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大学环境教育丛书
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Mackenzie L. Davis David A. Cornwell

Introduction to Environmental Engineering

(Fourth Edition)

环境工程导论

（第4版）

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出版前言

在21世纪之初，面临各种环境问题，人类清醒地认识到要走可持续发展之路。而发展环境教育是解决环境问题和实施可持续发展战略的根本。高等学校的环境教育，是提高新世纪建设者的环境意识，并向社会输送环境保护专门人才的重要途径。为了反映国外环境类教材的最新内容和编写风格，同时也为了提高学生阅读专业文献和获取信息的能力，我们精选了国外一些优秀的环境类教材，加以影印或翻译，组成大学环境教育丛书。所选教材均在国外被广泛采用，多数已再版，书中不仅介绍了有关概念、原理及技术方法，给出了丰富的数据，也反映了作者不同的学术观点。

我们希望这套丛书的出版能对高等院校师生和广大科技人员有所帮助，并为我国的环境教育事业作出贡献。

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2007年3月

To our students,
who make it worthwhile

To Mack's wife Elaine, for her understanding and support these 44 years.

To Mack's daughter, Laura Safran, son-in-law, John Safran, and especially to grandsons Aaron and Zachary Safran with the hope that those who use this book may make the environment of the future a sustainable one for you and all those generations that follow.

To Nancy Cornwell for her assistance in revising the Solid Waste chapter 9 and all of her hard work in researching information for the Water Treatment chapter 4. Nancy is a recognized expert in the environmental field in her own right and her assistance and contributions are greatly appreciated.

ABOUT THE AUTHORS

Mackenzie L. Davis is an Emeritus Professor of Environmental Engineering at Michigan State University. He received all his degrees from the University of Illinois. From 1968 to 1971 he served as a Captain in the U.S. Army Medical Service Corps. During his military service he conducted air pollution surveys at Army ammunition plants. From 1971 to 1973 he was Branch Chief of the Environmental Engineering Branch at the U.S. Army Construction Engineering Research Laboratory. His responsibilities included supervision of research on air, noise, and water pollution control and solid waste management for Army facilities. In 1973 he joined the faculty at Michigan State University. He has taught and conducted research in the areas of air pollution control and hazardous waste management.

In 1987 and 1989–1992, under an intergovernmental personnel assignment with the Office of Solid Waste of the U.S. Environmental Protection Agency, Dr. Davis performed technology assessments of treatment methods used to demonstrate the regulatory requirements for the land disposal restrictions ("land ban") promulgated under the Hazardous and Solid Waste Amendments.

Dr. Davis is a member of the following professional organizations: American Chemical Society, American Institute of Chemical Engineers, American Society for Engineering Education, American Meteorological Society, American Society of Civil Engineers, American Water Works Association, Air & Waste Management Association, Association of Environmental Engineering and Science Professors, and the Water Environment Federation.

His honors and awards include the State-of-the-Art Award from the ASCE, Chapter Honor Member of Chi Epsilon, Sigma Xi, election as a Fellow in the Air & Waste Management Association, and election as a Diplomate in the American Academy of Environmental Engineers with certification in hazardous waste management. He has received teaching awards from the American Society of Civil Engineers Student Chapter, Michigan State University College of Engineering, North Central Section of the American Society for Engineering Education, Great Lakes Region of Chi Epsilon, and the Amoco Corporation. In 1998, he received the Lyman A. Ripperton Award for distinguished achievement as an educator from the Air & Waste Management Association. He is a registered professional engineer in Michigan.

In 2003, Dr. Davis retired from Michigan State University.

David A. Cornwell is the Founder and President of the consulting firm Environmental Engineering & Technology, Inc. headquartered in Newport News, VA. He attended the University of Florida in Gainesville where he received his Ph.D. in Civil/Environmental Engineering, and has remained a loyal Gator fan ever since. He was an Associate Professor in the Civil and Environmental Engineering Department at Michigan State University prior to entering the consulting field. Many of Dr. Cornwell's students now are active members of the water industry.

