

This International Student Edition is for use outside of the U.S.

SIXTH EDITION



Introduction to
**ENVIRONMENTAL
ENGINEERING**

**Mc
Graw
Hill**

**MACKENZIE L. DAVIS
DAVID A. CORNWELL**

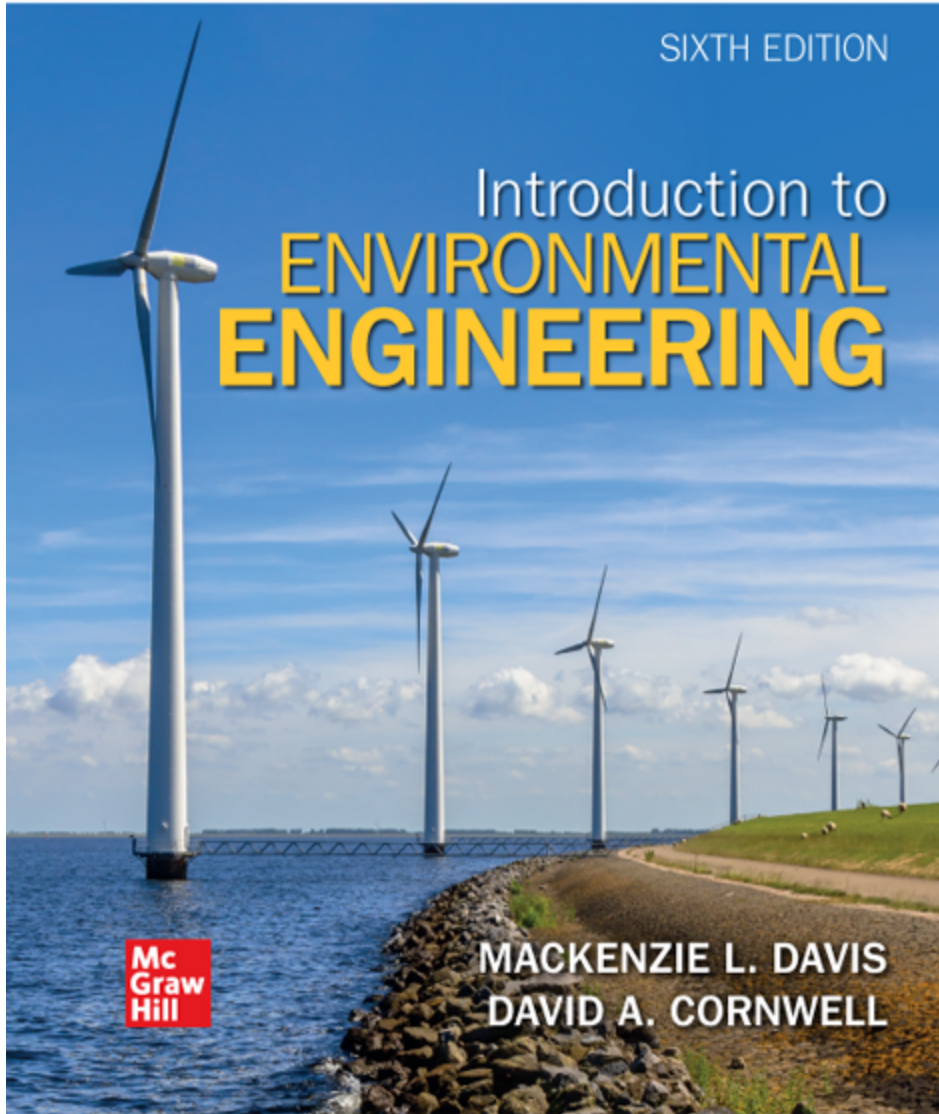
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**INTRODUCTION TO
ENVIRONMENTAL
ENGINEERING**

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Environmental
Engineering**

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INTRODUCTION TO ENVIRONMENTAL ENGINEERING

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**To Elaine, my critic, my cheerleader, page v
my wife . . . lo these 50 years, and my
love . . . forever**

—Mackenzie L. Davis

**To my wife Nancy, who not only puts up
with me in life, but has to put up with me
in business too . . . without you neither I
nor Cornwell Engineering Group would
be the same. Thank you for being my
wife, companion, and partner.**

—David A. Cornwell

Mackenzie L. Davis, Ph.D., P.E., BCEE, 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. In 2007, he was recognized as the Educational Professional of the Year by the Michigan Water Environment Association. He is a registered professional engineer in Michigan.

Dr. Davis is the author of a student and professional edition of *Water and Wastewater Engineering* and Co-author of *Principles of Environmental Engineering* with Dr. Susan Masten.

