Low-Energy Inland Brackish Water Desalination

WRRC Water Webinars 104(b) Student Research

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11/30/2023

United Nations Sustainable Development Goals

Introduction

SAFE AND AFFORDABLE DRINKING WATER

By 2030, achieve universal and equitable access to safe and affordable drinking water for all.

INCREASE WATER-USE EFFICIENCY AND ENSURE FRESHWATER SUPPLIES

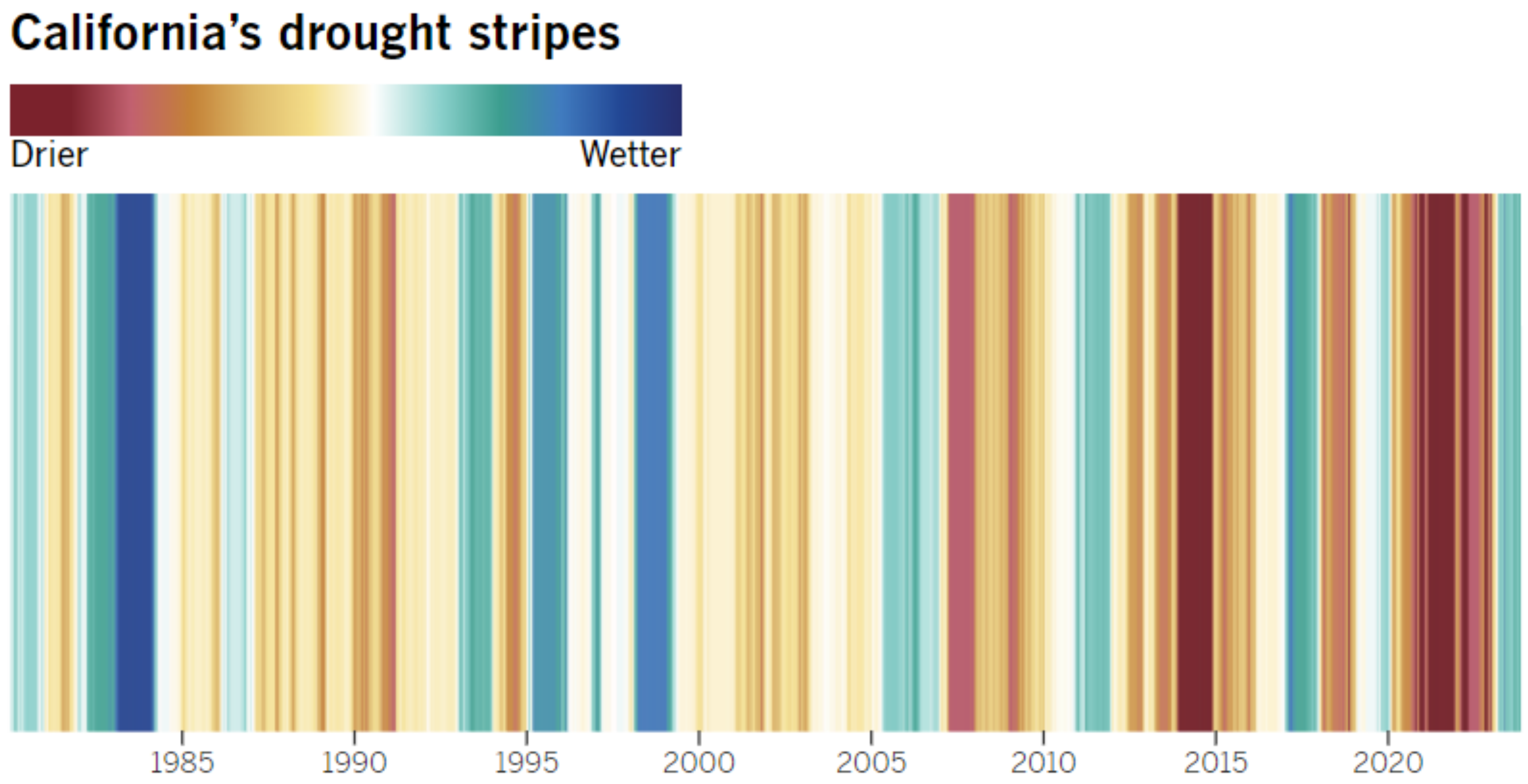
By 2030, substantially increase water-use efficiency across all sectors and ensure sustainable withdrawals and supply of freshwater to address water scarcity and substantially reduce the number of people suffering from water scarcity.

To meet the 2030 target year, the pace of progress will need to accelerate…

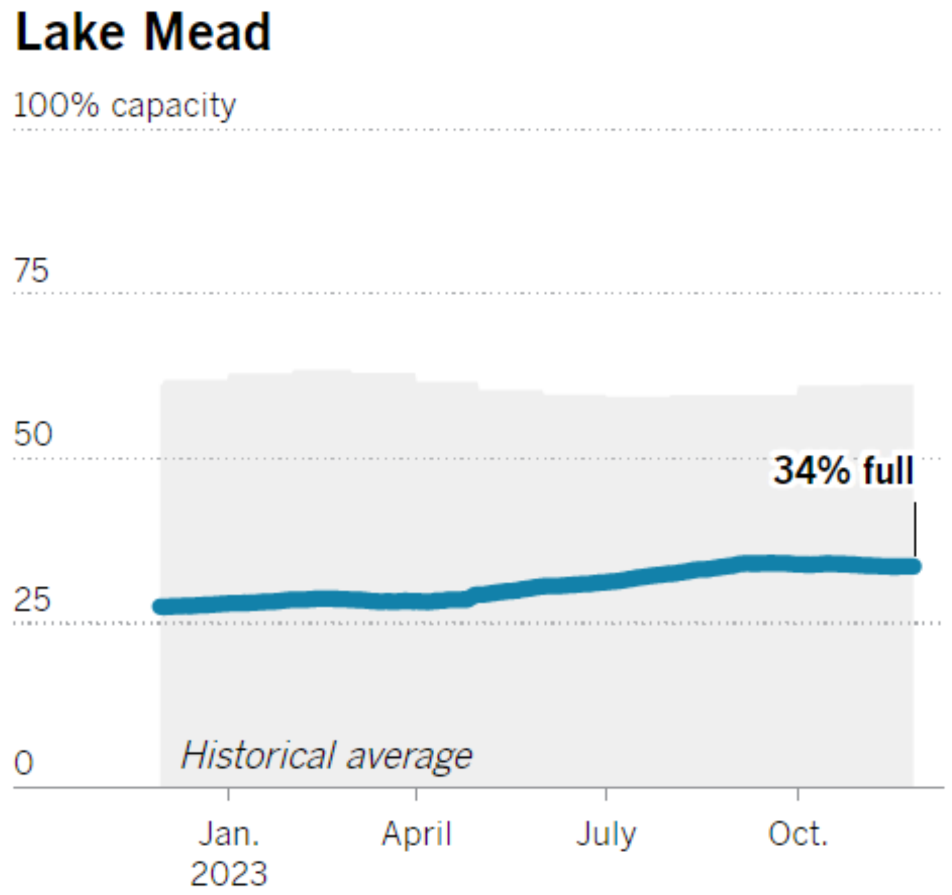
6X for global coverage of Drinking Water

Water Shortages

Introduction



Updated November 16th 2023



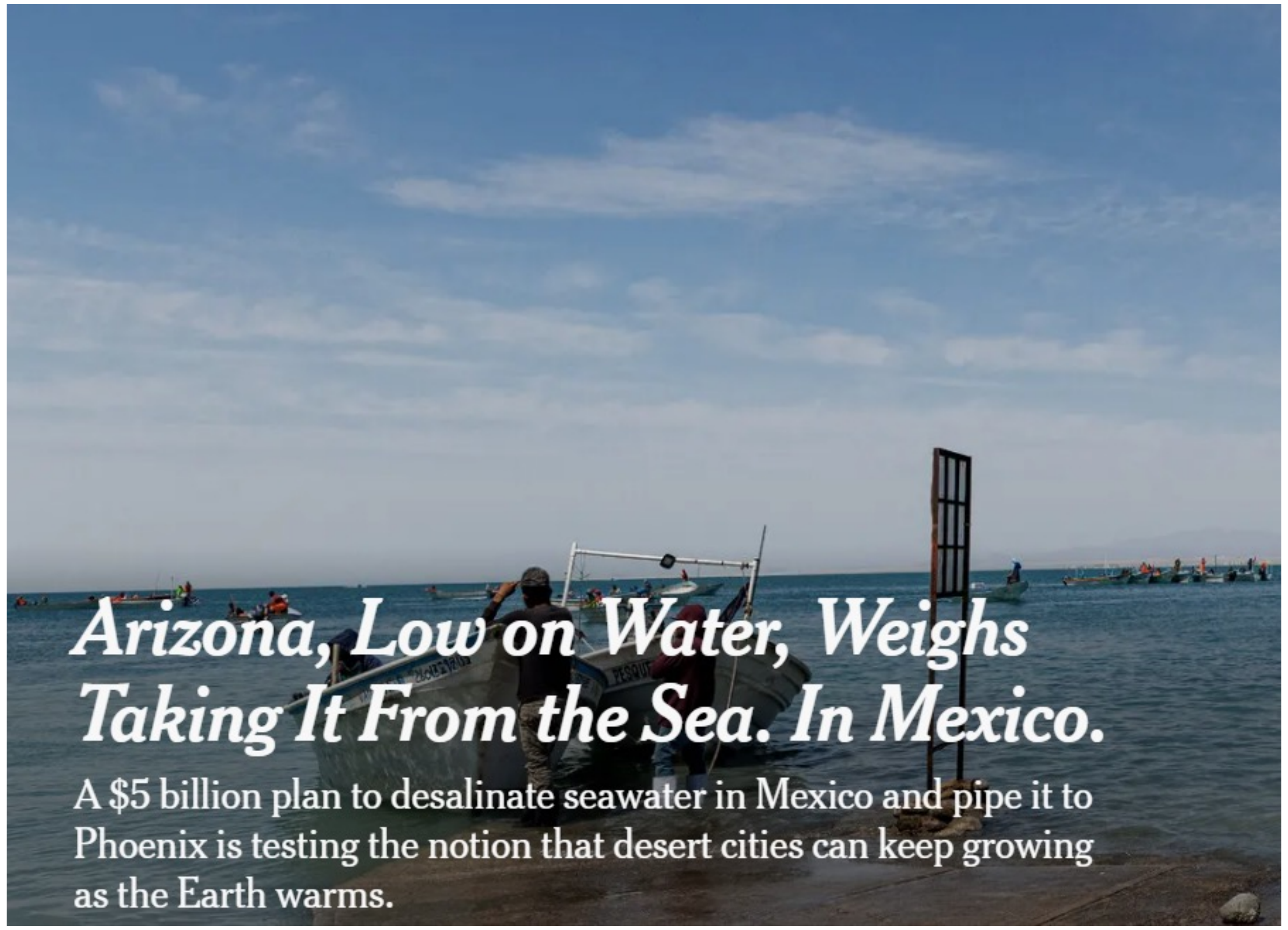
Updated November 25th 2023

Arizona Limits Construction Around Phoenix as Its Water Supply Dwindles

In what could be a glimpse of the future as climate change batters the West, officials ruled there's not enough groundwater for projects already approved.

