



**WATER  
SUPPLY  
AND  
POLLUTION  
CONTROL**  
FOURTH EDITION  
WARREN VIESSMAN, JR.  
MARK J. HAMMER

---

# **Water Supply and Pollution Control**

Warren Viessman, Jr.

University of Florida

Mark J. Hammer

**FOURTH EDITION**



1817

**HARPER & ROW, PUBLISHERS, New York**  
Cambridge, Philadelphia, San Francisco, Washington,  
London, Mexico City, São Paulo, Singapore, Sydney

Sponsoring Editor: *Cliff Robichaud*  
Project Editor: *Jonathan Haber*  
Cover Design: *Michel Craig*  
Cover Photo: *Michel Tcherevkoff*  
Text Art: *Fineline Illustration, Inc.*  
Production: *Marion Palen/Delia Tedoff*  
Compositor: *Black Dot, Inc.*  
Printer and Binder: *The Maple Press Company*

**Water Supply and Pollution Control**, Fourth edition  
Copyright © 1985 by Harper & Row, Publishers, Inc.

All rights reserved. Printed in the United States of America. No part of this book may be used or reproduced in any manner whatsoever without written permission, except in the case of brief quotations embodied in critical articles and reviews. For information address Harper & Row, Publishers, Inc., 10 East 53d Street, New York, NY 10022.

ISBN 0-06-046821-1

Harper International Edition  
ISBN 0-06-350738-1

86 87 88 89 9 8 7 6 5 4 3 2

---

**Water Supply  
and  
Pollution Control**

---

**Other Harper & Row books coauthored  
by Warren Viessman, Jr.**

*Introduction to Hydrology*, second edition, by Viessman, Knapp, Lewis,  
and Harbaugh

*Water Management, Technology and Institutions*, by Viessman and Welty

This book is dedicated to John W. Clark, who designed its first edition in 1963. John's guiding hand was sorely missed in the preparation of this latest version, but the principles he stood for are still its foundation. His knowledge, the fruits of his research, and his teaching of students lives on in these pages. He will long be remembered by his many friends, colleagues, and students—and by students yet to come.

---

# Preface

This fourth edition of *Water Supply and Pollution Control* has been updated significantly. Approximately 40% of the material is new. In particular, the presentation of many topics has been modernized, and several are introduced for the first time. These changes include new or newly updated treatments of toxic substances; sedimentation; filtration; demineralization processes; chemical kinetics; oxygen transfer; viruses; biological kinetics; rotating biological contactors; pressure filtration of sludges; wastewater reclamation and reuse; water quality modeling; and the technical, social, and environmental dimensions of managing water in a modern society. As in earlier editions, the emphasis is on the application of scientific methods to solve problems related to the development, movement, and treatment of water and wastewater.

The authors wish to acknowledge the advice and assistance of students, professors, and practicing engineers who have reviewed and commented on previous editions. Specific recognition is given to those persons who helped in preparing the manuscript for this edition. Mark J. Hammer, Jr., environmental engineer with Henningson, Durham and Richardson, provided valuable technical assistance on the chapters covering physical, chemical, and biological processes, sludge processing, and advanced wastewater treatment. Mrs. Audrey Hammer typed the draft and final manuscript copies of Chapters 8–14 and assisted in assembling and proofreading the final copy of these chapters. Mrs. Bette Viessman typed, edited, and proofread the remainder of the text. We are indebted to them for their perseverance and understanding and for the excellent quality of their work.

WARREN VISSMAN, JR.  
MARK J. HAMMER

---

# Contents

**Preface** xvii

**CHAPTER 1 Introduction** 1

References 5

**CHAPTER 2 Water Management:  
Institutions and Technology** 6

- 2.1 From Projects to Issues 6
- 2.2 Institutions 7
- 2.3 Legal Considerations 8
- 2.4 Technology and Water Management 14
- 2.5 Outlook for the Future 16
  - Problems 16
  - References 17

**CHAPTER 3 Water Management:  
Environmental Considerations** 18

- 3.1 Environmental Regulation and Protection 20
- 3.2 Effects of Environmental Regulations 24
- 3.3 The Future of Pollution Control Efforts in the United States 25
  - Problems 26
  - References 26

