

# ENVIRONMENTAL SCIENCE

*Earth As a Living Planet*

*Second Edition*



**DANIEL B. BOTKIN**



**EDWARD A. KELLER**

# ENVIRONMENTAL SCIENCE

EARTH AS A LIVING PLANET

Second Edition

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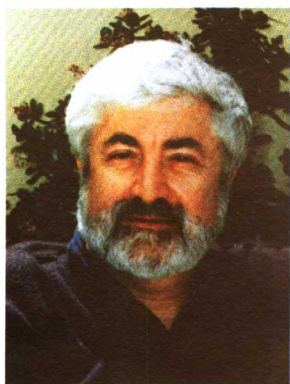
# *D*EDICATIONS ---

FOR VALERY  
who contributed so much to this book

AND

FOR ERENE,  
who gave and cared so much

# ABOUT THE AUTHORS



**Daniel B. Botkin** is President of The Center for the Study of Environment and Professor of Biology at George Mason University. From 1978 to 1993, he was Professor of Biology and Environmental Studies at the University of California, Santa Barbara, serving as Chairman of the Environmental Studies Program from 1978 to 1985.

For more than two decades, Professor Botkin has been active in the application of ecological science to environmental management. He is the winner of the Mitchell International Prize for Sustainable Development and the Ferron Prize for International Forestry, and he has been elected to the California Environmental Hall of Fame.

Trained in physics and biology, Professor Botkin is a leader in the application of advanced technology to the study of the environment. The originator of widely used forest gap-models, his research is focused on endangered species, characteristics of natural wilderness areas, the study of the biosphere, and attempts to deal

with global environmental problems. In recent years, Professor Botkin has advised the World Bank about tropical forests, biological diversity, and sustainability; the Rockefeller Foundation about global environmental issues; the government of Taiwan about approaches to solving environmental problems; and the state of California on the environmental effects of water diversion on Mono Lake. He served as the primary advisor to the National Geographic Society for their centennial edition map on "The Endangered Earth." He recently directed a study for the states of Oregon and California concerning salmon and their forested habitats.

He has published many articles and books about environmental issues. His latest books are *Our Natural History: The Lessons of Lewis and Clark* (Putnam), *Discordant Harmonies: A New Ecology for the 21st Century* (Oxford University Press), and *Forest Dynamics: An Ecological Model* (Oxford University Press).

Professor Botkin was on the faculty of the Yale School of Forestry and Environmental Studies (1968–1974) and was a member of the staff of the Ecosystems Center at the Marine Biological Laboratory, Woods Hole, MA (1975–1977). He received a B.A. from the University of Rochester, an M.A. from the University of Wisconsin, and a Ph.D. from Rutgers University.



**Edward A. Keller** was chair of the Environmental Studies and Hydrologic Sciences Programs from 1993 to 1997 and is Professor of Geological Sciences at the University of California, Santa Barbara, where he teaches geomorphology, environmental geology, environmental science, river processes, and engineering geology.

Prior to joining the faculty at Santa Barbara, he taught geomorphology, environmental studies, and earth science at the University of North Carolina, Charlotte. He was the 1982–1983 Hartley Visiting Professor at the University of Southampton, England.

Professor Keller has focused his research efforts into three areas: studies of Quaternary stratigraphy and tectonics as they relate to earthquakes, active folding, and mountain building processes; hydrologic process and wildfire in the chaparral environment of southern California; and the role of fluid pressure in the earthquake cycle of active fold-and-thrust belts. He is the recipient of various Water Resources Research Center grants to study fluvial processes and U.S. Geological Survey and Southern California Earthquake Center grants to study earthquake hazards.

Professor Keller has published numerous papers, and is the author of the textbooks *Environmental Geology* and (with Nicholas Pinter), *Active Tectonics* (Prentice-Hall). He holds bachelors degrees in both geology and mathematics from California State University, Fresno; an M.S. in geology from the University of California; and a Ph.D. in geology from Purdue University.



