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AWWA WEBINAR

SEPTEMBER 9, 2020 | 11:00 A.M. - 12:30 P.M. MT

Inland Desalination and Concentrate Management

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WEBINAR MODERATOR

Corinne Bertoia
Engineer
American Water Works Association

Corinne Bertoia is an Engineer at the American Water Works Association. Her responsibilities include reviewing and developing technical programs and supporting the Divisions and Committees of the Technical and Education Council. Corinne received her MASc. in Civil Engineering from the University of Toronto in 2018, where her research focused on the removal of NDMA precursors from drinking water biofilters.

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PANEL OF EXPERTS

Charlie He
Vice President, Chief Technologist – Decision Support
Carollo Engineers, Inc.

Brent Alspach, PE, BCEE
Director of Applied Research
Arcadis

Dave Stewart, PhD, PE
President
Stewart Environmental Consulting Group, LLC

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AGENDA

I.	Overview of M69 - Inland Desalination and Concentrate Management	Charlie He
II.	Cost-Effective ZLD Technology for Desalination Concentrate Management	Brent Alspach
III.	Chapter 7 – Regulatory, Safety, Operational and Environmental Issues	Dave Stewart, PhD, PE

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ASK THE EXPERT

Charlie He
Carollo Engineers, Inc.

Brent Alspach, PE, BCEE
Arcadis

Dave Stewart, PhD, PE
Stewart Environmental Consulting Group, LLC

Enter your **question** into the **question pane** on the right-hand side of the screen.

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Engineers...Working Wonders With Water®

OVERVIEW OF M69

Inland Desalination and Concentrate Management

Charlie He

Vice President,
Chief Technologist – Decision Support

Carollo Engineers, Inc.

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LEARNING OBJECTIVES

1. Gain an in-depth understanding of water quality impacts on pretreatment requirements, membrane processes, and non-ZLD and ZLD concentrate management technologies and disposal options
2. Broaden knowledge basis and access to useful resources for implementing inland desalination and concentrate management facilities
3. Learn mitigation measures and tools for assessing, addressing, and communicating the regulatory issues and environmental concerns associated with these technologies
4. Obtain guidance on available practices for reducing the energy consumption and treatment costs of inland desalination and concentrate management facilities

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OVERVIEW OF M69

INLAND DESALINATION AND
CONCENTRATE MANAGEMENT

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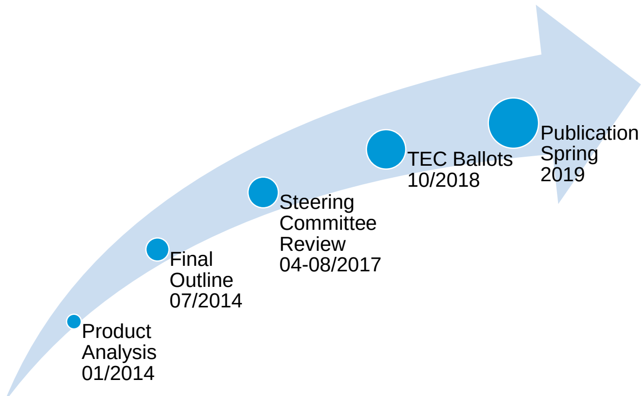
M69 - INLAND DESALINATION & CONCENTRATE MANAGEMENT



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M69 - INLAND DESALINATION & CONCENTRATE MANAGEMENT - TABLE OF CONTENTS

- Chapter 1 – Overview
- Chapter 2 – Water Quality and Planning Strategies
- Chapter 3 – Brakish Water Desalination Technologies
- Chapter 4 – Discharge Options for Concentrate Disposal
- Chapter 5 – Enhanced Recovery and Zero Liquid Discharge
- Chapter 6 – Cost of Desalination and Concentrate Management
- Chapter 7 – Regulatory, Safety, Operational and Environmental Issues
- Chapter 8 – Case Studies
- Chapter 9 – Salt Recovery, Beneficial Uses and Technology Trends

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M69 - INLAND DESALINATION & CONCENTRATE MANAGEMENT - ACKNOWLEDGING THE AUTHORS

- **Chapter 1:** Inland Desalination Overview ***(Greg Wettereau** and Mike Mickley**)***
- **Chapter 2:** Water Quality and Planning Strategies ***(Charlie He**, **Arun Subramani,** Greg Wetterau, and Vasu Veerapaneni**)***
- **Chapter 3:** Brackish Water Desalination ***(Val S. Frenkel and Greg Wettereau)***
- **Chapter 4:** Non ZLD Concentrate Disposal and Management ***(Rick Bond and Sandeep Sethi)***
- **Chapter 5:** ZLD Concentrate Management ***(Brent Alspach and Graham Juby)***
- **Chapter 6:** Cost of Treatment ***(J.T. Aguinaldo and Rick Bond)***
- **Chapter 7:** Regulatory, Safety, Operational and Environmental Issues ***(Dave Stewart,** Fred Bloetscher, **and Melanie Goetz)***
- **Chapter 8:** Case Studies ***(Howard E. Steiman and Qigang Chang,)***
- **Chapter 9:** Salt Recovery, Beneficial Uses and Technological Trends ***(Ali Sharbat** and Charlie He**)***

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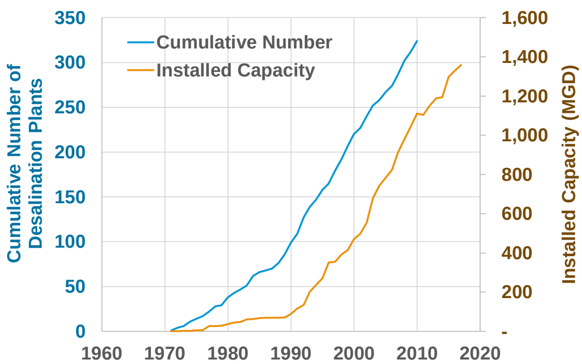
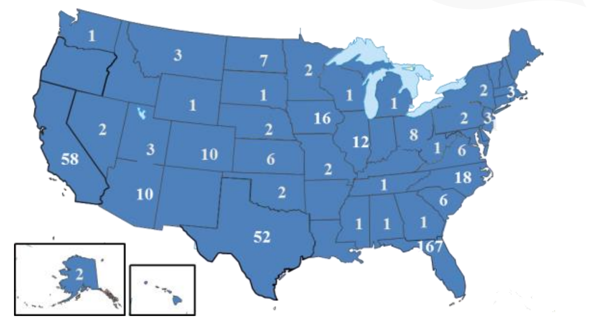
CHAPTER 1 – OVERVIEW OF INLAND DESALINATION



Cumulative number and capacity of US municipal desalination plants (Mickley 2018)



Number of U.S. municipal desalination plants by state (2017)

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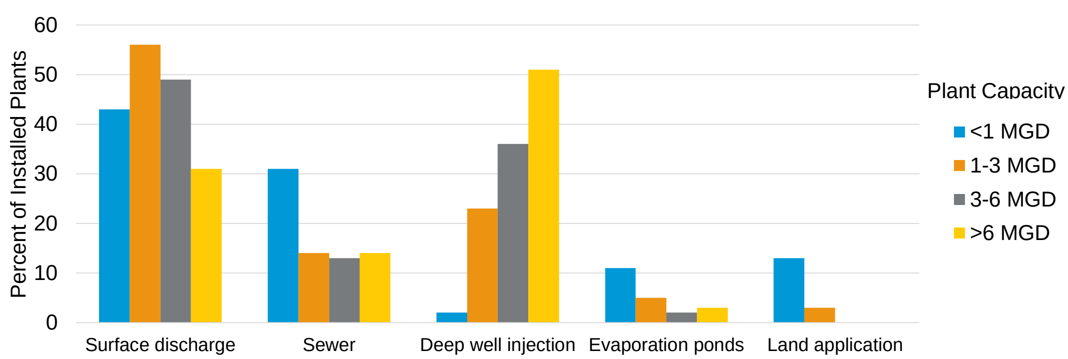
CONCENTRATE DISPOSAL OPTIONS FOR US MUNICIPAL DESALINATION PLANTS (CHAPTER 1 CONTINUED)



Concentrate disposal options for US municipal desalination plants (Mickley 2018)

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CHAPTER 2 – WATER QUALITY AND PLANNING STRATEGIES

- Evaluate **source water quality** / quantity, characteristics of **limiting** contaminants
- Establish site-specific **product water quality goals** and **discharge limits**
- Identify **treatment requirements** based on above and develop **site specific planning strategies**
- **Combine** strategies and technologies into a cost-effective solution and project design
- **Demonstrate** efficiencies of critical components through bench-scale and pilot **testing**.
- **Optimize and enhance** customized strategies and solutions.

