Western Coalition of Arid States

Winter Conference

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High Recovery RO & Enhanced Evaporation to Achieve Zero Liquid Discharge

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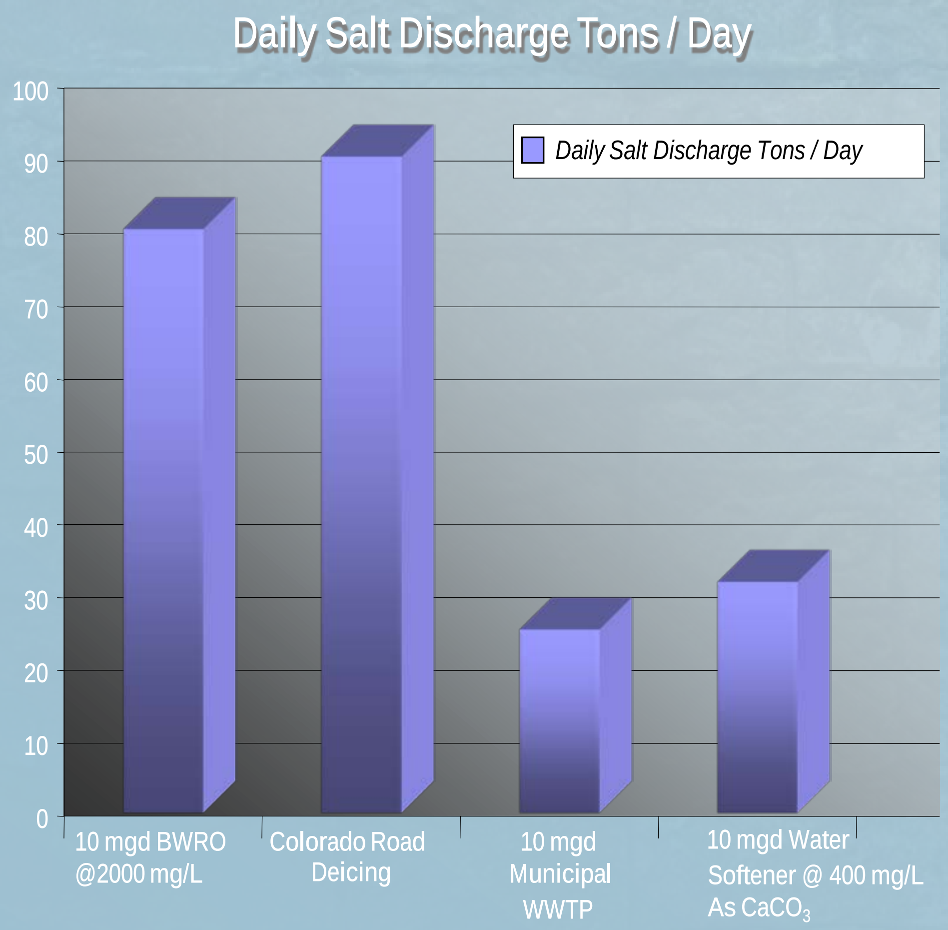
CDM

Disposal Options for Concentrate from Brackish Water and Wastewater Reclamation

1. Surface Water Discharge through NPDES permit
2. Discharge to Sanitary Sewer System
3. Deep Well Injection
4. Beneficial Uses
5. Zero Liquid Discharge Using:
    1. Thermal/mechanical evaporation systems
    2. Enhanced evaporation system
    3. Passive evaporation basins

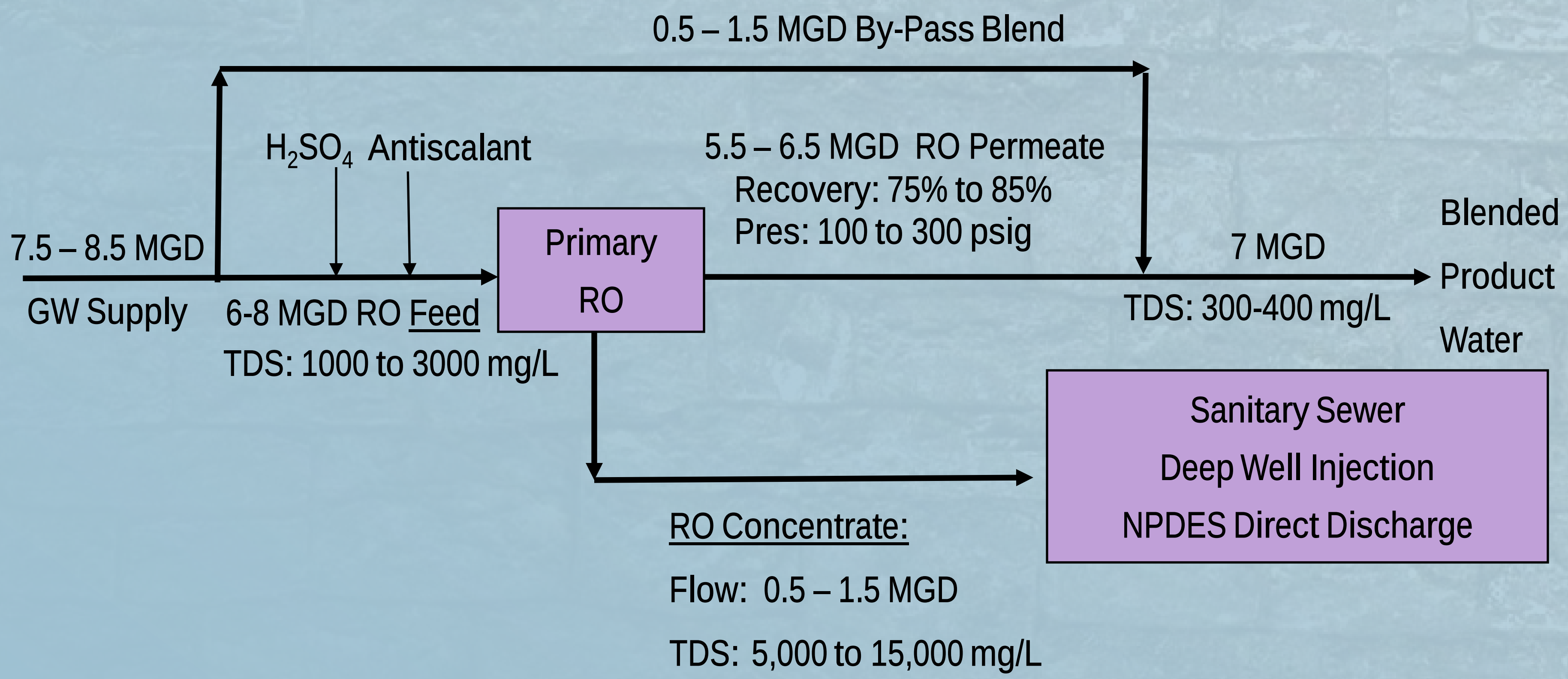
RO Concentrate Discharge to Fresh Water Not Desirable Since Daily Salt Discharged from a Brackish RO Project is Significant



