

Membrane Applications for Water Reuse

First Edition



American Water Works
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First Edition



**American Water Works
Association**

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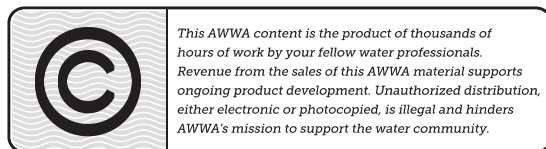
Library of Congress Cataloging-in-Publication Data

Names: Wong, Joseph, active 2018, author. | Alspach, Brent, author. | Chalmers, Bruce, author. | American Water Works Association, issuing body.
Title: M62 - Membrane applications for water reuse / by Joseph Wong, Brent Alspach, Bruce Chalmers.
Other titles: Membrane applications for water reuse
Description: First edition. | Denver, CO : American Water Works Association, [2018]
Identifiers: LCCN 2018008413 | ISBN 9781625762627
Subjects: LCSH: Water reuse. | Membranes (Technology)
Classification: LCC TD429 .W66 2018 | DDC 628.1/64--dc23
LC record available at <https://lccn.loc.gov/2018008413>

Printed in the United States of America

ISBN 978-1-62576-262-7

eISBN-13 978-1-61300-448-7



**American Water Works
Association**

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Contents

Figures, ix

Tables, xiii

Acknowledgments, xvii

Preface, xxi

Abbreviations, xxiii

Chapter 1	Development of Water Reuse Practices	1
	History of Water Reuse, 1	
	Terminology, 1	
	Unplanned Water Reuse, 2	
	Planned Water Reuse, 2	
	The Role of Membranes in Water Reuse, 3	
	How to Use This Manual, 4	
	References, 6	
Chapter 2	Planning for Reuse Applications	7
	Reuse Applications, 7	
	Nonpotable Reuse, 7	
	Potable Reuse, 9	
	Treatment Options for Water Reuse, 10	
	Effectiveness of Treatment, 11	
	Residuals, Disposal, and Regulatory Requirements, 11	
	Flow Equalization and Storage Requirements for Nonpotable Reuse, 14	
	Environmental Impacts, 14	
	Legal and Institutional Issues, 15	
	Regulatory Requirements and Permitting, Including Future Regulatory Impacts, 15	
	Public Education and Outreach Programs, 15	
	References, 16	
Chapter 3	Water Reuse Guidelines and Regulations.....	17
	World Health Organization Guidelines, 17	
	National Guidelines, 20	
	Reuse Requirements, 43	
	Guidelines for Other Countries, 45	
	References, 48	
Chapter 4	Source and Treated Water Quality	51
	Wastewater Treatment, 51	
	Wastewater Effluent Quality, 52	
	Specific Wastewater Quality Parameters, 53	
	Industrial Reuse, 57	
	Agricultural Reuse, 60	
	Water Supply Augmentation, 61	
	Augmentation of Indirect Potable Supplies, 62	
	Direct Potable Reuse, 63	

	Water Quality Treatment Requirements, 63	
	References, 66	
Chapter 5	Membrane Process Treatment Facility Design	69
	Pretreatment or Feedwater Conditioning for Membrane Treatment Processes, 69	
	Screening for Removal of Debris and Large Solids, 72	
	Removal of Chemicals Incompatible with Membrane Materials, 74	
	Foulant, Suspended Solids, and Particulates Removal, 76	
	Coagulation–Flocculation, 77	
	Clarification, 78	
	Dissolved Air Flotation, 78	
	Media Filtration, 79	
	Microfiltration–Ultrafiltration as PreTreatment, 80	
	Other Pretreatment Processes for Suspended Solids Removal, 80	
	Controlling Temperature, 80	
	pH, 80	
	Dissolved Ionic Species that Require Preconditioning, 80	
	Oxidation and Reduction Processes, 81	
	Softening, 81	
	Degasser, 83	
	Controlling Biological Fouling, 84	
	Chlorination, 85	
	Micellar-Enhanced Membrane Separation, 87	
	Optimization of Upstream Biological Wastewater Treatment, 87	
	MF–UF Design Considerations, 88	
	MF/UF Design Considerations, 89	
	MF–UF Filtrate Quality Requirements, 89	
	MF–UF Filtrate Quality Requirements for Water Reuse, 90	
	Impact of Feedwater Quality on PreTreatment and MF–UF System Design, 91	
	MF–UF Equipment, 92	
	Reverse Osmosis–Nanofiltration, 95	
	Impact of Feedwater Quality on Pretreatment and NF–RO System Design, 98	
	Post-Treatment, Stabilization, and Disinfection, 111	
	Stabilization, 112	
	Treatment Requirements, 114	
	Treatment Processes, 115	
	Advanced Oxidation Systems, 117	
	Design Considerations, 121	
	Water Quality Impacts, 121	
	References, 122	
Chapter 6	Operations	125
	Membrane System Data Collection and Analysis, 125	
	Operating Data, 127	
	Membrane Integrity Test, 129	
	Heterotrophic Plate Count, 131	
	Operational Considerations, 131	
	Membrane Cleaning and Flux Recovery, 135	
	Integrity Testing, 141	
	Membrane Storage, 143	

	Membrane Replacement, 143	
	New Membrane Procurement, 144	
	Maintenance, 145	
	Troubleshooting, 145	
Chapter 7	Residuals Management	149
	Residuals Management for Low-Pressure Membranes, 150	
	Residuals Management Techniques, 150	
	Concentrate Management for High-Pressure Membranes, 152	
	Issues Related to Concentrate Disposal, 153	
	Health and Environmental Issues, 154	
	Cost and Energy Issues, 154	
	Concentrate Disposal Options, 155	
	Current Research, 164	
	Regulatory Issues, 165	
	References, 169	
Chapter 8	Cost of Treatment	173
	Summarizing Project Costs, 173	
	Development of Construction Cost Model, 175	
	Contributing Factors to Capital Costs, 175	
	Development of an O&M Cost Model, 180	
	Cost of Water, 184	
	Example Cost Estimates, 185	
	References, 187	
Chapter 9	Case Studies	189
	Case Study: The Groundwater Replenishment System, 189	
	Project Photos, 194	
	Case Study: Broad Run Water Reclamation Facility, 197	
	Plant Description, 198	
	Membrane System Design Summary, 198	
	Plant Costs, 199	
	Conclusions, 200	
	Project Photos, 200	
	Case Study: Big Spring Raw Water Production Facility – Colorado River Municipal Water District, 202	
	Plant Description, 202	
	Reverse Osmosis Feedwater Pretreatment, 203	
	Water Quality, 204	
	Plant Costs, 204	
	Project Photos, 205	
	Case Study: Edward C. Little Water Recycling Facility, 206	
	Plant Description, 207	
	Treated Water Quality Produced, 210	
	Capital Costs, 211	
	Operation and Maintenance Costs, 211	
	Case Study: Singapore NEWater Facilities, 211	
	Singapore's First Initiative on Recycling: Industrial Water, 211	
	The NEWater Study, 212	
	Public Education, 213	
	Full-Scale Implementation of NEWater, 213	
	Project Photos, 215	

	Case Study: Bundamba 1A Advanced Water Reclamation Facility – Southeast Queensland Water, 218
	Water Quality, 219
	Operational Performance, 222
	Case Study: Gibson Island Advanced Water Treatment Plant – South East Queensland Water, 225
	Plant Description, 225
	Capital Costs, 227
	Conclusion, 228
	Project Photos, 228
	References, 230
	Case Study: Luggage Point Advanced Water Treatment Plant – Southeast Queensland Water, 231
	Influent Characteristics and Treated Water Quality Requirements, 231
	Treatment Process, 231
	Plant Performance Relative to Treated Water Requirements, 238
	Costs, 238
	Summary, 238
	References, 238
	Case Study: CAPCO Industrial Wastewater Reclamation Facility, 239
	Wastewater Reclamation System Description, 240
	Economic Analysis for the Reuse Project, 240
	Full-scale Implementation, 243
	A Brief Review of the 13 Years of Operation, 243
	References, 245
Chapter 10	Future Technology Trends and Contaminants of Emerging Concern....247
	Advances in Low-Pressure Membranes, 247
	Ceramic Membranes, 248
	Universal MF–UF Membrane Skid, 249
	Advances in Reverse Osmosis Membrane Cleaning, 249
	New Membrane Materials for Desalination, 251
	Novel Membrane Processes for Desalination, 254
	Contaminants of Emerging Concern, 257
	References, 267
Appendix A	The Groundwater Replenishment System Design Criteria and Water Quality Tables, 275
Appendix B	Broad Run Water Reclamation Facility Design Criteria and Water Quality Tables, 279
Appendix C	Big Spring Raw Water Production Facility Design Criteria and Water Quality Tables, 281
Appendix D	Edward C. Little Water Recycling Facility Design Criteria and Water Quality Tables, 283
Appendix E	Singapore NEWater Facilities Process Design Criteria and Water Quality Tables, 289

**Appendix F Western Corridor Water Recycling Scheme Design Criteria and
Water Quality Tables, 295**

**Appendix G CAPCO Industrial Wastewater Reclamation Facility Design Criteria
and Water Quality Tables, 307**

Index, 309

AWWA Manuals, 319

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Figures

- 2-1 Summary of water reuse applications in the United States, 8
- 4-1 Treatment technologies to achieve desired levels of reclaimed water quality, 52
- 5-1 Water reuse membrane treatment hierarchy, 70
- 5-2 Typical automatic backwashing screen used in microfiltration–ultrafiltration systems, 73
- 5-3 Automatic backwashing disc (left) and wound microfiber cassette filters (right), 74
- 5-4 Hillsboro Beach, Fla., pellet lime softener installation, 82
- 5-5 Integrated precipitative membrane treatment , 83
- 5-6 Ultrafiltration membrane surface showing pores, 88
- 5-7 Microfiltration–ultrafiltration filtration modes, 89
- 5-8 Principle of reverse osmosis, 96
- 5-9 Rejection capabilities of various membranes and required operating pressure, 97
- 5-10 Scanning electron microscope image of a fouled membrane used to treat secondary effluent. Severe fouling by calcium aluminum silicates is seen, 101
- 5-11 Microfiltration (foreground) and reverse osmosis (RO; background) installation at the Bundamba advanced water reclamation plant in Australia. The RO membranes are 18 in. in diameter, 105
- 5-12 Reverse osmosis trains at Changi NWater Facility, Singapore, 107
- 5-13 A three-stage reverse osmosis train, 108
- 5-14 Energy-recovery device in a reverse osmosis system that recovers the energy in the concentrate and reuses it to boost the second-stage feed pressure, 109
- 5-15 Flows and pressures through each stage of a reverse osmosis train, with and without an energy-recovery device, 109
- 5-16 Liqui-cel membrane contactor, 116
- 5-17 Clearwater, Fla., groundwater replenishment process flow diagram, 118
- 6-1 Illustration of the importance of maintaining sufficient start pressures for a membrane integrity test, 129
- 6-2 Particulate and debris collected within the cartridge filter housing (left) and on the cartridge filters (right), 134
- 6-3 Scanning electron microscopy images of a clean reverse osmosis membrane surface (left) and one containing silicate scale (right), 135
- 6-4 Changing reverse osmosis system performance parameters in response to a membrane fouling event, 136
- 6-5 Ratio of specific flux at the tail-end stage to the total system specific flux. Note the declining ratio while the overall system specific flux remains unchanged, 136
- 6-6 Scanning electron microscopy images of a membrane hollow fiber (left) and accumulated foulant on the outside fiber surface (right), 137

