



**McGRAW-HILL SERIES IN
WATER RESOURCES AND
ENVIRONMENTAL ENGINEERING**

WASTEWATER ENGINEERING: TREATMENT DISP SAL REUSE

SECOND EDITION

METCALF & EDDY, INC.

Revised by
GEORGE TCHOBANOGLIOUS
Professor of Civil Engineering
University of California, Davis

McGRAW-HILL BOOK COMPANY

New York	St. Louis	San Francisco	Auckland	Bogotá	Düsseldorf	
Johannesburg	London	Madrid	Mexico	Montreal	New Delhi	Panama
Paris	São Paulo	Singapore	Sydney	Tokyo	Toronto	

WASTEWATER ENGINEERING TREATMENT, DISPOSAL, REUSE

Copyright © 1979, 1972 by McGraw-Hill, Inc. All rights reserved.
Printed in the United States of America. No part of this publication
may be reproduced, stored in a retrieval system, or transmitted, in any
form or by any means, electronic, mechanical, photocopying, recording, or
otherwise, without the prior written permission of the publisher.

234567890K PK P7832109

This book was set in Times Roman. The editors were Frank J. Cerra
and J. W. Maisel; the production supervisor was Dominick Petrellese.
New drawings were done by J & R Services, Inc.
Kingsport Press, Inc., was printer and binder.

Library of Congress Cataloging in Publication Data

Metcalfe and Eddy, Boston.
Wastewater engineering.

(McGraw-Hill series in water resources and environmental engineering)

Bibliography: p.

Includes index.

1. Sewerage. 2. Sewage disposal.

I. Tchobanoglous, George. II. Title.

TD645.M57 1979 628'.2 78-6173

ISBN 0-07-041677-X

PREFACE

Following the widespread acceptance and use of *Wastewater Engineering: Collection, Treatment, Disposal*, and the many developments in the field since it was first written, we felt that an update of the book that included use of the metric system was advisable. This second edition has been prepared (1) to keep pace with the new technical development in the field of environmental engineering since the publication of the first edition, (2) to reflect the impact of recent federal legislation dealing with water quality and pollution control, (3) to provide leadership in the wider adoption and use of the metric International System of Units (or SI, for short) in the design and analysis of treatment facilities, and most importantly (4) to make the book more useful for students, teachers, practicing engineers, and other users.

To meet the objectives established for the second edition, it was necessary to revise and rewrite the first edition completely. Because the basic data and information related to the treatment, disposal, and reuse of wastewater and sludge has expanded so dramatically in the past 6 years, the chapters in the first edition that deal with collection and pumping of wastewater have been omitted from this edition. Accordingly, the subtitle of this edition has been changed to *Treatment, Disposal, Reuse*.

The chapters that have been removed are to be issued along with new material as a separate textbook entitled *Collection and Pumping of Wastewater*. The space made available by the omission of these chapters is being taken up by new material and expanded coverage of first-edition material.

Passage of the Federal Water Pollution Control Act Amendments of 1972 (Public Law 92-500) has had a major impact on wastewater engineering. New material presented in this edition reflects the changes brought about by the law. With the establishment for the first time of national goals and objectives, greater emphasis has been placed on reuse of wastewater and land disposal. A new chapter on land-treatment systems addresses the important engineering aspects associated with the treatment and disposal of wastewater and sludge on land.

Most of the world is now using some form of metric units. For this reason and because the United States is using them more and more, this edition uses the SI system along with conversions to U.S. customary units. Inasmuch as both sets of units will be in use for some time to come, we have given complete conversion tables in Appendix A. To increase the usefulness of the text, we have furnished conversions from metric-unit data to U.S. customary units in footnotes to all tables.

To make this second edition more useful as a teaching and reference text, a number of significant changes have been made. To provide the reader with a general introduction to the field of wastewater engineering, a new chapter on wastewater treatment objectives, methods, and design has been provided. The material in this chapter is intended to serve as an introduction to the chapters that follow it. Discussions dealing with fundamentals of process analysis have been gathered together and amplified under the heading "Fundamentals of Process Analysis." And to reflect current knowledge and practice, presentations of the fundamentals of the unit operations and processes used for the treatment of wastewater have all been revised. Sections dealing with the solids flux analysis for the design of secondary settling facilities and the preparation of solids balances for alternative treatment flowsheets are cited as two examples of the many new topics that have been included in this edition.

