INDUSTRIAL WATER REUSE

LESSONS LEARNED AND NEW TECHNOLOGIES

IWC 24 - W03

At a glance …

IWC 2024 – WSP's Schedule

Sunday PM	Ballroom 8	Workshop 03	Industrial Water Reuse - New Technologies and Lessons Learned
		Moderator	Robert Kimball, PE. BCEE.
		Moderator	Karen Budgel, PE.
		Moderator	Ed Greenwood, P.Eng. BCEE.

Monday AM	Ballroom 8	Session M4	Water Treatment Project Delivery: Create a Gameplan for Success
		Paper 24-10	Production Expansion and Changing Discharge Limits at Grifols Therapeutics, North Carolina, USA Calls For Wastewater Treatment Plant Upgrades
		Discusser	Linea Miller, EIT.

Tuesday AM	Ballroom 8	Session T4	IWC's First Ever Food and Beverage Session
		Discussion Leader	Bill Malyk. P.Eng. BCEE.
		Paper 24-44	Novel Zwitterionic Membranes Enable High-Strength Food & Beverage Wastewater Treatment & Reuse
		Discusser	Ed Greenwood, P.Eng. BCEE.

Tuesday PM	Ballroom 8	Session T8	Solutions in Brine Management – Applications for Mining
		IWC EC Rep	Ed Greenwood, P.Eng. BCEE.
		Paper 24-57	An Effective Selenium Passive Removal Process that Meets Mine Closure Challenges - Removal of Nitrate and Selenium from Mine-Influenced Water Using a Saturated Rock Fill (SRF) Process
		Authors	Maria Borja, PMP. CIP. and Tom Rutkowski, PE.

Workshop Overview 2024

Primary objective is knowledge transfer – Identify drivers of water conservation, water reuse, water recycle

Topics include:

- Navigating the challenging and changing water treatment technology landscape
- Common problems (design issues and performance issues)
- Emerging membrane and brine concentration/minimization technologies
- Optimizing cost and reliability
- Case Studies (success stories and cautionary tales)

Participants will leave the workshop with a broad understanding of:

- The industrial water reuse landscape
- Available reuse technologies
- How to apply commonly used reuse strategies
- Common issues that can occur when applying reuse strategies

Speakers

Robert Kimball · 1st
Industrial Process Water Leader
Helena, Montana, United States · Contact info

WSP USA
Montana State University-Bozeman

Karen Budgell, PE · 1st
Senior Industrial Wastewater Treatment Engineer at WSP
Athens, Texas, United States · Contact info

WSP
Colorado School of Mines

Ed Greenwood
Process Engineering Lead with WSP E&I Canada Limited
Oakville, Ontario, Canada · Contact info

WSP in Canada
Western University

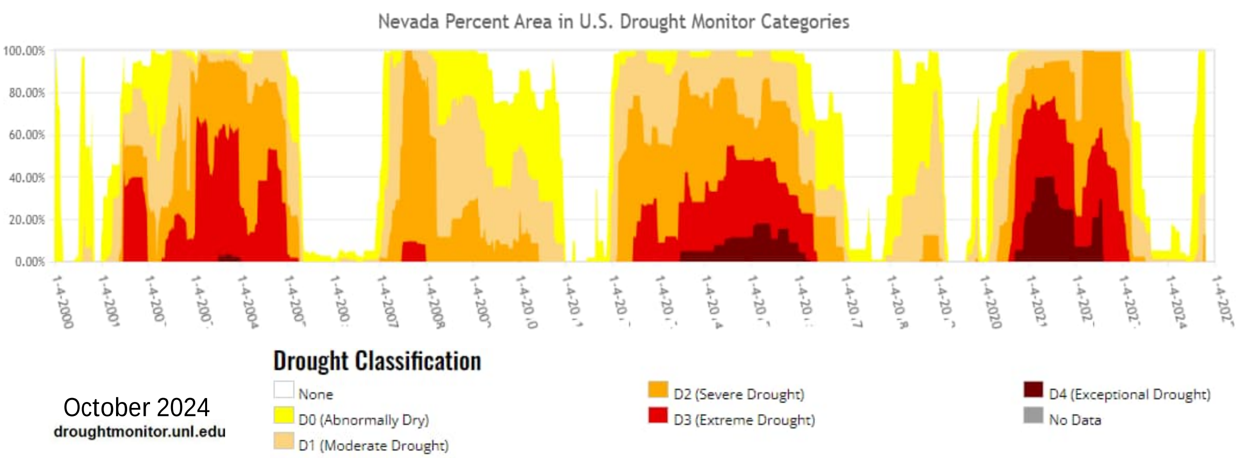
Workshop Agenda 2023

- Introduction / Background
- Roadmap
- Basis of Design
- BFD / Mass Balance
- Technology Selection
- Case Studies
- Review and Wrap-up

Water, Water, Water, Water …

Nevada is one of the driest states in the US

- 18 of the last 24 years, Nevada was extremely impacted by drought conditions



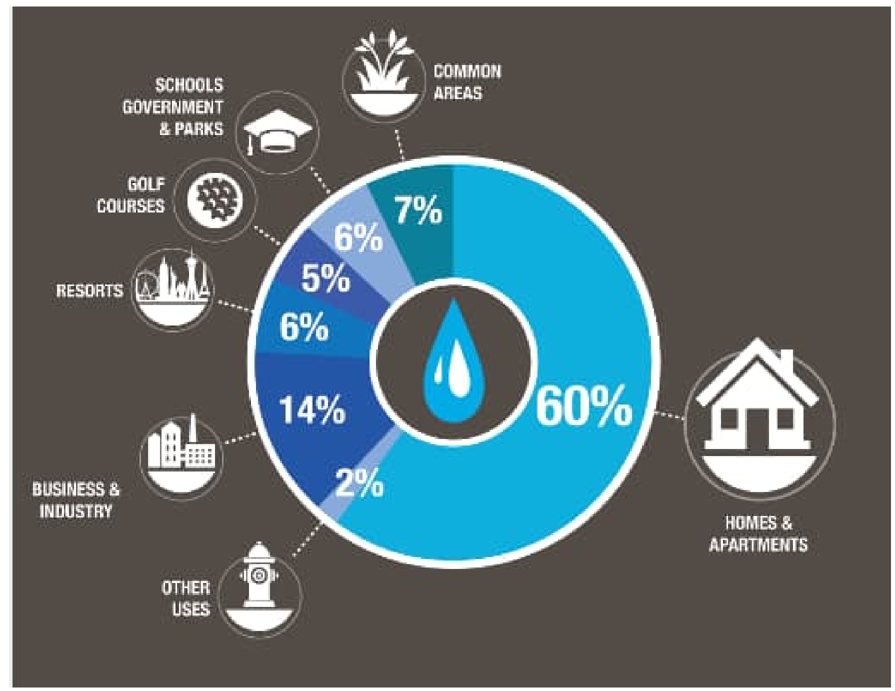
October 2024
droughtmonitor.unl.edu

Lake Mead

Nevada Water

Major water users in Nevada: Municipal, Industry, Resorts

- Casinos, golf courses, dairy farms, mining, manufacturing, hydroelectricity



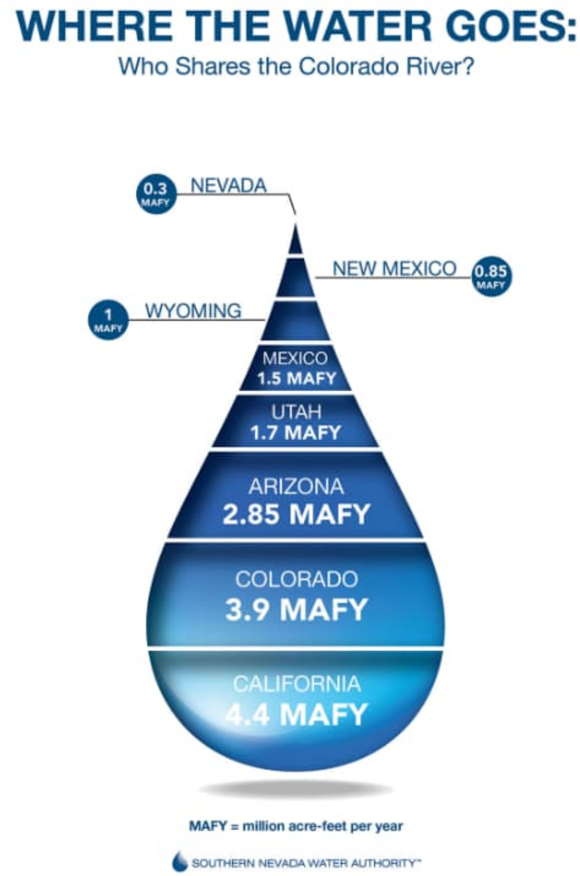
Nevada Water

Sources of Water

- 70% from Colorado River (90% in Southern Nevada) which is stored in Lake Mead
  - Colorado River supplies source water for 7 states only 1.8% is allocated to Nevada
- 30% from groundwater (10% in Southern Nevada)

Over 100 years ago, the Colorado River allocation was negotiated, and Nevada received only 1.8% of the allocation which is still the current allocation

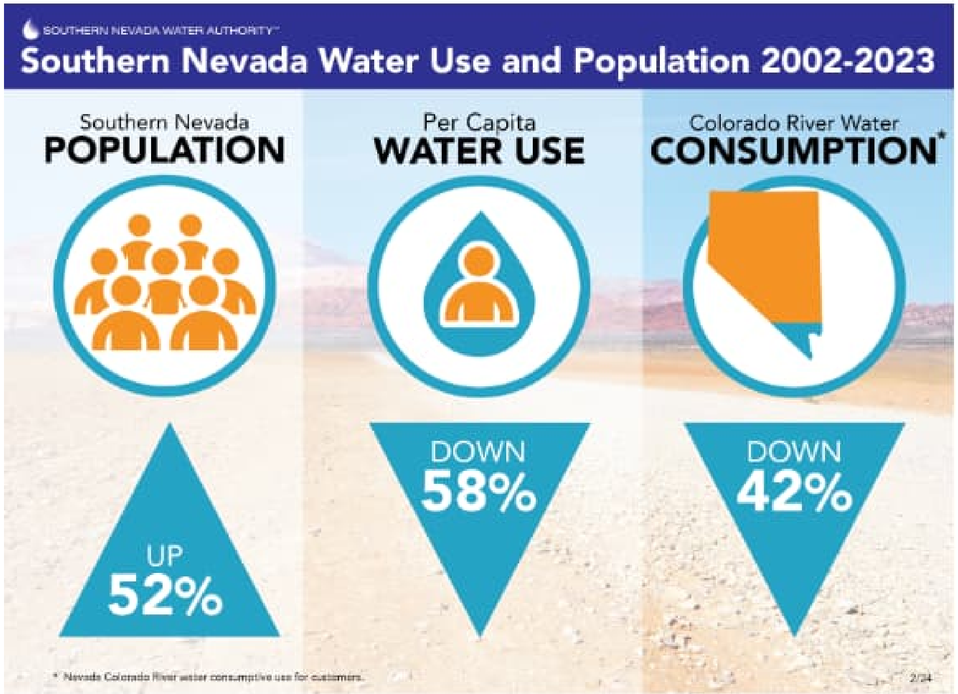
- *Population in 1920: 78,000*
- *Population in 2023: 3,200,000 (41x higher)*



A total of 16.5 million acre-feet per year is apportioned *among* the seven states that share the Colorado River, as well as the country of Mexico.

Saving Water in Nevada

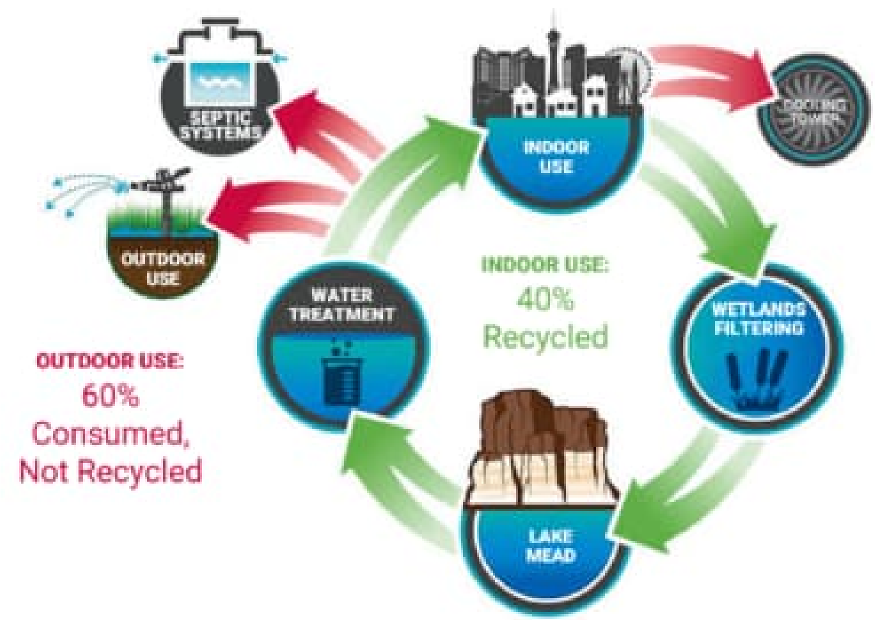
- Recycling and Reuse
- Mandatory seasonal water restrictions
- Rebate Programs
  - o Water Efficient Technologies
    - High efficiency toilet retrofits
    - Efficient showerhead
    - Retrofitting standard cooling towers with high-efficiency drift elimination technologies
  - o Converting grass to artificial surface or Water Smart Landscaping
  - o Water Smart Homes



*Nevada Colorado River water consumptive use for customers.