Inland Desalination

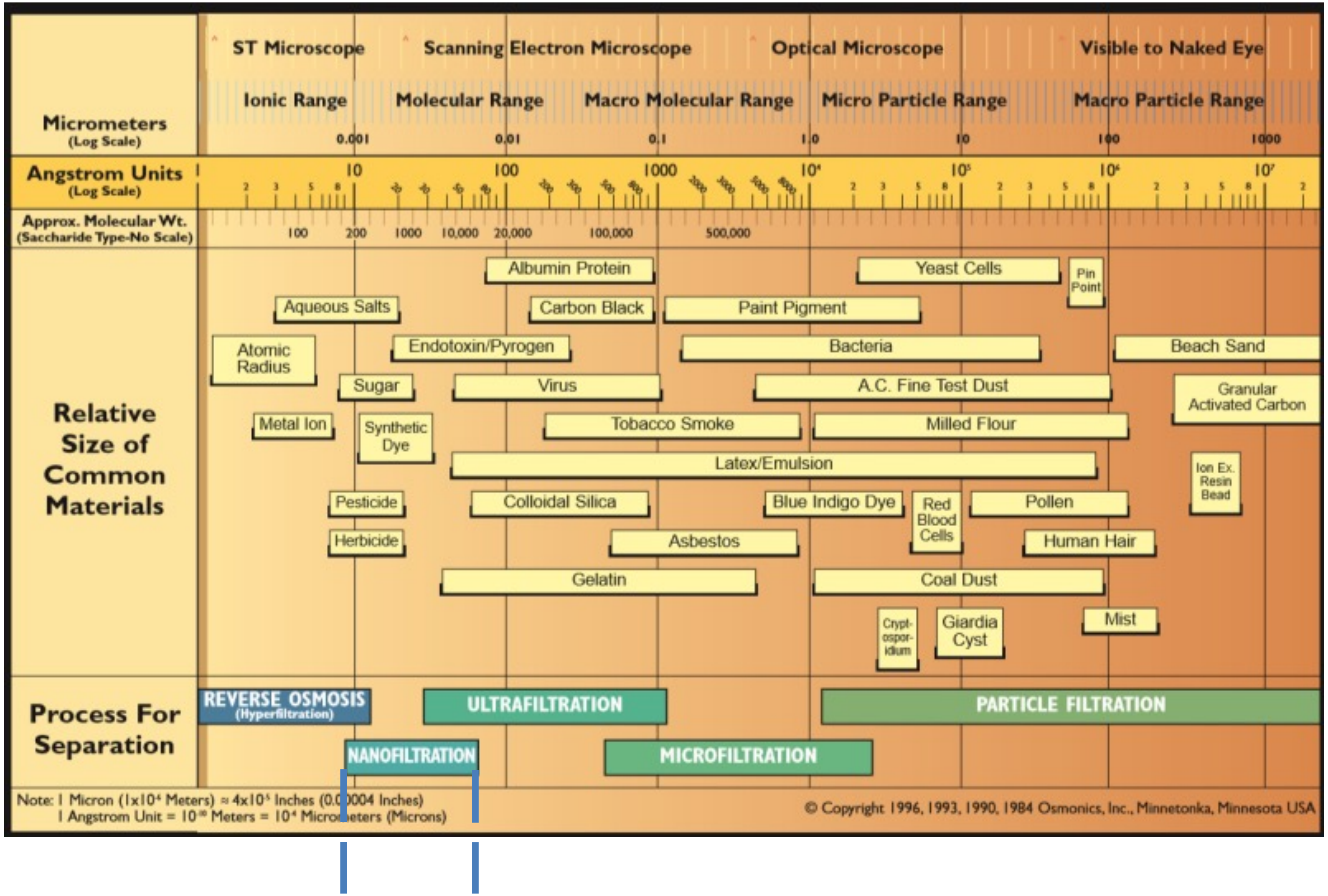
Introduction



The world's drinking water supply is at risk and desalination plants are set to make more saltwater potable. But to make the process sustainable and affordable, new and improved technologies need to be further developed

Introduction

Reverse Osmosis and Nanofiltration



NF90 NF270

Yuma Desalting Facility

Methods

Working with ESU unit

- 2:1 array
- RO feed water is pretreated main outlet drain extension (MODE) surface water available at the YDP (2000 mg/L TDS).
- We used BW30- 2540, NF90-2540 and NF270-2540 membranes

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Hypothesis

Introduction

Including Nanofiltration in the industry baseline desalination treatment train at different stages or as a pre/post treatment to reverse osmosis (RO) can aid the desalination process by improving RO performance and overall lowering energy requirements of the desalination process.

Objectives

Methods

1. Assess the best hybrid configuration to increase membrane lifetime, further concentrate brine, decrease specific energy consumption (SEC), and increase water quality.

2. Identify a modeling strategy that can effectively compare the trade-offs between rejection, water flux, cost, and system energetics of NF-RO and RO-NF compared to conventional RO.

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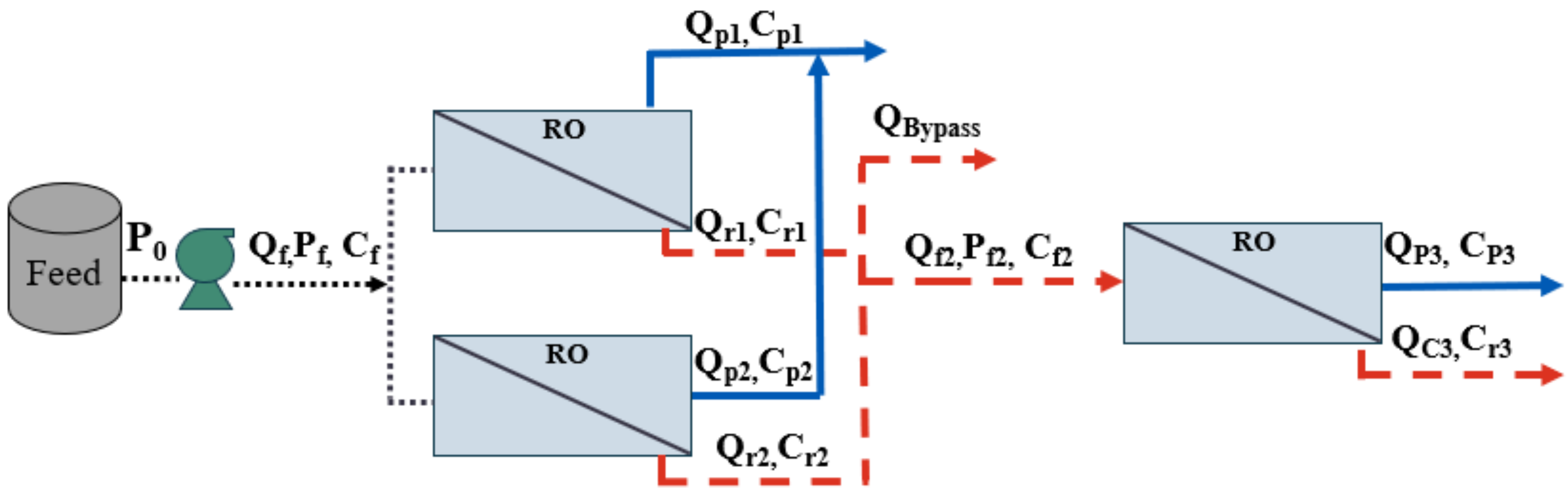
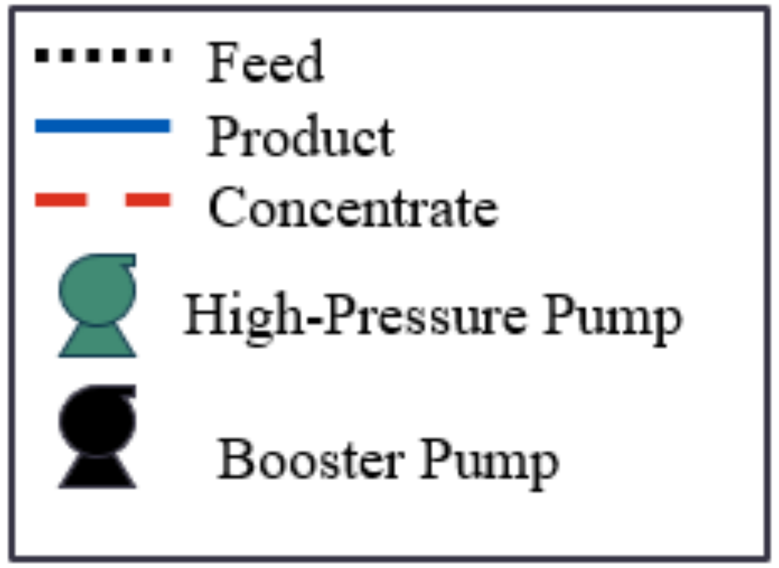
Reverse Osmosis System Configuration

