McGRAW-HILL SERIES IN
WATER RESOURCES AND
ENVIRONMENTAL ENGINEERING

INTRODUCTION TO ENVIRONMENTAL ENGINEERING

Second Edition

Mackenzie L. Davis
Michigan State University

David A. Cornwell
Environmental Engineering and Technology

McGraw-Hill, Inc.
New York St. Louis San Francisco Auckland Bogotá
Caracas Hamburg Lisbon London Madrid
Mexico Milan Montreal New Delhi Paris
San Juan São Paulo Singapore Sydney Tokyo Toronto

This book was set in Times Roman by Publication Services.
The editors were B. J. Clark and John M. Morriss;
the production supervisor was Diane Renda.
The cover was designed by John Hite.
Project supervision was done by Publication Services.
R. R. Donnelley & Sons Company was printer and binder.

INTRODUCTION TO ENVIRONMENTAL ENGINEERING

3 4 5 6 7 8 9 0 DOC DOC 9 0 9 8 7 6 5 4 3 2

ISBN 0-07-015911-4

Library of Congress Cataloging-in-Publication Data

Davis, Mackenzie Leo, (date).
Introduction to environmental engineering / Mackenzie L. Davis, David A. Cornwell. — 2nd ed.
p. cm. — (McGraw-Hill series in water resources and environmental engineering)
Includes bibliographical references and index.
ISBN 0-07-015911-4
1. Environmental engineering. I. Cornwell, David A., (date). II. Title. III. Series.
TD145.D26 1991
628—dc20 90-6156

INTRODUCTION TO ENVIRONMENTAL ENGINEERING

McGraw-Hill Series in Water Resources and Environmental Engineering

Consulting Editors

Rolf Eliasen, Paul H. King, and Ray K. Linsley

Bailey and Ollis: *Biochemical Engineering Fundamentals*
Bishop: *Marine Pollution and Its Control*
Bouwer: *Groundwater Hydrology*
Canter: *Environmental Impact Assessment*
Chanlett: *Environmental Protection*
Chow, Maidment, and Mays: *Applied Hydrology*
Davis and Cornwell: *Introduction to Environmental Engineering*
Eckenfelder: *Industrial Water Pollution Control*
Linsley and Franzini: *Water Resources Engineering*
Metcalf and Eddy, Inc.: *Wastewater Engineering: Collection and Pumping of Wastewater*
Metcalf and Eddy, Inc.: *Wastewater Engineering: Treatment, Disposal, Reuse*
McGhee: *Water Supply and Sewerage*
Peavy, Rowe, and Tchobanoglous: *Environmental Engineering*
Sawyer and McCarty: *Chemistry for Environmental Engineering*
Tchobanaglous, Theisen, and Eliassen: *Solid Wastes: Engineering Principles and Management Issues*

Also Available from McGraw-Hill

Schaum's Outline Series in Civil Engineering

Most outlines include basic theory, definitions, and hundreds of solved problems and supplementary problems with answers.

Titles on the Current List Include:

Advanced Structural Analysis
Basic Equations of Engineering
Descriptive Geometry
Dynamic Structural Analysis
Engineering Mechanics, 4th edition
Fluid Dynamics
Fluid Mechanics & Hydraulics
Introduction to Engineering Calculations
Introductory Surveying
Mathematical Handbook of Formulas & Tables
Mechanical Vibrations
Reinforced Concrete Design, 2d edition
Space Structural Analysis
State Space & Linear Systems
Statics and Strength of Materials
Strength of Materials, 2d edition
Structural Analysis
Structural Steel Design, LFRD Method
Theoretical Mechanics

Schaum's Solved Problems Books

Each title in this series is a complete and expert source of solved problems containing thousands of problems with worked out solutions.

Related Titles on the Current List Include:

3000 Solved Problems in Calculus
2500 Solved Problems in Differential Equations
2500 Solved Problems in Fluid Mechanics & Hydraulics
3000 Solved Problems in Linear Algebra
2000 Solved Problems in Numerical Analysis
700 Solved Problems in Vector Mechanics for Engineers: Statics
800 Solved Problems in Vector Mechanics for Engineers: Dynamics

Available at your College Bookstore. A complete list of Schaum titles may be obtained by writing to: Schaum Division
McGraw-Hill, Inc.
Princeton Road, S–1
Hightstown, NJ 08520

ABOUT THE AUTHORS

Mackenzie L. Davis is an Associate 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 teaches and conducts research in the areas of air pollution control and hazardous waste management.

In 1987 and 1989–90, 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 Meteorological Society; American Society of Civil Engineers; Air & Waste Management Association; Association of Environmental Engineering Professors; and the Water Pollution Control Federation. Currently, he serves on the editorial review board of the *Journal of the Air & Waste Management Association*.

His honors and awards include the State-of-the-Art award from A.S.C.E., Chapter Honor Member of Chi Epsilon, Sigma Xi, and election as a Diplomate in the American Academy of Environmental Engineers with certification in hazardous waste management. He is a registered professional engineer in Illinois and Michigan.