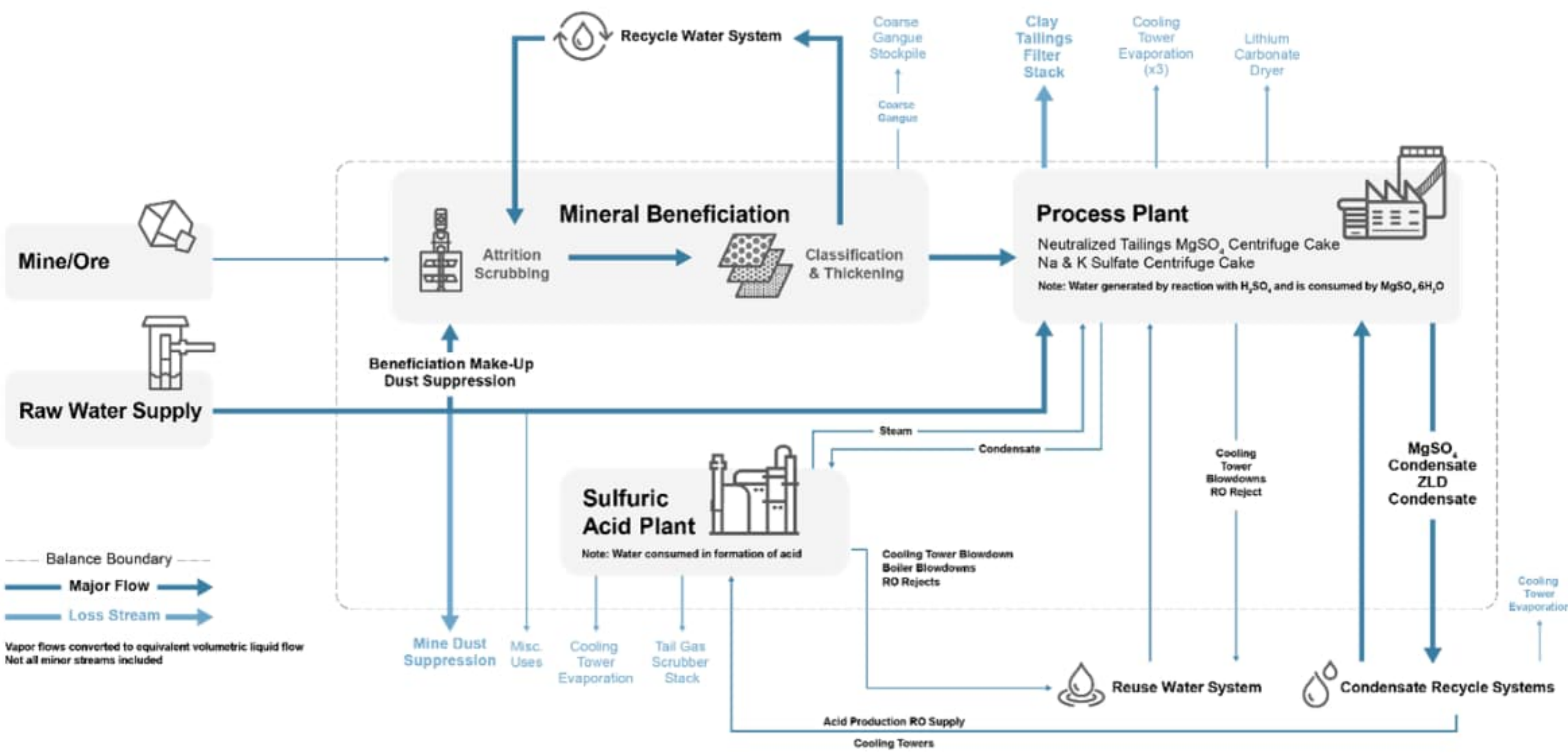
Water Reuse in Nevada

- Approximately 40% of water is used indoors and almost all of it is recycled for direct or indirect use
  - Direct reuse is used for irrigation of park, golf courses
  - Indirect reuse water is recycled back to Lake Mead for “return-flow credits”
    - ➢Return-flow credits have allowed Nevada to use nearly 60% higher than the allocated amount of the Colorado River



Industrial Water Reuse in Nevada

Thacker Pass Lithium Mine

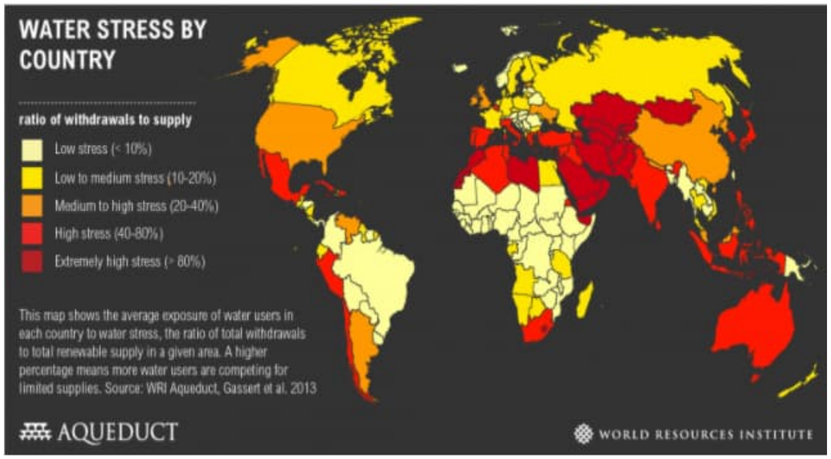


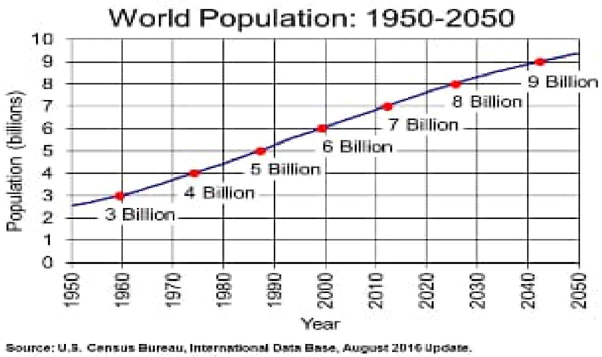
- Zero liquid discharge
- Recycling 85% of the total water use

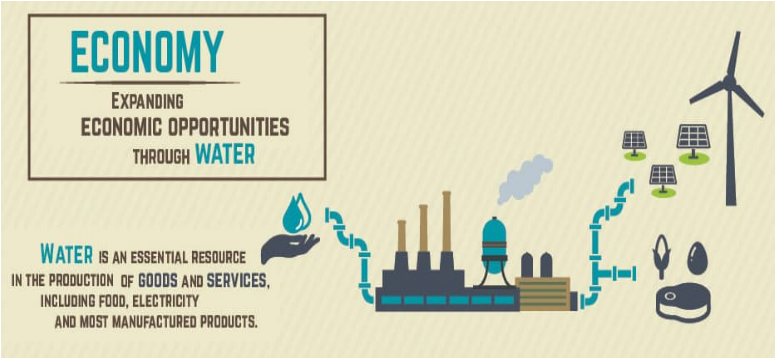
Water Reuse Background

Why?	• Drivers, benefits, drawbacks of water reuse
When?	• Decisions on implementation timelines and when the time is right
What?	• Uses and technology drivers of water reuse in industry
Where?	• Geographic and location specific water reuse opportunities
How?	• Strategies for water reuse in industry

Why? – Scarcity and Economy

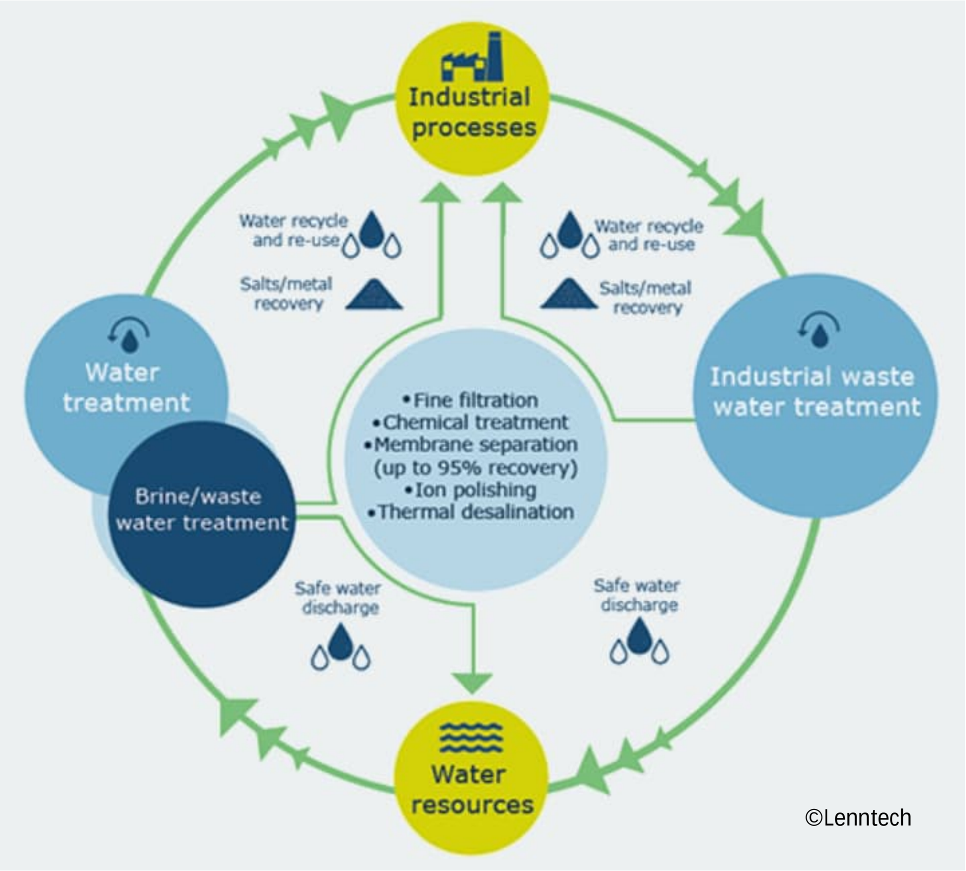






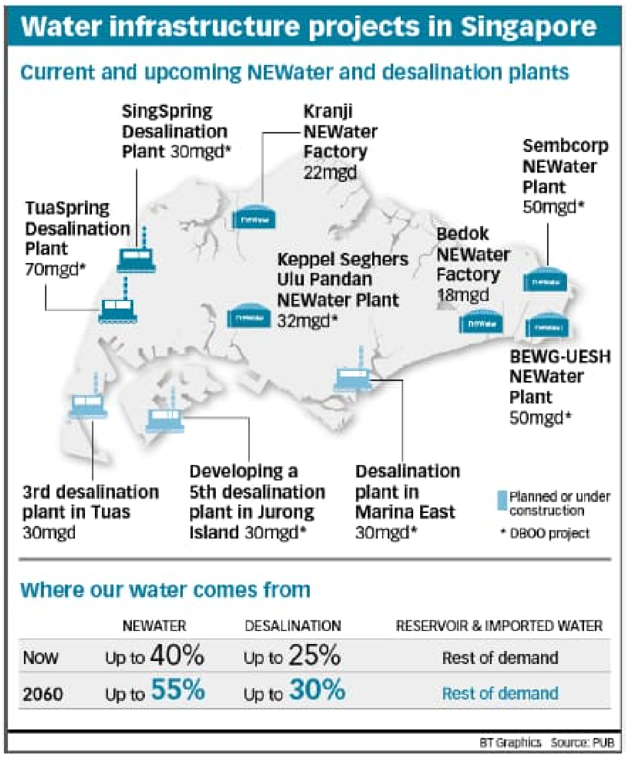
Why? – Industry Drivers

- Water supply is costly or poor quality
- Water supply is restricted (water rights, droughts, or groundwater issues)
- Government, stockholder, or stakeholder pressures to achieve sustainability by reducing water usage
- May even receive rebates
- Effluent has low barriers to be recycled



When? – Is it practical now?

- Desalination and reuse, including direct reuse, is happening now!



	NEWATER	DESALINATION	RESERVOIR & IMPORTED WATER
Now	Up to 40%	Up to 25%	Rest of demand
2060	Up to 55%	Up to 30%	Rest of demand

Timeline
-1965: Singapore independence
-1970s: DPR first proposed
-1974: “toilet to tap” piloted
-1998: NEWater study completed
-2002: 1st NEWater plant operational

The first of NEWater's treatment plants went into operation in 2002 *Image: DW / Roxana Isabel Duerr*

What? – Industrial Water Reuse Applications

- Food industry may have the most practical applications

CDM GE Water 2010, GE is now Veolia

Frito Lay has a 1 mgd activated sludge-filtration-reverse osmosis plant which has a 75% recovery (reuse) rate in Casa Grande, AZ. Reject is placed in evaporation ponds

Driver: No water rights available, stockholder pressure

What? – Industrial Water Reuse Applications

- JR Simplot Potato Flake Manufacturing, Caldwell, ID

CDM GE Water 2014, GE is now Veolia

J.R. Simplot has a 1.5 mgd activated sludge-filtration-reverse osmosis plant which has a 80% recovery (reuse) rate in Caldwell, ID. Reject is placed in evaporation ponds

Driver: No water rights available, stockholder pressure

What? – Industrial Water Reuse Applications

- Water Reuse at NM Refinery

Two (2) 500 gpm RO units which take reject from a primary RO unit and extract more clean water for refinery use. Able to achieve 75-92% recovery in secondary RO system.