**CHAPTER 4 Water Requirements, Water Supply,  
and Waste Volumes** 27

- 4.1 Primary Water-Using Sectors 27
- 4.2 Water Supply Considerations 41
- 4.3 Quantities of Wastes 50



4.4 Industrial Waste Volumes 54  
4.5 Agricultural Wastes 54  
Problems 54  
References 56

**CHAPTER 5 Development of Water Supplies 60**

**Water Quantity 60**

5.1 Soil Moisture 60  
5.2 Surface Waters and Groundwater 61  
5.3 Runoff Distribution 61  
5.4 Groundwater Distribution 62

**Water Quality 64**

5.5 Groundwater 65  
5.6 Surface Water 65  
**Objectives of Water Resources Development 66**  
5.7 Planning for Water Resources Development 66  
5.8 The Water Budget 69

**Surface-Water Supplies 71**

5.9 Basin Characteristics Affecting Runoff 71  
5.10 Natural and Regulated Runoff 71  
5.11 Storage 72

**Reservoirs 73**

5.12 Determination of Required Reservoir Capacity 73  
5.13 Classical Method of Computation 73  
5.14 Frequency of Extreme Events 76  
5.15 Probabilistic Mass Type of Analysis 77  
5.16 Losses from Storage 78

**Groundwater 80**

5.17 The Subsurface Distribution of Water 80  
5.18 Aquifers 81  
5.19 Fluctuations in Groundwater Level 82  
5.20 Safe Yield of an Aquifer 82  
5.21 Groundwater Flow 84  
5.22 Hydraulics of Wells 87  
5.23 Boundary Effects 95  
5.24 Regional Groundwater Systems 96  
5.25 Saltwater Intrusion 100  
5.26 Groundwater Recharge 101  
5.27 Concurrent Development of Groundwater  
and Surface-Water Sources 102  
Problems 103  
References 105

**CHAPTER 6 Transportation and Distribution of Water 107**

- 6.1 Types of Aqueducts 107
- 6.2 Hydraulic Considerations 108
- 6.3 Design of Transportation Systems 112
  - Distribution Systems 117**
- 6.4 System Configurations 117
- 6.5 Basic System Requirements 117
- 6.6 Hydraulic Design 119
- 6.7 Distribution System Design and Analysis 148
- 6.8 Distribution Reservoirs and Service Storage 151
  - Pumping 159**
- 6.9 Pumping Head 159
- 6.10 Power 159
- 6.11 Cavitation 160
- 6.12 System Head 161
- 6.13 Pump Characteristics 161
- 6.14 Selection of Pumping Units 163
  - Problems 165
  - References 169

**CHAPTER 7 Wastewater Systems 171**

- Hydraulic Considerations 171**
- 7.1 Uniform Flow 171
- 7.2 Gradually Varied Flow and Surface Profiles 174
- 7.3 Velocity Considerations 178
  - Design of Sanitary Sewers 179**
- 7.4 House and Building Connections 179
- 7.5 Collecting Sewers 179
- 7.6 Intercepting Sewers 180
- 7.7 Materials 180
- 7.8 System Layout 180
- 7.9 Hydraulic Design 183
- 7.10 Protection Against Floodwaters 185
- 7.11 Inverted Siphons 185
- 7.12 Wastewater Pumping Stations 187
  - Design of Storm Drainage Systems 187**
- 7.13 Hydrologic Considerations 188
- 7.14 Design Flow 188
- 7.15 Procedures for Estimating Runoff 189
- 7.16 Stormwater Inlets 200
- 7.17 System Layout 203
- 7.18 Hydraulic Design of Urban Storm Drainage Systems 205

Problems 212  
References 214

**CHAPTER 8 Water Quality 216**

**Drinking-Water Standards 216**

8.1 Microbiology of Drinking Water 216  
8.2 Inorganic Chemicals 220  
8.3 Organic Chemicals 223  
8.4 Trihalomethanes 227  
8.5 Radionuclides 228  
8.6 Turbidity 229  
8.7 Secondary Standards 230

