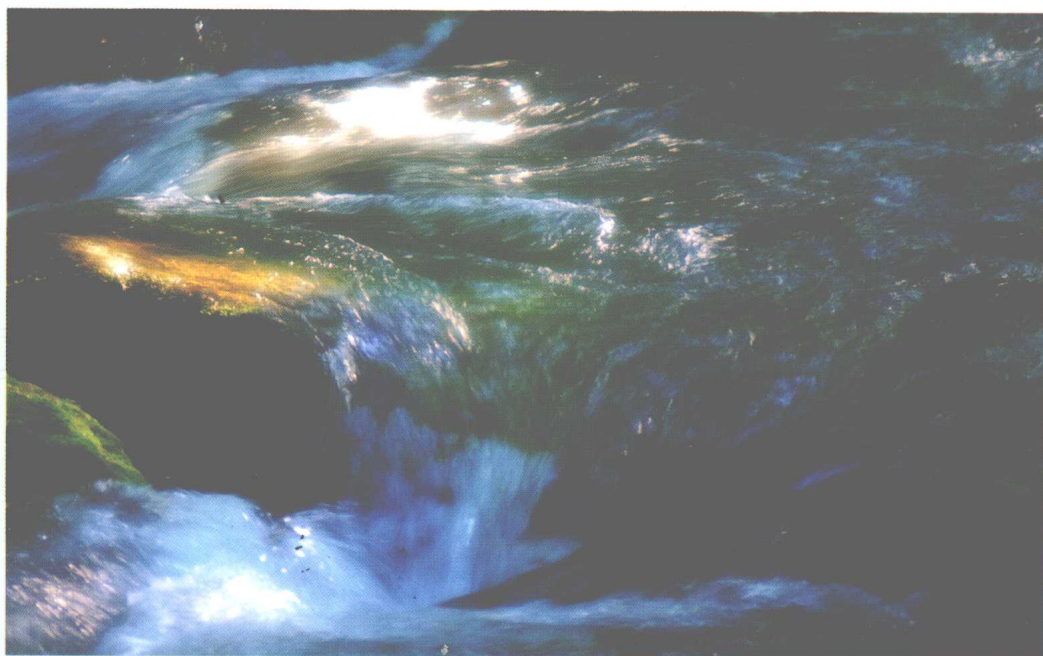


Metcalf & Eddy | AECOM

Water Reuse
Issues, Technologies, and Applications

水回用
问题、技术与实践

—— II ——



清华大学出版社

Second Edition

Water Reuse

Systems, Technologies, and Applications

水回用

問題、技術と応用

II



Springer

大学环境教育丛书

(影印版)

Water Reuse
Issues, Technologies, and Applications

水回用
问题、技术与实践

—— II ——

Metcalf & Eddy | AECOM

Written by

Takashi Asano
Franklin L. Burton
Harold L. Leverenz
Ryujiro Tsuchihashi
George Tchobanoglous

清华大学出版社
北 京

北京市版权局著作权合同登记号 图字: 01-2007-3197

水回用: 问题、技术与实践

Water Reuse: Issues, Technologies, and Applications

Metcalf & Eddy | AECOM

All Rights reserved. No part of this publication may be reproduced or transmitted in any form or by any means, electronic or mechanical, including photocopying, recording, taping, or any information and retrieval system, without the written permission of the publisher.

Copyright © 1997 by Metcalf & Eddy, Inc.

This authorized bilingual edition is jointly published by McGraw-Hill Education (Asia) Co and Tsinghua University Press. This edition is authorized for sale in the People's Republic of China only, excluding Hong Kong, Macao SAR and Taiwan.

本书双语注释版由清华大学出版社和美国麦格劳-希尔教育出版(亚洲)公司合作出版。未经出版者预先书面许可,不得以任何方式复制或抄袭本书的任何内容。此版本仅限在中华人民共和国境内(不包括中国香港、澳门特别行政区及中国台湾地区)销售。

Copyright © 2008 by McGraw-Hill Education and Tsinghua University Press.

本书封面贴有McGraw-Hill公司防伪标签,无标签者不得销售。

版权所有,侵权必究。侵权举报电话:010-62782989 13701121933

图书在版编目(CIP)数据

水回用:问题、技术与实践=Water Reuse: Issues, Technologies, and Applications: 英文/美国AECOM集团梅特卡夫和埃迪公司编.一影印本.一北京:清华大学出版社,2008.7

(大学环境教育丛书)

ISBN 978-7-302-18030-2

I. 水… II. 美… III. 废水综合利用-高等学校-教材-英文 IV. X703

中国版本图书馆CIP数据核字(2008)第096915号

责任编辑:柳 萍

责任印制:孟凡玉

出版发行:清华大学出版社

地 址:北京清华大学学研大厦A座

<http://www.tup.com.cn>

邮 编:100084

社 总 机:010-62770175

邮 购:010-62786544

投稿与读者服务:010-62776969, c-service@tup.tsinghua.edu.cn

质 量 反 馈:010-62772015, zhiliang@tup.tsinghua.edu.cn

印 刷 者:北京密云胶印厂

装 订 者:三河市金元印装有限公司

经 销:全国新华书店

开 本:185×230 印 张:102.25

版 次:2008年7月第1版 印 次:2008年7月第1次印刷

印 数:1~3000

定 价:188.00元

本书如存在文字不清、漏印、缺页、倒页、脱页等印装质量问题,请与清华大学出版社出版部联系调换。联系电话:(010)62770177 转 3103 产品编号:024892-02