Methods

RO-RO





Challenges

-High energy consumption

-High scaling potential

Additional

-Large volumes of brine as a byproduct

-High cost depending on TDS

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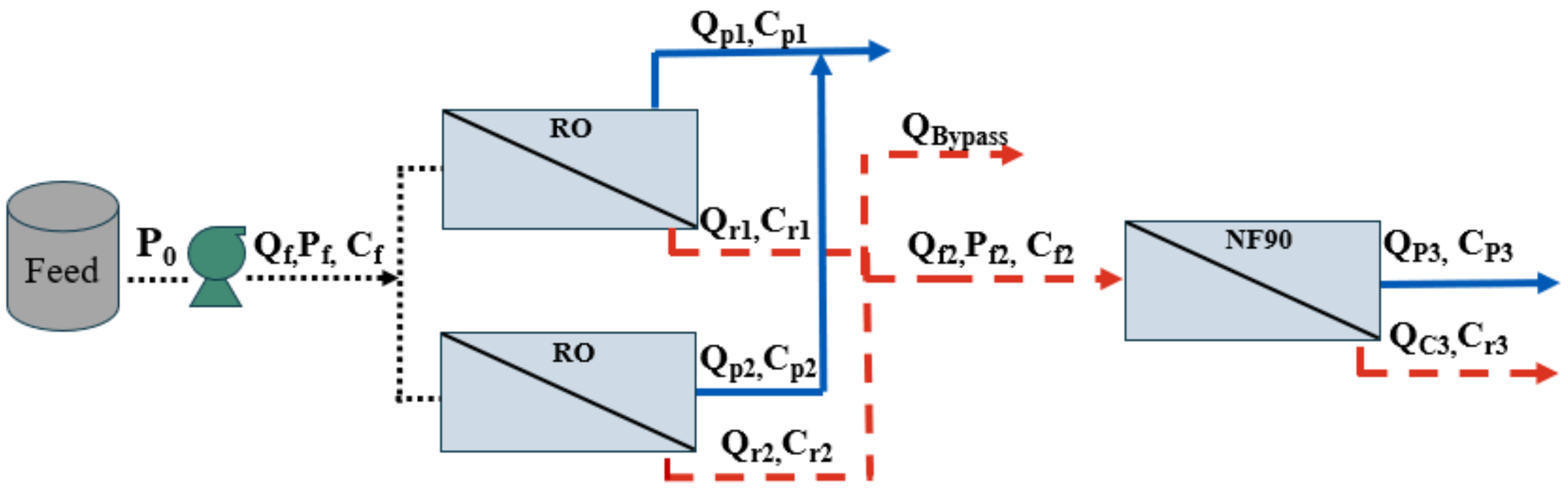
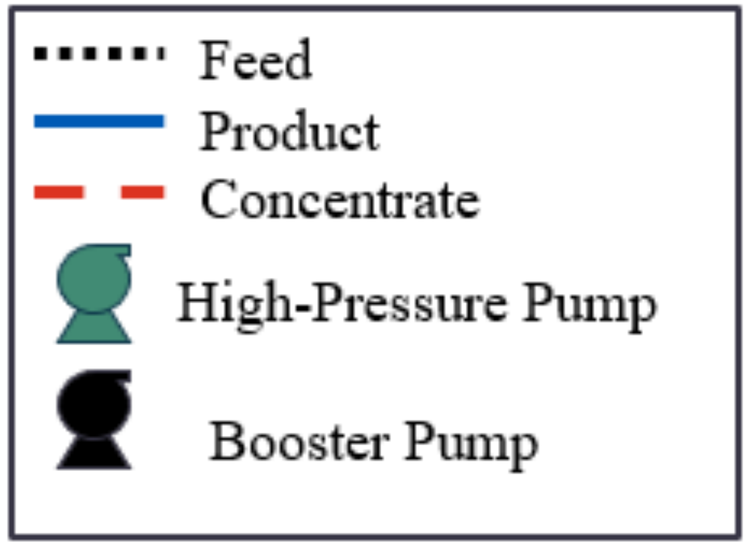
Reverse Osmosis System Configuration Integrating NF90 Membrane

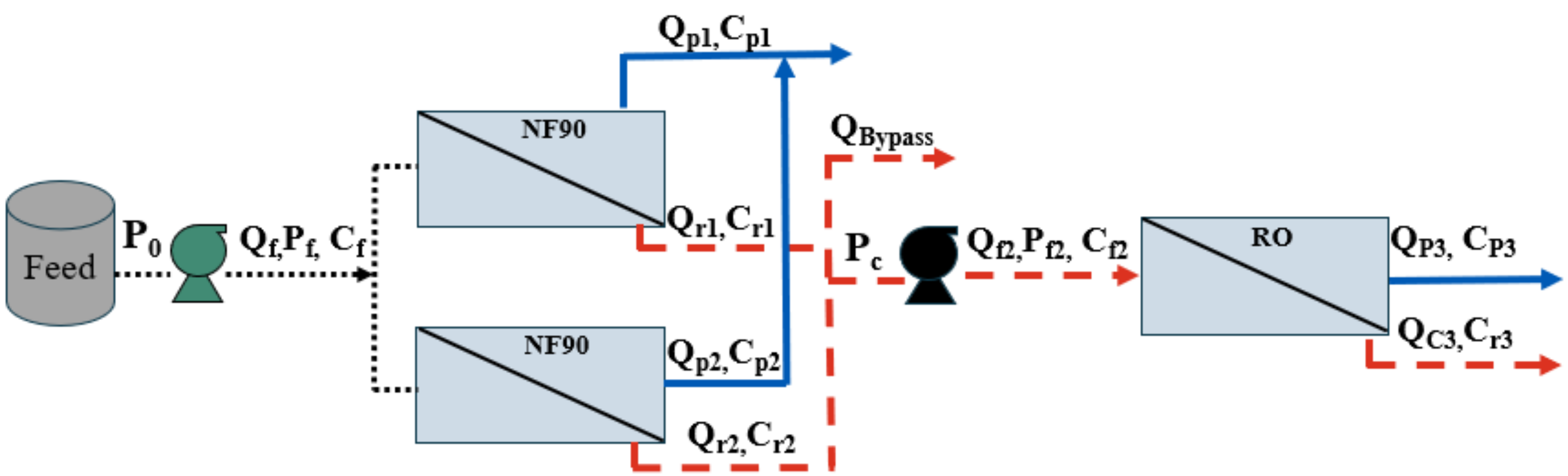
Methods

RO-NF90





NF90-RO



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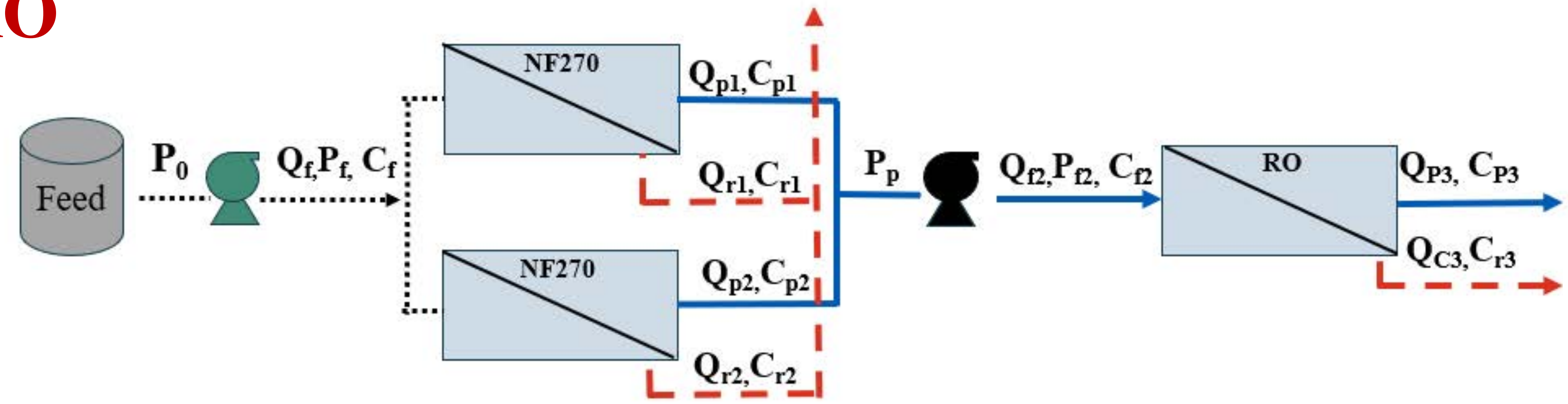
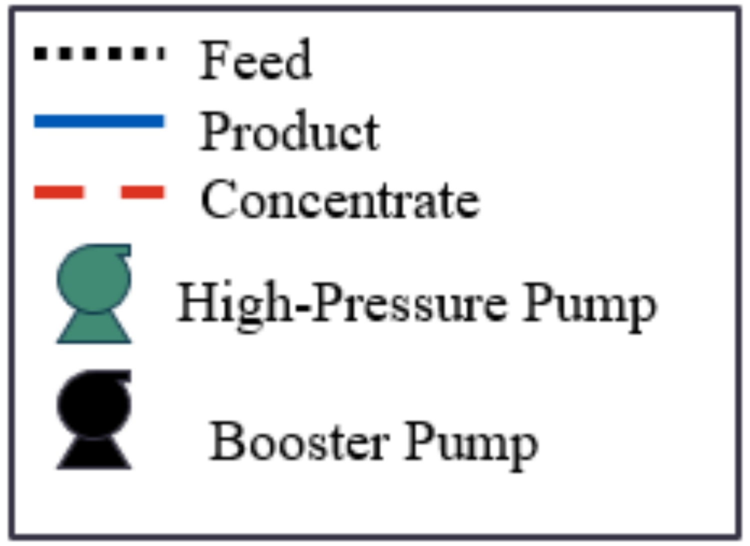
One Stage Reverse Osmosis System Configuration Pre/Post Treating using NF270

