DESIGN OF MUNICIPAL WASTEWATER TREATMENT PLANTS

WEF Manual of Practice No. 8
ASCE Manuals and Reports on Engineering Practice No. 76
Fifth Edition

Prepared by the Design of Municipal Wastewater Treatment Plants Task Force of the Water Environment Federation and the American Society of Civil Engineers/Environmental and Water Resources Institute

WEF Press

Water Environment Federation Alexandria, Virginia

American Society of Civil Engineers/Environmental and Water Resources Institute
Reston, Virginia

New York Chicago San Francisco Lisbon London Madrid
Mexico City Milan New Delhi San Juan Seoul
Singapore Sydney Toronto

Copyright © 2010 by the Water Environment Federation
and the American Society of Civil Engineers/Environmental and Water Resources Institute

Preface

This manual, updated from the 4th edition, continues its goal to be one of the principal references of contemporary practice for the design of municipal wastewater treatment plants (WWTPs). The manual was written for design professionals familiar with wastewater treatment concepts, the design process, and the regulatory basis of water pollution control. It is not intended to be a primer for the inexperienced or the generalist. The manual is intended to reflect current plant design practices of wastewater engineering professionals, augmented by performance information from operating facilities. The design approaches and practices presented in the manual reflect the experiences of more than 300 authors and reviewers from around the world.

This three-volume manual consists of 27 chapters, with each chapter focusing on a particular subject or treatment objective. The successful design of a municipal WWTP is based on consideration of each unit process and the upstream and downstream effects of that unit's place and performance in the overall scheme of the treatment works. The chapters that compose Volume 1 generally cover design concepts and principles that apply to the overall WWTP. Volume 2 contains those chapters that discuss liquid-train-treatment operations or processes. Volume 3 contains the chapters that deal with the management of solids generated during wastewater treatment.

In the 11 years since the publication of the 4th edition of this manual, key technical advances in wastewater treatment have included the following:

- Membrane bioreactors replaced conventional secondary treatment processes in a smaller footprint;
- Advancements within integrated fixed-film/activated sludge (IFAS) systems and moving-bed biological-reactors systems;
- Disinfection alternatives to chlorine;
- Biotrickling filtration for odor control;
- Increased use of ballasted flocculation;
- Sidestream nutrient removal to reduce the loading on the main nutrient-removal process; and
- Use and application of modeling wastewater treatment processes for the basis of design and evaluations of alternatives.

In response to these advancements, this edition includes some significant changes from the 4th edition. As with prior editions, technologies that are no longer

Copyright © 2010 by the Water Environment Federation
and the American Society of Civil Engineers/Environmental and Water Resources Institute

considered current industry practice have been deleted, such as vacuum filters for sludge dewatering. While not intended to be all-inclusive, the following list describes some of the other pertinent processes and newer processes or concepts:

- Concept of sustainability,
- Energy management,
- Odor control and air emissions,
- Chemically assisted/ballast flocculation clarification,
- Membrane bioreactors,
- IFAS processes,
- Enhanced nutrient-control systems,
- Sidestream treatment, and
- Approaches to minimizing biosolids production.

Additionally, the focus of the manual has been sharpened. Like earlier editions, this manual presents current design guidelines and practices of municipal wastewater engineering professionals. Design examples also are provided, in some instances, to show how the guidelines and practice can be applied. However, information on process fundamentals, case histories, operations, and other related topics is covered to a lesser extent than in the previous edition. Readers are referred to other publications for information on those topics.

This 5th edition of this manual was produced under the direction of Terry L. Krause, P.E., BCEE, *Chair;* Roderick D. Reardon, Jr., P.E., BCEE, *Volume 1 Leader;* Albert B. Pincince, Ph.D., P.E., BCEE, *Volume 2 Leader;* and Thomas W. Sigmund, P.E., *Volume 3 Leader*.

Principal authors of the publication are:

Chapter 1	Terry L. Krause, P.E., BCEE Hannah T. Wilner
Chapter 2	Julian Sandino, P.E., Ph.D. Hannah T. Wilner
	Rachel Carlson Albert W. Goodman, P.E. Indra N. Mitra, Ph.D., P.E. Ignasi Rodriguez-Roda, Ph.D. Chip Ullstad, P.E., BCEE Don Vandertulip, P.E.