In addition, more than 60 tables containing a summary of design data and information are included. To illustrate basic concepts and physical applications more clearly, approximately 200 drawings and 90 photographs are furnished. Of this number, about 120 of the drawings and essentially all the photographs are new.

Different example problems have been prepared for this edition, with units carried through all the computational steps to facilitate the reader's understanding of the principles involved. Where appropriate, comments are included at the end of an example problem to elucidate basic concepts and highlight additional applications. To make this edition more useful, it has been reorganized such that the concepts and principles are stated clearly so that the transition from basic principles to design applications follows a more logical sequence. All these factors have contributed to making this book a more complete presentation of wastewater engineering and management by the profession of consulting engineering.

Rolf Eliassen
Chairman of the Board
Metcalf & Eddy, Inc.

George Tchobanoglous
Professor of Civil Engineering
University of California, Davis

ACKNOWLEDGMENTS

Metcalf & Eddy, Inc., is fortunate in having had the services of Dr. George Tchobanoglous as consultant on many important engineering projects over the past decade. But we believe that his greatest contribution to the firm—and, it is hoped, to the profession of wastewater engineering—is this complete revision and expansion of the first edition of our book. His devotion to this task entailed far more than conceptual design and writing. He had responsibility for the entire project, including coordination of the activities, reviews, and contributions of many of the members of the staffs of our Boston and Palo Alto offices.

No undertaking of the magnitude involved in the preparation of this new edition can be accomplished alone. Thus it is with grateful appreciation that we acknowledge the assistance of the following individuals. From the Palo Alto office, Ronald W. Crites served as coordinator for the project, also being responsible for the preparation of Chapter 13 on land-treatment systems. Franklin L. Burton read portions of the manuscript and made technical and editorial comments. Donald J. Schroeder helped secure photographs and checked metric units. Arthur L. Holland coordinated standardization of the figures, most of which were drawn by Diosdado C. Cantimbuhan. In addition to typing the final manuscript, Donald F. Newton made valuable editorial contributions. Marcella S. Tennant served again as general technical editor. Her editing skills are reflected throughout the text, especially in its readability.

Personnel from the Boston office reviewed the manuscript to ensure its consistency with current practice and provided much of the information given in the summary tables. Francis C. Sampson was in charge of the Boston review. David P. Bova served as general coordinator: he reviewed all the chapters and was responsible for providing much of the data used in preparation of tables. Abu M. Z. Alam, Bradley W. Behrman, Stephen L. Bishop, John G. Chalas, Joseph Goss, David S. Graber, Frank M. Gunby, Jr., Winfield A. Peterson, Francis C. Tyler, and Jakobs P. Vittands reviewed various chapters. Randolph A. Johnson helped with the photographs. Allen J. Burdoin, a consultant to Metcalf & Eddy, reviewed and revised portions of the manuscript.

Other individuals who reviewed various sections and contributed to the preparation of this text include Takashi Asano, Max E. Burchett, Jeffrey R. Hauser, Larry J. Karns, Edward D. Schroeder, Sam A. Vigil, and George E. Wilson. Mark R. Matsumoto reviewed all the example problems and checked the metric units. Rosemary Tchobanoglous typed the rough draft and provided moral support. Professor Edward Foree of the University

of Kentucky reviewed the manuscript for the publisher and made valuable editorial suggestions.

We also wish to acknowledge the many constructive comments received from teachers, as well as practicing engineers, who used the first edition. Wherever possible, we have incorporated their suggestions in this revised edition.

Finally, we acknowledge our gratitude to Peter J. Gianacakes, president of Metcalf & Eddy, Inc., for his leadership on this edition and his commitment of the resources of the firm to the accomplishment of this important task.

Rolf Eliassen
Chairman of the Board
Metcalf & Eddy, Inc.