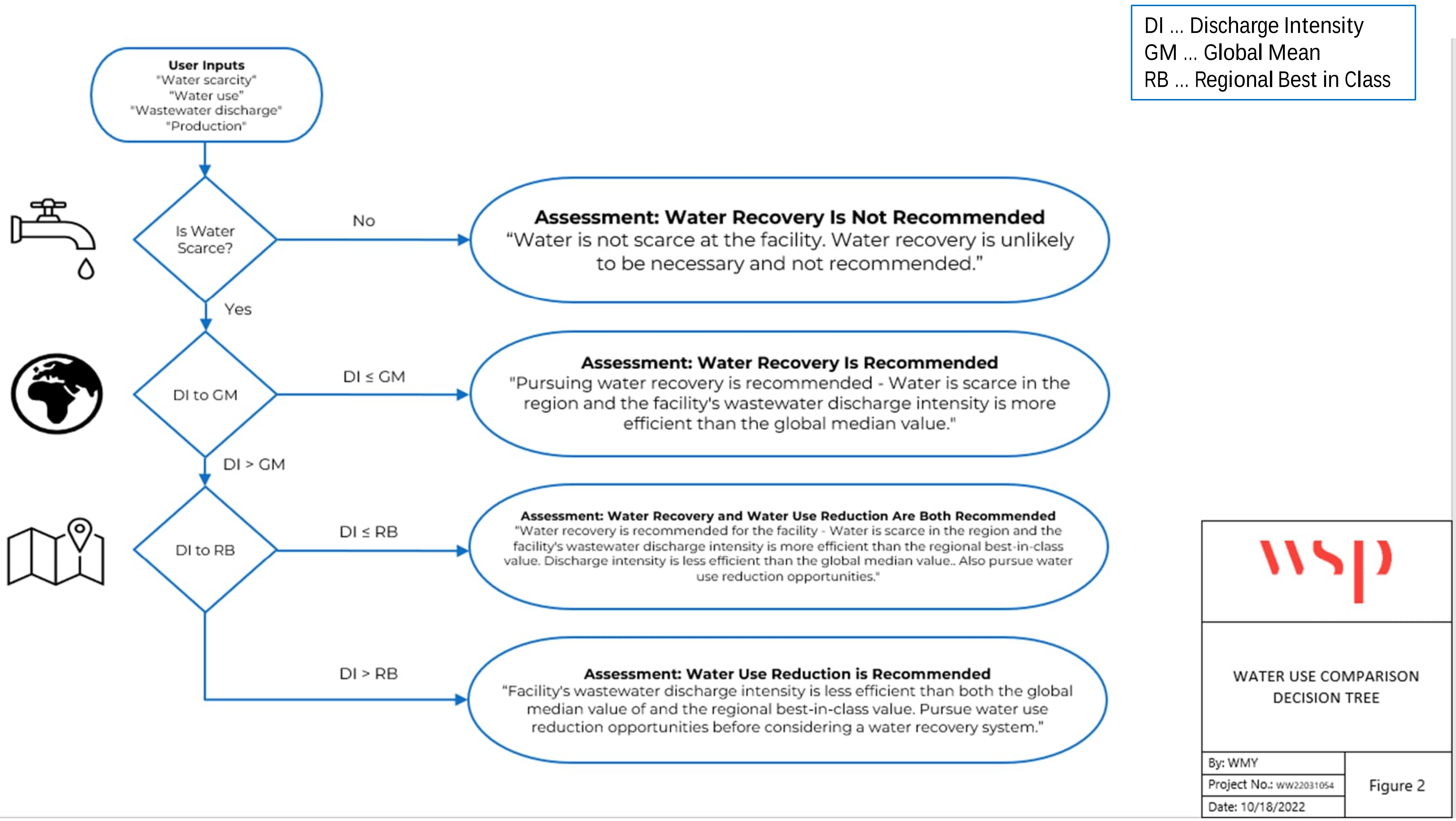
Driver: Expensive poor quality, public water

Where? – Industrial Opportunities

- Unit process by process conservation
- Make water do more than one pass through process
- Reuse treated sewage effluent
- Reuse wastewater effluent with inorganic contaminants (cooling water, boiler blowdown, Demin regen/rinse)
- Reuse wastewater effluent with organic contaminant
- Drill wells and use brackish or non potable water (with treatment, if necessary)
- Reuse stormwater

How? – General Strategies of Reduction & Reuse

Benchmarking: Define Water Supply and Current Use	Water Sources: Define Available Water Sources	Water Use Reduction: Define Goals
-Water balance where the supply to discharge balance is closed to within 10-15% -Water "Audit" to examine large single water users -Identify "wasting" to conserve water	-Fresh groundwater is reserved for emergency withdrawal -Brackish or saline GW may be available -Treated sewage effluent may be available (and be high quality)	-Use the water balance to identify major water users -Compare to available water sources -Optimize operation


DI ... Discharge Intensity
GM ... Global Mean
RB ... Regional Best in Class
User Inputs
"Water scarcity"
"Water use"
"Wastewater discharge"
"Production"
Is Water Scarce?
No
Assessment: Water Recovery Is Not Recommended
"Water is not scarce at the facility. Water recovery is unlikely to be necessary and not recommended."
Yes
DI to GM
DI ≤ GM
Assessment: Water Recovery Is Recommended
"Pursuing water recovery is recommended - Water is scarce in the region and the facility's wastewater discharge intensity is more efficient than the global median value."
DI > GM
DI to RB
DI ≤ RB
Assessment: Water Recovery and Water Use Reduction Are Both Recommended
"Water recovery is recommended for the facility - Water is scarce in the region and the facility's wastewater discharge intensity is more efficient than the regional best-in-class value. Discharge intensity is less efficient than the global median value.. Also pursue water use reduction opportunities."
DI > RB
Assessment: Water Use Reduction is Recommended
"Facility's wastewater discharge intensity is less efficient than both the global median value of and the regional best-in-class value. Pursue water use reduction opportunities before considering a water recovery system."
WATER USE COMPARISON DECISION TREE
By: WMY
Project No.: WW22031054
Date: 10/18/2022
Figure 2

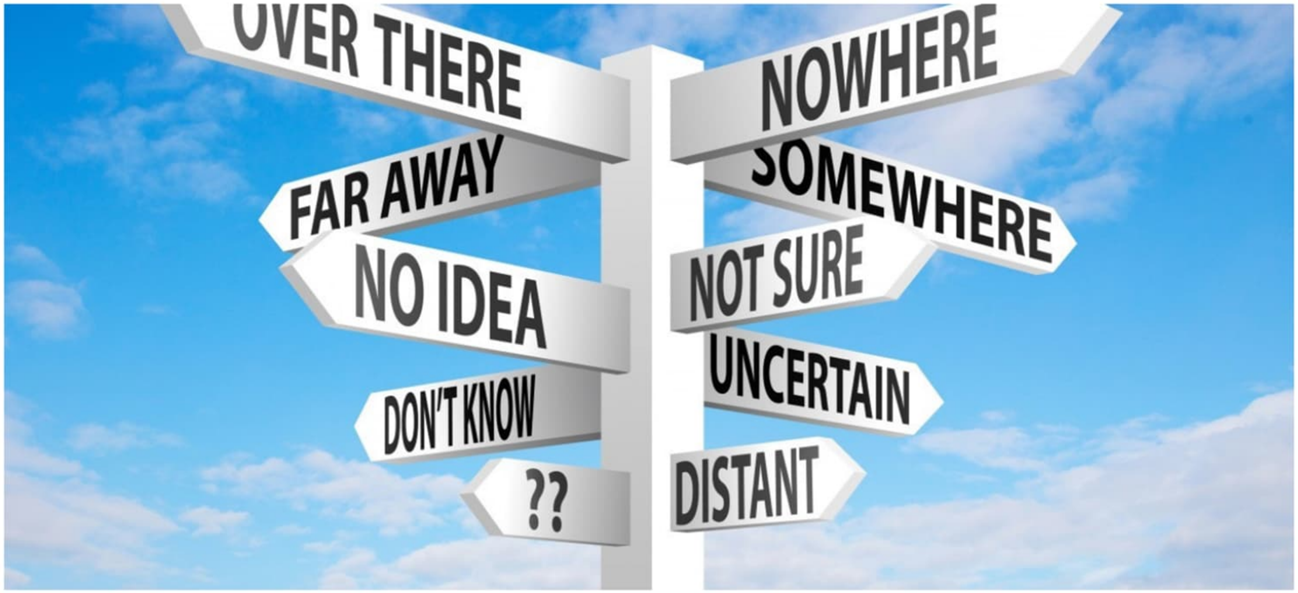

KEEP
CALM
AND
REUSE
WATER

INDUSTRIAL WATER REUSE

LESSONS LEARNED AND NEW TECHNOLOGIES

IWC 24 - W03

Water Reuse Roadmap



Now that you want to reuse wastewater
… Where do you start?

Roadmap – Step by Step – Concept to Design

1. Design Basis
2. Block Flow Diagram & Mass Balance
3. Treatment Technology Selection
4. Vendor Interviews
5. RFP
6. Bid Evaluation
7. Detailed Scope Review
8. Budget

Roadmap – Step by Step

Step 1 — Design Basis

- Includes all water sources and all reuse water users
- Understand all the goals (i.e. restrictions on waste)
- Includes all relevant info that influences the design

Step 2 — BFD and Mass Balance

- Breakdown the treatment steps (building blocks)
- Focus on pretreatment requirements
- Build reliability into the design

Step 3 — Treatment Technologies

- Consider all alternative approaches (new and old)
- Less proven approaches may require piloting
- Stay focused on the project's goals

Step by Step – From Concept to Design

Step 4 — Vendor Interviews

- Vendors can assist with developing preliminary designs
- Drill down into advantages and disadvantages
- Discuss potential upset conditions and contingency plans

Step 5 — RFP

- Includes Design Basis, BFD and MB
- Prepare Equipment Specs
- Define scope by Owner/Contractor/Vendor

Step 6 — Bid Evaluation

- Breakdown Scope and Responsibilities
- Understand Risks (i.e. who owns process guarantee?)
- Rank Vendor(s) technically and commercially

Step by Step – From Concept to Design

Step 7

Detailed Scope Review

- Develop Preliminary Dwgs with Vendor
- Review project goals, design basis with Vendor
- Review process upsets, contingency plans with Vendor

Step 8

Budget

- Obtain Contractor Quotes
- Design Review, HAZOP, FMEA
- Value Engineering

Design Basis

Step 1 - Design Basis

The Design Basis is the most critical step

→ It defines the problem and the solution

→ Simple problem – simple solution – simple design basis

→ Difficult problem – difficult solution – difficult design basis

Design Basis

Step 1 - Design Basis

1) Start with a Water Audit for the Facility

- Understand the current and future water sources and water needs
- Sample and Analyze all the sources of water and wastewater