David A. Cornwell is president of the consulting firm Environmental Engineering & Technology, Inc. He received his Ph.D. in Civil/Environmental Engineering

from the University of Florida. He was an Associate Professor in the Civil and Environmental Engineering Department at Michigan State University prior to entering the consulting field. He has chaired many American Water Works Association committees and activities, including serving as a trustee to the Research Division, and he received the 1986 AWWA Engineering Division Best Paper Award. He is also an author in the latest edition of AWWA's *Water Quality and Treatment* book.

To our students,
who make it worthwhile

PREFACE

This text is for use in an introductory sophomore level engineering course. It is written in a language and style that will appeal to sophomores. (Some pundits claim it is puerile; we claim that it is at least sophomoric.) We assume that the book will be used in one of the first engineering courses encountered by the student. Over the 36 offerings of the course material in this format, we have found that mature college seniors in allied fields—such as biology, chemistry, resource development, fisheries and wildlife, microbiology, and soils science—have no difficulty with the material. Likewise, we suspect that any bright science/mathematics-oriented high school senior would find the material easy to master. Senior level engineering students will find the material a snap, and perhaps beneath their dignity.

We have emphasized concepts, definitions, descriptions, abundant illustrations (to the horror of our beloved publisher), and a tad of humor. In the mathematical presentations we have provided only a few derivations. Engineering professors will complain (it must be confessed with justice) of insufficient rigor. But to this question there are two sides; however important it may be to maintain a uniformly high standard in pure mathematics, the engineering professional may occasionally do well to rest content with the result of the argument. To our minds, the more stringent procedures of the pure mathematician may yield a result that is not more but less demonstrative—and even confusing—to the beginning engineering student. And to insist on the highest standard would mean exclusion of many important subjects altogether in view of the space that would be required.

Two themes are carried through the text. The first is an introduction to the concept of mass balance as a tool for problem solving. The concept is introduced in the first 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 chemical reaction kinetics, reactor design, and sludge mass balance in Chapter 3. The DO sag curve is developed using a mass balance approach. The design equations for a completely mixed activated sludge system

and a more elaborate sludge mass balance are developed in Chapter 5. 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 6. In Chapter 9, a mass balance approach is used for waste audit.

The second theme is the concept that pollution control begins with the minimization of the generation waste. This is introduced in Chapter 2 under the heading of water conservation. It is addressed again in the sludge management section of the water treatment chapter, in air pollution control, resource conservation and recovery in solid waste management, and the reduction of hazardous waste generation rates.

A solution manual and computer disk are available for qualified instructors. Please inquire with your McGraw-Hill representative. We appreciate any comments, suggestions, corrections, and contributions of problems for future revisions.

As it stands in the curriculum at Michigan State University, the course bearing the title of this book provides the foundation for four follow-on senior level environmental engineering courses. We believe in and support the philosophy of the Association of Environmental Engineering Professors that the undergraduate environmental engineering curriculum must be expanded if we are to maintain modern, rigorous graduate programs. The fact that our better high schools provide opportunities for first-year calculus and college level chemistry, physics, and computer courses allows us to push advanced undergraduate courses down to the introductory level. And we can thus push introductory graduate courses into the undergraduate curriculum to make room for more advanced and more rigorous graduate courses. If future generations are to advance our civilization and redeem the sins of their forbears, this must be done.

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.

First and foremost we want to thank Ann Greenfield and Vicki Switzer, who did the bulk of the typing. In addition, the following individuals also have put their fingers to the keyboard in our behalf: Sherri Rich, Jodi Doerner, Nancy Hunt, Kathy Haller, and Sue Smith. Linda Clowater and Elizabeth Fry converted the original typed manuscript to computer format.

The following students helped to solve problems, proofread text, prepare illustrations, raise embarrassing questions, and generally make sure that other students could understand it: Deb Allen, Mark Bishop, Jeff Brown, Kristen Brandt, Linda Clowater, John Cooley, Ted Coyer, Marcia Curran, Kimberly Doherty, Craig Fricke, Elizabeth Fry, Kathy Hulley, Edith Hooten, Angela Ilieff, Gary Lefko, Lynelle Marolf, Lisa McClanahan, Tim McNamara, Becky Mursch, Cheryl Oliver, Jim Peters, Bob Reynolds, Laurene Rhyne, Sandra Risley, Lee Sawatzki, Mary Stewart, and Rick Wirsing. To them a hearty thank you!

We would also like to thank the following reviewers for their many helpful comments and suggestions: Wayne Chudyk, Tufts University; Michael J. Humenick, University of Wyoming; and Paul King, Northeastern University.

To John Eastman, our esteemed friend and former colleague, we offer our sincere appreciation. His contribution of Chapter 4, as well as constructive criticism and "independent" testing of the material, have been exceptionally helpful.

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

Mackenzie L. Davis
David A. Cornwell

INTRODUCTION TO ENVIRONMENTAL ENGINEERING

CONTENTS