CONTENTS

PREFACE	xv
ACKNOWLEDGMENTS	xvii
1 WASTEWATER ENGINEERING: AN OVERVIEW	1
1-1 WASTEWATER TREATMENT	2
Background Current Status New Directions	
1-2 EFFLUENT AND SLUDGE DISPOSAL AND REUSE	6
Background Current Status and New Directions	
1-3 THE ROLE OF THE ENGINEER	8
REFERENCES	10
2 WASTEWATER FLOWRATES	11
2-1 COMPONENTS OF WASTEWATER FLOWS	11
2-2 WATER USED FOR PUBLIC SUPPLIES	12
Water Withdrawals for Public Water Supplies Variations in Usage in Cities Water Use by Various Establishments and Devices Fluctuations in Water Use Proportion of Water Supply Reaching Sewers	
2-3 WASTEWATER SOURCES AND FLOWRATES	20
Sources and Rates of Domestic Wastewater Flows Sources and Rates of Industrial Wastewater Flows Infiltration/Inflow Variations in Wastewater Flows	
2-4 ANALYSIS OF WASTEWATER FLOWRATE DATA	29
Peaking Factors for Wastewater Flows Peak Infiltration Flows Peak Inflow Design Allowance Sustained Flows Statistical Analysis	
2-5 REDUCTION OF WASTEWATER FLOWS	36
2-6 MEASUREMENT OF WASTEWATER FLOWS	38
Direct-Discharge Methods Velocity-Area Methods	
DISCUSSION TOPICS AND PROBLEMS	53
REFERENCES	54

3 WASTEWATER CHARACTERISTICS	56
3-1 PHYSICAL, CHEMICAL, AND BIOLOGICAL CHARACTERISTICS OF WASTEWATER	56
3-2 WASTEWATER CHARACTERIZATION STUDIES	59
Sampling Sample Preservation Methods for Sample Analysis Expression of Analysis Results	
3-3 WASTEWATER COMPOSITION	64
Constituents in Wastewater and Septage Need for Additional Analyses Mineral Pickup from Water Use	
3-4 UNIT LOADING FACTORS	67
3-5 VARIATIONS IN CONCENTRATIONS OF WASTEWATER CONSTITUENTS	68
Short-Term Variations Seasonal Variations Industrial Variations	
3-6 ANALYSIS OF WASTEWATER LOADING DATA	72
Simple Average Flow-Weighted Average Mass Loadings Sustained Peak Mass Loadings	
3-7 PHYSICAL CHARACTERISTICS: DEFINITION AND APPLICATION	76
Total Solids Odors Temperature Color	
3-8 CHEMICAL CHARACTERISTICS: DEFINITION AND APPLICATION	82
Organic Matter Measurement of Organic Content Inorganic Matter Gases	
3-9 BIOLOGICAL CHARACTERISTICS: DEFINITION AND APPLICATION	104
Microorganisms Pathogenic Organisms Coliform Organisms Ratio of Fecal Coliforms to Fecal Streptococci Bioassay Tests	
DISCUSSION TOPICS AND PROBLEMS	113
REFERENCES	116
 4 WASTEWATER-TREATMENT OBJECTIVES, METHODS, AND DESIGN	 119
4-1 WASTEWATER-TREATMENT OBJECTIVES AND REGULATIONS	119
4-2 CLASSIFICATION AND APPLICATION OF WASTEWATER-TREATMENT METHODS	121
Classification of Treatment Methods Application of Treatment Methods	
4-3 ELEMENTS OF PLANT ANALYSIS AND DESIGN	125
Treatment-Process Flowsheets Process Design Criteria Solids Balance Hydraulic Profiles Plant Layout	
4-4 OTHER IMPORTANT CONSIDERATIONS	129
Energy and Resource Requirements Cost Analysis Environmental-Impact Assessment Plans and Specifications	
DISCUSSION TOPICS AND PROBLEMS	139
REFERENCES	140