Contents

目 录

Preface xxvii
Acknowledgments xxxiii
Foreword xxxvii

Part 1 Water Reuse: An Introduction 1

1 Water Issues: Current Status and the Role of Water Reclamation and Reuse 3

Working Terminology 4

1-1 Definition of Terms 6

1-2 Principles of Sustainable Water Resources Management 6

The principle of sustainability 7

Working definitions of sustainability 7

Challenges for sustainability 7

*Criteria for sustainable water resources
management* 7

Environmental ethics 13

1-3 Current and Potential Future

Global Water Shortages 15

*Impact of current and projected world
population* 15

Potential global water shortages 19

Water scarcity 19

*Potential regional water shortages in the
continental United States* 20

1-4 The Important Role of Water Reclamation and Reuse 23

Types of water reuse 24

Integrated water resources planning 24

Personnel needs/sustainable engineering 27

Treatment and technology needs 27

Infrastructure and planning issues 28

1-5 Water Reclamation and Reuse and Its Future 30

Implementation hurdles 31

Public support 31

*Acceptance varies depending on opportunity
and necessity* 31

*Public water supply from polluted water
sources* 31

*Advances in water reclamation
technologies* 31

*Challenges for water reclamation
and reuse* 32

Problems and Discussion Topics 32

References 33

2 Water Reuse: Past and Current Practices 37

Working Terminology 38

2-1 Evolution of Water Reclamation and Reuse 39

Historical development prior to 1960 39

*Era of water reclamation and reuse
in the United States-post-1960* 41

2-2 Impact of State and Federal Statutes on Water Reclamation and Reuse 45

The Clean Water Act 45

The Safe Drinking Water Act 46

2-3 Water Reuse—Current Status in the United States 46

*Withdrawal of water from surface
and groundwater sources* 46

Availability and reuse of treated wastewater 46

*Milestone water reuse projects and research
studies* 47

2-4 Water Reuse in California: A Case Study 47

Experience with water reuse 47
Current water reuse status 48

- Water reuse policies and recycling regulations* 51
- Potential future uses of reclaimed water* 52
- 2-5** *Water Reuse in Florida: A Case Study* 53
 - Experience with water reuse* 54
 - Current water reuse status* 54
 - Water reuse policies and recycling regulations* 56
 - Potential future uses of reclaimed water* 56
- 2-6** *Water Reuse in Other Parts of the World* 58
 - Significant developments worldwide* 58
 - The World Health Organization's water reuse guidelines* 59
 - Water reuse in developing countries* 59
- 2-7** *Summary and Lessons Learned* 63
 - Problems and Discussion Topics* 65
 - References* 66

Part 2 Health and Environmental Concerns in Water Reuse 71

3 Characteristics of Municipal Wastewater and Related Health and Environmental Issues 73

- Working Terminology* 74
- 3-1** *Wastewater in Public Water Supplies—de facto Potable Reuse* 77
 - Presence of treated wastewater in public water supplies* 78
 - Impact of the presence of treated wastewater on public water supplies* 78
- 3-2** *Introduction to Waterborne Diseases and Health Issues* 78
 - Important historical events* 79
 - Waterborne disease* 80
 - Etiology of waterborne disease* 81
- 3-3** *Waterborne Pathogenic Microorganisms* 83
 - Terminology conventions for organisms* 83

- Log removal* 83
- Bacteria* 83
- Protozoa* 87
- Helminths* 89
- Viruses* 89
- 3-4** *Indicator Organisms* 92
 - Characteristics of an ideal indicator organism* 92
 - The coliform group bacteria* 93
 - Bacteriophages* 93
 - Other indicator organisms* 94
- 3-5** *Occurrence of Microbial Pathogens in Untreated and Treated Wastewater and in the Environment* 94
 - Pathogens in untreated wastewater* 94
 - Pathogens in treated wastewater* 97
 - Pathogens in the environment* 102
 - Survival of pathogenic organisms* 102
- 3-6** *Chemical Constituents in Untreated and Treated Wastewater* 103
 - Chemical constituents in untreated wastewater* 103
 - Constituents added through domestic commercial and industrial usage* 104
 - Chemical constituents in treated wastewater* 108
 - Formation of disinfection byproducts (DBPs)* 113
 - Comparison of treated wastewater to natural water* 114
 - Use of surrogate parameters* 115
- 3-7** *Emerging Contaminants in Water and Wastewater* 117
 - Endocrine disruptors and pharmaceutically active chemicals* 117
 - Some specific constituents with emerging concern* 118
 - New and reemerging microorganisms* 120
- 3-8** *Environmental Issues* 120
 - Effects on soils and plants* 121
 - Effects on surface water and groundwater* 121
 - Effects on ecosystems* 121
 - Effects on development and land use* 122
 - Problems and Discussion Topics* 122
 - References* 124

