of course, but as living organisms ourselves, we are most interested in how life and the physical environment interact (Figure 1.1) and in what ways, as humans who can (and do) have a great impact on the environment, we can develop sustainable approaches to land use, emissions, and general resource utilization.



**FIGURE 1.1** The Earth's environment is a complex system of interacting processes between the solid earth, soils, oceans and other water, the atmosphere, and living organisms. Each part of the global environment depends to various degrees on all the other parts.

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## Environmental Goods and Services

Centuries ago, in Europe and other parts of the world, the environment was a frightening concept that brought storms, floods, predators, disease, and death to people and their families, and thus was something to fight against in order to sustain humanity. As knowledge and technology advanced, humans became very adept at altering their environment to suit their needs, such as personal security from predators, disease, and the elements; availability of food for a growing population; and resources for a growing industrial complex that became increasingly efficient at converting natural resources into useful or otherwise desired products. For centuries, the environment was the venue where such natural resources could be found, and found they were, underground in mines, at the surface in soils, in streams, groundwater and the ocean, in the myriad ecosystems globally, and in the atmosphere. The environment became a fountain of goods and services to provide people with whatever they wanted, with little thought given to replacing anything that was removed or destroyed in the process. There was plenty more where that came from. Humanity (in its increasingly vast numbers) became so efficient at exploiting natural resources that the rate at which resources were desired began to exceed the rate at which the global ecosystems could provide them, leading to concerns about sustainability (Figure 1.2).

The types of environmental goods and services most useful to the technologically developing societies in recent centuries include (see Table 1.1):



**FIGURE 1.2** EPA research ship, *Lake Guardian*

With careful monitoring of environmental conditions in the atmosphere, soils, rivers, lakes, and oceans the U.S. Environmental Protection Agency and many others can observe the health of both the living and physical parts of our environment so that hazardous conditions can be avoided and the most active production of ecosystem goods and services can be maintained.

## GOODS:

- Fresh water (clean and plentiful)
- Fertile soil (for growing crops)
- Fish (from the ocean)
- Wood and fiber (for construction, clothing, etc.)
- Fuels (for heating, transportation, electricity generation, industry)
- Special or exotic materials (for medicines, specialized applications, etc.)
- Minerals (for construction, products, various industries, ornaments)

## SERVICES:

- Net Primary Production (Conversion of CO<sub>2</sub>, H<sub>2</sub>O and sunlight into biomass and oxygen)
- Water cycling (water availability for drinking, agriculture, and transportation)
- Climate regulation (temperature, rainfall, storm tracks, winds, etc.)
- Atmospheric composition regulation (CO<sub>2</sub>, O<sub>2</sub>, contaminant and radiation absorption)
- Physical protection (from storms, tidal surges, floods)
- Water purification (removal of sediments, contaminants)
- Soil retention (prevention of wind and water erosion)
- Waste regulation (breaking down biological wastes)
- Nutrient cycling (N, K, P, etc.)

## Equilibrium of Processes within the Environment

There is a multitude of processes constantly operating throughout the Earth System, and the interaction between these controls the nature of the environment at all scales. Examples of processes include radiative balance between incoming solar radiation and outgoing infrared from the earth; the cycling of carbon and nutrients between various **reservoirs** in the solid, liquid, gaseous, and living parts of the environment; predation between animals; and the movement of water in the hydrologic cycle. These and many other processes interact with each other, such that a steady state is maintained in the amount of material stored in various reservoirs (e.g., CO<sub>2</sub> in the atmosphere, nutrients in the soil, fish in the sea, water in aquifers, etc.) and in the fluxes of energy and materials between reservoirs.

**Reservoirs:** Places where a stock (amount of stuff) is stored, at least temporarily. Reservoirs are characterized by how much they contain, as well as the fluxes in and out.

### FIGURE IT OUT

Describe two environmental goods and two services YOU value most highly. Why are these most important to you?

