

**M69**

# Inland Desalination and Concentrate Management

click buy full version



American Water Works  
Association

# Inland Desalination and Concentrate Management



**American Water Works  
Association**

## Inland Desalination and Concentrate Management

Copyright © 2019 American Water Works Association

All rights reserved. No part of this publication may be reproduced or transmitted in any form or by any means, electronic or mechanical, including scanning, recording, or any information or retrieval system. Reproduction and commercial use of this material is prohibited, except with written permission from the publisher.

### Disclaimer

The authors, contributors, editors, and publisher do not assume responsibility for the validity of the content or any consequences of its use. In no event will AWWA be liable for direct, indirect, special, incidental, or consequential damages arising out of the use of information presented in this book. In particular, AWWA will not be responsible for any costs, including, but not limited to, those incurred as a result of lost revenue. In no event shall AWWA's liability exceed the amount paid for the purchase of this book.

Editorial Manager – Book Products: Melissa Valentine  
Technical Editors: Dianne Rose and Suzanne Snyder  
Cover Art/Technical Illustrator: Michael Labruyere  
Production: Innodata  
Manuals Specialists: Sue Weikel and Willadee Hitchcock

---

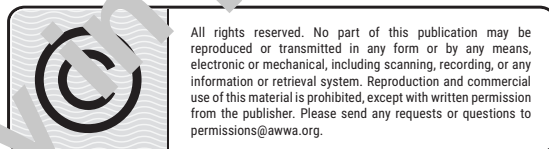
### Library of Congress Cataloging-in-Publication Data

Names: He, Charlie (Qun), author. | Bond, Rick G., author. | American Water Works Association, issuing body.  
Title: Inland desalination & concentrate management / by Charlie (Qun) He and Rick G. Bond.  
Other titles: Inland desalination and concentrate management | AWWA manual ; M69.  
Description: First edition. | Denver, CO : American Water Works Association, [2019] | Series: Manual of water supply practices—M69 | Includes bibliographical references and index.  
Identifiers: LCCN 2018061027 | ISBN 9781627763003  
Subjects: LCSH: Saline water conversion  
Classification: LCC TD479 .H4 2019 | DDC 628.1/67--dc23  
LC record available at <https://lcn.loc.gov/2018061027>

Printed in the United States of America

ISBN 978-1-62576-350-3

eISBN-13 978-1-61300-502-6



**American Water Works  
Association**

American Water Works Association  
6666 West Quincy Avenue  
Denver, CO 80235-3098  
[awwa.org](http://awwa.org)

# Contents

List of Figures, v

List of Tables, ix

Preface, xiii

Acknowledgments, xv

<b>Chapter 1</b>	<b>Overview of Inland Desalination</b> .....	<b>1</b>
	Brackish Water Sources, 2	
	Status of Desalination, 2	
	Concentrate Management Options, 7	
	Manual Overview, 11	
	References, 12	
<b>Chapter 2</b>	<b>Water Quality and Planning Strategies</b> .....	<b>13</b>
	Source Water Quality Affecting Desalination, 14	
	Product Water Quality Goals, 18	
	Water Quality Analysis And Monitoring, 21	
	RO and EDR Performance Modeling, 23	
	Treatment Levels, 23	
	Types of Brackish Water Desalination Technologies, 25	
	Types of Concentrate Management Technologies, 26	
	Planning Strategies, 28	
	Conclusions, 32	
	References, 32	
<b>Chapter 3</b>	<b>Brackish Water Desalination</b> .....	<b>35</b>
	Pressure-Driven Membrane Desalination, 36	
	Reverse Osmosis Pretreatment, 47	
	Reverse Osmosis Post-treatment, 50	
	Electrolysis Desalination, 51	
	Electrolysis/Electrodialysis Reversal Pretreatment, 65	
	Electrolysis/Electrodialysis Reversal Post-treatment, 67	
	References, 68	
<b>Chapter 4</b>	<b>Discharge Options for Concentrate Disposal</b> .....	<b>71</b>
	Discharge to Surface Water, 72	
	Discharge to Sewer, 75	
	Deep-well Injection, 76	
	Evaporation Ponds, 80	
	Enhanced Evaporation Systems, 84	
	Irrigation, 87	
	References, 91	