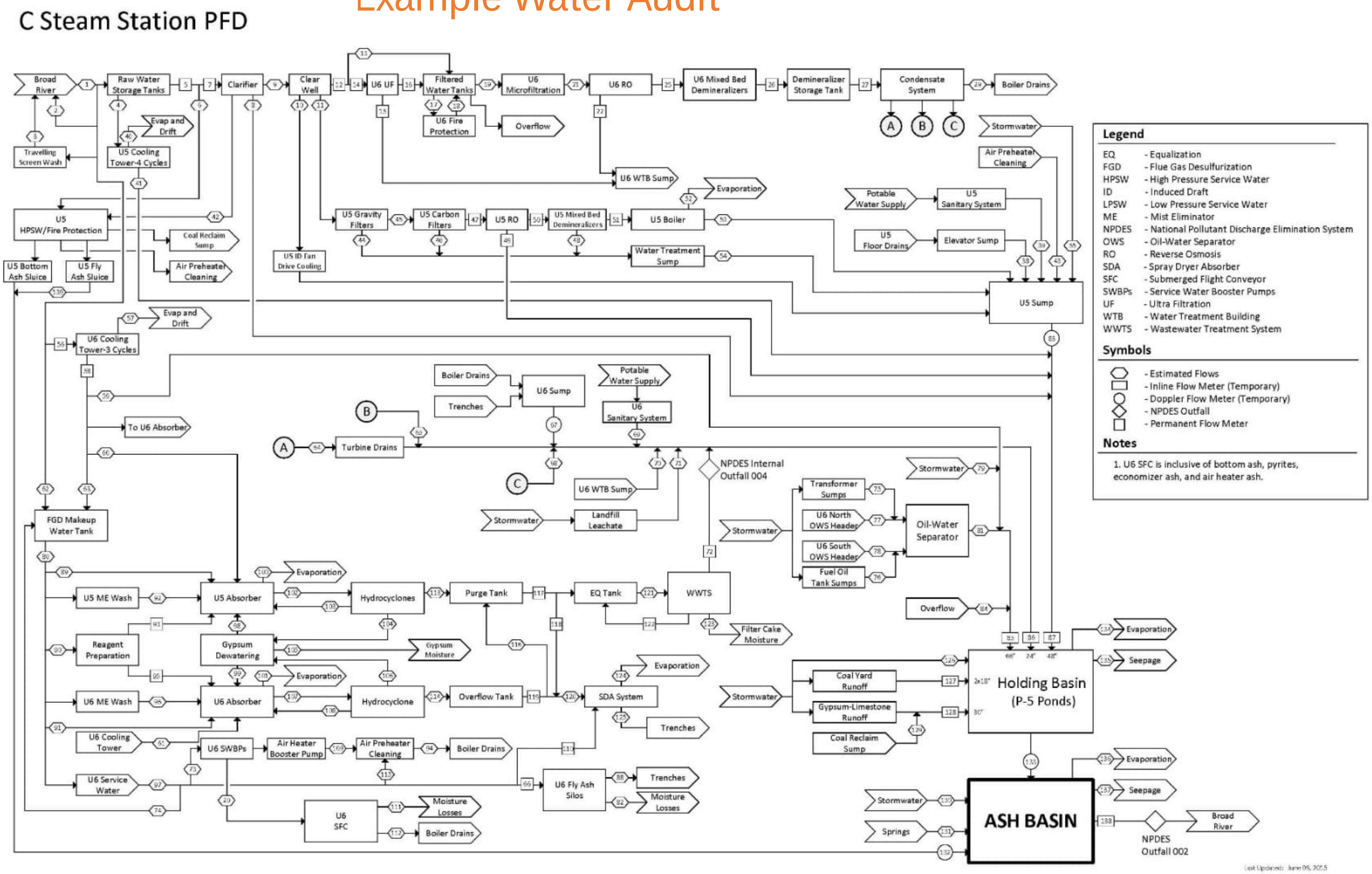
Fresh Water Sources

- Potable (City Water)
- Well water
- River water
- Seawater
- Other

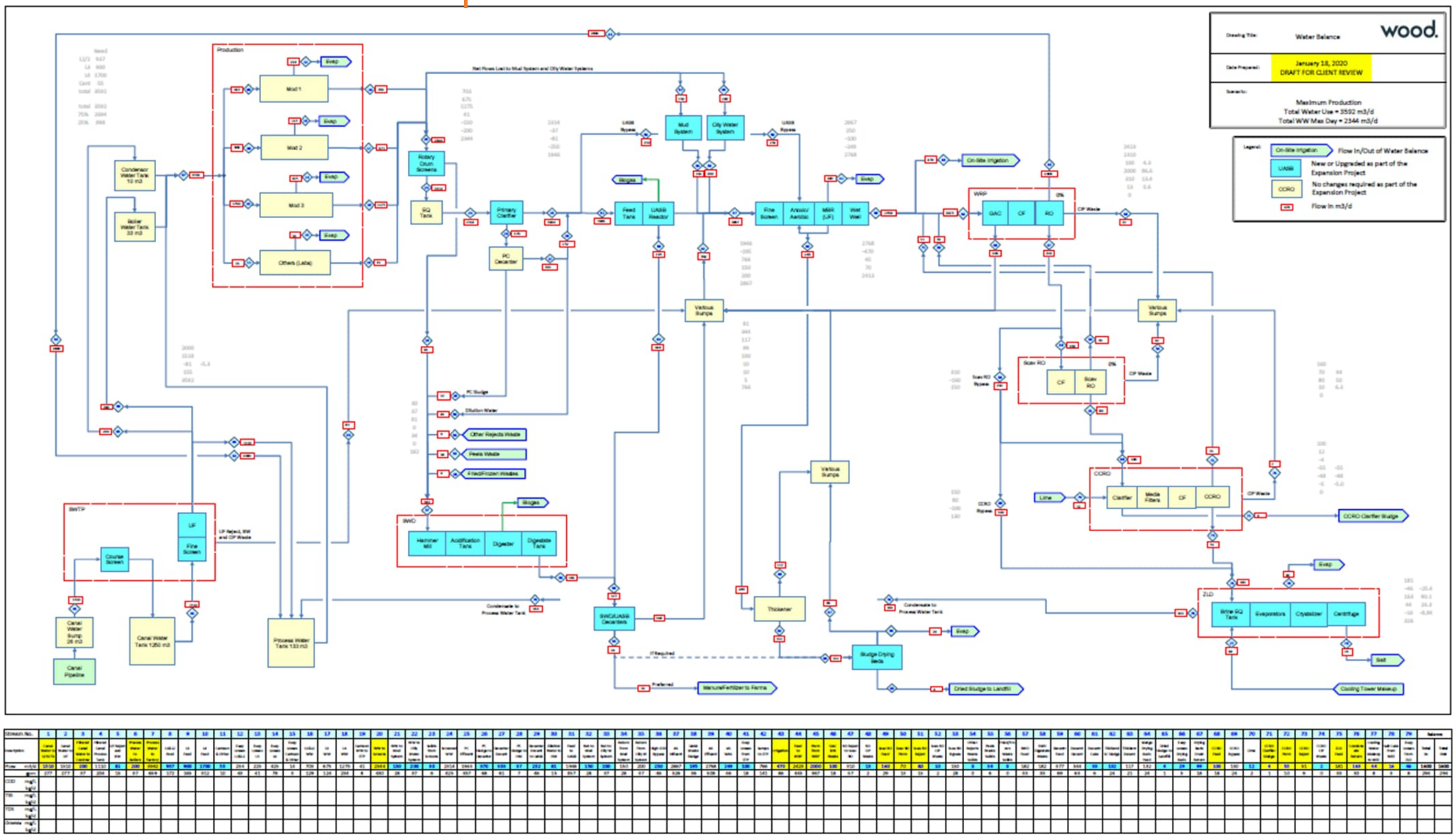
Wastewater Sources

- Various industrial processes
- Plant drains (wash water)
- Blowdown from cooling towers
- Blowdown from boilers
- Sewage
- Other

Example Water Audit



Example Water Audit



Design Basis

Step 1 - Design Basis

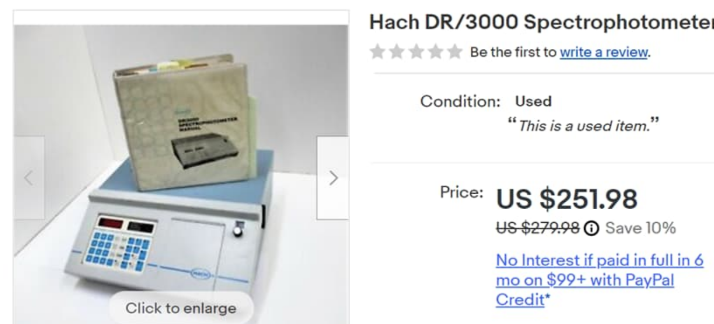
2) Quantify the flows and water quality requirements for each need

- Cooling Towers
- Boilers
- Process Water
- Wash Water
- Irrigation Water

Prosonic Flow W 400

3) Identify the major contaminates in each water source and wastewater stream

- Oil and Grease (Emulsified and Free)
- Suspended Solids (Settleable and Colloidal)
- Organics (Biologically Degradable and Recalcitrant)
- Salts (high and low solubility)
- Heavy Metals, Toxins, etc.



Design Basis

Step 1 - Design Basis

Type of Contaminant

Suspended Solids		
TSS (Total Suspended Solids)	mg/L	43
Turbidity	NTU	108
SDI (Silt Density Index)	-	5
Organics/Biological		
TOC (Total Organic Carbon)	mg/L	50
COD (Chemical Oxygen Demand)	mg/L	825
BOD (Biochemical Oxygen Demand)	mg/L	333
Total Coliforms	mg/L	333
Dissolved Salts (Anions)		
Cl (Chloride)	mg/L	19813
SO4 (Sulphate)	mg/L	2889
NO2 (Nitrite)	mg/L	2
NO3 (Nitrate)	mg/L	82.0
F (Fluoride)	mg/L	1
PO4 (Phosphate)	mg/L	23.9
SiO2 (Silica)	mg/L	24
Dissolved Salts (Cations)		
Na (Sodium)	mg/L	0.66
Ca (Calcium)	mg/L	87
Mg (Magnesium)	mg/L	0.13
K (Potassium)	mg/L	1.4
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Mn (Manganese)	mg/L	0.15
Ba (Barium)	mg/L	<LOQ
St (Strontium)	mg/L	5.1
Z (Zinc)	mg/L	<LOQ
Other		
TDS (Total Dissolved Solids)	mg/L	42866
Conductivity @ 25 C	uS/cm	49200
pH	-	8.5
Total Alkalinity (as CaCO3)	mg/L	2434
Total Hardness (as CaCO3)	mg/L	3786

Filtration	Media (Sand, Multi, Carbon, Greensand, Biological) Cloth (Disc. Bag, Belt, Cartridge) Membrane (Microfilter, Ultrafilter)
Oxidation/Disinfection	Chemical (Chlorine, Peroxide, Ozone) Ultraviolet Light Advanced Oxidation (Hydroxyl Radical)
Desalination	Membrane (NF, RO) Ion Exchange (Cation, Anion, Mixed) Electrodionization (EDI) Electrodialysis Reversal (EDR) Evaporators & Crystallizers (Falling Film, MEE, BC) Multistage Flash Distillation (MSF)

Design Basis

Step 1 - Design Basis

4) Consider the opportunities for reuse. For example …
   - Treated wastewater can be reused in Cooling Towers or Boilers as make-up
   - Treated Process Wastewater can often be used in place of fresh water sources
   - Irrigation needs (agriculture/industrial/municipal)
   - All of the above … "Designer Water"

5) Consider the obstacles for reuse
   - Cost (capital/operating)
   - Space (footprint)
   - Existing plant infrastructure restraints (locations of sources and needs, access to underground drains)
   - Unknowns (treatability study, bench top tests, technology pilot)
   - Disposal of byproducts (i.e. RO Concentrate)

Step 1 - Design Basis

Other Factors (i.e. RO creates a concentrated waste brine)

Option	Consideration
1. Blend with WWTP effluent and irrigate on site …	consider impact on soil (i.e. SAR)
2. Blend with WWTP effluent and discharge to sea or river	need a permit
3. Blend with WWTP effluent and send to sewer	minimal cost but there are limits
4. Evaporation pond	need space and $
5. Deep well injection (Class 1 or 5 disposal well)	need a permit and expensive ($$$)
6. Evaporation & crystallization	can be very expensive ($$$$$$)
6. Haul offsite for evaporation or disposal by others	can be very expensive ($$$$$$)

Avoid brine concentration … if you can

Once you create a concentrated brine the disposal options are limited and/or costly.

Step 1 - Design Basis

To complete the Design Basis List All Other Factors and Requirements

- Neighbors complain about noise or odors
- City requires buildings and/or equipment to be < 30 ft tall
- The only place to put the Reuse Plant is in the parking lot … or on the roof???
- Not enough power at the site … diesel generator?
- Freeze protection?
- Stormwater?

Result: Basis of Design
for Treatment and Reuse

- Design Flows (peak, average)
- Feed Water Quality (max, min, average)
- Treatment Requirements (e.g., cooling tower makeup, boiler feed makeup, fresh water offset, etc.)
  - Site Specific Limitations
  - Footprint
  - Power
  - Cost
  - Residuals disposal
  - Etc.


KEEP
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BFD and Mass Balance

Step 2 - Block Flow Diagram

Suspended Solids		
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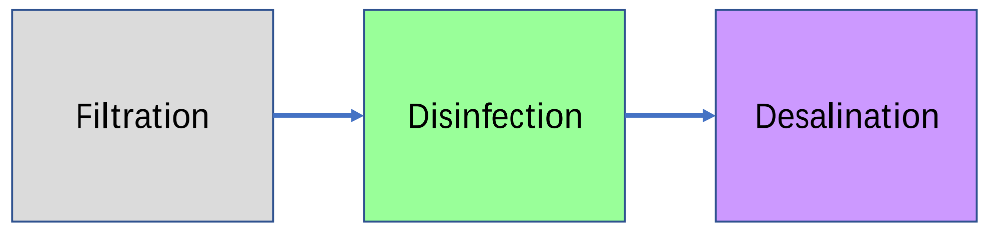
- Start with the product water quality that is needed
- Build the Block Flow Diagram of treatment steps from the last step forward
- Each treatment step is pretreatment for the step that follows



BFD and Mass Balance

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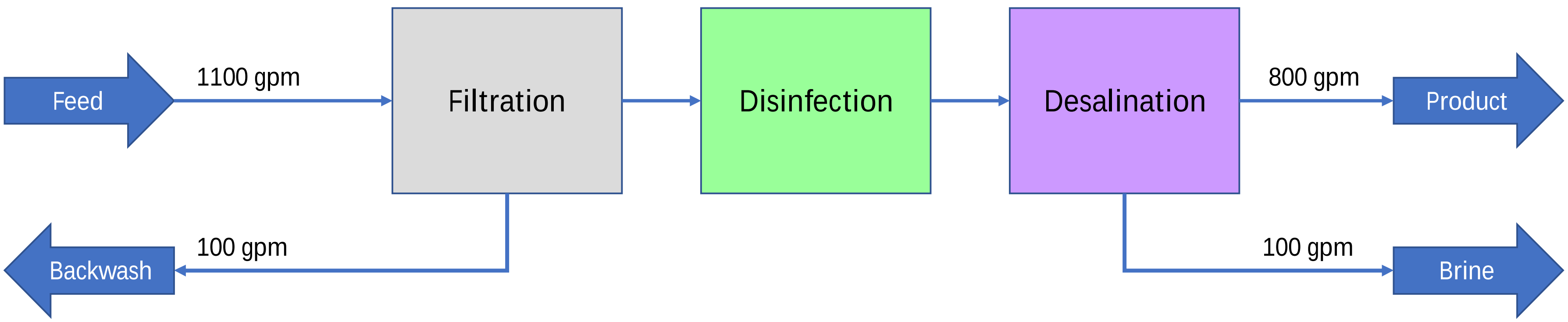
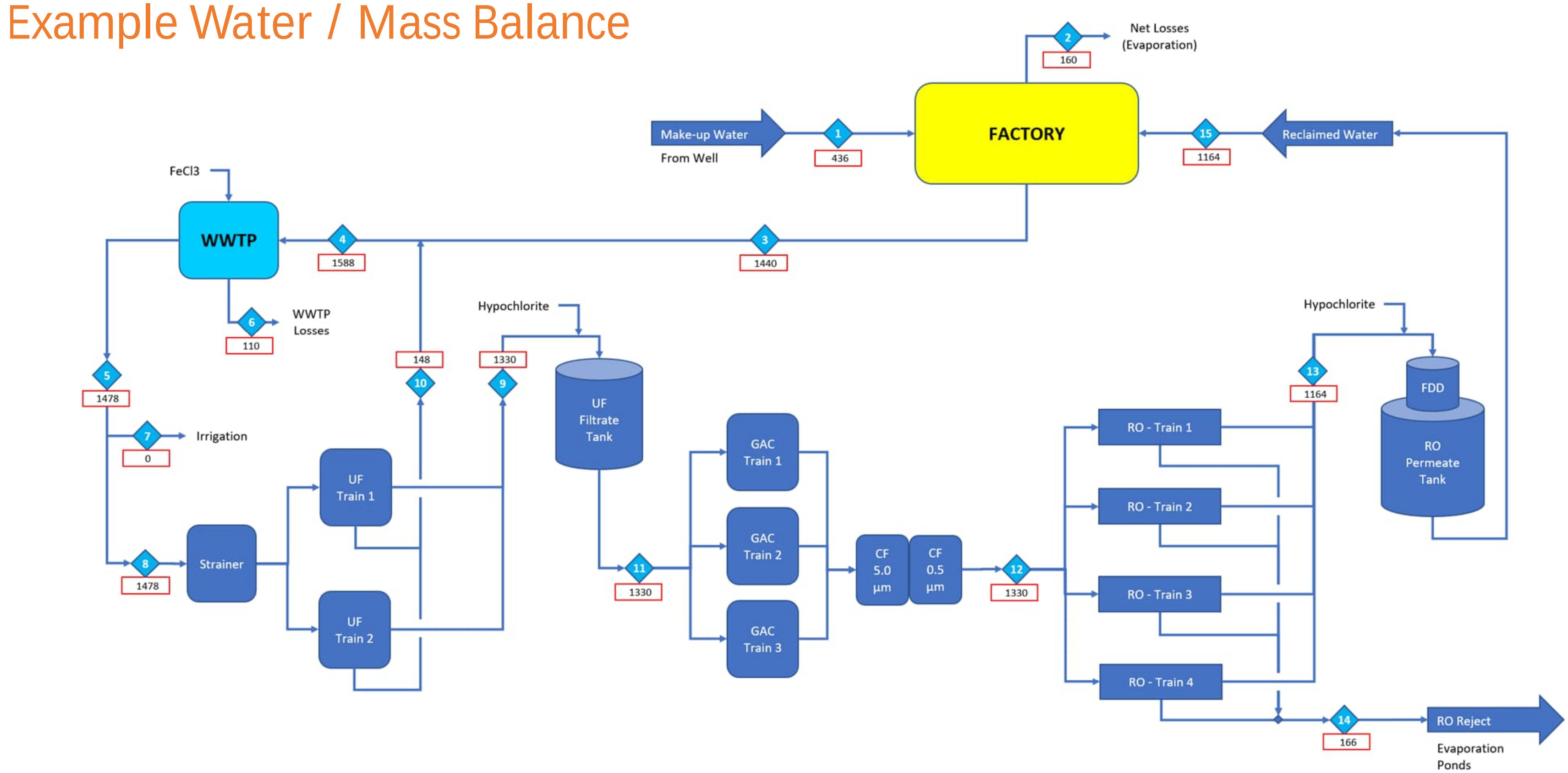
- Add Flowrates
- Don’t forget the waste