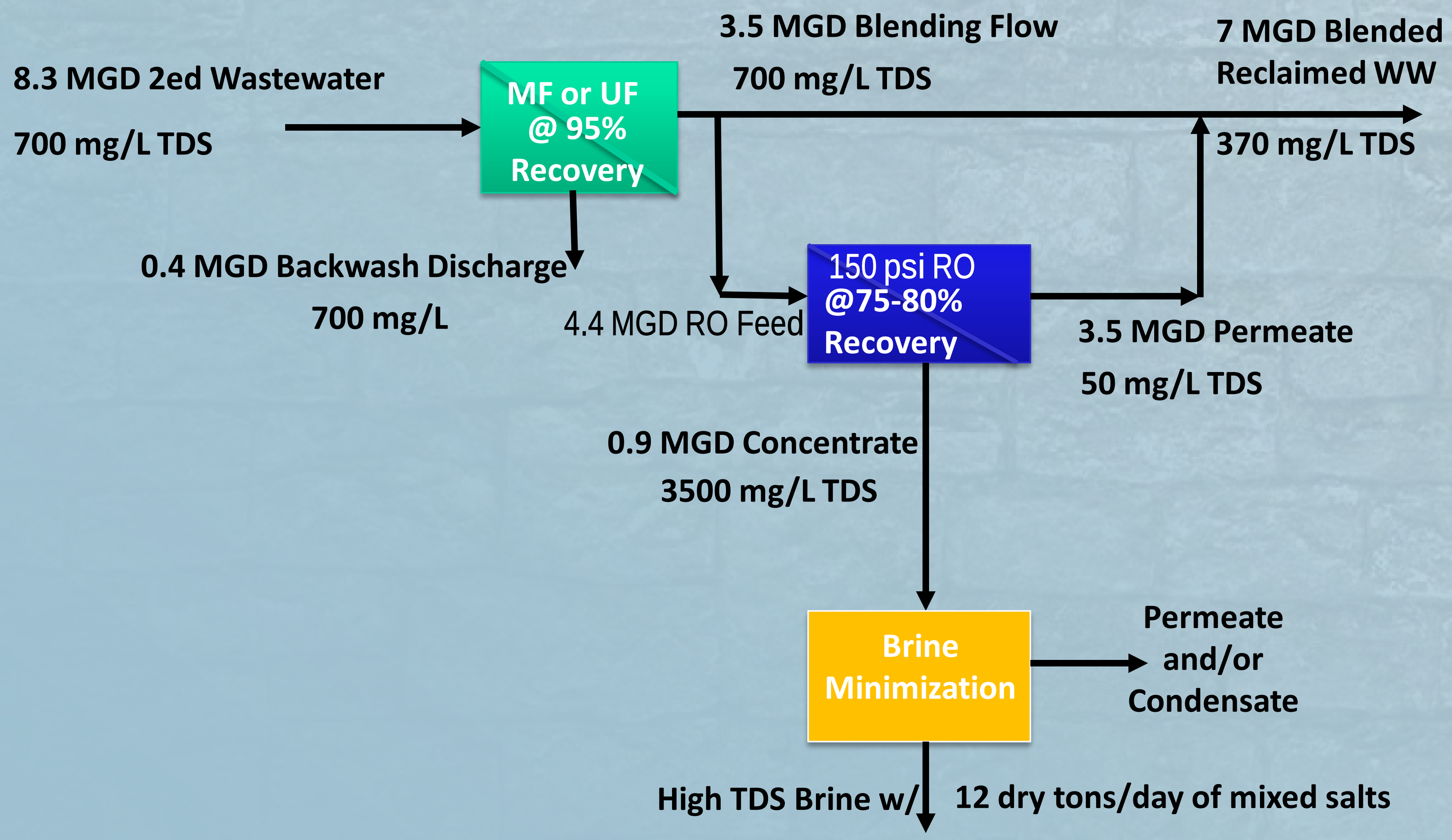
Presentation Objectives

- Provide Better Understanding of Typical RO Concentrate Quality
- Present the Test Results for a Cost Effective Brine Minimization Process
- Understand How Brine Minimization Can Make Development of Brackish Water More Feasible

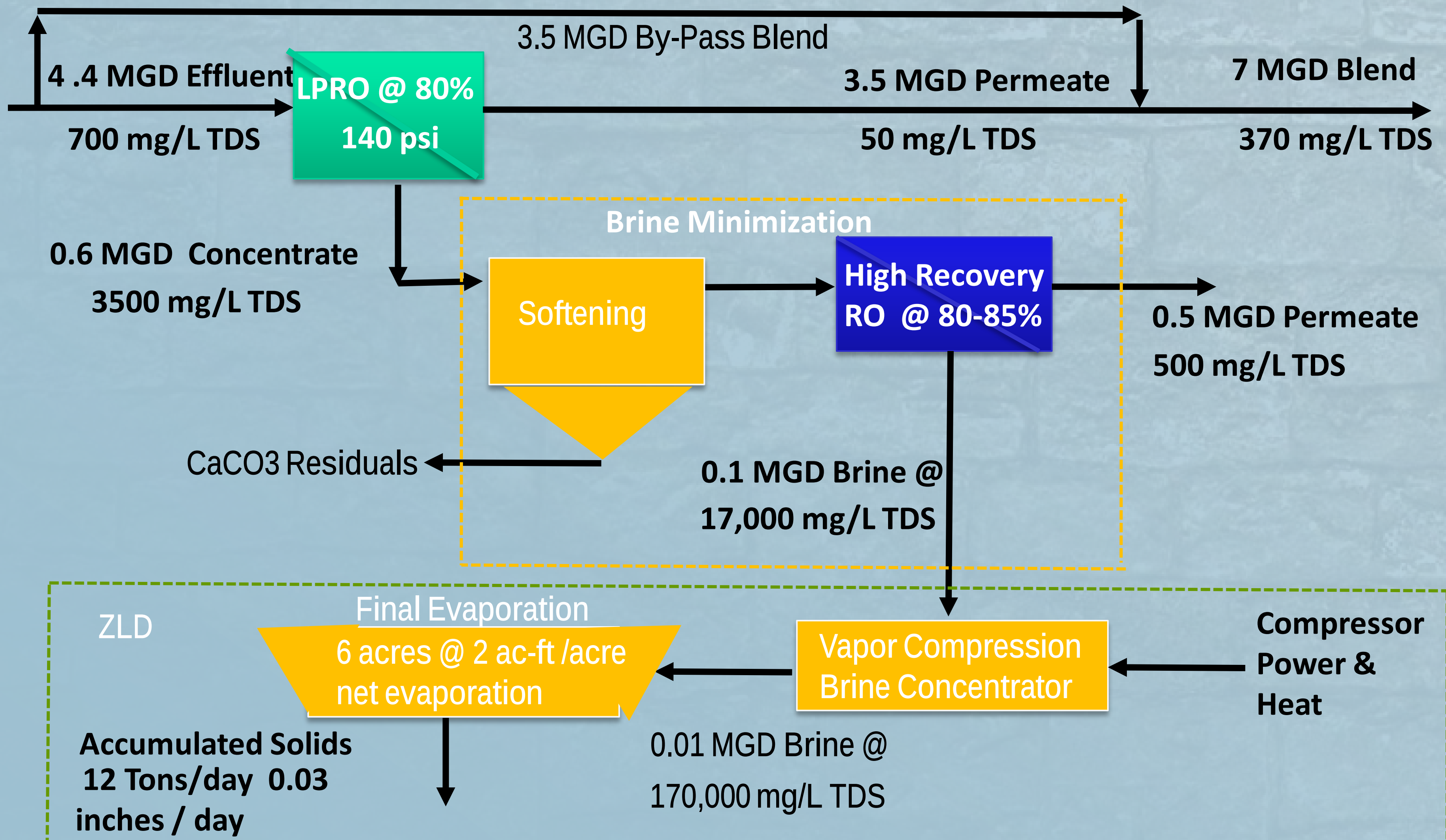
Example of Typical Brackish Well Water System with By-Pass Blending to Produce Stable Water