# PREFACE

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A study of the environment on the cusp of the twenty-first century is an exciting endeavor as we attempt to move from confrontation to cooperative problem-solving and place the study of the environment on a sound scientific basis. The enthusiasts of the 1960s have matured into today's environmental professionals: executives in alternative energy corporations, applied scientists who work on international projects to spread appropriate technologies to our inner cities and to developing nations, economists who calculate cost and benefits of pollution controls, environmental lawyers who mediate problems and help write laws to promote wise use of our resources, and other people in many related fields.

In recent years our understanding of many aspects of the environment has greatly increased. This has ranged from our understanding of the transport and fate of pollutants and toxins in the air and water, to appreciation of what is really necessary to save endangered species, to understanding how the Earth as a system operates.

Study of our environment has undergone tremendous change during the past four decades. In the 1960s and 1970s a grass roots movement to protect the environment began with the recognition of potential and real adverse effects of modern civilization on our environment. Views became polarized. Some environmentalists argued that everything about the environment was good and should be protected without change—that is, all development of natural resources was bad. Some environmentalists believed that the world would be destroyed if we did not change our approach to the environment. Opponents argued that these extreme “environmentalists” were opposed to progress and possibly to everything good stemming from civilization and technology. Nevertheless, during this period progress was made in dealing with environmental issues and problems. Enthusiasm for the environment remained high.

Environmentalism in the 1980s was characterized by a conscious shift from enthusiastic rhetoric to development of alternative ways to solve environmental problems associated with local, regional, and global issues such as human population, hazardous waste, acid precipitation, global warming, and stratospheric ozone depletion. People and institutions began putting more energy and resources into

solving environmental problems and learning more about how the earth works as a system.

During the 1990s there has been a return to considerable confrontation and emotionalism surrounding the environment. Some activists place the Earth's life support system, the biosphere, at the top of the moral pyramid, to be protected at all cost from adverse human interference. At the other extreme some people see environmentalists and environmentalism as a threat to private property rights and their “way of life.” Finding solutions to environmental problems in the twenty-first century will require that a spectrum of potential solutions be carefully evaluated in light of our values and scientific knowledge, while at the same time insuring social justice.

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## GOALS OF BOOK

The purpose of *Environmental Science* is to provide an up-to-date introduction to the most important and useful concepts in the study of the environment. Information is presented from an analytical and interdisciplinary perspective from which we must view environmental issues in order to deal successfully with them.

### Critical Thinking

We must do more than simply identify and discuss environmental problems and solutions. To be effective, we must think critically about them. Critical thinking is so important that we have made it the focus of its own chapter, Chapter 2. With this in mind we have also developed *Environmental Science* to present the material in a factual, unbiased format. Our goal is to help you think through the issues, not tell you what to think. To this purpose, at the end of each chapter, critical thinking exercises, called “Environmental Issues,” are provided.

### Interdisciplinary Approach

The approach of *Environmental Science* is interdisciplinary in nature. Environmental science integrates many disciplines and includes some of the most important topics of modern civilization as well as some of the oldest philosophical concerns of human be-

ings—that of the nature of our relationship with our environment. Applied and basic aspects of environmental sciences require a solid foundation in the natural sciences, in addition to fields such as anthropology, economics, history, sociology, and philosophy of the environment. Not only do we need the best ideas and information to deal successfully with our environmental problems, but we also must be aware of the cultural and historical context in which we make decisions about the environment and understand ways in which choices are made and implemented. Thus, the field of environmental science integrates the natural sciences with environmental ethics, environmental economics, environmental law, environmental impact, and environmental planning. As a result, *Environmental Science* provides an introduction to the entire spectrum of relationships between people and the environment.

## THEMES

*Environmental Science* is based on the philosophy that several threads of inquiry are of particular importance to environmental science. These key themes are woven throughout the book.

### Human Population

Underlying nearly all environmental problems is the rapidly increasing human population. Ultimately, we cannot expect to solve these other problems unless we can limit the total number of people on Earth to an amount the environment can sustain. We believe that education is important to solving the population problem. As people become more educated, and as the rate of literacy increases, population growth tends to decrease.