Steps for Solving Concentrate Management Problems

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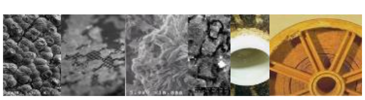
NO COOKIE CUTTER BUT TOOLS ARE AVAILABLE TO HELP UTILITIES MANAGE SALINITY (CHAPTER 2 CONTINUED)

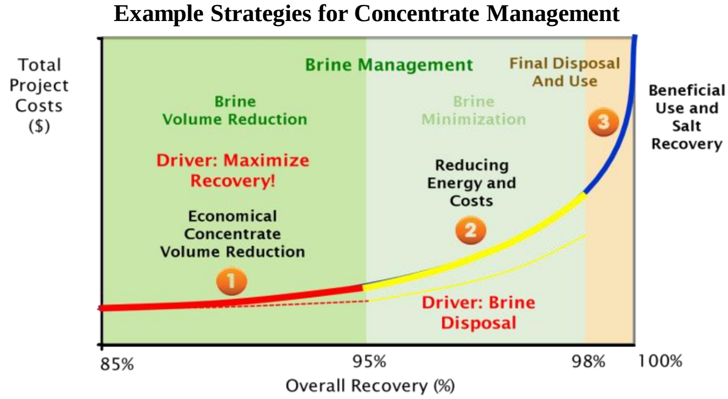


Understanding Water Quality Issues

RO and EDR Performance Projection Tools

Salt Balance and Decision Support Tools

Example Strategies for Concentrate Management



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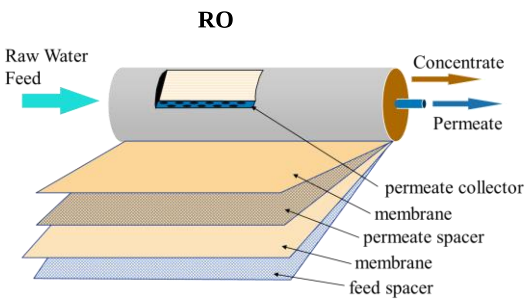
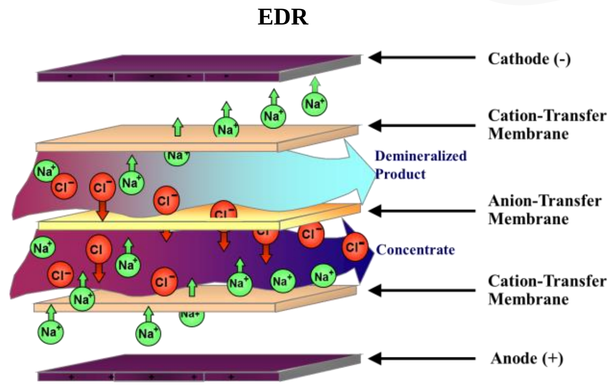
CHAPTER 3 – BRACKISH WATER DESALINATION TECHNOLOGIES





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CHAPTER 3 KEY TOPICS (CHAPTER 3 CONTINUED)

Basics of Process	TFC, Osmotic, Efficiency	Stacks, Ion exchange membrane, Spacer
Membrane Characteristics	NF vs. RO, Spiral Wound, Array, Stage	ED vs. EDR, Electrical and Hydraulic Stages
Design Considerations	Recovery, Flux Balancing, Energy Recovery	Current Density and Polarization, Current Leakage, Current Efficiency, Polarity Reversal
Operation and Safety	Integrity Monitoring, Chemical Cleaning, Safety	Off Spec, Electrode Stream Recycle, Chemical Cleaning, Stack Repair, Safety
Pretreatment	Cartridge Filters, Sand, Iron / Mn, Integrated membrane system	Turbidity, Iron, Manganese, Hydrogen Sulfide, Chlorine
Post-treatment	pH adjustment, stabilization, disinfection	

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CHAPTER 4 – DISCHARGE OPTIONS FOR CONCENTRATE DISPOSAL

Disposal and Discharge Options

- Discharge to surface water
- Discharge to sewer or brine-line
- Deep-well injection
- Evaporation ponds
- Enhanced evaporation systems
- Irrigation

Deep injection well

Evaporation ponds

Halophyte Wetlands

Enhanced Evaporation

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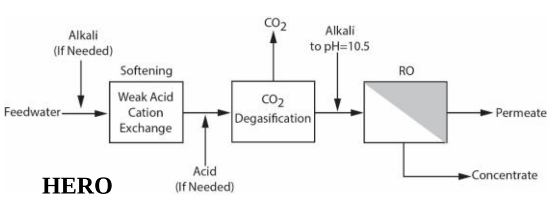
CHAPTER 5 – ENHANCED RECOVERY AND ZERO LIQUID DISCHARGE



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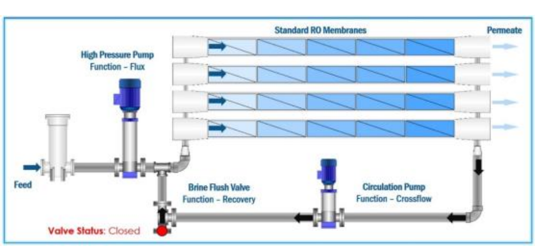

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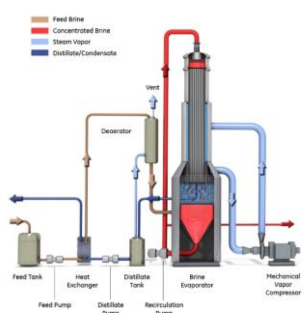
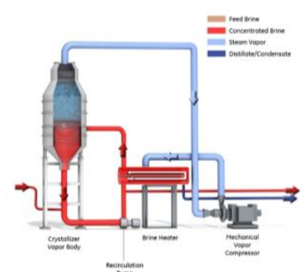


Brine Concentrator



Crystallizer

Other ZLD and Near ZLD Process Presented in this Chapter:
Enhanced Recovery (Softening), EDM, MD, SPARRO, VSEP, FO

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CHAPTER 6 – COST OF DESALINATION AND CONCENTRATE MANAGEMENT

Capacity in mgd	MF/UF Train Cost	Unit Cost ($/gpd)
0.5	$ 400,000	$ 0.8
1.0	$ 700,000	$ 0.7
2.0	$1,200,000	$ 0.6
3.0	$1,500,000	$ 0.5
5.0	$2,000,000	$ 0.4
7.5	$2,850,000	$ 0.38
10.0	$3,700,000	$ 0.36

Typical MF/UF construction cost*
- * 2014 ENR CCI = 10,732

Capacity, mgd	NF/RO Train Cost	Unit Cost ($/gpd)
0.50	$600,000	$ 1.20
0.75	$860,000	$ 1.15
1.0	$1,100,000	$ 1.10
1.5	$1,500,000	$ 1.00
2.0	$1,800,000	$ 0.90
3.0	$2,400,000	$ 0.80
5.0	$3,500,000	$ 0.70
7.5	$4,950,000	$ 0.66
10.0	$6,250,000	$0.65

Typical brackish water NF/RO membrane construction cost*
- * 2014 ENR CCI = 10,732

Highlight Key Contents

- Example capital costs for
  - MF/UF
  - NF/RO
  - Solids contact clarifier
  - Pelletized softening
  - Brine concentrator and crystallizer
  - Deep well injection
  - Evap pond
- O&M Costs
  - Power
  - Chemical
  - Membrane replacement
  - Labor
  - Solids

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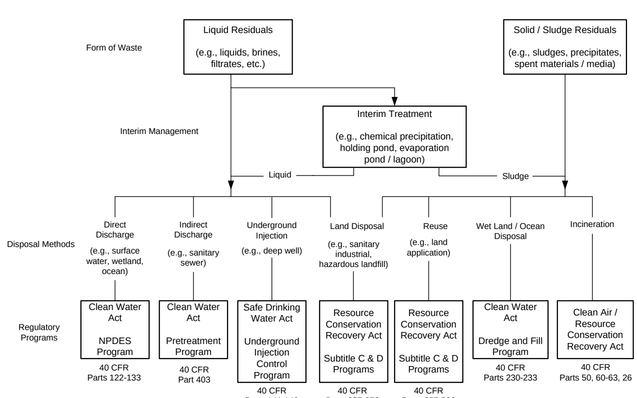
CHAPTER 7 – REGULATORY, SAFETY, OPERATIONAL AND ENVIRONMENTAL ISSUES



Federal Regulations wrt Inland Desalination

Federal Regulations

Clean Water Act (Discharge to surface waters)
Safe Drinking Water Act
Resource Conservation and Recovery Act (Solid Waste)
Comprehensive Environmental Response, Compensation and Liability Act (Superfund)
TENROMS – radioactive particles