<b>Chapter 5</b>	<b>Enhanced Recovery and Zero Liquid Discharge.....</b>	<b>93</b>
	Enhanced Recovery Processes, 93	
	Zero Liquid Discharge, 105	
	References, 117	
<b>Chapter 6</b>	<b>Cost of Desalination and Concentrate Management.....</b>	<b>119</b>
	Overall Cost Considerations, 120	
	Methods for Estimating Class 4 and Class 5 Construction Costs, 121	
	Construction Costs for Major Processes Used in Desalination and Concentrate Management, 122	
	Annual Costs, 127	
	References, 130	
<b>Chapter 7</b>	<b>Regulatory, Safety, Operational, and Environmental Issues.....</b>	<b>131</b>
	Current Concentrate Management Issues, 131	
	Regulatory Issues, 132	
	Federal Regulations, 133	
	State Regulations, 138	
	Relevant International Regulations, 140	
	Future Permitting Considerations, 141	
	Environmental Impacts, Operations, and Permitting Requirements, 141	
	References, 152	
<b>Chapter 8</b>	<b>Case Studies.....</b>	<b>155</b>
	City of Chandler Ocotillo Brine Reduction Facility, 155	
	City of Palm Coast Zero Liquid Discharge Reverse Osmosis Concentrate Management, 160	
	Irwin Water Works, Army National Training Center, Fort Irwin, Calif., 164	
	Fargo Wastewater Treatment Facility, Effluent Reuse Facility, 167	
	Kay Bailey Hutchison Desalination Plant, El Paso, Tex., 171	
	Zero Liquid Discharge Water Treatment Facility, 175	
	Laguna County Sanitation District Deep-Well Concentrate Disposal, 179	
	Chino Desalter Community Concentrate Reduction Facility, 182	
<b>Chapter 9</b>	<b>Technological Trends, Salt Recovery, and Beneficial Uses.....</b>	<b>187</b>
	Industry Trends, 188	
	Innovations in Membrane Technology, 188	
	Innovations in Design and Operation, 190	
	Innovative Processes, 192	
	Energy Efficiency Enhancement, 194	
	Improved Salt Recovery and Beneficial Uses of Concentrate, 196	
	References, 202	
	<b>Index, 203</b>	
	<b>List of AWWA Manuals, 213</b>	

# Figures

- 1-1 Depth to brackish groundwater in the United States, 3
- 1-2 Total worldwide installed desalination capacity by feedwater category, 3
- 1-3 Total worldwide installed desalination capacity by user type, 4
- 1-4 Cumulative number of US municipal desalination plants, 5
- 1-5 Cumulative installed capacity of US municipal desalination plants, 5
- 1-6 Number of US municipal desalination plants by state as of 2017, 6
- 1-7 Number of US municipal desalination plants installed by state in different time periods, 7
- 1-8 Concentrate disposal options for US municipal desalination plants, 10
  
- 2-1 Treatment and disposal levels for inland desalination and concentrate management, 24
- 2-2 Three strategic focuses for inland desalination and concentrate management, 27
  
- 3-1 Composite polyamide membrane structure, 36
- 3-2 Basic concept of natural osmosis and reverse osmosis, 37
- 3-3 Schematic representation of a spiral-wound membrane module, 40
- 3-4 Eight-inch RO membrane modules being loaded into a membrane pressure vessel, 41
- 3-5 Schematic representation of a two-stage RO process, 41
- 3-6 Schematic representation of a two-stage RO process with a turbocharger energy recovery device, 43
- 3-7 Energy recovery device installed in a brackish water desalination facility, 44
- 3-8 Horizontal cartridge filter vessels used as RO pretreatment, 49
- 3-9 The Taunton River Desalination plant in Brockton, Mass., uses integrated membrane systems to treat a brackish surface water supply, 50
- 3-10 Water treatment spectrum, 52
- 3-11 Electrodialysis process schematic, 52
- 3-12 Structure of a cation membrane, 53
- 3-13 Structure of an anion membrane, 54
- 3-14 Spacers, 54
- 3-15 Baffled flow pattern created by spacer, 55
- 3-16 An ED system with three hydraulic and three electrical stages, 56
- 3-17 Hydraulic staging within a single membrane stack, 56
- 3-18 Membrane stack with two electrical stages and three hydraulic stages, 57
- 3-19 Raw water concentration and current density, 58
- 3-20 EDR stack shorting, 59

- 4-1 Class I injection well schematic (number of casing stages varies), 78
- 4-2 Salt gradient solar pond schematic, 86
- 4-3 Plant salt tolerance classifications, 90
  
