

Electrodialysis Research Update

Mono-Valent Selective Ion Exchange Membranes for Saline Water Reuse and Desalination

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Acknowledgement

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John Balliew, Fernie Rico, Art Ruiz, City of El Paso




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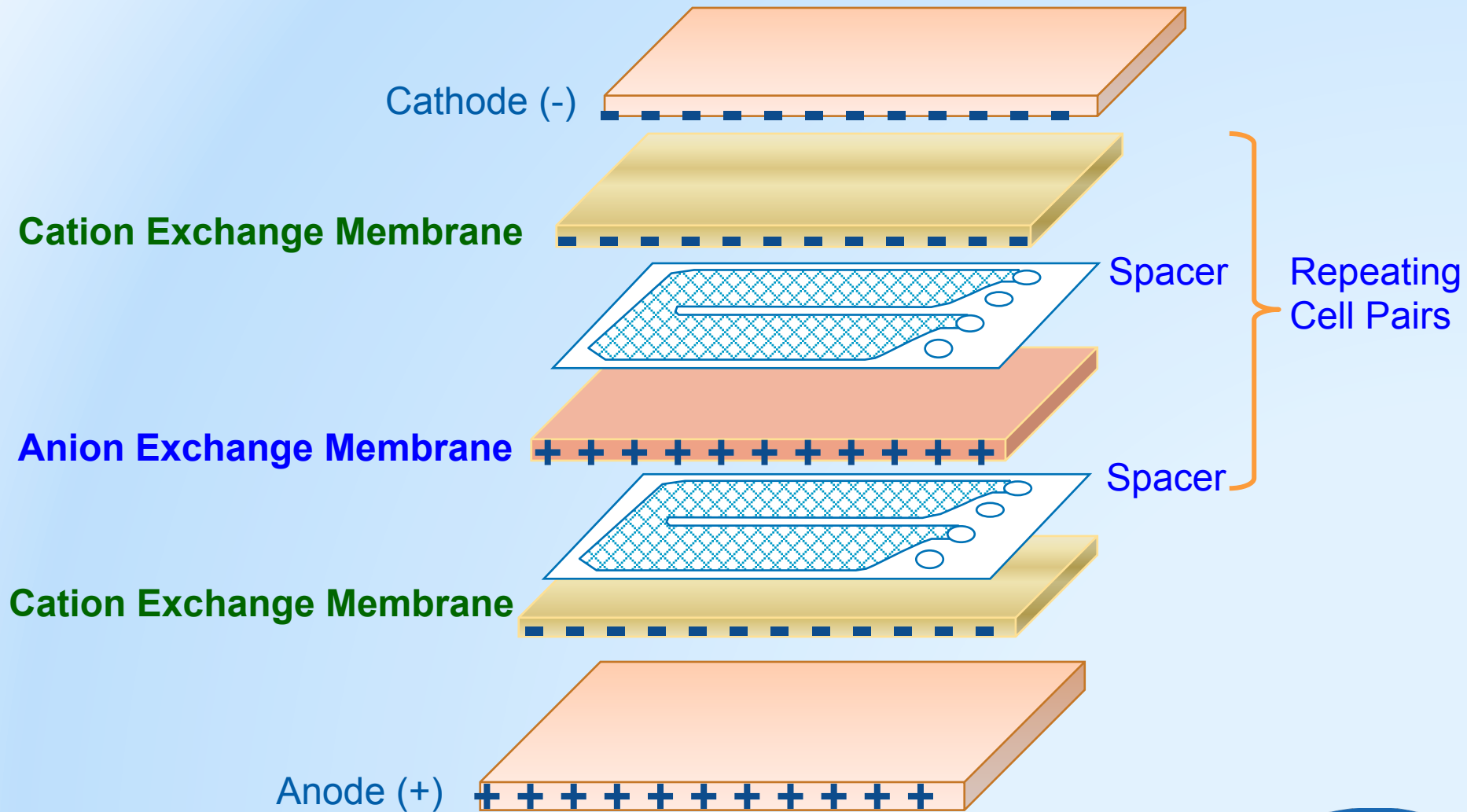
Presentation Outline

- ED/EDR Research Update
 - Need of Selective Removal of Sodium
 - Selected Testing Results
 - Modeling and Blending Analysis
 - Take Home Messages
- 

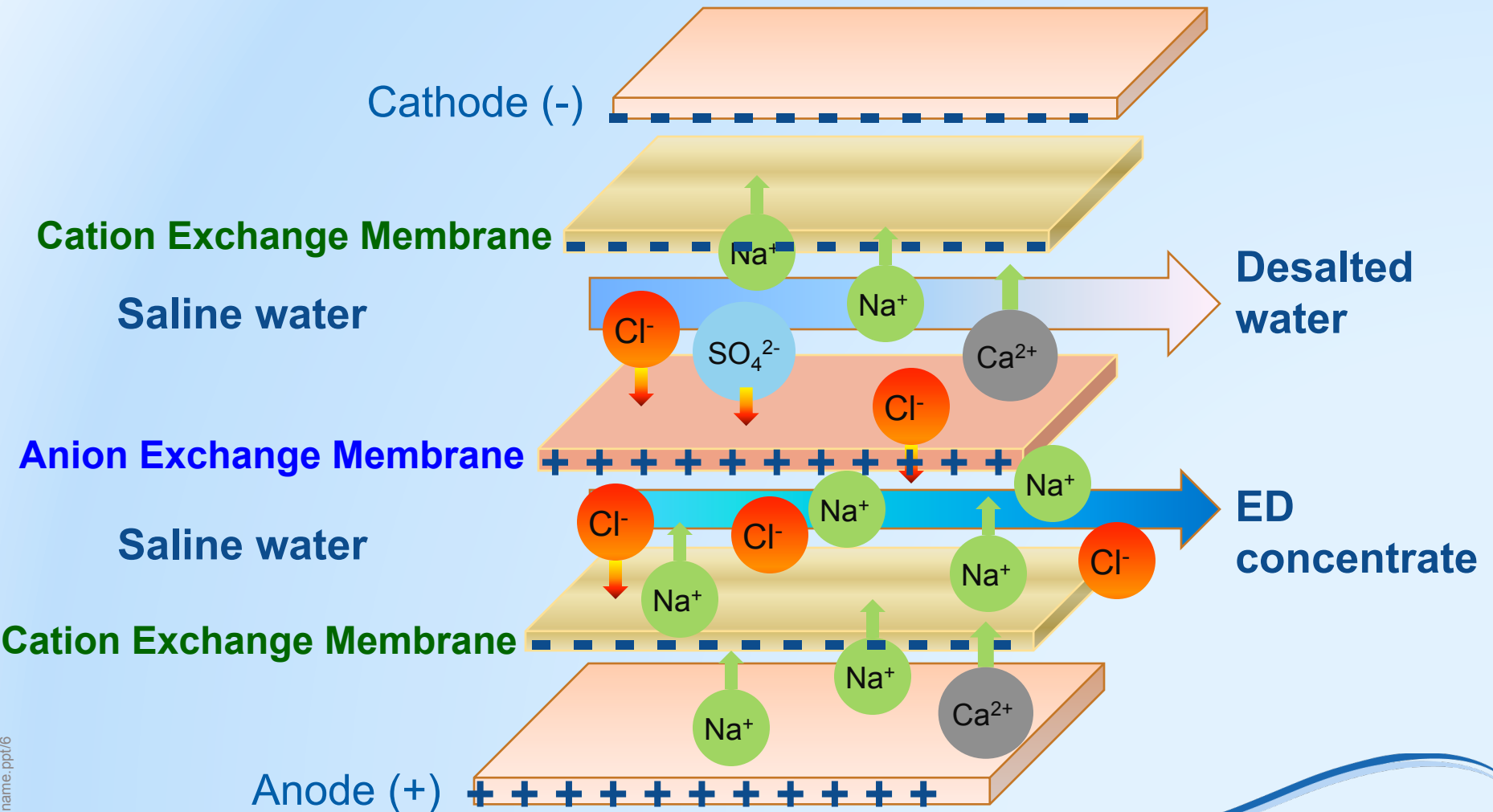


ED/EDR Research Update

Electrodialysis Consists of Electrodes and A Stack of Membrane Cell Pairs



Electrodialysis with Normal Grade IX Membranes Remove All Cations and Anions



Electrodialysis, An Old Technology Finding New Applications

1948 - Ionics develops ion exchange membranes

1950-1959 – ED Technology is developed

1970 - Ionics introduces reversal process to Electro dialysis

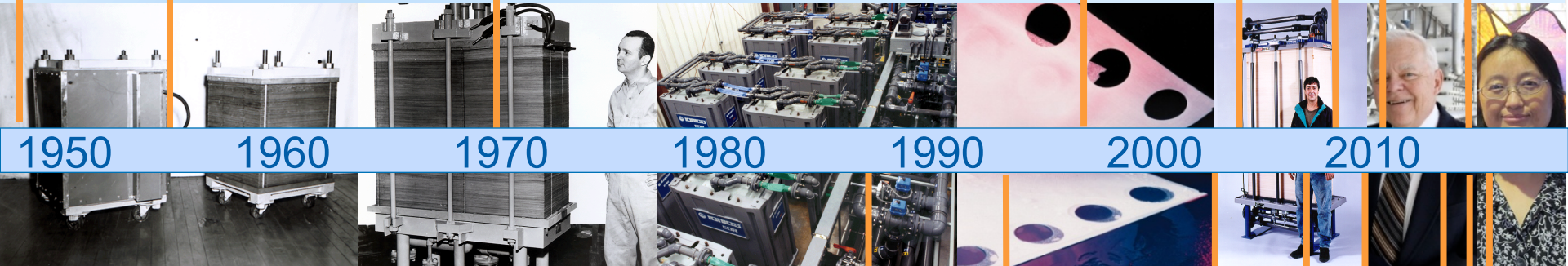
1997 – Introduction of Ionics EDR 2020 System