**TABLE 1.1** ECOSYSTEM FUNCTIONS AND SERVICES

Ecosystem functions and services	Examples
Nutrient cycling (storage, processing, and acquisition of nutrients within the biosphere)	Nitrogen cycle; phosphorus cycle
Net primary production (conversion of sunlight into biomass)	Plant growth
Pollination and seed dispersal (movement of plant genes)	Insect pollination; seed dispersal by animals
Habitat (the physical place where organisms reside)	Refugium for resident and migratory species; spawning and nursery grounds
Hydrological cycle (movement and storage of water through the biosphere)	Evapotranspiration; stream runoff; groundwater retention
Water supply (filtering, retention, and storage of fresh water)	Provision of fresh water for drinking; medium for transportation; irrigation
Food (provisioning of edible plants and animals for human consumption)	Hunting and gathering of fish, game, fruits, and other edible animals and plants; small-scale subsistence farming and aquaculture
Raw materials (building and manufacturing; fuel and energy; soil and fertilizer)	Lumber, skins, plant fibers, oils, dyes; fuelwood, organic matter (e.g., peat); topsoil, leaves, litter, excrement
Genetic resources (genetic resources)	Genes to improve crop resistance to pathogens and pests and other commercial applications
Medicinal resources (biological and chemical substances for use in drugs and pharmaceuticals)	Quinine; Pacific yew; Echinacea
Gas regulation (regulation of the chemical composition of the atmosphere and oceans)	Biotic sequestration of carbon dioxide and release of oxygen; vegetative absorption of volatile organic compounds
Climate regulation (regulation of local to global climate processes)	Direct influence of land cover on temperature, precipitation, wind, and humidity
Disturbance regulation (dampening of environmental fluctuations and disturbance)	Storm surge protection; flood protection
Biological regulation (species interactions)	Control of pests and diseases; reduction of herbivory (crop damage)
Water regulation (flow of water across the planet surface)	Modulation of the drought-flood cycle; purification of water
Nutrient regulation (maintenance of major nutrients within acceptable bounds)	Prevention of premature eutrophication in lakes; maintenance of soil fertility
Ornamental resources (resources for fashion, handicraft, jewelry, pets, worship, decoration, and souvenirs)	Feathers used in decorative costumes; shells used as jewelry

Modified after: Farber, S., R. Costanza, D. L. Childers, J. Erickson, K. Gross, M. Grove, C. S. Hopkinson, J. Kahn, S. Pincetl, A. Troy, P. Warren, and M. Wilson. 2006. "Linking Ecology and Economics for Ecosystem Management: A Services-Based Approach with Illustrations from LTER Sites." *BioScience* 56:117–129.

The ability of the Earth System to maintain equilibrium conditions depends on the presence of negative feedbacks within the various component subsystems, as we will explore in Chapter 3. With a suite of such stabilizing feedbacks, the Earth has maintained a surface temperature between the freezing and boiling points of water for billions of years. (However, there is evidence of several “snowball Earth” events that occurred between about 750 and 650 million years ago, each lasting perhaps millions of years, during which the planet was almost completely frozen over until feedbacks drove warming to melt the ice.)

## Human Perturbations

The equilibrium of Earth System processes has been maintained for billions of years because with few exceptions, the fluxes (and changes in fluxes) of materials between reservoirs have been slow relative to the size of the reservoirs. Humans were the first species (that we know of) that learned to influence the environment at rates that drastically altered some key fluxes, and thus reservoirs, throughout the Earth System. This was accomplished in two basic ways: cutting and burning, with the invention of the saw (axe) and the discovery of fire. In the broader sense in the modern world, this involves land use and emissions, the two primary means by which people affect (usually adversely) the environment.

**Emissions:** Chemicals (usually liquid or gaseous) that are expelled into the environment (atmosphere or water bodies) as a result of human activities, such as fossil fuel burning. Of particular interest are emissions of greenhouse gases into the atmosphere.

A major human perturbation is **emissions** from burning of fuels such as coal, oil, gas, and wood (Figure 1.3). While

wood burning has occurred since man discovered fire, it was originally done at a slow rate, such that the regrowth of trees could keep up with cutting. In many places today, it is cut much faster than it can regrow, and is thus non-renewable. (Renewable and non-renewable energy sources will be explored in Chapter 11.) Further, and much more significantly, fossil fuels were discovered. These could produce a great deal of energy, as they contained the equivalent of millions of years of the Sun’s energy concentrated and stored in the chemistry of coal, oil, and natural gas that could be combined with atmospheric oxygen to produce heat,  $\text{CO}_2$ , and in the case of oil and gas, water vapor. While the  $\text{CO}_2$  and water were discarded to the atmosphere (Figure 1.4), the heat was used to cook, heat buildings, drive turbines to generate electricity, and operate motors for vehicles of all kinds.



