American Water Works Association

Manual of Water Supply Practices

M61

Second Edition



Desalination of Seawater

Manual of Water Supply Practices

M61

Desalination of Seawater

Second Edition

American Water Works Association

Manual of Water Supply Practices—M61, Second Edition

Desalination of Seawater

Copyright © 2026 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 their 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.

Sr. Editorial Manager, Books: Suzanne Snyder
Manager – Manuals: Molly Beach
Manager – Publishing Operations: Gillian Wink
Specialist – Copyright and Permissions: Peggy Tyler
Director of Publishing: John Fedor
Technical Editor: Anne Lanctôt
Technical Illustrations: Michael Labruyere
Cover Image: antishock/Shutterstock.com
Production: Innodata

Library of Congress Cataloging-in-Publication Data
CIP data pending from the Library of Congress.

ISBN 978-1-64717-260-2 ISBN, electronic 978-1-61300-783-9
http://doi.org/10.12999/AWWA.M61ed2

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. Please send any requests or questions to permissions@awwa.org.

American Water Works Association

American Water Works Association
6666 West Quincy Avenue
Denver, CO 80235-3098
awwa.org

Contents

Figures, v

Tables, vii

Acknowledgments, ix

Preface, xi

Chapter 1 Seawater Desalination Overview 1

1.1 Introduction, 1
1.2 Desalination Technologies Overview, 5
1.3 Membrane Separation, 5
1.4 Thermal Evaporation, 9
1.5 Novel Desalination Processes in Development, 12
References, 17

Chapter 2 Water Quality 19

2.1 Source Water Quality, 19
2.2 Product Water Quality, 22
2.3 Health Concerns, 23
2.4 Product Water Stability, 26
2.5 Irrigation and Industrial Use Concerns, 27
2.6 General Aesthetic Concerns, 30
References, 30

Chapter 3 Treatment Approaches 33

3.1 Pretreatment, 33
3.2 SWRO Design Parameters, 40
3.3 Disinfection, 44
3.4 Posttreatment, 45
3.5 Energy Recovery, 45
3.6 Corrosion and Materials of Construction, 52
References, 56

Chapter 4 Environmental Impacts and Mitigation 57

4.1 Introduction, 57
4.2 General Environmental Considerations in Desalination Plant Design, 59
4.3 Source Water Intakes, 62
4.4 Concentrate Discharge Considerations, 69
4.5 Concentrate Disposal Alternatives, 74
4.6 Management of Desalination Plant Physical Residuals, 81
4.7 Other Environmental Considerations, 93
References, 94

Chapter 5 Cost of Treatment 101

5.1 Introduction, 101
5.2 Cost Overview, 101
5.3 Estimating Capital Costs, 103

5.4 Finished/Treated Water Quality Goals, 107
5.5 Price Market Disruption and Recent Cost Trends, 112
5.6 Estimating O&M Costs, 115
5.7 Cost of Water, 118
References, 122

Chapter 6 Construction and Procurement of Desalination Facilities 125

6.1 Introduction, 125
6.2 Construction and Procurement Methods, 127
6.3 Project Delivery Selection Approach, 136
6.4 Procurement Methods Breakdown, 137
6.5 Summary, 137

Chapter 7 Plant Operations and Maintenance 139

7.1 Introduction, 139
7.2 Management and Staffing, 140
7.3 Process Monitoring and Control, 142
7.4 Membrane Cleaning, 146
7.5 Maintenance, 151
7.6 Chemical Inventory Management, 155
7.7 Spare Parts Management, 156
7.8 Personnel Training, 156
7.9 Safety, 156
7.10 Resiliency, 159
References, 161

Chapter 8 Case Studies 163

Case Study: Claude "Bud" Lewis Carlsbad Desalination Plant (CDP), 164
Reference, 167
Case Study: Escondida Water Supply (EWS) Project, 168
Case Study: Point Lisas Seawater Desalination Facility, 170
Case Study: Sand City Coastal Desalination Project, 174
Case Study: Charles Meyer Desalination Facility, 178
Acknowledgement, 181
References, 181
Case Study: Sorek Seawater Desalination Plant, 183
Case Study: Tampa Bay Desalination Plant (TBWDP), 186
References, 189