- 5-1 Schematic of pellet-softening process, 95
- 5-2 Schematic of an EDR system, 96
- 5-3 Process flow diagram of an EDR system, 97
- 5-4 Schematic of lime/soda softening plus secondary RO or EDR, 98
- 5-5 EDM process schematic and picture of full-scale stack, 99
- 5-6 SPARRO process schematic, 99
- 5-7 Integrated EDR-SPARRO process schematic, 100
- 5-8 Vacuum-enhanced direct contact membrane distillation process schematic, 101
- 5-9 Membrane brine concentrator process schematic, 102
- 5-10 Concept of the VSEP, 103
- 5-11 Example of the VSEP configuration, 103
- 5-12 Schematic of the HERO™ process, 104
- 5-13 Overview of the CCRO process, 104
- 5-14 Brine concentrator process schematic (typical), 107
- 5-15 Crystallizer (left) and brine concentrators (typical), 110
- 5-16 Crystallizer process schematic (typical), 110
  
- 7-1 USEPA classification of waste streams, 134
- 7-2A Solid residuals TENORM decision tree, 137
- 7-2B Liquid residuals TENORM decision tree, 138
- 7-3 Surface water discharge, 146
  
- 8-1 CHRO process flow schematic (prior to spring 2014), 156
- 8-2 OBRF process flow schematic (after spring 2014), 159
- 8-3 ZLD process schematic, 162
- 8-4 Screenshot of ZLD SCADA system, 164
- 8-5 Facility location map, 165
- 8-6 Irwin Water Works process flow diagram, 166
- 8-7 Facility location map, 168
- 8-8 Fargo waste water reuse project schematic, 168
- 8-9 Kay Bailey Hutchison Desalination Plant location (El Paso County, Tex.), 171
- 8-10 Kay Bailey Hutchison plant desalination process schematic, 172
- 8-11 Kay Bailey Hutchison plant RO trains, 172
- 8-12 ZLD treatment schematic, 175
- 8-13 Falling film vapor compression evaporator, 176
- 8-14 One of the triple-lined evaporation ponds used for final disposal of concentrate from the thermal evaporator, 178
- 8-15 Facility location map, 179
- 8-16 LCSD treatment schematic, 180

- 8-17 Facility location map, 183
- 8-18 Chino II CRF process schematic, 183
- 8-19 Pellet reactors (left) and secondary RO (right) at the Chino II CRF, 185
  
- 9-1 General schematic of the thermo-ionic process, 193
- 9-2 Selective salt recovery from sodium carbonate crystals, 199

# Tables

- 1-1 Number of different US municipal desalination membrane processes as of 2017, 6
- 1-2 Concentrate management options, 8
- 1-3 Number of states using the disposal options for municipal desalination concentrate, 9
- 1-4 States using various disposal options and number of plants in each state, 9
  
- 2-1 Example of brackish water quality variations, 15
- 2-2 Examples of drinking water quality goals, 19
- 2-3 Examples of short-term salinity goals, 20
- 2-4 Regulations in California for groundwater recharge into potable aquifers, 21
- 2-5 Example of product water quality criteria for direct potable reuse applications, 22
- 2-6 Reverse osmosis and nanofiltration design computer models, 24
- 2-7 Types of desalination technologies, 27
  
- 3-1 Impact of operational changes on removal efficiency and pressure, 39
- 3-2 Methods used for balancing flux between stages, 42
- 3-3 Typical water impurities and corresponding pre-treatments, 65
  
- 4-1 Advantages and disadvantages of discharge of concentrate to surface water, 74
- 4-2 Advantages and disadvantages of discharge of concentrate to sewer, 76
- 4-3 Advantages and disadvantages of deep well injection, 79
- 4-4 Advantages and disadvantages of discharge of concentrate to evaporation ponds, 83
- 4-5 Advantages and disadvantages of spray systems, 84
- 4-6 Advantages and disadvantages of WAIV, 85
- 4-7 Advantages and disadvantages of salt-gradient solar ponds, 87
- 4-8 Examples of crop salt tolerance, 90
- 4-9 Advantages and disadvantages of irrigation with concentrate, 90
  