**FIGURE 1.3** Oil Platform

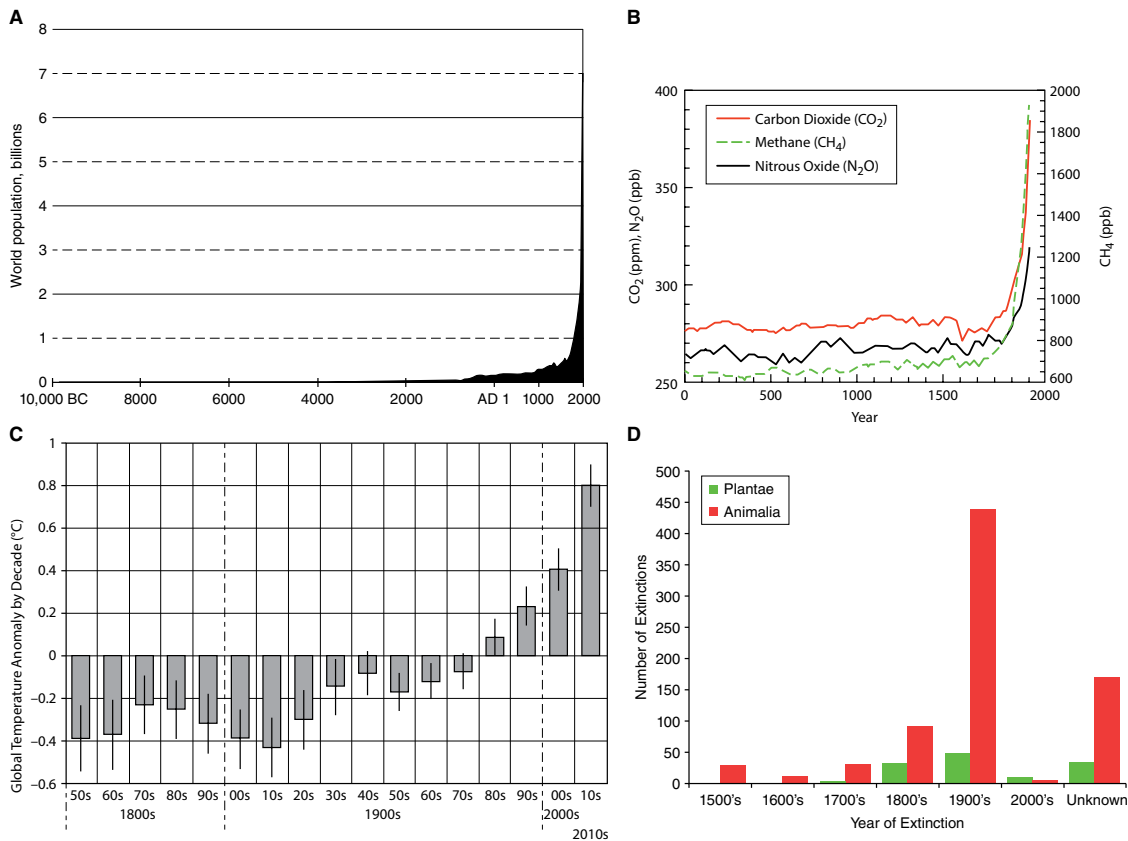
Fossil fuels have been the primary source of global energy production since the industrial revolution in the mid-19th century. While the local pollution impacts of mining, processing, and distributing coal, oil, and natural gas are significant, the most significant impact may be in their actual use by burning and thus conversion to  $\text{CO}_2$  released to the atmosphere. This leads to global climate change in ways that are becoming ever more clear as we continue to burn fossil fuels at an increasing rate. This will be further explored in Chapters 12 and 13.

Early industrial societies were focused on the value of the energy to be extracted from fossil fuels, but did not consider the role of the rest of the combustion process in altering the environment. While the greenhouse effect and the role of CO<sub>2</sub> has been understood since before the industrial revolution, it was assumed impossible for people to actually alter anything so vast as the atmosphere and the planetary energy balance. It has since been revealed that the burning of fossil fuels has released sufficient CO<sub>2</sub> (and other greenhouse gases) into the atmosphere to drastically alter the radiative balance between the earth and the sun. Since the industrial revolution (mid-19th century), we have increased atmospheric CO<sub>2</sub> concentration from about 280 ppm to a 2018 level of over 400 ppm. This rate of change of atmospheric composition is unprecedented in Earth history. In effect, we are conducting an experiment on the planet. Take a planet, drastically alter atmospheric composition to perturb the radiative balance with its star (also change the land cover so you can further alter the atmospheric chemistry), and drive the system until temperature, ice cover, land cover, biome distribution, water temperature, and air/water circulation are profoundly out of equilibrium with each other. Stand by and see what happens. (Scientists love this sort of thing.) Of course, it might be more convenient to conduct this experiment on a planet we didn't actually need to live on ...