4 Water Reuse Regulations and Guidelines 131

Working Terminology 132

4-1 Understanding Regulatory Terminology 134

Standard and criterion 134

Standard versus criterion 134

Regulation 135

Difference between regulations and guidelines 135

Water reclamation and reuse 135

4-2 Development of Standards, Regulations, and Guidelines for Water Reuse 135

Basis for water quality standards 136

Development of water reuse regulations and guidelines 136

The regulatory process 139

4-3 General Regulatory Considerations Related to Water Reclamation and Reuse 139

Constituents and physical properties of concern in wastewater 139

Wastewater treatment and water quality considerations 142

Reclaimed water quality monitoring 145

Storage requirements 146

Reclaimed water application rates 147

Aerosols and windborne sprays 147

4-4 Regulatory Considerations for Specific Water Reuse Applications 149

Agricultural irrigation 149

Landscape irrigation 150

Dual distribution systems and in-building uses 151

Impoundments 152

Industrial uses 153

Other nonpotable uses 153

Groundwater recharge 154

4-5 Regulatory Considerations for Indirect Potable Reuse 155

Use of the most protected water source 155

Influence of the two water acts 155

Concerns for trace chemical constituents and pathogens 156

Assessment of health risks 157

4-6 State Water Reuse Regulations 157

Status of water reuse regulations and guidelines 158

Regulations and guidelines for specific reuse applications 158

Regulatory requirements for nonpotable uses of reclaimed water 165

State regulations for indirect potable reuse 167

4-7 U.S. EPA Guidelines for Water Reuse 169

Disinfection requirements 169

Microbial limits 178

Control measures 178

Recommendations for indirect potable reuse 178

4-8 World Health Organization Guidelines for Water Reuse 179

1989 WHO guidelines for agriculture and aquaculture 180

The Stockholm framework 180

Disability adjusted life years 180

Concept of tolerable (acceptable) risk 181

Tolerable microbial risk in water 181

2006 WHO guidelines for the safe use of wastewater in agriculture 182

4-9 Future Directions in Regulations and Guidelines 184

Continuing development of state standards, regulations, and guidelines 184

Technical advances in treatment processes 184

Information needs 184

Problems and Discussion Topics 185

References 187

5 Health Risk Analysis in Water Reuse Applications 191

Working Terminology 192

5-1 Risk Analysis: An Overview 193

Historical development of risk assessment 194

Objectives and applications of human health risk assessment 194

	<i>Elements of risk analysis</i>	194
	<i>Risk analysis: definitions and concepts</i>	196
5-2	Health Risk Assessment	197
	<i>Hazard identification</i>	198
	<i>Dose-response assessment</i>	198
	<i>Dose-response models</i>	200
	<i>Exposure assessment</i>	204
	<i>Risk characterization</i>	204
	<i>Comparison of human health and ecological risk assessment</i>	205
5-3	Risk Management	205
5-4	Risk Communication	206
5-5	Tools and Methods Used in Risk Assessment	207
	<i>Concepts from public health</i>	207
	<i>Concepts from epidemiology</i>	208
	<i>Concepts from toxicology</i>	209
	<i>National toxicology program cancer bioassay</i>	213
	<i>Ecotoxicology: environmental effects</i>	214
5-6	Chemical Risk Assessment	215
	<i>Safety and risk determination in regulation of chemical agents</i>	215
	<i>Risks from potential nonthreshold toxicants</i>	220
	<i>Risk considerations</i>	224
	<i>Chemical risk assessment summary</i>	225
5-7	Microbial Risk Assessment	225
	<i>Infectious disease paradigm for microbial risk assessment</i>	225
	<i>Microbial risk assessment methods</i>	227
	<i>Static microbial risk assessment models</i>	227
	<i>Dynamic microbial risk assessment models</i>	229
	<i>Selecting a microbial risk model</i>	232
5-8	Application of Microbial Risk Assessment in Water Reuse Applications	234
	<i>Microbial risk assessment employing a static model</i>	234
	<i>Microbial risk assessment employing dynamic models</i>	239
	<i>Risk assessment for water reuse from enteric viruses</i>	244
5-9	Limitations in Applying Risk Assessment to Water Reuse Applications	249
	<i>Relative nature of risk assessment</i>	249

	<i>Inadequate consideration of secondary infections</i>	249
	<i>Limited dose-response data</i>	250
	<i>Problems and Discussion Topics</i>	250
	<i>References</i>	251