State Regulations

Texas
Colorado
California
Toxicity Issues

Public Participation and Outreach

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CHAPTER 8 – CASE STUDIES

Facility	Owner	Concentrate Management Approach
Ocotillo Brine Reduction Facility	Intel Corporation, Chandler, Ariz.	Zero liquid discharge utilizing softening for enhanced recovery with a brine concentrator and evaporation ponds
Water Treatment Plant No. 2	City of Palm Coast, Fla.	Zero liquid discharge using lime and soda ash softening and recycling
Fort Irwin, Calif.	US Army	Deep-well injection
City of Fargo Wastewater Effluent Reuse	City of Fargo, N.Dak.	Surface water discharge
Kay Bailey Hutchison Brackish Groundwater Desalination Plant	El Paso Water Utilities, El Paso, Tex.	Current: deep-well injection; future: enhanced concentrate recovery through recovery of saleable minerals employing treatment processes such as softening, nanofiltration, and electrodialysis
Confidential, Calif.	Confidential, Calif.	Zero liquid discharge using brine concentrator and evaporation ponds
Laguna County Sanitation District, Santa Maria, Calif.	Laguna County Sanitation District	Concentrate volume minimization and deep-well injection
Chino II	Chino Basin Desalter Authority, Calif.	Enhanced concentrate recovery and brine line disposal

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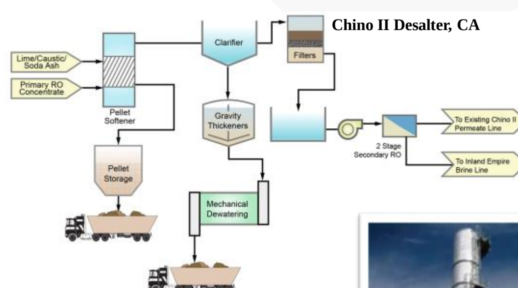
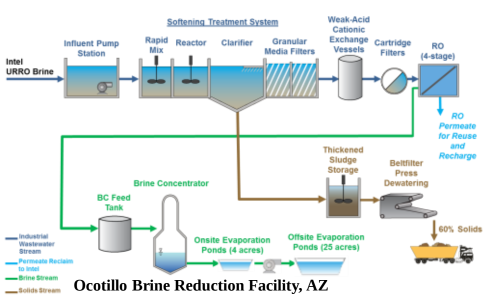
CASE STUDY FACILITIES



Chino II Desalter, CA



Ocotillo Brine Reduction Facility, AZ

City of Palm Coast ZLD Reverse Osmosis Concentrate Management

Kay Bailey Hutchison Brackish Groundwater Desalination Plant , TX

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CHAPTER 9 – SALT RECOVERY, BENEFICIAL USES AND TECHNOLOGY TRENDS

Key Trends Discussed:

- **Innovation in membrane technology**
- Innovative system design and operation
- Innovative processes
- Improvements in energy efficiency
- Improved salt recovery and beneficial uses of concentrate

New NF/RO Membranes
- **m-phenylenediamine (MPD) and trimesoyl chloride (TMC)**
- **Mixed matrix membranes (MMM)**
- **Nano-modified membranes**

Ion selective EDR membranes
Carbon nanotubes
Biomimetic membranes

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CHAPTER 9 – SALT RECOVERY, BENEFICIAL USES AND TECHNOLOGY TRENDS

Key Trends Discussed:

- Innovation in membrane technology
- **Innovative system design and operation**
- Innovative processes
- Improvements in energy efficiency
- Improved salt recovery and beneficial uses of concentrate

- **Innovations in Membrane Scaling Monitoring**
- **Reversible RO Configuration**
- **Closed-circuit Desalination Process**
- **Advancement in Reverse Osmosis Membrane Cleaning**

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CHAPTER 9 – SALT RECOVERY, BENEFICIAL USES AND TECHNOLOGY TRENDS

Key Trends Discussed:

- Innovation in membrane technology
- Innovative system design and operation
- **Innovative processes**
- Improvements in energy efficiency
- Improved salt recovery and beneficial uses of concentrate

- **Vortex-based Anti-fouling Membrane System**
- **Electrodialysis Metathesis**
- **Thermo-ionic Technology**
- **AquaSel™**
- **Adsorption Desalination**
- **Customized hybrid systems**

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CHAPTER 9 – SALT RECOVERY, BENEFICIAL USES AND TECHNOLOGY TRENDS

Key Trends Discussed:

- Innovation in membrane technology
- Innovative system design and operation
- Innovative processes
- **Improvements in energy efficiency**
- Improved salt recovery and beneficial uses of concentrate

- **Energy Recovery Devices**
- **Hybridization of Desalination and Power Plants**
- **Use of Renewable Energy**

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CHAPTER 9 – SALT RECOVERY, BENEFICIAL USES AND TECHNOLOGY TRENDS

Key Trends Discussed:

- Innovation in membrane technology
- Innovative system design and operation
- Innovative processes
- Improvements in energy efficiency
- **Improved salt recovery and beneficial uses of concentrate**

- **Pelletized Lime Softening Process**
- **SAL-PROC™ Process**
- **Selective Salt Recovery Techniques**
- **Advanced Solar Dryer Process**
- **Advanced Solar Dryer Process**
- **Other Chemical Precipitation Processes**
- **Biological Precipitation Process**
- **Recoverable Salts**

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SUMMARY

- Inland concentrate management practice undertook a fast growth period and became more and more “tried and true”
- First Manual on Inland Desalination and Concentrate Management coming soon
- A wide range of issues, technologies, tools presented in depth, along with useful flow charts, example costs, case studies
- Equip utilities with “all you need to know” on implementing inland desalt and concentrate management

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ASK THE EXPERT

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Enter your **question** into the **question pane** on the right-hand side of the screen.

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ARCADIS

Cost-Effective ZLD Technology for Desalination Concentrate Management

Brent Alspach, PE BCEE
Director of Applied Research
Arcadis

September 9, 2020

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ZLD Overview

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ZLD Defined

As defined in this work:

- Applied to desalination residuals
  - Could also apply to conventional treatment residuals handling
  - Literature can be vague
- Assumed ~100% recovery
  - Not "near" ZLD (NZLD)
  - Solid slurry discharge transported offsite for beneficial use or disposal
- Not a boutique process
  - Not limited to certain concentrate water quality characteristics
  - Applicable virtually anywhere

→ "Conventional" ZLD

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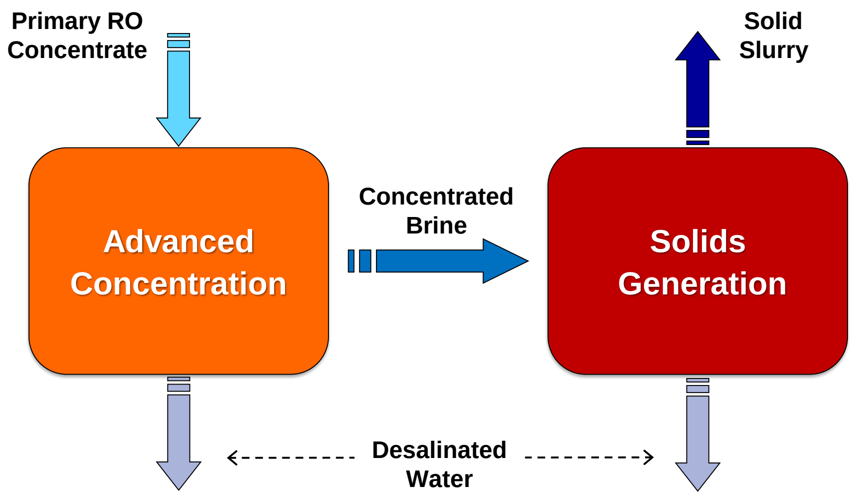
Conventional ZLD Concept



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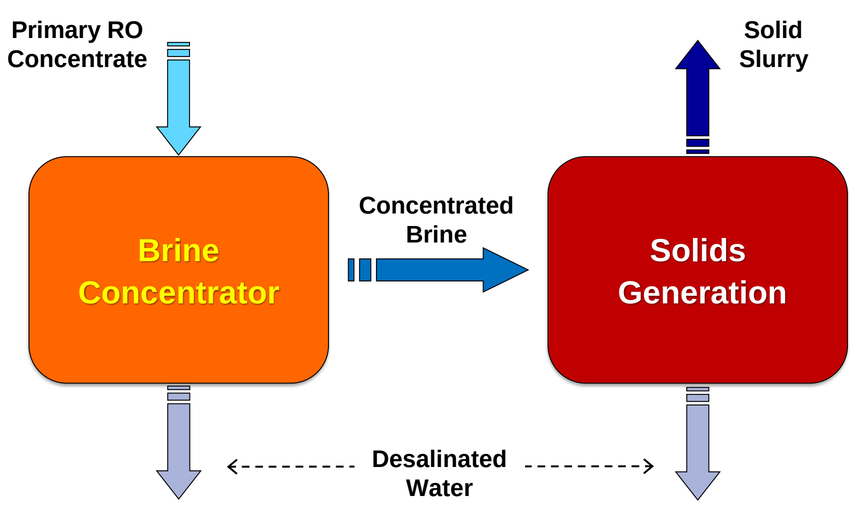
Conventional ZLD Concept