**Toxic Water Pollutants 231**

8.8 Priority Toxic Pollutants 231  
8.9 Volatile Organic Chemicals 235

**Quality Criteria for Surface Waters 237**

8.10 Conventional Water Pollutants 237  
8.11 Toxic Water Pollutants 240

**Selected Pollution Parameters 242**

8.12 Total and Suspended Solids 242  
8.13 Biochemical and Chemical Oxygen Demands 244  
8.14 Coliform Bacteria 248  
Problems 251  
References 252

**CHAPTER 9 Systems for Treating Wastewater and Water 254**

**Wastewater Treatment Systems 254**

9.1 Industrial Wastewaters 254  
9.2 Infiltration and Inflow 257  
9.3 Combined Sewers 257  
9.4 Purposes of Wastewater Treatment 258  
9.5 Selection of Treatment Processes 261

**Water Treatment Systems 270**

9.6 Water Sources 270  
9.7 Purpose of Water Treatment 272  
9.8 Selection of Water-Treatment Processes 273  
9.9 Water-Processing Sludges 279

**CHAPTER 10 Physical-Treatment Processes 281**

**Flow-Measuring Devices 281**

10.1 Measurement of Water Flow 281  
10.2 Measurement of Wastewater Flow 282

	<b>Screening Devices</b>	<b>283</b>
10.3	Water-Intake Screens	284
10.4	Screens in Wastewater Treatment	285
10.5	Comminutors	286
	<b>Hydraulic Characteristics of Reactors</b>	<b>287</b>
10.6	Residence Time Distribution	287
10.7	Ideal Reactors	287
10.8	Dispersed Plug Flow	291
	<b>Mixing and Flocculation</b>	<b>296</b>
10.9	Rapid-Mixing Devices	296
10.10	Flocculation	296
10.11	Recommended Standards for Water Works	301
	<b>Sedimentation</b>	<b>301</b>
10.12	Type I Sedimentation	302
10.13	Type II Sedimentation	306
10.14	Zone Settling	308
10.15	Compression	311
10.16	Sedimentation in Water Treatment	312
10.17	Sedimentation in Wastewater Treatment	315
10.18	Grit Chambers in Wastewater Treatment	320
	<b>Filtration</b>	<b>322</b>
10.19	Gravity Granular-Media Filtration	322
10.20	Description of a Typical Gravity Filter System	325
10.21	Flow Control Through Gravity Filters	328
10.22	Head Losses Through Filter Media	336
10.23	Backwashing and Media Fluidization	338
10.24	Pressure Filters	344
10.25	Diatomaceous-Earth Filters	345
10.26	Slow Sand Filters	345
	Problems	346
	References	349
<b>CHAPTER 11</b>	<b>Chemical-Treatment Processes</b>	<b>351</b>
	<b>Chemical Considerations</b>	<b>351</b>
11.1	Inorganic Chemicals and Compounds	351
11.2	Hydrogen Ion Concentration	356
11.3	Alkalinity and pH Relationships	356
11.4	Chemical Equilibria	358
11.5	Ways of Shifting Chemical Equilibria	359
11.6	Chemical Process Kinetics	360
11.7	Colloidal Dispersions	365
11.8	Coagulation and Flocculation	367

**Coagulation 371**

- 11.9 Coagulants 371
- 11.10 Coagulant Aids 374
- 11.11 Jar Test 376

**Water Softening 377**

- 11.12 Chemistry of Lime–Soda Ash Process 377
- 11.13 Process Variations in Lime–Soda Ash Softening 378
- 11.14 Ion Exchange Softening and Nitrate Removal 386

**Iron and Manganese Removal 388**

- 11.15 Chemistry of Iron and Manganese 388
- 11.16 Preventative Treatment 389
- 11.17 Iron and Manganese Removal Processes 389

**Corrosion and Corrosion Control 391**

- 11.18 Electrochemical Mechanism of Iron Corrosion 392
- 11.19 Water Stabilization 393
- 11.20 Cathodic Protection 397
- 11.21 Corrosion of Sewer Pipes 398

**Disinfection 398**

- 11.22 Chemistry of Chlorination 399
- 11.23 Disinfection of Drinking Water 401
- 11.24 Disinfection of Wastewater Effluents 403
- 11.25 Chlorine Handling and Dosing 404
- 11.26 Chlorine Dioxide 404
- 11.27 Ozone 405
- 11.28 Control of Trihalomethanes 406

