# Contents

**Preface** xvii

**Chapter 1** Introduction 1

1.1 Drinking Water Systems 1  
1.2 Drainage and Sewerage Systems 3  
References 5

**Chapter 2** Water Management 6

2.1 From Projects to Issues 6  
2.2 Institutions 7  
2.3 Integrated Water Management 8  
2.4 Roadblocks to Be Overcome 10  
2.5 Environmental Regulation and Protection 10  
2.6 Effects of Environmental Regulations 15  
2.7 A Look to the Future 16  
2.8 Conclusions 18  
Problems 18  
References 18

**Chapter 3** Water Resources Development 20

**Water Quantity** 20  
3.1 Soil Moisture 21  
3.2 Surface Waters and Groundwater 21  
3.3 Runoff Distribution 22  
3.4 Groundwater Distribution 22  
**Water Quality** 24  
3.5 Groundwater 26  
3.6 Surface Water 26  
**Hydrology and Water Management** 26  
3.7 The Water Budget 27  
**Surface Water Sources** 28  
3.8 Basin Characteristics Affecting Runoff 28
Contents

3.9 Natural and Regulated Runoff 28
3.10 Storage 29
  Reservoirs 29
3.11 Determination of Required Reservoir Capacity 30
3.12 Methods of Computation 30
3.13 Frequency of Extreme Events 32
3.14 Probabilistic Mass Type of Analysis 33
3.15 Losses from Storage 34
  Groundwater 36
3.16 The Subsurface Distribution of Water 36
3.17 Aquifers 37
3.18 Fluctuations in Groundwater Level 37
3.19 Safe Yield of an Aquifer 39
3.20 Groundwater Flow 39
3.21 Hydraulics of Wells 44
3.22 Boundary Effects 55
3.23 Regional Groundwater Systems 56
3.24 Salt Water Intrusion 59
3.25 Groundwater Recharge 60
3.26 Concurrent Development of Groundwater and Surface
  Water Sources 61
3.27 Aquifer Storage and Recovery (ASR) 62

Problems 63
References 67

Chapter 4 Water Use 69
  4.1 Water Sources 69
  4.2 Water-Using Sectors 72
  4.3 The Impact of Climate Change on Water
    Availability and Use 81
  4.4 Water Use Trends 83
  4.5 Factors Affecting Water Use 88
  4.6 Population 89
  4.7 Water Use Forecasting 100

Problems 111
References 113

Chapter 5 Wastewater Generation 117
  5.1 Quantities of Wastewater 117
  5.2 Waste Flows from Urban Areas 117
  5.3 Industrial Waste Volumes 122
  5.4 Agricultural Wastes 123
  5.5 A Closing Note 123

Problems 123
References 124
Chapter 6  Conveying and Distributing Water  126

6.1 Aqueducts  126
6.2 Hydraulic Considerations  127
6.3 Design Considerations  138

Distribution Systems  139
6.4 System Configurations  139
6.5 Distribution System Components  140
6.6 System Requirements  144
6.7 Distribution System Design and Analysis  144
6.8 Hydraulic Design  147
6.9 Network Modeling Software  170
6.10 Distribution Reservoirs and Service Storage  185

Pumping  193
6.11 Pumping Head  193
6.12 Power  193
6.13 Cavitation  194
6.14 System Head  195
6.15 Pump Characteristics  195
6.16 Selection of Pumps  197

Problems  199
References  206

Chapter 7  Wastewater and Storm Water Systems  208

Hydraulics  208
7.1 Uniform Flow  209
7.2 Gradually Varied Flow and Surface Profiles  213
7.3 Velocity  217

Design of Sanitary Sewers  218
7.4 House and Building Connections  218
7.5 Collecting Sewers  219
7.6 Intercepting Sewers  219
7.7 Materials  220
7.8 System Layout  221
7.9 Hydraulic Design  223
7.10 Protection Against Floodwaters  231
7.11 Inverted Siphons  231
7.12 Wastewater Pumping Stations  232

Storm Water Management  233
7.13 Alternative Strategies  233

Water Quality  233
7.14 Best Management Practices  235
7.15 Treatment Processes  236

Water Quantity  236
7.16 Hydrologic Considerations  237
7.17 Design Flow  237
Chapter 8  Water Quality  286

Microbiological Quality  286
8.1 Waterborne Diseases  287
8.2 Coliform Bacteria as Indicator Organisms  291

Chemical Quality of Drinking Water  294
8.3 Monitoring Drinking Water for Pathogens  295
8.4 Assessment of Chemical Quality  296
8.5 Chemical Contaminants  299

Quality Criteria for Surface Waters  308
8.6 Water Quality Standards  308
8.7 Pollution Effects on Aquatic Life  309
8.8 Conventional Water Pollutants  310
8.9 Toxic Water Pollutants  313