2005 – Ionics purchased by GE Water

2010 – GE High Reject and High Recovery EDR R&D

2011 – GE Announce New Non-Thermal Brine Concentrator (AquaSEL)

Ongoing – Monovalent Selective Membrane Research



1987 – CEDI Commercialized by Millipore

1995 – CDI Commercialized

2004 – BPED Commercialized by ASTOM

2009 – ZDD Commercialized

2010 – Therm-Ionic™ Commercialized

Ongoing – EDR IX & EDR SPARRO Pilot Testing

Ongoing – Lesico Modular ED
Ongoing – RED, MFC, MDC Research



Your Weakness Can be Your Strength

Disorganized

Inflexible

Inconsistent

Stubborn

Emotionless

Unrealistic

Negative



Creative

Organized

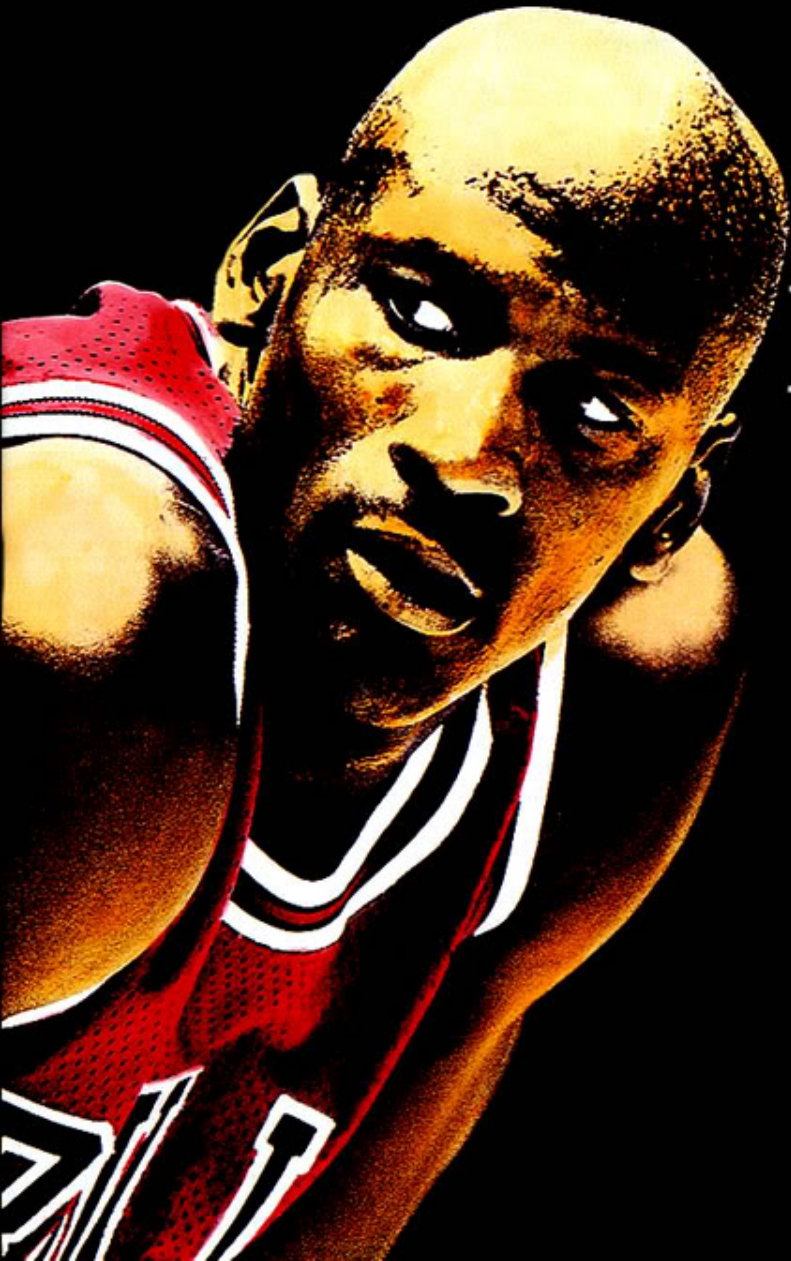
Flexible

Dedicated

Calm

Positive

Realistic



23

Michael Jordan

My attitude is that if you push me towards something that you think is a weakness, then I will turn that perceived weakness into a strength.

Research and Engineering Expertise Turns Weakness into Strength

No Silica Removal

Not efficient for TDS < 100

Electrode reactions and hazardous gas

Not an organic barrier

Not suitable for high TDS?

GE Proprietary

No Specialties?

No ERD?



Silica limiting RO applications

EDI Technologies

New carbon electrode; Bipolar ED

High tolerance to organics and particulates

Strong in brine treatment & high TDS applications

Innovative competitions

Unique Selectivity

RED, MDC, Thermo-ionic, etc.

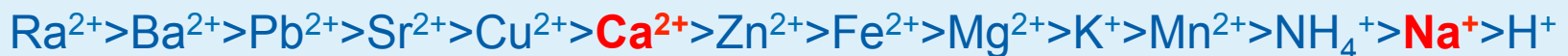


Selective Removal of Sodium

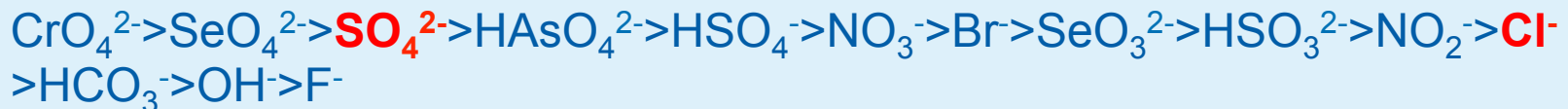
Selectively Removing Sodium is Desirable but Challenging – Ion Exchange & Softening

	Lime Softening	Ion Exchange
Sodium		x
Calcium	X	X
TDS		
Selectivity	No	Yes, but
Beneficial Selectivity	No	No

Selectivity Sequence for Typical Strong Acid Cationic Resin

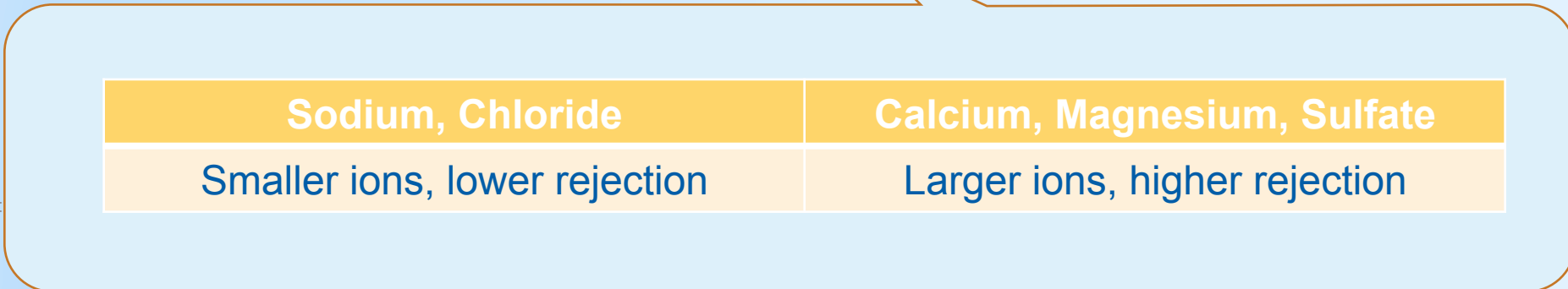


Selectivity Sequence for Typical Strong Base Anionic Resin



Selectively Removing Sodium is Desirable but Challenging - Membranes

	Lime Softening	Ion Exchange	RO	NF	ED/EDR
Sodium		x	X	X	X
Calcium	X	X	X	X	X
TDS			X	X	X
Selectivity	No	Yes, but	No	Yes, but	Yes
Beneficial Selectivity	No	No	No	No	No



Selectively Removing Sodium is Desirable but Challenging - Membranes

	Lime Softening	Ion Exchange	RO	NF	ED/EDR
Sodium		x	X	X	X
Calcium	X	X	X	X	X
TDS			X	X	X
Selectivity	No	Yes, but	No	Yes, but	Yes
Beneficial Selectivity	No	No	No	No	No

	NF90	NF270
Description	Tightest (lower MWCO)	Loosest (higher MWCO)
NaCl Rejection	90-96%	50%
MgSO ₄ Rejection	98+%	98+%

Selectively Removing Sodium is Desirable but Challenging - Membranes

	Lime Softening	Ion Exchange	RO	NF	ED/EDR
Sodium		x	X	X	X
Calcium	X	X	X	X	X
TDS			X	X	X
Selectivity	No	Yes, but	No	Yes, but	Yes
Beneficial Selectivity	No	No	No	No	No

Sodium	Calcium, Magnesium
Monovalent, lower charge, smaller ion	Divalent, higher charge, bigger ion

Selectively Removing Sodium is Desirable but Challenging – Innovative Membrane

	Lime Softening	Ion Exchange	RO	NF	ED/EDR	Monovalent Selective ED/EDR
Sodium		x	X	X	X	X
Calcium	X	X	X	X	X	X
TDS			X	X	X	X
Selectivity	No	Yes, but	No	Yes, but	Yes	Reported Yes
Beneficial Selectivity	No	No	No	No	No	Reported Yes

Defining Selectivity

- Selectivity based on ppm

$$\text{Selectivity}_{\text{Ca/Na}} = \frac{\text{Removal}_{\text{Ca}}}{\text{Removal}_{\text{Na}}} = \frac{(\text{Ca}_{\text{feed}} - \text{Ca}_{\text{product}}) / \text{Ca}_{\text{feed}}}{(\text{Na}_{\text{feed}} - \text{Na}_{\text{product}}) / \text{Na}_{\text{feed}}}$$

- Selectivity based on meq/L

$$\text{Selectivity}_{\text{Ca/Na}} = \frac{[\text{Ca}_{\text{feed}}] - [\text{Ca}_{\text{product}}]}{[\text{Na}_{\text{feed}}] - [\text{Na}_{\text{product}}]}$$

- Lower value means better removal of sodium

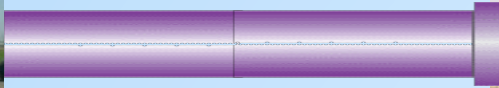


Problem Statement

For Scottsdale, Salinity Poses A Challenge to Irrigation Reuse



**Water
Reclamation Plant
to Reuse**



SAR = Sodium Adsorption Ratio

$$\text{SAR} = \frac{[\text{Na}^+]}{\{([\text{Ca}^{2+}] + [\text{Mg}^{2+}]) / 2\}^{1/2}}$$

[]: use meql units

≤ 3

6 to 9

> 9

- CAP Water SAR ~ 5 on average
- Verde River < 2 on average
- Salt River > 9 on average
- Scottsdale Water Campus Effluent 5-8

Advanced Treatment Using RO Solved The Problem, But ...