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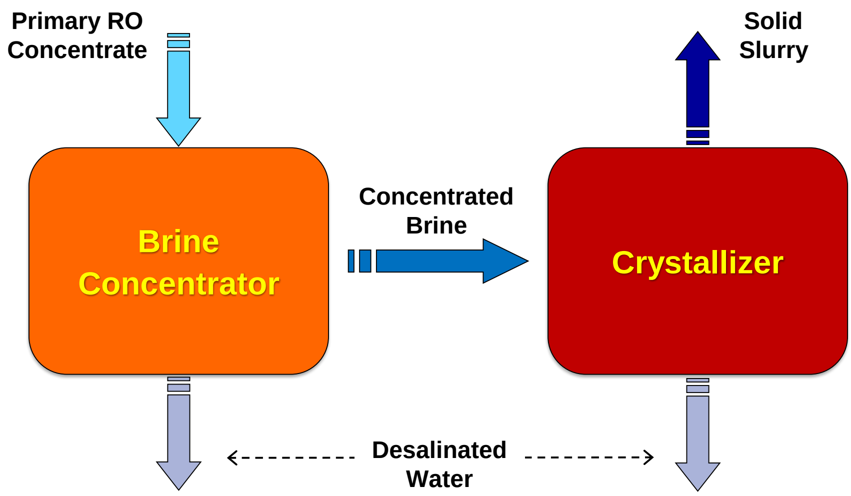
Conventional ZLD Concept



Conventional ZLD Concept

Feasibility Benefits:

- ✓ Application not limited by water quality
- ✓ Minimal environmental impact (if any)
- ✓ Few regulatory limitations (if any)
- ✓ Minimal practical restrictions (e.g., scale, footprint, etc.)

Feasibility Detriments:

- ✗ Cost

Conventional ZLD Concept

Feasibility Benefits:

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- ✓ Minimal practical restrictions (e.g., scale, footprint, etc.)

Feasibility Detriments:

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Maybe.

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Brine Concentrators

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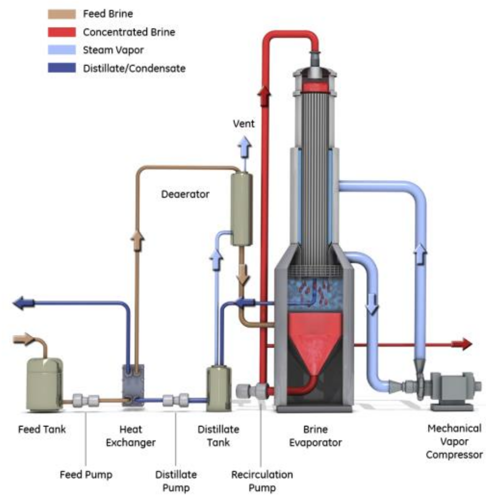
Brine Concentrators



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Brine Concentrators

<u>What You Need to Know</u>

- Utilize mechanical vapor compression (thermal) technology
- Pretreatment is important

Process / Additive	Purpose
Acid	Prevent scaling; convert bicarbonate to carbon dioxide
Deaeration	Strip carbon dioxide to prevent corrosion
$CaSO_4$ Crystals	Introduce precipitation nuclei to prevent surface scaling
Scale Inhibitor	Prevent scaling / maintain efficient heat transfer

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Brine Concentrators

What You Need to Know

- Utilize mechanical vapor compression (thermal) technology
- Pretreatment is important

Process / Additive	Purpose
Acid	Prevent scaling; convert bicarbonate to carbon dioxide
Deaeration	Strip carbon dioxide to prevent corrosion
$CaSO_4$ Crystals	Introduce precipitation nuclei to prevent surface scaling
Scale Inhibitor	Prevent scaling / maintain efficient heat transfer

Scale control is a key consideration.

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Brine Concentrators

What You Need to Know

- Utilize mechanical vapor compression (thermal) technology
- Pretreatment is important
- Distillate (treated water) TDS < 10 mg/L
- Brine TDS ≈ 180,000 - 250,000 mg/L
  - Maximum TDS = f(scaling potential)
  - May achieve up to ~300,000 mg/L with softening pretreatment
- Specific energy requirements ≈ 60 - 90 kWh/kgal distillate
  - Higher specific energy requirements for higher degrees of concentration
  - Assumes the use of electric (grid) power (i.e., no waste heat)

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Brine Concentrators

Disadvantages

- System complexity
- Minimal institutional operations knowledge / experience
- Responds slowly to flow changes → equalization storage required
- Requires a source of steam for start-up, including after every maintenance event
  - Dedicated boiler
  - Other on-site stream generating process
- Aesthetics

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Crystallizers

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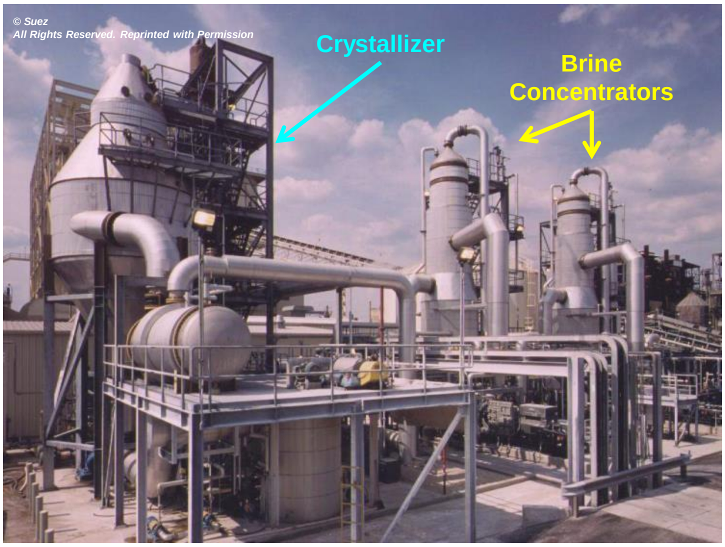
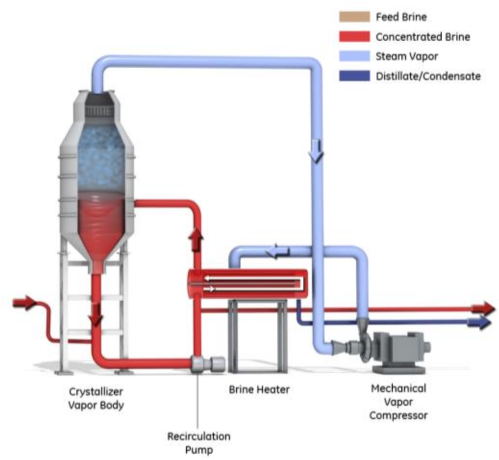
Crystallizers





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Crystallizers

What You Need to Know

- Utilize mechanical vapor compression (thermal) technology
- Pretreatment for scale control is not used
- Distillate (treated water) TDS ≈ 30 - 50 mg/L
- Centrifuges are used to dewater the solid slurry residuals
- Specific energy requirements ≈ 180 - 250 kWh/kgal distillate
  - Higher specific energy requirements for more highly soluble species (e.g., higher concentrations of nitrate salts)
  - Assumes the use of electric (grid) power (i.e., no waste heat)

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Crystallizers

Disadvantages

- System complexity
- Minimal institutional operations knowledge / experience
- Responds slowly to flow changes → equalization storage required
- Requires a source of steam for start-up, including after every maintenance event
  - Dedicated boiler
  - Other on-site stream generating process
- Aesthetics

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Crystallizers

Disadvantages

- System complexity
- Minimal institutional operations knowledge / experience
- Responds slowly to flow changes → equalization storage required
- Requires a source of steam for start-up, including after every maintenance event
  - Dedicated boiler
  - Other on-site stream generating process
- Aesthetics

Same disadvantages as brine concentrators

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Cost Considerations

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The Influence of Energy

Desalination Costs Hinge on Energy!

Desalination Process Specific Energy Comparison		
Process	**Specific Energy (kWh/kgal)**	**Specific Energy Ratio[1]**
Seawater Desalination	10 - 15	1
Brine Concentrators	60 - 90	4x - 9x
Crystallizers	180 - 250	12x - 25x

1 Relative to seawater desalination

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Examples of ZLD Cost

Sample ZLD Treatment Cost Summary[1]

Case	Capacity[2] (MGD)	Capital Cost ($/gpd)	O&M Cost ($/kgal)	Amortized Cost[3] ($/kgal)
ZLD-1	1	$41.11	$19.11	$29.12
ZLD-2	0.5	$56.77	$20.29	$34.25
ZLD-3	0.25	$86.13	$23.67	$44.24
ZLD-4	0.125	$133.11	$28.07	$59.87

1 USBR Desalination and Water Purification Research and Development Program, Report No. 149 (Juby et al. 2008)
2 Assumes 100 percent recovery (i.e., ZLD feed flow = ZLD treated water flow)
3 Amortization over 20 years at a 6 percent annual interest rate

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Examples of ZLD Cost

Sample ZLD Treatment Cost Summary[1]

Case	Capacity[2] (MGD)	Capital Cost ($/gpd)	O&M Cost ($/kgal)	Amortized Cost[3] ($/kgal)
ZLD-1	1	$41.11	$19.11	**$29.12**
ZLD-2	0.5	$56.77	$20.29	**$34.25**
ZLD-3	0.25	$86.13	$23.67	**$44.24**
ZLD-4	0.125	$133.11	$28.07	**$59.87**

Carlsbad SWRO Costs:
~ $6 - $7 per kgal

1 USBR Desalination and Water Purification Research and Development Program, Report No. 149 (Juby et al. 2008)
2 Assumes 100 percent recovery (i.e., ZLD feed flow = ZLD treated water flow)
3 Amortization over 20 years at a 6 percent annual interest rate

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Examples of ZLD Cost

Sample ZLD Treatment Cost Summary[1]				
Case	Capacity[2] (MGD)	Capital Cost ($/gpd)	O&M Cost ($/kgal)	Amortized Cost[3] ($/kgal)
[redacted]	[redacted]	[redacted]	[redacted]	**$29.12**
[redacted]	[redacted]	[redacted]	[redacted]	**$34.25**
[redacted]	[redacted]	[redacted]	[redacted]	**$44.24**
[redacted]	[redacted]	[redacted]	[redacted]	**$59.87**

What about brackish water RO?