- 6-7 Example of transmembrane pressure increases versus time for consecutive cleaning intervals. Note the baseline, declining, and restoration of membrane permeability are reflective of potential irreversible fouling or chemical cleaning effectiveness, 139
- 6-8 Restoration of reverse osmosis membrane flux to initial baseline permeability after chemical cleaning, 141
- 7-1 Mechanical vapor compression brine concentrator, 163
- 7-2 Mechanical vapor compression crystallizer, 163
- 8-1 Nonpotable reuse treatment plant construction cost for a microfiltration-based facility, 176
- 8-2 Potable reuse treatment plant construction cost for a microfiltration–reverse osmosis–based facility, 177
- 8-3 Typical nonpotable reuse treatment plant operations and maintenance cost breakdown for a microfiltration-based facility, 181
- 8-4 Typical potable reuse treatment plant operations and maintenance cost breakdown for a microfiltration–reverse osmosis–based facility, 181
- 8-5 Nonpotable reuse treatment plant cost of water for a microfiltration-based facility, 184
- 8-6 Potable reuse treatment plant cost of water for a microfiltration–reverse osmosis–based facility, 185
- 9-1 Groundwater Replenishment System components, 190
- 9-2 Groundwater Replenishment System process flow diagram and sampling points, 191
- 9-3 Aerial view of the Groundwater Replenishment System and adjacent Orange County Sanitation District facility, 194
- 9-4 Groundwater Replenishment System facility entrance, 195
- 9-5 Microfiltration system, 195
- 9-6 Reverse osmosis treatment trains, 196
- 9-7 Ultraviolet light–advanced oxidation process treatment facility, 196
- 9-8 Process schematic for the Broad Run Water Reclamation Facility, 198
- 9-9 Membrane bioreactor tanks and pipework, 200
- 9-10 Granular activated carbon contactors and pipework, 201
- 9-11 Ultraviolet light reactors, 201
- 9-12 Process schematic for the Colorado River Municipal Water District raw water production facility in Big Spring, Texas, 203
- 9-13 Microfiltration system, 205
- 9-14 Reverse osmosis system, 205
- 9-15 Process schematic of the Edward C. Little Water Recycling Facility, 208
- 9-16 Ozone injection system, 209
- 9-17 Phase III CMF units, 209
- 9-18 Flow schematic of NEWater factories, 214
- 9-19 Zeeweed ultrafiltration at Bedok NEWater Factory, phase 1, 215
- 9-20 Microza microfiltration at Bedok NEWater Factory, phase 2, 215

- 9-21 Large-diameter (16-in.) reverse osmosis trains at Bedok NEWater Factory, phase 2, 216
- 9-22 Memcor CMF-S system at Kranji NEWater Factory, phases 1 and 2, 216
- 9-23 Reverse osmosis units at Kranji NEWater Factory, phases 1 and 2, 217
- 9-24 Process flow diagram for Bundamba advanced wastewater treatment plant, 220
- 9-25 Microfiltration unit 2 operating performance at the Bundamba advanced wastewater treatment plant, 222
- 9-26 Permeability trends for reverse osmosis units at the Bundamba advanced wastewater treatment plant, 223
- 9-27 Energy consumption at the Bundamba advanced wastewater treatment plant, 224
- 9-28 Gibson Island advanced wastewater treatment process schematic, 225
- 9-29 Gibson Island advanced wastewater treatment plant ultrafiltration unit, 228
- 9-30 Gibson Island advanced wastewater treatment plant reverse osmosis unit, 229
- 9-31 Gibson Island advanced wastewater treatment plant. In the foreground are ultraviolet units, on the left are ultrafiltration units, and in the back are reverse osmosis units, 229
- 9-32 Process flow diagram for the Luggage Point advanced water treatment plant, 232
- 9-33 Pall Microza microfiltration racks, 234
- 9-34 Beneficial impact of fouling management modifications on microfiltration permeability, 234
- 9-35 Three-stage reverse osmosis skid. The hydraulic turbocharger is shown on bottom left, 235
- 9-36 Normalized permeate flow for the Luggage Point advanced water treatment plant reverse osmosis train 1 from start-up to Sept. 3, 2010, 236
- 9-37 Normalized salt passage for the Luggage Point advanced water treatment plant reverse osmosis train 1 from start-up to Sept. 3, 2010, 236
- 9-38 Normalized differential pressure for the Luggage Point advanced water treatment plant reverse osmosis train 1 from start-up to Sept. 3, 2010, 237
- 9-39 One of the four Trojan ultraviolet PHOX units, 237
- 9-40 Relation of wastewater reclamation system with plant water systems, 241
- 9-41 Wastewater recovery treatment system block flow diagram, 241
- 9-42 Conductivity of reverse osmosis feed and combined permeate from all trains from April 2001 to March 2003, 244

- 10-1 Categories of constituents of emerging concern by chemical characteristics, 261
- 10-2 Rejection diagram for organic micropollutants during membrane treatment, 265

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Tables

- 1-1 Selected worldwide indirect and direct potable reuse facilities, 3
- 2-1 Indicative log removals for various stages of treatment and unit processes, 12
- 2-2 Filter pore size comparison, 13
- 3-1 Health-based targets and helminth reduction targets for wastewater use in agriculture, 18
- 3-2 Maximum tolerable soil concentrations of various toxic chemicals based on human health protection, 19
- 3-3 Recommended minimum verification monitoring for wastewater and excreta use in agriculture and aquaculture, 21
- 3-4 Victoria, Australia, reclaimed water classes, treatment, and pathogen reduction, 22
- 3-5 New South Wales, Australia, guidelines for reclaimed water use from municipal sewage treatment plants, 23
- 3-6 Japan's water reuse standards, 25
- 3-7 Suggested guidelines for water reuse, 26
- 3-8 Arizona water reuse types and classes, 36
- 3-9 California water reuse types and classes, 37
- 3-10 Florida water reuse types described in Florida Administrative Code 62-610, 41
- 3-11 Nevada water reuse types and classes, 42
- 3-12 Texas water reuse types and classes, 43
- 3-13 Washington water reuse types and classes, 44
- 3-14 Links to water reuse regulations, guidance, and fact sheets, 44
- 3-15 British microbial guidelines for graywater systems, 46
- 3-16 Singapore water quality standards, 2012, 47
- 3-17 Windhoek direct potable reuse water quality criteria, 47
- 4-1 Typical ranges of municipal wastewater and secondary treatment effluent quality, 53
- 4-2 Water quality parameters and their impact on membranes for water reuse applications, 54
- 4-3 Typical membrane product water quality for low- and high-pressure membranes, 56
- 4-4 Typical cycles of concentration, 58
- 4-5 Typical reclaimed water quality requirements for various industrial processes, 60
- 4-6 Typical reclaimed water quality requirements for various industrial processes, 61
- 4-7 Unit processes used for the removal of classes of constituents found in wastewater for reuse applications, 64

- 4-8 Typical product water quality for reverse osmosis membranes, 65
- 5-1 Filtration media pores sizes, 71
- 5-2 Polymeric membrane materials, 74
- 5-3 Typical microfiltration–ultrafiltration design criteria for water reuse facilities, 91
- 5-4 Example large-capacity water reuse projects that use microfiltration–ultrafiltration, 94
- 5-5 Monitoring methods for microfiltration–ultrafiltration systems, 95
- 5-6 Values of calcium carbonate precipitation potential, 113
- 5-7 Removal of microconstituents by ultraviolet (UV) irradiation, UV irradiation/hydrogen peroxide, and ozone, 120
- 6-1 General reverse osmosis data collection, 130
- 6-2 General reverse osmosis cleaning chemical guidelines, 140
- 7-1 Summary of coagulation–flocculation–sedimentation processes, 151
- 7-2 Microfiltration–ultrafiltration residuals and applicable regulations, 167
- 8-1 Membrane-based reuse treatment plant capital cost examples, with plant capacity of 10 mgd, 186
- 8-2 Membrane-based reuse treatment plant operations and maintenance cost examples, with plant capacity of 10 mgd, 186
- 8-3 Membrane-based reuse treatment plant cost of water, with plant capacity of 10 mgd, 187
- 9-1 Groundwater replenishment system capital cost breakdown, 193
- 9-2 Groundwater replenishment system operating costs, 194
- 9-3 Permit requirements for the Broad Run Water Reclamation Facility, 197
- 9-4 Cost information for NEWater factories, 218
- 9-5 Reverse osmosis performance at Bumdamba stage 1A, 223
- 9-6 Gibson Island advanced wastewater treatment plant log-removal values, 227
- 9-7 Gibson Island advanced wastewater treatment plant costs, 228
- 9-8 *N*-nitrosodimethylamine levels prior to and following preformed chloramination, 233
- 9-9 Estimated capital cost of the wastewater reclamation system: 3.0 mgd of product water, 1998, 242
- 9-10 Estimated annual operations and maintenance cost of the wastewater reclamation system: 3.0 mgd of product water, 1998, 242
- 9-11 Project cost analysis of the wastewater reclamation system: 3.0 mgd of product water, 1998, 243
- 10-1 Pharmaceutically active compounds and rank of use, 259
- 10-2 Commonly used personal care products, 259
- 10-3 Pesticides, herbicides, and insecticides found in water and wastewater, 259
- 10-4 Observed average efficiencies of membrane bioreactors in the removal of various constituents of emerging concern, 263

- 10-5 Predictions of removal of constituents of emerging concern by nanofiltration and reverse osmosis, 264
- 10-6 Efficiencies of nanofiltration and reverse osmosis in the removal of various constituents of emerging concern, 266