Part 3 Technologies and Systems for Water Reclamation and Reuse 255

6 Water Reuse Technologies and Treatment Systems: An Overview 257

	<i>Working Terminology</i>	258
6-1	Constituents in Untreated Municipal Wastewater	260
6-2	Technology Issues in Water Reclamation and Reuse	260
	<i>Water reuse applications</i>	262
	<i>Water quality requirements</i>	262
	<i>Multiple barrier concept</i>	263
	<i>Need for multiple treatment technologies</i>	265
6-3	Treatment Technologies for Water Reclamation Applications	265
	<i>Removal of dissolved organic matter, suspended solids, and nutrients by secondary treatment</i>	268
	<i>Removal of residual particulate matter in secondary effluent</i>	269
	<i>Removal of residual dissolved constituents</i>	271
	<i>Removal of trace constituents</i>	271
	<i>Disinfection processes</i>	271
6-4	Important Factors in the Selection of Technologies for Water Reuse	272
	<i>Multiple water reuse applications</i>	273
	<i>Need to remove trace constituents</i>	273
	<i>Need to conduct pilot-scale testing</i>	276
	<i>Process reliability</i>	276
	<i>Standby and redundancy considerations</i>	279
	<i>Infrastructure needs for water reuse applications</i>	280

- 6-5** Impact of Treatment Plant Location on Water Reuse 281
 - Centralized treatment plants* 282
 - Satellite treatment facilities* 282
 - Decentralized treatment facilities* 283
- 6-6** The Future of Water Reclamation
 - Technologies and Treatment Systems 286
 - Implication of trace constituents on future water reuse* 287
 - New regulations* 287
 - Retrofitting existing treatment plants* 288
 - New treatment plants* 289
 - Satellite treatment systems* 289
 - Decentralized treatment facilities and systems* 289
 - New infrastructure concepts and designs* 290
 - Research needs* 291
 - Problems and Discussion Topics 292
 - References 293

7 Removal of Constituents by Secondary Treatment 295

- Working Terminology 296
- 7-1** Constituents in Untreated Wastewater 299
 - Constituents of concern* 299
 - Typical constituent concentration values* 299
 - Variability of mass loadings* 301
- 7-2** Technologies for Water Reuse
 - Applications 304
- 7-3** Nonmembrane Processes for Secondary Treatment 307
 - Suitability for reclaimed water applications* 307
 - Process descriptions* 308
 - Process performance expectations* 310
 - Importance of secondary sedimentation tank design* 318
- 7-4** Nonmembrane Processes for the Control and Removal of Nutrients in Secondary Treatment 320
 - Nitrogen control* 320
 - Nitrogen removal* 321
 - Phosphorus removal* 324
 - Process performance expectations* 328

- 7-5** Membrane Bioreactor Processes for Secondary Treatment 328
 - Description of membrane bioreactors* 330
 - Suitability of MBRs for reclaimed water applications* 331
 - Types of membrane bioreactor systems* 332
 - Principal proprietary submerged membrane systems* 333
 - Other membrane systems* 338
 - Process performance expectations* 340
- 7-6** Analysis and Design of Membrane Bioreactor Processes 340
 - Process analysis* 340
 - Design considerations* 353
 - Nutrient removal* 358
 - Biosolids processing* 361
- 7-7** Issues in the Selection of Secondary Treatment Processes 361
 - Expansion of an existing plant vs. construction of a new plant* 362
 - Final use of effluent* 362
 - Comparative performance of treatment processes* 362
 - Pilot-scale studies* 362
 - Type of disinfection process* 362
 - Future water quality requirements* 363
 - Energy considerations* 363
 - Site constraints* 364
 - Economic and other considerations* 368
 - Problems and Discussion Topics 368
 - References 371

8 Removal of Residual Particulate Matter 373

- Working Terminology 374
- 8-1** Characteristics of Residual Suspended Particulate Matter from Secondary Treatment Processes 375
 - Residual constituents and properties of concern* 375
 - Removal of residual particles from secondary treatment processes* 385
- 8-2** Technologies for the Removal of Residual Suspended Particulate Matter 388

Technologies for reclaimed water applications 388

Process flow diagrams 390

Process performance expectations 390

Suitability for reclaimed water applications 392

8-3 Depth Filtration 392

Available filtration technologies 392

Performance of depth filters 398

Design considerations 407

Pilot-scale studies 415

Operational issues 417

8-4 Surface Filtration 417

Available filtration technologies 419

Performance of surface filters 422

Design considerations 423

Pilot-scale studies 425

8-5 Membrane Filtration 425

Membrane terminology, types, classification, and flow patterns 426

Microfiltration and ultrafiltration 430

Process analysis for MF and UF membranes 435

Operating characteristics and strategies for MF and UF membranes 436

Membrane performance 436

Design considerations 441

Pilot-scale studies 441

Operational issues 443

8-6 Dissolved Air Flotation 445

Process description 445

Performance of DAF process 448

Design considerations 448

Operating considerations 453

Pilot-scale studies 453

8-7 Issues in the Selection of Technologies for the Removal of Residual Particulate Matter 454

Final use of effluent 454

Comparative performance of technologies 455

Results of pilot-scale studies 455

Type of disinfection process 455

Future water quality requirements 455

Energy considerations 455

Site constraints 455

Economic considerations 455

Problems and Discussion Topics 456

References 459

9 Removal of Dissolved Constituents with Membranes 461

Working Terminology 462

9-1 Introduction to Technologies Used for the Removal of Dissolved Constituents 463