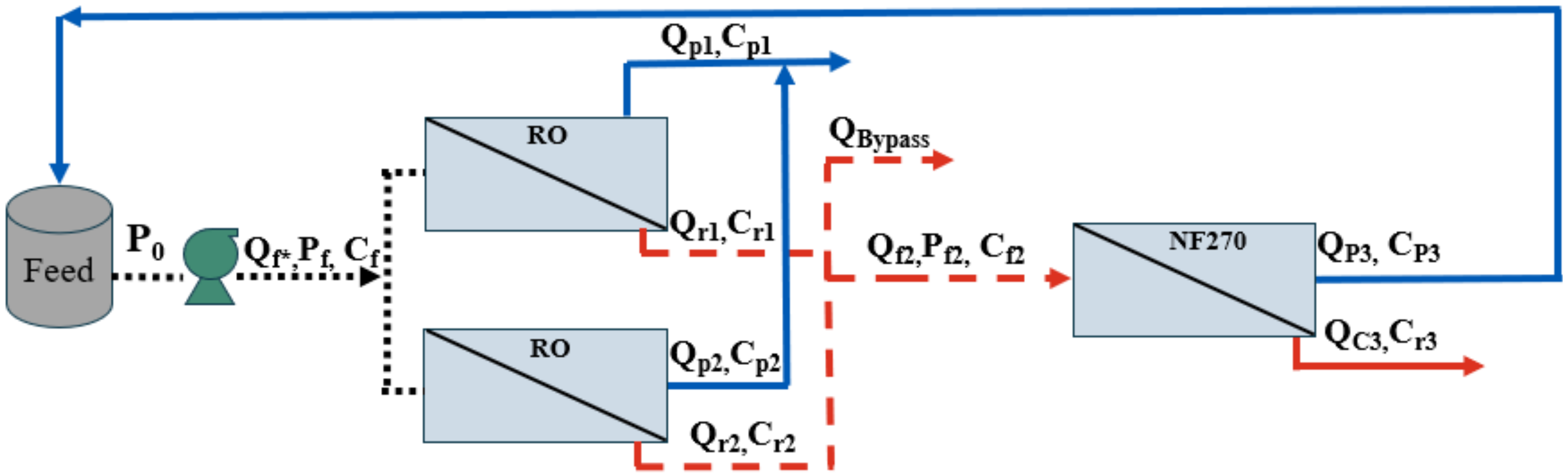
Methods

NF270-RO





RO-NF270



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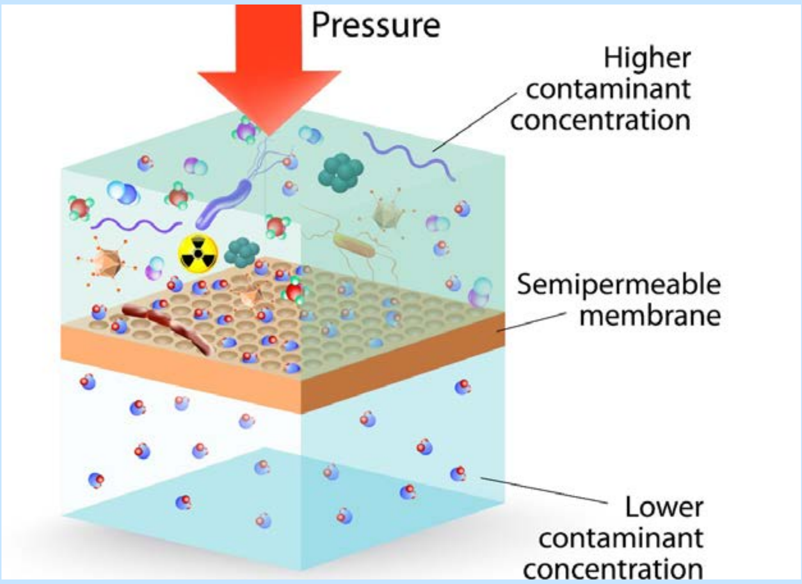
Equations for Performance Metrics

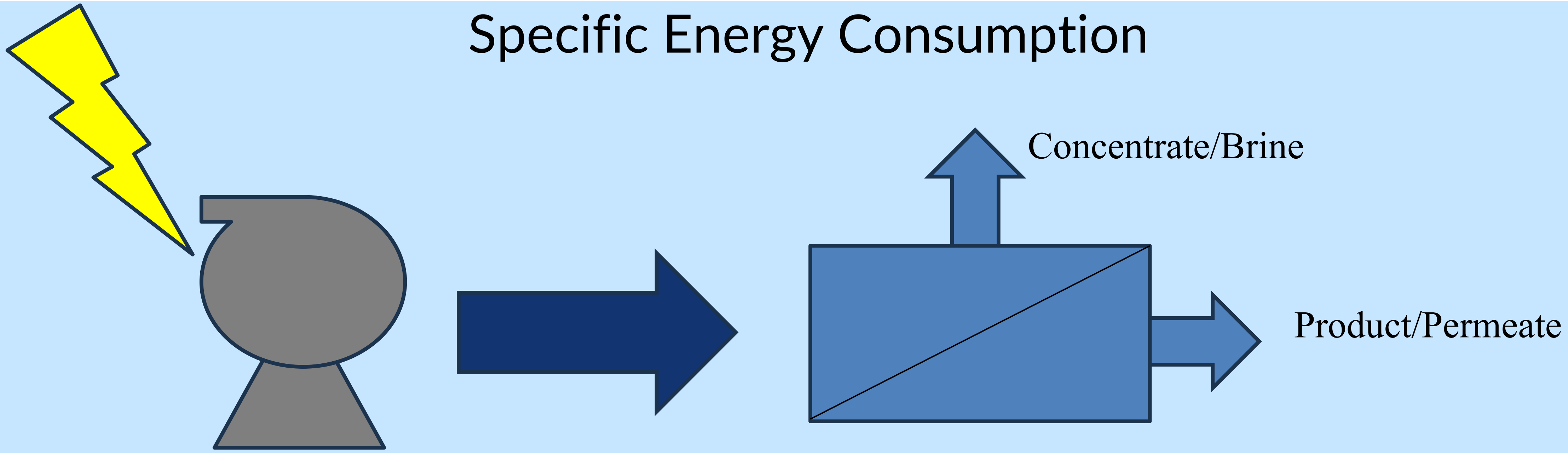
Salt Rejection



Recovery

$$\frac{Product\ Flow}{Feed\ Flow} * 100\%$$

Specific Energy Consumption



Methods

System Modeling

Methods

0.1 Million Gallons / Day

1 Million Gallons / Day

Scaling up the Units 10 X

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System Model Using WAVE

Methods

- Configured a larger pilot system on WAVE that simulates a 1MGD plant

- WAVE has inputs such as
  - Feed flows
  - Feed water quality
  - Recovery
  - Membrane type
  - Stages
  - Membrane elements

Feed water quality:

Table 1
Pretreated MODE Feed Water Composition

Ion	Concentration (mg/L)
Barium	0.012
Calcium	85.8
Chloride	541.5
Magnesium	50. 0
Nitrate as N	6.6
Potassium	6.9
Sodium	528.8
Strontium	1.26
Sulfate	764.9
Conductivity	3,192
pH	6.12
Total Alkalinity	5.8
TDS (mg/L)	2,015

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Model Calculations

Methods

Variable Operating and Management Inputs

- Electric
- Membrane replacement
- Water Disposal

Components

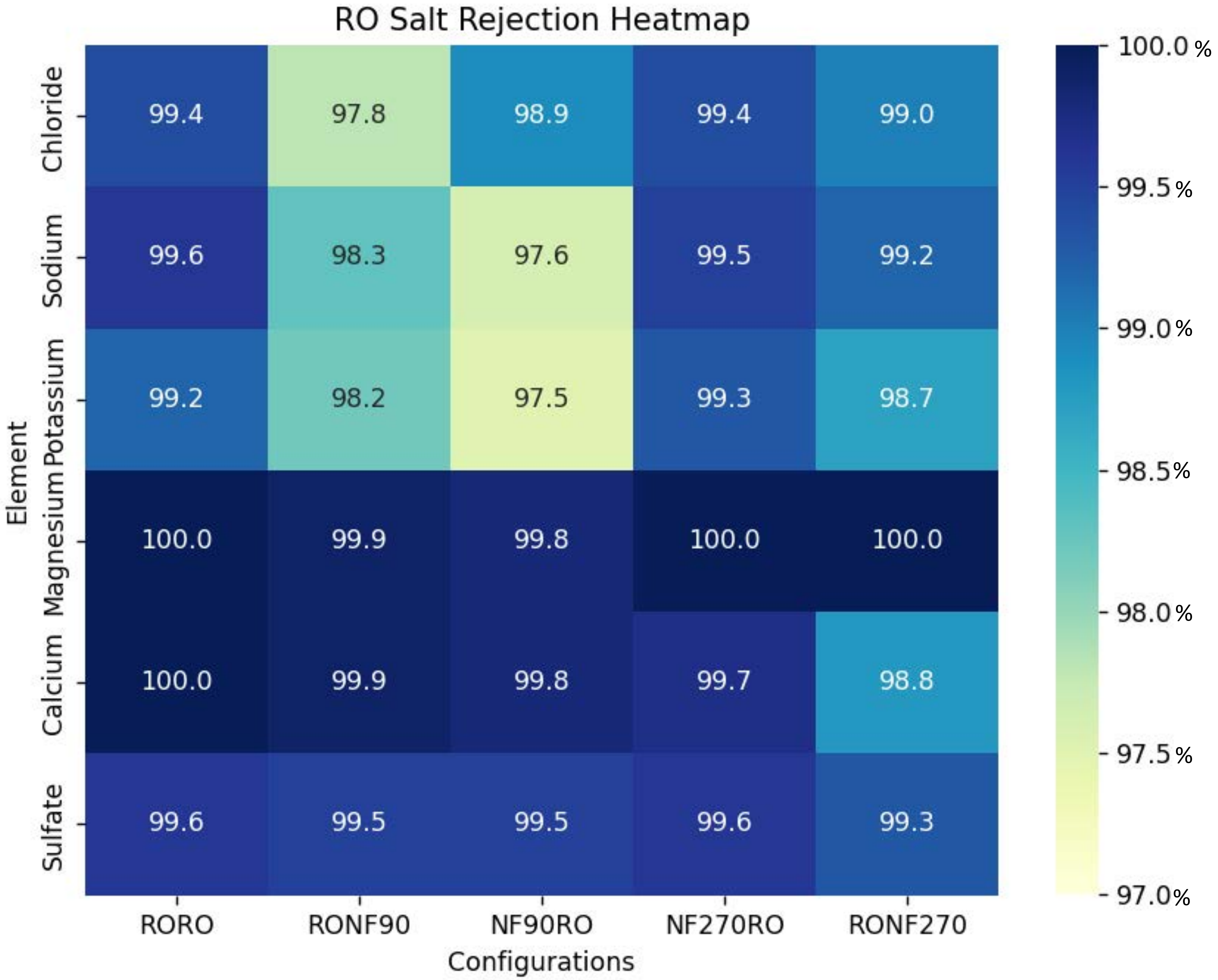
- High pressure pump +Booster pump + Membrane modules + Waste Disposal

Annual Fixed O&M

- Annual O&M cost divided by the total permeate water produced in one year

Pilot System Results - Salt Rejections

Results



- RO-NF90 and NF90-RO have lower rejections of monovalent ions compared to the baseline RO-RO and NF270 configurations
- NF270-RO has the highest rejections greater than 99% for monovalent and divalent ions

