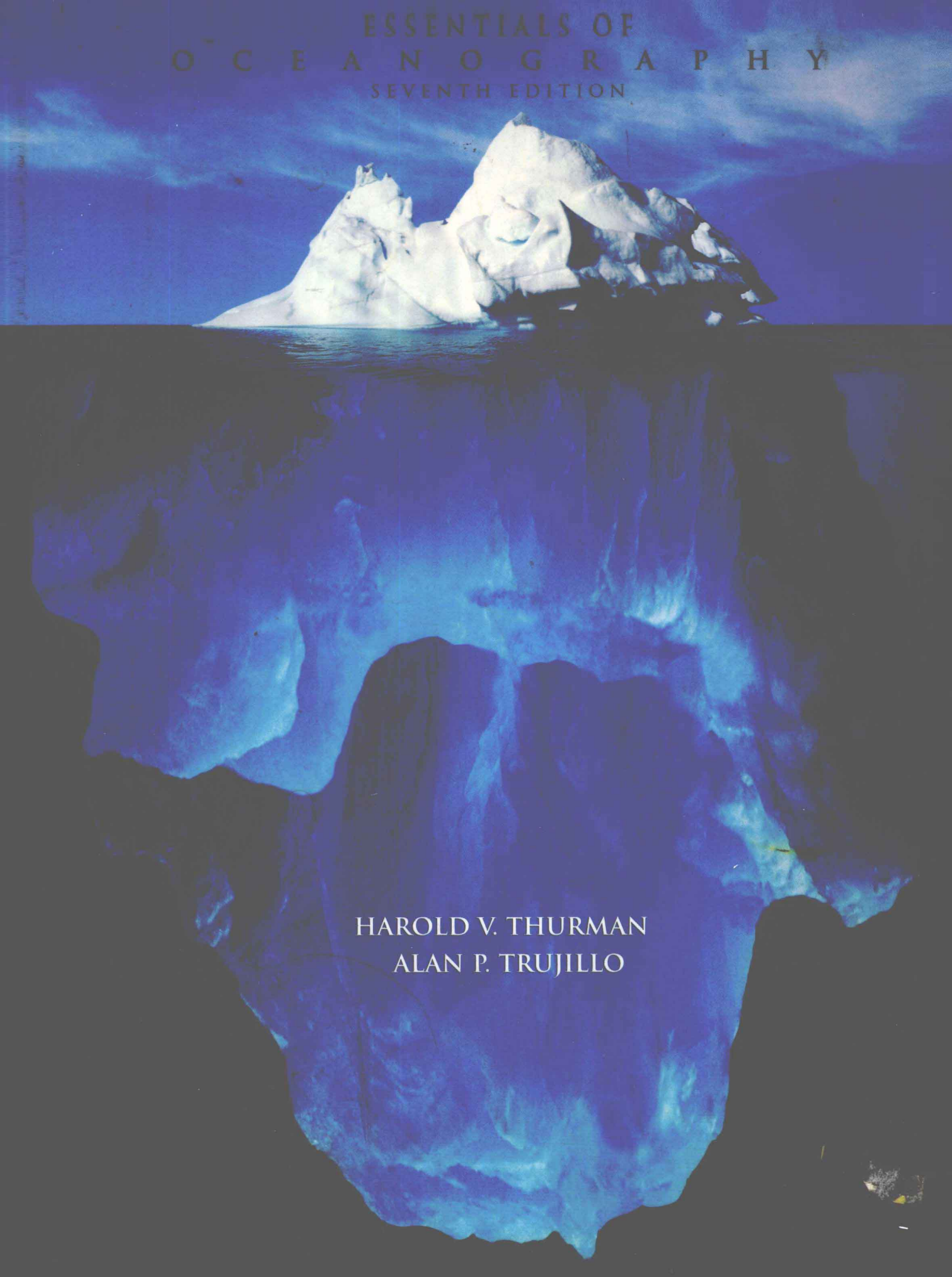
ESSENTIALS OF OCEANOGRAPHY

SEVENTH EDITION



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SEVENTH E

Essentials of Oceanography

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Preface

To the Student

Welcome! You're about to embark on a journey that is far from ordinary. Over the course of this term, you will discover the central role the oceans play in the vast global system of which you are a part.