Copyright © 2010 by the Water Environment Federation
and the American Society of Civil Engineers/Environmental and Water Resources Institute

	Drury Denver Whitlock Michael J. Wilson, P.E.
Chapter 3	Alvin C. Firmin, P.E., BCEE William C. McConnell
	Orris E. Albertson Kimberly R. Drake, RLA Brian M. Karmasin Cory Lancaster
Chapter 4	Jane W. Wheeler Philip C. Kennedy, AICP
	Kimberly R. Drake, RLA Sanath Bandara Palipana, B.E., G. Dip., M. Env. Eng. Sc., C.P. Eng.
Chapter 5	Ralph B. "Rusty" Schroedel, Jr., P.E., BCEE George V. Crawford, P. Eng.
	Peter V. Cavagnaro, P.E., BCEE Patrick E. Clifford Michael E. Davis, Ph.D. Arthur P. Malm, P.E. John H. McGettigan, P.E., LEED AP Erin Mosley, P.E. John W. Norton, Jr., Ph.D., LEED AP Don Vandertulip, P.E.
Chapter 6	Joseph C. Reichenberger, P.E., BCEE
	Katherine Bangs James Gallovich, P.E. David Terrill, P.E.
Chapter 7	Raymond C. Porter Charles M. Alix, P.E.
	Petros Dimitriou-Christidis, Ph.D., P.E. Chris Easter

Copyright © 2010 by the Water Environment Federation
and the American Society of Civil Engineers/Environmental and Water Resources Institute

	Charles M. McGinley, P.E. Richard J. Pope, P.E., BCEE Chris Quigley, Ph.D., P.E. Mark M. Smith, P.E. Tom Spooren Matthew Ward, P.E.
Chapter 8	Tim Page-Bottorff
	Chris Marlowe, CIH, CSP Douglas Prentiss
Chapter 9	Dave Ubert David Bloxom, P.E.
	Vic Smith, P.E., LEED AP Hannah T. Wilner
Chapter 10	Ronald R. Skabo, P.E. Wayne L. Kerns
	Misti Burkman, P.E. Damon Lau Robert J. Scott
Chapter 11	Joel C. Rife, P.E. Lucas Botero
Chapter 12	Thomas E. Weiland, P.E. Anne M. Carayon, P.E.
Chapter 13	Joshua Philip Boltz, Ph.D., P.E. Eberhard Morgenroth, Ph.D.
	Chris DeBarbadillo, P.E. Michael J. Dempsey Trevor Ghylin John Harrison, P.E. James P. McQuarrie, P.E. Robert Nerenberg, Ph.D., P.E.

Copyright © 2010 by the Water Environment Federation
and the American Society of Civil Engineers/Environmental and Water Resources Institute

Chapter 14	Roger V. Stephenson, Ph.D., P.E., BCEE Rudy J. Tekippe, Ph.D., P.E., BCEE
	Patrick F. Coleman, Ph.D., P. Eng. Anne Conklin George V. Crawford, P. Eng. Samuel S. Jeyanayagam, Ph.D., P.E., BCEE Bruce R. Johnson, P.E., BCEE Roderick D. Reardon, Jr., P.E., BCEE George Sprouse, Ph.D., P.E., BCEE
Chapter 15	Art K. Umble, Ph.D., P.E., BCEE Amanda L. Fox
	Kenneth N. Abraham, P.E., P. Eng. Dipankar Sen, Ph.D.
Chapter 16	Val S. Frenkel, Ph.D., P.E., D. WRE Onder Caliskaner, Ph.D., P.E.
Chapter 17	Dimitri Katehis Cindy Wallis-Lage
	Timothy A. Constantine Heather M. Phillips, P.E.
Chapter 18	Ronald W. Crites Robert Beggs, Ph.D., P.E.
	Brian L. Book, P.E. Kristin Evans, Ph.D., P.E.
Chapter 19	Jay L. Swift, P.E. Russell Porter, P.E.
	Somnath Basu, Ph.D., P.E., BCEE Leonard W. Casson, Ph.D., P.E., BCEE Robert W. Emerick, Ph.D., P.E. Gary L. Hunter, P.E. Frank Loge, Ph.D.