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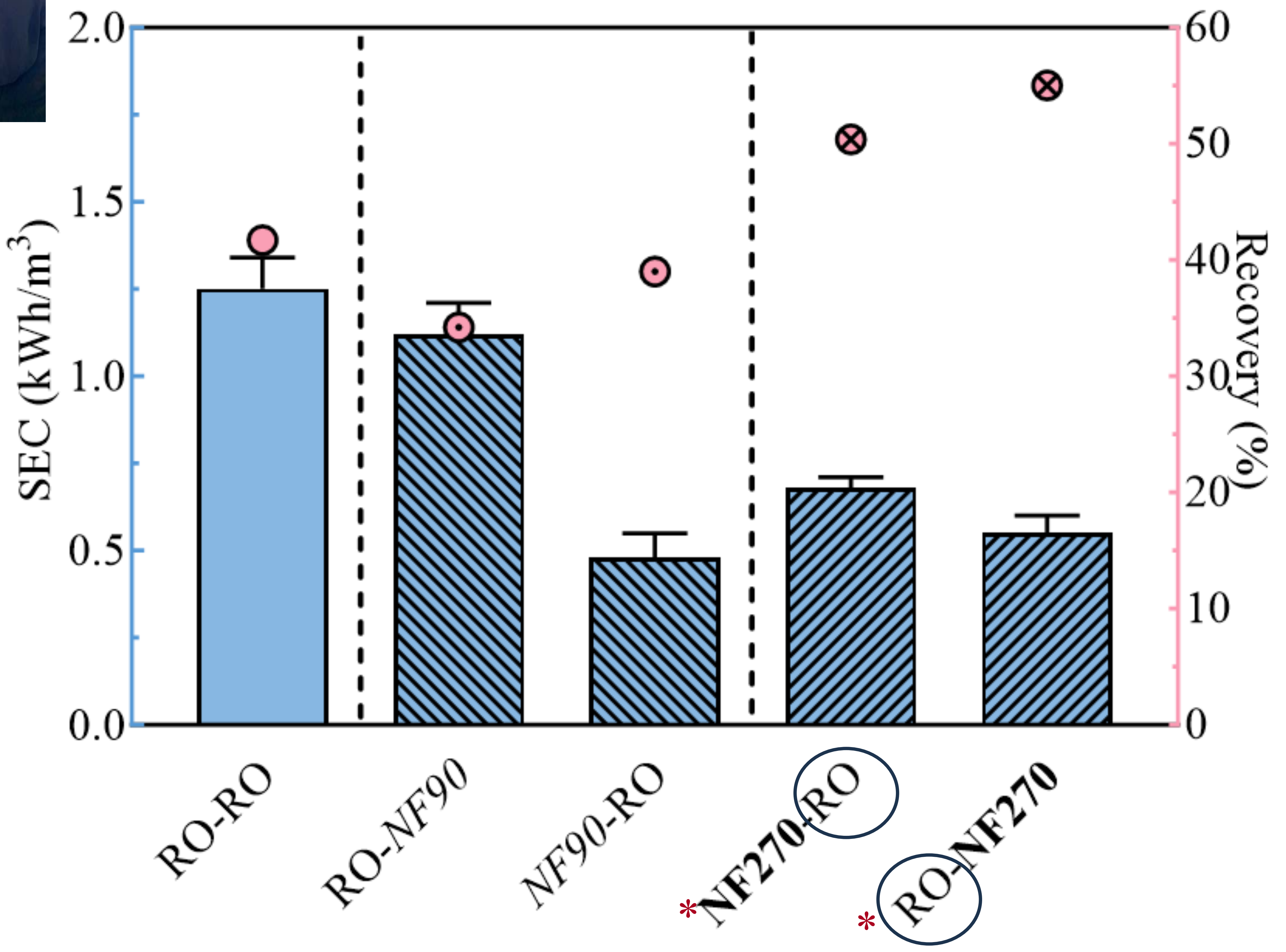
Pilot System Results– Recovery and SEC



* Comparing the function of the RO when pre/post-treating

- ~50% lower SEC of the RO element when pre/post-treating while increasing the recovery of the system by ~25%
- NF90-RO is ~60% less than the baseline RO-RO configuration

Results

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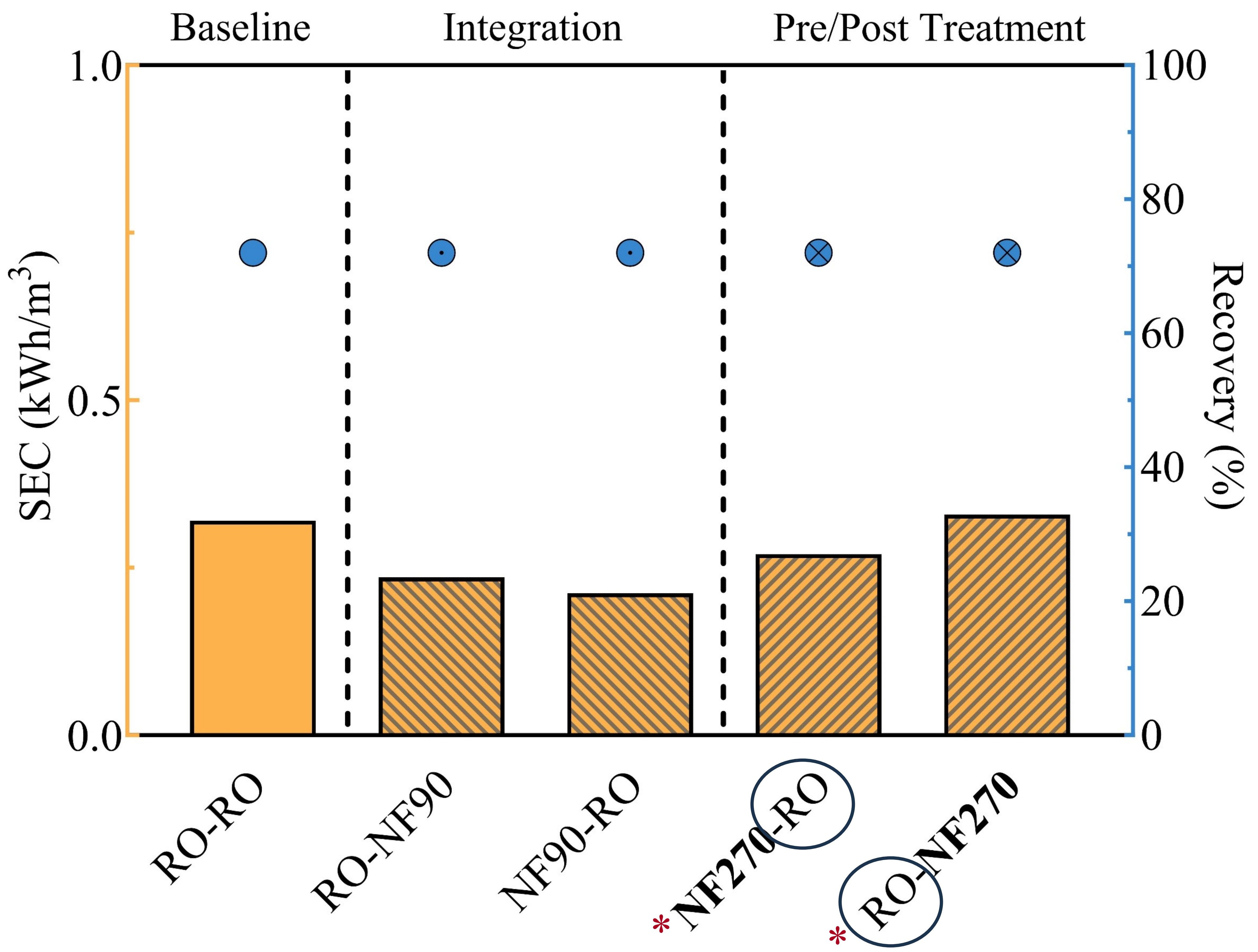
Modeled Results– SEC and Recovery



* Comparing the function of the RO when pre/post-treating

- Closer to typical SEC values of BW desalination
- Follows the same trend as the pilot system

Results

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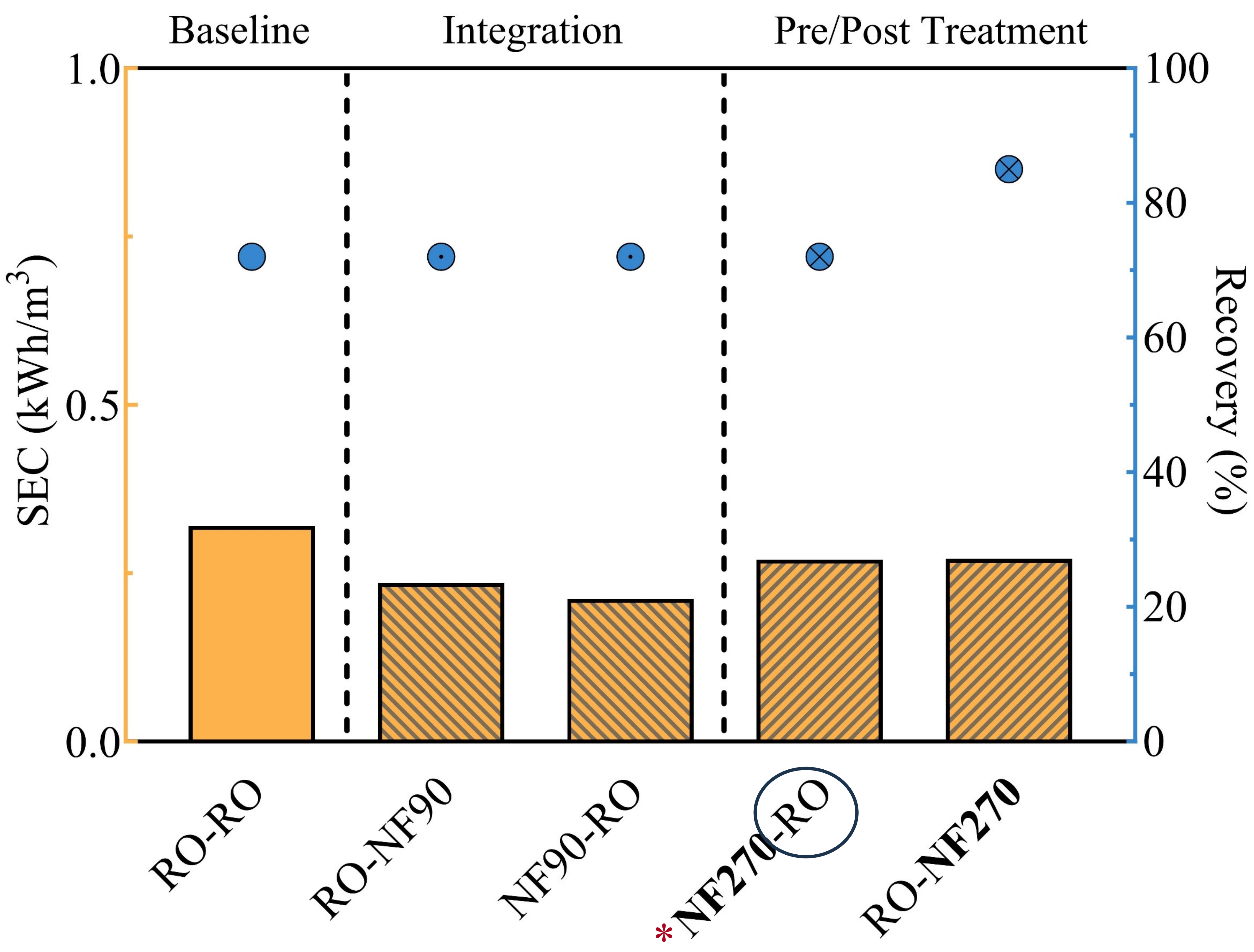
Modeled Results– Recovery and SEC