Index, 191

AWWA Manuals, 197

Figures

1-1 Global growth of seawater desalination facilities, 2
1-2 Total worldwide installed desalination capacity by feedwater category, 3
1-3 Basic concept of osmosis and reverse osmosis, 6
1-4 Structure of cellulose acetate (CA, left) and thin-film composite (TFC, right) membranes, 7
1-5 Multistage flash distillation, 11
1-6 Multiple effect distillation, 11
1-7 Vapor compression, 12
1-8 Salinity concentration profile during forward osmosis (FO) process, 14

2-1 Global sea-surface salinities, 20
2-2 Boston ivy with tip burn from chloride, 27
2-3 Boron toxicity on camphor, 28

3-1 Projected impact of recovery on power consumption for seawater reverse osmosis (SWRO), 42
3-2 Projected seawater reverse osmosis (SWRO) feed pressure requirements as a function of influent water temperature for different flux rates and element types, 42
3-3 Projected impact of temperature on seawater reverse osmosis (SWRO) permeate boron, 43
3-4 Pelton wheel generator at a seawater reverse osmosis (SWRO) facility, 46
3-5 Hydraulic turbocharger (HTC) in a single-stage reverse osmosis (RO) system., 47
3-6 Hydraulic turbocharger (HTC) in an interstage configuration for brackish water reverse osmosis (BWRO), seawater reverse osmosis (SWRO), and zero liquid discharge applications, 48
3-7 One hydraulic turbocharger (HTC) for a 5.7-mgd train at Ras Al Khair (360,000 m^3/d [97 mgd]), Saudi Arabia, commissioned in 2015. Only one ERD per train, no auxiliary equipment required. Approximate volumetric footprint is 1 m^3 (35 ft^3)., 48
3-8 Isobaric energy recovery device (ERD) flow diagram, 49
3-9 Isobaric PX™ pressure exchanger device (ERD) installation in Sand City, Calif., 49
3-10 Dual work pressure exchanger (DWEER) flow diagram, 50
3-11 Installation of flowserve dual work exchangers (DWEER) energy recovery device (ERD), 50
3-12 Three-center design layout, 51
3-13 Resistance to crevice corrosion, 52

4-1 Current concentrate management practices, 74
4-2 Costs of water produced by renewable versus fossil fuel–driven desalination, 93

5-1 Unit construction cost of seawater reverse osmosis (SWRO) desalination facilities worldwide 1996–2020 (2020 US$), 112

5-2 Unit construction cost of seawater reverse osmosis (SWRO) desalination facilities worldwide from 1996–2020 (2020 US$) with recent 2023 facilities, 114

6-1 Desalination capacities by continents (a) and percentage by continents out of total capacity 97M m^3/d (b) annual increase, 126

7-1 Screen shot of a reverse osmosis (RO) clean-in-place system SCADA screen, 146

7-2 Seawater reverse osmosis (SWRO) membrane heavily fouled with suspended solids as a result of undersized upstream multimedia filters, 148

7-3 Scanning electron microscope image of foulants (in green) on a reverse osmosis (RO) membrane, 149

7-4 Membrane relocation alternative method examples, 152

7-5 Operators performing maintenance on an inline turbidimeter for raw water feed to a seawater reverse osmosis (SWRO) plant, 153

7-6 A reverse osmosis (SWRO) facility with security fencing and guard station, 161

8-1 Schematic of the Claude "Bud" Lewis Carlsbad Desalination Plant system, 165

8-2 Process flow diagram for Point Lisas Desalination Plant, 171

8-3 Point Lisas microfiltration (MF) system, 172

8-4 Point Lisas seawater reverse osmosis (SWRO) system, 173

8-5 Sand City (Calif.) Desalination Facility, 175

8-6 Sand City, Calif., reverse osmosis (RO) system, 176

8-7 Containerized treatment systems used in 2017 plant retrofit (City of Santa Barbara 2022), 180

8-8 Schematic of the treatment system, 187

Tables

1-1 Operational seawater desalination facilities in the United States, 4
1-2 Membrane-based desalination processes, 6

2-1 Seawater mineral quality compared to conventional source waters, 20
2-2 Log reduction requirements, 25