BFD and Mass Balance

Example Water / Mass Balance



Stream No.		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15		
Stream Name		Make-Up Well Water	Production Losses (Evap)	Raw Wastewate	WWTP Influent Total	Secondary Clarifier Effluent	WWTP Losses	Irrigation Water	UF Feed	UF Filtrate	UF Reject	GAC Feed	RO Feed	RO Permeate	RO Reject	Product Water For Reuse	Total In	Total Out
Flow	m3/d	**436**	**160**	1440	**1588**	1478	**110**	0	**1478**	1330	148	1330	1330	1164	166	1164	1478	1478
TDS	mg/L	**150**	**150**	**4000**	**4000**	**4000**	4000	4000	4000	4000	4000	4000	4000	46	31680	46		
TDS	kg/d	65.4	24	5760.8	6352	5912	440	0	5912	5320.8	591.2	5320.8	5320.8	53.208	5267.592	53.208	5912	5912
SiO2	mg/L	**25**	**25**	**25**	**25**	**25**	25	25	25	25	25	25	25	0.3	**198**	0.3		
SiO2	kg/d	10.9	4.0	36.0	39.7	36.95	2.75	0	36.95	33.3	3.7	33.3	33.3	0.3	32.9	0.3	37.0	37.0
RO Recovery										**90.0%**				**87.5%**				
RO TDS Rejection														**99.0%**				

McCain Foods
Mehsana Water Balance
Block Flow Diagram &
Simplified Water/Mass Balance

2014 - Original Design Condition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WATER

Treatment Technologies

Step 3 – Technology Selection

Secondary Clarifier → **Screening** → **Filtration** → **Disinfection / Organic Carbon Removal** → **Desalination** → **pH Neutralization** → **Disinfection** → **Reuse Water Storage**

	Screening	Filtration	Disinfection / Organic Carbon Removal	Desalination	pH Neutralization	Disinfection
Options	Self Cleaning Strainer Rotary Drum Screen	Sand Filtration Multimedia Filtration (MMF) Microfiltration (MF) Ultrafiltration (UF)	Sodium Hypochlorite Dosing Ozone Activated Carbon (GAC)	Reverse Osmosis (RO) Ion Exchange (IX)	Caustic Dosing Forced Draft Decarbonator (FDD)	Sodium Hypochlorite Ultraviolet System (UV)
Selection	Self Cleaning Strainer	Ultrafiltration (UF)	Sodium Hypochlorite and Activated Carbon (GAC)	Reverse Osmosis (RO)	Forced Draft Decarbonator (FDD)	Sodium Hypochlorite
Primary Reasons Why	Low solids/trash loading was expected Small footprint Low capital cost	Positive Barrier to Coliforms Higher solids loading Reliable filtrate quality Reliable performance during upsets	Ozone was too expensive Footprint for a future Ozone System was included in the building design	Positive barrier to Coliforms Low capital cost	Easy to operate and control	Client was comfortable with Hypochlorite Dosing Low capital cost

Note: Evaporation Ponds were installed in 2013 and were used to collect and store the RO Reject. For the first 2-3 years of the Water Reclamation Plant operation the ponds gradually filled up with RO Reject. However, the Evaporation Ponds were too small to be a permanent solution.

Brine Concentration Technology Selection

RO Reject → Brine Concentration → Softening → Filtration → Brine Concentration → Evaporation → Crystallization → **Salt Cake**

	Brine Concentration	Softening	Filtration	Brine Concentration	Evaporation	Crystallization
Options	Seawater RO (1000 psi) Ultra High Pressure RO (1800 psi) Closed Circuit RO (CCRO)	Membrane Softening (NF) Softening Clarifier Ion Exchange	Sand Filtration Multimedia Filtration (MMF) Microfiltration (MF) Ultrafiltration (UF)	Seawater RO (1000 psi) Ultra High Pressure RO (1800 psi) Closed Circuit RO (CCRO)	Multiple Effect Evaporator (MEE) Mech Vapor Compressor (MVR) Spray Dryer Direct Contact Evaporator	Forced Circulation Crystallizer Spray Dryer Direct Contact Evaporator
Selection	Seawater RO (SRO)	Softening Clarifier	Multimedia Filtration (MMF)	Closed Circuit RO (CCRO)	Multiple Effect Evaporator (MEE)	Forced Circulation Crystallizer
Primary Reasons Why	Simple Low capital cost	Client wanted highest possible recovery	MMF is very reliable when operating conditions are stable/constant Low capital cost	Organic fouling is mimized in CCRO by cycling TDS conc CCRO recovery can be optimized after start-up by adjusting cycle times	Low capital cost	Waste heat was not available Low capital cost

Note: In 2015, McCain decided to replace the Evaporation Ponds with a Brine Concentration system, an Evaporation system and a Crystallizer system. The Brine Concentration system is refered to as the Scavenger RO (SRO) and is a simple two stage RO with Seawater RO membranes.
In 2018, McCain decided to install a Softening System and another Brine Concentration step upstream of the MEE and Crystallizer to reduce flow/loading to the evaporation system. This would help with equipment redundancy of the MEE and Crystallizer during maintenance (i.e. HX tube cleaning) and reduce operating costs (evaporator steam consumption).

Treatment Technologies

Step 3 – Technology Selection

HERO vs. CCRO			
	HERO	CCRO	Comments
Description	High Efficiency RO system operates at very high recovery. Includes Ion Exchange softening followed by RO operating at a high pH	High Recovery RO operates in semi batch mode - continuous feed and permeate flowrate with batch RO reject cycling between concentration mode and purge mode	-
Key Advantages	Operating at high pH: - minimizes silica scaling - silica is very soluble at high pH - minimizes biological fouling - biological cells don't like high pH	Large TDS swinges on conc side of membrane: - minimizes scaling - salts redissolve when TDS drops - minimizes biological activity - biological cells don't like rapid TDS changes Adjustable operating parameters offer ability to tune CCRO for varying conditions	Both processes have key advantages over conventional RO HERO very effective for high silica CCRO very effective if feed water quality is unknown or may change in future
Key Disadvantage	Ion Exchange can be very expensive when TDS and Hardness levels are very high	Membrane systems are single stage system with fewer membranes in each housing - larger more expensive systems than conventional RO	HERO less competitive when TDS and hardness is high. CCRO less completive for primary RO.


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INDUSTRIAL WATER REUSE

NEW TECHNOLOGIES

IWC 24 - W03

U.S. DEPARTMENT OF ENERGY

ZwitterCo Awarded $1.25M Grant from Department of Energy

Oct 7, 2019

"The focus of the grant is to accelerate the development and commercialization of innovative treatment technologies that will transform the energy sector's produced water from an environmentally hazardous waste to a recoverable resource..."

ZwitterCo Wins Breakthrough Technology Company of the Year Award at 2023 Global Water Summit

May 10, 2023

ZwitterCo was named the winner in the Breakthrough Technology Company of the Year category during the Global Water Awards ceremony at the 2023 Global Water Summit hosted by Global Water Intelligence (GWI) Magazine.

Various Notes From Three IWC Papers

IWC 22-13

Driving High Recoveries in Water Reuse Applications with Novel, Zwitterionic Membranes

CHRIS ROY and JUDY LEDLEE, Ph.D., P.E.
ZwitterCo
Woburn, MA

IWC 23-44

Full-Scale Implementation of Novel, Zwitterionic Membranes for Water Reuse in High-Strength Wastewaters

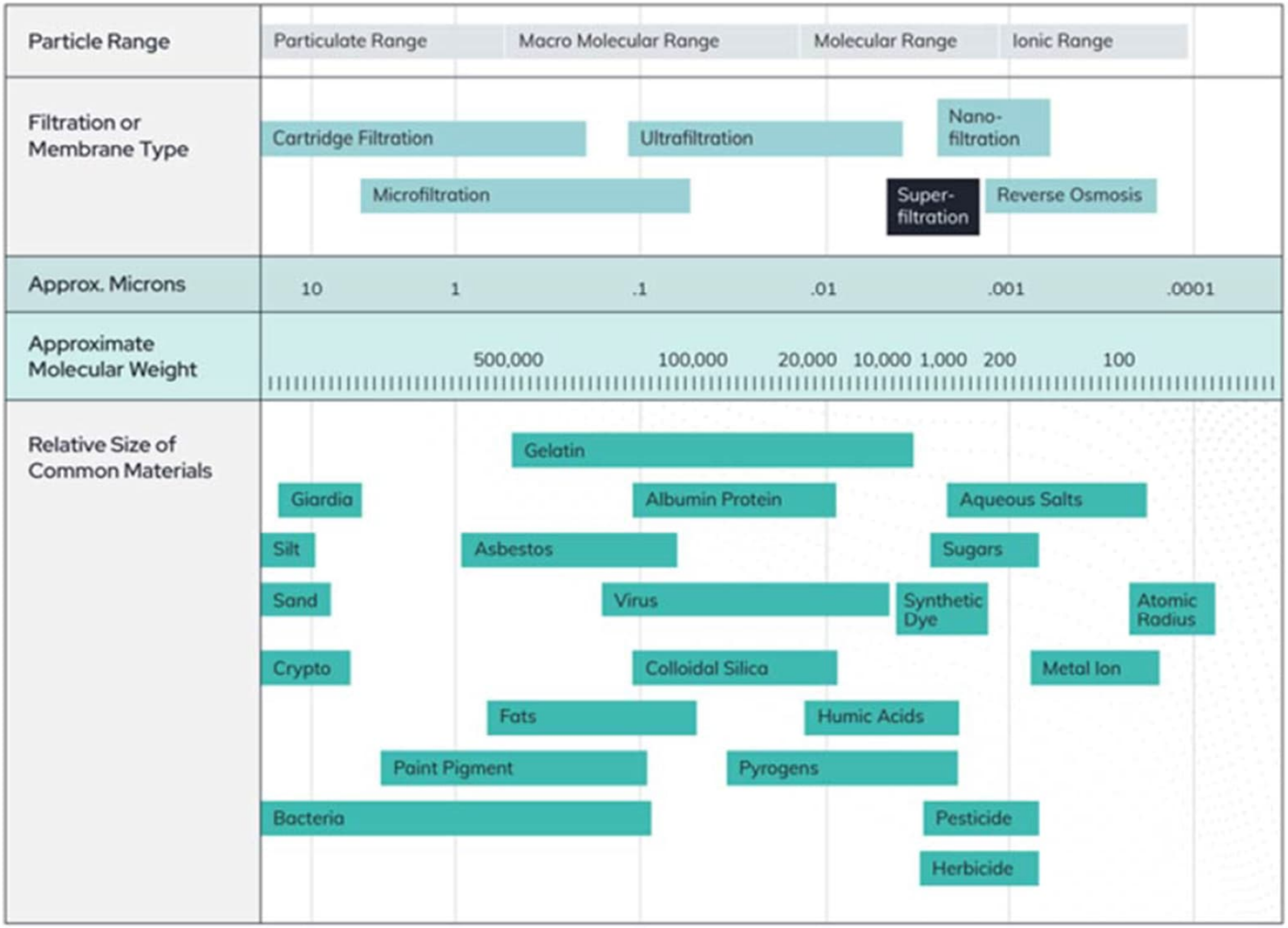
CHRIS ROY
ZwitterCo
Woburn, MA

IWC 24-44

Novel Zwitterionic Membranes Enable High-Strength Food & Beverage Wastewater Treatment & Reuse

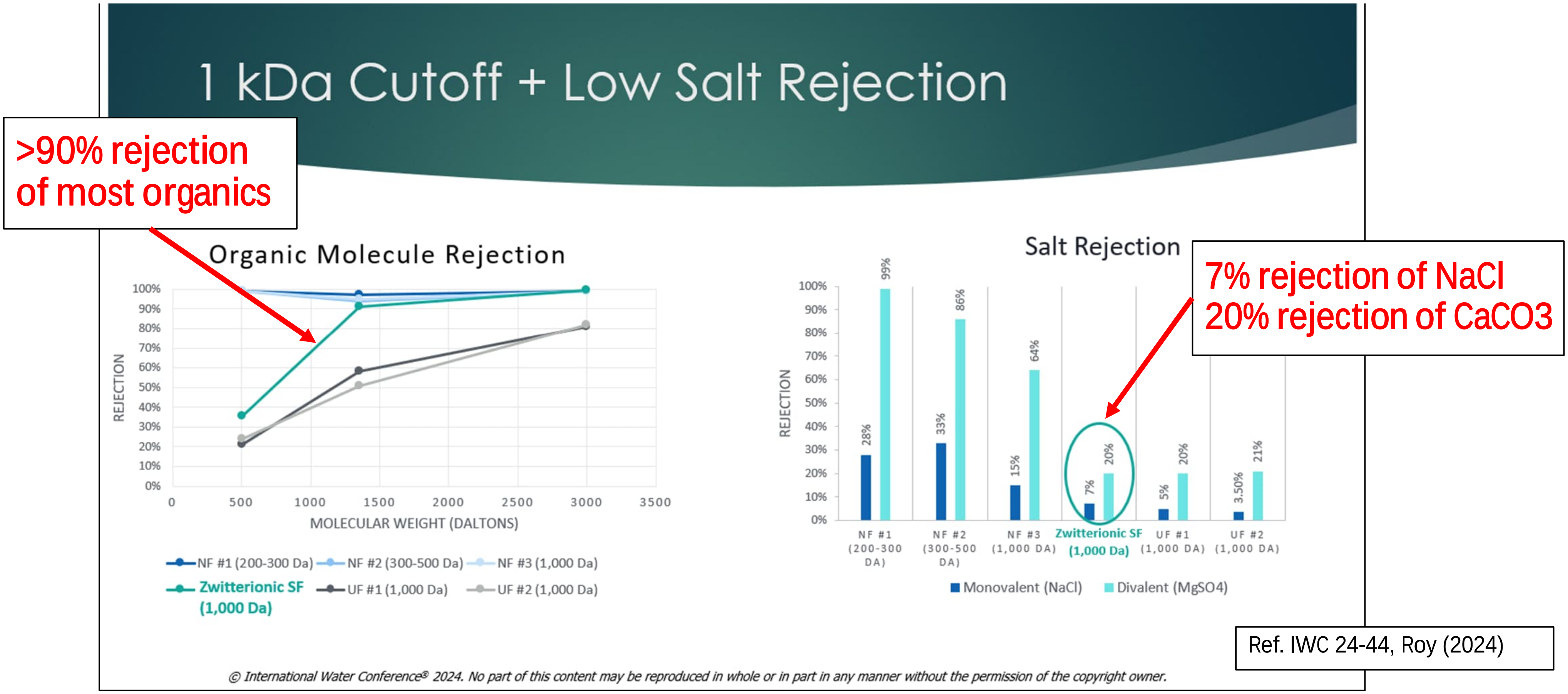
CHRIS ROY and ANDREW HUNT
ZwitterCo
Woburn, MA

What are Zwitterionic Membranes?