Typical Wastewater Reclamation Process for TDS and Hardness Reduction



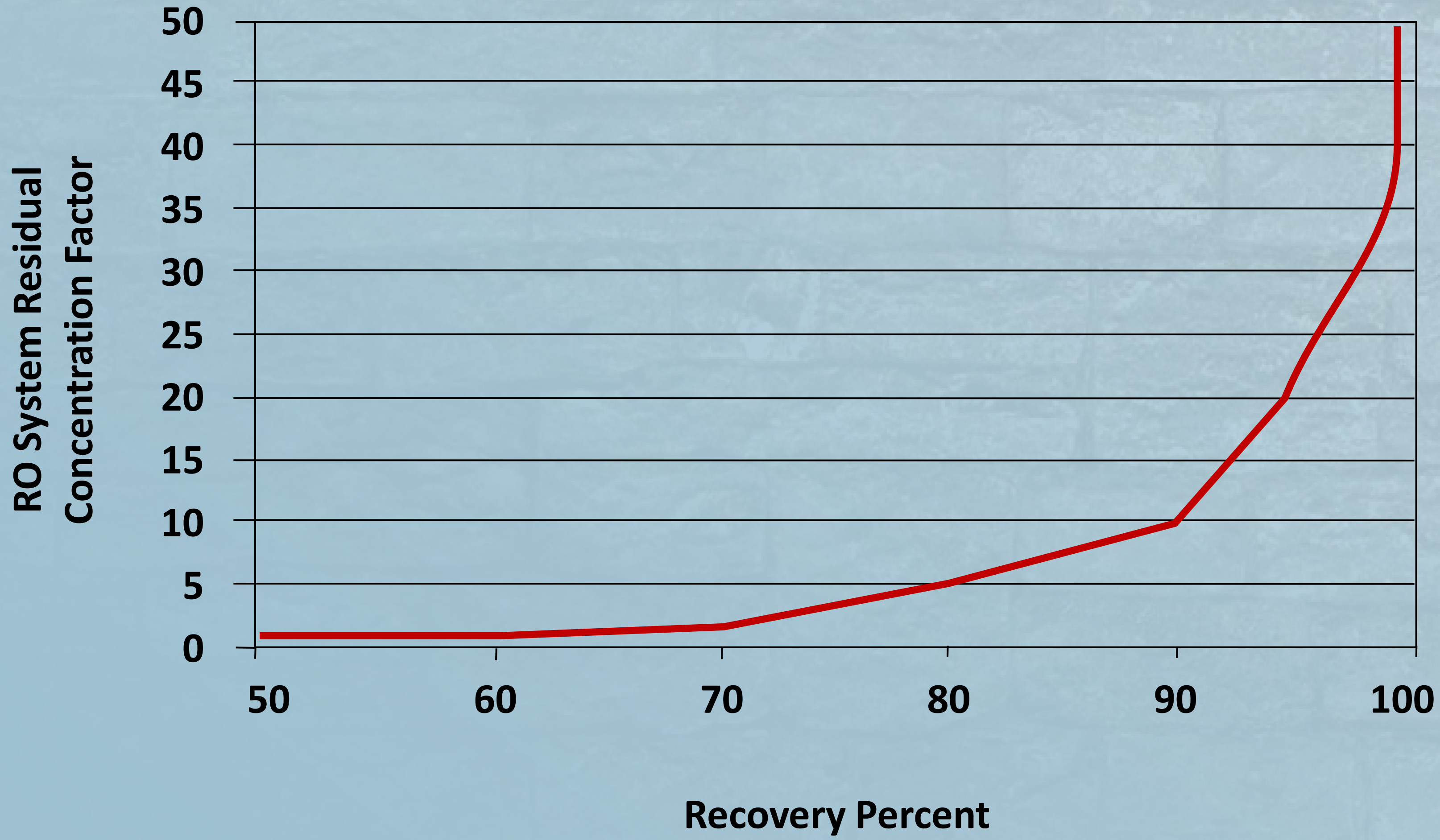
Example of How Brine Minimization and Evaporation Are Used to Achieve ZLD



Concentrate Water Quality Comparison

Parameter	Brackish Water	LPRO @ 80% REC. Concentrate	High Rec. RO @ 85% Concentrate
Characterization	Medium TDS	High Hardness	Low Hardness High TDS
pH (su)	8.2	8.1	9.1
Total Alkalinity (mg/L $CaCO_3$)	120	560	2800
Total Hardness (mg/L $CaCO_3$)	310	1600	130
Silica (mg/L)	10	50	250
TDS (mg/L)	1,200	6000	38000
Calcium	70	370	20
Magnesium	30	150	20
Sodium	290	1400	12500
Sulfate	260	1300	8900
Chloride	380	1850	11400
Nitrate as N	25	105	200

Concentration Factor Vs. Recovery



Scale Inhibitors and Kinetics Allow RO Systems to Operate above Theoretical Saturation Limits

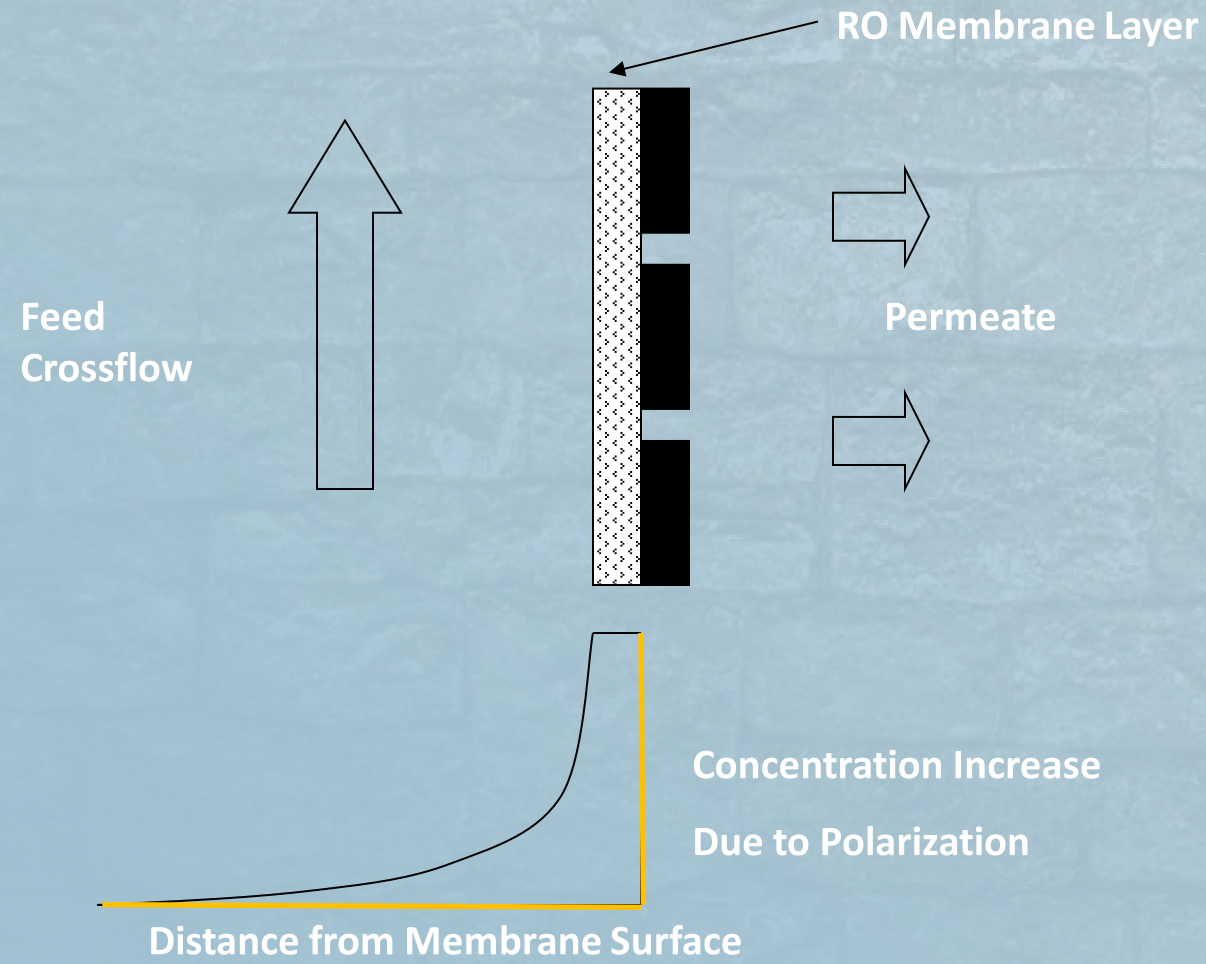
Recommended RO Design Limits for Sparingly Soluble Salts
in the Concentrate in Percent Saturation

Index	Typical	Aggressive
LSI	<1.8	<2.5
$CaSO_4$ (% Sat)	230	N/A
$BaSO_4$ (% Sat)	6,000	N/A
$SrSO_4$ (% Sat)	800	N/A
SiO_2 (% Sat)	100	150