3-1 Seawater reverse osmosis (SWRO) pretreatment components for surface seawater sources, 36
3-2 Seawater reverse osmosis (SWRO) pretreatment nonconventional technologies for surface seawater sources, 38
3-3 Partial list of pretreatment installations in seawater reverse osmosis (SWRO) plants since 2005, 39
3-4 Log removal credits for potential treatment processes, 44
3-5 Energy recovery devices (ERDs): pros and cons, 51
3-6 Galvanic series for alloys in flowing seawater at 4 m/s and 24°C, 53
3-7 Pitting resistance equivalent number (PREN) values for common materials, 54

4-1 Energy use for alternative freshwater production methods, 58
4-2 Cost of water of recent desalination projects in the Middle East and Israel, 61
4-3 Potential impingement/entrainment (I&E) reduction technologies, 68
4-4 Residuals from seawater desalination processes, 82
4-5 Comparison of waste streams from granular media and membrane pretreatment, 82
4-6 Carlsbad desalination project net greenhouse gas (GHG) emission zero balance, 90
4-7 Indicative pricing for greenhouse gas (GHG) offsets based on locational hierarchy as of September 2020, 91

5-1 Estimated construction cost range of surface intakes (US$), 106
5-2 Cost estimates for constructing subsurface intakes (SSIs), 107
5-3 Examples of cost indices, 113
5-4 Construction cost estimates, 114
5-5 Water production costs for medium and large seawater reverse (SWRO) osmosis desalination facilities worldwide, 118
5-6 An example of a seawater reverse osmosis (SWRO) plant capital costs, 119
5-7 An example of annual operation and maintenance (O&M) costs for treatment technology: seawater reverse osmosis (SWRO), 120
5-8 An example of total costs water treatment technology: seawater reverse osmosis (SWRO), 121

7-1 Desalination operations and maintenance (O&M) staff, 142
7-2 Process parameter monitoring for seawater reverse osmosis (SWRO) desalination plants, 143

7-3 Typical standard operating procedures (SOPs) for seawater reverse osmosis (SWRO) desalination plants, 145

7-4 Impact of process variable on clean-in-place (CIP) frequency and possible actions to mitigate, 147

7-5 Routine maintenance activities, 154

8-1 Israel drinking water quality targets, 184

Acknowledgments

The AWWA Technical & Educational Council, the Water Resources Sustainability Division, and the Water Desalting Committee gratefully acknowledge the contributions made by those volunteers who drafted, edited, and provided the significant and critical commentary essential to updating M61.

Chair

Greg Wetterau, CDM Smith, Rancho Cucamonga, Calif.

Quality Control Committee

Angie Brown, AWWA, Denver, Colo.

Casey Rodriguez, AWWA, Denver, Colo.

John Thompson, Desalination Company of Trinidad & Tobago Ltd., Point Lisas, Trinidad

John Tonner, American Membrane Technology Association, Englewood, Fla.

Greg Wetterau, CDM Smith, Rancho Cucamonga, Calif.

Contributors

Giancarlo Barassi, Aquatech, Tampa, Fla.

Mark Donovan, GHD, Inc., Irvine, Calif.

Keith Downer, Seven Seas Water, Tampa, Fla.

Val S. Frenkel, TYLin International, San Francisco, Calif.

Mo Malki, American Water Chemicals, Inc., Plant City, Fla.

Laila Martin, Tampa Bay Water, Tampa, Fla.

Erin Messner, Colorado Water Congress, Denver, Colo.

Chris Morss, US Water Services Corporation, Truckee, Calif.

Rubén Muñoz, CDM Smith, Dallas, Tex.

Chandra Mysore, CHA Solutions, Atlanta, Ga.

Christine Owen, Hazen and Sawyer, Tampa, Fla.

Christian Sanders, Veolia Water, Sydney, Australia

Say Sengsouvanna, Iv3 Aqua Corporation, Lakeland, Fla.

Kevin Thomas, Kimley-Horn and Associates, Inc., Riverside, Calif.

John Thompson, Desalination Company of Trinidad & Tobago Ltd., Point Lisas, Trinidad

Cecile Toupiol, CDM Smith, Amman, Jordan

Rajendra Vaidya, PCL Construction, Inc., Tampa, Fla.