Membrane separation 463

Definition of osmotic pressure 463

Nanofiltration and reverse osmosis 465

Electrodialysis 466

Typical process applications and flow diagrams 467

9-2 Nanofiltration 467

Types of membranes used in nanofiltration 468

Application of nanofiltration 471

Performance expectations 471

9-3 Reverse Osmosis 473

Types of membranes used in reverse osmosis 473

Application of reverse osmosis 474

Performance expectations 474

9-4 Design and Operational Considerations for Nanofiltration and Reverse Osmosis Systems 475

Feedwater considerations 475

Pretreatment 477

Treatability testing 479

Membrane flux and area requirements 482

Membrane fouling 487

Control of membrane fouling 490

Process operating parameters 490

Posttreatment 492

9-5 Pilot-Plant Studies for Nanofiltration and Reverse Osmosis 499

9-6 Electrodialysis 501

Description of the electrodialysis process 501

Electrodialysis reversal 502

Power consumption 503

Design and operating considerations 506

Membrane and electrode life 507

Advantages and disadvantages of electrodialysis versus reverse osmosis 508

- 9-7** Management of Membrane Waste Streams 509
Membrane concentrate issues 509
Thickening and drying of waste streams 511
Ultimate disposal methods for membrane waste streams 515
 Problems and Discussion Topics 519
 References 522

10 Removal of Residual Trace Constituents 525

- Working Terminology 526
- 10-1** Introduction to Technologies Used for the Removal of Trace Constituents 528
Separation processes based on mass transfer 528
Chemical and biological transformation processes 531
- 10-2** Adsorption 532
Applications for adsorption 532
Types of adsorbents 533
Basic considerations for adsorption processes 536
Adsorption process limitations 551
- 10-3** Ion Exchange 551
Applications for ion exchange 552
Ion exchange materials 554
Basic considerations for ion exchange processes 555
Ion exchange process limitations 559
- 10-4** Distillation 560
Applications for distillation 560
Distillation processes 560
Basic considerations for distillation processes 562
Distillation process limitations 563
- 10-5** Chemical Oxidation 563
Applications for conventional chemical oxidation 563
Oxidants used in chemical oxidation processes 563
Basic considerations for chemical oxidation processes 566
Chemical oxidation process limitations 567

- 10-6** Advanced Oxidation 567
Applications for advanced oxidation 568
Processes for advanced oxidation 569
Basic considerations for advanced oxidation processes 574
Advanced oxidation process limitations 577
- 10-7** Photolysis 578
Applications for photolysis 578
Photolysis processes 579
Basic considerations for photolysis processes 579
Photolysis process limitations 586
- 10-8** Advanced Biological Transformations 586
Basic considerations for advanced biological treatment processes 587
Advanced biological treatment processes 588
Limitations of advanced biological transformation processes 590
 Problems and Discussion Topics 591
 References 594

11 Disinfection Processes for Water Reuse Applications 599

- Working Terminology 600
- 11-1** Disinfection Technologies Used for Water Reclamation 602
Characteristics for an ideal disinfectant 602
Disinfection agents and methods in water reclamation 602
Mechanisms used to explain action of disinfectants 604
Comparison of reclaimed water disinfectants 605
- 11-2** Practical Considerations and Issues for Disinfection 606
Physical facilities used for disinfection 606
Factors affecting performance 609
Development of the $C_R t$ Concept for predicting disinfection performance 616
Application of the $C_R t$ concept for reclaimed water disinfection 617
Performance comparison of disinfection technologies 618
Advantages and disadvantages of alternative disinfection technologies 618