The book's content was carefully developed to provide a foundation in science by examining the vast body of oceanic knowledge. This knowledge includes information from a variety of scientific disciplines—geology, chemistry, physics, and biology—as they relate to the oceans. However, no formal background in any of these disciplines is required to successfully master the subject matter contained within this book. Our desire is to have you take away from your oceanography course much more than just a collection of facts. Instead, we want you to develop a fundamental understanding of *how the oceans work.*

This book is intended to help you in your quest to know more about the oceans. Taken as a whole, the components of the ocean—its sea floor, chemical constituents, physical components, and life forms—comprise one of Earth's largest interacting, interrelated, and interdependent systems. Because humans are beginning to impact Earth systems, it is important to understand not only how the oceans operate, but also how the oceans interact with Earth's other systems (such as its atmosphere, biosphere, and hydrosphere) as part of a larger picture. Thus, this book uses a systems approach to highlight the interdisciplinary relationship between oceanographic phenomena and how those phenomena affect other Earth systems.

To that end—and to help you make the most of your study time—we focused the presentation in this book by organizing the material around three essential components:

1. **Concepts:** General ideas derived or inferred from specific instances or occurrences (for instance, the concept of density can be used to explain why the oceans are layered).
2. **Processes:** Actions or occurrences that bring about a result (for instance, the process of waves breaking at an angle to the shore results in the movement of sediment along the shoreline).
3. **Principles:** Rules or laws concerning the functioning of natural phenomena or mechanical processes (for instance, the principle of sea floor spreading suggests that the geographic positions of the continents have changed through time).

Interwoven within these concepts, processes, and principles are hundreds of photographs, illustrations, real-world examples, and applications that make the material relevant and accessible (and maybe sometimes even *entertaining*) by bringing the science to life.

New in this edition are web-based **Environmental Issues in Oceanography (EIO)** features that are designated within selected chapters by a special notation. Each EIO calls attention to a content-related environmental concern, many of which are the result of human interaction with the marine environment. The EIO features are web-based activities with worksheets in an accompanying workbook. The EIO exercises have been specially designed by two dedicated environmental scientists (Dan Abel of Coastal Carolina University and Robert McConnell of Mary Washington College). Page xix of this Preface explains the EIO feature in more detail.

Ultimately, it is our hope that by understanding how the oceans work, you will develop a new awareness and appreciation of all aspects of the marine environment and its role in Earth systems. To this end, the book has been written for you, the student of the oceans. So enjoy and immerse yourself! You're in for an exciting ride.

Alan Trujillo
Harold Thurman

To the Instructor

The seventh edition of *Essentials of Oceanography* is designed to accompany an introductory college-level course in general or physical oceanography taught to students with no formal background in mathematics or science. Like previous editions, the goal of this edition of the textbook is to clearly present the relationships of scientific principles to ocean phenomena in an engaging and meaningful way. Further, this edition has benefited from being thoroughly student reviewed and edited by hundreds of students.

This edition has also been reviewed by a dozen instructors from leading institutions across the country. As one reviewer of the sixth edition stated, *"The material is presented in a nicely organized fashion, with clarity and in a readable style. The diagrams are well done and the tables neatly delineate passages of text into a simple, presentable form. The boxes provide interesting diversions to the text, and are nicely linked in terms of their general interest and importance to the chapter material. The 'Students Sometimes Ask...' sections are a neat trick*

for engaging the reader in additional topics, and these follow nicely from the level of the chapters."

The 15-chapter format of this textbook is designed for easy coverage of the material in a 15- or 16-week semester. For courses taught on a 10-week quarter system, the instructor may need to select those chapters that cover the topic and concepts of primary relevance to their course. Chapters are self-contained and thus can be covered in any order. Following the introductory chapter (Chapter 1, which covers the general geography of the oceans, a historical perspective of oceanography, the reasoning behind the scientific method, and a discussion of the origin of Earth, the atmosphere, the oceans, and life itself), the four major academic disciplines of oceanography are represented in these chapters:

- Geological oceanography (Chapters 2, 3, 4, and parts of Chapters 10 and 11)
- Chemical oceanography (Chapter 5 and part of Chapter 11)
- Physical oceanography (Chapters 6–9 and parts of Chapters 10 and 11)
- Biological oceanography (Chapters 12–15)

However, we believe that oceanography is at its best when it links together several scientific disciplines and shows how they are interrelated in the oceans. Therefore, this interdisciplinary approach is a key element of every chapter.