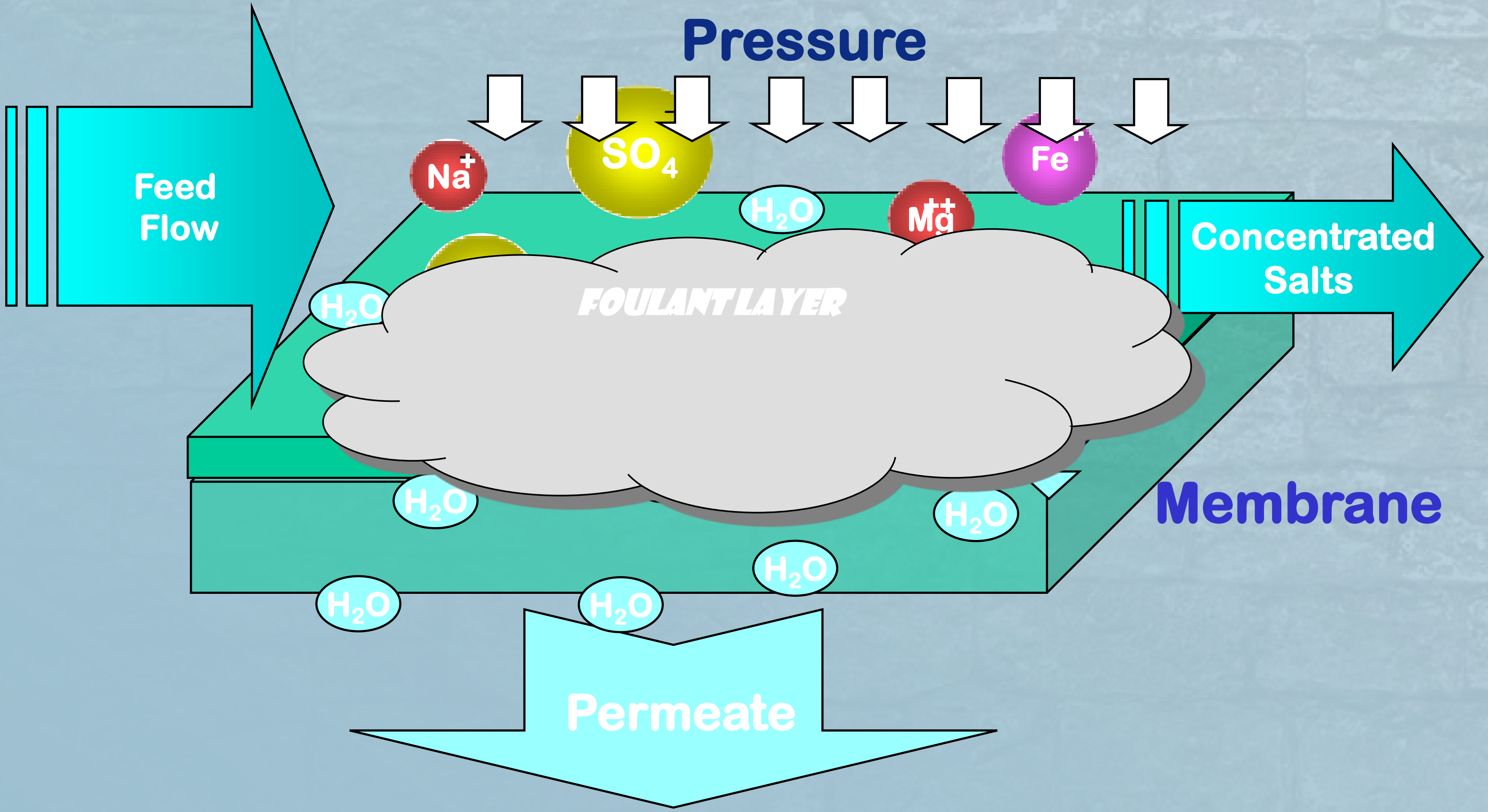
Sparingly Soluble Salts that Limit RO Recovery Reported as Solution Concentration

Salt	Saturation Concentration (mg/L)
Calcium Carbonate ($CaCO_3$)	8
Calcium Fluoride (CaF_2)	29
Calcium Orthophosphate ($CaHPO_4$)	68
Calcium Sulfate ($CaSO_4$)	680
Strontium Sulfate ($SrSO_4$)	146
Barium Sulfate ($BaSO_4$)	3
Silica, amorphous (SiO_2)	120

Concentration Polarization at Membrane Surfaces Can Result in Local Concentration Exceeding Bulk Solution Concentration



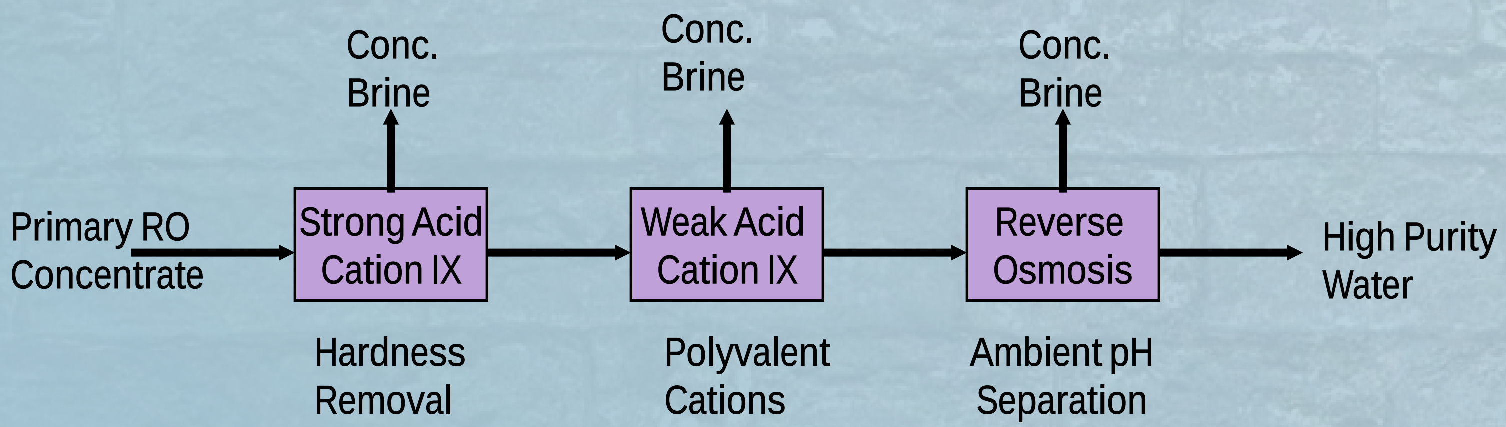
The Key to Success at High RO Recovery: Minimize Deposition on the Surface



Case Studies

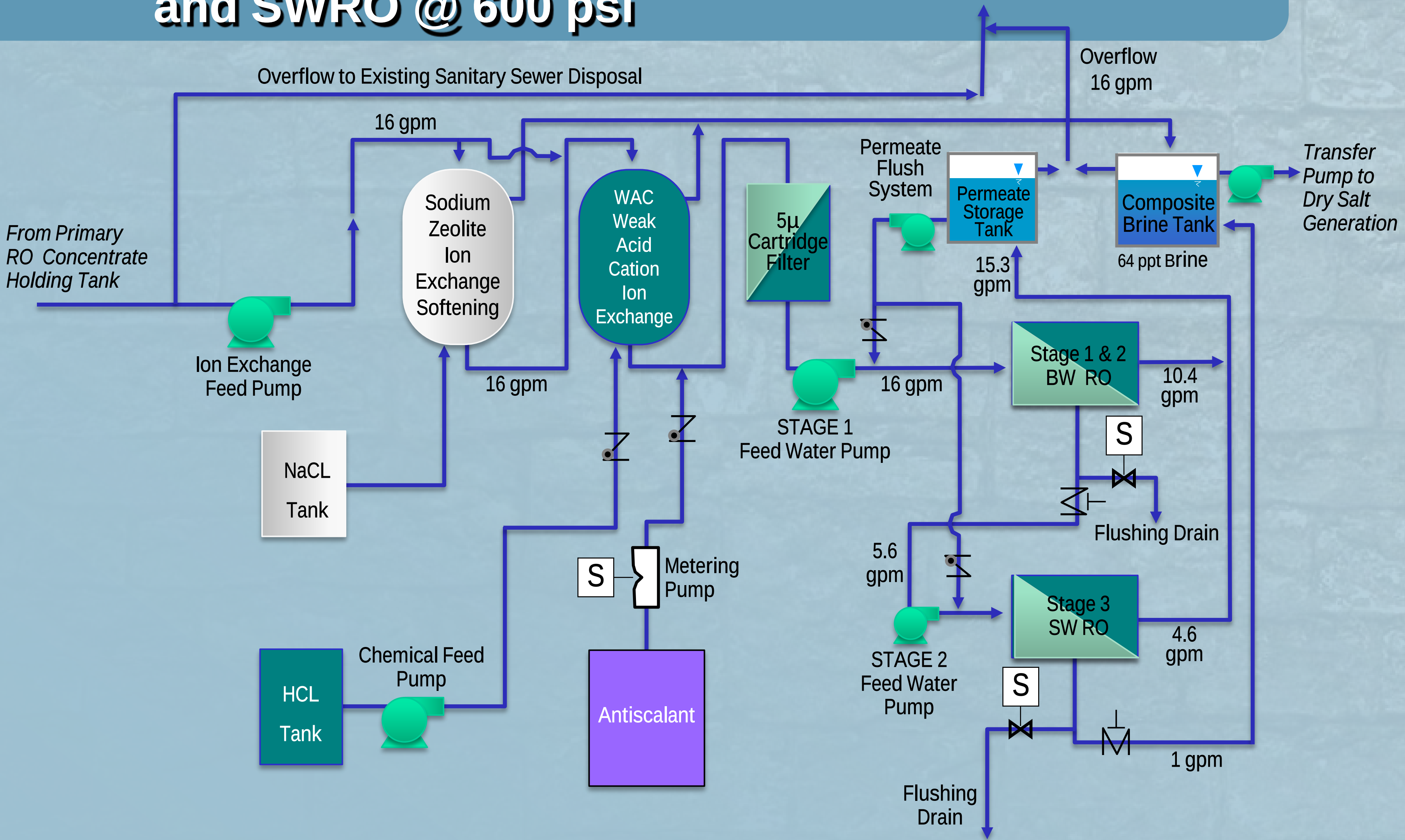
- East Cherry Creek Valley Water and Sanitation District Brackish RO System and Zero Liquid Discharge (ZLD) High Recovery RO Pilot Test
- Coal Bed Methane Gas Produced Water High Recovery RO System