- A-1 MF system key design parameters, 275
- A-2 RO system key design parameters, 275
- A-3 GWRS typical water quality, 276

- B-1 Design summary—Broad Run WRF Membrane Bioreactor System, 279
- B-2 Broad Run Water Reclamation Facility—influent and effluent characteristics, 280

- C-1 Membrane system design criteria, 281
- C-2 Feed water quality (July 2008–March 2013), 282

- D-1 Feed water quality, 283
- D-2 Ozone system design criteria, 283
- D-3 Microfiltration design criteria, 284
- D-4 Reverse osmosis design criteria, 284
- D-5 Advanced oxidation process, 285
- D-6 Barrier recycled water constituents (2012), 285
- D-7 Single pass low pressure boiler feed water, 287
- D-8 Double pass high pressure boiler feed water, 287

- E-1 Design characteristics of treatment processes used at NEWater Demonstration Plant, 289
- E-2 Feedwater characteristics of Bedok NEWater Demonstration Plant, 289
- E-3 Design criteria for plant processes and equipment at Bedok NEWater factory, 290
- E-4 Design criteria for plant processes and equipment at Kranji NEWater factory, 291
- E-5 Details of plant processes and equipment at Ulu Pandan & Changi NEWater factories, 292
- E-6 Treated water quality criteria for NEWater treatment processes, 293
- E-7 Typical NEWater quality, 294

- F-1 Raw water quality for Bundamba Advanced Water Reclamation Facility, 295
- F-2 Treated water quality requirements for Bundamba Advanced Water Reclamation Facility (selected parameters, in addition to Australian Drinking Water Guidelines), 296
- F-3 Concentrate water quality requirements for Bundamba AWTF 1A, 297
- F-4 MF design criteria and performance at Bundamba AWTF, 297
- F-5 Gibson Island AWTP feed water design basis, 297
- F-6 Gibson Island AWTP treated water quality requirements, 298
- F-7 Gibson Island AWTP UF system design criteria, 298
- F-8 Gibson Island AWTP RO system design criteria, 299

- F-9 Gibson Island AWTP treated water quality requirements (ADWG and owner) and typical values, 299
- F-10 Gibson Island AWTP performance vs. reclaimed water requirements, 300
- F-11 Luggage Point AWTP influent (feed water) quality design basis (selected parameters), 303
- F-12 Luggage Point AWTP treated water quality requirements (supplement to ADWG), 304
- F-13 Luggage Point AWTP MF system design criteria, 304
- F-14 Luggage Point AWTP RO system design criteria, 305
- F-15 Luggage Point AWTP treated water quality: requirements versus plant performance test, 305

- G-1 Wastewater effluent characteristics and discharge requirements, 307
- G-2 Effluent water quality, 308

Acknowledgments

The AWWA Technical and Educational Council, the Water Quality and Technology Division, and the Membrane Processes committee gratefully acknowledge the contributions of the volunteers who drafted, edited, and provided the significant and critical commentary essential to the development of AWWA M62. The Technical Review Board members dedicated many hours in the final stages of preparation of this edition to ensure the overall technical quality, consistency, and accuracy of the manual.

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Preface



Reverse osmosis (RO) membranes have been used in water reuse since the 1960s. Cellulose acetate membranes for treating conventionally clarified municipal effluent was initially applied to small industrial applications and as irrigation water for golf courses. In the 1970s, Orange County Water District in southern California used cellulose acetate membranes to produce 5 mgd of RO permeate that was blended with imported water for injection into seawater intrusion barrier wells. The use of membranes in full-scale reuse applications has changed dramatically based on research performed in the 1980s and 1990s. Those efforts demonstrated that microfiltration-ultrafiltration (MF-UF) membranes can offer superior pretreatment compared to RO when treating municipal effluents. Those efforts also incorporated polyamide membrane, which has all but replaced cellulose acetate in this application.

In the 1990s, many municipal agencies began operating full-scale MF-UF and polyamide RO membrane systems to treat secondary and tertiary municipal effluents. At that time, early adopters of large-scale membrane treatment processes for water reuse were rare. These membrane users transitioned the industry from theoretical and pilot-scale investigations into full-scale operations, bringing about a new facet of water reuse. In the years since, the industry has learned much about membrane performance and sustainability over long-term operation, including handling unanticipated operational challenges brought on by organic-laden, variable feed sources that can change not only year to year but sometimes day to day.

Operational considerations for low- and high-pressure membrane technologies in water reuse applications are similar to their potable system analogs. However, there are subtle differences that can pose additional problems or issues to the water reuse operator if these are not considered or anticipated. Membrane system operators in reuse applications need to understand that “industry guidance” has historically been based on potable water treatment applications. Irreversible fouling and flux loss that lead to increased cleaning intervals and reduced membrane life are constant challenges in this environment. Finding the balance between cleaning frequency and chemical and energy costs is often the goal for membrane facilities in water reuse applications. Fiber breakage and loss of RO membrane rejection are significant problems that can be accelerated by this source water. This manual presents a comprehensive description of the issues related to applying membrane technologies in water reuse projects.

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Abbreviations

ACH	aluminum chlorohydrate
ANL	Argonne National Laboratory
ANSI	American National Standards Institute
AOC	assimilable organic carbon
AOP	advanced oxidation process
ASR	aquifer storage and recovery
AWT	advanced water treatment
AWWA	American Water Works Association
BAC	biologically active carbon
BIRM	biological immune response modulator
BNR	biological nutrient removal
BOD	biological oxygen demand
CA	cellulose acetate
Ca(OCl) ₂	calcium hypochlorite
CEC	chemicals of emerging concern
CIP	clean in place
COC	cycles of concentration
COD	chemical oxygen demand
CTA	cellulose triacetate
DAF	dissolved air flotation
DALY	disability-adjusted life year
DOE	Department of Energy
DPR	direct potable reuse
EC	electrical conductivity
ED	electrodialysis
ED–EDR	electrodialysis–electrodialysis reversal
EDC	endocrine-disrupting chemical
EDR	electrodialysis reversal
efOM	effluent organic matter
ESA	Endangered Species Act
FAC	free available chlorine
FeCl ₃	ferric chloride
GRRP	groundwater recharge reuse projects
GWI	Global Water Intelligence
GWRRDR	Groundwater Replenishment Reuse Draft Regulation
HPM	high-pressure membrane
IMS	integrated membrane system

IPR	indirect potable reuse
LPM	low-pressure membrane
LRV	log-reduction value
MBR	membrane bioreactor
MCL	maximum contaminant limit
MF	microfiltration
MFI	modified fouling index
MGD	million gallons per day
MIC	microbiologically induced corrosion
MMFI	mini-plugging factor index
NaOCl	sodium hypochlorite
NDMA	<i>N</i> -nitrosodimethylamine
NF	nanofiltration
NOM	natural organic matter
NPDES	National Pollutant Discharge Elimination System
NTU	nephelometric turbidity unit
NWRI	National Water Research Institute
O&M	operations and maintenance
PA	polyamide
PAC	powdered activated carbon
PACl	polyaluminum chloride
PES	polyether sulfone
PP	polypropylene
PPCP	pharmaceuticals and personal care products
ppm	parts per million
PSU	polysulfone
PVDF	polyvinyl fluoride
RIB	rapid infiltration basins
RO	reverse osmosis
RWC	recycled water contribution
RWQCB	regional water quality control board
SAR	soil adsorption ratio
SAT	soil aquifer treatment
SBS	sodium bisulfite
SDI	silt density index
SMP	soluble microbial products
TCEQ	Texas Commission on Environmental Quality
TDC	total direct cell
TDS	total dissolved solids

TKN	total Kjeldahl nitrogen
TMDL	total maximum daily load
TOC	total organic carbon
TSS	total suspended solids
UF	ultrafiltration
USEPA	US Environmental Protection Agency
VOC	volatile organic compound
WHO	World Health Organization
WRA	WateReuse Association
WTP	water treatment plant
WWTP	wastewater treatment plant

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Chapter **1**

Development of Water Reuse Practices

HISTORY OF WATER REUSE

Reuse of water has occurred for centuries beginning with reuse of liquid waste in agricultural practice. Sewage farming was practiced in the United States in the 1800s and peaked in California in 1923, with 70 communities applying their municipal wastewater directly on food crops (NRC 2012). Agricultural water reuse was prominent in Texas south of San Antonio starting in the 1880s, with a formal contract between the City of San Antonio and the San Antonio Irrigation Company in 1901. Other Texas cities followed—Amarillo in 1920, Lubbock in 1930, Odessa in 1940, and Abilene in 1960—providing reclaimed water to farmers and ranchers. As cities grew, centralized wastewater treatment was more widely used and improved water quality, allowing for the first small urban water reuse system for irrigation of Golden Gate Park in San Francisco in 1912 (WRA 2012).

Industrial reuse of water reclaimed from treated municipal wastewater was documented in the 1940s, with the city of Big Spring, Texas, supplying the Cosden Oil and Chemical refinery in 1944. The cities of Odessa and Amarillo followed in the 1950s and the 1960s; this was the beginning of reclaimed water use for power plant cooling in several Texas cities (Texas Water Development Board 2011). In the early 1970s, Bethlehem Steel in Baltimore, Md., began using 100 mgd of reclaimed water for industrial purposes (USEPA 2004). By 2010, 57 power plants in 16 states were using reclaimed water for power plant cooling (DOE–ANL 2007).

TERMINOLOGY

ANSI/AWWA G481 (2014), *Reclaimed Water Program for Operation and Management*, describes the critical requirements for effective operation and management of a reclaimed water program and defines reclaimed water as water recovered following treatment of domestic

wastewater to the level appropriate for the end use. This AWWA Standards Committee for Reclaimed Water formally approved the following: “Throughout the industry the terms *reclaimed water*, *recycled water*, and *water reuse* are used, in some instances reflecting a geographic preference, in other cases due to regulatory definition and requirements, and still other cases due to end use. The terms are often used interchangeably, but the end user should be cautioned that there are specific instances when one term is more appropriate than the other.”

UNPLANNED WATER REUSE

The July 2012 National Academy of Science report, “Water Reuse: Potential for Expanding the Nation’s Water Supply Through Reuse of Municipal Wastewater” (NRC 2012), identified the unplanned reuse of return flows from upstream dischargers as *de facto* reuse, which has been occurring since wastewater systems began discharging upstream of other communities. In 1980, of water utilities serving 76 million residents, 20 million were served from source waters with 1 percent or more from a wastewater-derived source and another 20 million were served from sources that contained more than 10 percent wastewater during low flow periods (NRC 2012). The US Environmental Protection Agency (USEPA) has published guidelines for water reuse (2012) that provide extensive discussion of both unplanned and planned reuse projects. The Guidelines define *de facto* reuse as “a situation where reuse of treated wastewater is, in fact, practiced but is not officially recognized (for example, a drinking water supply intake located downstream from a wastewater treatment plant [WWTP] discharge point).”