Selected Pollution Parameters  316
8.10 Total and Suspended Solids  316
8.11 Biochemical and Chemical Oxygen Demands  317
8.12 Coliform Bacteria  322

Problems  325
References  328

Chapter 9  Systems for Treating Wastewater and Water  330

Wastewater Treatment Systems  330
9.1 Purpose of Wastewater Treatment  331
9.2 Selection of Treatment Processes  332

Water Treatment Systems  339
9.3 Water Sources  339
9.4 Selection of Water Treatment Processes  343
9.5 Water-Processing Sludges  347

Chapter 10  Physical Treatment Processes  351

Flow-Measuring Devices  351
10.1 Measurement of Water Flow  351
10.2 Measurement of Wastewater Flow  352

Screening Devices  354
10.3 Water-Intake Screens  354
10.4 Screens in Wastewater Treatment  354
10.5 Shredding Devices  355

Hydraulic Characteristics of Reactors  355
10.6 Residence Time Distribution 356
10.7 Ideal Reactors 357
10.8 Dispersed Plug Flow 361
**Mixing and Flocculation** 365
10.9 Rapid Mixing 365
10.10 Flocculation 366
**Sedimentation** 370
10.11 Fundamentals of Sedimentation 370
10.12 Types of Clarifiers 371
10.13 Sedimentation in Water Treatment 374
10.14 Sedimentation in Wastewater Treatment 377
10.15 Grit Chambers in Wastewater Treatment 382
**Filtration** 384
10.16 Gravity Granular-Media Filtration 384
10.17 Description of a Typical Gravity Filter System 387
10.18 Flow Control Through Gravity Filters 392
10.19 Head Losses Through Filter Media 398
10.20 Backwashing and Media Fluidization 401
10.21 Pressure Filters 407
10.22 Membrane Filtration 407
Problems 411
References 416

