

Environmental Science

earth
as a
living
planet



4TH
EDITION

BOTKIN • KELLER

Environmental Science

EARTH AS A
LIVING PLANET

Fourth Edition

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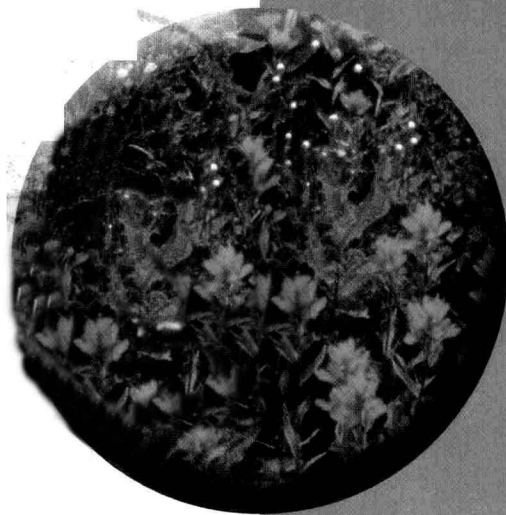
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A Special Note to Students

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 multi-faceted, 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.

Daniel B. Botkin
Edward A. Keller

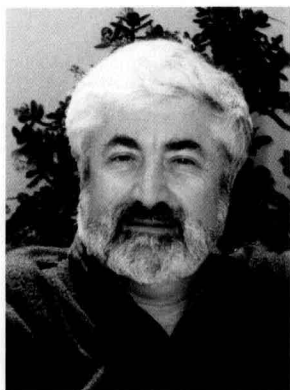
Dedications

- **FOR JANE O'BRIEN,**
who, during her life, gave joy and spirit to my work.
Dan Botkin

and

- **FOR VALERY RIVERA**
who contributed so much to this book and
is a fountain of inspiration in our work and lives.
Ed Keller

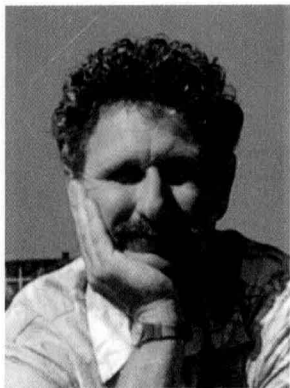
About the Authors



Daniel B. Botkin is President of The Center for the Study of Environment and Research Professor of Ecology, Evolution and Marine Biology, University of California, Santa Barbara. 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 three 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 Fernow 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 has involved endangered species, characteristics of natural wilderness areas, the study of the biosphere, and attempts to deal with global environmental problems. During



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 and a Visiting Fellow in 2000 at Emmanuel College of Cambridge University, England.

his career, 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 *Passage of Discovery: The American Rivers Guide to the Missouri River of Lewis and Clark* (Penguin-Putnam), *The Blue Planet* (Wiley), *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.

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 physical habitat requirements for the endangered southern California steelhead trout. 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*, *Introduction to 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

A study of the environment in the 21st century is an exciting endeavor as we continue 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 sustainable 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 was 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 21st 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 ensuring social justice.

● 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. The goal is to teach the student *how* to think through environmental issues.

Critical Thinking

We must do more than simply identify and discuss environmental problems and solutions. To be effective, we must know what science is and is not. Then, we need to develop critical thinking skills. 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 and 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 “Critical Thinking Issues,” are provided. Critical thinking is further emphasized throughout the text in analytical discussions of topics, evaluation of perspectives, and integration of important Themes, which are described in detail later.

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 beings—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 contexts 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.

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. They are further emphasized in the Closer Look boxes, each of which is highlighted by an icon suggesting the major underlying Theme of the discussion. In many cases, more than one Theme is relevant, again showing the inter-relationships at work.



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 ensuring that future gen-

erations 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 that they continue to provide benefits for people and other living things on our planet.



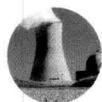
A Global Perspective

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.



Science and Values

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.

● 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 the 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 the environment, environmental impact and planning, and how we might achieve sustainability.

● 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 15, 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 at the beginning of each 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 4.1 (Matter and Energy) discusses some basic physics and chemistry. Many of these special features contain figures and other data to enrich the reader’s understanding, and relate back to the book themes.
- Near the end of each chapter, a **Critical Thinking 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 20 presents the environmental issue of how wet is a wetland? The issue in Chapter 17 examines the important environmental question of whether or not we should raise the gasoline tax.
- Following the Summary, a special section, **Reexamining 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 Readings** are provided with each chapter 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 on, and so that the reader may draw upon these references as needed for additional reading and research.

● CHANGES IN THE FOURTH EDITION

Environmental Science is a rapidly developing set of fields. Populations grow; species become threatened or released from near-extinction; our actions change. To remain contemporary, a textbook in Environmental Sciences requires frequent updating. For example, human populations continue to grow and the distribution changes, as does the rate of urbanization. Data have been brought up to date throughout. As information and ideas

change, references also require updating, and this has been done throughout.

A major revision of the fourth edition is the re-organization of Parts III and IV on ecological processes, restoration ecology, and sustaining living resources. Biogeography and Biological Productivity have been split into separate chapters (8 and 9). There is a new Chapter 10 on the important subject of restoration ecology.