One of the major additions to this edition of the text is the inclusion of web-based "Environmental Issues in Oceanography" (EIO) features within selected chapters. EIO features are on-line projects designed to: add relevance to the material by tying the concepts in the text to environmental issues, involve students in critical-thinking exercises, and help students better evaluate and understand the ecological significance of problems that have been in the forefront of recent news stories. Each EIO can be found on-line at http://www.prenhall.com/oceanissues and the projects can be completed in the accompanying workbook for submission. The EIO projects are authored by two environmental scientists (Dan Abel of Coastal Carolina University and Robert McConnell of Mary Washington College) with a special interest in critical thinking regarding environmental issues. Page xix of this Preface explains the EIO feature in more detail.

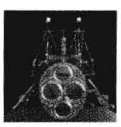
What's New in this Edition?

Changes in this edition are designed to increase the readability, relevance, and appeal of this book. The major changes include:

- Incorporation of comments from hundreds of students who thoroughly reviewed and edited the previous edition in small focus group discussions and one-on-one meetings with author Al Trujillo
- Inclusion of new chapter-related web-based "Environmental Issues in Oceanography" features that are designed to increase environmental awareness and critical-thinking activities
- Addition of "Key Questions" at the beginning of each chapter and a revised "Chapter in Review" summary feature at the end of each chapter
- Use of yellow highlighted "Concept Statements" imbedded within the text to focus attention on key concepts
- Inclusion of eight new feature boxes that present some of the most recent discoveries in oceanography
- Feature boxes are organized around three new themes:

Research Methods in Oceanography, which highlights how oceanographic knowledge is obtained

People and the Ocean Environment, which illustrates human interaction with the ocean



Historical Feature, which focuses on historical developments in oceanography

- Addition or modification of over a dozen tables, which organize and summarize important data
- Inclusion of over 100 new photos and illustrations, and modification or redrawing of over 150 existing figures to add clarity and improve the illustration package
- Major reorganization, revision, and/or additions to Chapters 1, 2, 4, 5, 7, 11, 12, and 13
- Addition of a new appendix, "A Chemical Background: Why Water has 2 H's and 1 O"
- All text in the chapters has been thoroughly reviewed and edited in a continued effort to refine the style and clarity of the writing

Additionally, this edition continues to offer some of the previous edition's most popular features, including:

- Chapter-opening features that highlight an important aspect of the history of oceanography related to each chapter
- Use of the international metric system (Système International or SI units) with comparable English system units in parenthesis
- Explanation of word etymons (*etumon* = the true sense of a word) as new terms are introduced in an

effort to demystify scientific terms by showing what the terms actually mean

- Notation of key terms with **bold print,** which are defined when they are introduced and are included in the glossary
- The "Students Sometimes Ask..." section at the end of each chapter that contains actual student questions, along with the authors' answers
- The end-of-chapter questions and exercises
- A dedicated Web site (http://www.prenhall.com/thurman) that features chapter-specific learning objectives, on-line quizzes, critical-thinking exercises, links to the EIO Web site, and relevant Internet links

The New Instructional Package

For the Student:

- A **Companion Web site** (http://www.prenhall.com/thurman), which is designed to function both as an on-line study guide and as a launching pad for further exploration. The site is designed using the latest technology, written by co-author Al Trujillo and Molly Trecker, and tied chapter-by-chapter to the text.
  - **To aid in reviewing the text material,** the site contains several self-testing modules, including multiple choice and true/false, fill-in-the-blanks, and image-labeling exercises. The answers can be submitted via the Internet to Prentice Hall's server for a grade, which can then be submitted to your instructor via e-mail.
  - **To foster critical thinking,** the site contains *Web Essay* questions—short-answer questions that require the student to use the Internet to research an issue, evaluate the information, and formulate a response. Responses to the Web Essays can also be e-mailed to your instructor for grading.
  - **To encourage and enable further exploration** using the incredible array of resources now available on the Internet, every chapter contains both general and chapter-specific annotated *Destinations* links to some of the best oceanography sites on the World Wide Web. These sites are researched and annotated by oceanography instructors to insure quality and relevancy and continually checked by Prentice Hall to insure validity.
- An **Environmental Issues in Oceanography workbook,** which is packaged free with *Essentials of Oceanography.* The workbook contains all the questions from the web-based EIO projects in a format suitable for submission to your instructor.
- The **New York Times *Themes of the Times*—Oceanography** is a unique newspaper-format supplement featuring recent articles about oceanography culled from the pages of the *New York Times.* This supplement, available for wrapping with the text at no charge, encourages you to make connections between what you're learning in the classroom and recent news events as reported in the media.
- ***Science on the Internet: A Student's Guide*** is a "guidebook" resource that helps science students locate and explore myriad science resources on the World Wide Web. It also provides an over-view of the Web itself, general navigational strategies, and brief student activities. *Science on the Internet* can be packaged free with *Essentials of Oceanography.*

For the Instructor:

- A **Transparency Set** of all line illustrations, some tables, and selected photographs from the text, enlarged for excellent classroom visibility. (Note: All line illustrations are available on the Digital Image Gallery CD-ROM.)
- A **Slide Set** of 180 slides from the text including key line illustrations plus most photographs not available with the transparency set. (Note: All photographs for which permission could be acquired are available on the Digital Image Gallery CD-ROM.)
- The **Digital Image Gallery (DIGIT) CD-ROM,** which includes all illustrations, tables, and photographs (for which permission could be acquired) from the text in high-resolution, 16-bit JPEG files. The JPEG files are organized by chapter and can be easily imported into lecture presentation software (such as Microsoft® PowerPoint®). The CD-ROM comes with a comprehensive reference list of all figures and their captions.
- A customizable **PowerPoint® presentation** for each chapter, written by Al Trujillo. All PowerPoint presentations are included on the Digital Image Gallery CD-ROM and can be easily modified to suit each instructor's needs.
- A new **Instructor's Manual,** written by Al Trujillo and containing answers to end-of-chapter questions, a selection of various types of exam questions, and a wealth of instructional resources for each chapter.
- **Computerized Test Manager CD-ROM,** with which you can easily create and tailor exams to your own needs: produce multiple versions of your exam, with answer keys; select questions by number, type, level of difficulty, or random distribution; export your exam to a rich text file for import into your word processing program; and more. The software comes with a comprehensive reference guide and includes the toll-free technical support line.

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The authors are indebted to many individuals for their helpful comments and suggestions during the revision of this book. Al Trujillo is particularly indebted to his colleagues at Palomar Community College, Patty Deen and Lisa DuBois, for their keen interest in the project and for allowing him to use some of their creative ideas in the book. They are simply the finest colleagues imaginable.

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Many people were instrumental in helping the text evolve from its manuscript stage. Patrick Lynch, Geoscience Editor at Prentice Hall, expertly guided the project and offered many insightful suggestions to improve the text. Developmental Editor John Murdzek read the entire manuscript and made vast improvements in the writing style. The editorial staff at Lithokraft II also made many thoughtful suggestions to improve the manuscript.

Al Trujillo would also like to thank his students, whose questions provided the material for the "Students Sometimes Ask..." sections and whose continued input has proved invaluable for improving the text. Since scientists (and good teachers) are always experimenting, thanks also for allowing yourselves to be a captive audience with which to conduct my experiments.

Al Trujillo also thanks his patient and understanding family for putting up with his absence during the long hours of preparing "The Book." Lastly, appreciation is extended to the chocolate manufacturers Hershey, See's, and Ghiradelli for providing inspiration. A heartfelt thanks to all of you!

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Although this book has benefited from careful review by many individuals, the accuracy of the information rests with the authors. If you find errors or have comments about the text, please contact us at:

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EIO

Environmental Issues in Oceanography

by Daniel C. Abel, Coastal Carolina University and Robert L. McConnell, Mary Washington College

What are the EIO projects?