### Sustainability

*Sustainability* is a term that has gained much popularity recently. Speaking generally, it means that a resource is used in such a way that it continues to be available. However, the term is used vaguely and it is something we are struggling to clarify. Some would define it as insuring that future generations have equal opportunities to the resources that our planet offers. Others would argue that sustainability refers to types of developments that are economically viable, do not harm the environment, and are socially just. We all agree that we must learn how to sustain our environmental resources so they continue to provide benefits for people and other living things on our planet.

## A Global Perspective

Until recently we generally believed that human activity caused only local, or at most regional, environmental change. We now know that effects of human activity on Earth are of such an extent that we are involved in a series of unplanned planetary experiments. The main goal of the emerging science known as *Earth System Science* is to obtain basic understanding of how our planet works as a system. This understanding can then be applied to help solve global environmental problems. The emergence of Earth System Science has opened up a new area of inquiry for faculty and students. Understanding the relationships between biological and physical sciences requires interdisciplinary cooperation and education.

## The Urban World

An ever-growing number of people are living in urban areas. Unfortunately our urban centers have long been neglected and the quality of the urban environment has suffered. It is here we experience air pollution, waste disposal problems, social unrest, and other stresses of the environment. In the past we have centered our studies of the environment more on wilderness than the urban environment. In the future we must place greater focus on towns and cities as livable environments.

## Values, Knowledge, and Social Justice

Finding solutions to environmental problems involves more than simply gathering facts and understanding the scientific issues of a particular problem. It also has much to do with our systems of values and issues of social justice. To solve our environmental problems, we must understand what our values are, and which potential solutions are socially just. Then, we can apply scientific knowledge about specific problems and find acceptable solutions.

These five key themes or threads of inquiry are discussed in more detail in Chapter 1. They are also revisited at the end of each chapter where we discuss some of the pertinent material relative to these themes.

## ORGANIZATION

We believe a real strength of *Environmental Science* is the systematic and in-depth coverage of the multitude of subjects that comprise the field of Environmental Science. An important objective is to integrate physical and biological processes within a

social framework. We recognize that environmental education is a life-long process and any one course may not be able to cover in depth all of the subjects presented in *Environmental Science*. The goal is to provide an instrument of learning useful to educators and students today so that future generations of students will be more informed and able to make judgments concerning the environment based upon sound scientific knowledge. We believe that the understanding of, and critical thinking about, environmental problems is much more important than mere presentation of facts and information.

To support this goal, our text is divided into eight parts. *Part I* provides a broad overview of the key themes in *Environmental Science*, the scientific method, and thinking critically about the environment. *Part II* presents the study of the Earth as a system, emphasizing how systems work and the basic biochemical cycles of our planet. *Part III* focuses on life and the environment and includes subjects such as human population, ecosystems, biological diversity, biological productivity and energy flow, and restoration and recovery of ecosystem response to disturbance. *Part IV* presents living resources from a sustainability viewpoint, and topics covered include world food supply, agriculture and environment, plentiful and endangered species, forest ecology, conserving and managing life in the oceans, and environmental health and toxicology. *Part V* introduces and discusses a wide variety of topics related to energy including basics necessary for understanding energy, fossil fuels and environment, alternative energy, and nuclear energy. *Part VI* presents the water environment on Earth in terms of water supply use and management, and water pollution treatment. *Part VII* concerns the air environment, from global issues such as climate, global warming, and stratospheric ozone depletion to regional issues such as acid rain, to local issues including urban air pollution and indoor air pollution. *Part VIII* is concerned with relationships between environment and society. Topics include environmental economics, the urban environment, integrated waste management, minerals and environment, environmental impact and planning, and integrating values and knowledge.