Ref. IWC 23-44, Roy (2023)

Zwitterionic Membrane Rejection



Zwitterionic Membrane Production

Standard Polyamide RO + Zwitterionic Copolymer = Zwitterionic RO

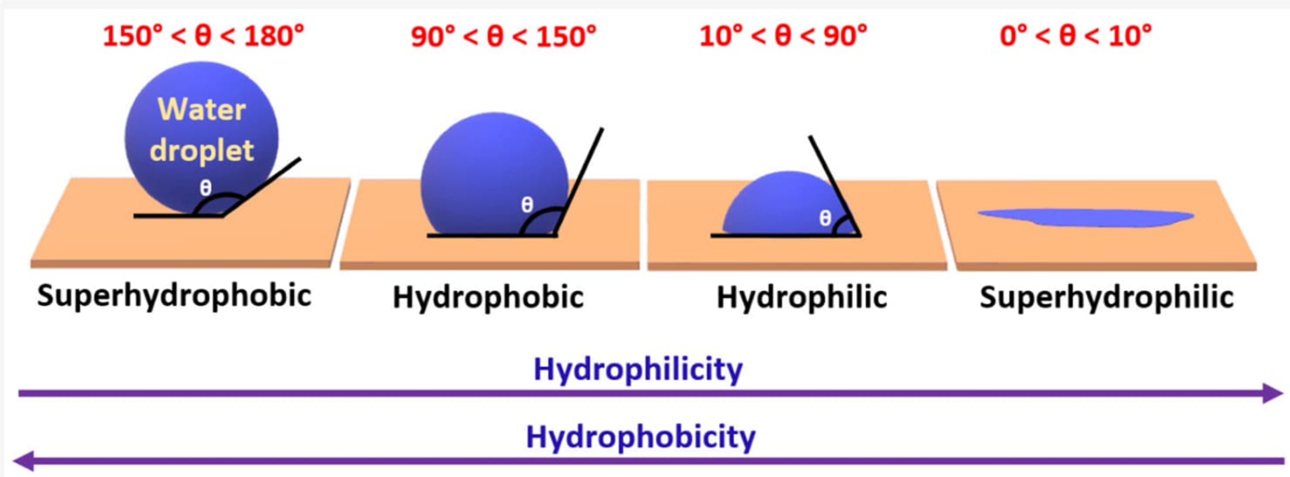
- Recent advancement in zwitterionic membranes
- Utilizes standard polyamide RO chemistry = same salt rejections
- Adds permanent zwitterionic barrier resistant to organic fouling

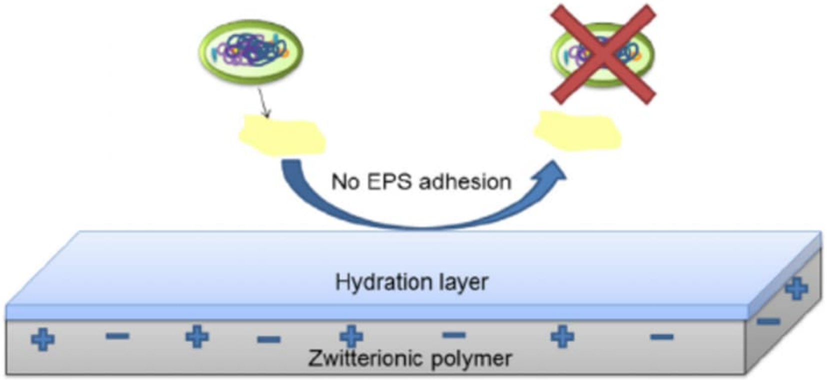
Ref. IWC 24-44, Roy (2024)

Membrane rolling equipment at ZwitterCo ZWITTERCO

Ref. https://www.forbes.com/sites/jeffkart/2023/11/30/zwitterco-builds-innovation-center-to-scale-up-membranes-for-industrial-wastewater-treatment/

Why are Zwitterionic Membranes Resistant to Fouling?

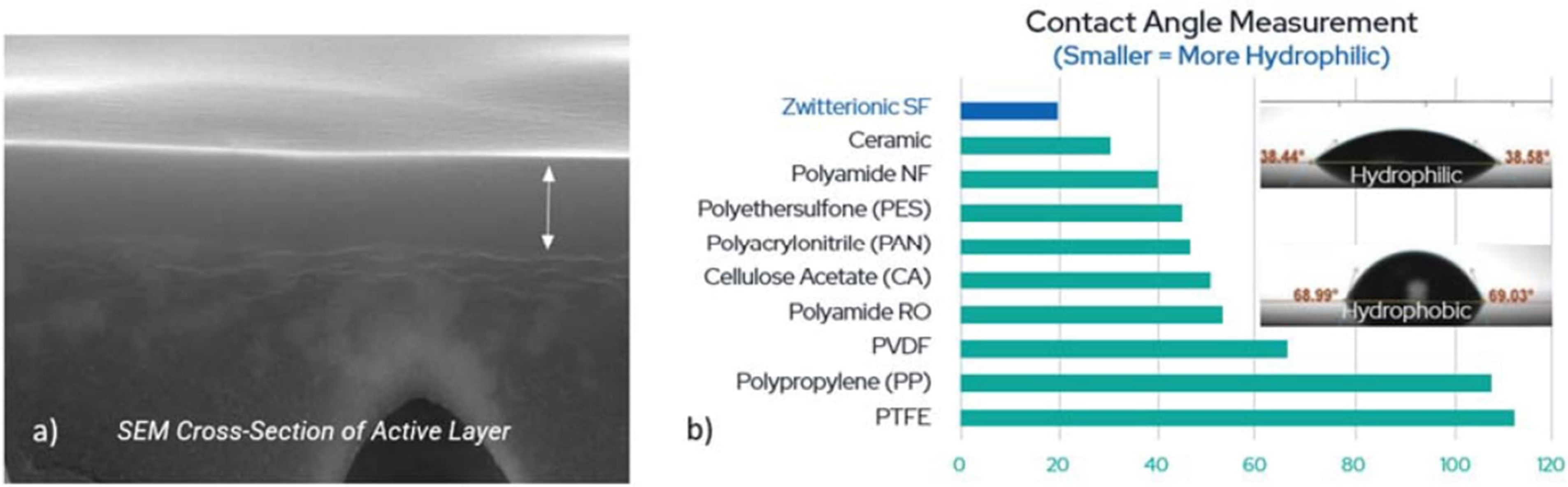




Ref: (Singh, 2015)

Fig. 13. Zwitterionic mechanism of antifouling: The hydration layer formed by the electrostatic hydrogen bonds between the water molecules and zwitterions prevent the attachment of the extrapolymeric substance (EPS) produced by the microbial cells. The EPS helps the microbes in attaching to the coatings. However, in the case of zwitterionic coatings, the hydration layer prevents this attachment and inhibits antimicrobial attachment to the device.

Figure 2: a) An SEM cross sectional image of a zwitterionic membrane active layer that shows the smoothness of the membrane surface. b) Contact angle measurements comparing the hydrophilicity of zwitterionic membranes to other commonly available membrane materials



Ref. IWC 23-44, Roy (2023)

FLOWSHEET (MEAT PROCESSING)

Figure 13(a): *Overall process train treating pork cook facility*

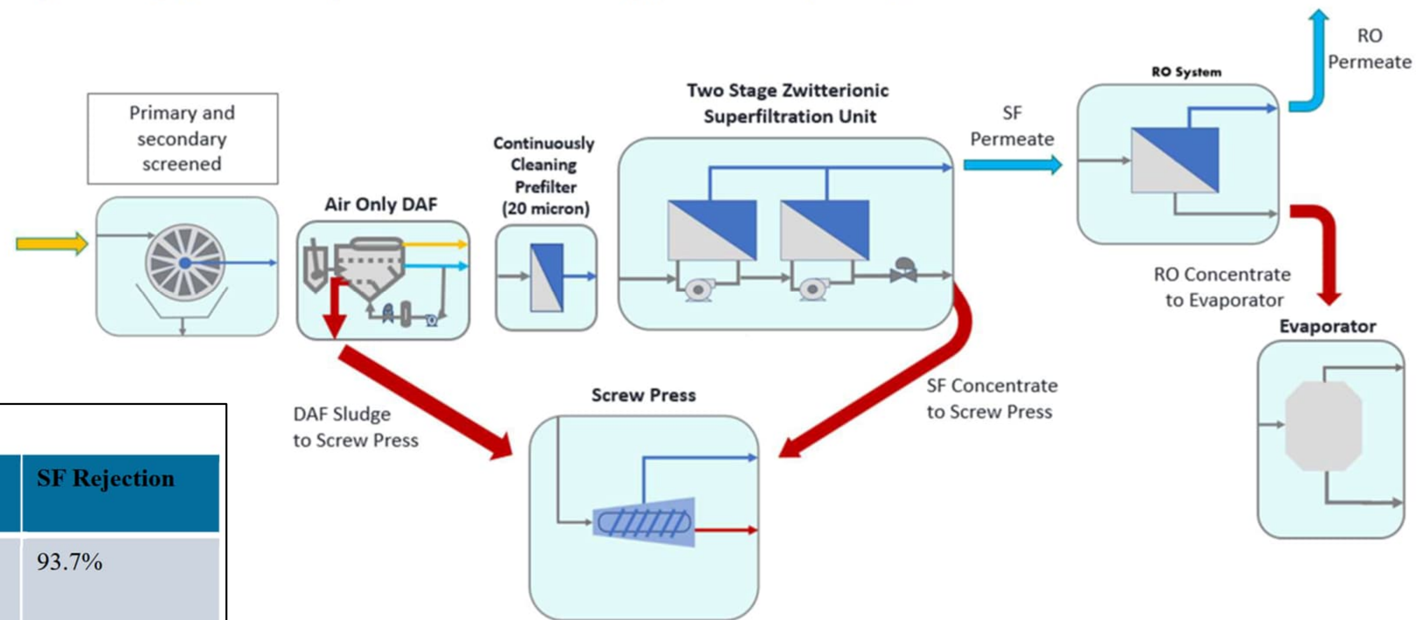


Table 3: *Pork cook wastewater analytical data*

Parameter	SF Feed	SF Permeate	SF Rejection
Fats/Oils/Grease – HEM (ppm)	62	3.9	93.7%
COD (ppm)	4,043	1,255	69%
TSS (ppm)	1,188	2.3	99.8%

CLEAN WATER PERMEABILITY (POULTRY PROCESSING)

Figure 8: *Clean water permeance (CWP) recovery over the pilot trial*

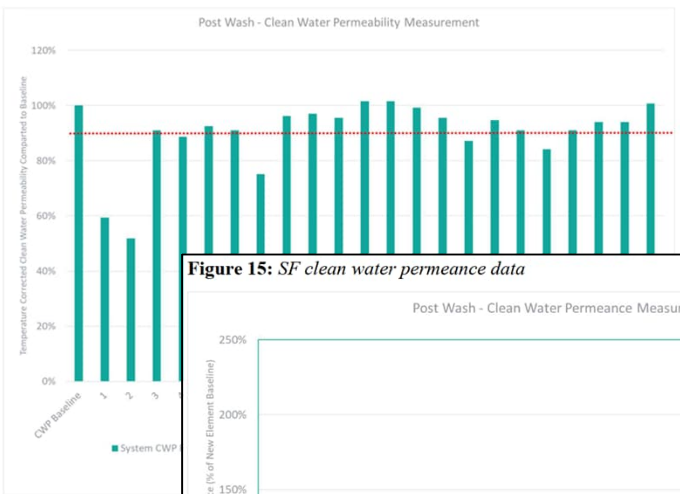
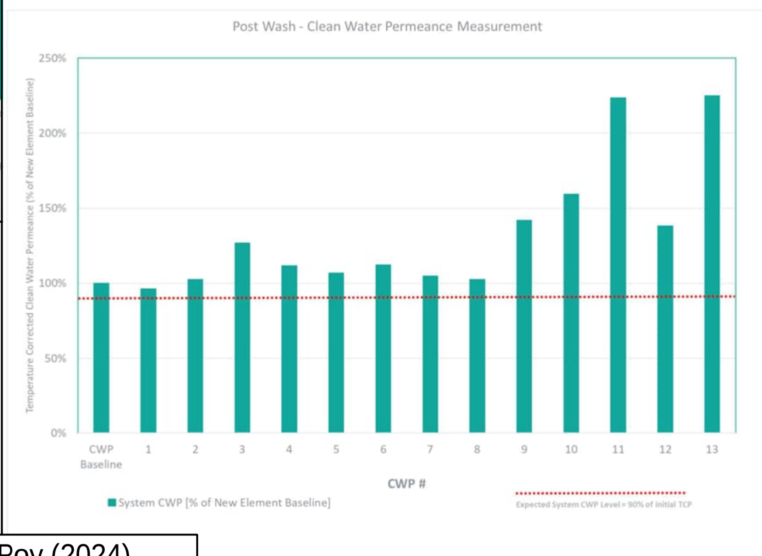


Figure 15: *SF clean water permeance data*



Ref. IWC 23-44, Roy (2024)

QUESTIONS

- Are these charts over a 2 to 3 week period?
- What is the CWP Baseline in (gfd/psi) or (lmh/bar) and why did the permeability increase in figure 15?
- Membranes typically have a breaking period after which the membrane permeability stabilizes (assuming operation is below the critical flux). Have you found this to be the case with your SF Zwitterionic membranes?
- Have you done any accelerated fouling studies over longer periods of time to try and characterize the performance of the membranes over several years of operation in different applications?
- Have you done any membrane autopsies (SEM with EDS/EDX) to identify any potential “irreversible foulants” that may have remained on the membrane after piloting (after several intensive chemical cleans)? Note SEM would allow comparison of the membrane surface before and after, and EDS/EDX would identify the chemistry of any remaining foulants.