Water Quality Goal
Contractual Limit: <125
ppm Sodium
Operating Target: <110
ppm Sodium



**Water
Reclamation
Plant to Reuse**

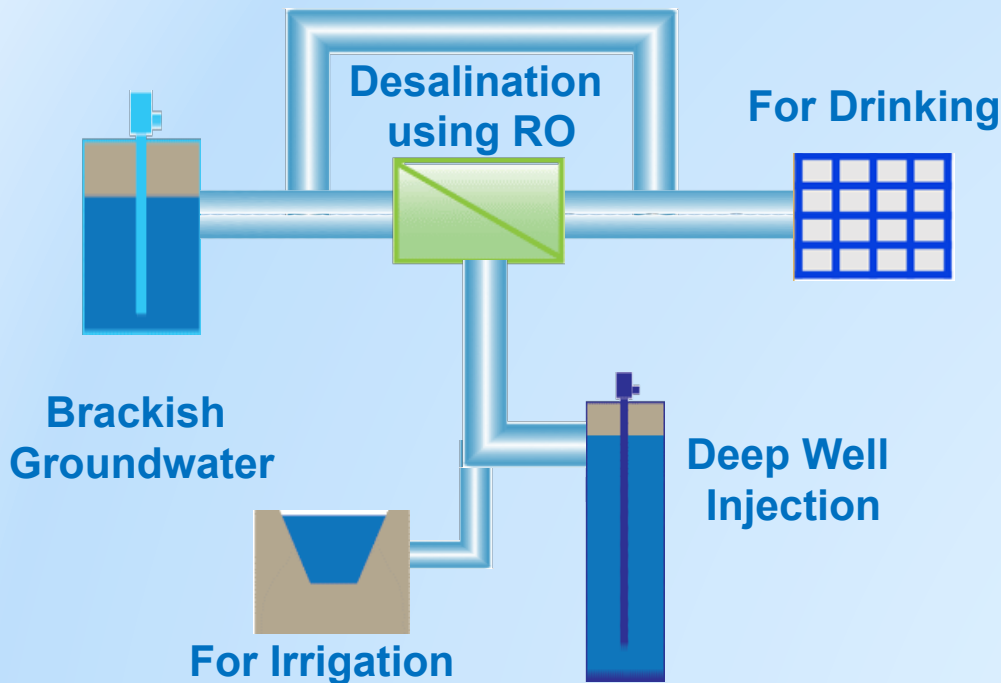


**Advanced Water
Treatment Plant**



**Concentrate
Management**

For El Paso, Brackish Groundwater Desalination Using RO is Successful. But Can We Do Better?



**15 - 20% Water resource lost as concentrate;
Limited deep well capacity.**

Recovered Water Quality Goal
Based on Minimum Effluent Standard for Discharging into the American Canal Extension

TDS < 1,200~2,500 mg/L
SAR ≤ 29 – 6 logTDS

TDS (mg/L)	SAR
2500	8.6
2300	8.8
2000	9.2
1900	9.3
1500	9.9
1200	10.5

Reference: Texas Natural Resources Conservation Commission

DWPR Funded Project Included Bench and Pilot Testing at Two Sites

	Phase 1 - Scottsdale Water Campus	Phase 2 - El Paso KBH Desalination Plant	
Site	Scottsdale Water Campus	El Paso Kay Bailey Hutchison Desalination Plant	
Duration	July to December 2015	January to April 2016	
Objective	Saline Water Reuse	Concentrate Management	
Water Source	Reclaimed Water	Brackish Groundwater	Groundwater Brine
Feed TDS	1,150	3,252	11,000
Feed Sodium	235	738	2,900
Goal	125 mg/L Sodium in product	TDS < 1,200~2,500 mg/L SAR ≤ 29 – 6 logTDS	
Summary	Unexpected low selectivity due to coating method	Improved Coating Method = Improved Selectivity	

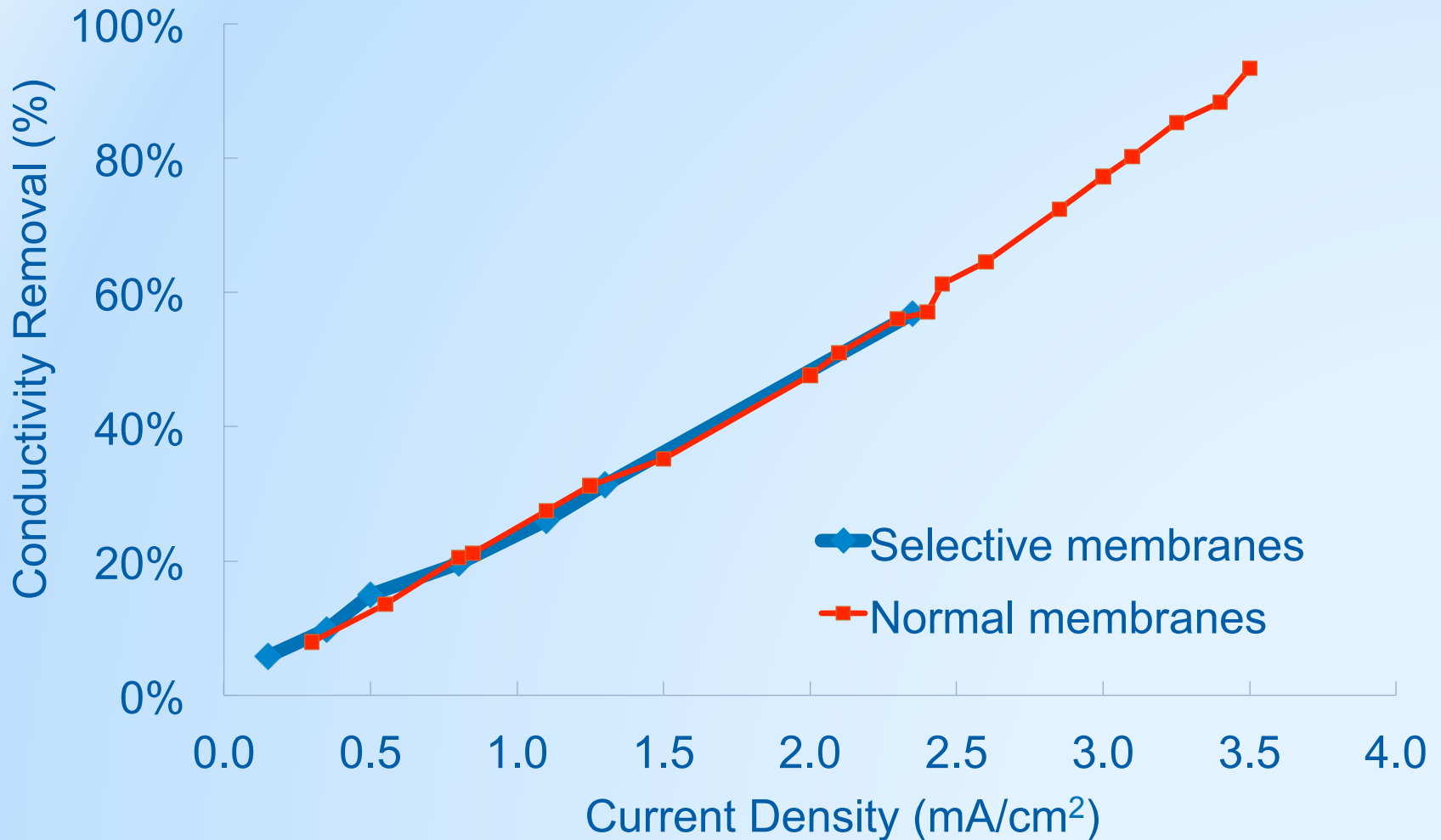
Several Types of Conventional & Innovative Membranes Were Used for the Testing

Membrane	AR204	CR67	AR112	CR671
Manufacturer	Ionics/GE	Ionics/GE	Ionics/GE	Ionics/GE
Characteristics	Normal grade	Normal grade	Mono – anion permselective	Mono – cation permselective
Thickness (μm)	500	560-580	580-690	560-580
Water content (g H ₂ O/g dry membrane)	46% of wet resin	46% of wet resin	20-25% of wet resin	46% of wet resin
Electrical resistance ($\Omega\text{-cm}^2$ in 0.01N NaCl)	8	12	22-26	12
Ion exchange capacity (meq/g dry membrane)	2.40	2.10	1.6-1.8 Strong base 0.3-0.6 weak base	2.0-2.1

Note: NEOSEPTA membranes are also used in bench testing: normal grade membranes (AMX and CMX-SB) and NEOSEPTA monovalent permselective membranes (ACS and CMX-S).