## SPECIAL FEATURES

In writing *Environmental Science* we have designed a text that incorporates a number of special features that we believe will help teachers to teach and students to learn. These include:

- A **Case Study** introduces each chapter. The purpose is to interest the reader in the subject

being discussed and to raise important questions on the subject matter. For example, in Chapter 14, which deals with Environmental Health and Toxicology, the Case Study introduces the problem of lead toxicity and asks the question, "Is lead in the urban environment contributing to antisocial (criminal) behavior?"

- **Learning Objectives** are introduced early in the chapter to help students focus on what is important in the chapter and what they should achieve after reading and studying the chapter.
- A **Closer Look** is the name of special learning modules presented in most of the chapters. The purpose here is to present more detailed information concerning a particular concept or issue. For example, A Closer Look 3.1, in the chapter on Systems and Change, discusses the important concept of electromagnetic radiation. Many of these special features contain figures and other data to enrich the reader's understanding.
- Near the end of each chapter, an **Environmental Issue** is presented as a method of encouraging critical thinking about the environment and to help students understand how these issues may be studied and evaluated. For example, Chapter 19 presents the environmental issue of how wet is a wetland? The issue in Chapter 16 examines the important environmental question of whether or not we should raise the gasoline tax.
- Following the Summary, a special section, **Re-examining Themes and Issues** reinforces the five major themes of the textbook. Here we also make value judgments concerning important environmental issues and questions.
- **Study Questions** for each chapter are provided. The purpose is to provide a study aid for students and utilize critical thinking skills.
- **Further Reading** and **Internet Resources** are provided at the end of most chapters so that students may expand their knowledge and reading through major sources of information (both print and electronic) on the environment.
- **References** cited in the text are provided at the end of the book as notes for each chapter. These are numbered according to their citation in the text. We believe it's very important that introductory textbooks carefully cite sources of information used in the writing. These are provided to recognize those scholars whose work we depend upon, and so that the reader may draw upon these references as needed for additional reading and research.

## IMPROVEMENTS IN THE SECOND EDITION

One of the primary purposes of the Second Edition is to update the facts and keep the book current with rapidly changing information about the environment. This has been done throughout.

### Updated References

Environmental sciences are new, with rapid changes in the field. Therefore, it is necessary to update references and suggested further reading, while retaining references to the classic works.

### New Chapter Feature

The Second Edition continues to integrate five major themes. However, we have replaced the icons (sometimes perceived as disruptive) with a review section—"Reexamining Themes and Issues"—at the end of each chapter discussing how the themes relate to the discussion in that chapter; for example, see p. 47 in chapter 3.

### New Case Studies

The chapter introductory "Case Studies" were very well received in the first edition. We have retained this feature and updated the most dated of the studies. In the Second Edition we provide case histories that we believe will be more relevant to today's student, selecting Cases Studies that deal with major issues as well as illustrative issues. Some examples of new Case Studies include: shrimp farming in Thailand (Ch. 1) because it involves each of the five themes; pollution of Lake Washington, Seattle (Ch. 4) because it is a success story about an altered biogeochemical cycle; purple loosestrife (Ch. 7) because it shows how the invasion of an alien species affects the diversity of species; logging in Clayoquot Sound, British Columbia (Ch. 13) because it is very current and controversial; lead in the urban environment (Ch. 14) because it may cause antisocial behavior; and sick building syndrome (Ch. 23) because it shows the effects on indoor air pollution.

## Important Content Changes

- *The Special Section on Earth's Biomes* has been expanded to discuss the connection between environment and biomes, with many new illustrations.
- *Chapter 2, Thinking Critically about the Environment* includes a new set of models and computer simulation. The use of computer models is becoming an important tool for many environmental issues, including forecasts of global climate change and the management of wild living resources.