5 FUNDAMENTALS OF PROCESS ANALYSIS	141
5-1 REACTIONS AND REACTION KINETICS	142
Types of Reactions Rate of Reaction Specific Reaction Rate Effects of Temperature on Specific Rate Constants Analysis of Rate Equations	
5-2 MASS-BALANCE ANALYSIS	149
The Mass Balance Mass Balance for Batch Reactor Solution Procedures Steady-State Simplification	
5-3 REACTORS AND THEIR HYDRAULIC CHARACTERISTICS	154
Types of Reactors Hydraulic Characteristics of Reactors	
5-4 PROCESS ANALYSIS	163
Selection of Reaction Rate Expressions or Loading Criteria Selection of the Type of Reactor	
5-5 REACTION KINETICS AND REACTOR SELECTION	166
Continuous-Flow Stirred-Tank Reactors in Series with Conversion Plug-Flow Reactor with Conversion Comparison of Continuous-Flow Stirred-Tank and Plug-Flow Reactors Plug-Flow Reactors with Axial Dispersion and Conversion Other Reactor Flow Regimes and Reactor Combinations	
5-6 PRACTICAL ASPECTS OF REACTOR DESIGN	174
DISCUSSION TOPICS AND PROBLEMS	175
REFERENCES	179
 6 PHYSICAL UNIT OPERATIONS	 180
6-1 SCREENING	182
Description Analysis	
6-2 FLOW EQUALIZATION	187
Description Analysis	
6-3 MIXING	196
Description/Application Analysis	
6-4 FLOCCULATION	199
Description Analysis	
6-5 SEDIMENTATION	201
Description Analysis of Discrete Particle Settling (Type 1) Analysis of Flocculant Settling (Type 2) Analysis of Tube Settlers Analysis of Hindered Settling (Type 3) Analysis of Compression Settling (Type 4)	
6-6 FLOTATION	221
Description Analysis	
6-7 GRANULAR-MEDIUM FILTRATION	227
Description of the Filtration Operation Classifications of Filtration Systems Filtration-Process Variables Particle-Removal Mechanisms General Analysis of Filtration Operation Analysis of Wastewater Filtration Need for Pilot-Plant Studies	
DISCUSSION TOPICS AND PROBLEMS	252
REFERENCES	255

7 CHEMICAL UNIT PROCESSES	257
7-1 CHEMICAL PRECIPITATION	258
Description of Chemical Precipitation for Improving Plant Performance Description of Chemical Precipitation for Phosphate Removal and for Physical-Chemical Treatment Theoretical Aspects of Chemical Precipitation	
7-2 GAS TRANSFER	268
Description Analysis of Gas Transfer Evaluation of Aerator Performance	
7-3 ADSORPTION	276
Description Analysis of Activated-Carbon Adsorption Process Analysis	
7-4 DISINFECTION	284
Description of Disinfection Methods and Means Mechanisms of Disinfectants Analysis of Factors Influencing the Action of Disinfectants	
7-5 DISINFECTION WITH CHLORINE	292
Description of Chlorine Chemistry Breakpoint Reaction Factors That Affect Disinfection Efficiency of Chlorine	
7-6 DECHLORINATION	303
Toxicity of Chlorine Residuals Analysis of Dechlorination	
7-7 DISINFECTION WITH OZONE	306
Description Analysis	
7-8 OTHER CHEMICAL APPLICATIONS	307
DISCUSSION TOPICS AND PROBLEMS	308
REFERENCES	310
 8 DESIGN OF FACILITIES FOR PHYSICAL AND CHEMICAL TREATMENT OF WASTEWATER	 312
8-1 RACKS AND COARSE SCREENS	312
Racks Coarse Screens Quantities of Screenings Disposal of Screenings	
8-2 COMMINUTION	319
Description Application and Design	
8-3 GRIT CHAMBERS	322
Types Quantities of Grit Disposal of Grit	
8-4 FLOW EQUALIZATION	330
Basin Construction Mixing and Air Requirements Pump and Pump Control	
8-5 OTHER PRETREATMENT OPERATIONS	333
Skimming Tanks Flocculation Preaeration	
8-6 PRIMARY SEDIMENTATION TANKS	336
Basis of Design Tank Type, Size, and Shape Quantities of Sludge	
8-7 OTHER SOLIDS-REMOVAL OPERATIONS AND UNITS	349
Flotation Fine Screens Imhoff and Septic Tanks	
8-8 CHEMICAL PRECIPITATION	355
Improved Sedimentation Tank Performance Independent Physical-Chemical Treatment Phosphorus Removal Estimation of Sludge Quantities Chemical Storage, Feeding, Piping, and Control Systems	