During his career as a consultant, Dr. Cornwell has provided design and operational services to water utilities around the world. He has lectured and written on many aspects of this field, including over 50 peer reviewed technical articles and reports. Much of his work has included the development of new and optimized water treatment processes. He is a registered professional engineer in more than 15 states.

Dr. Cornwell has an extensive record of service to the water industry. He has been an active member of AWWA since the early 1970s and has served on numerous committees in that organization. In addition, he is an active member of the Water Environment Federation, AWWA Research Foundation (subscriber), the American Chemical Society, the American Consulting Engineers Council, the Association of Environmental Engineering Professors, and is a Diplomate of the American Academy of Environmental Engineers.

In 2005, Dr. Cornwell was the recipient of the A.P. Black Research Award, given by AWWA to recognize excellence in water treatment research. He has also been the recipient of two AWWA Best Publication Awards, and was elected an Honorary Member of AWWA.

About the Cover Artist

Barbara Masten Cobb attended art school before completing an associate degree in nursing in 1983. Barbara is employed as the lead floor nurse in a New Jersey nursing home. In her spare time she pursues her avocation—painting. The water color used for the cover for this book is her third painting to grace a McGraw-Hill textbook cover.

PREFACE

Following the format of previous editions, the fourth edition of *Introduction to Environmental Engineering* is designed for use in an introductory sophomore-level engineering course with sufficient depth to allow its use in more advanced courses. The book covers the basic, traditional subject matter that forms the foundation of more advanced courses. As such, it provides the fundamental science and engineering principles that instructors in more advanced courses may assume are common knowledge for an advanced undergraduate. In the more than 60 offerings of this course, we have found that mature college students in allied fields—such as biology, chemistry, resource development, fisheries and wildlife, microbiology and soils science—have no difficulty with the material.

We have assumed the students using this text have had courses in chemistry, physics, and biology as well as sufficient mathematics to understand the concepts of differentiation and integration. Basic and environmental chemistry concepts are introduced at the beginning of the chapters in which they are relevant. This format integrates the chemistry fundamentals with their application to the subject matter of the chapter. It provides the student with the tools to analyze and understand the environmental engineering issues described in the chapter, in addition to providing an immediate feedback of the relevance of the basic chemistry. There are over 100 end-of-chapter chemistry-related problems spread throughout the text. In a similar manner, the fundamental concepts of microbiology are introduced as an introduction to biological treatment of wastewater. In the mathematical presentations, we have provided only a few derivations. In our experience, the more rigorous approach of derived mathematics may yield a result that is not more but less demonstrative—and even confusing—to the beginning engineering student.

Two themes are carried through the text. The first is an introduction to the concept of materials and energy balance as a tool for understanding environmental processes and solving environmental engineering problems. This concept is introduced in a new stand-alone chapter and then applied for conservative systems in hydrology (hydrologic cycle, development of the rational formula, and reservoir design). This theme is expanded to include sludge mass balance in Chapter 4, and the DO sag curve in Chapter 5. The design equations for a completely mixed activated sludge system and a more elaborate sludge mass balance are developed in Chapter 6. Mass balance is used to account for the production of sulfur dioxide from the combustion of coal and in the development of absorber design equations in Chapter 7. In Chapter 10, a mass balance approach is used for waste audit. There are over 100 materials and energy balance end-of-chapter problems spread throughout the text.

The second theme of the book is the concept of sustainability. First introduced in Chapter 1, the methods of waste minimization are discussed in each succeeding chapter under the topics of water conservation, sludge minimization in water treatment, land treatment of wastewater, protection of the ozone layer, global warming, resource

conservation and recovery of solid waste, hazardous waste management, and reduction of the volume of radioactive waste.

Each chapter concludes with a list of review items, the traditional end-of-chapter problems, and, perhaps less traditional, discussion questions. The review items have been written in the "objective" format of the Accreditation Board for Engineering and Technology (ABET). Instructors will find this particularly helpful for directing student review for exams, for assessing continuous quality improvement for ABET and for preparing documentation for ABET curriculum review. We have found the discussion questions useful as a "minute check" or spot quiz item to see if the students understand concepts as well as number crunching.