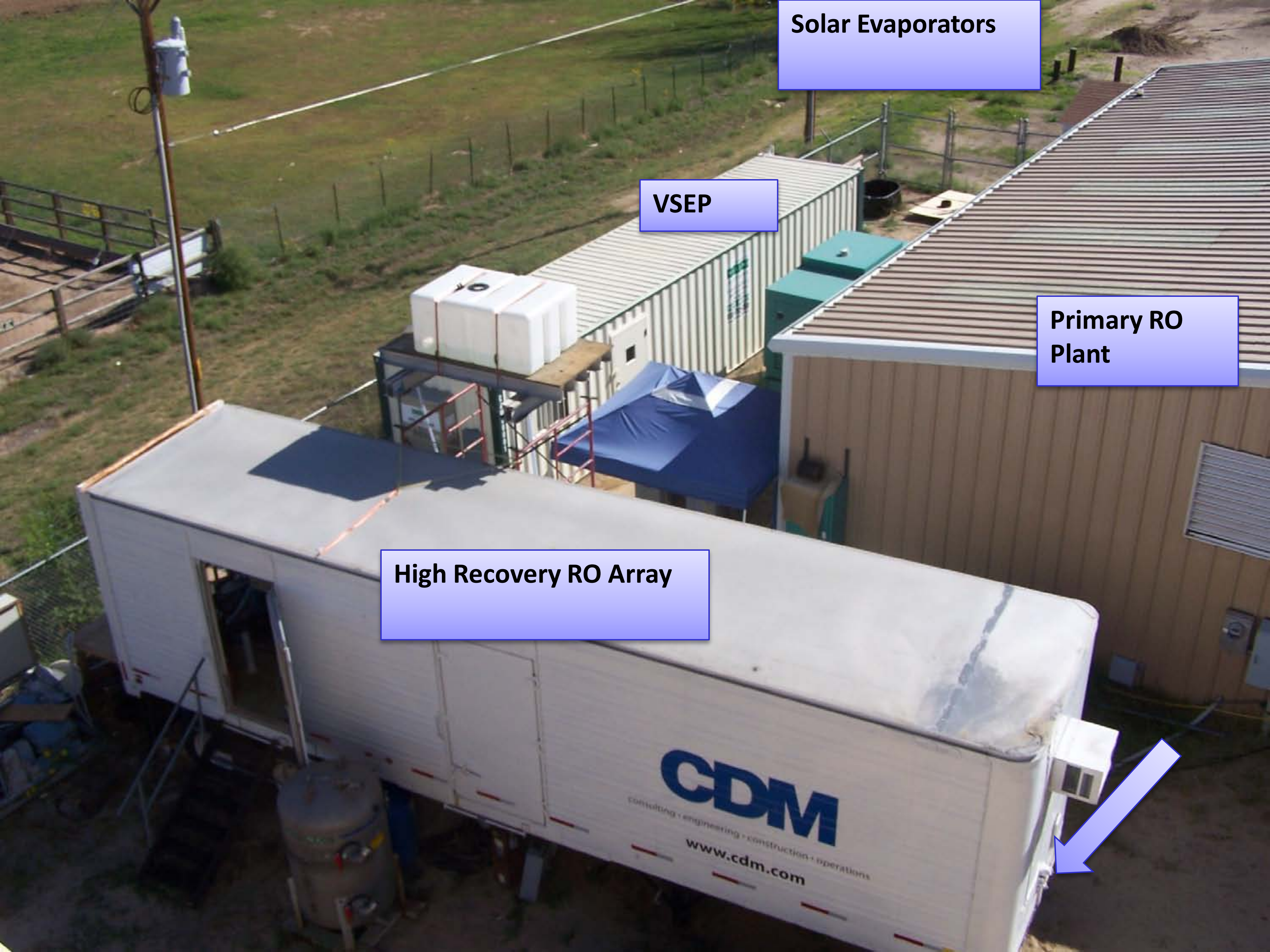
High Recovery RO Using both Weak Acid and Strong Acid Cation Exchange



- Removes Ions That
  - Form Scale
  - Calcium
  - Magnesium
  - Barium
  - Strontium
  - Iron
  - Manganese
  - Aluminum
- Ambient pH RO Operation
  - Controls Silica Scaling
  - Eliminates NaOH Feed

ECCV Pilot treated LPRO Concentrate w/ High Hardness and Sulfates Using BWRO @ 300 psi and SWRO @ 600 psi




Solar Evaporators
VSEP
Primary RO Plant
High Recovery RO Array
CDM
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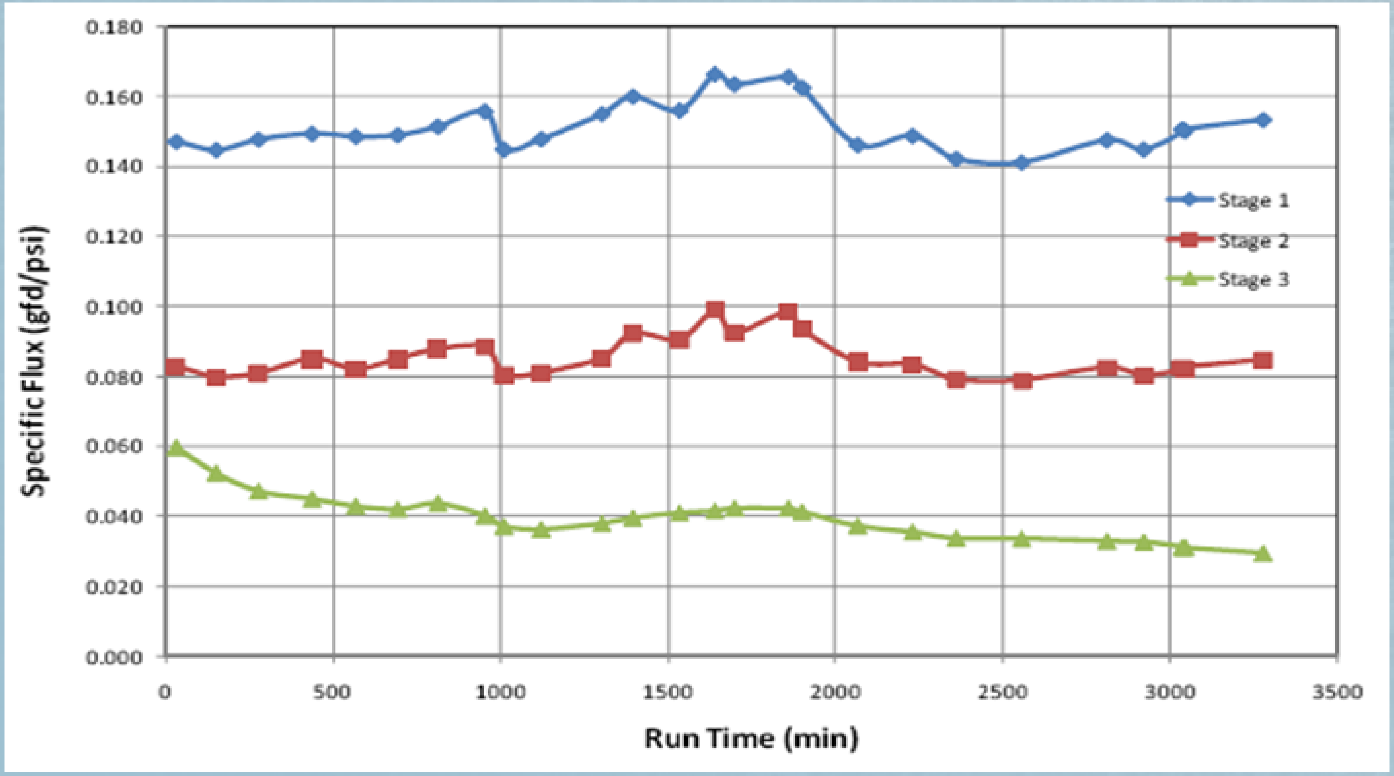
16 gpm RO system
Stage 3 - SW
Stage 2 - BW
Stage 1 - BW
Stage 1 - BW
CAUTION
NALGENE