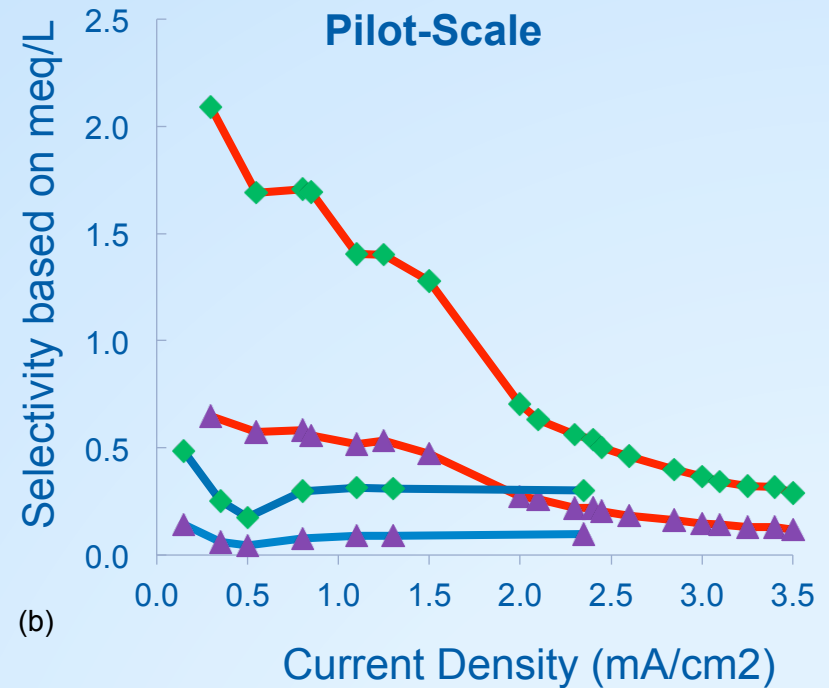
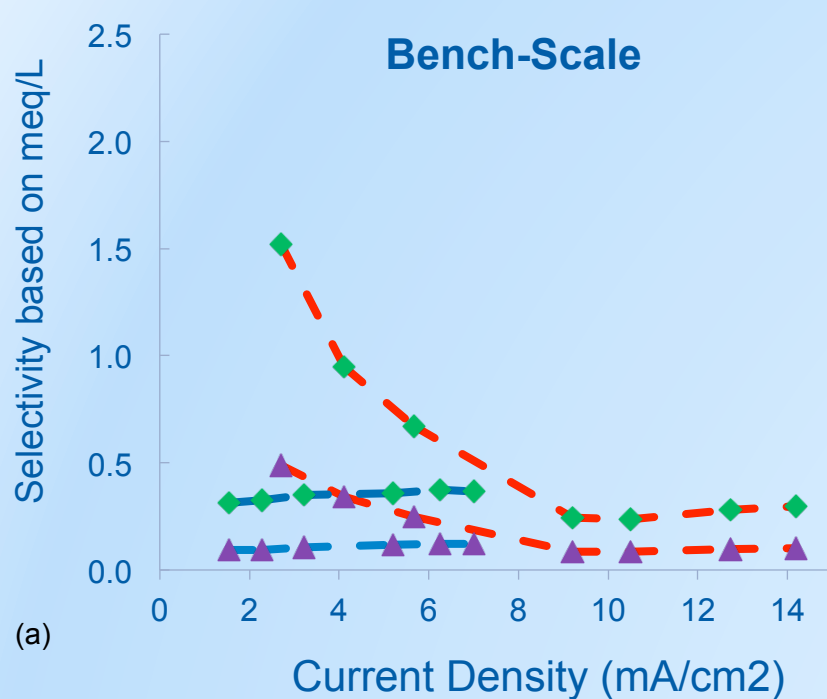
Selective and Normal Membranes Demonstrates Same Desalination Efficiency

El Paso Brackish Groundwater 2 Stage Pilot ED



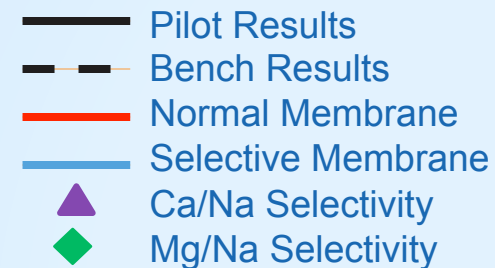
Selective Membrane Demonstrates Better Selectivity of Divalent Cations over Monovalent than Normal Membrane

El Paso **Brackish** Groundwater



Highlight:

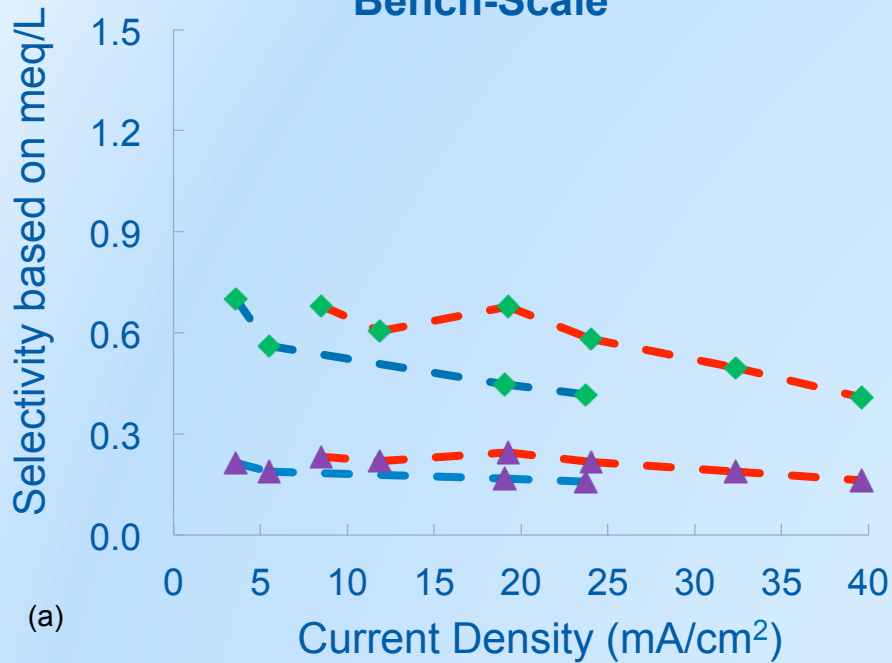
- Normal membrane has low selectivity at low current;
- Selective membrane has consistently better selectivity;
- Bench vs. Pilot: Different operating conditions but same trends.



Selective Membrane Demonstrates Better Selectivity of Divalent Cations over Monovalent than Normal Membrane

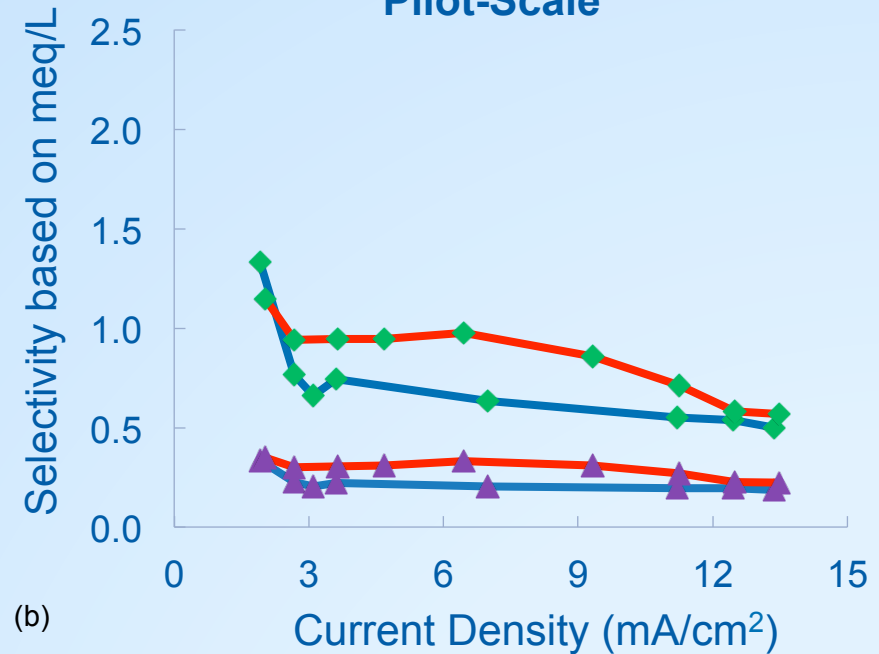
El Paso RO Concentrate

Bench-Scale



(a)

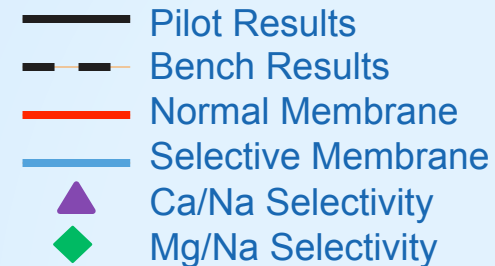
Pilot-Scale



(b)