**Land use** is another major human perturbation and stems from the evolution of societies from hunting/gathering to agriculture. Climate became relatively stable after the last glacial period at the start of the Holocene Epoch, about 12,000 years ago. This is said to have enabled the people of the time to stop chasing migrating resources north and south, and settle down to plant crops for a more stable and productive food source by 10,000 years ago. This, of course, led to increasing population, as more people could be fed from specialized crops than from the limited number of (parts of) plants that could be eaten in the natural ecosystems available to them. This led to further destruction of the ecosystems in favor of planting more crops to feed more people. At the time, people were unaware of the various goods and services being provided to them by the environment, and some cultures collapsed due to inadvertently “biting the hand that fed them” (e.g., Easter Island). At a much larger scale, this is beginning to occur globally now, which is the cause for concern by many scientists and others throughout the world.

Land use over the last few centuries has involved massive deforestation, first of northern regions (e.g., Europe, North America) and more recently the tropics, where highly productive rainforests are found. Elimination of northern forests in favor of farmland began to erode soil that had taken centuries to millennia to develop, and it is still being eroded today (with about half of America's fertile topsoil already gone). However, with modern industrial farming methods, large corporate farms have taken over the market, leaving subsistence or otherwise small farmers to find other employment. This has led to regrowth of many of the forests in eastern North America. Meanwhile, deforestation of the tropics

**Land use:** The destruction of natural ecosystems by conversion to some other land cover, such as agriculture, industry, or residential (mostly agriculture).



**FIGURE 1.4A-D** Trend Graphs

Critical observational trends show the importance of humanity in the Earth System. The recent human population explosion has led to altered atmospheric chemistry, while intensified land use for agriculture has caused a new “mass extinction” of species globally. Greenhouse gas emissions and land use have combined to lead to observed climate change, which is predicted to change further in the coming decades.

has accelerated, but the soil in rainforests is very thin and fragile, with little carbon and few nutrients stored in the soil (most is stored in litterfall and decaying vegetation). Once the surface is cleared for agriculture, the soil fails very quickly, and in just a few years, the farms become unproductive, with loss of the ecosystem as well as all the services it had been providing. It is difficult for such an ecosystem to redevelop once it is destroyed over a large area.

The loss of forests and other ecosystems eliminates all the goods and services they provide, most notably at the global level, the sequestration of CO<sub>2</sub> out of the atmosphere. As such, the emissions from fossil fuel burning that would potentially be alleviated by ecosystem uptake remain in the atmosphere, leading to an exacerbated greenhouse effect and global warming. This will be explored further in Chapters 12 and 13.

## The Commons

In an “open world” in which the impact of humans is negligible, and the amount of energy and resources available is effectively infinite, people would be able

to take what they need from the environment, discard what they don't want, and the Earth System could easily regenerate, absorb, or reprocess in a way that would make people feel as if they could live as they like forever. This was the case for millennia, until recent centuries, when technology advanced and human population exploded. When anyone is authorized to remove natural resources from the environment but no one is responsible for maintaining or replacing those resources, the resources become depleted, contaminated, or destroyed, making them unavailable for the future. This is called the “**tragedy of the commons**” and has already occurred in many parts of the environment. The commons is any communal natural resource (such as a community grazing pasture, or the fish in the ocean, or even the atmosphere). To date, there has been little regulation of the commons, and these resources are being depleted to the point of uselessness, in addition to obliterating the parts of the global ecosystem of which they are a part, thus losing many essential ecosystem goods and services upon which we rely as a modern society.