8-9 GRANULAR-MEDIUM FILTRATION	362
Driving Force, Number, and Size of Filter Units Filter-Bed Selection Filtration Backwashing Systems Filter Appurtenances Filter Problems Filter Control Systems and Instrumentation	
8-10 MICROSCREENING	373
Description Functional Design	
8-11 CHLORINATION	375
Application Chlorine Compounds Chlorination Equipment and Dosage Control Chlorination Facilities	
8-12 ODOR CONTROL	388
DISCUSSION TOPICS AND PROBLEMS	390
REFERENCES	391
9 BIOLOGICAL UNIT PROCESSES	393
9-1 BIOLOGICAL TREATMENT: AN OVERVIEW	394
Some Useful Definitions Role of Microorganisms Treatment Processes	
9-2 SOME FUNDAMENTALS OF MICROBIOLOGY	398
Basic Concepts Important Microorganisms Cell Physiology	
9-3 BACTERIAL GROWTH AND BIOLOGICAL OXIDATION	411
General Growth Patterns in Pure Cultures Growth in Mixed Cultures Bacterial Oxidation	
9-4 KINETICS OF BIOLOGICAL GROWTH	414
Logarithmic Growth: Batch Culture Substrate Limited Growth Cell Growth and Substrate Utilization Effects of Endogenous Metabolism Effects of Temperature Application of Kinetics to Biological Treatment Determination of Kinetic Coefficients Other Rate Expressions	
9-5 AEROBIC SUSPENDED-GROWTH TREATMENT PROCESSES	430
Activated-Sludge Process Suspended-Growth Nitrification Aerobic Aerated Lagoons Aerobic Digestion Aerobic Stabilization Ponds	
9-6 AEROBIC ATTACHED-GROWTH TREATMENT PROCESSES	442
Trickling Filters Roughing Filters Rotating Biological Contactors Packed-Bed Reactors	
9-7 ANOXIC SUSPENDED-GROWTH AND ATTACHED-GROWTH PROCESSES	454
Suspended-Growth Denitrification Fixed-Film Denitrification	
9-8 ANAEROBIC SUSPENDED-GROWTH TREATMENT PRO- CESSES	455
Anaerobic Digestion Anaerobic Contact Process	
9-9 ANAEROBIC ATTACHED-GROWTH TREATMENT PROCESSES	460
Anaerobic Filter Anaerobic Ponds	
9-10 COMBINED AEROBIC/ANOXIC OR ANAEROBIC TREAT- MENT PROCESSES	461
Facultative Lagoons (Ponds) Tertiary-Maturation Ponds	
DISCUSSION TOPICS AND PROBLEMS	463
REFERENCES	465

10 DESIGN OF FACILITIES FOR THE BIOLOGICAL TREATMENT OF WASTEWATER	468
10-1 ACTIVATED-SLUDGE (AEROBIC SUSPENDED-GROWTH) TREATMENT	470
Process Design Considerations Process Design Types of Processes and Modifications Use of Pure Oxygen Diffused-Air Aeration Mechanical Aerators Generation of Pure Oxygen Design of Aeration Tanks and Appurtenances Design of Solids-Separation Facilities Operational Difficulties	
10-2 AERATED-LAGOON (AEROBIC SUSPENDED-GROWTH) TREATMENT	523
Process Design Considerations Process Design Solids Separation	
10-3 TRICKLING-FILTER (AEROBIC ATTACHED-GROWTH) TREATMENT	534
Filter Classification Process Design Design of Physical Facilities	
10-4 COMBINED AEROBIC TREATMENT PROCESSES	547
Series Trickling-Filter and Activated-Sludge Processes Series Activated-Sludge and Trickling-Filter Processes	
10-5 STABILIZATION PONDS	548
Pond Classification Application Process Design and Analysis Solids Separation Design of Physical Facilities	
DISCUSSION TOPICS AND PROBLEMS	566
REFERENCES	570
 11 DESIGN OF FACILITIES FOR THE TREATMENT AND DISPOSAL OF SLUDGE	 573
11-1 SLUDGE-TREATMENT FLOWSHEETS	575
11-2 SOLIDS AND SLUDGE SOURCES, CHARACTERISTICS, AND QUANTITIES	580
Sources Characteristics Quantities	
11-3 SLUDGE AND SCUM PUMPING	588
Pumps Application of Pumps to Types of Sludge Head-Loss Determination Sludge Piping	
11-4 PRELIMINARY OPERATIONS	595
Sludge Grinding Sludge Degritting Sludge Blending Sludge Storage	
11-5 CONCENTRATION (THICKENING)	600
Application Description of Thickening Equipment Design of Thickeners	
11-6 STABILIZATION: CHEMICAL AND THERMAL PROCESSES	607
Chlorine Oxidation Lime Stabilization Heat Treatment	
11-7 STABILIZATION: ANAEROBIC SLUDGE-DIGESTION PROCESS	609
Process Description Process Design Gas Production, Collection, and Utilization Digester Mixing Digester Heating	
11-8 STABILIZATION: AEROBIC SLUDGE-DIGESTION PROCESS	627
Process Description Conventional-Air Aerobic Digestion Pure-Oxygen Aerobic Digestion Thermophilic Aerobic Digestion	