- 11-3** Disinfection with Chlorine 622
 - Characteristics of chlorine compounds* 622
 - Chemistry of chlorine compounds* 624
 - Breakpoint reaction with chlorine* 626
 - Measurement and reporting of disinfection process variables* 631
 - Germicidal efficiency of chlorine and various chlorine compounds in clean water* 631
 - Form of residual chlorine and contact time* 631
 - Factors that affect disinfection of reclaimed water with chlorine* 633
 - Chemical characteristics of the reclaimed water* 635
 - Modeling the chlorine disinfection process* 639
 - Required chlorine dosages for disinfection* 641
 - Assessing the hydraulic performance of chlorine contact basins* 644
 - Formation and control of disinfection byproducts* 650
 - Environmental impacts* 654
- 11-4** Disinfection with Chlorine Dioxide 654
 - Characteristics of chlorine dioxide* 655
 - Chlorine dioxide chemistry* 655
 - Effectiveness of chlorine dioxide as a disinfectant* 655
 - Byproduct formation and control* 656
 - Environmental impacts* 657
- 11-5** Dechlorination 657
 - Dechlorination of reclaimed water treated with chlorine and chlorine compounds* 657
 - Dechlorination of chlorine dioxide with sulfur dioxide* 660
- 11-6** Disinfection with Ozone 660
 - Ozone properties* 660
 - Ozone chemistry* 661
 - Ozone disinfection systems components* 662
 - Effectiveness of ozone as a disinfectant* 666
 - Modeling the ozone disinfection process* 666
 - Required ozone dosages for disinfection* 669
 - Byproduct formation and control* 670
 - Environmental impacts of using ozone* 671
 - Other benefits of using ozone* 671
- 11-7** Other Chemical Disinfection Methods 671
 - Peracetic acid* 671
 - Combined chemical disinfection processes* 672
- 11-8** Disinfection with Ultraviolet Radiation 674
 - Source of UV radiation* 674
 - Types of UV lamps* 674
 - UV disinfection system configurations* 678
 - Mechanism of inactivation by UV irradiation* 682
 - Factors affecting germicidal effectiveness of UV irradiation* 684
 - Modeling the UV disinfection process* 690
 - Estimating UV dose* 691
 - Ultraviolet disinfection guidelines* 700
 - Analysis of a UV disinfection system* 708
 - Operational issues with UV disinfection systems* 708
 - Environmental impacts of UV irradiation* 711
 - Problems and Discussion Topics* 712
 - References* 718
- 12 Satellite Treatment Systems for Water Reuse Applications 725**
 - Working Terminology* 726
 - 12-1** Introduction to Satellite Systems 727
 - Types of satellite treatment systems* 728
 - Important factors in selecting the use of satellite systems* 730
 - 12-2** Planning Considerations for Satellite Systems 730
 - Identification of near-term and future reclaimed water needs* 730
 - Integration with existing facilities* 731
 - Siting considerations* 731
 - Public perception, legal aspects, and institutional issues* 734
 - Economic considerations* 735
 - Environmental considerations* 735
 - Governing regulations* 735
 - 12-3** Satellite Systems for Nonagricultural Water Reuse Applications 735

- Reuse in buildings* 736
- Landscape irrigation* 736
- Lakes and recreational enhancement* 736
- Groundwater recharge* 736
- Industrial applications* 737
- 12-4** Collection System Requirements 738
 - Interception type satellite system* 738
 - Extraction type satellite system* 738
 - Upstream type satellite system* 739
- 12-5** Wastewater Characteristics 739
 - Interception type satellite system* 740
 - Extraction type satellite system* 740
 - Upstream type satellite system* 741
- 12-6** Infrastructure Facilities for Satellite Treatment Systems 741
 - Diversion and junction structures* 741
 - Flow equalization and storage* 744
 - Pumping, transmission, and distribution of reclaimed water* 745
- 12-7** Treatment Technologies for Satellite Systems 745
 - Conventional technologies* 745
 - Membrane bioreactors* 746
 - Sequencing batch reactor* 746
- 12-8** Integration with Existing Facilities 748
- 12-9** Case Study 1: Solaire Building New York, New York 751
 - Setting* 751
 - Water management issues* 751
 - Implementation* 752
 - Lessons learned* 753
- 12-10** Case Study 2: Water Reclamation and Reuse in Tokyo, Japan 755
 - Setting* 755
 - Water management issues* 755
 - Implementation* 756
 - Lessons learned* 758
- 12-11** Case Study 3: City of Upland, California 760
 - Setting* 760
 - Water management issues* 760
 - Implementation* 760
 - Lessons learned* 761
 - Problems and Discussion Topics* 761
 - References* 762
- 13 Onsite and Decentralized Systems for Water Reuse 763**
 - Working Terminology* 764
 - 13-1** Introduction to Decentralized Systems 766
 - Definition of decentralized systems* 766
 - Importance of decentralized systems* 767
 - Integration with centralized systems* 770
 - 13-2** Types of Decentralized Systems 770
 - Individual onsite systems* 771
 - Cluster systems* 771
 - Housing development and small community systems* 772
 - 13-3** Wastewater Flowrates and Characteristics 774
 - Wastewater flowrates* 774
 - Wastewater constituent concentrations* 778
 - 13-4** Treatment Technologies 785
 - Source separating systems* 786
 - In-building pretreatment* 788
 - Primary treatment* 788
 - Secondary treatment* 792
 - Nutrient removal* 797
 - Disinfection processes* 802
 - Performance* 804
 - Reliability* 804
 - Maintenance needs* 804
 - 13-5** Technologies for Housing Developments and Small Community Systems 806
 - Collection systems* 807
 - Treatment technologies* 815
 - 13-6** Decentralized Water Reuse Opportunities 816
 - Landscape irrigation systems* 816
 - Irrigation with greywater* 818
 - Groundwater recharge* 818
 - Self-contained recycle systems* 821
 - Habitat development* 821
 - 13-7** Management and Monitoring of Decentralized Systems 821
 - Types of management structures* 821
 - Monitoring and control equipment* 824
 - Problems and Discussion Topics* 826
 - References* 827