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

David A. Cornwell, Ph.D., P.E., BCEE, is a registered page vii professional engineer in over 20 states and is the founder and CEO of the consulting firm Cornwell Engineering Group headquartered in Newport News, VA. He attended the University of Florida in Gainesville, FL, where he received his Ph.D. in civil/environmental engineering and has remained a loyal Gator fan ever since, serving as a Bull Gator, Dean's Advisory Board, and on the President's Council. He is also currently a Full Adjunct Professor at UF. He was an associate professor in the Civil 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 profession.

During his career as a consultant, Dr. Cornwell has provided process, design, and operational troubleshooting services to water utilities around the world. He has lectured and written on many aspects of water treatment, including over 75 peer-reviewed technical articles and reports. Much of his work has included the development of new and optimized water treatment processes. His non-profit corporation, Cornwell Research Group is dedicated to *safe water for all* and is actively working to reduce lead exposure to children. He has won three *JAWWA* Division best paper awards and the overall *JAWWA* publication award. Dr. Cornwell has an extensive record of service to the water profession. He has been an active member of American Water Works Association (AWWA) since the early 1970s and has served on numerous committees in that organization. He has chaired the Research Division and the Technical and Education Council, and served on the board of directors and executive committee of AWWA.

In 2005, Dr. Cornwell was the recipient of the A.P. Black Research Award given by AWWA to recognize excellence in water treatment research, recognizing his contributions to bridging the gap between research and application. He recently received the Water Research Foundation Dr. Pankaj Parekh Research Innovation Award. Dr. Cornwell has been a principal investigator on over 20 Water Research Foundation research projects.

Following the format of previous editions, the sixth edition of *Introduction to Environmental Engineering* is designed for use in an introductory sophomore-level environmental engineering course with sufficient depth to allow its use in more advanced courses. We assume that the book will be used in one of the first environmental engineering courses encountered by the student. We have provided sufficient depth that it may also be used for more advanced courses. It 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.

The Fundamentals of Engineering (FE) examination for civil and environmental engineering has been highlighted as a focal point in this edition. Seventy percent of the topics included in the environmental engineering specific Fundamentals of Engineering (FE) examination are covered in *Introduction to Environmental Engineering*. These include the following subject areas: ethics in Chapter 1, mass balance in Chapter 2, hydrology and watershed processes in Chapter 4, water and wastewater engineering in Chapters 6, 7, and 8, air quality engineering in Chapter 9, the noise pollution aspects of occupational and health safety in Chapter 10, solid and hazardous waste engineering in Chapters 11 and 12, and radiological health, safety, and waste management in Chapter 13. To highlight the Fundamental of Engineering connections, we have identified over 112 equations, 12 tables, and 6 figures in *Introduction to Environmental Engineering* that also appear in the *Fundamentals of Engineering Supplied-Reference Handbook*.

Because the FE exam uses both SI units and U.S. Customary System (USCS) units, USCS units are introduced in Chapter 1 and then utilized in numerous example problems as well as the FE Exam Formatted Problems. A conversion factor table is presented in Appendix C.

Specific examples of revisions that appear in the sixth edition include: updated ASCE code of ethics in Chapter 1; updated discussion of risk perception; annual risk of death; revised slope factors for inhalation risk and revised slope factors for inhalation risk in Chapter 3; addition of a

discussion of nanoparticles in Chapter 7; update of NAAQS; update of auto emission standards; discussion of the use of bromine to enhance fabric filter's removal of mercury; new global warming data; development of new refrigerant gases to lower global warming potential; update of CO₂ levels and new end of chapter problems in Chapter 9; addition of a discussion of direct and indirect potable reuse and tables of communities that have implemented direct and indirect reuse; examples of reuse standards implemented by California, Arizona, New Mexico and Texas; graphs of coal use in recent years in Chapter 13.

Each chapter concludes with a list of review items, the traditional end of chapter problems, and, perhaps less traditional, discussion questions and FE formatted problems. 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.

An instructor's manual and set of PowerPoint® slides are page ix 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 text.

Numerous Michigan State University alumni have indicated that *Introduction to Environmental Engineering* is an excellent text for review and preparation for the Professional Engineers examination. It is both readable for self-study as well as a good source of 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

Acknowledgments

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 six 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, Glenna Wood, and Ya-yun Wu. To them a hearty thank you!

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To John Eastman, our now deceased 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. We especially want to thank Dave’s wife, Nancy McTigue, for all her work on making revisions to the Solid Waste Management chapter and her help in reviewing the Water Treatment chapter.

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

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