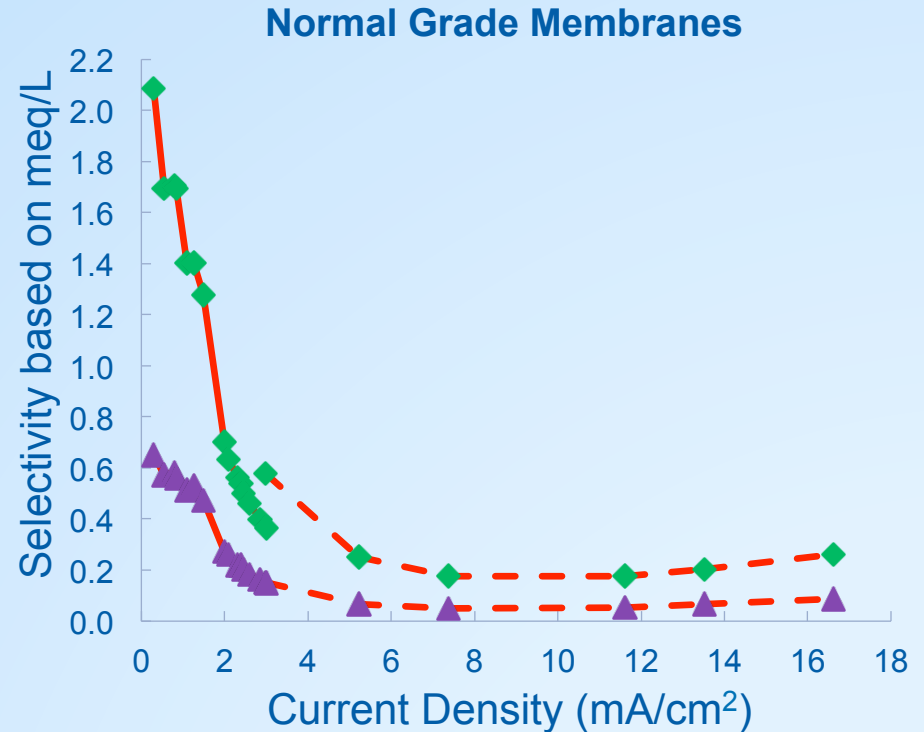
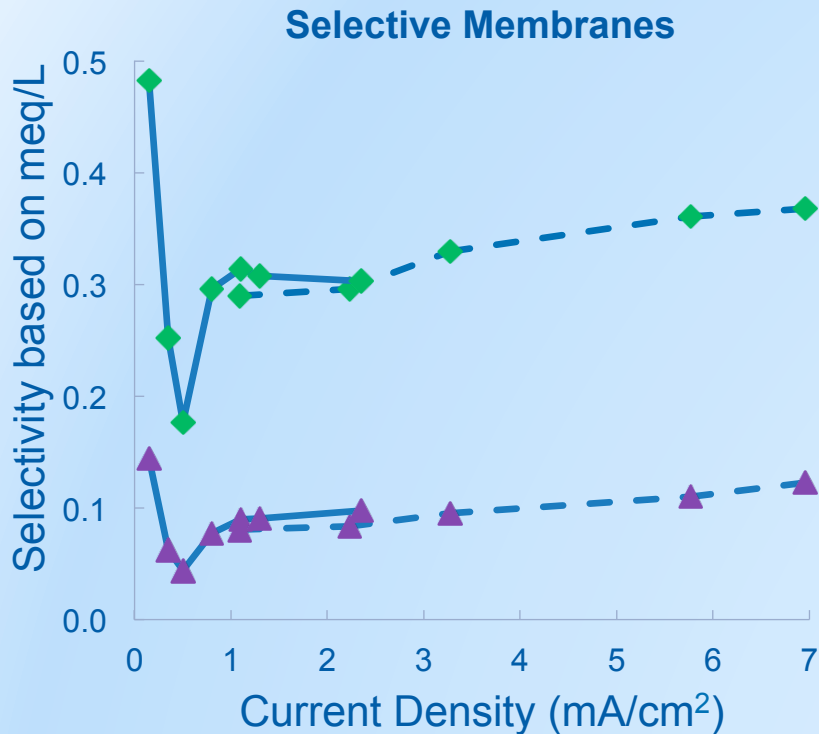
Highlight:

- Similar to previous slide
- Selectivity reduced with increase in feed water TDS



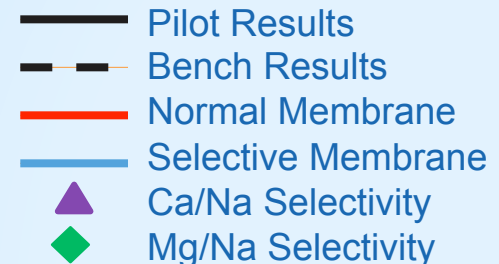
Bench Testing Data Matches Well with Pilot Testing Results

El Paso **Brackish** Groundwater

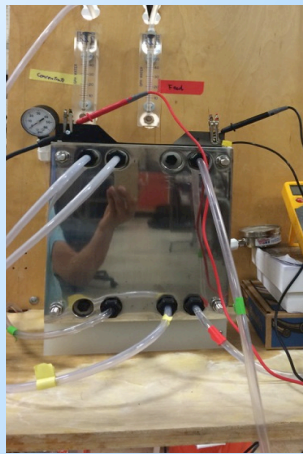


Highlight:

- Bench and pilot operates under different conditions
- Bench testing can be used for pilot or full scale performance projections



Value Adding Research Links Bench Testing, Pilot Testing, Modeling, and Full Scale Design



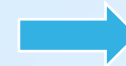
Bench Testing



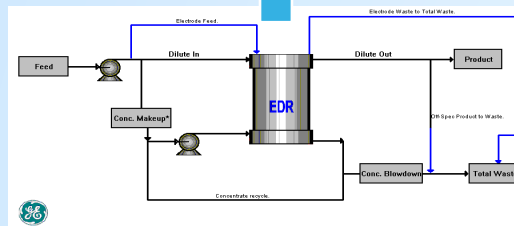
Data Fitting and Mathematical Modeling



BLUE PLAN-IT™
DECISION SUPPORT SYSTEM



Water and Salt Balance, Process Modeling
Cost Analysis



WATSYS: Specialty EDR Projection Model by GE
(Normal Grade Membrane Only)



Pilot Testing



Full Scale
Design

Scottsdale Blending Analysis and Cost Comparison

ExtendSim

File Edit Text Library Model Database Develop Run Window Help

[0] System Components <Blue Plan-it v3.9.0Mono_No Soften_Pei Removal-SC 2 stage not 4.mox>

carollo **BLUE PLAN-IT™**
Engineers...Working Wonders With Water™ DECISION SUPPORT SYSTEM

Steady-State 100%
00:00:03 15

TIME MANAGER UNIT \$ MANAGER SITE LAYOUT HYDRAULIX® LINK DEMAND CAPACITY PH CALCULATOR MODULE EQUATION EDITOR BPI HELP IMPORT & EXPORT

Scottsdale Water Campus Phase 1

INPUT MANAGER **Baseline Alternative - RO**

Flow (mgd) 1

39.5

UF

RO

DS

Parameter	Unit	Actual	Goal
0 Flow	mgd	0.884	
1 Calcium	mg/L	36.41	
2 Sodium	mg/L	109.17	125
3 TDS	mg/L	530.5	
4 SAR	mg/L	3.92	

15.62 acres

Final_Brine

Final_Brine_MC

Final_Brine_TS

Alternative 1 - Normal Grade Membrane

0

7.2

7.2

Normal ED

ED2

DS1

27.43

Parameter	Unit	Actual	Goal
0 Flow	mgd	0.9	
1 Calcium	mg/L	16	
2 Sodium	mg/L	129.78	125
3 TDS	mg/L	488.87	
4 SAR	mg/L	6.69	

Parameter	Unit	Actual
0 Flow	mgd	0.1
1 Calcium	mg/L	656
2 Sodium	mg/L	1190.98
3 TDS	mg/L	7130.15

Alternative 2 - Selective Membrane

33.5

7.2

0

Selective ED

ED_mono2

DS2

18.10

Parameter	Unit	Actual	Goal
0 Flow	mgd	0.934	
1 Calcium	mg/L	55.94	
2 Sodium	mg/L	110.38	125
3 TDS	mg/L	727.08	
4 SAR	mg/L	3.07	

Parameter	Unit	Actual
0 Flow	mgd	0.095
1 Calcium	mg/L	417.85
2 Sodium	mg/L	1984.11
3 TDS	mg/L	7130.15

Alternative 1 - Normal Grade Membrane - WATSYS

31

7.2

0

Normal ED

ED2

DS1

18.92

Parameter	Unit	Actual	Goal
0 Flow	mgd	0.931	
1 Calcium	mg/L	30.37	
2 Sodium	mg/L	109.6	125
3 TDS	mg/L	522.35	
4 SAR	mg/L	4.26	






Parameter	Unit	Actual
0 Flow	mgd	0.089
1 Calcium	mg/L	749.6
2 Sodium	mg/L	1927
3 TDS	mg/L	9982.14

MODEL SETUP


ONE REPORT REPORT REPORT

Cost Type	Option 1	Option 2	Option 3	Option 4
Total Capital Cost (\$M):	2.82	2.08	1.5	1.54
Annual O&M Cost (\$M):	0.18	0.04	0.03	0.02
Life Cycle Cost (\$M):	5.74	2.72	1.92	1.78