14 Distribution and Storage of Reclaimed Water 829

Working Terminology 830

- 14-1** Issues in the Planning Process 831
 - Type, size, and location of facilities* 831
 - Individual reclaimed water system versus dual distribution system* 832
 - Public concerns and involvement* 833
- 14-2** Planning and Conceptual Design of
 - Distribution and Storage Facilities 833
 - Location of reclaimed water supply, major users, and demands* 834
 - Quantities and pressure requirements for major demands* 834
 - Distribution system network* 836
 - Facility design criteria* 841
 - Distribution system analysis* 845
 - Optimization of distribution system* 847
- 14-3** Pipeline Design 856
 - Location of reclaimed water pipelines* 856
 - Design criteria for reclaimed water pipelines* 858
 - Pipeline materials* 858
 - Joints and connections* 860
 - Corrosion protection* 861
 - Pipe identification* 862
 - Distribution system valves* 863
 - Distribution system appurtenances* 863
- 14-4** Pumping Systems 866
 - Pumping station location and site layout* 866
 - Pump types* 867
 - Pumping station performance* 870
 - Constant versus variable speed operation* 870
 - Valves* 871
 - Equipment and piping layout* 872
 - Emergency power* 872
 - Effect of pump operating schedule on system design* 875
- 14-5** Design of Reclaimed Water Storage
 - Facilities 877
 - Location of reclaimed water reservoirs* 878
 - Facility and site layout for reservoirs, piping, and appurtenances* 879

Materials of construction 881
Protective coatings—interior and exterior 881

- 14-6** Operation and Maintenance of Distribution
 - Facilities 882
 - Pipelines* 883
 - Pumping stations* 884
- 14-7** Water Quality Management Issues in Reclaimed
 - Water Distribution and Storage 884
 - Water quality issues* 885
 - Impact of water quality issues* 887
 - The effect of storage on water quality changes* 887
 - Strategies for managing water quality in open and enclosed reservoirs* 889
- Problems and Discussion Topics 892
- References 898

15 Dual Plumbing Systems 901

- Working Terminology 902
- 15-1** Overview of Dual Plumbing
 - Systems 902
 - Rationale for dual plumbing systems* 902
 - Applications for dual plumbing systems* 903
- 15-2** Planning Considerations for Dual Plumbing
 - Systems 907
 - Applications for dual plumbing systems* 907
 - Regulations and codes governing dual plumbing systems* 908
 - Applicable health and safety regulations* 908
- 15-3** Design Considerations for Dual
 - Distribution Systems 908
 - Plumbing codes* 908
 - Safeguards* 908
- 15-4** Inspection and Operating Considerations 913
- 15-5** Case Study: Irvine Ranch Water District,
 - Orange County, California 915
 - Setting* 915
 - Water management issues* 915
 - Implementation* 916
 - Operational issues* 918
 - Lessons learned* 919
- 15-6** Case Study: Rouse Hill Recycled Water
 - Area Project (Australia) 919

Setting 919
Water management issues 920
Implementation 920
Lessons learned 920

- 15-7** Case Study: Serrano, California 921
Setting 922
Water management issues 922
Implementation 923
Lessons learned 925
 Problems and Discussion Topics 925
 References 926

Part 4 Water Reuse Applications 927

16 Water Reuse Applications: An Overview 929

Working Terminology 930

- 16-1** Water Reuse Applications 930
Agricultural irrigation 931
Landscape irrigation 931
Industrial uses 931
Urban nonirrigation uses 933
Environmental and recreational uses 933
Groundwater recharge 933
Indirect potable reuse through surface water augmentation 933
Direct potable reuse 934
Water reuse applications in other parts of the world 934
- 16-2** Issues in Water Reuse 934
Resource sustainability 934
Water resource opportunities 935
Reliability of water supply 935
Economic considerations 935
Public policy 935
Regulations 936
Issues and constraints for specific applications 937
- 16-3** Important Factors in the Selection of Water Reuse Applications 937
Water quality considerations 937
Types of technology 939

Matching supply and demand 939
Infrastructure requirements 939
Economic feasibility (affordability) 940
Environmental considerations 941

- 16-4** Future Trends in Water Reuse
Applications 941
Changes in regulations 942
Water supply augmentation 942
Decentralized and satellite systems 942
New treatment technologies 942
Issues associated with potable reuse 944
 Problems and Discussion Topics 944
 References 945

17 Agricultural Uses of Reclaimed Water 947

Working Terminology 948

- 17-1** Agricultural Irrigation with Reclaimed Water: An Overview 949
Reclaimed water irrigation for agriculture in the United States 950
Reclaimed water irrigation for agriculture in the world 952
Regulations and guidelines related to agricultural irrigation with reclaimed water 953
- 17-2** Agronomics and Water Quality
Considerations 954
Soil characteristics 955
Suspended solids 958
Salinity, sodicity, and specific ion toxicity 959
Trace elements and nutrients 966
Crop selection 971
- 17-3** Elements for the Design of Reclaimed Water Irrigation Systems 971
Water reclamation and reclaimed water quantity and quality 977
Selection of the type of irrigation system 977
Leaching requirements 986
Estimation of water application rate 989
Field area requirements 997
Drainage systems 998
Drainage water management and disposal 1003
Storage system 1003
Irrigation scheduling 1008