IWC 24-44D - DISCUSSER FINAL COMMENTS

1) In today's world of "Reduce-Reuse-Recycle", zwitterionic SF membranes have the potential to change the face of industrial wastewater treatment. Directly filtering wastewater with O&G, and generating valuable "coproducts" … without biological treatment will save our clients:

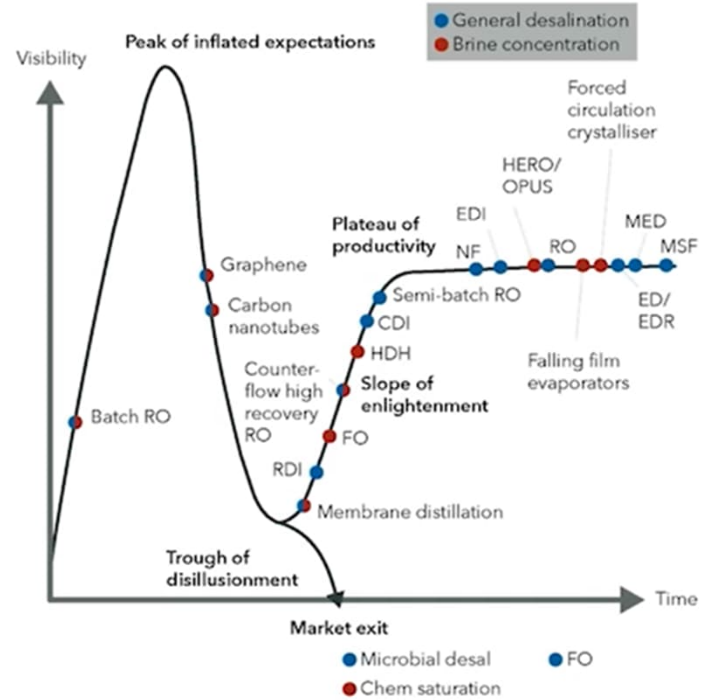
- Space (biological treatment plants have large footprints)
- CAPEX (biological treatment projects have large capital budgets)
- OPEX (biological treatment plants consume a lot of power and chemicals)
- Complexity (biological treatment plants require knowledgeable operators)

2) Controlling membrane fouling is a concern

3) IWC is looking forward to the Author's responses … and your next paper in 2025

Overview

- This schematic of a technology's journey towards commercialisation charts the initial excitement that surrounds a new technology, followed by disillusionment as practical difficulties set in, before a final move towards commercialisation and mainstream acceptance.
- Brine management is currently a key driver of adoption. Almost all of the technologies making the slow ascent to mainstream use are primarily used in brine concentration, with the notable exception of semi-batch reverse osmosis.
- The time needed to create reliable and affordable manufacturing methods for materials such as graphene and carbon nanotubes, means that these are among the slowest technologies to mature. However, 'operational R&D' such as semi-batch or counter-flow reverse osmosis system configurations are likely to take off much more quickly.

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INTERNATIONAL WATER CONFERENCE

INDUSTRIAL WATER REUSE

NEW TECHNOLOGIES

IWC 24 - W03

Osmotically Assisted Reverse Osmosis for Brine Concentration

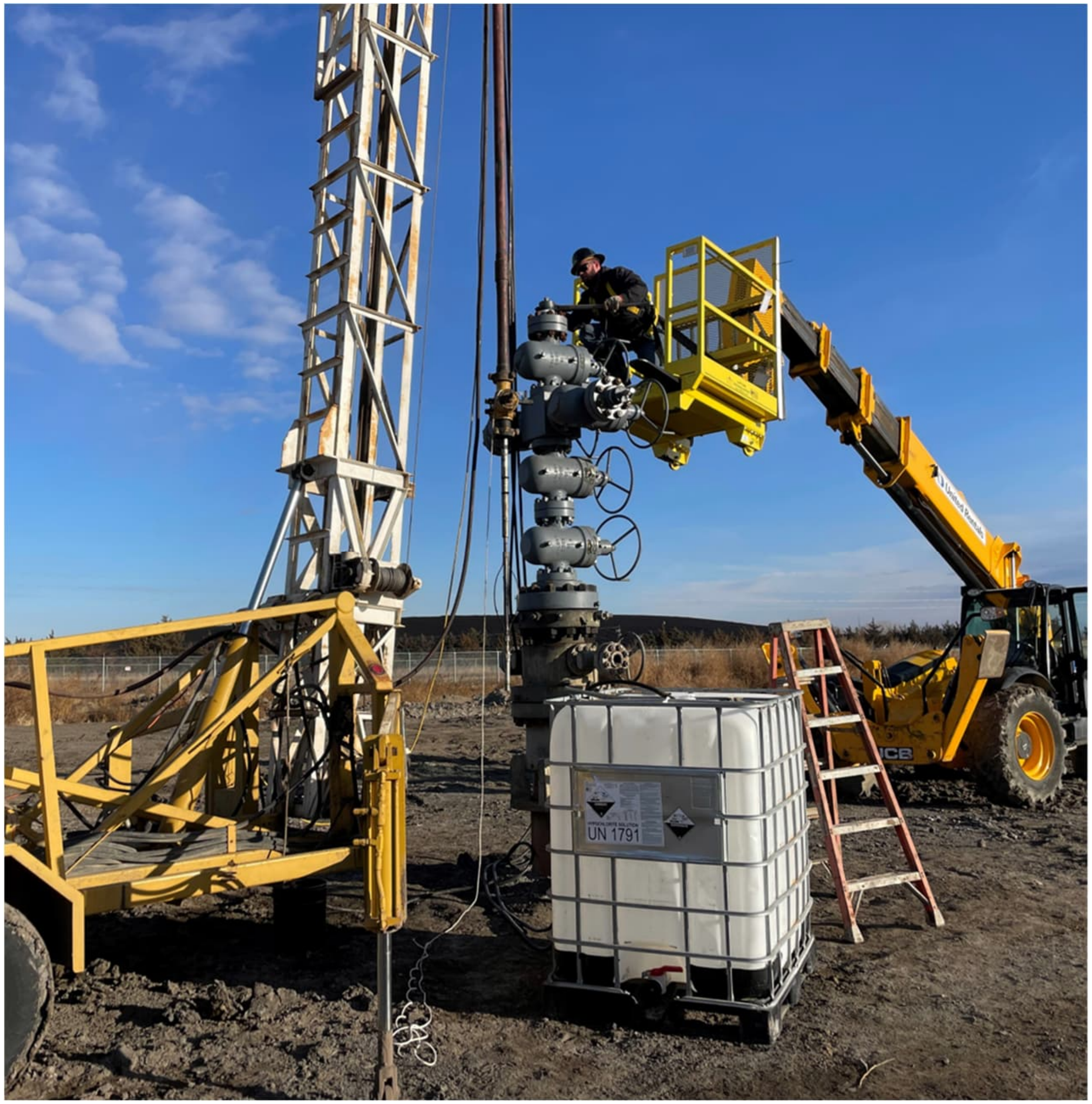
- New technology with potential to change the water reuse flowsheet for brine concentration
- Only two full scale plants in operation (2023)
- Many clients are piloting

Options for Brine Disposal

Deep Well Injection (Development)

- DWI facilitated through Underground Injection Control (UIC) Program
- Regulated through EPA or primacy granted States
- Six class types of DWI
  - (I) Industrial and Municipal, (II) Oil & Gas related, (III) Solution Mining, (IV)Shallow Hazardous & Radioactive, (V) Non-Hazardous Fluids/Drinking Water, (VI) CO2 Sequestration
- Class I most regulated, can be used for RCRA hazardous wastes
  - Composition determines RCRA
    - e.g. Organic wastes/solvents (flammable, explosivity) and Inorganic (ppm levels of arsenic)
- Takes Time and $
  - Application, Review (6 mos. minimum) followed by 30-day public comment periods
  - Millions $ to develop & drill
  - Thousands $ for monitoring & annual O&M
- https://www.epa.gov/sites/production/files/2015-07/documents/study_uic-class1_study_risks_class1.pdf

Brine
Disposal
Options



Class I Injection Well

Client

Nebraska Public Power District

Project Location

Sutherland, Nebraska

Key Elements

- Disposal of 300 gpm at a depth of 3600 ft
- Water management options evaluation
- Permitting
- Surface infrastructure design
- Yard piping design
- Wellhead construction assistance
- Aquifer testing analysis

Other Options to Consider

Concentration & Evaporation

Reverse Osmosis

Brine Concentrator

Crystallizer

Spray Dryer

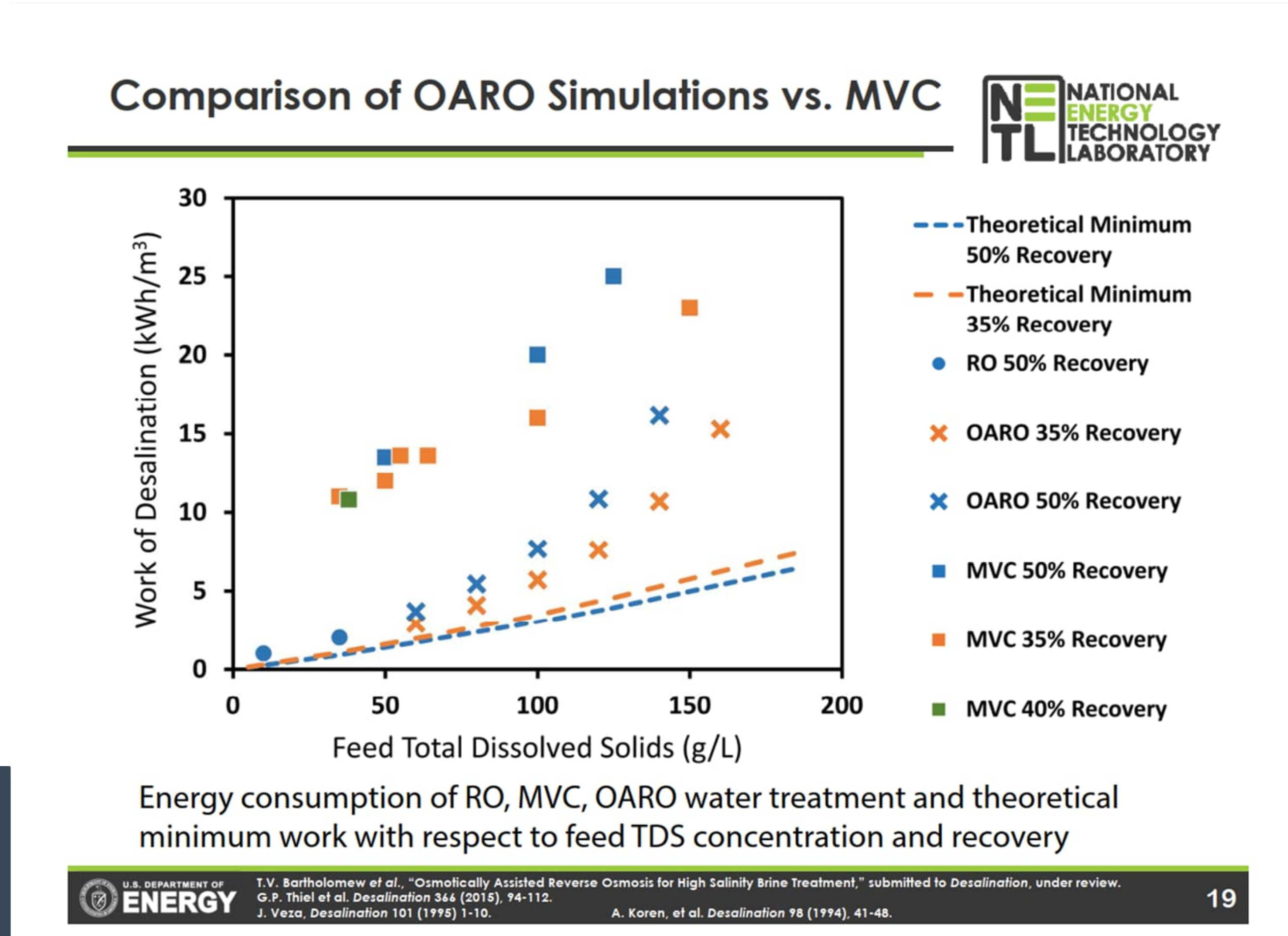
Evaporation Ponds

	Reverse Osmosis	Brine Concentrator	Crystallizer	Spray Dryer	Evaporation Ponds
+	1/10 energy as evaporators	Proven technology	Goes to Dryness	Goes to Dryness	Static Process
+	High water recoveries possible	High water recoveries possible (MVR)	Can treat water with high levels of TDS (up to 0.1%)	Rugged technology ….slurries with up to 20% solids as well as and mixed salts	Cost Effective
+	Lower capital cost and O&M cost vs. evaporators	Can configure to recovery a distillate or evaporate (atmospheric)	Ideal for crystallization of pure salts…..resale	Mechanically Simple	Possible benefit to birds
−	TDS Limited (up to 40,000 mg/L)	High energy consumption	May end up with unwanted low volume distillate	May not be economical without waste heat (I.e. use large amounts of natural gas)	Large footprint
−	May need pre-treatment (e.g. Multimedia filtration, phys-chem)	Does not go to dryness, produces a concentrated brine solution	High capital cost	Throughput	Climate dependent
−	Fouling & scaling potential	Process issues (e.g. foaming) – BC need solids pretreatment	Process & Technology is complex	Potential air emissions depending on configuration	Potential bird hazard