- Further concentrating the brine using the NF270, the recovery increases while the SEC decreases

* Comparing the function of the RO when pre/post-treating

Results

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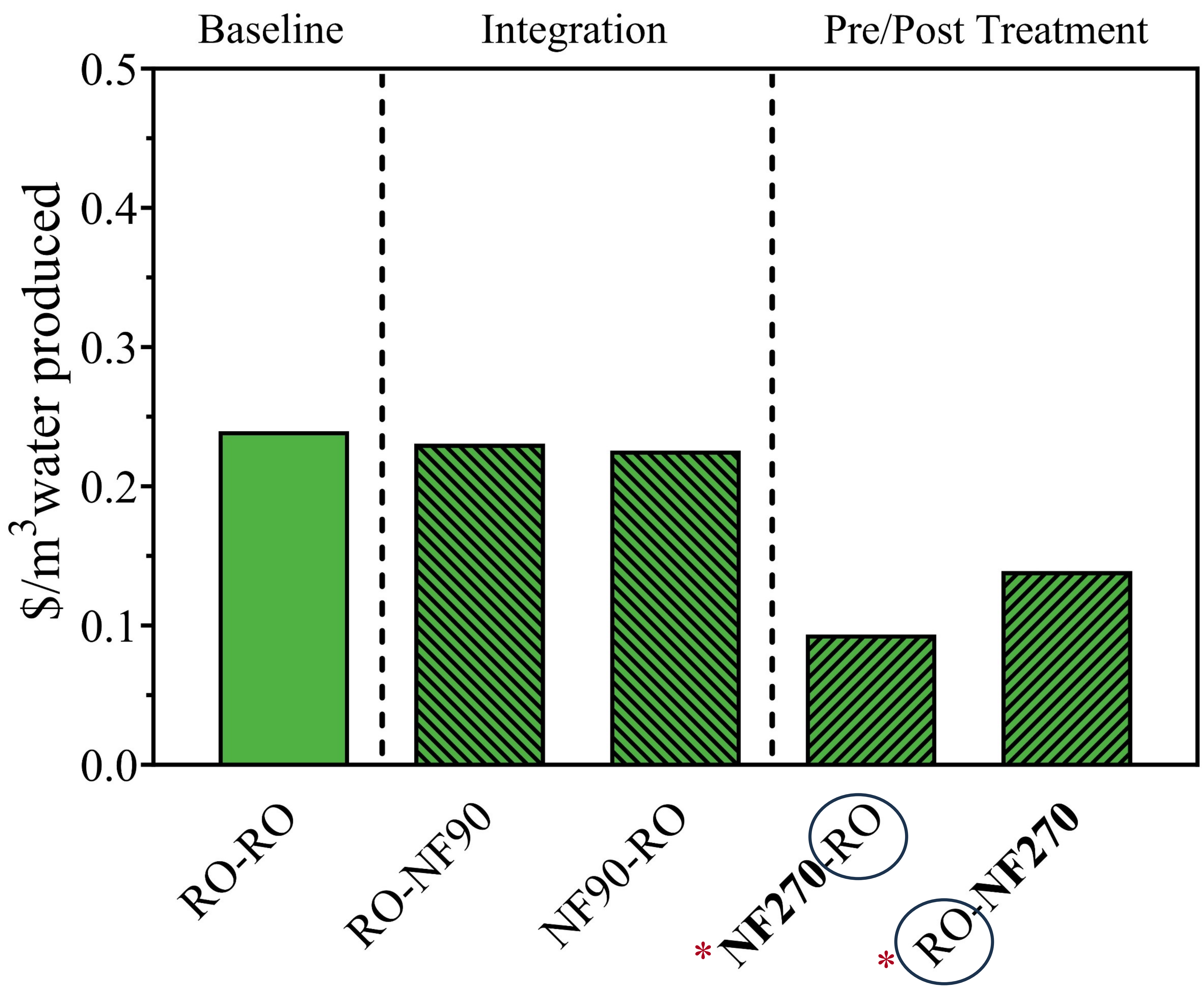
Modeled Results– Cost of Variable O&M

Results



- When pre-treating, the variable operating cost of RO decreases by 60%
- Post-Treating decreases cost buy 43%

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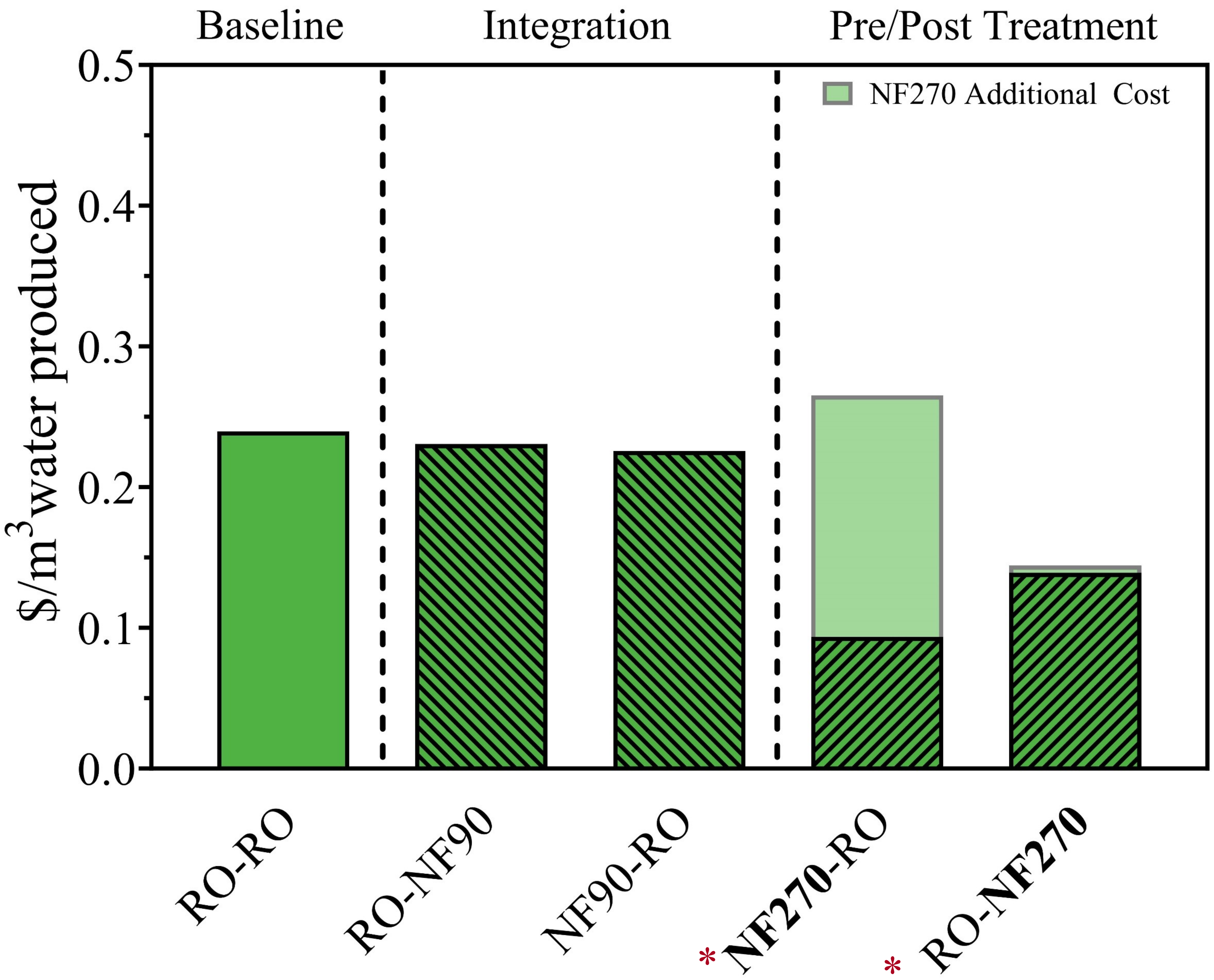
Modeled Results– Cost



- Adding the additional cost of treatment using the NF270 membranes drastically increases the NF270-RO cost
- RO-NF270 cost remains ~40% lower than RO-RO

Results

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Conclusions- Tradeoffs

Results

Metric	RO-RO	RO-NF90	NF90-RO	NF270-RO	RO-NF270
Water Quality	★ ★ ★	★ ★ ☆	★ ★ ☆	★ ★ ★	★ ★ ★
Recovery	★ ★ ☆	★ ★ ☆	★ ★ ☆	★ ☆ ☆	★ ★ ★
Energy Efficiency	★ ☆ ☆	★ ★ ★	★ ★ ★	★ ★ ☆	★ ★ ☆
Cost	$ $ $	$ $ $	$ $ $	$ $ $	$

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Next Steps- Analysis of Scaling of the systems