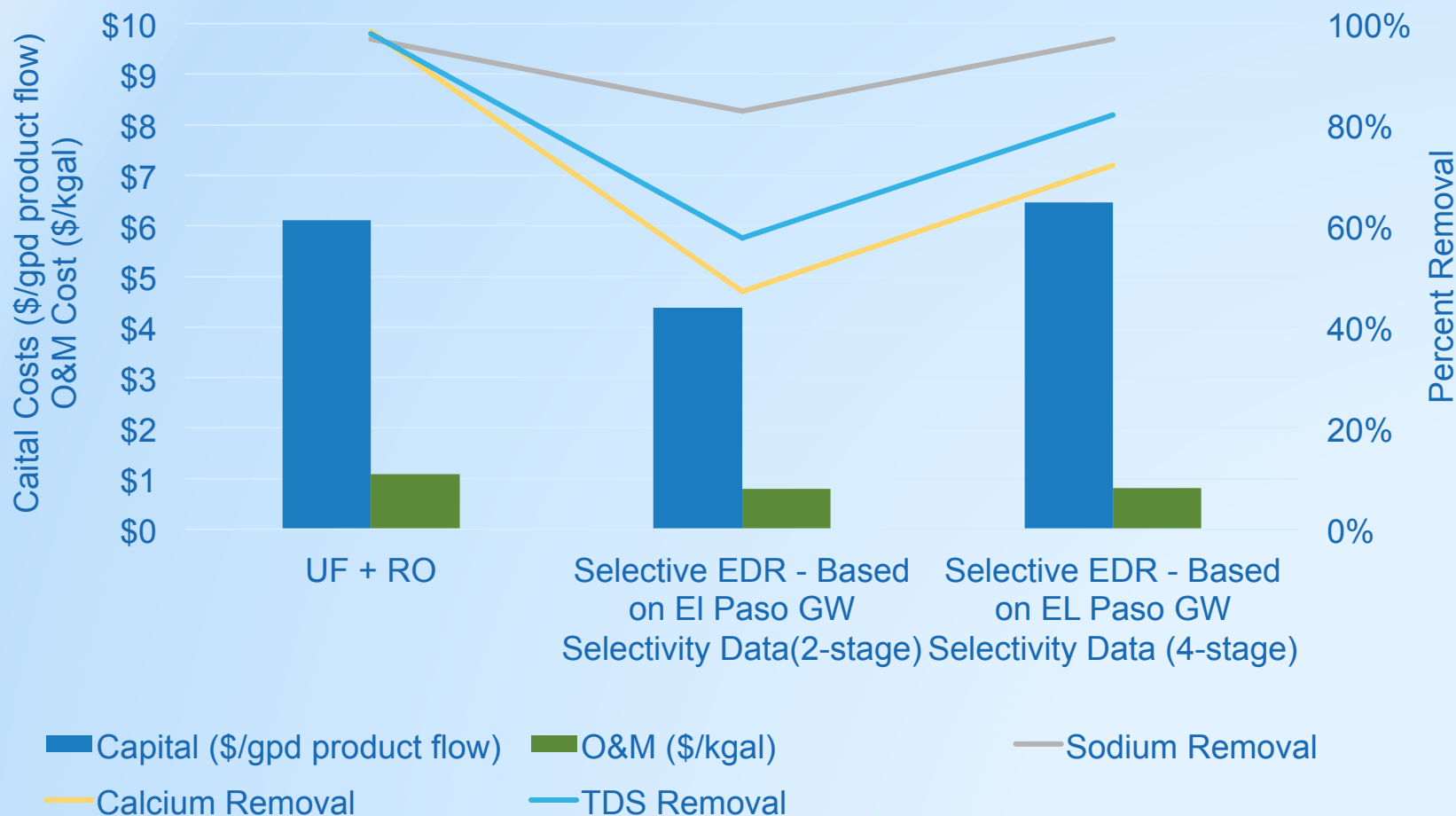
Scottsdale Blending Analysis and Cost Comparison – 1 MGD Reclaimed Water (2-stage)

	Baseline Alternative	Alternative 1A	Alternative 1	Alternative 2
	UF + RO	Normal EDR - WATSYS	Normal EDR - Testing	Selective EDR (Based on EP GW Testing)
Feed Water Flow (mgd)	1			
Feed Water Sodium (mg/L)	235			
% Flow Treated	60.5%	69.0%	 100.0%	66.5%
Overall Recovery	88%	93%	92%	93%
Unit Recovery	85%	90%	90%	90%
Blended Water Flow (mgd)	0.88	0.93	0.92	0.93
Product Water Sodium (mg/L)	 110	 110	 129	 110
Product TDS (mg/L)	530	522	489	727
Concentrate Flow (gpm)	60	48	69	46
Concentrate TDS (mg/L)	7530	9662	7130	7130
Concentrate Sodium (mg/L)	1524	2136	1715	3940
Number of Product Line	-	7	8	6
Number of Stages	-	2	2	2
Capital (\$/gpd product flow)	\$6.1	\$5.0	\$5.6	\$4.4
O&M (\$/kgal)	\$1.09	\$0.82	\$0.80	\$0.79
Note	Blending based on RO Projection Model	Based on Modeling	Based on Pilot Testing	Based on El Paso GW Testing

Scottsdale Blending Analysis and Cost Comparison – 1 MGD Reclaimed Water (4-stage)

	Baseline Alternative	Alternative 1A	Alternative 1	Alternative 2
	UF + RO	Normal EDR - WATSYS	Normal EDR - Testing	Selective EDR (Based on EP GW Testing)
Feed Water Flow (mgd)	1			
Feed Water Sodium (mg/L)	235			
% Flow Treated	60.5%	69.0%	78.0%	57.5%
Overall Recovery	88%	93%	92%	94%
Unit Recovery	85%	90%	90%	90%
Blended Water Flow (mgd)	0.88	0.93	0.92	0.94
Product Water Sodium (mg/L)	 110			
Product TDS (mg/L)	530	522	433	634
Concentrate Flow (gpm)	60	48	54	40
Concentrate TDS (mg/L)	7530	9662	9662	9662
Concentrate Sodium (mg/L)	1524	1927	1715	2287
Number of Product Line	-	7	6	6
Number of Stages	-	4	4	4
Capital (\$/gpd product flow)	\$6.1	\$6.5	\$7.6	\$6.5
O&M (\$/kgal)	\$1.09	\$0.88	\$0.83	\$0.81

Scottsdale Cost Estimates (UF RO vs. 2-stage and 4-stage Selective EDR)



Note: Costs include full system with residuals handling, chemical, and 30% contingency, 18% OH, admin & engineering. Does not include evaporation pond or other final concentrate disposal costs.

El Paso Blending Analysis and Cost Comparison

ExtendSim [0] System Components <Blue Plan-it v3.9.0Mono_No Soften_Pei Removal.mox>

El Paso

INPUT MANAGER | ONE REPORT | SIMULATION MANAGER

Well → RO → EP_RO Con (100%) → EP_Soften → DS → DWI

Baseline Alternative - EP

Alternative 1 - WATSYS

Recovery EP_ED (13.5) → EP_ED2 (0) → EP_ED3 (0) → EP_ED4 (0) → For Irrigation → DWI1

Alternative 2 - Normal

Recovery 2EP_ED (42) → 2EP_ED2 (8) → 2EP_ED3 (0) → 2EP_ED4 (0) → For Irrigation → DW2

Alternative 3 - Selective 4-stage

Recovery 3EP_ED (42) → 3EP_ED2 (8) → 3EP_ED3 (0) → 3EP_ED4 (100) → EP_DS3 → EP_DS3

Alternative 4 - Selective 5-stage

Recovery 3EP_ED (42) → 3EP_ED2 (8) → 3EP_ED3 (0) → 3EP_ED4 (100) → 4EP_ED5 (0) → EP_DS3 → EP_DS3

Cost Summary:

- Total Capital Cost (\$M): 2.8
- Annual O&M Cost (\$M): 0.21
- Life Cycle Cost (\$M): 6.29

REPORT

Parameter	Unit	Actual	Goal
0	Flow	mgd	1
1	Calcium	mg/L	717
2	Sodium	mg/L	2897.6
3	TDS	mg/L	10902.4
4	SAR		25.12

Parameter	Unit	Actual	Goal
0	Flow	mgd	0.58
1	Calcium	mg/L	64.53
2	Sodium	mg/L	579.62
3	TDS	mg/L	1973.23
4	SAR		16.23

Parameter	Unit	Actual	Goal
0	Flow	mgd	0.42
1	Calcium	mg/L	1618.03
2	Sodium	mg/L	6098.78
3	TDS	mg/L	23376.01
4	SAR		35.26

Parameter	Unit	Actual	Goal
0	Flow	mgd	0.3384
1	Calcium	mg/L	2.29
2	Sodium	mg/L	762.5
3	TDS	mg/L	2026.95
4	SAR		100.88

Parameter	Unit	Actual	Goal
0	Flow	mgd	0.36
1	Calcium	mg/L	249.59
2	Sodium	mg/L	483.62
3	TDS	mg/L	2026.95
4	SAR		7.04









Parameter	Unit	Actual	Goal
0	Flow	mgd	0.36
1	Calcium	mg/L	59.22
2	Sodium	mg/L	521.57
3	TDS	mg/L	1932.57
4	SAR		15.17

Parameter	Unit	Actual	Goal
0	Flow	mgd	0.64
1	Calcium	mg/L	979.92
2	Sodium	mg/L	4286.72
3	TDS	mg/L	15988.59
4	SAR		31.5

Parameter	Unit	Actual	Goal
0	Flow	mgd	0.64
1	Calcium	mg/L	1087
2	Sulfate	mg/L	1914.75
3	TDS	mg/L	16041.62
4	SAR		29.85

Help | IPFD

El Paso Blending Analysis and Cost Comparison – 1 MGD RO Concentrate

	Alternative 1A	Alternative 2	Alternative 3	Alternative 3A
	WATSYS	Normal Grade	Selective (Condition 1)	Selective (Condition 2)
RO Concentrate Water Flow (mgd)		1		
RO Concentrate Sodium (mg/L)		2898		
RO Concentrate Calcium (mg/L)		717		
RO Concentrate SAR		25.1		
RO Concentrate TDS (mg/L)		10962		
% Flow Treated	100%	100%	100%	100%
Unit Recovery	58%	34%	36%	37%
Recovered Water Flow (mgd)	0.58	0.34	0.36	0.37
Product Water Sodium (mg/L)	580	753	522	485
Product Calcium (mg/L)	65	2	59	124
Product Water SAR	 16.2	 101	 15.1	 10.2
Product TDS (mg/L)	 1973	 2026	 1933	 2323
Concentrate Flow (gpm)	291	461	444	439
Concentrate TDS (mg/L)	23376	15493	16042	15976
Concentrate Sodium (mg/L)	6099	3985	1915	4297
Number of Product Line	8	10	10	10
Number of Stages	4	4*	4*	4*
Capital (\$/gpd product flow)	\$4.1	\$10.9	\$9.2	\$9.2
O&M (\$/kgal)	\$5.62	\$7.44	\$8.25	\$8.25

* Line and stage design is specially configured. This table shows a 4-stage equivalent.