1 USBR Desalination and Water Purification Research and Development Program, Report No. 149 (Juby et al. 2008)
2 Assumes 100 percent recovery (i.e., ZLD feed flow = ZLD treated water flow)
3 Amortization over 20 years at a 6 percent annual interest rate

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Examples of BWRO Cost

Sample RO Treatment Cost Summary @ 80% Recovery						
Case	Capacity (MGD)			Capital Cost[1] ($/gpd)	O&M Cost[1] ($/kgal)	Amortized Cost[2] ($/kgal)
	Feed	Perm.	Conc.			
RO-1	5	4	1	$0.58	$0.30	$0.44
RO-2	2.5	2	0.5	$0.80	$0.40	$0.59
RO-3	1.25	1	0.25	$1.11	$0.60	$0.87
RO-4	0.625	0.5	0.125	$1.54	$0.70	$1.07

1 Adapted from Bergman and Elarde, 2003 (escalated to 2008 dollars)
2 Amortization over 20 years at a 6 percent annual interest rate

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Examples of BWRO Cost

Sample RO Treatment Cost Summary @ 80% Recovery

Case	Capacity (MGD)			Capital Cost[1] ($/gpd)	O&M Cost[1] ($/kgal)	Amortized Cost[2] ($/kgal)
	Feed	Perm.	Conc.			
RO-1	5	4	1	$0.58	$0.30	**$0.44**
RO-2	2.5	2	0.5	$0.80	$0.40	**$0.59**
RO-3	1.25	1	0.25	$1.11	$0.60	**$0.87**
RO-4	0.625	0.5	0.125	$1.54	$0.70	**$1.07**

Costs of BWRO are ~1-2 orders of magnitude lower than ZLD.

1 Adapted from Bergman and Elarde, 2003 (escalated to 2008 dollars)
2 Amortization over 20 years at a 6 percent annual interest rate

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Examples of BWRO Cost

Sample RO Treatment Cost Summary @ 80% Recovery

Case	Capacity (MGD)			Capital Cost[1] ($/gpd)	O&M Cost[1] ($/kgal)	Amortized Cost[2] ($/kgal)
	Feed	Perm.	Conc.			
RO-1	5	4	1	$0.58	$0.30	**$0.44**
RO-2	2.5	2	0.5	$0.80	$0.40	**$0.59**
RO-3	1.25	1	0.25	$1.11	$0.60	**$0.87**
RO-4	0.625	0.5	0.125	$1.54	$0.70	**$1.07**

Is this an equitable comparison?

1 Adapted from Bergman and Elarde, 2003 (escalated to 2008 dollars)
2 Amortization over 20 years at a 6 percent annual interest rate

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Normal Normalization…?

Comparison in Isolation

- RO: Normalized for permeate flow
- ZLD: Normalized for distillate flow

Real-World Facility (Example)

- ► Inland location
- ► Utilizes BWRO for primary desalination
- ► Employs ZLD for concentrate management

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Normal Normalization…?

Comparison in Isolation

- RO: Normalized for permeate flow
- ZLD: Normalized for distillate flow

Real-World Facility (Example)

- ► Inland location
- ► Utilizes BWRO for primary desalination
- ► Employs ZLD for concentrate management

Proper Normalization

$$\frac{\text{Total Cost (RO + ZLD)}}{\text{Total Desalinated Water Flow (RO + ZLD)}}$$

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Examples of BWRO Cost (Review)

Case	Capacity (MGD)			Capital Cost[1] ($/gpd)	O&M Cost[1] ($/kgal)	Amortized Cost[2] ($/kgal)
	Feed	Perm.	Conc.			
RO-1	5	4	1	$0.58	$0.30	$0.44
RO-2	2.5	2	0.5	$0.80	$0.40	$0.59
RO-3	1.25	1	0.25	$1.11	$0.60	$0.87
RO-4	0.625	0.5	0.125	$1.54	$0.70	$1.07

Sample RO Treatment Cost Summary @ 80% Recovery

1 Adapted from Bergman and Elarde, 2003 (escalated to 2008 dollars)
2 Amortization over 20 years at a 6 percent annual interest rate

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Examples of BWRO Cost (Review)

Case	Capacity (MGD)			Capital Cost[1] ($/gpd)	O&M Cost[1] ($/kgal)	Amortized Cost[2] ($/kgal)
	Feed	Perm.	Conc.			
RO-1	5	4	**1**	$0.58	$0.30	$0.44
RO-2	2.5	2	**0.5**	$0.80	$0.40	$0.59
RO-3	1.25	1	**0.25**	$1.11	$0.60	$0.87
RO-4	0.625	0.5	**0.125**	$1.54	$0.70	$1.07

Sample RO Treatment Cost Summary @ 80% Recovery

1 Adapted from Bergman and Elarde, 2003 (escalated to 2008 dollars)
2 Amortization over 20 years at a 6 percent annual interest rate

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Examples of ZLD Cost (Review)

Sample ZLD Treatment Cost Summary[1]				
Case	Capacity[2] (MGD)	Capital Cost ($/gpd)	O&M Cost ($/kgal)	Amortized Cost[3] ($/kgal)
ZLD-1	1	$41.11	$19.11	$29.12
ZLD-2	0.5	$56.77	$20.29	$34.25
ZLD-3	0.25	$86.13	$23.67	$44.24
ZLD-4	0.125	$133.11	$28.07	$59.87

1 USBR Desalination and Water Purification Research and Development Program, Report No. 149 (Juby et al. 2008)
2 Assumes 100 percent recovery (i.e., ZLD feed flow = ZLD treated water flow)
3 Amortization over 20 years at a 6 percent annual interest rate

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Examples of ZLD Cost (Review)

Sample ZLD Treatment Cost Summary[1]				
Case	Capacity[2] (MGD)	Capital Cost ($/gpd)	O&M Cost ($/kgal)	Amortized Cost[3] ($/kgal)
ZLD-1	**1**	$41.11	$19.11	$29.12
ZLD-2	**0.5**	$56.77	$20.29	$34.25
ZLD-3	**0.25**	$86.13	$23.67	$44.24
ZLD-4	**0.125**	$133.11	$28.07	$59.87

1 USBR Desalination and Water Purification Research and Development Program, Report No. 149 (Juby et al. 2008)
2 Assumes 100 percent recovery (i.e., ZLD feed flow = ZLD treated water flow)
3 Amortization over 20 years at a 6 percent annual interest rate

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Examples of BWRO + ZLD Cost

Sample RO + ZLD Treatment Cost Summary @ 80% RO Recovery

Case	RO System		ZLD System		RO + ZLD Treatment	
	Permeate Flow (MGD)	Amort. Cost ($/kgal)	Distillate Flow (MGD)	Amort. Cost ($/kgal)	Total Desal Flow (MGD)	Amort. Cost ($/kgal)
RO-1 → ZLD-1	4	$0.44	1	$29.12	5	**$6.18**
RO-2 → ZLD-2	2	$0.59	0.5	$34.25	2.5	**$7.32**
RO-3 → ZLD-3	1	$0.87	0.25	$44.24	1.25	**$9.54**
RO-4 → ZLD-4	0.5	$1.07	0.125	$59.87	0.625	**$12.83**

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Examples of BWRO + ZLD Cost

Sample RO + ZLD Treatment Cost Summary @ 80% RO Recovery

Case	RO System		ZLD System		RO + ZLD Treatment	
	Permeate Flow (MGD)	Amort. Cost ($/kgal)	Distillate Flow (MGD)	Amort. Cost ($/kgal)	Total Desal Flow (MGD)	Amort. Cost ($/kgal)
RO-1 → ZLD-1	4	$0.44	1	$29.12	5	**$6.18**
RO-2 → ZLD-2	2	$0.59	0.5	$34.25	2.5	**$7.32**
RO-3 → ZLD-3	1	$0.87	0.25	$44.24	1.25	**$9.54**
RO-4 → ZLD-4	0.5	$1.07	0.125	$59.87	0.625	**$12.83**

Carlsbad SWRO Costs:
~ $6 - $7 per kgal

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Examples of BWRO + ZLD Cost

Sample RO + ZLD Treatment Cost Summary @ 80% RO Recovery						
Case	RO System		ZLD System		RO + ZLD Treatment	
	Permeate Flow (MGD)	Amort. Cost ($/kgal)	Distillate Flow (MGD)	Amort. Cost ($/kgal)	Total Desal Flow (MGD)	Amort. Cost ($/kgal)
RO-1 → [redacted]	[redacted]	[redacted]	[redacted]	[redacted]	5	**$6.18**
RO-2 → [redacted]	[redacted]	[redacted]	[redacted]	[redacted]	2.5	**$7.32**
RO-3 → [redacted]	[redacted]	[redacted]	[redacted]	[redacted]	1.25	**$9.54**
RO-4 → [redacted]	[redacted]	[redacted]	[redacted]	[redacted]	0.625	**$12.83**

Much closer…!