Chapter 11 Chemical Treatment Processes 418

**Chemical Considerations** 418
11.1 Inorganic Chemicals and Compounds 419
11.2 Hydrogen Ion Concentration 423
11.3 Alkalinity and pH Relationships 424
11.4 Chemical Equilibria 425
11.5 Ways of Shifting Chemical Equilibria 426
11.6 Chemical Process Kinetics 427
11.7 Colloidal Dispersions 432
**Water Coagulation** 435
11.8 Coagulation Process 435
11.9 Coagulants 437
11.10 Polymers 441
**Water Softening** 442
11.11 Chemistry of Lime–Soda Ash Process 442
11.12 Process Variations in Lime–Soda Ash Softening 444
11.13 Cation Exchange Softening 454
**Iron and Manganese Removal** 455
11.14 Chemistry of Iron and Manganese 455
11.15 Preventive Treatment 456
11.16 Iron and Manganese Removal Processes 457
**Chemical Disinfection and By-Product Formation** 459
11.17 Chemistry of Chlorination 459
<table>
<thead>
<tr>
<th>Section</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>11.18</td>
<td>Chlorine Dioxide</td>
<td>463</td>
</tr>
<tr>
<td>11.19</td>
<td>Ozone</td>
<td>464</td>
</tr>
<tr>
<td>11.20</td>
<td>Disinfection By-Products</td>
<td>465</td>
</tr>
<tr>
<td>11.21</td>
<td>Control of Disinfection By-Products</td>
<td>467</td>
</tr>
<tr>
<td>11.22</td>
<td>Disinfection/Disinfection By-Products Rule</td>
<td>468</td>
</tr>
<tr>
<td></td>
<td><strong>Disinfection of Potable Water</strong></td>
<td></td>
</tr>
<tr>
<td>11.23</td>
<td>Concept of the C•t Product</td>
<td>469</td>
</tr>
<tr>
<td>11.24</td>
<td>Surface Water Disinfection</td>
<td>472</td>
</tr>
<tr>
<td>11.25</td>
<td>Groundwater Disinfection</td>
<td>476</td>
</tr>
<tr>
<td></td>
<td><strong>Disinfection of Wastewater</strong></td>
<td></td>
</tr>
<tr>
<td>11.26</td>
<td>Conventional Effluent Disinfection</td>
<td>481</td>
</tr>
<tr>
<td>11.27</td>
<td>Tertiary Effluent Disinfection</td>
<td>484</td>
</tr>
<tr>
<td></td>
<td><strong>Taste and Odor</strong></td>
<td></td>
</tr>
<tr>
<td>11.28</td>
<td>Control of Taste and Odor</td>
<td>486</td>
</tr>
<tr>
<td></td>
<td><strong>Fluoridation</strong></td>
<td></td>
</tr>
<tr>
<td>11.29</td>
<td>Fluoridation</td>
<td>487</td>
</tr>
<tr>
<td></td>
<td><strong>Corrosion and Corrosion Control</strong></td>
<td></td>
</tr>
<tr>
<td>11.30</td>
<td>Electrochemical Mechanism of Iron Corrosion</td>
<td>489</td>
</tr>
<tr>
<td>11.31</td>
<td>Corrosion of Lead Pipe and Solder</td>
<td>490</td>
</tr>
<tr>
<td>11.32</td>
<td>Corrosion of Sewer Pipes</td>
<td>491</td>
</tr>
<tr>
<td></td>
<td><strong>Reduction of Dissolved Salts</strong></td>
<td></td>
</tr>
<tr>
<td>11.33</td>
<td>Distillation of Seawater</td>
<td>492</td>
</tr>
<tr>
<td>11.34</td>
<td>Reverse Osmosis</td>
<td>494</td>
</tr>
<tr>
<td></td>
<td><strong>Volatile Organic Chemical Removal</strong></td>
<td></td>
</tr>
<tr>
<td>11.35</td>
<td>Design of Air-Stripping Towers</td>
<td>500</td>
</tr>
<tr>
<td></td>
<td><strong>Synthetic Organic Chemical Removal</strong></td>
<td></td>
</tr>
<tr>
<td>11.36</td>
<td>Activated Carbon Adsorption</td>
<td>504</td>
</tr>
<tr>
<td>11.37</td>
<td>Granular Activated Carbon Systems</td>
<td>505</td>
</tr>
<tr>
<td></td>
<td>Problems</td>
<td>506</td>
</tr>
<tr>
<td></td>
<td>References</td>
<td>517</td>
</tr>
<tr>
<td></td>
<td><strong>Chapter 12  Biological Treatment Processes</strong></td>
<td>520</td>
</tr>
<tr>
<td></td>
<td><strong>Biological Considerations</strong></td>
<td></td>
</tr>
<tr>
<td>12.1</td>
<td>Bacteria and Fungi</td>
<td>521</td>
</tr>
<tr>
<td>12.2</td>
<td>Algae</td>
<td>522</td>
</tr>
<tr>
<td>12.3</td>
<td>Protozoans and Higher Animals</td>
<td>523</td>
</tr>
<tr>
<td>12.4</td>
<td>Metabolism, Energy, and Synthesis</td>
<td>524</td>
</tr>
<tr>
<td>12.5</td>
<td>Enzyme Kinetics</td>
<td>527</td>
</tr>
<tr>
<td>12.6</td>
<td>Growth Kinetics of Pure Bacterial Cultures</td>
<td>529</td>
</tr>
<tr>
<td>12.7</td>
<td>Biological Growth in Wastewater Treatment</td>
<td>533</td>
</tr>
<tr>
<td>12.8</td>
<td>Factors Affecting Growth</td>
<td>535</td>
</tr>
<tr>
<td>12.9</td>
<td>Population Dynamics</td>
<td>537</td>
</tr>
<tr>
<td></td>
<td><strong>Characteristics of Wastewater</strong></td>
<td></td>
</tr>
<tr>
<td>12.10</td>
<td>Flow and Strength Variations</td>
<td>542</td>
</tr>
<tr>
<td>12.11</td>
<td>Composition of Wastewater</td>
<td>545</td>
</tr>
<tr>
<td></td>
<td><strong>Trickling (Biological) Filters</strong></td>
<td></td>
</tr>
</tbody>
</table>
Chapter 12 Biological Process in Trickling Filtration 549
12.12 Biological Process in Trickling Filtration 549
12.13 Trickling-Filter Operation and Filter Media Requirements 550
12.14 Trickling-Filter Secondary Systems 552
12.15 Efficiency Equations for Stone-Media Trickling Filters 555
12.16 Efficiency Equations for Plastic-Media Trickling Filters 560
12.17 Combined Trickling-Filter and Activated-Sludge Processes 569
12.18 Description of Rotating Biological Contactor Media and Process 570

Activated Sludge 572
12.19 BOD Loadings and Aeration Periods 573
12.20 Operation of Activated-Sludge Processes 577
12.21 Activated-Sludge Treatment Systems 578
12.22 Kinetics Model of the Activated-Sludge Process 591
12.23 Laboratory Determination of Kinetic Constants 596
12.24 Application of the Kinetics Model in Process Design 601
12.25 Oxygen Transfer and Oxygenation Requirements 605
12.26 Determination of Oxygen Transfer Coefficients 610

Stabilization Ponds 616
12.27 Description of a Facultative Pond 616
12.28 BOD Loadings of Facultative Ponds 618
12.29 Advantages and Disadvantages of Stabilization Ponds 619
12.30 Completely Mixed Aerated Lagoons 621

