



# Water and Wastewater ENGINEERING

*Design Principles and Practice*

— SECOND EDITION —

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Hill**

Mackenzie L. Davis, Ph.D., P.E., BCEE



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**WATER AND  
WASTEWATER  
ENGINEERING**

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Design Principles and Practice

**Mackenzie L. Davis, Ph.D., P.E., BCEE**  
*Michigan State University*

SECOND EDITION



New York Chicago San Francisco Athens London  
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## **Dedication**

To Elaine, my wife and love forever!





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# ABOUT THE AUTHOR

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**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, hazardous waste management, and water and wastewater engineering.

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 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 Educational Professional of the Year by the Michigan Water Environment Association. He is a registered professional engineer in Michigan.

Dr. Davis is the co-author of two previous books: *Introduction to Environmental Engineering*, 5th ed., with Dr. David A. Cornwell and *Principles of Environmental Engineering and Science*, 4th ed., with Dr. Susan J. Masten.

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



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# PREFACE

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This book is designed for use by professionals. The book covers the design of municipal water and wastewater facilities. I have assumed that the reader has had an introductory environmental engineering course and a first course in fluid mechanics. That is, I have assumed the reader is familiar with notation such as mg/L and acronyms such as BOD as well as the concepts of mass balance, Bernoulli's equation, and friction loss. Because I could not assume that the reader has used either *Introduction to Environmental Engineering* or *Principles of Environmental Engineering and Science*, some material from those texts is used to introduce the subject matter included here.

A Professional Advisory Board has provided its experience and expertise to vet the material in *Water and Wastewater Engineering*. The Board is composed of licensed engineers, a licensed geologist, and licensed treatment plant operators. A short biographical sketch and affiliation for each Board member is presented following this Preface. The Board members have read and commented on all of the chapters. In addition, a number of operators have been interviewed to obtain hints on methods for improving designs.

The book format is one that I used successfully over the 20 years that I taught the material. The book starts with an overview of the design and construction process including the application of the code of ethics in the process. The first half of the book addresses water treatment. Because my course was built around a term design project, the subject matter follows the flow of water through the unit processes of coagulation, flocculation, softening (including NF and RO), sedimentation, filtration (including MF and UF), disinfection, and residuals management.

The topics of wastewater treatment follow a similar pattern of following the flow through a plant, that is, preliminary treatment, primary treatment, secondary treatment, tertiary treatment, and residuals management. Special attention is given to the application of membranes.

Each subject in each chapter is introduced with a discussion of the theoretical principles that are to be applied in the design of the unit process. In addition, in each chapter, appropriate design criteria from the Great Lakes–Upper Mississippi River Board of State and Provincial Public Health and Environmental Managers (known to the elders of the profession as the Ten State Standards) as well as alternative approaches from the literature are addressed.

The text features over 100 example problems, 500 end-of-chapter problems, and 300 illustrations. A highlight of the book is the inclusion of safety issues in the design requirements as well as operation and maintenance activities. “Hints from the Field” bring real-life experience to solving technical issues.

For those using this book for a formal university-level course, an instructor's manual is 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 for both a one-semester option and a two-semester option, 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.

McGraw-Hill hosts a website at [www.mhprofessional.com/wwe2e](http://www.mhprofessional.com/wwe2e). It includes over 500 annotated photos of equipment and the construction process, as well as a primer on engineering economics and seminar presentations by professional engineers and operators.

I appreciate any comments, suggestions, corrections, and contributions for future editions.

*Mackenzie L. Davis*

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# PROFESSIONAL ADVISORY BOARD FOR THE SECOND EDITION

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**Susan J. Masten, Ph.D., P.E., Professor, College of Engineering, Michigan State University**

Dr. Masten received her Ph.D. in Environmental Engineering from Harvard University in 1989. Before joining the faculty at Michigan State University, she worked for several years in environmental research at the University of Melbourne (Australia) and at the U.S. Environmental Protection Agency's Kerr Laboratory in Ada, Oklahoma.

Dr. Masten's research involves the use of chemical oxidants for the remediation of soils, water, and leachates contaminated with hazardous organic chemicals. She has conducted research on the in situ use of gaseous ozone to oxidize residual contaminants in saturated soils using ozone sparging and in unsaturated soils using soil venting. Dr. Masten has evaluated the toxicity of the by-products of chemical oxidation processes as measured by gap junction intercellular communication. Her work has focused on the ozonation and chlorination of several pesticides, including atrazine, alachlor, and lindane, and on the PAHs, especially pyrene. Dr. Masten has also conducted research on the use of ozone-ceramic membrane filtration for the treatment of drinking water containing organic matter and emerging contaminants. Her current work focuses on the development of treatment technologies to mitigate lead and arsenic in drinking water. She has authored over 100 publications and graduated over 50 M.S. students and 14 Ph.D. students.

Dr. Masten has more than 30 years of experience in drinking water treatment and presently holds a position on the Michigan Board of Drinking Water Examiners and an appointment to the State of Michigan Science Advisory Committee on PFAS Chemicals. She is leading efforts to perform independent lead testing of premises and public schools in Flint, Michigan, and will take a leadership role in the implementation of the proposed project.