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Examples of BWRO + ZLD Cost

Sample RO + ZLD Treatment Cost Summary @ 80% RO Recovery						
Case	RO System		ZLD System		RO + ZLD Treatment	
	Permeate Flow (MGD)	Amort. Cost ($/kgal)	Distillate Flow (MGD)	Amort. Cost ($/kgal)	Total Desal Flow (MGD)	Amort. Cost ($/kgal)
RO-1 → [redacted]	[redacted]	[redacted]	[redacted]	[redacted]	5	**$6.18**
RO-2 → [redacted]	[redacted]	[redacted]	[redacted]	[redacted]	2.5	**$7.32**
RO-3 → [redacted]	[redacted]	[redacted]	[redacted]	[redacted]	1.25	**$9.54**
RO-4 → [redacted]	[redacted]	[redacted]	[redacted]	[redacted]	0.625	**$12.83**

Much closer…!

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Examples of BWRO + ZLD Cost

Sample RO + ZLD Treatment Cost Summary @ 80% RO Recovery

What about 90% RO recovery?

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Connecting the Cases

Cases for 80% RO Recovery				
RO Case	Feed Flow (MGD)	Permeate Flow (MGD)	Concentrate Flow (MGD)	ZLD Case
RO-1	5	4	1	ZLD-1
RO-2	2.5	2	0.5	ZLD-2
RO-3	1.25	1	0.25	ZLD-3
RO-4	0.625	0.5	0.125	ZLD-4

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Connecting the Cases

Cases for 90% RO Recovery				
RO Case	Feed Flow (MGD)	Permeate Flow (MGD)	Concentrate Flow (MGD)	ZLD Case
RO-1A	5	4.5	0.5	
RO-2A	2.5	2.25	0.25	
RO-3A	1.25	1.125	0.125	
RO-4A	0.625	0.5625	0.0625	

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Connecting the Cases

Cases for 90% RO Recovery				
RO Case	Feed Flow (MGD)	Permeate Flow (MGD)	Concentrate Flow (MGD)	ZLD Case
RO-1A	5	4.5	0.5	
RO-2A	2.5	2.25	0.25	
RO-3A	1.25	1.125	0.125	
RO-4A	0.625	0.5625	0.0625	

Same feed flow… but with systems designed to achieve 90% recovery.

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Connecting the Cases

Cases for 90% RO Recovery				
RO Case	Feed Flow (MGD)	Permeate Flow (MGD)	Concentrate Flow (MGD)	ZLD Case
RO-1A	5	4.5	0.5	ZLD-2
RO-2A	2.5	2.25	0.25	ZLD-3
RO-3A	1.25	1.125	0.125	ZLD-4
RO-4A	0.625	0.5625	0.0625	NA

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Connecting the Cases

Cases for 90% RO Recovery				
RO Case	Feed Flow (MGD)	Permeate Flow (MGD)	Concentrate Flow (MGD)	ZLD Case
RO-1A	5	4.5	0.5	ZLD-2
RO-2A	2.5	2.25	0.25	ZLD-3
RO-3A	1.25	1.125	0.125	ZLD-4
RO-4A	0.625	0.5625	0.0625	NA

Companion ZLD cases for all
but the lowest capacity system

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Connecting the Cases

Cases for 90% RO Recovery				
RO Case	Feed Flow (MGD)	Permeate Flow (MGD)	Concentrate Flow (MGD)	ZLD Case
RO-1A	5	4.5	0.5	ZLD-2
RO-2A	2.5	2.25	0.25	ZLD-3
RO-3A	1.25	1.125	0.125	ZLD-4
RO-4A	0.625	0.5625	0.0625	NA

USBR Report No. 149 does not have a ZLD case study for this flow.

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Connecting the Cases

Cases for 90% RO Recovery				
RO Case	Feed Flow (MGD)	Permeate Flow (MGD)	Concentrate Flow (MGD)	ZLD Case
RO-1A	5	4.5	0.5	ZLD-2
RO-2A	2.5	2.25	0.25	ZLD-3
RO-3A	1.25	1.125	0.125	ZLD-4
RO-4A	0.625	0.5625	0.0625	NA

Eliminate this case.

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Examples of BWRO Cost

Sample RO Treatment Cost Summary @ 90% Recovery						
Case	Capacity (MGD)			Capital Cost[1] ($/gpd)	O&M Cost[1] ($/kgal)	Amortized Cost[2] ($/kgal)
	Feed	Perm.	Conc.			
RO-1A	5	4.5	0.5	$0.55	$0.25	$0.38
RO-2A	2.5	2.25	0.25	$0.76	$0.35	$0.53
RO-3A	1.25	1.125	0.125	$1.05	$0.60	$0.85

1 Adapted from Bergman and Elarde, 2003 (escalated to 2008 dollars)
2 Amortization over 20 years at a 6 percent annual interest rate

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Examples of BWRO + ZLD Cost

Sample RO + ZLD Treatment Cost Summary @ 90% RO Recovery						
Case	RO System		ZLD System		RO + ZLD Treatment	
	Permeate Flow (MGD)	Amort. Cost ($/kgal)	Distillate Flow (MGD)	Amort. Cost ($/kgal)	Total Desal Flow (MGD)	Amort. Cost ($/kgal)
RO-1A → ZLD-2	4.5	$0.38	0.5	$34.25	5	$3.77
RO-2A → ZLD-3	2.25	$0.53	0.25	$44.24	2.5	$4.90
RO-3A → ZLD-4	1.125	$0.85	0.125	$59.87	1.25	$6.75

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Examples of BWRO + ZLD Cost

Sample RO + ZLD Treatment Cost Summary @ 90% RO Recovery						
Case	RO System		ZLD System		RO + ZLD Treatment	
	Permeate Flow (MGD)	Amort. Cost ($/kgal)	Distillate Flow (MGD)	Amort. Cost ($/kgal)	Total Desal Flow (MGD)	Amort. Cost ($/kgal)
RO-1A → ZLD-2	4.5	$0.38	0.5	$34.25	5	**$3.77**
RO-2A → ZLD-3	2.25	$0.53	0.25	$44.24	2.5	**$4.90**
RO-3A → ZLD-4	1.125	$0.85	0.125	$59.87	1.25	**$6.75**

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The Influence of Recovery

Comparison of RO + ZLD Cost @ 80% vs. 90% RO Recovery					
Treated Water Capacity[1] (MGD)	80% RO Recovery		90% RO Recovery		Unit Cost Reduction
	Case	Amort. Cost[2] ($/kgal)	Case	Amort. Cost[2] ($/kgal)	
5	RO-1 → ZLD-1	$6.18	RO-1A → ZLD-2	$3.77	39%
2.5	RO-2 → ZLD-2	$7.32	RO-2A → ZLD-3	$4.90	33%
1.25	RO-3 → ZLD-3	$9.54	RO-3A → ZLD-4	$6.75	29%

1 Assumes 100 percent recovery (i.e., ZLD feed flow = ZLD treated water flow)
2 Amortization over 20 years at a 6 percent annual interest rate

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The Influence of Recovery

Comparison of RO + ZLD Cost @ 80% vs. 90% RO Recovery					
Treated Water Capacity[1] (MGD)	80% RO Recovery		90% RO Recovery		Unit Cost Reduction
	Case	Amort. Cost[2] ($/kgal)	Case	Amort. Cost[2] ($/kgal)	
5	RO-1 → ZLD-1	**$6.18**	RO-1A → ZLD-2	$3.77	39%
2.5	RO-2 → ZLD-2	**$7.32**	RO-2A → ZLD-3	$4.90	33%
1.25	RO-3 → ZLD-3	**$9.54**	RO-3A → ZLD-4	$6.75	29%

1 Assumes 100 percent recovery (i.e., ZLD feed flow = ZLD treated water flow)
2 Amortization over 20 years at a 6 percent annual interest rate