PLANNED WATER REUSE

Planned reuse refers to intentional nonpotable reuse or indirect or direct potable reuse. The USEPA Guidelines provide the following definitions:

Indirect potable reuse (IPR): Augmentation of a drinking water source (surface or groundwater) with reclaimed water followed by an environmental buffer that precedes drinking water treatment.

Direct potable reuse (DPR): The introduction of reclaimed water (with or without retention in an engineered storage buffer) directly into a drinking water treatment plant, either collocated or remote from the advanced wastewater treatment system. A key distinction is the absence of an environmental buffer, although an engineered buffer may be included. If the advanced water treatment processes are collocated at the reclamation plant, this approach is often referred to as “pipe to pipe” or “flange to flange.”

There are IPR projects in many countries, with more than 20 in the United States as of August 2014. Examples include the Orange County Water District (Calif.) Groundwater Replenishment Project that augments the groundwater aquifer and provides water to several seawater barrier injection wells; the Upper Occoquan Service Authority (Va.) that provides supplemental water to the Occoquan Reservoir for Fairfax, Va., water supply; and the Singapore Public Utility Board NEWater supply that augments surface water storage. While there are only three DPR plants worldwide to date, several are in the planning stage. The three current DPR facilities (as of August 2014) are located in Windhoek, Namibia (Africa; 1969); Big Spring, Texas (April 2013); and an emergency operating permit for Wichita Falls, Texas (July 2014). A facility in Cloudcroft, N.M., is currently under construction, and a project in Brownwood, Texas, has approval for construction with funding pending. El Paso Water Utilities (EPWU) has successfully completed a direct potable pilot project and is moving to the next phases of the project. EPWU has operated an IPR facility since 1985. Table 1-1, reprinted from Table 3-9 of the USEPA Guidelines, provides a partial list of

IPR and DPR reuse projects worldwide. The Case Study column references the case studies that are provided in the appendix of the 2012 USEPA Guidelines, with the exception of the Namibia Case Study, which is reported in the 2012 NAS report. Some project capacities may have increased over time, notably the Orange County Calif., project, which operates at 70 mgd and is currently (February 2015) under construction for expansion to 100 mgd.

THE ROLE OF MEMBRANES IN WATER REUSE

Membranes play the following roles in water reuse:

- High-pressure membrane (HPM) reverse osmosis (RO) and nanofiltration (NF) are used to desalinate reclaimed water or to remove specific dissolved contaminants (organic or inorganic).
- Low-pressure membrane (LPM) microfiltration (MF) and ultrafiltration (UF), collectively referred to as membrane filtration, are used to control suspended and colloidal particular matter in reclaimed water or applied as a pretreatment to HPM.
- Membrane bioreactors (MBRs), typically using membranes, consolidate secondary and tertiary treatment into one unit process to provide effluent water quality that is comparable to the tertiary effluent produced by LPM.

Table 1-1 Selected worldwide indirect and direct potable reuse facilities

Country	City	Project Capacity, mgd	Description of Advanced System for Potable Reuse	Case Study
Belgium	Wulpen	1.9	Reclaimed water is returned to the aquifer before being reused as a potable water source	Belgium-Recharge
India	Bangalore (planned)	36	Reclaimed water will be blended in the reservoir, which is a major drinking water source	India-Bangalore
Namibia	Windhoek	5.5	Reclaimed water is blended with conventionally treated surface water for potable reuse	NAS, 2012
United States	Big Spring, Texas	3	Reclaimed water is blended with raw surface water for potable reuse	US-TX-Big Spring
United States	Upper Occoquan, Va.	54	Reclaimed water is blended in the reservoir, which is a major drinking water source	US-VA-Occoquan
United States	Orange County, Calif.	40	Reclaimed water is returned to the aquifer before being reused as a potable water source	US-CA-Orange County
United Kingdom	Langford	10.5	Reclaimed water is returned upstream to a river, which is the potable water source	United Kingdom-Langford
Singapore	Singapore	122	Reclaimed water is blended in the reservoir, which is a major drinking water source	Singapore-NEWater
South Africa	Malahleni	4.2	Reclaimed water from a mine is supplied as drinking water to the municipality	South Africa-Malahleni Mine

Source: Adapted from Von Sperling and Chernicharo (2002).

Membrane desalination (RO or NF) became the leading industrial technology for reducing reclaimed water salinity and specific contaminants of concern due to the high salt and minerals rejection rates, efficiency, and economics of the process. Membrane desalination has become an integrated part of IPR and DPR processes where concentrate disposal allows its application.

Membrane filtration (MF or UF) may not be an economical solution when compared to conventional filtration processes. Membrane filtration typically provides superior effluent water quality consistently, which made membrane filtration a preferred technology as a pretreatment to RO or NF applications. Membrane filtration processes are often selected for pathogen removal and log-removal credits at water treatment plants. When combined using LPM followed by HPM, it is referred to as an integrated membrane system (IMS), which is a key concept for IPR and DPR. This concept was successfully implemented at the Orange County, Calif., new water reuse recharge plant and the Big Spring, Texas, DPR plant, and it is expected to be followed by many other water reuse treatment plants.

MBRs produce effluent water quality characteristics that are similar those produced by MF. MBRs can be followed by membrane desalination when salinity or specific contaminants are a concern. This type of IMS is gaining increased interest, particularly for industrial applications.

HOW TO USE THIS MANUAL

This manual introduces the topic of membrane application for water reuse. While not an exhaustive reference, the manual can be used to identify typical membrane applications that will meet desired water quality objectives, as in the use of MF or UF membranes to pretreat water prior to treatment through NF or RO membrane units.

The chapter summaries provided here introduce the reader to the contents included in this manual and facilitate selection of chapters of immediate interest to the reader.

Chapter 2, Planning for Reuse Applications, introduces the reader to approaches to planning agricultural, nonpotable, commercial/industrial, environmental, and potable reuse projects, with reference to case studies that support the multiple facets of effective project planning. This chapter describes various ways to identify the quality of reclaimed water that is appropriate for the intended use. This is followed by selection of appropriate treatment technologies to achieve the required water quality. The roles of various membrane processes, including MBRs, in achieving the intended water quality or providing pretreatment for subsequent advanced treatment processes are described. Chapter 2 concludes by introducing regulatory, permitting, and environmental trade-offs when selecting membrane treatment options and provides cautions in system design based on variable flow delivered to typical wastewater treatment facilities.

Chapter, 3 Water Reuse Guidelines and Regulations, summarizes guidelines and regulations developed in countries around the world, including the United States, to address water reuse in general and reuse specifically for potable water augmentation. Currently, there are no international regulations that cover the multiple potential water reuse applications. Many resource-constrained countries adopt the World Health Organization guidelines as an initial step in protecting public health and reducing waterborne illness. Guidelines established in Australia, Japan, the United States, the European Union, Singapore, and Namibia are provided. Finally, the approaches used in California for IPR and DPR are highlighted.

Chapter 4, Source and Treated Water Quality, provides an overview of source water qualities typically considered for reuse, with a focus on municipal and industrial applications. Wastewater effluent quality varies based on regional regulations and stream quality standards. The concept of “fit-for-purpose” treatment is used to identify the level of treatment needed to meet the water quality goals of the intended end use. For membrane applications, variations in source water quality require the designer to select the type and size of pretreatment and membrane components to achieve the desired end use water quality. Specific water quality parameters for typical reclaimed water applications are provided. Multiple barrier treatment approaches including membrane treatment options for potable reuse are discussed.

Chapter 5, Membrane Process Treatment Facility Design, discusses membrane pretreatment and operational considerations in process and membrane selection to meet water quality goals for the intended reuse application. Pretreatment strategies for membrane processes include removing material that may damage the membrane, enhancing membrane performance, minimizing membrane fouling, and changing operations to prolong membrane life. Membrane selection for reuse applications is described, with a focus on chemical requirements and wastewater disinfection in advance of the membrane process.

Chapter 6, Operations, provides information on the operational considerations for LPM and HPM systems and recommendations for standard operating procedures. Strategies to minimize the incidence of membrane fouling and for membrane cleaning to restore capacity and specific flux intended in the design are included. Integrity testing of membrane systems, both pressure decay and vacuum decay test methods, and continuous water quality testing are described as effective in controlling quality and monitoring the treatment integrity of the membrane system. Membrane storage, replacement, and procurement frequency, along with maintenance of membranes, are identified as critical components in facility operations.

Chapter 7, Residuals Management, presents information regarding the management of concentrated waste streams. The volume of concentrated reject water may be 10 to 30 percent of the feedwater, have up to 10 times the concentration of salts and other contaminants, and represent much greater capital and operating costs than for the primary membrane treatment system. Concentrate management is described in terms of health, safety, regulations, energy demands, and cost. Final discharge options to surface water, a sanitary sewer, underground injection, and land application and evaporation ponds are evaluated. Current research activities intended to expand new approaches to concentrate management and reduce the cost of concentrate management are also discussed.

Chapter 8, Cost of Treatment, notes that costs for membrane systems vary significantly depending on source water quality and whether the final product water is to be used for nonpotable or potable applications. Because actual costs for facilities need to account for site-specific differences that cannot be generalized, this chapter provides a framework for developing preliminary costs. Costs fall into the following two major categories: cost of potable reuse facilities and cost of membrane-based nonpotable reuse facilities. Costs are presented only for treatment facilities and do not incorporate costs of transmission, distribution, or injection into aquifers or reservoirs, which are beyond the scope of this manual. Costs presented include capital cost, equipment, operation and maintenance, indirect, and contingency allowances. Most costs are for IPR facilities since there are only three DPR facilities in operation. The DPR and IPR facilities often incorporate the same treatment unit processes, with the IPR facilities including an environmental buffer not present in a DPR facility.

Chapter 9, Case Studies, presents nine large-scale membrane projects in the United States, Singapore, Australia, and Taiwan. These case studies compare approaches, project scale, and cost data to assist planners with development of cost-effective supply solutions for the variety of physical conditions that may be encountered.