Silica Fouling Occurred at Lower Concentrations in the ECCV Pilot Study but High pH Chemical Cleaning Restored Performance

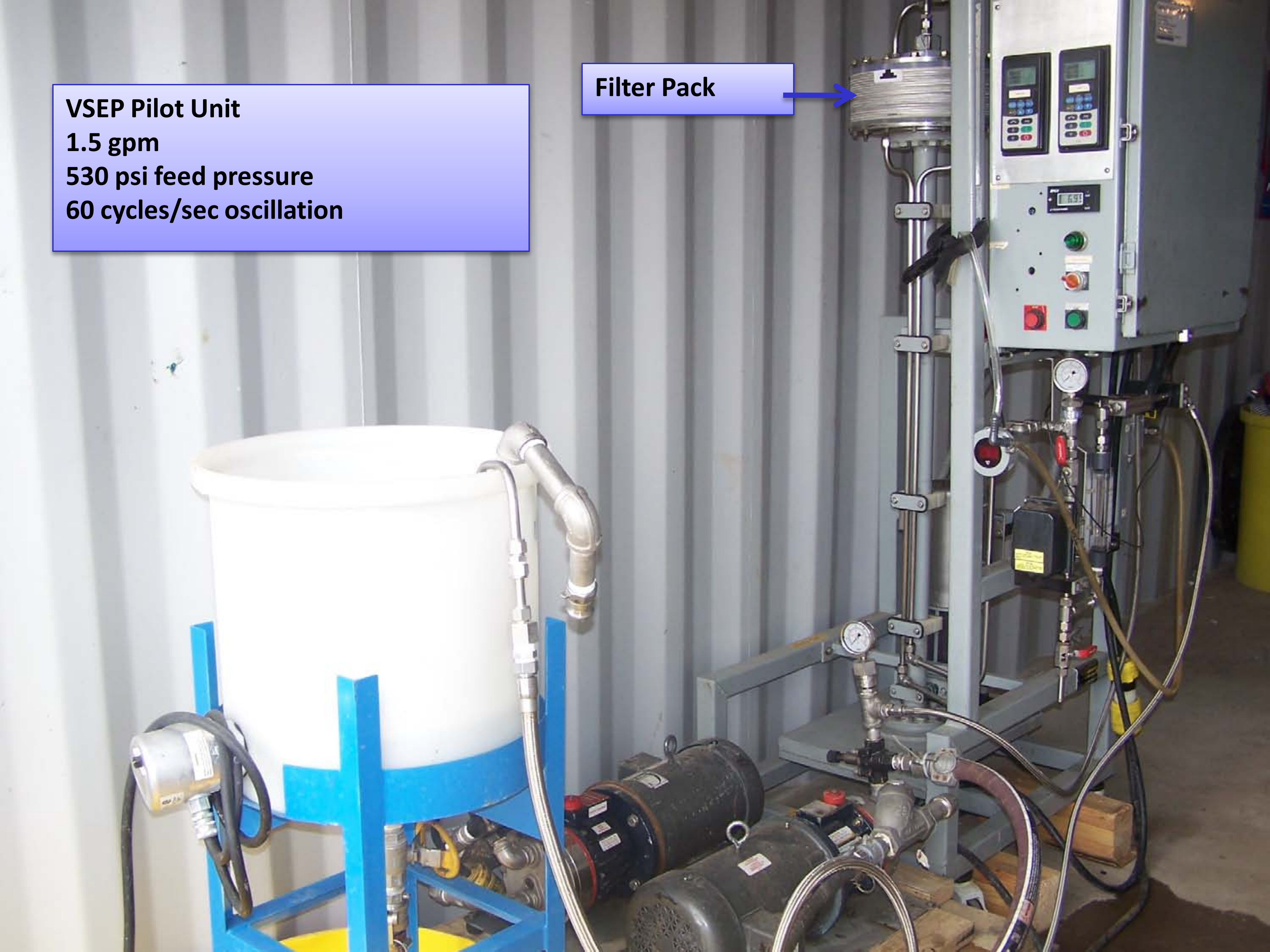
- Stages 1&2 stable @ 93% Overall Recovery
- Early onset of Stage 3 silica fouling attributed to high sulfate, sodium & fluorides



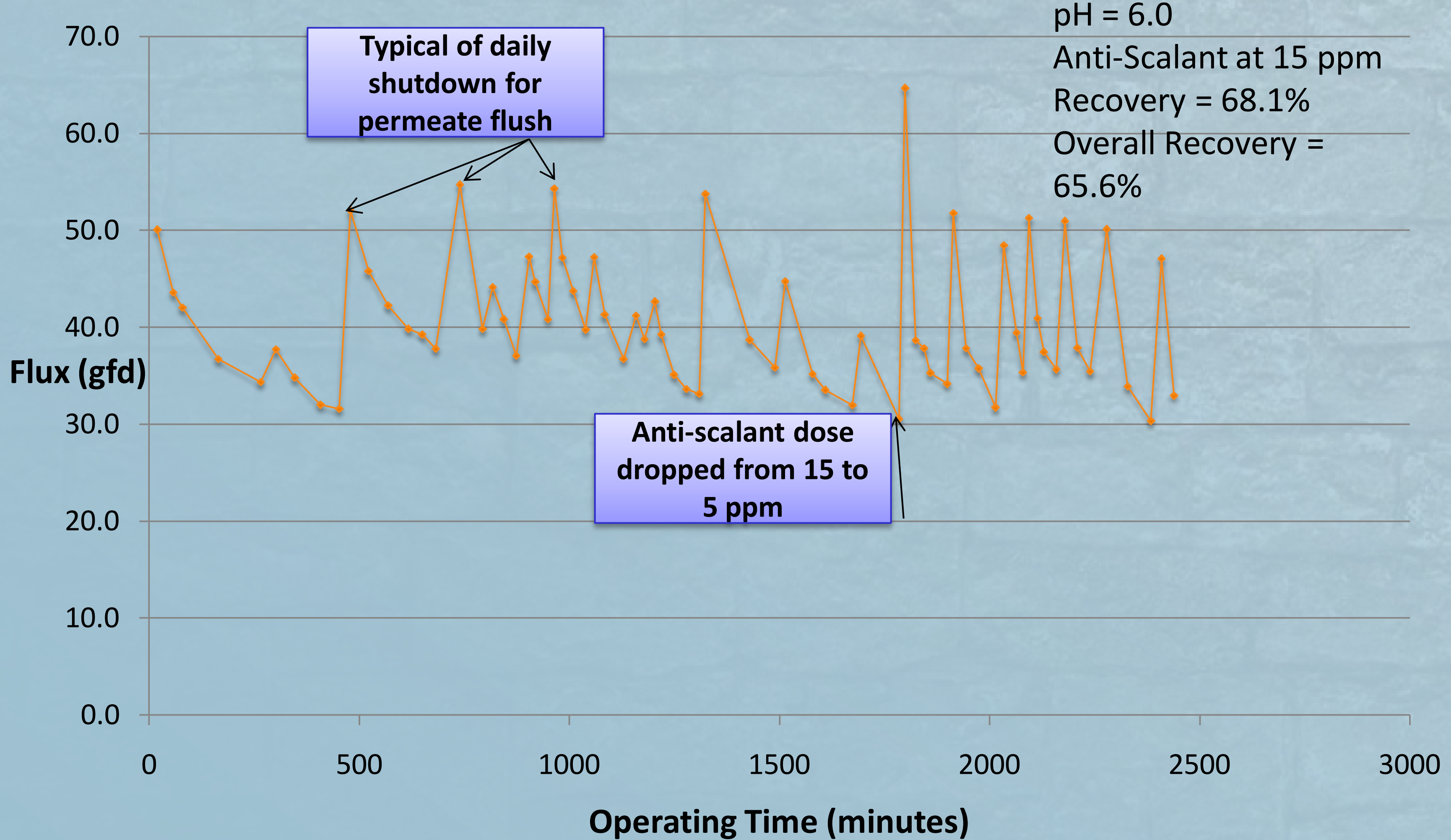
Brines from the High Recovery RO system Were Further Concentrated Until Intermediate Precipitates Formed to ID Potential Limiting Metastable Compounds