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The Influence of Recovery

Comparison of RO + ZLD Cost @ 80% vs. 90% RO Recovery					
Treated Water Capacity[1] (MGD)	80% RO Recovery		90% RO Recovery		Unit Cost Reduction
	Case	Amort. Cost[2] ($/kgal)	Case	Amort. Cost[2] ($/kgal)	
5	RO-1 → ZLD-1	$6.18	RO-1A → ZLD-2	**$3.77**	39%
2.5	RO-2 → ZLD-2	$7.32	RO-2A → ZLD-3	**$4.90**	33%
1.25	RO-3 → ZLD-3	$9.54	RO-3A → ZLD-4	**$6.75**	29%

1 Assumes 100 percent recovery (i.e., ZLD feed flow = ZLD treated water flow)
2 Amortization over 20 years at a 6 percent annual interest rate

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The Influence of Recovery

Comparison of RO + ZLD Cost @ 80% vs. 90% RO Recovery					
Treated Water Capacity[1] (MGD)	80% RO Recovery		90% RO Recovery		Unit Cost Reduction
	Case	Amort. Cost[2] ($/kgal)	Case	Amort. Cost[2] ($/kgal)	
5	RO-1 → ZLD-1	$6.18	RO-1A → ZLD-2	$3.77	**39%**
2.5	RO-2 → ZLD-2	$7.32	RO-2A → ZLD-3	$4.90	**33%**
1.25	RO-3 → ZLD-3	$9.54	RO-3A → ZLD-4	$6.75	**29%**

1 Assumes 100 percent recovery (i.e., ZLD feed flow = ZLD treated water flow)
2 Amortization over 20 years at a 6 percent annual interest rate

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ZLD Cost Strategy

Optimizing RO + ZLD System Economy

1. Maximize primary RO recovery
   – ZLD exerts substantial influence on system costs.
   – Minimizing proportional ZLD flow yields lower unit costs.

2. Maximize RO + ZLD system size (within budget)
   – ZLD economies of scale are significant.
   – Unit cost of desal water is much lower for larger systems.

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Summary

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Key Messages

ZLD is an expensive option
for concentrate management…

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Key Messages

…but it offers several critical advantages that broadly enhance the viability of desalination.

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Key Messages

ZLD Advantages

- ✓ Feasible deployment virtually independent of concentrate water quality
- ✓ Lack of environmental and regulatory permitting constraints that inhibit many other concentrate management options
- ✓ Overall costs (including primary RO + ZLD) that are roughly comparable to seawater desalination

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Key Messages

ZLD Advantages

Virtual elimination of the problem of desalination concentrate…

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Key Messages

ZLD Advantages

…albeit at high cost…

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Key Messages

ZLD Advantages

…but not prohibitively high!

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ASK THE EXPERT

Charlie He
Carollo Engineers, Inc.

Brent Alspach, PE, BCEE
Arcadis

Dave Stewart, PhD, PE
Stewart Environmental Consulting Group, LLC

Enter your **question** into the **question pane** on the right-hand side of the screen.

Please specify to whom you are addressing the question.

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Stewart Environmental Consulting Group, LLC
Engineering for Life

CHAPTER 7 – REGULATORY, SAFETY, OPERATIONAL AND ENVIRONMENTAL ISSUES

David R Stewart, PhD, PE

President

Stewart Environmental Consulting Group, LLC

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PURPOSE – LEARNING OBJECTIVES

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PURPOSE

- Discussion of the regulatory issues for inland desalination
  - Federal
  - State
  - Local
  - Concentrate disposal
  - Anti - degradation rules
  - Salt Content
    - Need for alternative disposal methods
    - Deep well injection
    - Site restrictions
    - Treatment of brine steams (covered in other talks)
- Understanding these issues will allow for more efficient planning and implementation of the water treatment plant

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LEARNING OBJECTIVES

- Provide for a logic progression through the permitting process
- Understand the constraints of the inland desalination due to regulations that might affect design of the process
- Potentially avoid large issues associated with the design and regulatory constraints
- Plan for differences between each state
- Communication of different processes to the public for acceptance

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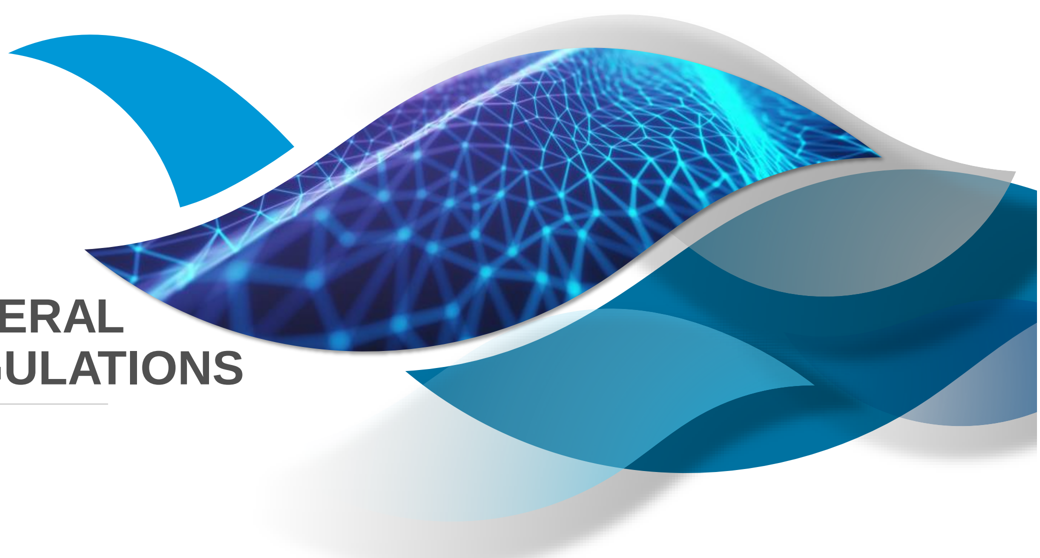

FEDERAL REGULATIONS

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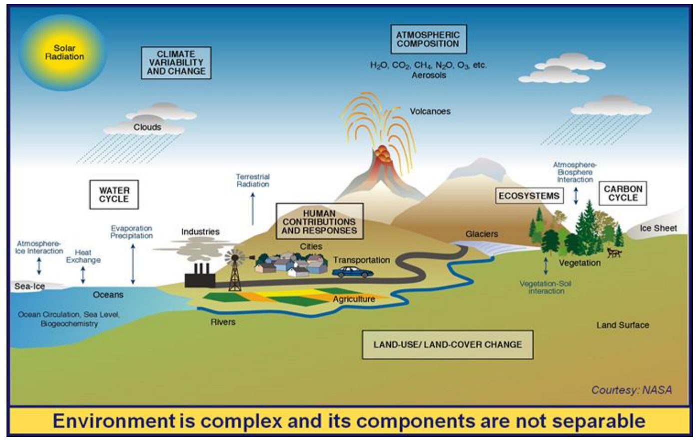
FEDERAL REGULATIONS

- Clean Water Act (Discharge to surface waters)
- Safe Drinking Water Act
- Resource Conservation and Recovery Act (Solid Waste)
- Comprehensive Environmental Response, Compensation and Liability Act (Superfund)
- TENROMS – radioactive particles



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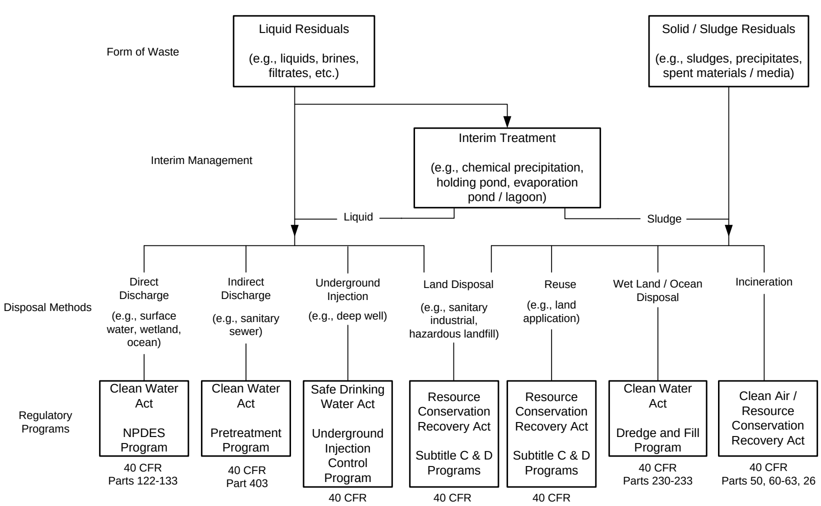
FEDERAL REGULATIONS WRT INLAND DESALINATION



- Regulations interact with different media at the same facility
- Need to be aware of these differences and it is the responsibility of the utility to identify and classify their different wastes

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Please consider the environment before printing.