Other changes and special features in the fourth edition include:

- A new companion Web site (www.wiley.com/college/botkin) provides activities for students and resources for instructors, including on-line quizzing, Virtual Field Trips, Environmental Debates, additional cases and critical thinking articles, and Web links to important environmental data and research
- A totally new design and re-organized layout to provide a clearer understanding of the topics and issues
- Increased emphasis on critical thinking
- Increased emphasis on the "Themes" of Human Population, Sustainability, Global Perspective, Urban World, and Values and Science. All are integrated within every chapter, highlighted in Closer Look boxes, and revisited at the end of each chapter
- Many new photos and illustrations
- New and updated Case Studies, Closer Look boxes and Critical Thinking Issues
- Short chapters allow for syllabus flexibility and manageable reading assignments

Augmentation of Web Site References

Valid information is becoming increasingly available over the Web, and easy access to these data is of great value. Government data that used to take weeks of library search are available almost instantly over the Web. For this reason, we have greatly augmented the number of Web site references and have gathered them all on the book's companion Web site.

Integration of Themes

The fourth edition continues to integrate five major themes, adding more references in the text to the connection between a specific discussion and one of these themes. Closer Look boxes also emphasize specific themes through icons in the design.

New Case Studies

Each chapter begins with a case study that helps the student learn about the chapter's topic through a specific example. A major improvement in the fourth edition is the replacement of some older case studies with new ones that discuss current issues and are more closely integrated into the chapter. New case studies are listed following the Table of Contents.

New Critical Thinking Issues

Each chapter ends with a discussion of an environmental issue, with critical thinking questions for the students. This is one of the ways that the text is designed to help the student learn to think for oneself about the analysis of environmental issues. In the fourth edition, some older environmental issues have been replaced with new ones and these have been more closely integrated into the text. These are listed following the Table of Contents.

● SUPPLEMENTARY MATERIALS

Environmental Science, Fourth Edition, features a full line of teaching and learning resources developed to help professors create a more dynamic and innovative learning environment. For students, we offer tools to build their ability to think clearly and critically. For the convenience of both the professors and students, we provide teaching and learning tools in print, software, and on the Web.

For Students

Student Review Guide (0-471-21885-5)

Prepared by Joseph Luczkovich and David Knowles, of East Carolina University, the student review guide offers students a great way to review materials from the text and test their knowledge. Each chapter in the text has a corresponding chapter in the review guide. The following tools have been included to help students master the material: an overview feature called The Big Picture, Frequently Asked Questions, Ecology in Your Backyard, references to related resource materials, and an Ecotest designed for chapter review.

Take Note! (0-471-41602-9)

This helpful student ancillary is composed of the same images as the Transparency Acetates, enlarged, and with added space next to the images for note-taking.

Student Web Site (www.wiley.com/college/botkin)

A completely new, redesigned, content-rich Web site has been created to provide enrichment activities and resources for students. These features include review of Learning Objectives, on-line quizzing, Virtual Field Trips, interactive Environmental Debates, additional case studies and critical thinking readings, and Web links to important data and research in the field of environmental studies.

For Instructors

Instructor's Resource CD-ROM (0-471-41600-2)

The Instructor's Resource CD (IRCD) is a multi-platform CD-ROM. The Instructor's Resource CD includes the *Instructor's Resource Guide*, the *Test Bank*, the

Computerized Test Bank, *PowerPoint Presentations*, and jpeg files for all the *Illustrations* in the text. The IRCD is designed to address the needs of all teaching levels. These assets are also available to professors at the Botkin/Keller text Web site (www.wiley.com/college/botkin).

Instructor's Resource Guide

Prepared by Ann S. Causey of Auburn University. Provides useful tools to highlight for instructors key concepts from each chapter of the text. Each chapter includes the following topics: Lecture Lead-Ins, Outline/Lecture Notes, Critical Thinking Activities, and Suggested Readings. In addition, the author includes a section titled "What You Can Do" to help you with additional resource ideas for providing engaging lectures.

Test Bank

Prepared by Nicholas Pinter, Southern Illinois University. Available on both the Instructor's Resource CD and the Wiley Botkin/Keller website (www.wiley.com/college/botkin). The test bank includes approximately 2000 questions, in multiple-choice, short answer, and essay formats. The Test Bank is provided in a word.doc format for your convenience to use and edit for your individual needs. For this edition, the author has created many new questions, and has labeled the boxed applications according to the five themes and issues set forth in the text. In addition, the author has created questions for the theme boxes and emphasized the themes in many of the questions throughout the test bank.

Computerized Test Bank

The Computerized Test Bank (CTB) is a multi-platform CD-ROM (*Diploma/Exam*) which is also available on the Wiley Botkin/Keller website (www.wiley.com

/college/botkin). The CTB includes all the files from the Test Bank, but, puts them into a dynamic computerized format. The easy-to-use test-generated program fully supports graphics, print tests, student answer sheets, and answer keys quickly and easily. The software's advanced features allow you to create an exam to your exact specifications, with an easy-to-use interface.

PowerPoint Slides

Available on the Wiley Botkin/Keller website (www.wiley.com/college/botkin) and Instructor's Resource CD, this classroom presentation tool incorporates all of the line art from the text which can be sequenced and customized by instructors to fit any lecture. Designed according to the organization of the material in the textbooks, this series of electronic transparencies can be used to illustrate concepts visually and graphically.

Transparency Acetates (0-471-23667-5)

Full-color traditional acetate transparencies of illustrations from the text are available for professors who are unable to use the slides available on the *Instructor's Resource CD-ROM*. Included are 100 images from the text, with large, boldface labels to aid instructors with classroom presentations.

Instructor's Web Site

The resources provided on the Instructor's Resource CD will also be available on the instructor section of the Wiley Botkin/Keller Web site (www.wiley.com/college/botkin).

Daniel B. Botkin

Edward A. Keller

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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. McGinnis for assistance in helping develop discussions concerning environmental law; Harold Ward for writing parts of Chapter 30, particularly relating to environmental legislation and review; Amy Selting for assistance in research; and Beverly Peavler for her excellent editing of the manuscript. Finally, we would like to thank Harold Morowitz for helpful suggestions on how to introduce the basic energy concepts.

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