Take Home Messages

- Selective electro dialysis membrane removes more monovalent cations (i.e., sodium) than normal grade membranes
 - Good selectivity under wide range of current
 - Similar power consumption compared to normal grade membrane
 - Better selectivity for low TDS water than for concentrate
- Selective membrane can meet the required water quality for Scottsdale (Based on El Paso GW Selectivity with improved coating method)
- Very close, but may not achieve SAR goals for recovering El Paso RO concentrate due to low Ca:Na ratio and high Na removal goal



Questions?

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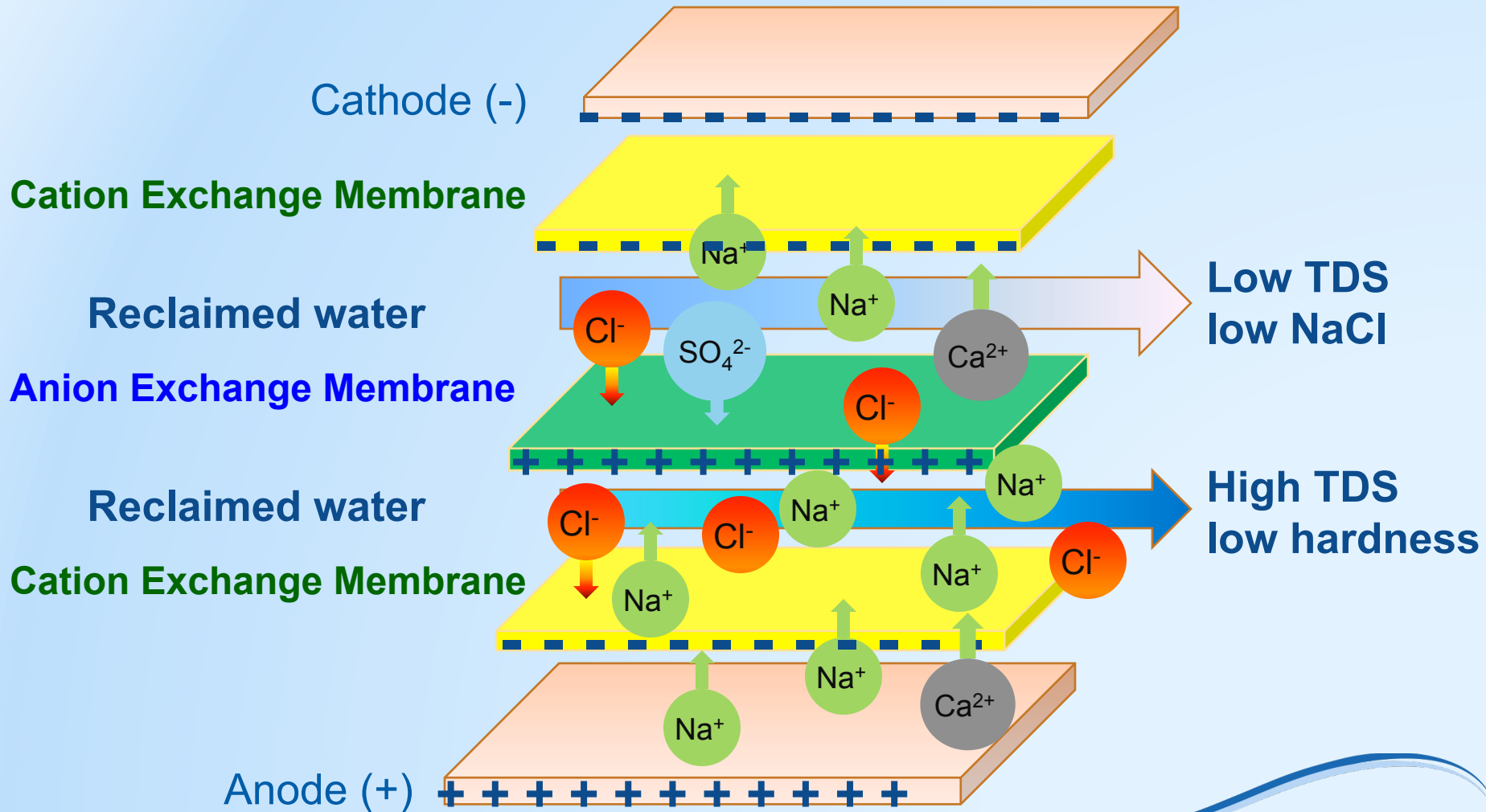
WATER
OUR FOCUS
OUR BUSINESS
OUR PASSION



carollo
Engineers...Working Wonders With Water®

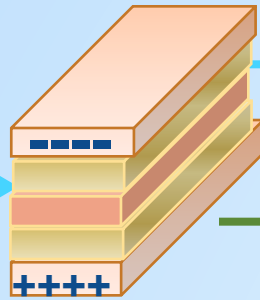
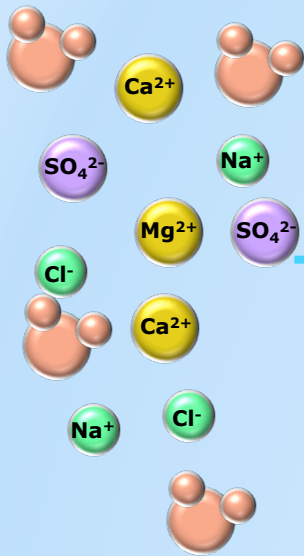


Electrodialysis with Selective IX Membranes Remove Monovalent Ions Preferably



Ion Switcher Concept Was Proposed to Solve Reclaimed Water Sodium Problem without Generating a Brine

Salty Reclaimed Water
1150 mg/L TDS
215 mg/L Sodium
80 mg/L Calcium

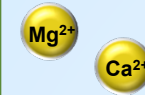


Not a brine
Reclaimed Water
with higher TDS
relatively low hardness

More
Na₂SO₄
NaCl



More
CaSO₄
MgCl₂
CaCl₂



Product Water
<125 ppm Sodium
Reclaimed Water
with lower TDS and sodium

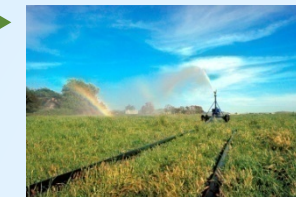
**Cooling
Water**



Wetland



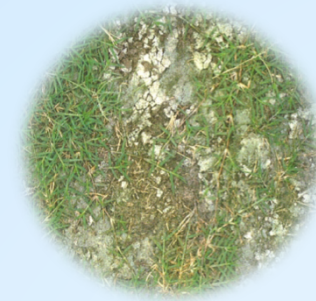
Irrigation



High Sodium to Hardness Ratio Resulted in Reuse Challenges

- SAR = Sodium Adsorption Ratio

$$\text{SAR} = [\text{Na}^+] / \{([\text{Ca}^{2+}] + [\text{Mg}^{2+}]) / 2\}^{1/2} \quad []: \text{ use meql units}$$



- CAP Water SAR ~ 5 on average
- Verde River < 2 on average
- Salt River > 9 on average
- Scottsdale Water Campus Effluent 5-8

Monovalent Anions Such As Chloride Also Pose A Compliance Challenge

Whole Effluent Toxicity
Permit Action Level:
Toxic Unit 2.0 or less



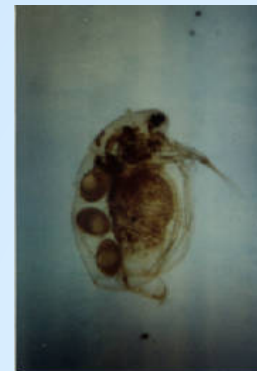
Fathead Minnow
(Pimephales promelas)
7-day larval survival
and growth test