Srinivas (Vasu) Veerapaneni, Black & Veatch, Overland Park, Kan.

Nikolay Voutchkov, NEOM, Sharma, Saudi Arabia

Steve Wait, GHD, Inc., Santa Cruz, Calif.

Peter Walkemeyer, Sedgman Onyx Pty Ltd., Perth, Australia

Greg Wetterau, CDM Smith, Rancho Cucamonga, Calif.

Richard Whiting, Water Sector Consulting LLC, Tampa, Fla.

Zita L.T. Yu, Jacobs, Los Angeles, Calif.

©2026 American Water Works Association

This page intentionally blank.

©2026 American Water Works Association

Preface

As global populations continue to grow and traditional water supplies become increasingly stressed, many municipalities have been considering the ocean as a potential source of sustainable and long-term water supply. Continuing technological advancements in water treatment, water quality monitoring, energy recovery, and renewable energy supply have been transforming seawater desalination from a niche water supply for wealthy desert regions into a realistic and competitive alternative for many coastal areas facing supply challenges in their futures. In the United States, most desalination facilities have historically treated brackish groundwater, with an increasing number treating municipal wastewater for potable reuse; however, seawater desalination plants globally outnumber brackish water plants by nearly 3 to 1. Desalination facilities treating ocean water are currently operated in the United States in Florida, California, Massachusetts, and Washington, among other locations, with moderate- and large-scale facilities being planned or evaluated in coastal areas across the country.

With the growing interest in and increasing need for desalination as a source of water supply, this manual provides guidance for municipalities, water supply planners, and industrial water users considering ocean desalination as an alternative in their supply portfolios. The manual is an update to the first edition AWWA Manual M61 published over a decade ago and includes updated information on the rapidly evolving industry, as well as new chapters on construction and procurement, operations and maintenance, and case studies.

The manual provides a summary of the current state of practice for seawater desalination, including an overview of technologies, delivery methods, and key issues associated with the implementation of seawater desalination. Environmental protection has become a major focus for desalination facilities as plants become larger and more widespread and society looks for sustainable solutions to our long-term challenges. While there are inherent environmental benefits to the introduction of new freshwater supplies into water stressed areas, there have also been concerns raised over the environmental impacts of seawater intakes, concentrate discharge, and greenhouse gas emissions. This manual includes a detailed discussion of strategies being used or considered to address these concerns while maintaining the social and environmental benefits of new freshwater supplies and ensuring that these sustainable supplies remain truly sustainable for the foreseeable future.

Greg Wetterau

Subcommittee Chair, M61 Desalination of Seawater

©2026 American Water Works Association

This page intentionally blank.

©2026 American Water Works Association

Chapter 1

Seawater Desalination Overview

Second Edition Author: Greg Wetterau

First Edition Authors: Sandeep Sethi, Greg Wetterau

1.1 INTRODUCTION

With global populations continuing to grow and freshwater supplies becoming increasingly stressed, many coastal areas have been turning to oceans and saline seas as a source of water supply. Three-quarters of the globe is covered with water; however, the vast majority is too saline for human consumption, and less than 0.3 percent is considered a renewable freshwater supply. More than half of the population in the United States lives within 50 mi (80 km) of an ocean gulf coast, and 40 percent of the world's population lives within 60 mi (100 km) of a type of saltwater coast, so the ability to convert seawater into a reliable source of drinking water supply holds tremendous interest, both within the United States and throughout the world. This type of adaptation is considered part of a growing blue economy (United Nations 2021) and can help boost sustainable development while relieving the pressures placed on overtaxed freshwater resources resulting from growing populations and increased urbanization.

The over-withdrawal of freshwater resources not only jeopardizes the communities that rely on them but degrades their surrounding habitats and disrupts essential ecosystem processes. As these finite resources become depleted, water utilities and their communities face the risk of elevated vulnerability in times of extreme drought or natural disasters unless alternative sources are secured. Seawater desalination presents an opportunity to provide a consistent and reliable water supply, reinforcing water security in coastal regions. As coastal populations continue to rise, with growth also predicted for the foreseeable future, seawater desalination provides a valuable tool to accommodate the unavoidable spikes in water demand.

©2026 American Water Works Association