**Taste and Odor 407**

- 11.29 Control of Taste and Odor 407

**Fluoridation 408**

- 11.30 Fluoridation 409
- 11.31 Defluoridation 410

**Reduction of Dissolved Salts 411**

- 11.32 Distillation of Seawater 411
- 11.33 Reverse Osmosis 413
- 11.34 Electrodialysis 419
  - Problems 419
  - References 425

**CHAPTER 12 Biological Treatment Processes 428**

**Biological Considerations 428**

- 12.1 Bacteria and Fungi 428
- 12.2 Algae 431
- 12.3 Protozoans and Higher Animals 433

12.4	Viruses	435
12.5	Metabolism, Energy, and Synthesis	438
12.6	Enzyme Kinetics	442
12.7	Growth Kinetics of Pure Bacterial Cultures	444
12.8	Biological Growth in Wastewater Treatment	447
12.9	Factors Affecting Growth	450
12.10	Population Dynamics	452
	<b>Characteristics of Wastewater</b>	<b>457</b>
12.11	Flow and Strength Variations	457
12.12	Composition of Wastewater	461
	<b>Trickling (Biological) Filters</b>	<b>463</b>
12.13	Description of a Trickling Filter	465
12.14	Trickling-Filter Secondary Systems	466
12.15	Loading Standards for Stone-Media Trickling Filters	469
12.16	Efficiency Equations for Stone-Media Trickling Filters	471
12.17	Operational Problems of Stone-Media Filters	477
	<b>Biological Filters with Synthetic Media</b>	<b>478</b>
12.18	Description of Plastic-Media Filters	478
12.19	Efficiency Equations for Plastic-Media Trickling Filters	480
12.20	Biological Towers with Redwood Media	487
	<b>Rotating Biological Contactors</b>	<b>490</b>
12.21	Description of Rotating Biological Contactor Media	490
12.22	Application of the RBC Process	492
12.23	Design of the RBC Process	495
	<b>Activated Sludge</b>	<b>497</b>
12.24	BOD Loadings and Aeration Periods	498
12.25	Activated-Sludge Treatment Systems	501
12.26	High-Purity-Oxygen Activated Sludge	513
12.27	Design Criteria for High-Purity-Oxygen Aeration	516
12.28	Kinetics Model of the Activated-Sludge Process	519
12.29	Laboratory Determination of Kinetic Constants	524
12.30	Application of the Kinetics Model in Process Design	528
12.31	Oxygen Transfer and Oxygenation Requirements	532
12.32	Determination of Oxygen-Transfer Coefficients	537
12.33	Operation and Control of Activated-Sludge Processes	543
	<b>Stabilization Ponds</b>	<b>546</b>
12.34	Description of a Stabilization Pond	546
12.35	BOD Loadings	546
12.36	Operation of Stabilization Ponds	548
12.37	Advantages and Disadvantages of Stabilization Ponds	548
12.38	Completely Mixed Aerated Lagoons	550
	<b>Odor Control</b>	<b>554</b>
12.39	Sources of Odors in Wastewater Treatment	555

- 12.40 Methods of Odor Control 556
- 12.41 Individual On-Site Wastewater Disposal 557
  - Marine Wastewater Disposal 559**
- 12.42 Ocean Outfalls 559
  - Problems 559
  - References 567