Water
Reclamation
Plant



Discharge to River



Water flea
Ceriodaphnia dubia
3-brood survival and
reproduction test



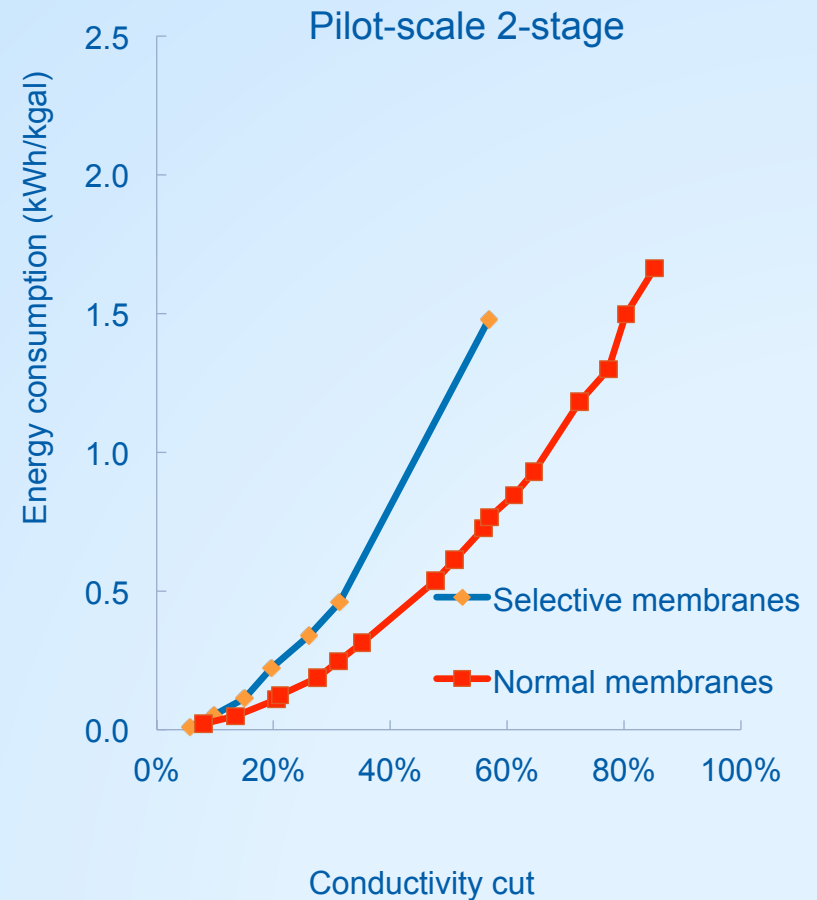
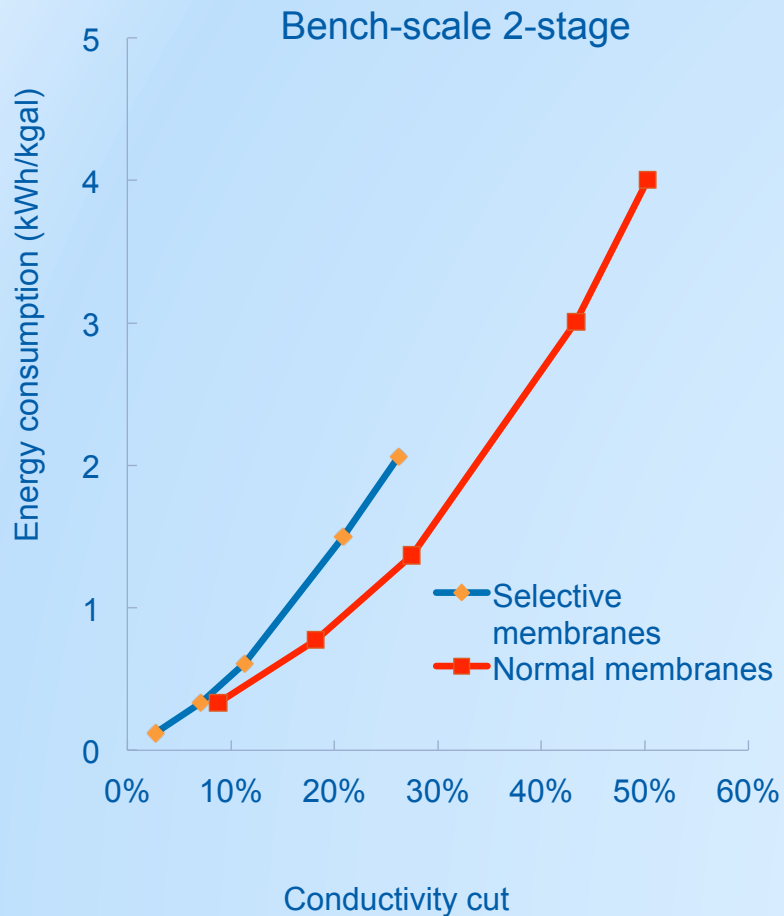
Selenastrum
capricornutum
Green Algae,
4-day growth test

Discussion:

	Scottsdale	El Paso RO Concentrate
Feed Water Sodium (ppm)	235	2898
Feed Water Calcium (ppm)	80	717
Feed Sodium : Calcium Ratio	0.34	0.25
Product Water Sodium Target (ppm)	110	~464
Target Sodium Removal %	53%	84%

Selective Membrane Consumes More Power than Normal Membranes, Especially at High Conductivity Cuts

El Paso Brackish Groundwater Power Consumption



Insert a video on model runs and misc. screens

ExtendSim

File Edit Text Library Model Database Develop Run Window Help

[0] System Components <Blue Plan-it v3.9.0 Mono.mox>

carollo BLUE PLAN-IT DECISION SUPPORT SYSTEM

Steady-State 100%

MODEL SETUP TIME MANAGER UNIT \$ MAN

00:00:01

Database Random Distribution

Generates random numbers according to a distribution.

Named distributions: None (Remove named distribution link)

Remove Randomness

Distribution Parameters

Distribution: Normal

Typical use: Errors of various types

Upper limit:

Lower limit:

Mean = 5

Std Dev = 2

Distribution Plotter

Percent Members

Member Value

Plot Distribution

Use this seed:

INPUT MANAGER

Simulation Manager

ONE REPORT REPORT

Scottsdale Water Campus

Baseline Alternative - SC

Alternative 1 - SC

Alternative 2 - SC

Parameter	Unit	Actu
Flow	mgd	0.87
Calcium	mg/L	37.6
Sodium	mg/L	118.0
TDS	mg/L	472.4
SAR		4.26

Total Capital Cost (\$M): 1.49

Annual O&M Cost (\$M): 0.2

Life Cycle Cost (\$M): 4.68

Help IPFD

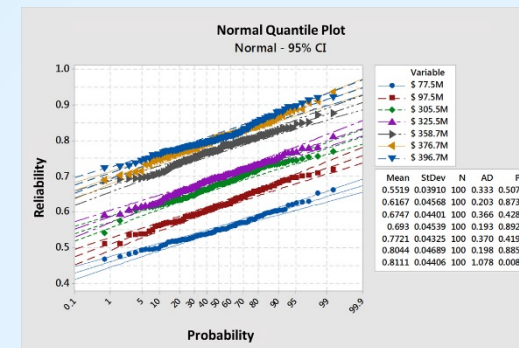
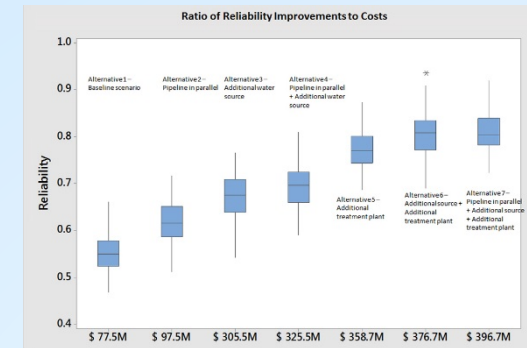
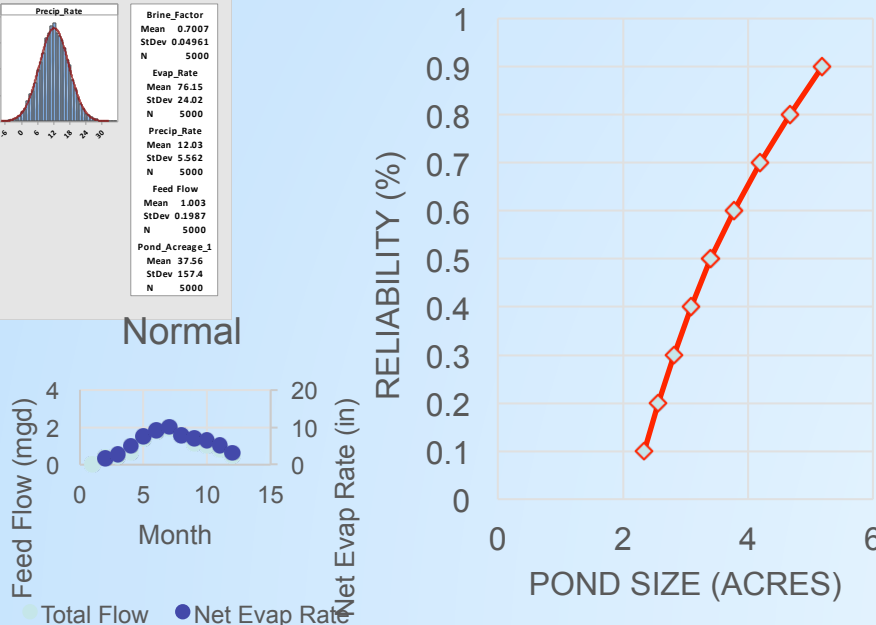
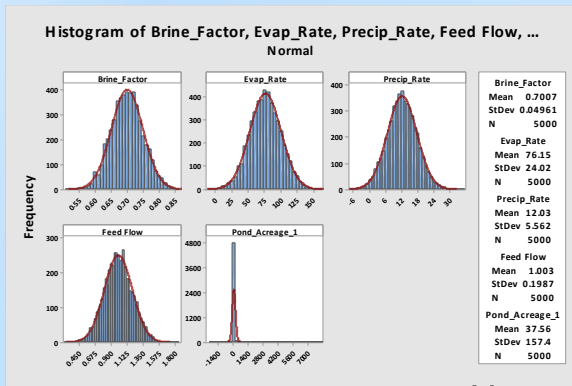
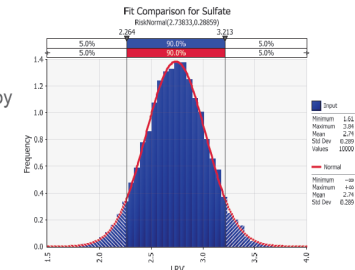
BPI Monte Carlo Simulation Have Many Applications for Desalination and Reuse

- Water System Resilience to Earthquake
- Hurricane Impact on SWRO Siting and Operation
- Microbial Risk Assessment and DPR Reliability
- Security and Vulnerability Assessment
- Pond sizing considering randomness in climate changes

RO Membranes: Sulfate as Surrogate for Giardia and Crypto

Limited short term test data available on virus removal by RO

Necessitated long-term surrogate data use



Scottsdale Cost Estimates (2 Stage Ion Switcher vs. UF RO)