Odor Control 625
12.31 Sources of Odors in Wastewater Treatment 625
12.32 Methods of Odor Control 626

Individual On-Site Wastewater Disposal 628
12.33 Septic Tank-Absorption Field System 628

Marine Wastewater Disposal 629
12.34 Ocean Outfalls 629

Problems 631
References 642

Chapter 13 Processing of Sludges 644

Sources, Characteristics, and Quantities of Waste Sludges 644
13.1 Weight and Volume Relationships 645
13.2 Characteristics and Quantities of Wastewater Sludges 648
13.3 Characteristics and Quantities of Water-Processing Sludges 655

Arrangement of Unit Processes in Sludge Disposal 658
13.4 Selection of Processes for Wastewater Sludges 658
13.5 Selection of Processes for Water Treatment Sludges 664

Gravity Thickening 668
13.6 Gravity Sludge Thickeners in Wastewater Treatment 668
13.7 Gravity Sludge Thickeners in Water Treatment 670

Gravity Belt Thickening 671
13.8 Description of a Gravity Belt Thickener 672
13.9 Layout of a Gravity Belt Thickener System 672
13.10 Sizing of Gravity Belt Thickeners 674
Contents

**Flotation Thickening** 677
13.11 Description of Dissolved-Air Flotation 678
13.12 Design of Dissolved-Air Flotation Units 679

**Biological Sludge Digestion** 681
13.13 Anaerobic Sludge Digestion 681
13.14 Single-Stage Floating-Cover Digesters 682
13.15 High-Rate (Completely Mixed) Digesters 684
13.16 Volatile Solids Loadings and Digester Capacity 686
13.17 Aerobic Sludge Digestion 690
13.18 Open-Air Drying Beds 694
13.19 Composting 695

**Pressure Filtration** 697
13.20 Description of Belt Filter Press Dewatering 697
13.21 Application of Belt Filter Dewatering 700
13.22 Sizing of Belt Filter Presses 702
13.23 Description of Filter Press Dewatering 704
13.24 Application of Pressure Filtration 706

**Centrifugation** 708
13.25 Description of Centrifugation 708
13.26 Applications of Centrifugation 710

**Cycling of Waste Solids in Treatment Plants** 715
13.27 Suspended-Solids Removal Efficiency 715

**Final Disposal or Use** 717
13.28 Land Application 718
13.29 Codisposal in a Municipal Solid-Waste Landfill 723
13.30 Surface Land Disposal 724

Problems 724

References 734

**Chapter 14** Advanced Wastewater Treatment Processes and Water Reuse 736

**Limitations of Secondary Treatment** 737
14.1 Effluent Standards 737
14.2 Flow Equalization 739

**Selection of Advanced Wastewater Treatment Processes** 741
14.3 Selecting and Combining Unit Processes 742
14.4 Granular-Media Filtration 743
14.5 Direct Filtration with Chemical Coagulation 747

**Carbon Adsorption** 749
14.6 Granular-Carbon Columns 749
14.7 Activated-Sludge Treatment with Powdered Activated Carbon 750

**Phosphorus Removal** 751
14.8 Biological Phosphorus Removal 752
14.9 Biological–Chemical Phosphorus Removal 753
14.10 Tracing Phosphorus Through Treatment Processes 757

**Nitrogen Removal** 760
Contents  xv

14.11  Tracing Nitrogen Through Treatment Processes  761
14.12  Biological Nitrification  763
14.13  Biological Denitrification  771
14.14  Single-Sludge Biological Nitrification-Denitrification  775
Water Reuse  781
14.15  Water Quality and Reuse Applications  781
14.16  Agricultural Irrigation  788
14.17  Agricultural Irrigation Reuse, Tallahassee, Florida  795
14.18  Citrus Irrigation and Groundwater Recharge, Orange County and
       City of Orlando, Florida  802
14.19  Urban Reuse  806
14.20  Urban Reuse, St. Petersburg, Florida  807
14.21  Indirect Reuse to Augment Drinking Water Supply  811
14.22  Fred Hervey Water Reclamation Plant, El Paso, Texas  814
14.23  Direct Injection for Potable Supply, El Paso, Texas  817
14.24  Water Factory 21 and Groundwater Replenishment System, Orange
       County, California  822
Problems  830
References  841

Appendix  844

Index  855
Find out why pollution control is vital as population levels continue to grow. Water treatment facilities take the water that has been used for waste and turn it back into fresh, local water that can be consumed again. Hydrologists not only look for ways to improve these facilities, they also try to find new underground wells of water and, perhaps even more importantly, figure out how to maintain these supplies with the ever-growing threat of pollution. Pollution is industrial waste, emissions from cars, runoff of pesticides and animal wastes from farms, and extra nutrients in the soils that cause an imbalance. These can run into lakes, rivers and streams; seep into the