- 17-4** Operation and Maintenance of Reclaimed Water Irrigation Systems 1008
Demand-supply management 1009
Nutrient management 1009
Public health protection 1011
Effects of reclaimed water irrigation on soils and crops 1011
Monitoring requirements 1014
- 17-5** Case Study: Monterey Wastewater Reclamation Study for Agriculture—Monterey, California 1015
Setting 1016
Water management issues 1016
Implementation 1016
Study results 1017
Subsequent projects 1021
Recycled water food safety study 1021
Lessons learned 1021
- 17-6** Case Study: Water Conserv II, Florida 1022
Setting 1023
Water management issues 1023
Implementation 1023
Importance of Water Conserv II 1027
Lessons learned 1027
- 17-7** Case Study: The Virginia Pipeline Scheme, South Australia—Seasonal ASR of Reclaimed Water for irrigation 1028
Setting 1028
Water management issues 1029
Regulatory requirements 1029
Technology issues 1029
Implementation 1030
Performance and operations 1032
Lessons learned 1035
 Problems and Discussion Topics 1035
 References 1038
- 18 Landscape Irrigation with Reclaimed Water 1043**
 Working Terminology 1044
- 18-1** Landscape Irrigation: An Overview 1045
Definition of landscape irrigation 1045
Reclaimed water use for landscape irrigation in the United States 1046
- 18-2** Design and Operational Considerations for Reclaimed Water Landscape Irrigation Systems 1047
Water quality requirements 1047
Landscape plant selection 1050
Irrigation systems 1054
Estimation of water needs 1054
Application rate and irrigation schedule 1065
Management of demand-supply balance 1065
Operation and maintenance issues 1066
- 18-3** Golf Course Irrigation with Reclaimed Water 1070
Water quality and agronomic considerations 1070
Reclaimed water supply and storage 1072
Distribution system design considerations 1075
Leaching, drainage, and runoff 1076
Other considerations 1076
- 18-4** Irrigation of Public Areas with Reclaimed Water 1076
Irrigation of public areas 1078
Reclaimed water treatment and water quality 1079
Conveyance and distribution system 1079
Aesthetics and public acceptance 1079
Operation and maintenance issues 1080
- 18-5** Residential Landscape Irrigation with Reclaimed Water 1080
Residential landscape irrigation systems 1080
Reclaimed water treatment and water quality 1081
Conveyance and distribution system 1081
Operation and maintenance issues 1082
- 18-6** Landscape Irrigation with Decentralized Treatment and Subsurface Irrigation Systems 1082
Subsurface drip irrigation for individual on-site and cluster systems 1082
Irrigation for residential areas 1086
- 18-7** Case Study: Landscape Irrigation in St. Petersburg, Florida 1086
Setting 1087
Water management issues 1087
Implementation 1087

Project Greenleaf and resource management 1089

Landscape irrigation in the city of St. Petersburg 1091

Lessons learned 1093

- 18-8** Case Study: Residential Irrigation in El Dorado Hills, California 1093
Water management issues 1094
Implementation 1094
Education program 1096
Lessons learned 1096
 Problems and Discussion Topics 1097
 References 1099

19 Industrial Uses of Reclaimed Water 1103

Working Terminology 1104

- 19-1** Industrial Uses of Reclaimed Water: An Overview 1105

Status of water use for industrial applications in the United States 1105

Water management in industries 1107

Factors affecting the use of reclaimed water for industrial applications 1108

- 19-2** Water Quality Issues for Industrial Uses of Reclaimed Water 1109

General water quality considerations 1110

Corrosion issues 1110

Indexes for assessing effects of reclaimed water quality on reuse systems 1115

Corrosion management options 1126

Scaling issues 1127

Accumulation of dissolved constituents 1129

- 19-3** Cooling Water Systems 1132

System description 1132

Water quality considerations 1132

Design and operational considerations 1135

Management issues 1138

- 19-4** Other Industrial Water Reuse

Applications 1141

Boilers 1141

Pulp and paper industry 1147

Textile industry 1150

Other industrial applications 1154

- 19-5** Case Study: Cooling Tower at a Thermal Power Generation Plant, Denver, Colorado 1155
Setting 1155

Water management issues 1156

Implementation 1158

Lessons learned 1158

- 19-6** Case Study: Industrial Uses of Reclaimed Water in West Basin Municipal Water District, California 1158

Setting 1158

Water management issues 1158

Implementation 1159

Lessons learned 1161

Problems and Discussion Topics 1161

References 1165

20 Urban Nonirrigation Water Reuse Applications 1169

Working Terminology 1170

- 20-1** Urban Water Use and Water Reuse Applications: An Overview 1171

Domestic potable water use in the United States 1171

Commercial water use in the United States 1172

Urban nonirrigation water reuse in the United States 1172

Urban nonirrigation water reuse in other countries 1172

- 20-2** Factors Affecting the Use of Reclaimed Water for Urban Nonirrigation Reuse Applications 1175

Infrastructure issues 1175

Water quality and supply issues 1176

Acceptance issues 1179

- 20-3** Air Conditioning 1179
Description of air conditioning systems 1179
Utilizing reclaimed water for air conditioning systems 1181

Water quality considerations 1181

Management issues 1183

- 20-4** Fire Protection 1183

Types of applications 1186

Water quality considerations 1187

Implementation issues 1187

Management issues 1188