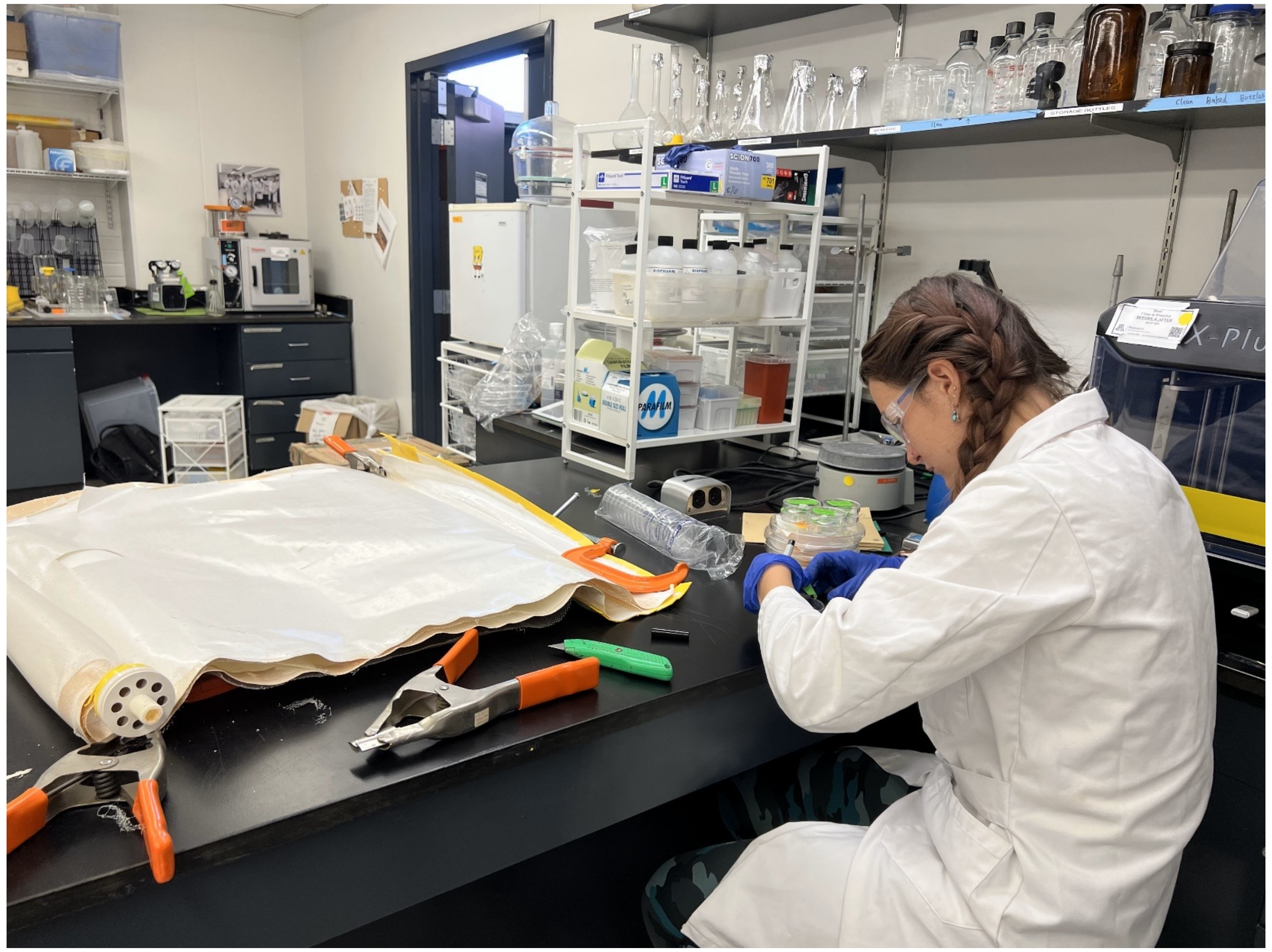
Results

Done

- Increased concentration of the feed stream to speed up scaling process
- Analyze flows and pressure changes

Working on

- Membrane Autopsies
- Analysis of the membranes (SEM, contact angle, zeta potential)



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Acknowledgments

- KORES, HER, and ART Research Group
- Macy Winn
- Dr. Tony Straub
- Luis Cruzado
- All the operators and lab technicians at the Yuma Desalting Plant

WATER RESOURCES RESEARCH CENTER

U.S. DEPARTMENT OF THE INTERIOR BUREAU OF RECLAMATION

USGS science for a changing world

Research Funding was made possible by the Bureau of Reclamation Desalination and Water Purification Research Program Pitch to Pilot Program and NSF-NRT IndigeFEWSS Grant #DGE1735173

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Thank you
Questions?

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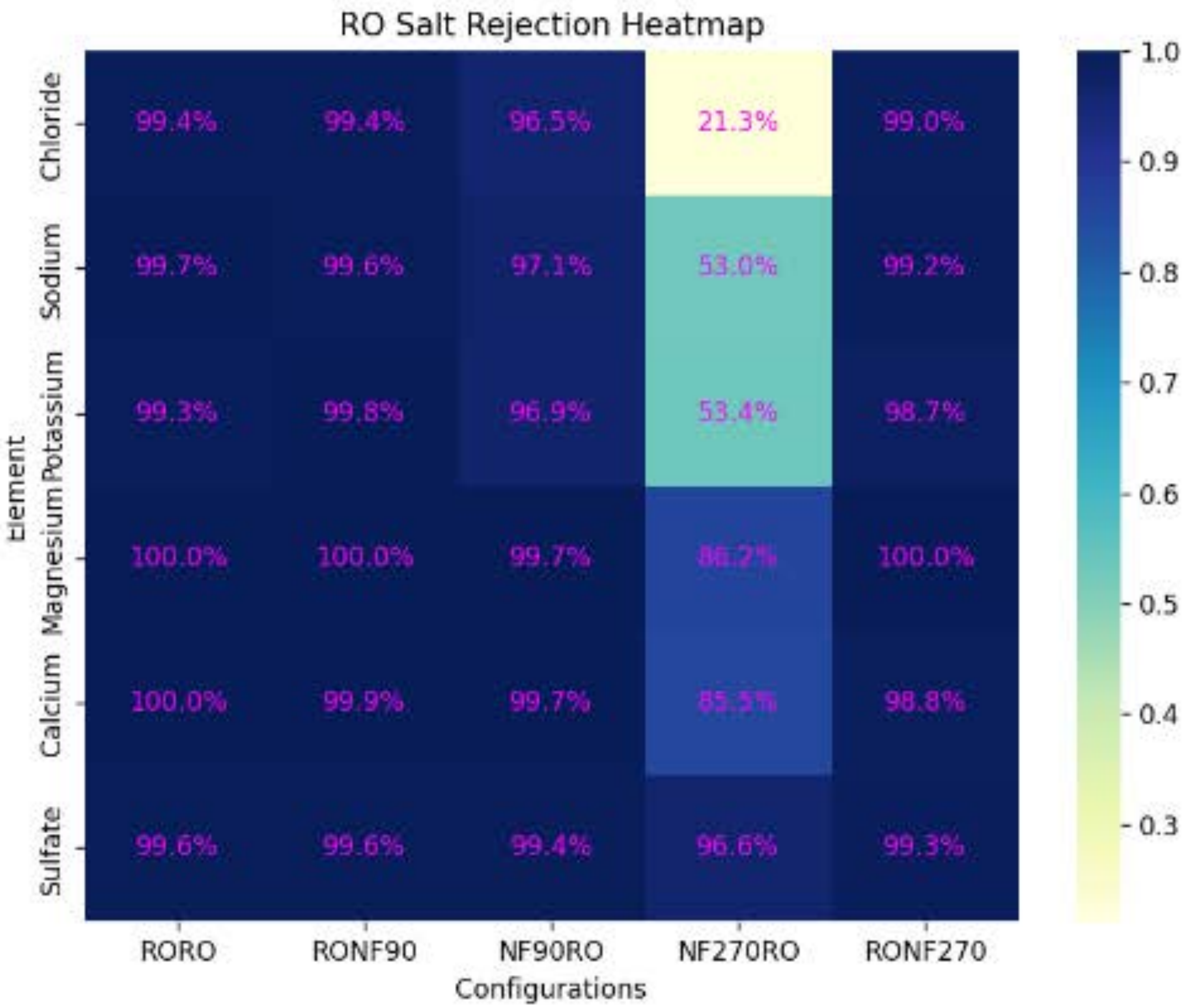
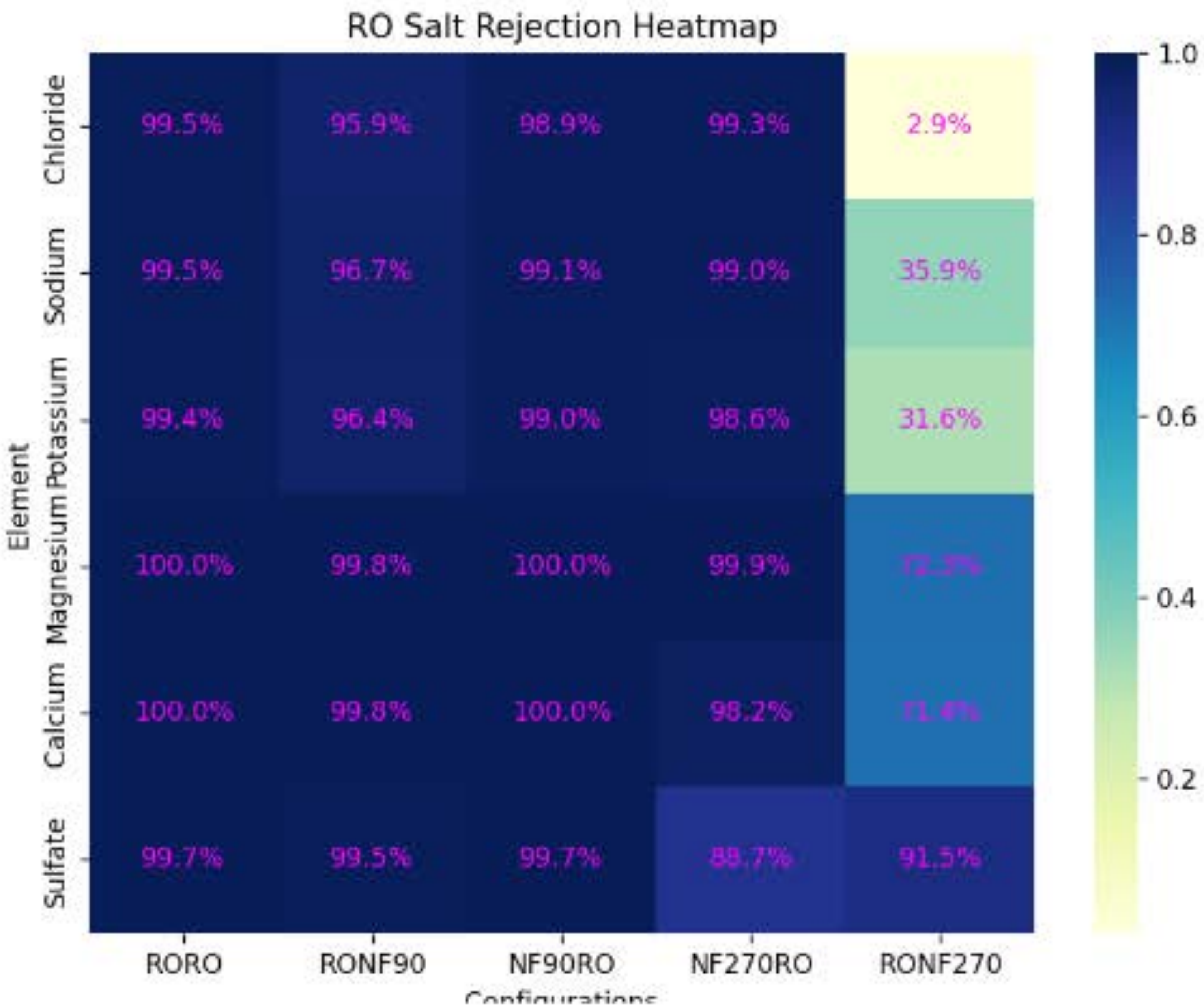
System parameters- Salt Rejections