11-9	CONDITIONING	634
	Chemical Conditioning Elutriation Heat Treatment Other Processes	
11-10	DISINFECTION	638
	Pasteurization Long-Term Storage	
11-11	DEWATERING	640
	Vacuum Filtration Centrifugation Filter Presses Horizontal Belt Filters Sludge-Drying Beds Lagoons	
11-12	HEAT DRYING	656
	Theory Heat-Drying Options	
11-13	COMPOSTING	660
	Process Description Cocomposting Options	
11-14	THERMAL REDUCTION	662
	Process Fundamentals Thermal-Reduction Processes	
11-15	PREPARATION OF SOLIDS MASS BALANCES	671
	Basis for Preparation of Mass Balances Performance Data for Sludge- Processing Facilities	
11-16	FINAL SLUDGE AND SOLIDS CONVEYANCE, STORAGE AND DISPOSAL	684
	Conveyance Methods Sludge Storage Final Disposal	
	DISCUSSION TOPICS AND PROBLEMS	690
	REFERENCES	694
12	ADVANCED WASTEWATER TREATMENT	696
12-1	EFFECTS OF CHEMICAL CONSTITUENTS IN WASTEWATER	697
12-2	UNIT OPERATIONS AND PROCESSES AND TREATMENT FLOWSHEETS	698
	Classification Process Selection and Development of Treatment Flow- sheets Typical Process Performance Data	
12-3	NITROGEN CONVERSION AND REMOVAL	699
	Forms of Nitrogen Sources of Nitrogen Operations and Processes for the Control of Nitrogen	
12-4	NITRIFICATION	708
	Nitrification Processes Nitrification Stoichiometry Process Analysis (Nitrification) Process Applications	
12-5	DENITRIFICATION AND NITRIFICATION-DENITRIFI- CATION	721
	Denitrification Processes Denitrification Stoichiometry Process Analysis (Denitrification) Process Application	
12-6	NITROGEN REMOVAL BY PHYSICAL AND CHEMICAL PROCESSES	734
	Air Stripping of Ammonia Breakpoint Chlorination Ion Exchange	
12-7	PHOSPHORUS REMOVAL	744
	Forms of Phosphorus Operations and Processes for Phosphorus Removal	
12-8	REMOVAL OF REFRACTORY ORGANICS	751
	Carbon Adsorption Chemical Oxidation	