Chapter 10, Future Technology Trends and Contaminants of Emerging Concern, describes current trends in the materials used to manufacture membranes for reclaimed water processes. As fouling is a significant operational issue, new cleaning processes to maintain membrane flux are identified. Advantages and disadvantages are discussed to support process selection. Two novel membrane processes, forward osmosis and membrane distillation, are described. The chapter concludes with a discussion of removing contaminants of concern and the capability of membranes to remove these contaminants in the wastewater source waters.

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Chapter **2**

Planning for Reuse Applications

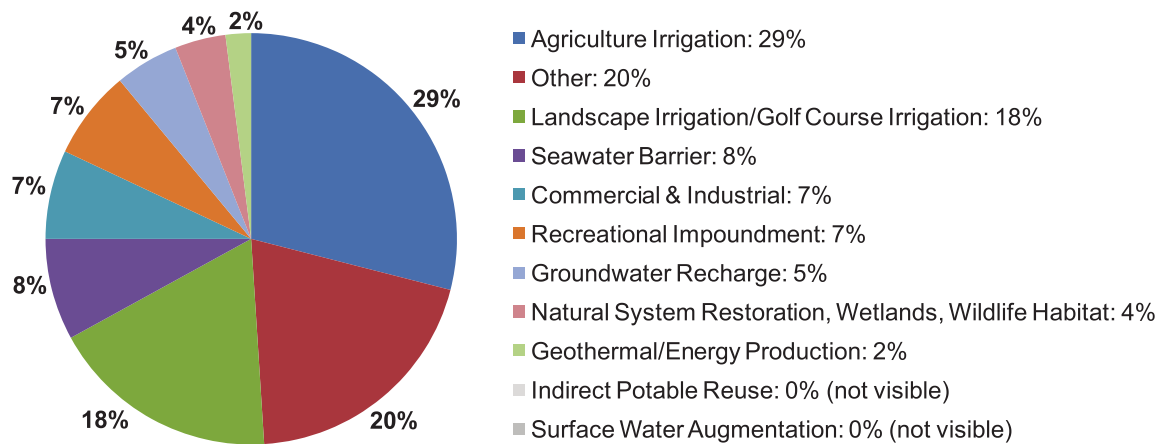
Planning for municipal use of an alternative water source or expansion of an existing water source is important, especially for systems that are reaching full allocation of their current water resources. The planning steps for industrial projects are likely to be different from those for municipal projects due to differences in project drivers, economics, and schedules. While each planning component is appropriate for each type of reclaimed water use, some planning steps require considerably more effort for applications in specific geographic areas.

REUSE APPLICATIONS

It has been reported that as much as 12 bgd (45 MCM/d) of the 32 bgd (121 MCM/d) produced in the United States could be beneficially reclaimed and reused (NRC 2012). Estimates by the WaterReuse Association and Global Water Intelligence indicate that approximately 7 to 8 percent of treated wastewater in the United States is reused (Miller 2006; GWI 2009). Based on these estimates, there is tremendous potential for expanding the use of reclaimed water. Challenges to increased reuse include cost-effective treatment, delivery of reclaimed water to new users, and retrofitting facilities to use reclaimed water. Figure 2-1 provides a summary of uses of reclaimed water in the United States.

NONPOTABLE REUSE

Based on a 2011 survey, almost all water reuse in the United States is for nonpotable applications. Nonpotable reuse includes irrigation (municipal or agricultural) and commercial applications. A small percentage (less than 1 percent) is used for planned potable reuse applications—indirect potable reuse (IPR) or direct potable reuse (DPR). The following sections describe each of these in more detail.



Reprinted from 2012 EPA Guidelines for Water Reuse
Source: USEPA (2012).

Figure 2-1 Summary of water reuse applications in the United States

Agricultural Reuse

As shown in Figure 2-1, 29 percent of reclaimed water is used for agricultural purposes. Individual states adopt their own regulations for specific uses and appropriate water quality. As of 2012, 27 states had adopted regulations or guidelines for food crop applications, while 43 states had regulations or guidelines for processed food crops and nonfood crops. In the United States, nearly 37 percent (128,000 mgd) of freshwater use is for agricultural irrigation. Significant discussion on individual state regulations and water quality requirements for agricultural use, including recent research results, are presented elsewhere (USEPA 2012). Parameters important in agricultural reuse projects include the level of required disinfection, the levels of total dissolved solids (TDS), and the sodium adsorption ratio (SAR), which is the ratio of the concentration of sodium ions to the concentration of calcium plus magnesium ions.

Removal of TDS and reduction in SAR both require desalination. Pretreatment to protect the nanofiltration (NF) or reverse osmosis (RO) membranes often includes use of microfiltration (MF) or ultrafiltration (UF) membranes to minimize the size and number of particles.

Commercial and Industrial Applications

As shown in Figure 2-1, approximately 7 percent of reclaimed water use in the United States, including large-scale power cooling, is for commercial and industrial applications. Reclaimed water can be used for the following:

- Dust control,
- Odor and contaminant control,
- Scrubber applications,
- Product mixing paints and carpet/fabric dyes,
- Boiler applications,
- Refineries,
- Cooling towers, and
- Manufacturing.

POTABLE REUSE

Indirect potable reuse (IPR) refers to the planned decision to supplement a utility's existing water supplies with highly treated reclaimed water. Four states (California, Washington, Florida, and Hawaii) have regulations or guidelines specific to IPR. Texas and Virginia handle IPR projects on a case-by-case basis. Georgia and other states are developing guidelines to expand options for reclaimed water use to help meet water supply demands under long-term drought conditions.

When considering augmentation of groundwater with reclaimed water, common requirements include the following: public hearings; an advanced wastewater pretreatment program; and groundwater monitoring, where the injected water quality meets or exceeds current potable water quality parameters. California's draft regulations have stringent regulatory requirements for groundwater augmentation, and similar draft regulations are anticipated for surface water augmentation based on state approval of an IPR pilot study for San Diego (USEPA 2012). Treatment process options are discussed in Chapter 4 and elsewhere (USEPA 2012). Most, though not all, treatment trains use membrane processes as one of the multiple treatment barriers, followed by an advanced oxidation process (AOP) to destroy specific contaminants. The AOP typically includes medium-pressure ultraviolet (UV) radiation followed by hydrogen peroxide or ozone to create scavenging hydroxyl free radicals. In addition to organic compound removal, both processes also add additional disinfection. RO–AOP is sometimes referred to as full advanced treatment (FAT).

Groundwater Recharge

Groundwater recharge consists of direct injection or surface recharge infiltration via ponds or basins. Direct injection entails injection at the aquifer or radose zone via wells. The Orange County (Calif.) Groundwater Replenishment Project uses both direct injection wells for seawater barrier protection and infiltration through spreading basins to support the groundwater supply with 70 mgd of highly treated water. This project has been expanded to 100 mgd with build-out to 130 mgd. Surface recharge can include land spreading that takes advantage of soil aquifer treatment processes or rapid infiltration basins. Infiltration in the Los Angeles County Montebello Forebay has been practiced for 52 years and currently supplies 40 percent of the Los Angeles County groundwater supply.

Groundwater augmentation has also been practiced in El Paso, Texas, since 1985 where advanced wastewater treatment is followed by ozone and carbon filtration (biologically active carbon, (BAC) with ozone) and final chlorine disinfection. Treated water is transported to injection wells along the Texas–New Mexico border. The extraction wells are located such that the time for the injected water to migrate to the entrance well is one year.

Surface Water Augmentation

Surface water augmentation is the intentional addition of reclaimed water to increase the firm yield of a surface water supply. Examples of this practice in the United States include the Occoquan Reservoir in northern Virginia, Lake Lanier in Georgia, and a new project near Dallas, Texas. The Dallas project increases the firm yield of Lavon Lake from 93 mgd to 184 mgd by “polishing” 91 mgd of mixed Trinity River–Dallas South wastewater treatment plant (WWTP) effluent through a 1,840-acre constructed wetland system. Internationally, the Singapore Public Utility Board augments surface water supplies with highly treated water known as NEWater and supplies reclaimed water for industrial processes.

Direct Potable Reuse

Direct potable reuse (DPR) refers to the introduction of reclaimed water directly into a municipal water supply system or to a water treatment plant without an environmental buffer. Several publications provide additional guidance on implementation of and regulations for DPR projects (Tchobanoglous et al. 2011; NRC 2012; Crook 2010).

Examples of DPR include a plant in Windhoek, Namibia, that has been in operation since 1968; during the fifth plant expansion project in 1997, the process train added UF for increased production and reliability. A small DPR facility is currently under construction in Cloudcroft, N.M., using RO–AOP followed by wastewater treatment via membrane bioreactors (MBRs). AOP product water will be blended with natural raw water and then treated using UF membranes and carbon filtration. Big Spring, Texas, has a 2-mgd DPR plant that started full-scale production in April 2013, discharging reclaimed water following MF–RO–AOP into a lake water transmission main that delivers the blended water to six surface water treatment plants. Wichita Falls, Texas, began a 7-mgd DPR project under an emergency permit issued by the Texas Commission on Environmental Quality in July 2014 (Lawler 2014). Effluent from the WWTP travels 12 miles in a temporary *high-density polyethylene* main to an RO membrane treatment system at the city’s water treatment plant. Reclaimed water is blended 50:50 with raw lake water and then treated through the conventional surface water treatment units at the same water treatment plant (Moody 2014).

TREATMENT OPTIONS FOR WATER REUSE

Domestic and industrial wastewater treatment processes are required to meet individual discharge permit requirements and can include pretreatment and primary and secondary treatment processes. Nitrification–denitrification and phosphorus removal for nutrient reduction may be required for permit compliance. For landscape and agricultural irrigation, there is typically no need for removal of nutrients as they provide value to the irrigators. Disinfection is required for most discharges, but disinfection requirements for reclaimed water typically require higher levels of disinfection for pathogen inactivation. For IPR and DPR applications, disinfection to meet potable water quality standards is typically required. In these cases, the choice of disinfectant is critical as disinfectant by-product concentrations may become elevated above regulated levels.

Advanced treatment processes may be required to meet discharge permits, but they are typically required to meet potable applications. Filtration is typically required, even for nonpotable applications, to consistently meet turbidity limits of 2 to 3 ntu. In order to meet drinking water quality criteria, more robust filtration processes may be required and often include membrane processes. Coagulation and sedimentation may be used in reclamation processes, especially if lime softening is applied to increase the number of cycles in cooling tower applications. Other advanced processes such as ion exchange, granular activated carbon, biologically activated carbon, and AOP may also be necessary for IPR or DPR applications to enhance water quality and final product stabilization.