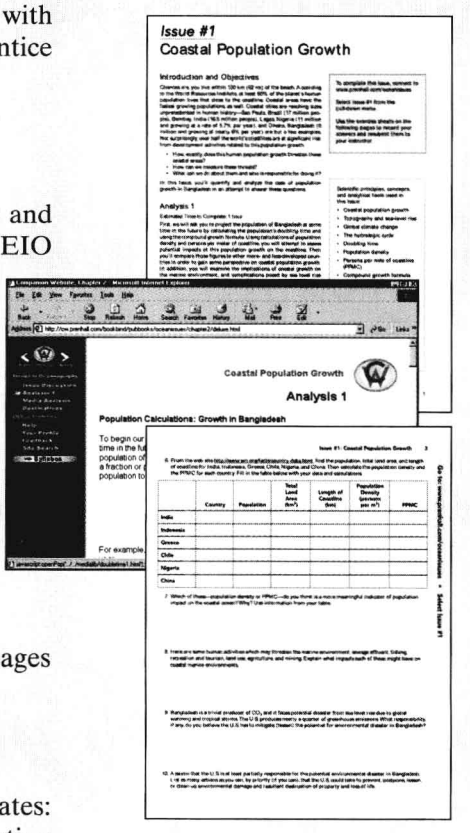
The **Environmental Issues in Oceanography (EIO)** are web-based, critical-thinking projects that guide you in applying the concepts of oceanography and scientific reasoning in analyzing a range of immediate, relevant environmental issues. The goal of these projects is not only to draw your attention to some pressing ecological issues, but to help your instructor in training you to gather, evaluate, and analyze information as a scientist would in order to draw your own conclusions—a skill that will benefit you for the rest of your life.

EIO

For more information and on-line exercises about the Environmental Issue in Oceanography (EIO) "Coastal Population Growth," visit the EIO Web site at **http://www.prenhall.com/oceanissues** and select Issue #1.

Where do you find them?

Twelve EIO boxes (pictured above) in selected chapters alert you that the concept you've just been studying in theory will be applied in practice to one of the eight EIO projects. You will see that each of these projects integrate many concepts across chapters, but to avoid cluttering the text they are called out only in discussions of the most critical concepts. The EIO workbook comes free with every *Essentials of Oceanography,* seventh edition text purchased from Prentice Hall.



How do you use them?

The EIO projects integrate the concepts and theory from the text, news and data sources from the Web, and the critical-thinking questions found in the EIO workbook. To use the resources most effectively:

- First, review the project in your EIO workbook. The first page of each project outlines the project, alerts you to the concepts and tools that you will be applying, and anticipates the time needed to complete each part of the project.
- Next, connect to the EIO Web site at www.prenhall.com/oceanissues and access the project. The Web site will lead you on a structured exploration of the issue, linking you to outside sources for data and other information necessary to complete your analysis.
- Lastly, use the workbook to record your responses, calculations, and conclusions. The questions on the Web site are recreated here, with space for your answers; perforated pages make it easy to tear out these pages and submit them to your instructor.

The Issues

1. Coastal Population Growth • 2. Sonar and Whales • 3. Methane Hydrates: Energy Boom or Climate Bust? • 4. Toxic Chemicals in Seawater • 5. The Lasting Influences of Hurricanes • 6. Beaches or Bedrooms?: The Dynamic Coastal Environment • 7. Illegal Immigration: Ballast Water and Exotic Species • 8. Lifestyles of the Large and Blubbery: How to Grow a Blue Whale

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Introduction

Welcome to a book about the oceans. As you read this book, we hope that it elicits a sense of wonder and a spirit of curiosity about our watery planet. The oceans represent many different things to different people. To some, it is a wilderness of beauty and tranquility, a refuge from hectic civilized lives. Others see it as a vast recreational area that inspires either rest or physical challenge. To others, it is a mysterious place that is full of unknown wonders. And to others, it is a place of employment unmatched by any on land. To be sure, its splendor has inspired artists, writers, and poets for centuries (Figure I–1). Whatever your view, we hope that understanding the way the oceans work will increase your appreciation of the marine environment. Above all, take time to admire the oceans.