12-9 REMOVAL OF DISSOLVED INORGANIC SUBSTANCES	753
Chemical Precipitation Ion Exchange Reverse Osmosis (Hyper-filtration) Electrodialysis	
12-10 ULTIMATE DISPOSAL OF CONTAMINANTS	756
DISCUSSION TOPICS AND PROBLEMS	756
REFERENCES	758
13 LAND-TREATMENT SYSTEMS	760
13-1 DEVELOPMENT OF LAND-TREATMENT SYSTEMS	760
Historical Practice Land Treatment of Wastewater Land Application of Sludge	
13-2 FUNDAMENTAL CONSIDERATIONS IN LAND-TREATMENT SYSTEMS	766
Wastewater Characteristics and Treatment Mechanisms Vegetation Public Health	
13-3 IRRIGATION SYSTEMS	772
Design Objectives Site Selection Preapplication Treatment Climate and Storage Loading Rate Land Requirements Crop Selection Distribution Techniques Underdrainage Surface-Runoff Control Case Study (Muskegon, Michigan)	
13-4 RAPID-INFILTRATION SYSTEMS	794
Design Objectives Site Selection Preapplication Treatment Climate and Storage Loading Rate Distribution Techniques Application Cycles Control of Underground Flow	
13-5 OVERLAND-FLOW SYSTEMS	804
Design Objectives Site Selection Preapplication Treatment Climate and Storage Application Rates Land Requirements Terrace Characteristics Crop Selection Distribution Techniques Runoff Collection	
13-6 OTHER SYSTEMS	809
Wetlands Application Aquaculture	
13-7 LAND APPLICATION OF SLUDGE	814
Design Objectives Sludge Characteristics Site Selection Market Considerations Operational Methods Application Rates	
DISCUSSION TOPICS AND PROBLEMS	823
REFERENCES	824
14 EFFLUENT DISPOSAL AND REUSE	829
14-1 WATER-POLLUTION CONTROL	830
Receiving-Water Standards Effluent Standards Setting of Standards Effluent Disposal by Dilution	
14-2 DISPOSAL INTO LAKES	832
Problem Analysis Stratification in Large Lakes	
14-3 DISPOSAL INTO RIVERS	836
Reoxygenation in Rivers Deoxygenation in Rivers Development of Oxygen-Sag Model Design of River Diffusers	

14-4 DISPOSAL INTO ESTUARIES	845
Mathematical Analysis of Estuaries Determination of Coefficient of Eddy Diffusion	
14-5 DISPOSAL INTO THE OCEAN	849
Estimation of Initial Dilution Dilution Due to Dispersion Dilution Due to Decay Outfall Design	
14-6 DIRECT AND INDIRECT REUSE OF WASTEWATER	859
Municipal Reuse Industrial Reuse Agricultural Reuse Recreational Reuse Groundwater Recharge	
DISCUSSION TOPICS AND PROBLEMS	861
REFERENCES	864
APPENDIXES	865
A Metric Conversion Factors	866
B Physical Properties of Water	875
C Dissolved Oxygen Solubility Data	878
D Most Probable Number (MPN) Tables	879
E Example of Summary Table Listing Basic Design Data for Wastewater Treatment Plant	881
INDEXES	885
Name Index	
Subject Index	

WASTEWATER ENGINEERING: AN OVERVIEW

Every community produces both liquid and solid wastes. The liquid portion—wastewater—is essentially the water supply of the community after it has been fouled by a variety of uses. From the standpoint of sources of generation, wastewater may be defined as a combination of the liquid or water-carried wastes removed from residences, institutions, and commercial and industrial establishments, together with such groundwater, surface water, and storm water as may be present.

If untreated wastewater is allowed to accumulate, the decomposition of the organic materials it contains can lead to the production of large quantities of malodorous gases. In addition, untreated wastewater usually contains numerous pathogenic or disease-causing microorganisms that dwell in the human intestinal tract or that may be present in certain industrial wastes. It also contains nutrients, which can stimulate the growth of aquatic plants, and it may contain toxic compounds. For these reasons, the immediate and nuisance-free removal of wastewater from its sources of generation, followed by treatment and disposal, is not only desirable but also necessary in an industrialized society. In the United States, it is now mandated by numerous federal and state laws.

Wastewater engineering is that branch of environmental engineering in which the basic principles of science and engineering are applied to the problems of water-pollution control. The ultimate goal—wastewater management—is the protection of the environment in a manner commensurate with economic, social, and political concerns.

To provide an initial perspective of the treatment, disposal, and reuse of wastewater, a brief review of the historical background, current status, and expected new directions in these areas of wastewater engineering is presented in