Dr. Masten is a co-author of the textbook *Principles of Environmental Engineering and Science*, now in its Fourth Edition.

College of Engineering  
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**Heather Cheslek, P.E., Project Manager, Black & Veatch**

Ms. Cheslek is a Project Manager in Black & Veatch's Grand Rapids, Michigan, office and has practiced civil engineering for nearly 20 years. She has a bachelor's degree in civil engineering from Michigan State University and a master's degree in environmental engineering from the Massachusetts Institute of Technology. Ms. Cheslek is a registered professional engineer in Michigan and Indiana. She has experience with hydraulic, hydrologic, and water quality modeling of open and closed channel systems; water distribution modeling and design; and water and wastewater treatment planning, design, and construction.

Ms. Cheslek is an active member of the Water Environment Federation, the Michigan Water Environment Association, and the Indiana Water Environment Association and is the Past President of the Indiana Water Environment Association.

Black & Veatch is an employee-owned, global leader in building critical human infrastructure in energy, water, telecommunications, and government services. Since 1915, the company has helped clients to improve the lives of people in more than 100 countries through consulting, engineering, construction, operations, and program management. Black & Veatch's more than 10,000 professionals work out of over 100 offices worldwide. Visit the company at [bv.com](http://bv.com). Black & Veatch's water business helps communities and clients all over the world with the innovative use of water resources, including treatment, conveyance infrastructure, water reuse systems, desalination, dams and hydropower, irrigation, flood management, and aquifer storage and recovery.



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**Geneva Vanlerberg, P.E., Manager of Water Production, Lansing Board of Water & Light (BWL)**

Ms. Vanlerberg is a licensed professional engineer and licensed F-1 drinking water plant operator in the State of Michigan. She has a B.S. in Civil Engineering and an M.S. in Environmental Engineering from Michigan State University. Her progressive experience in design, project management, and plant operation and management includes groundwater wells, lime-soda softening, filtration, chemical feed systems, chloramination, high-service pumping, energy efficiency, hydraulic modeling, and master planning. Ms. Vanlerberg manages two lime-soda softening plants with total rated capacity of 50 MGD, five booster pumping stations, and over 125 groundwater wells.

The BWL was established in 1885 by a vote of the people of Lansing to fund a publicly owned utility to meet their need for adequate fire protection, proper sanitation, and improved street lighting. The water utility serves 166,000 retail customers and over 40,000 people through wholesale contracts. Water is supplied by 125 wells, approximately 400 feet deep, to two water conditioning plants, which produce on average 19.2 million gallons of water each day.



Lansing Board of Water & Light  
1232 Haco Drive  
Lansing, MI 48912

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# PROFESSIONAL ADVISORY BOARD FOR THE FIRST EDITION

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## **Myron Erickson, P.E., Laboratory Services Manager, City of Wyoming, MI**

Mr. Erickson holds a bachelor's degree from the University of Evansville (IN) and a master's degree in environmental engineering from Michigan State University. He is licensed as a Class B operator in the State of Michigan. In his 15 years with the City of Wyoming (MI) utilities department he has served as the environmental compliance and research specialist for the City's programs in industrial sewer use, biosolids disposition, disinfection byproducts, and PPCPs. Currently he manages the laboratories for both the wastewater and drinking water utility plants. While the biosolids and IPP programs were under his direction, the City won a First Place EPA Award for Biosolids Public Education and a Second Place EPA Award for overall excellence of their IPP program.

The 35 employees of City of Wyoming Clean Water Plant serve a population of about 170,000. The maximum design flow of the plant is 24 MGD. With about 35 employees, the Drinking Water Plant serves a population of about 210,000. The maximum design flow is 120,000 MGD. The laboratory is a certified drinking water lab.



City of Wyoming Clean Water Plant  
2350 Ivanrest, SW  
Wyoming, MI 49418

## **Thomas C. Gavin, P.E., Senior Process Engineer, FTC&H**

Mr. Gavin received his B.S. in Civil Engineering and his M.S. in Environmental Engineering from Northwestern University. His 30 years of experience in process design includes three new water treatment plants and renovation/expansion of eight others. This experience includes conventional surface water treatment, lime-soda softening, deep-bed high-rate direct filtration, and membrane filtration. His wastewater experience includes design and start-up of eight activated sludge plants treating high-strength industrial wastewaters. In addition, his experience includes design of four water distribution systems and three wastewater collection systems. Mr. Gavin has been with FTC&H for 21 years.

Established in 1956, Fishbeck, Thompson, Carr & Huber (FTC&H) is a full-service engineering and architectural firm with 350 employees that is headquartered in Grand Rapids, Michigan.

FTC&H has four other offices located in Michigan and Ohio. FTC&H specializes in engineering, architecture, environmental science, and construction management.