- *Chapter 4, Biogeochemical Cycles* has been heavily revised to make chemical cycling more accessible to the average student. We have updated significant aspects of the carbon cycle to reflect the current thought. Discussion of the chemical cycles has been simplified and the more technical material has been omitted or moved to "Closer Look" boxes. The presentation now moves from the local to the global scale. Each section begins with a discussion about why it is important to understand the topic and case histories used.
- *Chapter 8, Biological Productivity and Energy Flow* has been reordered to present the big picture, then the examples and details. The presentation has been simplified, eliminating much of the detail on equations and calculations.
- *Chapter 9, Succession and Restoration: How Ecosystems Respond to Disturbance* has been reorganized for better pedagogical structure, focusing on general principles; the details of specific examples have become optional.
- *Chapter 12, Wild Living Resources* has been updated to reflect the new international agreements and new listings from the International Union for the Conservation of Nature. The discussion of conserving forests now proceeds from regional to global perspectives.
- *Chapter 13, Landscapes and Seascapes* now discusses "new forestry" and the certification of sustainable forest practices.
- *Chapter 19, Water Supply, Use, and Management* has been updated to include experiments to improve river ecology through the release of large volumes of water to simulate floods, using the Colorado River as an example.
- *Chapter 20, Water Pollution and Treatment* has a new discussion of the use of wetlands in wastewater treatment.
- *Chapter 26, Urban Environments* has been updated to include coverage of the recent floods on the Mississippi and their effects on cities such as St. Louis.

## SUPPLEMENTS

A variety of supplements for both students and instructors is available for *Environmental Science*, Second Edition:

- **Student Review Guide with Internet Companion**, prepared by Joseph Luczkovich and David Knowles, of East Carolina University. This exciting new supplement integrates the

power of the World Wide Web for the first time! The Review Guide contains concise chapter summaries, chapter concepts, and chapter review questions. In addition, it contains an Internet component, which provides students with “hot links” to related environmental web sites and other relevant points of interest on the World Wide Web.

- **Regional Case Books** supplement the case studies that are featured within the text. Cases have been carefully selected to allow instructors to tailor their courses specifically for their own locale. Case Books, compiled by Dorothy Rosenthal for the Eastern, Western, Southern, and Northern regions of the United States, are available. Monica Mulrennan, of Concordia University, designed a Case Study specifically for Canada, which provides a wide range of case studies for a diverse selection of regions.
- **Student Review CD** will provide students with an interactive environment in which they can access all of the information contained in the printed version of the Review Guide. Bonus features include on-line testing and on-line assessment, immediate access to related web sites through embedded hot links, and full color graphs and illustrations that will reinforce important topics and concepts.
- **Instructor's Manual**, prepared by Ann S. Causey, of Auburn University. The Manual contains teaching suggestions for all instructors, both experienced as well as the first-time lecturer; lecture and outline notes; a list of suggested supplemental readings, and lead-ins

and critical thinking activities to give instructors ideas on how to begin and finish lectures. In addition, most chapters contain a list of five to ten ways individuals can minimize their impact on Earth's available resources.

- **Test Bank**, prepared by Nicholas Pinter of University of California, Santa Barbara. This Test Bank contains approximately 1,700 multiple-choice, short-answer, and essay questions.
- **Transparency Acetates** of figures from the text with large bold-face labels aid in classroom presentations.
- **CD-ROM** contains an electronic library of the illustrations found in the text.
- **Environet** (<http://www.wiley.com/college/environet>) is an exciting new website designed to enhance any course using Botkin and Keller's *Environmental Science: Earth as a Living Planet, 2e*. For each chapter of the text, the site expands on either the *Case Study*, the *Environmental Issue*, or *A Closer Look*, providing current news items, reports, historical context, and a multimedia component. The site also contains frequently asked questions relating to the key concepts of environmental science along with links to other sites for help in answering those questions. The correct answers are provided in the *Student Review Guide with Internet Companion*. Both students and instructors will find this a rich site for interactive learning and exploration.