MBR treatment offers many advantages, producing high-quality permeate water that can be used directly for nonpotable water reuse applications. MBR units may be used for satellite treatment units to provide point-of-use application of the reclaimed water, either as an onsite treatment and reuse application or for mining raw wastewater from a sewer outfall. Midland, Texas, has a satellite MBR facility under construction; it will use a 0.2-mgd MBR treatment unit sited in a city park within a building that includes odor control. Reclaimed water will be supplied to the adjacent Midland College for landscape irrigation and cooling tower makeup water. A satellite plant was selected because the alternative would have required construction on a significant amount of developed city property. MBR units typically include MF or UF membranes for nonpotable quality applications.

Membrane desalination using NF or RO membranes is typically required for TDS reduction and greater removal of microorganisms and organics. NF and RO are common in IPR and DPR applications, with RO membranes able to reduce levels of most, but not all, organic contaminants. Most NF and RO unit processes require pretreatment, which is typically provided by MF or UF systems. An AOP unit process is typically added for disinfection and to destroy recalcitrant organics that cannot be removed through the RO process. RO is also widely applied in industrial treatment units to provide ultrapure water for the electronics industry and for boiler feedwater. Reuse of water used in food and beverage manufacturing following treatment with a combination of membranes with or without AOP can minimize the water footprint of those industries and reduce demands on municipal water supplies.

EFFECTIVENESS OF TREATMENT

A comparison of membrane and conventional treatment processes is recommended during process design for a water reclamation plant. Comparison of physical treatment process effectiveness, including membrane processes, is described more fully in Chapter 4.

An important focus of treatment evaluation is bacteriological quality. The designer must ensure that the final water quality is appropriate for the specific intended use. This also includes multiple disinfectants to follow conventional or membrane unit processes.

In meeting regulatory log-removal criteria, treatment with membranes results in greater log removals of bacteria, protozoa, and viruses, which may allow for use of less disinfectant than for a conventional treatment system. Table 2-1 provides indicative log reductions for various stages of treatment and unit processes. While secondary treatment can reduce *Escherichia coli* by 1 to 3 logs, membrane filtration can be expected to reduce *E. coli* by 4 to 6 logs. For *Giardia*, secondary treatment can be expected to provide 0.5- to 1.5-log reduction, while membrane filtration can be expected to provide greater than 6-log reduction. Therefore, if the specific end use requires a 6-log reduction, minimal disinfection would be required following membrane filtration, while high disinfectant doses would be required to achieve an additional 4.5- to 5.5-log inactivation of *Giardia* for secondary treatment.

The effectiveness of filtration depends on the pore sizes of the membrane filters and can generally produce better effluent quality than either surface or depth filters. However, MF and UF systems have higher capital and operation and maintenance costs compared to depth and granular media filtration systems. NF and RO life-cycle costs can be substantially higher due to high energy use and specialized equipment. See Chapter 8 for an expanded discussion of membrane process costs.

RESIDUALS, DISPOSAL, AND REGULATORY REQUIREMENTS

For a reclamation plant that treats WWTP effluent, there is a stream of water to be treated and recycled or discharged to a unit process in the WWTP. The WWTP may also have backwash water treatment and recycling from conventional filtration systems.

Conventional media filtration systems generate only one waste stream, a waste filter backwash that varies between 2 and 6 percent of the total plant intake source water volume. Granular media filters require feedwater to be preconditioned with coagulant prior to filtration, typically adding an additional 60 to 80 percent to the solids load, which typically results in higher solids handling costs. In addition to the solids that were originally in the source water, the conventional filter backwash waste stream likely contains coagulant (typically iron or aluminum salt) and polymer. See AWWA Manual M46 (2007) for more details on residuals and concentrate management.

Table 2-1 Indicative log removals for various stages of treatment and unit processes

Type of Microorganism	Indicator Microorganisms			Pathogenic Microorganisms				
	<i>Escherichia coli</i> (indicator bacteria)	<i>Clostridium perfringens</i>	Phage (indicator virus)	Enteric Bacteria (e.g., <i>Campylobacter</i>)	Enteric Viruses	<i>Giardia lamblia</i>	<i>Cryptosporidium parvum</i>	Helminths
Bacteria	x	x		x				
Protozoa and helminths						x	x	x
Viruses			x		x			
Indicative Log Reductions in Various Stages of Wastewater Treatment*								
Secondary treatment	1–3	0.5–1	0.5–2.5	1–3	0.5–2	0.5–1.5	0.5–1	0–2
Dual-media filtration [†]	0–1	0–1	1–4	0–1	0.5–3	1–3	1.5–2.5	2–3
Membrane filtration (ultrafiltration, nanofiltration, and reverse osmosis) [‡]	4–>6	>6	2–>6	>6	2–>6	>6	4–>6	>6
Reservoir storage	1–5	N/A	1–4	1–5	1–4	3–4	1–3.5	1.5–>3
Ozonation	2–6	0–0.5	2–6	2–6	3–6	2–4	1–2	N/A
Ultraviolet disinfection	2–>6	N/A	3–>6	2–>6	1–>6	3–>6	3–>6	N/A
Advanced oxidation	>6	N/A	>6	>6	>6	>6	>6	N/A
Chlorination	2–>6	1–2	0–2.5	2–>6	1–3	0.5–1.5	0–0.5	0–1

Sources: Bitton (1999); EPHC (2008); Mara & Horan (2003); NRC (1998, 2012); Rose et al. (1996, 2001); USEPA (1999, 2003, 2004); WHO (1989).

* Reduction rates depend on specific operating conditions such as retention times, contact times, concentrations of chemicals used, pore size, filter depths, pretreatment, and other factors. Ranges given should not be used as design or regulatory bases—they are meant to show relative comparisons only.

[†] Including coagulation.

[‡] Removal rates vary dramatically depending on the installation and maintenance of the membranes.

Abbreviation: N/A, not available.

Membrane residual streams include the minerals and silt particles retained on the membranes, inorganic and biological foulants that accumulated on the membrane surface, and cleaning solutions used to restore production capacity. The quantity and quality of membrane residual waters depend on the efficiency of pretreatment. In wastewater and reclamation systems, pretreatment for membranes seldom includes coagulation. The volume of the MF–UF membrane wash-water stream is typically 5 to 10 percent of the plant intake volume, or approximately twice the waste filter backwash volume generated by conventional pretreatment systems (AWWA 2007).

For reclaimed water systems, biological fouling is more pronounced than in freshwater water treatment applications because the organic content in the wastewater effluent provides a higher concentration of trace organics and a continuous food source. A membrane's large surface area provides an ideal environment for growth of microorganisms, which secrete a polysaccharide that forms a biofilm that covers the membrane, causing deterioration in flux and salt rejection. NF and RO membranes may be damaged by the oxidants used to control microorganisms in MF–UF pretreatment systems, which may lead to higher biological fouling rates.

Table 2-2 Filter pore size comparison*

Filter Type	Filtration Driving Force	Nominal Pore Size, μm	Contaminants Targeted for Removal
Depth			
Noncompressible media	Gravity or pressure differential	60–300	TSS, turbidity, some protozoan oocysts and cysts
Compressible media			
Surface Filtration			
Surface filtration	Gravity	5–20	TSS, turbidity, some protozoan oocysts and cysts
Membrane [†]			
Microfiltration	Pressure differential	0.05	TSS, turbidity, some protozoan oocysts and cysts, some bacteria and viruses
Ultrafiltration	Pressure differential	0.002–0.050	Macromolecules, colloids, most bacteria, some viruses, proteins
Nanofiltration	Pressure differential	<0.002	Small molecules, some hardness, viruses
Reverse osmosis	Pressure differential	<0.002	Very small molecules, color, hardness, sulfates, nitrate, sodium, other ions

Reprinted from USEPA (2012).

* Information taken from the California Department of Public Health (2011) and Metcalf & Eddy (2003).

[†] Information taken from *Water Treatment Membrane Processes* (AWWA 1996).

Abbreviation: TSS, total suspended solids.

Both MF–UF and NF–RO systems use a chemical clean-in-place (CIP) process to clear inorganic and organic contaminants from the membrane surface. A typical CIP system consists of one or more CIP tanks. These tanks typically include mixers and/or a solution heater and, for specific process temperature control, a cooling system, pump(s), cartridge filter, feed and recirculation piping, instrumentation, power supply, and control equipment. Nonchlorinated permeate is typically used to supply the CIP tank for cleaning solution makeup. Powdered or liquid chemicals may be fed directly into the CIP tank, a separate smaller solution tank, or a CIP feed–recycle line used for chemical mixing (AWWA 2007).

RO concentrate creates significant operations, management, and regulatory challenges that are typically more significant for inland facilities. Coastal reclamation plants often have access to a seawater outfall where the concentrate can be directed. While this increases the TDS concentration in the wastewater effluent, the concentrate constituents were in the wastewater effluent prior to RO treatment and are returned to the ocean outfall in the same quantity as would be discharged without RO removal. The increased TDS may also buffer the TDS gradient between the freshwater, wastewater effluent and seawater. Most discharge permits require that TDS in the discharge plume closely match the ambient seawater TDS concentration. Inland facilities are often faced with more costly options including deep well injection into nonpotable groundwater, typically a brackish source with more than 10,000 mg/L TDS. These sources and the well casing must isolate the concentrate from potential potable water supplies. Concentrate may also be stored on site in evaporation ponds if climatic conditions support net evaporative loss and the land is available and affordable. An example of this is found at the Palo Verde Nuclear

Generation Station in Arizona, where reclaimed water from a regional WWTP in Phoenix supplies up to 85 mgd for power plant cooling. The reclamation plant provides additional onsite softening and recirculates the cooling water to obtain 25 cycles of operation. The blowdown (that is, concentrate) TDS is basically seawater (approximately 32,000 mg/L) and is stored in evaporation ponds that cover 650 acres on the site (Carpenter, Cavazos, & Cook 2012). Other more costly zero liquid discharge alternatives may require the use of crystallizers, which have high capital and energy costs.

After feasibility and cost, regulations typically dictate the choice of concentrate discharge or disposal option. Discharge to surface waters is typically controlled by state wastewater discharge regulations. Many states limit high TDS discharges to maintain receiving stream water quality. TDS or specific constituents can be limited in concentration or mass in the discharge. Many cities and utilities have industrial pretreatment regulations that limit the TDS level of discharges to the municipal treatment system. This is done to reduce operating costs at the wastewater treatment facility and potentially improve reclaimed water quality. Deep well injection requires a permit for injection from the primary regulatory agency; these may require audit option public hearings similar to those required for wastewater discharge permits. Deep well injection is becoming an increasingly popular alternative, but it can be expensive.