Copyright © 2010 by the Water Environment Federation
and the American Society of Civil Engineers/Environmental and Water Resources Institute

	Lokesh Padhye Andrew Salveson, P.E. Justyna Kempa-Teper, Ph.D., P. Eng. Andrea Turriciano, P.E. G. Elliott Whitby, Ph.D.
Chapter 20	Jeanette Brown, P.E., DEE, D. WRE
Chapter 21	Paul A. Bizier, P.E., BCEE George P. Anipsitakis, Ph.D., P.E.
Chapter 22	Harold E. Schmidt, Jr., P.E., BCEE Derya Dursun, Ph.D. Mikel E. Goldblatt
Chapter 23	Jeff Berk, P.E. Benjamin T. Porter, P.E. May Kyi Brian Hemphill, P.E. Adam Evans, P.E. Greg Moen, P.E.
Chapter 24	Carl M. Koch, Ph.D., P.E., BCEE Angela S. Essner, P.E. Laura B. Baumberger, P.E. Morgan R. Gagliano David C. Hagan, P.E. John C. Kabouris, Ph.D., P.E. Peter LaMontagne Nathan Lester Rebecca Overacre Rick Shanley Julia Spicher Tracy Stigers Steven Swanback
Chapter 25	Sudhir N. Murthy Perry L. Schafer, P.E., BCEE

Copyright © 2010 by the Water Environment Federation
and the American Society of Civil Engineers/Environmental and Water Resources Institute

	Charles M. Alix, P.E. Anne Conklin Kari Beth Fitzmorris, Sc.D. Terry J. Logan, Ph.D. Christopher Muller, Ph.D. Chris J. Peot James W. Schettler, P.E. Miguel Vera Todd O. Williams, P.E., BCEE
Chapter 26	Peter Burrowes Ky Dangtran, Ph.D. Scott Carr Webster Hoener Raymond J. Kearney, P.E., BCEE James M. Rowan, P.E. Hari Santha James E. Welp
Chapter 27	Lynne H. Moss Alexandra Doody, LEED AP Tom A. Kraemer, P.E. Terry J. Logan, Ph.D. Robert E. Pepperman
Glossary	Kendra D. Sveum Matt Peyton

The following also contributed to the development of this manual: Murali Erat (Chapter 15), Sarah Hubble (Chapter 15), Vikram Pattarkine (Chapter 15), Frank Rogalla (Chapter 13), and Stephen Tarallo (Chapter 13).

Authors' and reviewers' efforts were supported by the following organizations:

AECOM, Philadelphia, Pennsylvania; Alexandria, Virginia; and Sheboygan, Wisconsin
Advanced Bioprocess Development, Ltd., Manchester, England
Aqualia, Madrid, Spain
Associated Engineering, Calgary, Alberta, Canada

Copyright © 2010 by the Water Environment Federation
and the American Society of Civil Engineers/Environmental and Water Resources Institute

Bassett Engineering, Inc., Montoursville, Pennsylvania
Beaumont Cherry Valley Water District, Beaumont, California
Binkley and Barfield, Inc., Consulting Engineers, Houston, Texas
Black & Veatch, Los Angeles, California; Sacramento, California; Atlanta, Georgia; Gaithersburg, Maryland; Kansas City, Missouri; and Cincinnati, Ohio
Brown and Caldwell, Davis, California; Rancho Cordova, California; Walnut Creek, California; Washington, D.C.; and Seattle, Washington
Caboolture Shire Council, Caboolture, QLD
Carollo Engineers, Phoenix, Arizona; Walnut Creek, California; Broomfield, Colorado; Littleton, Colorado; Sarasota, Florida; Winter Park, Florida; Portland, Oregon; Dallas, Texas; and Seattle, Washington
CDM, Phoenix, Arizona; Los Angeles, California; Maitland, Florida; Chicago, Illinois; Louisville, Kentucky; Baton Rouge, Louisiana; Cambridge, Massachusetts; Kansas City, Missouri; Manchester, New Hampshire; Edison, New Jersey; Albuquerque, New Mexico; Providence, Rhode Island; Austin, Texas; Dallas, Texas; and San Antonio, Texas
CH2M HILL, Englewood, Colorado; Tampa, Florida; Chicago, Illinois; Boston, Massachusetts; Kansas City, Missouri; Henderson, Nevada; Parsippany, New Jersey; Knoxville, Tennessee; Austin, Texas; Salt Lake City, Utah; Chantilly, Virginia; Richmond, Virginia; Bellevue, Washington; and Milwaukee, Wisconsin
CH2M Hill Canada, Ltd., Kitchener, Ontario, Canada; and Toronto, Ontario, Canada
Chastain-Skillman, Inc., Lakeland, Florida; and Orlando, Florida
City of Missoula, Missoula, Montana
City of Phoenix, Phoenix, Arizona
City of Stamford, Stamford, Connecticut
Consoer Townsend Envirodyne Engineers, Nashville, Tennessee
County Sanitation Districts of Los Angeles County, Whittier, California
Degremont Technologies – Infilco (Suez Environnement), Richmond, Virginia
District of Columbia Water and Sewer Authority, Washington, D.C.
DLT&V Systems Engineering, Oceanside, California
Donohue and Associates, Chesterfield, Missouri
Eco-logic Eng., Rocklin, California
Eimco Water Technologies, Salt Lake City, Utah
EnerTech Environmental, Inc., Los Angeles, California
Entex Technologies, Chapel Hill, North Carolina
Enviro Enterprises, Inc., La Barge, Wyoming
Environmental Group Services, Baltimore, Maryland
Environmental Operating Solutions, Inc., Bourne, Massachusetts