Daniel B. Botkin  
Edward A. Keller

# ACKNOWLEDGMENTS

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Completion of this book was only possible due to the cooperation and work of many people. To all those who so freely offered their advice and encouragement in this endeavor, we offer our most sincere appreciation. We are indebted to our colleagues who made contributions: Dorothy A. Rosenthal for writing Chapter 2 and the environmental issues at the end of each chapter; Mel S. Manalis for assistance in developing the energy chapters, global warming, and stratospheric ozone depletion; Marc J. McGinnes for assistance in helping develop discussions concerning environmental law; Harold Ward for writing parts of Chapter 29, particularly relating to environmental legislation and review; Bill Kuhn for assistance in research; Joan Melcher for her excellent editing of the manuscript; and Nicholas Pinter who helped in many ways including review of the manuscript, suggested text revisions, and development of suggested readings for students. Finally, we would like to thank Harold Morowitz for helpful suggestions on how to introduce the basic energy concepts.

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Of particular importance to the development of the book were the individuals who read the book chapter by chapter and provided valuable comments and constructive criticism. This was a particularly difficult job given the wide variety of topics covered in the text and we believe that the book could not have been successfully completed without their assistance. These reviewers are offered our special gratitude:

## First Edition Reviewers

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James Melville, Mercy College  
Chris Migliaccio, Miami-Dade Community College-Wolfson  
Clayton Penniman, Central Connecticut State University  
Jeffery Schneider, SUNY-Oswego

### **Student Reviewers**

One of our goals in writing this book was to help students to think critically about the environment. In developing the Second Edition, we solicited feedback from students who studied from the First Edition. Their response has been gratifying and also constructive. We wish to thank the following students for their input.

### **Student Evaluators**

Bonnie Carvelli, Mohawk Valley Community College  
C. Ehitz, Miami-Dade Community College-Wolfson  
Dari Loreno, Adirondack Community College  
Joan Petrie, Mohawk Valley Community College  
Balkis Sierra, Miami-Dade Community College-Wolfson  
Kelly Toloza, Miami-Dade Community College-Wolfson

### **Student Focus Groups**

Professor Craig Fusaro at Santa Barbara City College coordinated a group of his students:

John Barthel  
Tino Gutierrez  
Jon Humfrey  
Thomas Haug  
Phillip Hellyer  
Darren Hudson  
Linda Martin  
Patrick Park  
Mark Wilde  
Elizabeth Williams

Professor Vincent Breslin at SUNY-Stony Brook coordinated a group of his students

Heather Bittner  
Lesia Clarke  
Deborah Luby  
Jessie Mayer  
Orly Pinchas  
Jason Terhune  
Valerie Tierce  
Andy Winslow  
Richard Worthington  
Dongqiang Zheng

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The University of California, Santa Barbara, and George Mason University provided the stimulating atmosphere necessary for writing. Parts of the text were also written while E. A. Keller was on leave at the Departamento de Geodinamica, Universidad de Granada, España, working with Professor Jose Chacon as well as at the Mediterranean Agromomic Institute of Chania on the island of Crete in Greece. Fellowships to Daniel B. Botkin from the East-West Center Honolulu and Rockefeller Bellagio Study and Conference Center, Bellagio, Italy, and from the Woodrow Wilson International Center for Scholars, Washington, D.C., provided time and stimulating environments in which ideas in the text underwent growth and enrichment.

Daniel B. Botkin  
Edward A. Keller



## SPECIAL NOTE TO STUDENTS

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We have written this book with the belief that students really want to be challenged to think about the important environmental problems that face the world today. We are attempting to bring the environment to the forefront of education. This is in response to tremendous public concern about the environment. Public opinion polls confirm that the environment is an important social and political issue. We also believe that scientific literacy and critical thinking are very important. As a result, we have chosen to discuss important environmental issues, some of which are multifaceted, difficult, and challenging. We all need to recognize that solutions to the many environmental problems facing us today are not easy to find. There are differing opinions on which problems we should address and what solutions should be attempted. This is something we cannot teach you. We can present information and arguments, but ultimately you must think for yourself and develop solutions based on your value system and understanding. If this appears as a vague concept—it is! You are responsible for future generations just as are your instructors. Making informed decisions requires a lot of study as well as a commitment to be responsible in helping to insure that our planet maintains a healthy productive environment. We believe that if our book, *Environmental Science*, helps you in that endeavor, then it has been successful.