The fourth edition has been thoroughly revised and updated. With the addition of 222 new end-of-chapter problems there are now a total of 650 problems. Sixty-six of the problems have been set up for spreadsheet solutions. The following paragraphs summarize the major changes in this edition.

- A discussion of sustainability and a discussion of the process by which laws and regulations are developed has been added to the first chapter. The discussion of ethics has been expanded.
- A new, stand-alone chapter on material and energy balances has been added.
- The hydrology chapter has been reorganized and slimmed down.
- The water treatment chapter has been revised to include a new treatment of Henry's law, new material on waterborne disease and arsenic, updated water quality standards, an updated technique for design of mixing systems, a new discussion of membrane treatment technology, and a revised and expanded discussion of ultraviolet disinfection. Two new example problems have been added.
- The water quality management chapter has been expanded to include discussions of endocrine disrupting compounds (EDCs), total maximum daily load (TMDL), water quality management in estuaries, and groundwater quality, including uncontrolled releases of contaminants and saltwater intrusion into aquifers.
- A new introduction, a new section on treatment standards, and a new section on membrane treatment have been added to the wastewater chapter. In addition, the chapter has been rearranged to place the microbiology review closer to the application of microbiology to activated sludge treatment.
- The air pollution standards have been updated and new material on mercury, lead, and $PM_{2.5}$ has been added to the air pollution chapter. In addition, the sections on origin and fate, indoor air, acid rain, ozone depletion, global warming, and control of automobile emissions have been updated. New discussions on catalytic combustion, baghouses, and mercury control have been added. Two new example problems on catalytic combustion and baghouse design have been added.
- A revised introduction to the noise pollution chapter includes the impact of hearing loss on people, as well as the economic impact of noise pollution on civil engineering projects and businesses. A new discussion of the L_{dn} concept and a

complete revision of the method of calculating airborne transmission to reflect the ISO calculation procedure are included in the noise pollution chapter.

- The solid waste chapter introduction and discussion of collection methods has been updated. A new section on bioreactor landfills has been added. All cost data have been updated.
- In the hazardous waste chapter, the section on risk assessment has been updated. The discussions on generator requirements, transporter regulations, and underground storage tanks have been slimmed down and updated. Two new sections and example problems, on retardation of uncontrolled releases into the groundwater and on pump and treat, have been added.
- The chapter on ionizing radiation has been revised to conform to the SI units of notation. Three new example problems have been added. The discussion of radioactive waste management has been updated.

As it stands in the curriculum at Michigan State University (MSU), the course bearing the title of this book provides the foundation for four follow-on senior level environmental engineering courses. The initial portions of selected chapters (hydrology, materials and energy balances, water treatment, water quality, wastewater treatment, air pollution, noise pollution, and solid waste) are included in the introductory course. Advanced material, including most of the design concepts, are covered in the upper level courses (hydrology, water and wastewater treatment plant design, solid and hazardous waste management). Some of the material is left for the students to pursue on their own (environmental legislation, ionizing radiation).

An instructor's manual and set of PowerPoint® slides are available online for qualified instructors. Please inquire with your McGraw-Hill representative for the necessary access password. The instructor's manual includes sample course outlines, solved example exams, and detailed solutions to the end-of-chapter problems. In addition, there are suggestions for using the pedagogic aids in the next.

Numerous MSU alumni have indicated that *Introduction to Environmental Engineering* is an excellent text for review and preparation for the Professional Engineers examination. It is not only readable for self-study but also provides sufficient example problems and data for practical application in the exam. Many have taken it to the exam as one of their reference resources. And they have used it!

As always, we appreciate any comments, suggestions, corrections, and contributions for future revisions.

Mackenzie L. Davis
David A. Cornwell

Acknowledgements

As with any other text, the number of individuals who have made it possible far exceeds those whose names grace the cover. At the hazard of leaving someone out, we would like to explicitly thank the following individuals for their contribution.