The tragedy of the commons was a term coined by Garrett Hardin in 1968, when he presented the idea that any property held in common, but that no one is responsible to maintain, will deteriorate (Hardin, 1968). His example was of cattle herders with access to a community grazing ground (Figure 1.5). While it was available to all to use, there was no limit, nor was there anyone responsible for maintaining (or even monitoring) the usability of the common resource. From the perspective of an individual herder, it was to his advantage to add more cattle to graze. After all, he did not have to pay for the grazing rights, did not have to replace the grass that was eaten, and was able to profit personally from the sale of the milk and meat from the cattle.

The cost of overgrazing the common land was not borne by the individual who added more cattle, but to the community as a whole. Thus each individual kept the profit, yet transferred the cost to the community. Naturally, since everyone was doing this, there was no net gain for anyone, and the commons was destroyed—the tragedy of the commons. This should have been no surprise, as even Aristotle of ancient Greece knew that “What is common to the greatest number has the least care bestowed upon it.” The tragedy of the commons emerges from the practice of externalizing costs of an activity while internalizing the profits. This is what the herders were doing, and what ocean fishermen do, as well as oil companies, farmers, and many others, who exploit natural resources at a

**Tragedy of the commons:**

Destruction of publicly available environmental goods or services caused by over-utilization due to free availability to all with no one responsible for maintenance and sustainability.



**FIGURE 1.5** Cattle herd

Cows evolved to eat grass. People cannot eat grass (or at cannot digest it to gain energy from it). Therefore, when people eat grass-fed beef, they can extract at least a fraction of the energy stored in grass. However, if people eat corn-fed beef, they lose most of the energy stored in corn because people can eat corn directly. The reasons for this are explored in Chapter 5.

profit while transferring the environmental and other costs to others, either in time or in space. Especially important commons being degraded at present are the oceans (fish, ability to absorb carbon from the atmosphere and contaminants from the land), atmosphere (ability to hold CO<sub>2</sub> and pollutants that harm human and ecosystem health), forests (carbon storage, water storage and mediation, biogeochemical cycling, and much more), soils (carbon storage, nutrient storage, ability for future generations to grow crops), and many others.

## Externalization of Environmental Costs

It is well known in the business world that one maximizes profit by internalizing that profit while externalizing costs of operation. If the costs of doing business can be borne by someone else who does not demand a share of the profit, it is the ideal scenario for a business person who looks no farther than the immediate bottom line. This, in part, leads to the tragedy of the commons if the cost is borne by the community. There are numerous environmental costs associated with modern society, and while individuals profit from their own activities, the costs are externalized to others, either alive today, or who have not yet been born, but will have to pay in loss of environmental services, restoration of degraded ecosystems, or simply in more expensive ways of doing things that would otherwise be cheaper if the appropriate environmental goods and services were still available (Constanza et al., 1998; Constanza et al., 1997). In a sense, this is a market failure, as the costs of goods and services that externalize environmental costs do not fully reflect the costs of doing business.

For example, the cost of fossil fuels such as gasoline does not reflect the cost of air, water, and soil contamination caused by producing and ultimately burning the fuels. These costs are borne by others, either through current taxes or by the degradation of the services that would otherwise have been enjoyed by the provision of clean air, water, and soil. There is a more serious externalization involved in fossil fuels, however, as will be explored in Chapter 11. Companies that sell fossil fuels charge the cost merely of delivering those fuels to the customer (and a bit of processing). The customer does not pay for the production of these fuels, as they were produced by concentration of solar energy over tens to hundreds of millions of years of geologic processes. If the costs of concentration of solar energy in this manner were internalized into the cost of electricity generated by burning coal, for example, such electricity would be far more expensive than that generated from wind or photovoltaic cells. As such, externalizing to the geologic past the production costs of fossil fuels artificially depresses the cost of those fuels to merely the cost of delivery—a small fraction of the actual cost.