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**Timothy D. McNamara, P.E., Senior Vice President, FTC&H**

Mr. McNamara received his B.S. in Civil Engineering and his M.S. in Sanitary Engineering from Michigan State University. He is Principal-in-Charge of his firm's Process Engineering Department and of their Construction Division. He has over 28 years of progressive design and management experience with water supply and treatment, wastewater collection and treatment, and environmental engineering projects. His design experience includes 27 water supply projects, 18 water treatment plants, and 12 wastewater treatment projects. He has particular expertise with membrane filtration, iron filtration, and lime-soda softening processes, and has been with his firm for 25 years. He is the former Chair of the Michigan Section of the American Water Works Association.

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**Thomas Newhof, P.E., BCEE, Chairman of the Board, Prein&Newhof**

Mr. Newhof received his B.S. degree from Calvin College and his M.S. in Sanitary Engineering from the University of Michigan. He is a licensed professional engineer in Michigan, Wisconsin, and Illinois. As both a Project Manager and Principal-in-Charge of many of Prein&Newhof's environmental and civil engineering projects, his experience includes: planning and design of water treatment and wastewater treatment facilities with conventional or membrane filtration

technology, water and sewer systems, intakes, pipelines, pumping stations, storm drainage and flood control, airport and road improvements, and residential and commercial development.

The American Water Works Association recognized Thomas Newhof's contributions to the profession with the 1998 George Warren Fuller Award. The University of Michigan honored him with the Jack A. Borchardt Award in 2008.

Mr. Newhof co-founded Prein&Newhof in 1969 with a fellow civil engineer. He is the Chairman of the firm's Board of Directors, providing leadership for Prein&Newhof's 100 employees who work in its environmental laboratory and five offices located throughout West Michigan.

**Prein&Newhof**

Prein&Newhof  
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**Lucy B. Pugh, P.E., BCEE, Vice President, AECOM**

Ms. Pugh received her B.S.E. and M.S.E. in Civil/Environmental Engineering from the University of Michigan. Her 28 years of experience in municipal process water and wastewater treatment design includes three new water treatment plants, two new wastewater treatment plants, and renovation/expansion of seven other wastewater treatment plants. Ms. Pugh's industrial water and wastewater design experience includes over 25 facilities. She has also provided process troubleshooting and optimization at numerous other municipal and industrial treatment facilities. Her experience spans a broad range of technologies, including ion exchange, greensand filtration, low pressure membrane filtration, reverse osmosis, dissolved air flotation, conventional activated sludge, oxidation ditches, SBRs, biological nutrient removal, PACT, UV disinfection, upflow anaerobic sludge blanket reactors, anaerobic fluidized bed reactors, and first application of GAC/fluidized bed for perchlorate removal.

AECOM is a global provider of professional, technical, and management support services to a broad range of markets, including water/wastewater, environmental, transportation, building and energy. With 43,000 employees providing services in over 100 countries around the globe, AECOM is a leader in all key markets that it serves. Ms. Pugh has been with AECOM for 22 years.

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**Carlos A. Sanlley Pagán, Ph.D., Design Engineer, Greeley and Hansen**

Dr. Sanlley received his Ph.D. from Michigan State University in 2009. His thesis research identified byproducts formed during Advance Oxidation Processes. His work experience includes the design of CSO control structures, design of a fermentation system to enhance VFA production for a Bardenpho wastewater treatment process, and design and analysis of a water intake structure in Lake Michigan. He is the firm-wide resource on AQUIFAS modeling and IFAS process design.

Greeley and Hansen, founded in 1914, is a leader in developing innovative engineering solutions for a wide array of water, wastewater, water reuse, and solid waste challenges aimed at improving public health, safety, and welfare. The projects that Greeley and Hansen has completed for clients continue to receive various industry awards for design and engineering excellence. *Engineering News-Record* ranks Greeley and Hansen among the Top 25 Designers in Wastewater Treatment, Sewerage, and Solid Waste Management.



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**Jimmy L. Spangler, P.E., Senior Manager, Municipal Group, Tetra Tech**

Mr. Spangler received his B.S. in Civil Engineering from Michigan State University. He holds a Class A operator's license from the State of Michigan. His 36 years of experience includes 29 years of wastewater collection and treatment as a certified operator in positions of Plant Engineer (Washington Suburban Sanitary Commission—3 yrs), Assistant Superintendent (City of Pontiac, MI—3 yrs), and Superintendent (City of Lansing, MI—19 yrs) and 4 years as Deputy Public Service Department Director (City of Lansing). These facilities ranged in capacity from 40,000 gpd to 50 mgd. The processes included screening, grit removal, primary treatment, various activated sludge processes, phosphorous and ammonia nitrogen removal, chemical precipitation, tertiary filtration, chlorination, dechlorination, UV disinfection, aerobic digestion, anaerobic digestion, elutriation, WAS thickening, wet air oxidation, dewatering, incineration, and land application of biosolids. He also has had direct involvement in facility expansion and rehabilitation projects. For the last seven years he has been with Tetra Tech, Inc. His work includes conducting facility evaluations, reviewing designs, preparing and reviewing operation and maintenance manuals, plant operation reviews and inspections, process evaluations, preparing studies, and long-term capital plans.