**CHAPTER 13 Processing of Sludges 569**

- Sources, Characteristics, and Quantities of Waste Sludges 569**
- 13.1 Weight and Volume Relationships 569
- 13.2 Characteristics and Quantities of Wastewater Sludges 572
- 13.3 Characteristics and Quantities of Water-Processing Sludges 579
  - Arrangement of Unit Processes in Sludge Disposal 582**
  - 13.4 Selection of Processes for Wastewater Sludges 583
  - 13.5 Selection of Processes for Water Treatment Sludges 589
  - Gravity Thickening 593**
  - 13.6 Description of Gravity Thickeners 593
  - 13.7 Design of Wastewater Sludge Thickeners 595
  - 13.8 Design of Water-Treatment Sludge Thickeners 596
  - Flotation Thickening 597**
  - 13.9 Description of Dissolved-Air Flotation 597
  - 13.10 Design of Dissolved-Air Flotation Units 598
  - Biological Sludge Digestion 600**
  - 13.11 Anaerobic Sludge Digestion 601
  - 13.12 Single-Stage Floating-Cover Digesters 601
  - 13.13 High-Rate (Completely Mixed) Digesters 603
  - 13.14 Volatile Solids Loadings and Detention Times 605
  - 13.15 Anaerobic Digester Capacity 606
  - 13.16 Startup and Monitoring of Digesters 609
  - 13.17 Aerobic Sludge Digestion 609
  - 13.18 Open-Air Drying Beds 610
  - 13.19 Composting 611
  - Vacuum Filtration 613**
  - 13.20 Description of Rotary Vacuum Filtration 614
  - 13.21 Theory of Vacuum Filtration 616
  - 13.22 Sizing Vacuum Filters 619
  - 13.23 Vacuum Filtration of Wastewater Sludges 621
  - Pressure Filtration 623**
  - 13.24 Description of Belt Filter Press Dewatering 624
  - 13.25 Application of Belt Filter Dewatering 625
  - 13.26 Sizing of Belt Filter Presses 628

- 13.27 Description of Filter Press Dewatering 631  
 13.28 Application of Pressure Filtration 633  
**Centrifugation 636**  
 13.29 Description of Centrifugation 636  
 13.30 Applications of Centrifugation 639  
 13.31 Suspended-Solids-Removal Efficiency 640  
**Recovery of Chemicals 642**  
 13.32 Lime Recovery 642  
 13.33 Alum Recovery 643  
**Ultimate Disposal 644**  
 13.34 Land Application of Sludge 644  
 13.35 Land Burial of Dewatered Sludge 649  
 13.36 Combustion of Organic Sludges 649  
 13.37 Sludge Incinerators 651  
 13.38 Ocean Disposal of Sludge 653  
 Problems 654  
 References 661

## **CHAPTER 14 Advanced Wastewater Treatment Processes 662**

- Limitations of Secondary Treatment 662**  
 14.1 Effluent Standards 663  
 14.2 Flow Equalization 664  
**Selection of Advanced Wastewater Treatment Processes 666**  
 14.3 Selecting and Combining Unit Processes 666  
**Suspended-Solids Removal 669**  
 14.4 Granular-Media Filtration 669  
 14.5 Filtration and Chlorination for Virus Removal 674  
 14.6 Microscreening 676  
**Carbon Adsorption 677**  
 14.7 Granular-Carbon Columns 677  
 14.8 Carbon Regeneration 680  
**Phosphorus Removal 680**  
 14.9 Biological Phosphorus Removal 682  
 14.10 Biological-Chemical Phosphorus Removal 683  
 14.11 Tracing Phosphorus Through Treatment Processes 687  
 14.12 Physical-Chemical Processing 690  
**Nitrogen Removal 692**  
 14.13 Tracing Nitrogen Through Treatment Processes 693  
 14.14 Biological Nitrification 695  
 14.15 Biological Denitrification 701



**xvi** CONTENTS

14.16 Biological Nitrification–Denitrification 706  
14.17 Ammonia Stripping 710  
14.18 Breakpoint Chlorination 713  
14.19 Ion Exchange for Ammonia Ions 713  
**Wastewater Reclamation 714**  
14.20 Wastewater Reclamation Processes 715  
14.21 Water Factory 21, Orange County, California 716  
**Land Treatment of Wastewater 722**  
14.22 Methods of Applying Wastewater to Land 722  
14.23 Spray Irrigation 725  
    Problems 731  
    References 735

**CHAPTER 15 Water-Quality Models 737**

15.1 Types of Water-Quality Models 739  
15.2 An Elementary Water-Quality Model 741  
15.3 EPA Stormwater Management Model 748  
15.4 EPA Qual II Model 753  
15.5 Lake and Reservoir Modeling 759  
15.6 Groundwater-Quality Models 763  
15.7 Reliability of Water-Quality Models 765  
    Problems 765  
    References 766

**Appendix 769**

**Index 781**