Over the many years of the four editions, the following students helped to solve problems, proofread text, prepare illustrations, raise embarrassing questions, and

generally make sure that other students could understand the material: Shelley Agarwal, Stephanie Albert, Deb Allen, Mark Bishop, Aimee Bolen, Kristen Brandt, Jeff Brown, Amber Buhl, Nicole Chernoby, Rebecca Cline, Linda Clowater, Shauna Cohen, John Cooley, Ted Coyer, Marcia Curran, Talia Dodak, Kimberly Doherty, Bobbie Dougherty, Lisa Egleston, Karen Ellis, Craig Fricke, Elizabeth Fry, Beverly Hinds, Edith Hooten, Brad Hoos, Kathy Hulley, Geneva Hulslander, Lisa Huntington, Angela Ilieff, Alison Leach, Gary Lefko, Lynelle Marolf, Lisa McClanahan, Tim McNamara, Becky Mursch, Cheryl Oliver, Kyle Paulson, Marisa Patterson, Lynnette Payne, Jim Peters, Kristie Piner, Christine Pomeroy, Susan Quiring, Erica Rayner, Bob Reynolds, Laurene Rhyne, Sandra Risley, Carlos Sanlley, Lee Sawatzki, Stephanie Smith, Mary Stewart, Rick Wirsing, and Ya-yun Wu. To them a hearty thank you!

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To John Eastman, our esteemed friend and former colleague, we offer our sincere appreciation. His contribution to the initial work of Chapter 5 in the first edition, as well as constructive criticism and "independent" testing of the material was exceptionally helpful. Kristin Erickson, Radiation Safety Officer, Office of Radiation, Chemical and Biological Safety, Michigan State University, contributed to the Chapter 11 revisions for the third edition. To her we offer our hearty thanks.

And last, but certainly not least, we wish to thank our families, who have put up with the nonsense of book writing.

CONTENTS

CHAPTER 1

INTRODUCTION

概 论

1-1 WHAT IS ENVIRONMENTAL ENGINEERING?

Professions, Learned and Otherwise

Webster's dictionary defines the learned professions as law, medicine, and theology. It has been suggested that engineers may not be learned enough to rank among these because the study of law, medicine, or theology requires considerably more than four years of undergraduate work. There was a time, some hundred years ago, when the four-year engineering program was two years longer than those of the learned professions! At any rate, *Webster's* is willing to concede that engineering, along with teaching and writing, is a profession even if it is not "learned." At a minimum, a profession is an occupation that requires advanced training in the liberal arts or sciences and mental rather than manual work.

But being a professional is more than being in or of a profession. True professionals are those who pursue their learned art in a spirit of public service (ASCE, 1973). True professionalism is defined by the following seven characteristics:

1. Professional decisions are made by means of general principles, theories, or propositions that are independent of the particular case under consideration.
2. Professional decisions imply knowledge in a specific area in which the person is expert. The professional is an expert only in his or her profession and not an expert at everything.
3. The professional's relations with his or her clients are objective and independent of particular sentiments about them.
4. A professional achieves status and financial reward by accomplishment, not by inherent qualities such as birth order, race, religion, sex, or age or by membership in a union.
5. A professional's decisions are assumed to be on behalf of the client and to be independent of self-interest.
6. The professional relates to a voluntary association of professionals and accepts only the authority of those colleagues as a sanction on his or her own behavior.
7. A professional is someone who knows better what is good for clients than do the clients. The professional's expertise puts the client into a very vulnerable position. This vulnerability has necessitated the development of strong professional codes and ethics, which serve to protect the client. Such codes are enforced through the colleague peer group (Schein, 1968).

The branch of engineering called civil engineering, from which environmental engineering is primarily, but not exclusively, derived, has an established code of ethics that embodies these principles. The code is summarized in Figure 1-1.

And What Is Engineering?

Engineering is a profession that applies mathematics and science to utilize the properties of matter and sources of energy to create useful structures, machines, products, systems, and processes.