- 5-1 Influence of feed TDS and maximum concentrated brine effluent TDS on brine concentrator recovery, 108
- 5-2 Influence of flow on crystallizer operating costs (example), 111
- 5-3 ZLD treatment cost example, 112
- 5-4 RO treatment cost example at 80% recovery, 113
- 5-5 RO+ZLD combined treatment cost example at 80% RO recovery, 113
- 5-6 Sample RO and ZLD treatment cost comparison at 80% RO recovery, 114
- 5-7 RO treatment cost example at 90% recovery, 114
- 5-8 RO+ZLD combined treatment cost example at 90% RO recovery, 114

- 5-9 Sample RO and ZLD treatment cost comparison at 90% RO recovery, 114
- 5-10 Comparison of RO+ZLD combined treatment costs at 80% versus 90% RO recovery, 115
  
- 6-1 Summary of major treatment cost by category, 120
- 6-2 Guidelines for cost estimate classes, 121
- 6-3 Examples of cost add-ons, 123
- 6-4 Cost estimation example, 124
- 6-5 Typical MF/UF construction cost, 124
- 6-6 Typical brackish water NF/RO membrane construction cost, 125
- 6-7 Typical seawater NF/RO membrane construction cost, 125
- 6-8 Equipment costs for reactor clarifier for installation in 15-ft deep concrete circular wall, 126
- 6-9 Pellet softener equipment costs including sand wash/feed pump and control, 126
- 6-10 Deep-well injection costs from recent installations, 127
- 6-11 MVC brine concentrator equipment costs, 128
- 6-12 MVC crystallizer equipment costs, 128
- 6-13 Chemical cost example based on 10 mgd brackish water RO plant, 129
- 6-14 Manpower cost example based on 10 mgd brackish water RO plant, 129
- 6-15 Power consumption example based on 10 mgd brackish water RO plant, 130
  
- 7-1 Disposal methods in the United Kingdom, 142
- 7-2 Comparison of raw water and concentrate, 143
- 7-3 Comparison between salinities of seawater and membrane-filtered concentrates, 143
- 7-4 State of Florida potable water reverse osmosis and nanofiltration systems that discharge to surface waters or ocean outfalls, 145
  
- 8-1 Case study facilities, 156
- 8-2 ZLD water quality parameters, 162
- 8-3 UF membrane design criteria, 162
- 8-4 Concentrate ZLD design flows, 163
- 8-5 EDR system design criteria, 166
- 8-6 EDR water qualities, 167
- 8-7 UF membrane characteristics, 169
- 8-8 RO unit parameters, 169
- 8-9 MF water quality, 170
- 8-10 RO unit parameters, 173
- 8-11 KBH water quality (February 2015), 173
- 8-12 RO system characteristics, 176
- 8-13 Brine concentrator system, 177
- 8-14 Evaporation ponds, 177
- 8-15 MBR system characteristics, 181
- 8-16 RO system characteristics, 181

- 8-17 WDR permit limits for discharge, 181
- 8-18 Monitoring requirements for deep well, 182
- 8-19 Primary RO characteristics, 184
- 8-20 Water quality summary, 184
- 8-21 Secondary RO characteristics, 184
- 8-22 Anticipated chemical usage, 185
  
- 9-1 Water quality before and after pelletized treatment, 197
- 9-2 List of recoverable salts and their potential application, 201

# Preface



With population and economic growth stressing global freshwater supplies, desalination of brackish water and the appropriate management and disposal of concentrate are increasingly attractive options. In the past few decades, the number and capacity of US municipal desalination plants increased rapidly. More than one-third of these facilities are in inland areas. Many concentrate management and disposal options were proven at these facilities, including surface water discharge, discharge to sewer, deep-well injection, land application, discharge to evaporation ponds, near-zero liquid discharge, and zero liquid discharge.

Because of rapid growth, the need for a manual is urgent. The industry has accumulated enough knowledge and experience to provide guidance. After several years of diligent coordination, the AWWA Water Desalting Committee proudly presents AWWA Manual M69, *Inland Desalination and Concentrate Management*.

This manual provides technical and planning guidance for inland water utilities (public and private) that are operating, developing, or considering brackish water desalination. It presents practical information on inland desalination, concentrate treatment technologies and management strategies, permitting procedures, environmental impacts, costs, safety, and more.

The concentrate management topic of this manual is also relevant to direct and indirect potable reuse practices where nanofiltration and reverse osmosis might be utilized. It can also apply to produced water treatment, industrial ultrapure water system brine management, and cooling water blowdown management.

Charlie (Qun) He  
Chair  
*M69 Inland Desalination and  
Concentrate Management*