Mineral Name	Chemical Formula	Approximate wt%
Halite	$NaCl$	18
Thenardite	Na_2SO_4	<3
Quartz	SiO_2	8
Burkeite	$Na_6CO_3(SO_4)_2$	35
Trona	$Na_3H(CO_3)_2\text{-}2H_20$	35
Unidentified	?	<5

Typical Sulfate, Silica, Hydroxide and Carbonate Intermediate Precipitates Generated from Concentrated Brines


VSEP Pilot Unit
1.5 gpm
530 psi feed pressure
60 cycles/sec oscillation
Filter Pack

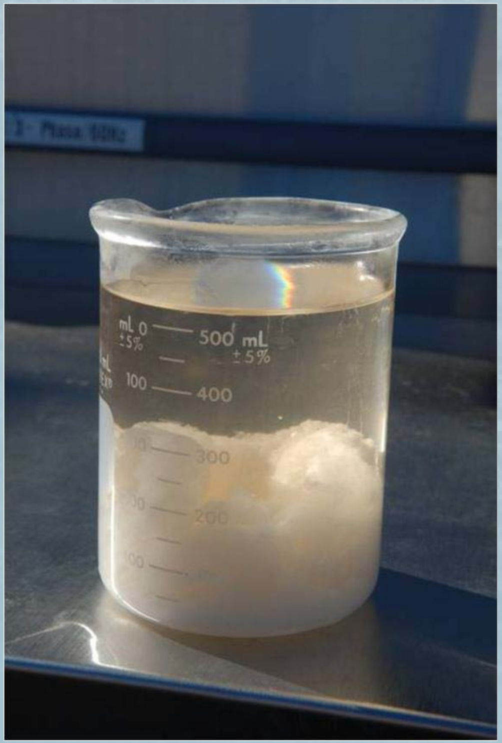
VSEP Tested with Un-Softened Concentrate at ECCV & Achieve Stable Operation w/ Aux. Permeate Flush Cycle



Pilot Testing High Recovery RO to Reduce Volume of Waste from Coal Bed Methane Gas (CBMG) Wells

Secondary RO processes can recovery high quality permeate from supersaturated solutions. $NaHCO_3$ precipitates formed in high recovery RO concentrate overnight

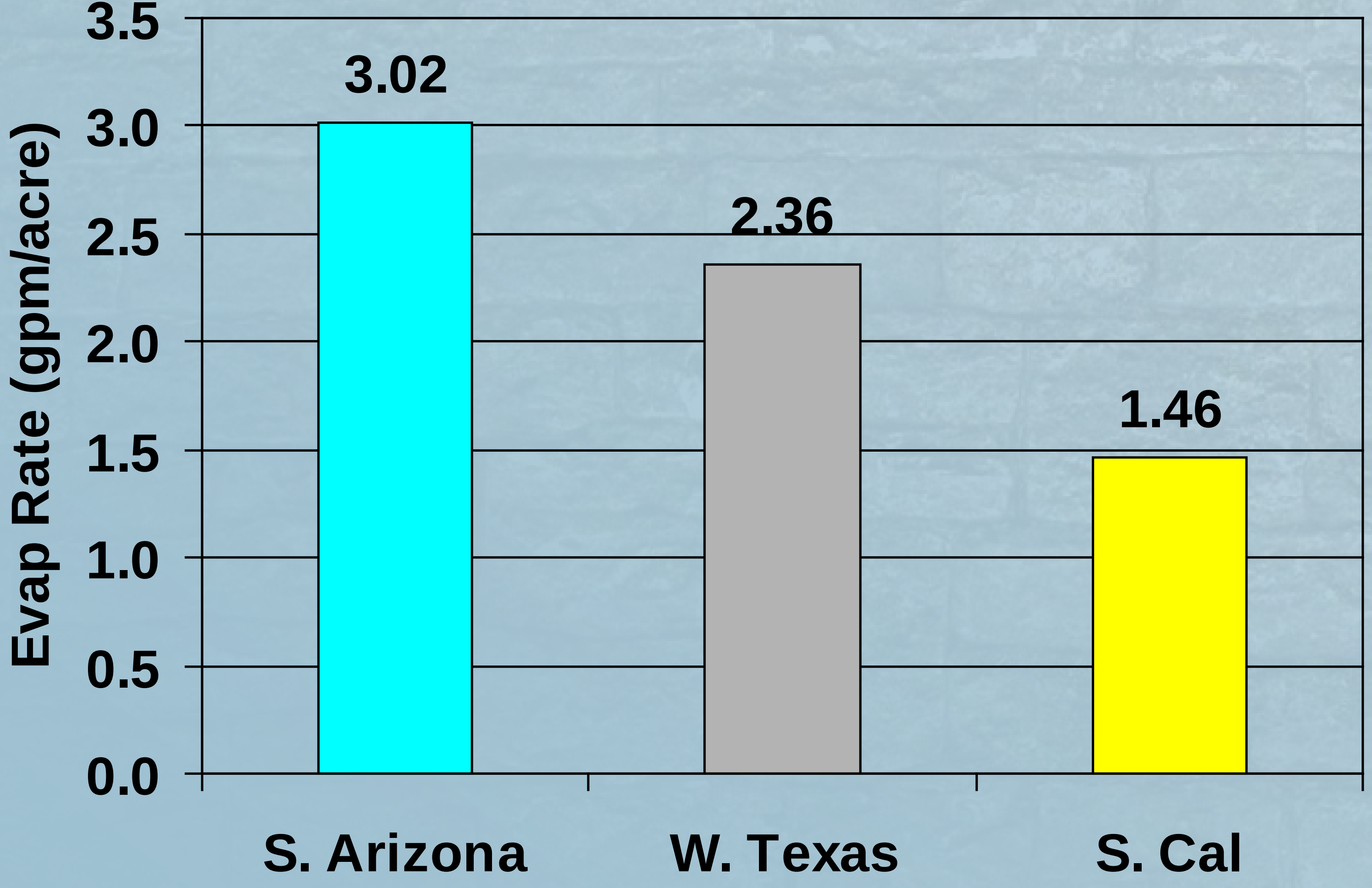
Reduce Disposal Cost of Brackish water from CBMG and Capture Usable Irrigation Water



Key Factors Identified During Pilot Testing at ECCV, Powder River Coal Fields & New Mexico Geothermal Well for Achieving High RO Recovery

1. Weak acid IX effective in Limiting precipitation of sparingly-soluble salts (Ca, Mg, Ba, Fe, silica, etc.) on the surface of the membrane
2. Operating pressure to overcome higher osmotic pressure are less than maximum 1200 psig rating of pressure vessels and seawater RO membranes
3. More frequent chemical cleaning of the RO membranes in the final stages should be anticipated
4. Good RO array design critical to minimizing concentration polarization

Passive Evaporation Basins Generally Not Practical for Large Flows Even in the Desert Southwest



Thermal Mechanical Brine Concentrators Have Been Used by Power Plants and Industry When Evaporation Basins Not Feasible

- Historically higher capital costs ($3 million/ 100 gpm of capacity
- Greater mechanical complexity
- Higher energy usage
- Potential for mineral scaling and corrosion in heat exchangers