FORMS OF WASTE TO BE MANAGED

- Brine concentrates
- Spent membrane cleaning solutions
- Conditioning chemicals
- Sludges and solid wastes from operations
  - Raw water will dictate most of the regulatory concerns regarding disposal

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CLEAN WATER ACT

- Individual permit – State dependent – very long lead time – changing conditions – selenium example – mixing possible
- Statewide permit – meet the discharge standards at discharge point – standards are set with statewide permit – example of Colorado and the Produced Water Discharge permit system
- WET Testing – organisms are very sensitive to salt concentrations - acute and chronic testing

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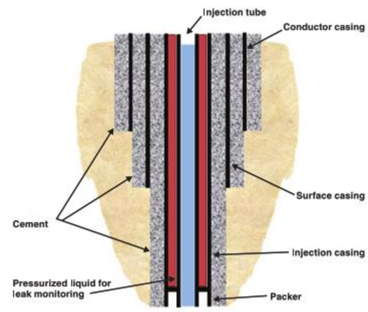
SAFE DRINKING WATER ACT

- Injection wells – typically Class I wells – Class V wells are possible
- Underground Source for Drinking Water (USDW) – classified as less than 10,000 mg/l
- Permits are difficult to obtain but sometimes is the only way to dispose of the brine – 6 to 9 months
- Caution with potential for earthquake activity



Class I injection well schematic (number of casing stages varies)

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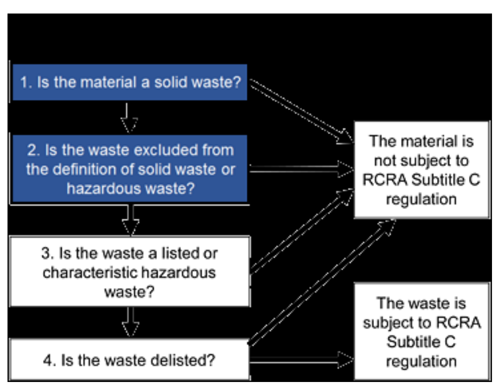
RESOURCE CONSERVATION AND RECOVERY ACT (HAZ WASTE)

- 40 CFR 257 to 270
- 40 CFR 261 – waste characterization
- Two types of wastes
  - Listed waste – discarded wastes
  - Characteristic waste – ignitable, corrosive, reactive, TCLP testing
- Disposal at landfills – landfill restrictions like TNORM



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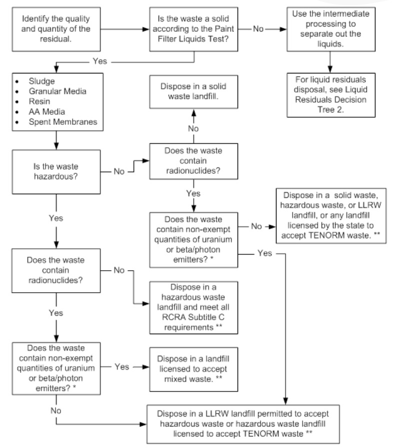
TNORM – TECHNICALLY ENHANCED NATURALLY OCCURRING RADIOACTIVE WASTE

- Testing for radium 226 and 228 and other radioactive materials
  - Gross alpha and beta
  - Strontium 90
  - Tritium
  - Uranium
- State testing requirements
- Subtitle D landfills
- Stabilization of wastes



* Check with the state Radiation Program to see if beta/photon emitters are considered byproduct material and advise system to contact the NRC Regional Office or relevant Agreement State Agency to discuss potential licensing requirements.

** LDR Treatment Standards also apply. Check with the state Radiation Program to determine the proper disposal methods for waste containing radionuclides and hazardous waste.

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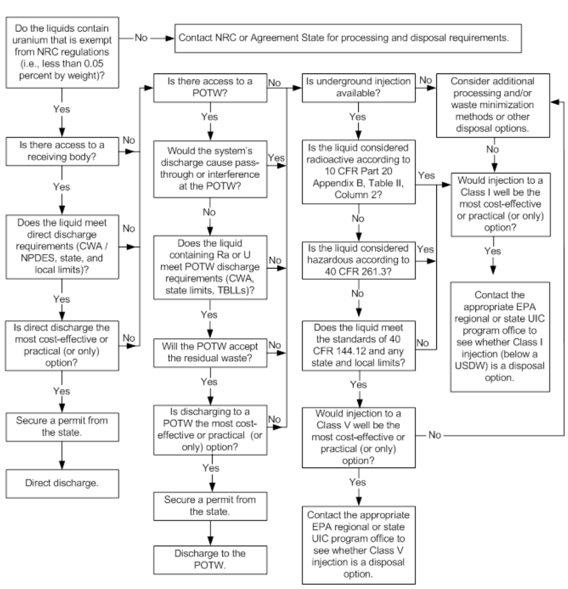
TNORM CONTINUED – IDENTIFICATION FLOW CHART



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STATE REGULATIONS

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STATE REGULATIONS

- Examples
  - Texas
    - TCEQ – evaporation ponds and linings
  - Colorado
    - Injection well limitations – earthquakes
  - California
    - Coastal water discharges
    - Land applications
  - Toxicity issues

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SOME STATES REQUIRE WATER RIGHTS

- Colorado example
  - Fresh water cost verses brackish water
    - Cost of Raw water - $110,000 per AF (perpetual supply)
    - Cost of Brackish water - $10,000 per AF (Augmentation Water)
  - Cost savings to project using brackish water (90% of the cost of raw water)
  - For 500 homes - $1.1M verse $100,000
  - Depending on location of groundwater
    - Ease of infrastructure installation
    - Stream is “made whole” at the wastewater plant plus consumptive use water augmentation
  - Consumptive use water and augmentation plans are worked out through the court system in Colorado
  - Savings due to raw water was 75% over freshwater

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COMMUNICATION

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PUBLIC PARTICIPATION AND OUTREACH

- Recognize the problem
- Public risk and explanations
- Level of involvement
- Communication after implementation of the solution

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SUMMARY

- Regulatory issues can dictate the process
- Beware of issues regarding brine disposal, TENORM
- Water rights can be used to the advantage of the brackish water system design
- Communication with the public is critical to obtain local approvals

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ASK THE EXPERT

Charlie He
Carollo Engineers, Inc.

Brent Alspach, PE, BCEE
Arcadis

Dave Stewart, PhD, PE
Stewart Environmental Consulting Group, LLC

Enter your **question** into the **question pane** on the right-hand side of the screen.

Please specify to whom you are addressing the question.

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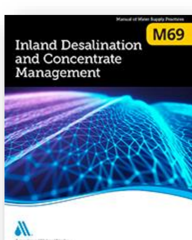
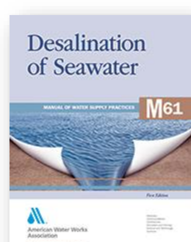
ADDITIONAL RESOURCES

- Desalination Resource Community
- Water Resources Planning and Sustainability Resource Community



M69 Inland Desalination & Concentrate Management
AWWA catalog no: 30069



M61 Desalination of Seawater
AWWA catalog no: 30061

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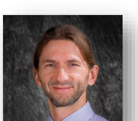
PRESENTER BIOGRAPHY INFORMATION

Charlie (Qun) He, a vice president and chief technologist with Carollo, has more than 19 years of experience in water and wastewater treatment, water quality, and water resources. Mr. He has extensive experience in water and wastewater treatment, with an expertise in developing and optimizing treatment strategies for complex industrial wastewater treatment. He has gained experienced working with semiconductor, data center, mining, chemical, power, textile, food and beverage, and manufacturing industries. He leads the company's integrated decision support system team and is leading the research and development of Blue Plan-it® Decision Support System, an advanced water and wastewater system simulation and optimization tool. He is Carollo's membrane desalination and concentrate management expert for the southwest region and one of the R&D Innovation Lead for the Carollo's Research Group. He is the chair of AWWA Manual of Practice 69 – Inland Desalination and Concentrate Management and the vice chair of the AWWA Joint Research Committee. He is the ex-chair of AZ Water Association Research Committee and the ex-chair of the AWWA Joint Research Committee. In addition, Mr. He is a LEED AP and has gained extensive exposure to the field of sustainability.



Brent Alspach holds both Bachelor and Master of Science degrees in Civil and Environmental Engineering from Cornell University in Ithaca, NY. Mr. Alspach joined Arcadis in 1997 and currently serves as Director of Applied Research. He the Chair of the AWWA Water Quality and Technology Division and is the immediate past President of the American Membrane Technology Association (AMTA).

Dr. David Stewart is President and CEO of Stewart Environmental Consultants Consulting Group, LLC in Fort Collins, Colorado. Dr. Stewart holds a PhD in Environmental Engineering, a Master of Business Administration, and a BS in Civil Engineering from Colorado State University, as well as a Master's in Environmental Engineering from the University of Arizona. Dr. Stewart has done permitting and regulatory compliance for water and wastewater systems for over 40 years. Dr Stewart is involved in several RO-ZLD projects at this time and is obtaining all of the necessary permits for the project. He also is an adjunct professor at Colorado State University.

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