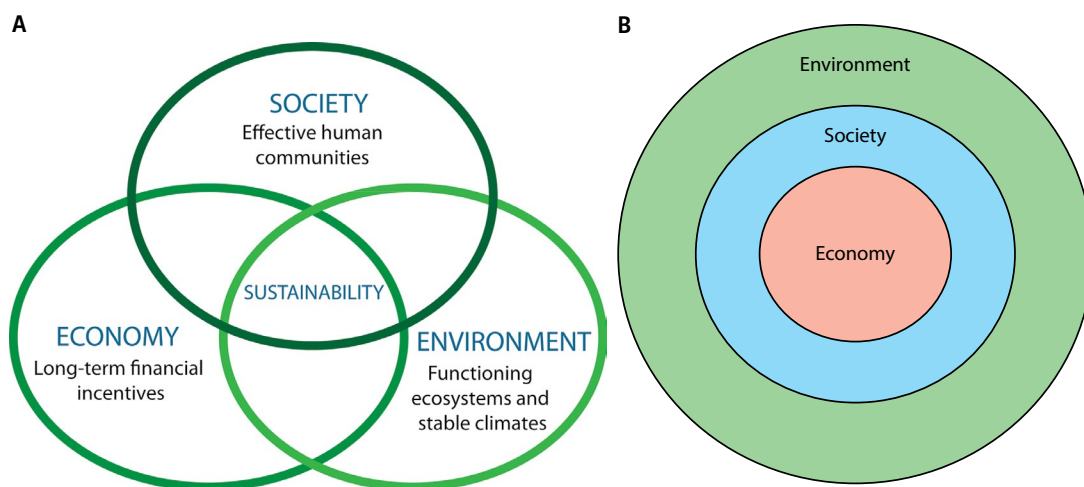
Another example is the water mined from aquifers that do not recharge at a significant rate, such as the Ogallala Aquifer in the U.S. Great Plains. If farmers had to pay for (and charge for) the cost of replacing that water, the

food they produced from it would be vastly more expensive than it is now. How much more would a fish cost if, rather than simply catching one from the ocean, a fisherman had to raise it from an egg, ensure that its marine environment was preserved and healthy, refrain from catching it until it had reproduced in sufficient numbers, and then replace it upon removal? While aquaculture and mariculture take a few steps in that direction, they have their own environmental impacts, as discussed in Chapter 9.

## Sustainability

There has been a great deal of discussion of late regarding the desirability of being sustainable. The exact meaning of that has been somewhat unclear. According to the United Nations (at the Rio Summit in 1987), “sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs.” How many future generations? What will be “their own needs” relative to the current generation’s “needs”? Shall we declare that “they” can get by with much less than “we” need? Is “sustainable development” an oxymoron? These questions remain a matter of debate that becomes moot when there are no effective mechanisms to ensure that current populations will enable future generations to consume as much energy and resources as is done at present. Native Americans considered activities sustainable if they could continue for seven generations. While this is only about 150 years, it is a far longer-term view than any current policy found in “modern” societies.

Various aspects of sustainability have arisen to the point that while it is becoming a household word, it has so many meanings and interpretations that



**FIGURE 1.6** Sustainability Diagrams

a) Traditional Venn diagram showing the limited intersection between the three factors. This is now considered inadequate because the economy depends entirely on society, and both depend entirely on the environment. As such, another diagram considers these as concentric circles, as in b).

its meaning is becoming bent, if not broken. Some companies sell products that they market as sustainable without providing any indications of what that means. All products require energy and resources to produce. As such, the “greenest” product is the one you leave on the market shelf so that no more need to be made. This is certainly not what the selling company has in mind. Consequently, sustainability and economic growth sometimes appear to collide head-on. This need not be the case, however. Use and reuse of materials is sustainable indefinitely, given careful mass management (i.e., recycling) and sufficient energy to reform old or dysfunctional products into new and marketable products (Figure 1.6). While management can be arranged by human diligence, energy is more difficult to come by, except, at present, from fossil fuels, the burning of which is far from sustainable for a host of reasons. Until sustainable energy sources of sufficient magnitude are developed, some means will need to be found to reduce consumption of not only energy, but also the products that are made from it. This will be a very difficult political and economic nut to crack, and many are pessimistic about modern society’s ability to do it or even willingness to try.

## Tools for Studying the Environment

How do scientists monitor the environment to observe changes and perturbations? What means are there for understanding the critical processes so that reliable model-based predictions can be made of future environmental conditions and processes? As in any science, a set of basic tools is necessary for scientists to use to study the system at hand. Some of these are conceptual, while others are technical. Conceptually, a somewhat trivialized hierarchy of science can be viewed as follows:

For math, you just need math.

For physics, you need math.