Copyright © 2010 by the Water Environment Federation
and the American Society of Civil Engineers/Environmental and Water Resources Institute

Forsgren Associates, Inc., Rexburg, Idaho
Freese and Nichols, Inc., Fort Worth, Texas
GE Water and Process Technologies, Oakville, Ontario, Canada; and Portland, Oregon
Georgia Institute of Technology, Atlanta, Georgia
Gloversville Johnstown Joint Wastewater Treatment Plant, Johnstown, New York
Gray and Osborne, Seattle, Washington
Greeley and Hansen, L.L.C., Phoenix, Arizona; Wilmington, Delaware; Tampa, Florida; Sarasota, Florida; Chicago, Illinois; Gary, Indiana; Indianapolis, Indiana; Landover, Maryland; Las Vegas, Nevada; New York City, New York; and Philadelphia, Pennsylvania; Richmond, Virginia; Roanoke, Virginia; and Springfield, Virginia
Green Bay Metropolitan Sewerage District, Green Bay, Wisconsin
Hazen and Sawyer, P.C., New York, New York; and Raleigh, North Carolina
HDR Engineering, Inc., Folsom, California; Irvine, California; Riverside, California; Portland, Oregon; Dallas, Texas; Bellevue, Washington; and Burlington, Washington
Herbert Rowland and Grubic, Inc., State College, Pennsylvania
Jiann-Ping Hsu College of Public Health, Georgia Southern University, Statesboro, Georgia
Johnson Controls, Inc., Milwaukee, Wisconsin
Kennedy/Jenks Consultants, Palo Alto, California; Sacramento, California; and San Francisco, California
Knowledge Automation Partners, Inc., Wellesley, Massachusetts
Lake County Public Works, Libertyville, Illinois
Lettinga Associates Foundation, Wageningen, The Netherlands
Logan Environmental, Inc., Beaufort, South Carolina
Louisiana State University, Baton Rouge, Louisiana
Loyola Marymount University, Los Angeles, California
Malcolm Pirnie, Inc., Columbus, Ohio; Wakefield, Massachusetts; and White Plains, New York
Metcalf and Eddy, Inc., Philadelphia, Pennsylvania
MWH Americas, Inc., Arcadia, California; Denver, Colorado; Tampa, Florida; Chicago, Illinois; Boston, Massachusetts; and Cleveland, Ohio
MWH EMEA, Inc., Mechelen, Belgium
Metropolitan Water Reclamation District of Greater Chicago, Chicago, Illinois; and Schaumburg, Illinois
Nanyang Technological University, Singapore
North Carolina State University Department of Biological and Agricultural Engineering, Raleigh, North Carolina

Copyright © 2010 by the Water Environment Federation
and the American Society of Civil Engineers/Environmental and Water Resources Institute

Regional Municipality of Waterloo, Ontario, Canada
Short Elliott Hendrickson, Inc., Sheboygan, Wisconsin
St. Croix Sensory, Inc., Lake Elmo, Minnesota
Stantec Consulting Ltd., Windsor, Ontario, Canada
Stearns and Wheler, Bowie, Maryland
Tetra Tech, Inc., Pasadena, California
Total Safety Compliance, Mesa, Arizona
Trinity River Authority of Texas, Arlington, Texas
University of California, Davis, California
University of Delaware, Newark, Delaware
University of Girona, Girona, Spain
University of Illinois, Urbana, Illinois
University of Notre Dame, Notre Dame, Indiana
University of Wyoming, Laramie, Wyoming
Westin Engineering, Elk Grove, California
Woodard & Curran, Inc., Cheshire, Connecticut

Copyright © 2010 by the Water Environment Federation
and the American Society of Civil Engineers/Environmental and Water Resources Institute