FLOW EQUALIZATION AND STORAGE REQUIREMENTS FOR NONPOTABLE REUSE

Managing variable reclamation influent flows to optimize the supply for reuse requires effective design of wastewater effluent storage, membrane production capacity, permeate product water storage, and distribution system pumping and storage capacity. Each system must be sized to provide cost effectiveness. Because of the high capital costs, including cost of the membrane systems, it is not economical to provide excess peak production capacity to meet peak-period user demands. Effluent supply to a membrane reclamation plant may also be limited during low flow periods. Onsite storage to equalize the reclaimed water supply is beneficial because it can preclude reduction in membrane treatment throughput. Sizing the membrane units for continuous operation also prevents shutdown of individual trains when their capacity is not required, which protects the membrane systems. Equalization storage for reclaimed water in advance of the high-service distribution system pumping should be sized to adequately meet user demands.

As with potable water systems, nonpotable distribution system storage can be used to balance both system pressure and localized demands. With reclaimed water systems, it is also common to include a portion of the system storage in proximity to high-demand users. This may reduce the required size of the distribution system pumps and piping while allowing constant delivery to high-demand users at average daily rates. This provides reliability for the high-volume users as they have onsite storage and can better control their reclaimed water supply.

ENVIRONMENTAL IMPACTS

Selection of membrane treatment process units over conventional physical or chemical process units for water reclamation does not eliminate environmental impacts; however, membrane units may have lower environmental impacts compared to conventional alternatives. Typically, membrane unit (MF-UF and NF-RO) housing has a smaller footprint, which reduces site disturbance and grading. Membrane filtration can result in increased log removal of bacteria, protozoa, and viruses compared to granular media filtration, reducing the use of disinfecting chemicals. If chlorine gas is the disinfectant of choice, reduction of the stored volume of chlorine gas cylinders reduces health risks to workers

and neighbors near the treatment plant. MF–RO–AOP treatment processes were selected for several southern California reclamation plants including the West Basin Water District, Orange County Water District, San Diego demonstration pilot plant (USEPA 2012), to meet treatment process requirements and reduce net energy use. Selection was based on lower energy demands for reclamation compared to pumping raw water over long distances, which was an alternative in these specific cases.

LEGAL AND INSTITUTIONAL ISSUES

Regulations and design criteria for IPR and DPR facilities are evolving, and no state has developed DPR regulations. Four states have guidelines, regulations, or draft regulations for IPR facilities, and several states handle IPR projects on a case-by-case basis. California issued revised (draft) groundwater replenishment regulations in 2011 after adopting a new recycled water policy in 2009 and issuance of reports from an expert panel specific to monitoring for contaminants of emerging concern (CDPH 2011). Part of these current draft regulations define specific treatment unit processes to be included to meet minimum water quality standards and provide redundancy in the treatment process. To date (September 2014), the FAT process, which requires RO with appropriate pretreatment, must be used or pilot studies with documentation that supports an alternate process must be reviewed and approved by the Division of Drinking Water and Environmental Management (formerly CDPH) as providing equivalent public health protection and equal water quality. Other state regulations are not as stringent as the draft from California, which is the only state to require a specific treatment process such as FAT. New Mexico and Texas each have one authorized, constructed DPR facility in initial operation. El Paso (Texas) Water Utilities began full-scale operation of its IPR facility using ozone and biologically active carbon filtration in 1985, so there is precedence in the United States for non-RO treatment processes.

REGULATORY REQUIREMENTS AND PERMITTING, INCLUDING FUTURE REGULATORY IMPACTS

With the exception of IPR and DPR facilities, permitting of a reclamation plant would be similar using conventional secondary treatment processes or using membrane processes if both processes meet the same water quality criteria for the end use. The distinction between conventional and membrane processes becomes more evident when RO is needed to remove TDS, creating concentrate or a brine stream that must be managed. In a project under construction in California, sanitary sewer capacity to transport increased volumes of concentrate was not available for the MF–RO–AOP plant expansion from 3 to 8 mgd. The Vander Lans Reclamation Plant in Orange County (Calif.), has added a third-stage RO unit to increase process recovery and limit concentrate discharge to the same volume discharged from the 3-mgd facility. In this example, permit limitations to the sanitary sewer required process innovation to facilitate the expansion.

PUBLIC EDUCATION AND OUTREACH PROGRAMS

Stakeholder identification and inclusion in project development are critical components of any new reclamation project. As the public and water users become more aware of advances in treatment, membrane treatment processes may be perceived as a requirement by many stakeholders. While a membrane unit process may be a good selection, stakeholders and the public must be educated on available treatment processes, and the relative costs for construction and operations must be communicated. Pilot studies with comparable

conventional and membrane units can identify relative construction and operations and maintenance costs for the quality of water produced by both systems. Inclusion of the stakeholders in the selection of treatment options and identification of the impact on individual water rates may help influence process selection based on the science at a specific facility. Beyond the unit process selection and cost impacts, public education and outreach for a membrane treatment process should be comparable to any other project effort in the community.

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Chapter 3

Water Reuse Guidelines and Regulations

Water recycling and reuse have been practiced for more than 100 years, initially on an informal, unregulated basis. As the practice gained acceptance around the world as a way to stretch diminishing freshwater supplies, the need for guidance and/or regulations became a necessity from human health and environmental perspectives. In recent decades, controlled uses for reclaimed water for nonpotable and industrial applications have become more common in the United States and other countries. Guidelines and regulations for nonpotable and indirect potable uses of reclaimed water have evolved and vary widely from state to state and country to country. This chapter summarizes guidelines and regulations for reclaimed water use in representative states and countries and is not meant to be exhaustive. As the emphasis of this manual is on membrane applications, discussions on water reuse categories that do not involve membrane usage may not be included.

WORLD HEALTH ORGANIZATION GUIDELINES

No international regulations exist for the myriad of reclaimed water uses. Several countries with water reuse programs have referenced or adopted elements of the World Health Organization's (WHO's) *Guidelines for the Safe Use of Wastewater, Excreta and Greywater*, volumes 1 to 4 (WHO 2006a, 2006b, 2006c, 2006d) and *Water Quality—Guidelines, Standards and Health: Assessment of Risk and Risk Management for Water-related Infectious Disease* (WHO 2006). These documents provide guidance to economically constrained countries for establishing reuse programs that use domestic wastewater and waste. These programs can help in the conservation of existing freshwater supplies; promote the use of waste streams as a resource; and reduce poverty, hunger, and disease in the absence of a treatment infrastructure.

Hazards and Health Risks

The primary human health risks related to water reuse are excreta-borne and vector-borne pathogens that often survive long enough to be a threat to humans. To a lesser extent, chemical-borne disease can also pose a threat through uptake by plants and presence in soil. The WHO developed a risk management outline for its guidelines and standardized health risk by using disability-adjusted life-years (DALYs) as the unit to compare a population's health with its disease burden or other risk factors. WHO set a tolerable risk value of 1×10^{-6} DALY/person/year for pathogenic microorganisms and chemical constituents. The DALY value is the basis for log reduction of microbes in the WHO guidelines for agriculture and aquaculture. Microbial log-reduction goals are based on crop type (leaf or root crops, high-growing or low-growing crops), irrigation type (restricted, unrestricted, localized), and any wastewater/waste treatment prior to application.

Risk Management Targets

Table 3-1 shows the corresponding log reductions for pathogens and helminth ova to achieve the WHO DALY goal.

Soil and food crops can uptake and absorb chemicals and contribute to health risks. Table 3-2 shows maximum soil concentrations for trace metals and organics based on WHO health risk assessment.

Table 3-1 Health-based targets and helminth reduction targets for wastewater use in agriculture

Exposure Scenario	Health-based Target, DALY/person/year	Log ₁₀ Pathogen Reduction Needed	Number of Helminth Eggs per Liter
Unrestricted irrigation			
Leaf crops	$\leq 10^{-6}, *$	6	$\leq 1^{\dagger, \S}$
Root crops	$\leq 10^{-6}, *$	7	$\leq 1^{\dagger, \S}$
Restricted irrigation			
Highly mechanized	$\leq 10^{-6}, *$	3	$\leq 1^{\dagger, \S}$
Labor intensive	$\leq 10^{-6}, *$	4	$\leq 1^{\dagger, \S}$
Localized (drip) irrigation			
High-growing crops	$\leq 10^{-6}, *$	2	No recommendation [§]
Low-growing crops	$\leq 10^{-6}, *$	4	$\leq 1^{\dagger, \S}$

Source: WHO (2006a).

* Rotavirus reduction. The health-based target can be achieved for unrestricted and localized irrigation by a 6–7 log unit pathogen reduction (obtained by a combination of wastewater treatment and other health protection measures); for restricted irrigation, it is achieved by a 2–3 log unit pathogen reduction.

[†] When children aged <15 years are exposed, additional health protection measures should be used (for example, treatment to ≤ 0.1 egg/L, protective equipment such as gloves or shoes/ boots, or chemotherapy).

[‡] An arithmetic mean should be determined throughout the irrigation season. The mean value of ≤ 1 egg/L should be obtained for at least 90 percent of samples in order to allow for the occasional high-value sample (that is, with >10 eggs/L). With some wastewater treatment processes (for example, waste stabilization ponds), the hydraulic retention time can be used as a surrogate to ensure compliance with ≤ 1 egg/L.

[§] No crops to be picked up from the soil.

Table 3-2 Maximum tolerable soil concentrations of various toxic chemicals based on human health protection

Chemical	Soil Concentration, mg/kg
Trace metals	
Antimony	36
Arsenic	8
Barium*	302
Beryllium*	0.2
Boron*	1.7
Cadmium	4
Fluorine	635
Lead	84
Mercury	7
Molybdenum*	0.6
Nickel	107
Selenium	6
Silver	3
Thallium*	0.3
Vanadium*	47
Organics	
Aldrin	0.48
Benzene	0.14
Chlordane	3
Chlorobenzene	211
Chloroform	0.47
2,4-D	0.25
DDT	1.54
Dichlorobenzene	15
Dieldrin	0.17
Dioxins	0.00012
Heptachlor	0.18
Hexachlorobenzene	1.4
Lindane	12
Chemical	
Methoxychlor	4.27
Polycyclic aromatic hydrocarbons (as benzo(a)pyrene)	16
Polychlorinated biphenyls	0.89
Pentachlorophenol	14
Phthalate	13,733
Pyrene	41
Styrene	0.68
2,4,5-T	3.82
Tetrachloroethane	1.25
Tetrachloroethylene	0.54
Toluene	12
Toxaphene	0.0013
Trichloroethane	0.68

Source: WHO (2006).