1st stage



2nd stage

Results

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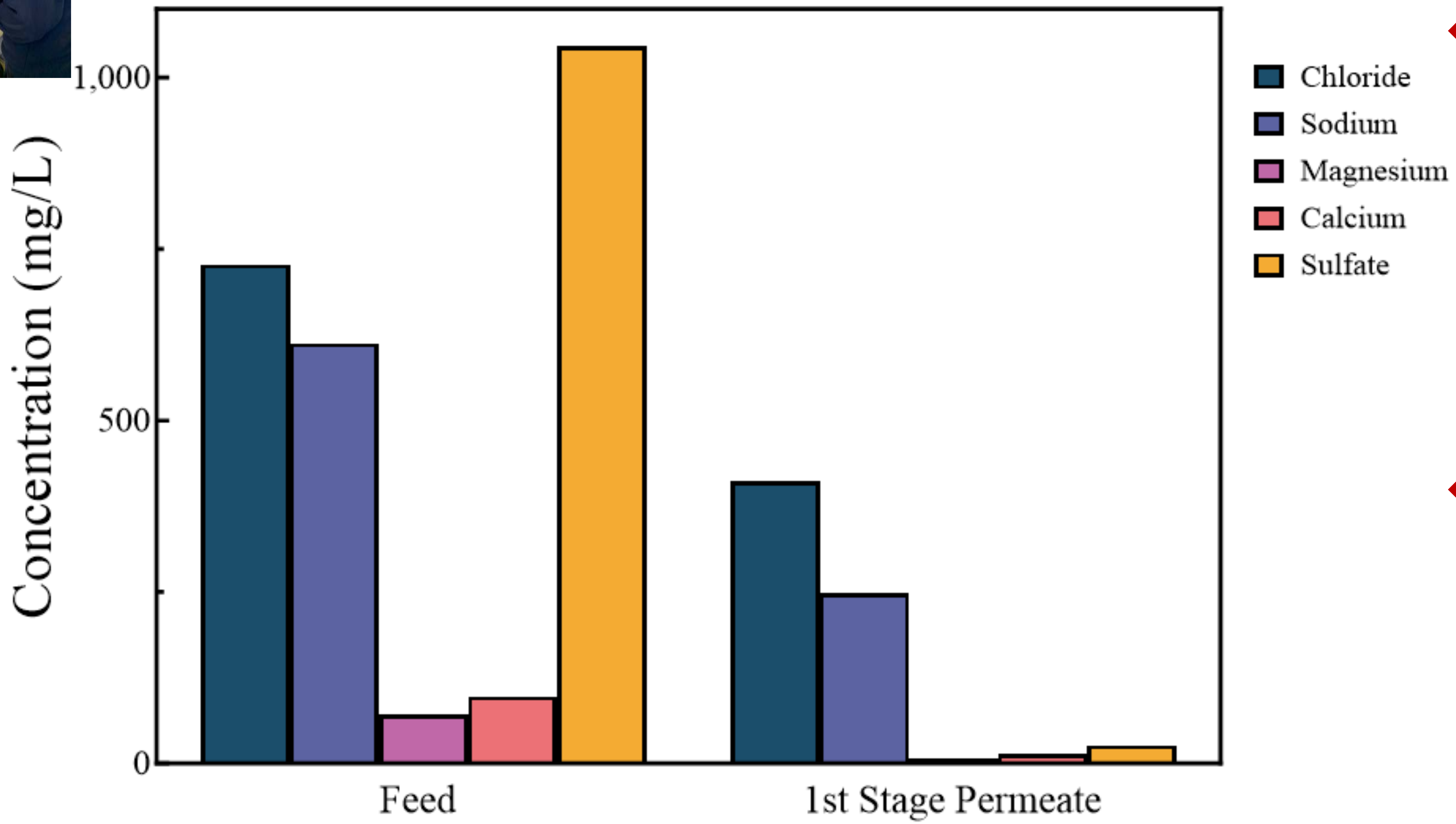
Pilot System Results–



- Feed of the overall configuration versus the feed entering the 2nd stage RO membranes
- Mainly consists of monovalent ions

Results

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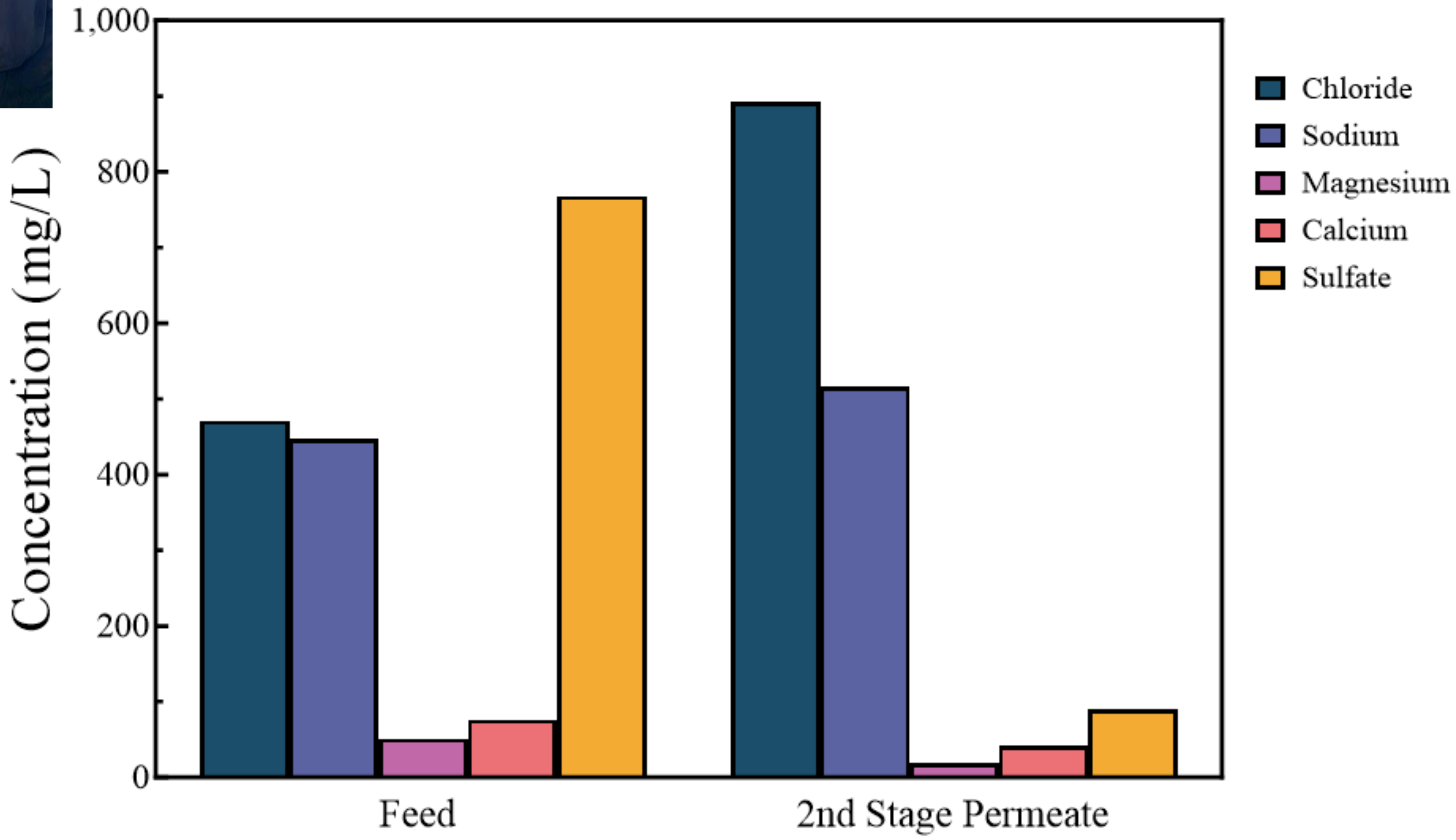
Pilot System Results– Recovery and SEC



- Typical Feed concentrations of the configurations and the 2nd stage permeate that will be entering back into the feed.
- Higher Monovalent ions, less divalent
- Reduced Sulfate concentrations

Results

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	Feed
NH_4^+	0.00
K^+	6.93
Na^+	528.6
Mg^{+2}	50.26
Ca^{+2}	85.74
Sr^{+2}	1.25
Ba^{+2}	0.01
CO_3^{-2}	0.00
HCO_3^-	7.08
NO_3^-	6.64
F^-	2.60
Cl^-	541.9
Br^{-1}	0.00
SO_4^{-2}	765.5
PO_4^{-3}	2.60
SiO_2	8.91
Boron	0.80
CO_2	5.88

	Feed
NH_4^+	0.00
K^+	8.15
Na^+	624.2
Mg^{+2}	51.18
Ca^{+2}	88.22
Sr^{+2}	1.28
Ba^{+2}	0.01
CO_3^{-2}	0.00
HCO_3^-	8.75
NO_3^-	9.53
F^-	3.63
Cl^-	757.3
Br^{-1}	2.97
SO_4^{-2}	678.2
PO_4^{-3}	0.00
SiO_2	11.98
Boron	0.87

	Feed
NH_4^+	0.00
K^+	8.79
Na^+	674.9
Mg^{+2}	53.18
Ca^{+2}	92.04
Sr^{+2}	1.33
Ba^{+2}	0.01
CO_3^{-2}	0.00
HCO_3^-	8.97
NO_3^-	10.92
F^-	4.08
Cl^-	851.3
Br^{-1}	2.20
SO_4^{-2}	671.7
PO_4^{-3}	1.60
SiO_2	13.60
Boron	0.89
CO_2	[illegible]

	Feed
NH_4^+	0.00
K^+	9.08
Na^+	698.2
Mg^{+2}	54.08
Ca^{+2}	93.78
Sr^{+2}	1.36
Ba^{+2}	0.02
CO_3^{-2}	0.00
HCO_3^-	9.08
NO_3^-	11.59
F^-	4.28
Cl^-	893.1
Br^{-1}	2.68
SO_4^{-2}	670.7
PO_4^{-3}	1.17
SiO_2	14.43
Boron	0.90
CO_2	5.88

	Feed
NH_4^+	0.00
K^+	9.21
Na^+	708.7
Mg^{+2}	54.47
Ca^{+2}	94.52
Sr^{+2}	1.37
Ba^{+2}	0.02
CO_3^{-2}	0.00
HCO_3^-	9.07
NO_3^-	11.92
F^-	4.37
Cl^-	911.7
Br^{-1}	2.55
SO_4^{-2}	670.4
PO_4^{-3}	1.42
SiO_2	14.86
Boron	0.90
CO_2	5.90

	Feed
NH_4^+	0.00
K^+	9.27
Na^+	713.4
Mg^{+2}	54.63
Ca^{+2}	94.84
Sr^{+2}	1.37
Ba^{+2}	0.02
CO_3^{-2}	0.00
HCO_3^-	9.07
NO_3^-	12.08
F^-	4.41
Cl^-	919.9
Br^{-1}	2.62
SO_4^{-2}	670.3
PO_4^{-3}	1.35
SiO_2	15.09
Boron	0.90

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