Essentials of Oceanography was first written in the late 1970s to help students develop an *awareness about the marine environment*—that is, develop an appreciation for the oceans by learning about oceanic processes (how the oceans behave) and their interrelationships (how physical entities are related to one another in the oceans). In this seventh edition, our goal is the same: to give the reader the scientific background to understand the basic principles underlying oceanic phenomena. In this way, one can then make informed decisions about the oceans in the years to come. We hope that some of you will be inspired so much by the oceans that you will continue to study them formally or informally in the future. (For those who may be considering a life-long career in oceanography, see Appendix V, "Careers in Oceanography.")

- What is oceanography?
- How have the oceans influenced conditions on Earth?
- What is rational use of technology?

What Is Oceanography?

Oceanography (*ocean* = the marine environment, *graphy* = the name of a descriptive science) is quite literally the description of the marine environment. Unfortunately, this definition does not fully portray the extent of what oceanography encompasses: oceanography is much more than just *describing* marine phenomena. Oceanography could be more accurately called the scientific study of all aspects of the marine environment. Hence, the field of study called oceanography could (and maybe *should*) be called oceanology (*ocean* = the marine environment, *ology* = the study of). However, the science of studying the oceans has traditionally been called oceanography. It is also called *marine science* and includes the study of the water of the ocean, the life within it, and the (not so) solid earth beneath it.

Since prehistoric time, people have used the oceans as a means of transportation and as a source of food. However, the importance of ocean processes has been studied technically only since the 1930s. The impetus for this study began with the search for petroleum, continued with the emphasis on ocean warfare during World War II, and more recently has been expressed in the concern for the well-being of the ocean environment. Historically, those who make their living fishing in the ocean go where the

Oceanography is not so much a science as a collection of scientists who find common cause in trying to understand the complex nature of the ocean. In the vast salty seas that encompass the earth, there is plenty of room for persons trained in physics, chemistry, biology, and engineering to practice their specialties. Thus, an oceanographer is any scientifically trained person who spends much of his [or her] *career on ocean problems.*

— Willard Bascom (1980)

Figure I–1 The ocean environment at Jalama Beach, California.

physical processes of the oceans offer good fishing. But how marine life interrelates with ocean geology, chemistry, and physics to create good fishing grounds has been more or less a mystery until only recently when scientists in these disciplines began to investigate the oceans with new technology.

Oceanography is typically divided into different academic disciplines (or subfields) of study. The four main disciplines of oceanography that are covered in this book are:

- *Geological oceanography,* which is the study of the structure of the sea floor and how the sea floor has changed through time; the creation of sea floor features; and the history of sediments deposited on it.
- *Chemical oceanography,* which is the study of the chemical composition and properties of seawater; how to extract certain chemicals from seawater; and the effects of pollutants.
- *Physical oceanography,* which is the study of waves, tides, and currents; the ocean-atmosphere relationship that influences weather and climate; and the transmission of light and sound in the oceans.
- *Biological oceanography,* which is the study of the various oceanic life forms and their relationships to one another; adaptations to the marine environment; and developing ecologically sound methods of harvesting seafood.

Other disciplines include ocean engineering, marine archaeology, and marine policy. Since the study of oceanography often examines in detail all the different disciplines of oceanography, it is frequently described as being an *interdisciplinary* science, or one covering all the disciplines of science as they apply to the oceans (Figure I–2). The content of this book includes the broad range of interdisciplinary science topics that comprises the field of oceanography. In essence, this is a book about *all* aspects of the oceans.

Earth's Ocean

The oceans are the largest and most prominent feature on Earth. In fact, they are the single most defining feature of our planet. As viewed from space, our planet is a beautiful blue, white, and brown globe (Figure I–3). It is our oceans of liquid water that sets us apart in the solar system. No other planet has an ocean; however, a recent discovery of fluid-filled cracks on some of Jupiter's moons—most notably Europa—has lead to speculation that there may be an ocean of liquid water beneath the ice. The fact that our planet has so much water, *and in the liquid form,* is unique in the solar system.

The oceans determine where our continents end, and thus have shaped political boundaries and human history many times. The oceans conceal many features; in fact, the majority of Earth's geographic features are on the ocean floor. Remarkably, there was once more