Implementing Mitigation Measures

The WHO guidelines also describe basic, universal protection measures to reduce risks from water reuse, such as promoting health and hygiene, handling and preparing food properly, reducing vector contact and improving vector control, washing and cooking produce, accessing safe drinking water, treating wastewater/excreta, immunizing as appropriate, timing of waste application, and using personal protective equipment (for example, footwear, gloves).

For example, the highest pathogen reduction of 7 log is suitable for root and nonroot crops that are irrigated with wastewater and may be eaten uncooked. Pathogen reduction of up to 7 log can be achieved with the following options:

- Allowing pathogen die-off between the last irrigation and human consumption (2-log reduction);
- Washing crops with clean water prior to consumption (1-log reduction);
- Peeling produce (2-log reduction);
- Cooking produce (6- to 7-log reduction);
- Using localized irrigation such as subsurface or drip irrigation (2- to 4-log reduction); and
- Using conventional wastewater treatment, if available (4- to 7-log reduction).

System Assessment and Monitoring

Implementation of a risk management plan includes confirming that any new system can operate within acceptable limits, ongoing operational monitoring to ensure continued performance within design specifications, and verifying that end-use products meet acceptable health limits. Table 3-3 provides recommended minimum monitoring frequencies and target limits for agriculture and aquaculture.

NATIONAL GUIDELINES

The two primary factors that drive countries to develop water reuse guidance are increasing demands on freshwater supplies and limits of freshwater supplies. Population demographics; geography; resources; economics; infrastructure; social, cultural, and institutional constraints; and weather trends also factor into the nature, content, and scope of any national guidance.

Economically constrained countries that do not have institutions or infrastructure to protect human health may choose to adopt the WHO guidelines using “fit-for-purpose” principles to suit their unique needs. Conversely, economically developed countries can more easily develop, implement, and support guidelines through existing institutions.

Representative water reuse guidelines are presented here for Australia, the United States, and Japan.

Australia Guidelines

According to the National Program for Sustainable Irrigation (2006), Australia’s per capita annual water use of 343,000 gal is the third highest in the world. More than 65 percent of that use is for agriculture (primarily crops and livestock grazing). The burden of using potable supplies for agriculture is offset by increased use of reclaimed water.

No national water reuse regulations exist in Australia. In lieu of national regulations, national guidelines were developed in two phases using management and policy documents for overall water resources and drinking water as the basis. States and territories establish reuse regulations based on the guidelines.

Table 3-3 Recommended minimum verification monitoring for wastewater and excreta use in agriculture and aquaculture

Activity or Exposure	Water Quality Monitoring Parameters*	
Agriculture	<i>Escherichia coli</i> /100 mL [†] (arithmetic mean)	Helminth Eggs/Liter [†] (arithmetic mean)
Unrestricted irrigation		
Root crops	≤10 ³	≤1
Leaf crops	≤10 ⁴	
Drip irrigation, high-growing crops	≤10 ⁵	
Restricted irrigation		
Labor-intensive, high-contact agriculture	≤10 ⁴	≤1
Highly mechanized agriculture	≤10 ⁵	
Septic tank	≤10 ⁶	
Aquaculture	<i>Escherichia coli</i> /100 mL [†] (arithmetic mean)	Viable Trematode Eggs/Liter ^{†, b}
Produce consumers		
Pond	≤10 ⁴	Not detected
Wastewater	≤10 ⁵	Not detected
Excreta	≤10 ⁶	Not detected
Workers, local communities		
Pond	≤10 ³	No viable eggs
Wastewater	≤10 ⁴	No viable eggs
Excreta	≤10 ⁵	No viable eggs

Source: WHO (2006).

* Monitoring should be conducted at the point of use or the point of effluent discharge. Frequency of monitoring is as follows:

- Urban areas: one sample every two weeks for *Escherichia coli* and monthly for helminth eggs.
- Rural areas: monthly sample for *E. coli* and one sample every one to two weeks for helminth eggs.

Five-liter composite samples are required for helminth eggs prepared from grab samples taken six times per day. Monitoring for trematode eggs is difficult due to a lack of standardized procedures. The inactivation of trematode eggs should be evaluated as part of system validation.

[†] For excreta, weights may be used instead of volumes, depending on the type of excreta: 100 mL of wastewater is equivalent to 1 to 4 g of total solids; 1 L = 10 to 40 g of total solids. The required *E. coli* or helminth numbers would be the same per unit of weight.

Phase 1, published in 2006 (NRMMC/EPHC/AHMC 2006), covers guidance and management practices for recycled water quality and end uses for treated sewage and graywater, as follows:

- Residential uses (landscape irrigation, toilet flushing, and laundry);
- Irrigation for agriculture and horticulture, open spaces, and urban recreation;
- Firefighting;
- Industrial uses (cooling towers, process water, wash-down water, dust control); and
- Onsite business and residential graywater treatment for nonpotable use.

The phase 1 guidance is founded on a risk management framework of 12 elements grouped into the following four categories: commitment to the reuse program and water quality, analysis of the reuse system and its management, support of the system and management, and review and improvement of the system. The framework is modeled after a similar risk management framework for Australia's 2004 Drinking Water Guidelines (NHRMC 2004).

Phase 2, published in 2008–2009, consists of the following three modules and expands the material covered in phase 1 to include recharge and drinking water supply augmentation and stormwater harvesting:

- Module 1: covers the planned use of reclaimed water, either from treated sewage or stormwater, to augment drinking water supplies (NRMMC/EPHC/NHMRC 2008);
- Module 2: provides guidelines for stormwater nonpotable reuse (NRMMC/EPHC/NHMRC 2009); and
- Module 3: provides guidelines for groundwater recharge with all water types including recycled water (NRMMC/EPHC/NHMRC 2008).

Regional Australian regulations and guidance. The individual states and territories of Victoria, New South Wales, Queensland, South Australia, Western Australia, Tasmania, Capital Territory, and Northern Territory have statutes and controls that govern phase 1 and phase 2 uses of recycled water for urban, agricultural, industrial, augmentation, and recharge uses. State regulatory criteria may be more stringent than the national guidelines. National and local codes from animal husbandry, plumbing, water supply, and sewerage agencies may also apply. The end user conducts additional treatment for water quality-specific end uses such as MF and reverse osmosis (RO) for boiler feedwater or nitrification for cooling tower makeup water. Examples of phase 1 reuse regulations for two representative states, Victoria and New South Wales, are presented below.

Victoria regulations and guidance. Table 3-4 provides a summary of Victoria's phase 1 water reuse categories, water quality objectives, and range of nonpotable end uses.

Table 3-4 Victoria, Australia, reclaimed water classes, treatment, and pathogen reduction

Class	Water Quality Objective (annual median unless specified)	Treatment Process	Range of Uses
A	<i>Escherichia coli</i> : <10 cfu/100 mL Turbidity: <10 ntu BOD ₅ : <10 mg/L TSS: <5 mg/L pH: 6–9 Chlorine residual: 1 mg/L or equivalent at point of use	Tertiary treatment; sufficient log reduction to achieve: <10 <i>E. coli</i> /100 mL <1 helminth/L <1 protozoa/50 L <1 virus/50 L	Urban nonpotable: with uncontrolled public access Agricultural: all crops including food crops eaten raw Industrial: open systems with worker exposure potential
B	<i>E. coli</i> : <100 cfu/100 mL BOD ₅ : <20 mg/L TSS: <30 mg/L pH: 6–9	Secondary treatment; pathogen reduction (including helminth reduction)	Agricultural: for example, dairy cattle grazing Industrial: for example, wash-down water
C	<i>E. coli</i> : <1,000 cfu/100 mL BOD ₅ : <20 mg/L TSS: <30 mg/L pH: 6–9	Secondary treatment; pathogen reduction (including helminth reduction)	Urban nonpotable: with controlled public access Agricultural: for example, food crops eaten cooked or processed; grazing/livestock fodder Industrial: systems with no worker exposure potential
D	<i>E. coli</i> : <10,000 cfu/100 mL BOD ₅ : <20 mg/L TSS: <30 mg/L pH: 6–9	Secondary treatment	Agricultural: nonfood crops, including turf, wood lots, flowers

Source: EPA Victoria (2003).

Abbreviations: BOD₅, 5-day biochemical oxygen demand; TSS, total suspended solids.

New South Wales regulations and guidance. Table 3-5 provides a summary of New South Wales' phase 1 water reuse guidelines and controls for nonpotable end uses.

Table 3-5 New South Wales, Australia, guidelines for reclaimed water use from municipal sewage treatment plants

Reuse Type— Agricultural	Treatment	Water Quality Criteria	Effluent Monitoring	Control
Food crops: crops to be eaten raw and in direct contact with irrigation (for example, salad greens)	Tertiary pathogen reduction (via chlorine or detention)	pH: 6.5–8.5 Predisinfection turbidity: ≤2 ntu Chlorine residual: 1 mg/L or equivalent Thermotolerant coliforms: <10 cfu/100 mL Intestinal nematode egg or larva: <1/L	pH weekly Turbidity continuous Disinfection system daily (chlorine, UV, other) Coliforms weekly	Limit application rates to protect groundwater quality Salinity a factor in irrigation Control helminths with minimum of 25 days ponding or equivalent treatment (for example, sand filtration)
Food crops: crops to be eaten cooked or processed and not in direct contact with irrigation	Secondary pathogen reduction (via chlorine or detention)	pH: 6.5–8.5 Thermotolerant coliforms: <1,000 cfu/100 mL	pH weekly BOD weekly TSS weekly Coliforms weekly	Limit application rates to protect groundwater quality Salinity a factor in irrigation Do not harvest dropped crops Cook crops at >70°C for 2 minutes commercially
Food production: pasture and fodder for grazing animals (exc. pigs and dairy animals—cattle, sheep, and goats)	Secondary pathogen reduction (via chlorine or detention)	pH: 6.5–8.5 Thermotolerant coliforms: <1,000 cfu/100 mL	pH weekly TSS weekly Disinfection system daily (chlorine, UV, other) Coliforms weekly	Limit application rates to protect groundwater quality Withhold access 4 hours or until irrigated space is dry Helminth controls
Food production: pasture and fodder for dairy animals (with withholding period)	Secondary pathogen reduction (via chlorine or detention)	pH: 6.5–8.5 Thermotolerant coliforms: <1,000 cfu/100 mL	pH weekly TSS weekly Disinfection system daily (chlorine, UV, other)	Limit application rates to protect groundwater quality Withhold access 5 days

(Continued)