If our book has helped you to think more critically about environmental problems, we would like to hear from you. Please share your ideas or questions with us at [DBotkin@Wiley.com](mailto:DBotkin@Wiley.com).

Daniel B. Botkin  
Edward A. Keller



# STUDENT-TO-STUDENT PREFACE

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When I came to college, my goal was to learn all I could about the environment and the problems facing it. *Environmental Science* is a text that I found to be essential for students looking to learn about the environment and current problems facing that environment. This was the first text dealing with the environment that I had ever used, and it was in a class entitled "Environmental Problems and Solutions." Both the class and the text helped to inform me of the problems facing the environment and gave me the opportunity to explore solutions to these problems. The text offers a broad description of environmental problems, while giving you a detailed explanation of specific problems. It is important for you, as a student, to obtain a sound basis in your study of the environment. A thorough understanding will better prepare you to make intelligent decisions in the future. This text gives you the opportunity to do just that by successfully introducing you to a problem, fully explaining that problem, and encouraging you to formulate your own opinion of the subject at hand.

When using this text, I suggest that you take advantage of everything that *Environmental Science* has to offer. Within each chapter, you will come across examples of specific issues that have occurred or are occurring in the environment. These sections are entitled "Case Study" at the beginning of each chapter, "A Closer Look" within the chapter, and "Environmental Issue" at the end of each chapter. You will find it useful to read through these sections as they will help give you a more focused definition of the issue or issues dealt with in the chapter. I would also recommend going over the Study Questions at the end of each chapter. They are designed to help you in your understanding of the more important points discussed in each chapter.

When studying for any environmental class, I suggest that you first look to your notes from the class itself. This will provide an outline for possible test topics that you may need to know. After you have obtained an outline of topics, go to the text to fine tune your understanding of the topics being dealt with in the notes. The text will provide you with the information that your instructor did not, as it is impossible for them to give you all of the facts in the time allotted to them. This is why the text will be essential to your studies, just as it was to mine.

In closing let me say that it has been over a year since I took this class and *Environmental Science* still sits on my desk and is used for many of my reference needs. You will find this text to be a good investment, not only now, but in the future as well.

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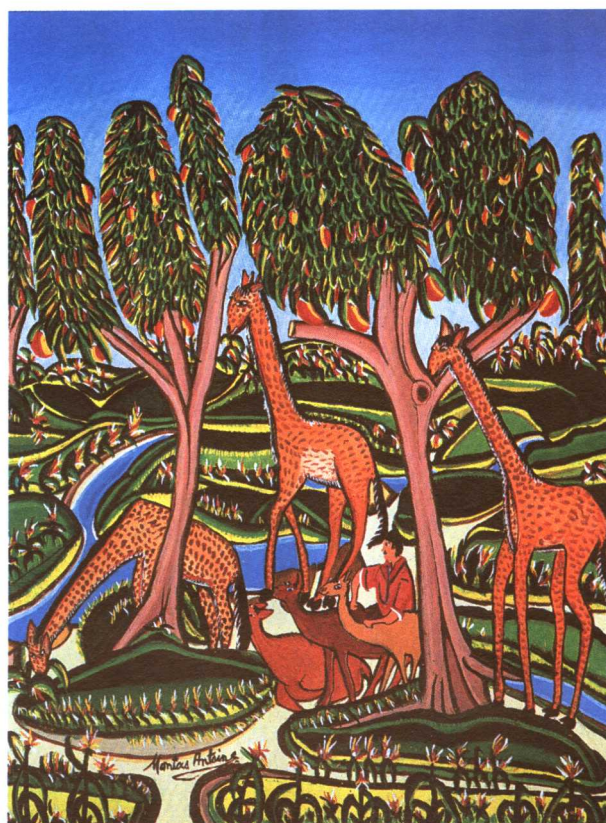
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