300 gpm Vapor Compression System

Photo courtesy GE Infrastructure

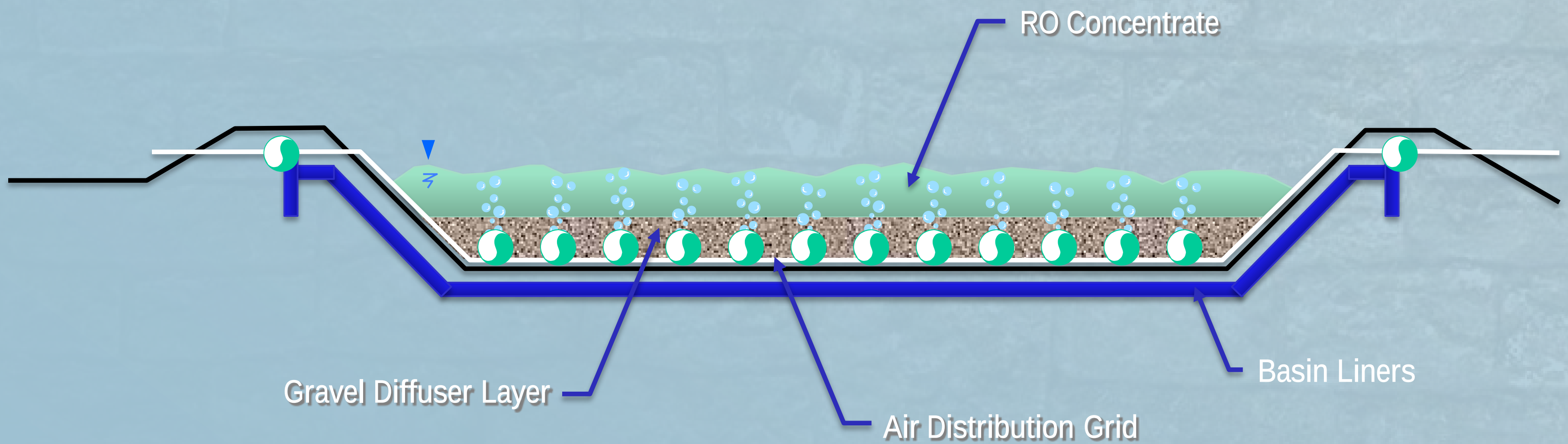
Simple Commercial Systems Utilize Air Flow Through Cascading Water to Increase the net Evaporation Rate

- Small ambiant heat evaporator rated at 25-30 lbs/hour or 75 gallons per day
- Systems are not design to produce dry salts
- Not practical for large municipal operation

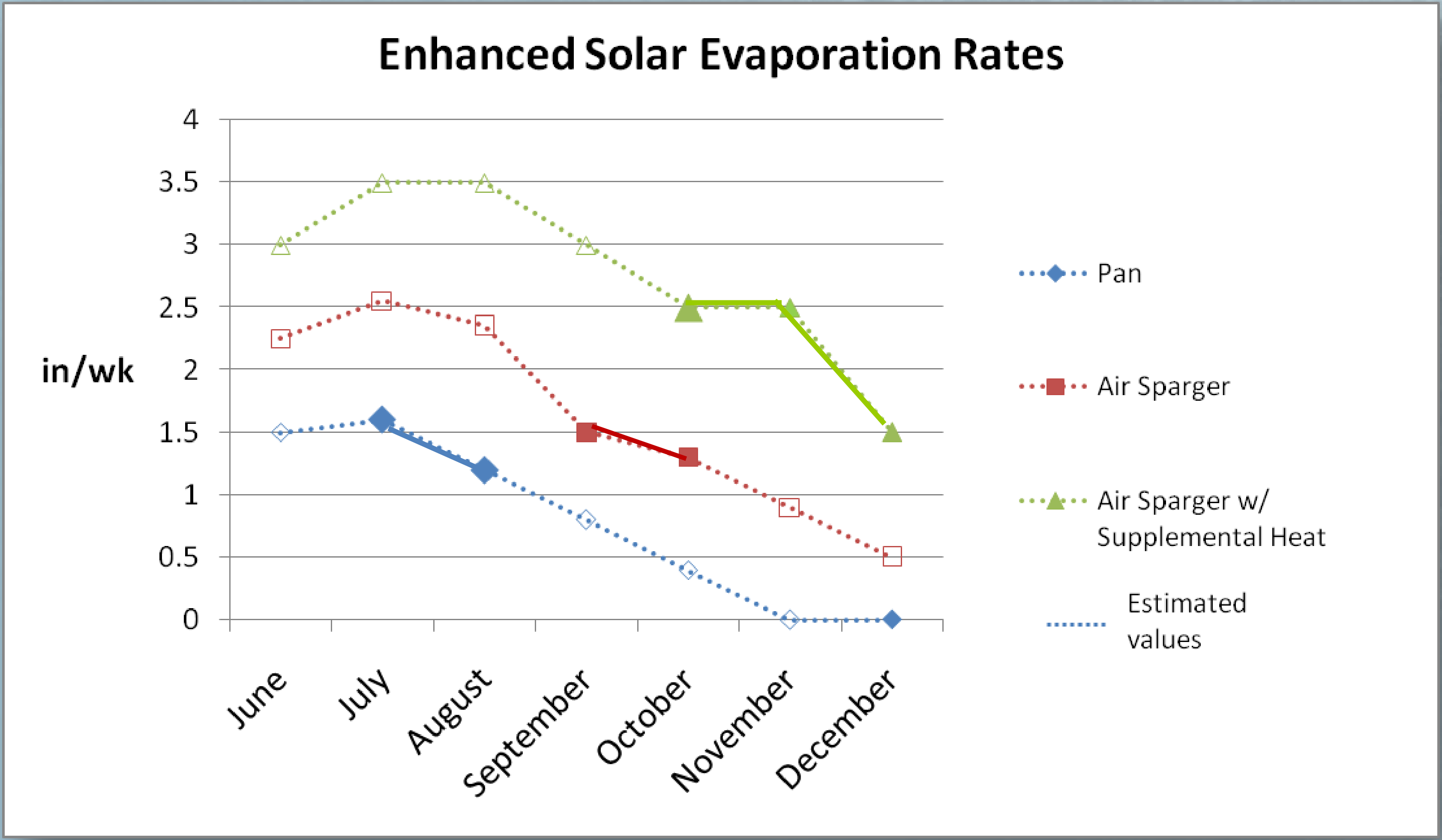
ECCV ZLD Pilot Study Focused on Simple Enhanced Evaporation Processes Rather High Tech Thermal/Mechanical Systems

- Reduce Capital Costs
- Reduce Mechanical Complexity
- Reduce Potential for Mineral Scaling
- Sacrifice last 3% of the water
- Reduce Energy Usage

A Low-Cost Solar Basin with an Air Sparger Used to Increase Net Evaporation Rates



Observed On-Site Evaporation Rates in Northern Colorado



Formation of Sulfates & Carbonates During Pan Evaporation at ECCV Pilot Site in Northern Colorado

Un-Softened Concentrate Dry Salt Composition

Mineral Name	Chemical Formula	Approximate wt%
Halite	$NaCl$	37
Gypsum	$CaSO_4$ - $2H_2O$	42
Bassanite	$CaSO_4$ - $1/2H_2O$	<10
Polyhalite	$K_2Ca_2Mg(SO_4)4\text{-}2H_20$	<3
Huntite	$Mg_3Ca(CO_3)4$	<5
Quartz	SiO_2	<5
Unidentified	?	<5

Softened Concentrate Dry Salt Composition

Mineral Name	Chemical Formula	Approximate wt%
Halite	$NaCl$	40
Thenardite	Na_2SO_4	54
Quartz	SiO_2	<5
Burkeite	$Na_6CO_3(SO_4)_2$	<3
Trona	$Na_3H(CO_3)_2$-$2H_20$	<3
Unidentified	?	<5

Large Scale Enhanced Evaporation Demonstration Testing Considerations

- Simulating seasonal atmospheric conditions for wind, temperature and precipitation
- Scaling equipment to provide reasonable evaluation of environmental impacts (noise, mist drift, odors)
- Duration of the test to identify potential for mineral scaling, corrosion and excessive maintenance

Thank You

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