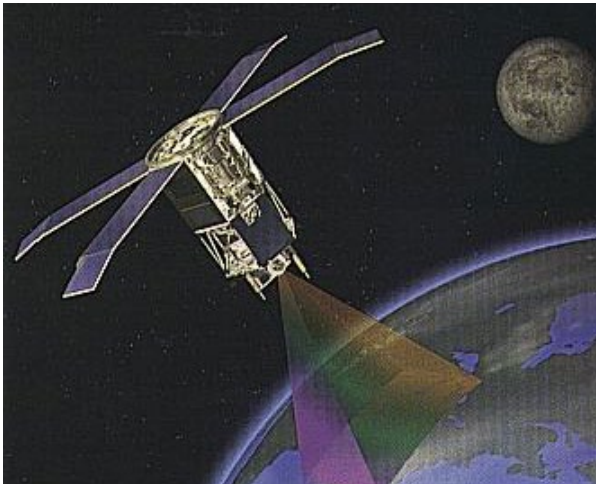
For chemistry, you need physics and math.

For biology, you need chemistry and physics and math.

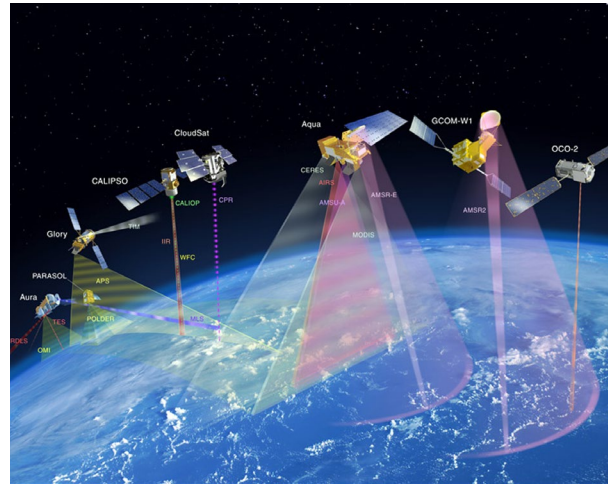
For Earth science, you need biology and chemistry and physics and math.

For environmental science, you need Earth science and biology and chemistry and physics and math.

As such, the environmental scientists must draw on a broad body of knowledge to even begin to approach the complexity of the problems found in the environment. This makes environmental science highly interdisciplinary (not just multidisciplinary) and the environmental scientist must take a problem-based approach that may call upon any of a wide spectrum of tools to solve. Some of these tools are as follows:



**FIGURE 1.7** The invention and deployment of orbiting satellites has greatly expanded our ability to observe and monitor environmental conditions on Earth. No part of the planet remains unobserved.



**FIGURE 1.8** NASA satellite missions  
 Numerous missions have been conducted, and many are ongoing. Satellites with a variety of sensors are used to measure temperatures, chemical composition, gravity, hydrology, leaf color and photosynthesis, and many other environmentally important parameters.

**Fieldwork:** Most observations have historically been accomplished by direct observation and monitoring in the field. The field may be a forest, wetland, or any other biome, or it may be the deep sea, watershed, individual stream, or other physiographic entity. In some cases, it may be a water treatment plant or cement manufacturing facility. In the field, scientists may use a variety of tools such as rock hammers, drills, coring tubes, gas collection enclosures, automated water collection devices, in situ chemical analysis instruments, light meters, and a plethora of other instrumentation, some of it very specialized, that enables scientists to gather the data needed to answer pressing environmental questions in their research. In all cases, careful observation, monitoring, and recording of data are needed to solve any well-posed problem.

**Remote Sensing:** Some of the most exciting new data sets now come from a long-distance extension of fieldwork with a bird’s-eye view of the earth from airplanes, balloons, and orbiting satellites in space (Figures 1.7 and 1.8). Remote sensing provides an entire new dimension for environmental data collection because the global data sets they can provide would be impractical at best, and in most cases impossible to collect by instrumentation on the ground.

Yet most satellites can do nothing more than look down at the earth. However, they can “look” in virtually any wavelength. This includes the visible, of course, and one obvious observation is the tracking of storms and weather systems from the cloud formations visible from space, leading to a quantum leap forward in weather forecasting ability. Land cover can be determined simply by looking down at the ground during cloudless times. Another type of observation in the visible band, for example, is the greenness of vegetation in an ecosystem, as characterized by the **Fraction of Photosynthetically Active**

**Fraction of Photosynthetically Active Radiation (FPAR):** The portion of the electromagnetic spectrum arriving from the sun (with wavelengths between 0.4- and 0.7-microns) that is actually used (absorbed) by plants.