Brine Concentration Relative Costs

- New Membrane Technologies vs. Thermal Evaporation

Reference: *Arena, J.T.; Bartholomew T.V.; Mauter, M.S.; Siefert, N.S.* Dewatering of High Salinity Brines 625 by Osmotically Assisted Reverse Osmosis. Proceedings of the 2017 AWWA-AMTA Membrane 626 Technology Conference and Exposition. February 13-17, 2017, Long Beach, CA, USA



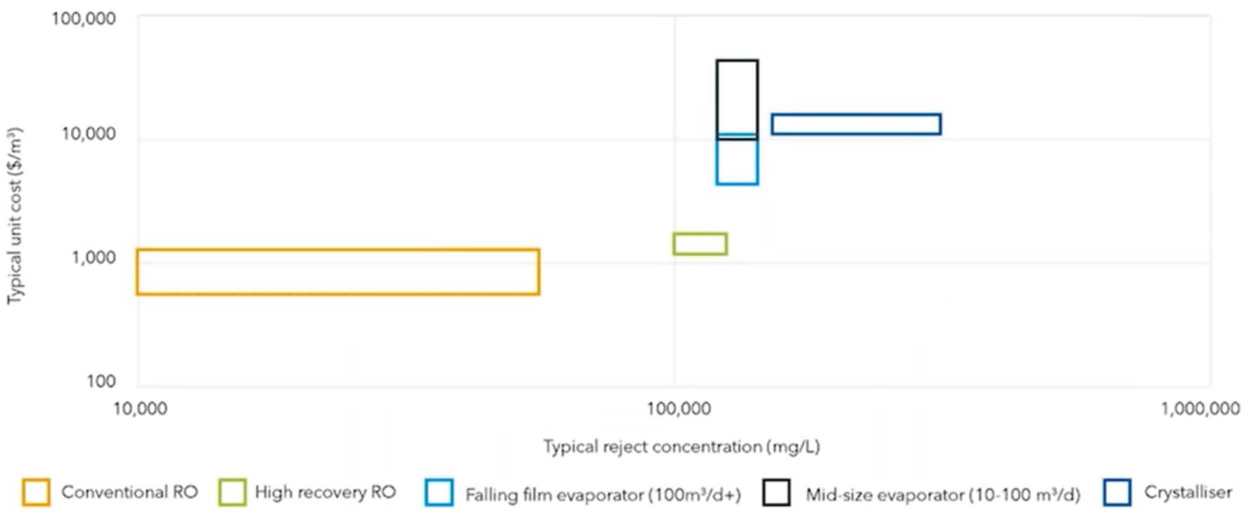
Just a Few Years Ago …

GWI | DESALDATA

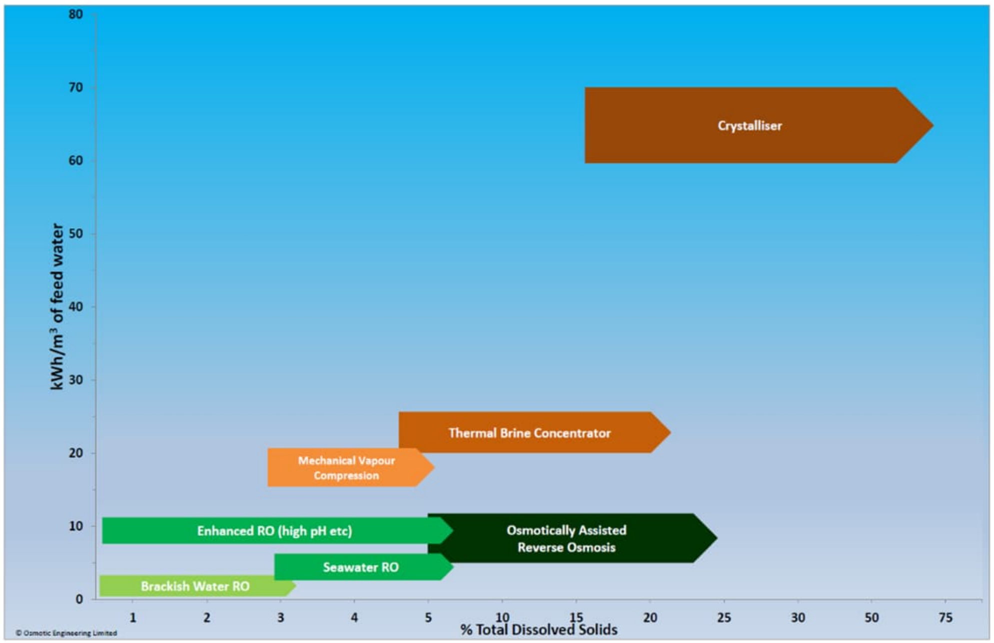
Assessing the cost of brine concentration

As the concentration of a solution increases, the energy required to separate the remaining free water rises exponentially. This means that the final step to ZLD (crystallisation) can represent the majority of a ZLD system's total energy consumption.

Conventional brine concentration technologies rely on thermal processes, but new reverse osmosis (RO) configurations are able to produce brine rejects of up to 175,000mg/l. Membrane processes do not require a phase change, which reduces both costs and operational complexity.

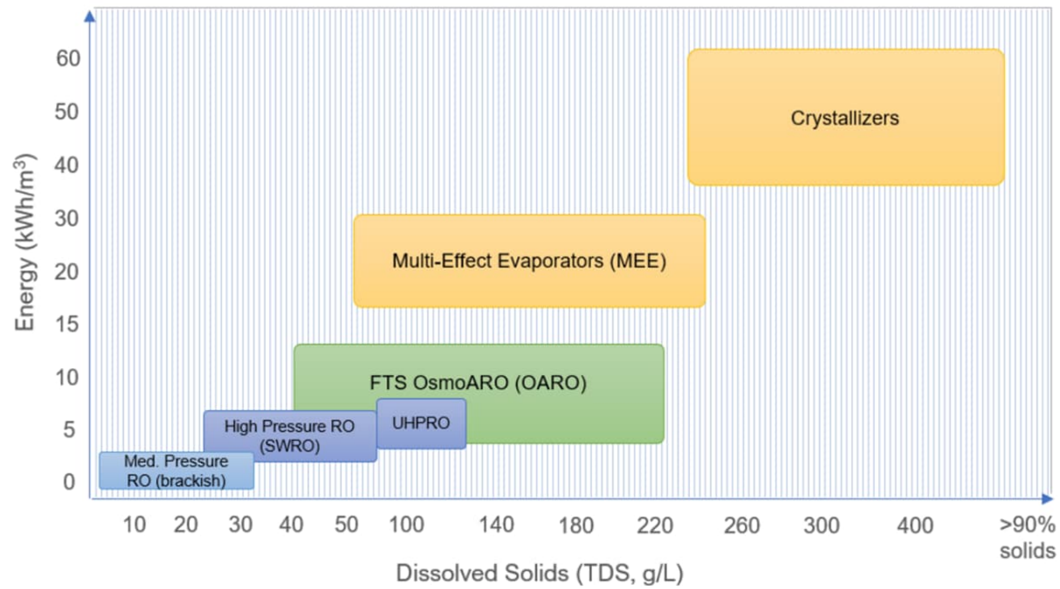


Why OARO? → Brine Disposal is $$$



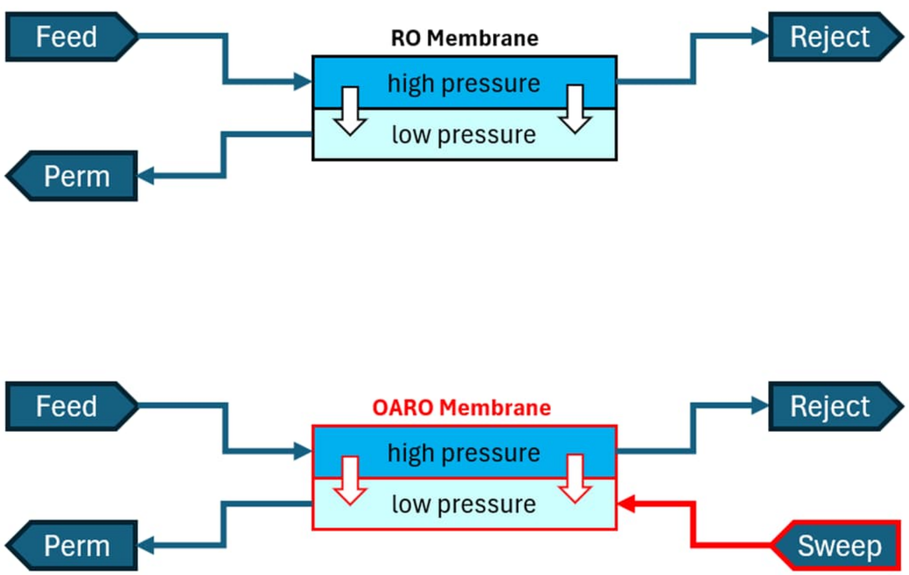
Brine concentration processes

https://www.osmotic-engineering.com/brine-concentration



- https://ftsh2o.com/wp-content/uploads/2021/02/FTS-Industrial-Brochure_FTSIND-1020.pdf

What is OARO (Osmotically Assisted RO)?

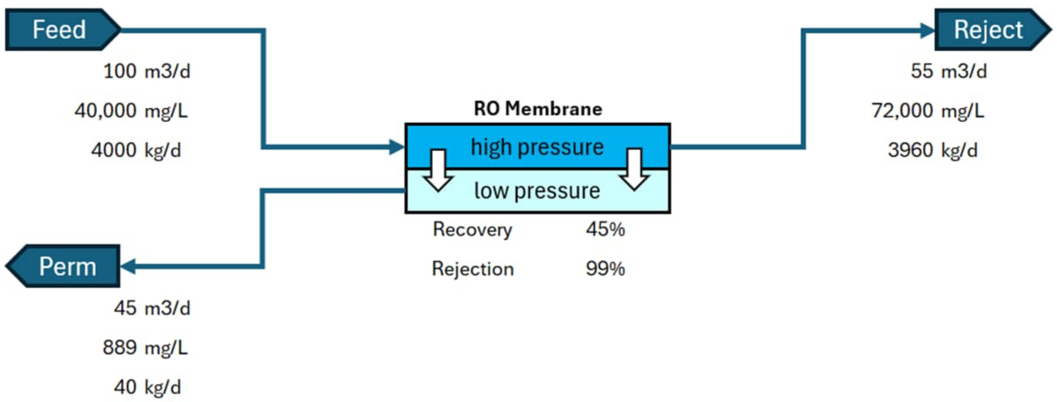


- RO used to purify water
- OARO used to concentrate brine

- RO has three streams
- OARO has four streams

- Sweep is added to decrease the Osmotic Pressure

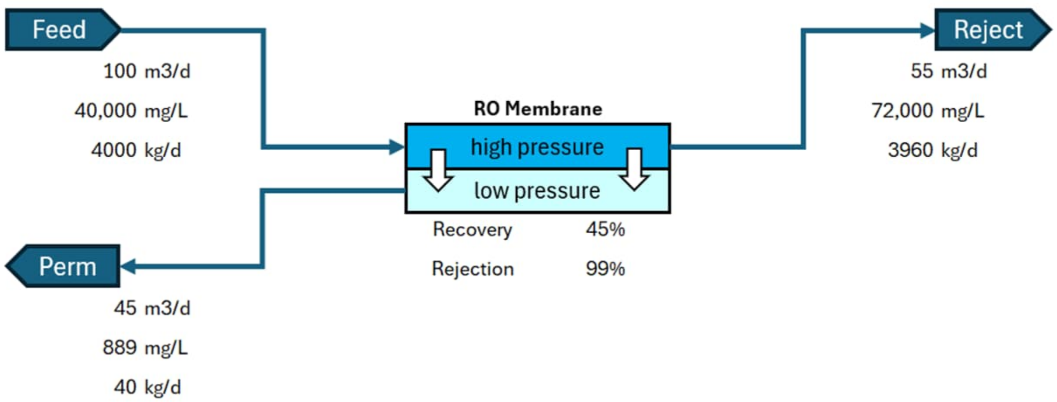
SWRO vs OARO (Osmotically Assisted RO)



RO is limited by the osmotic pressure …
related to the difference in the TDS

(72+40)/2 - 0.9 = 55 g/L

SWRO vs OARO (Osmotically Assisted RO)



RO is limited by the osmotic pressure … related to the difference in the TDS

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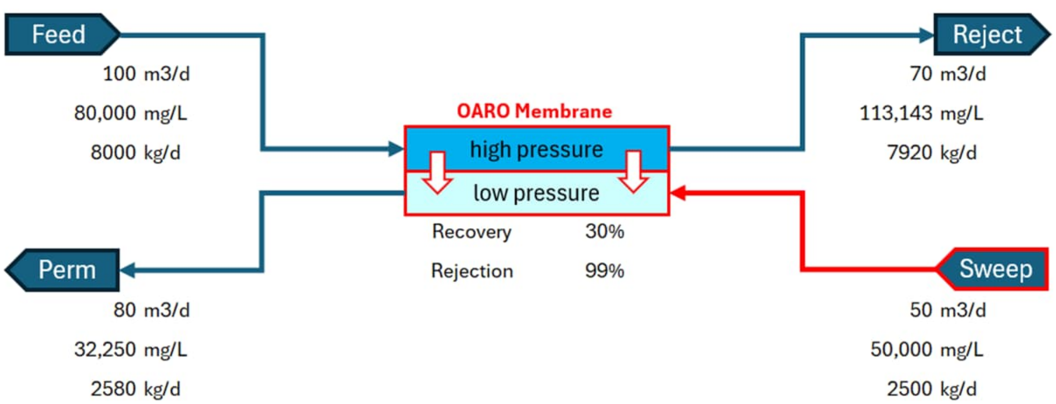
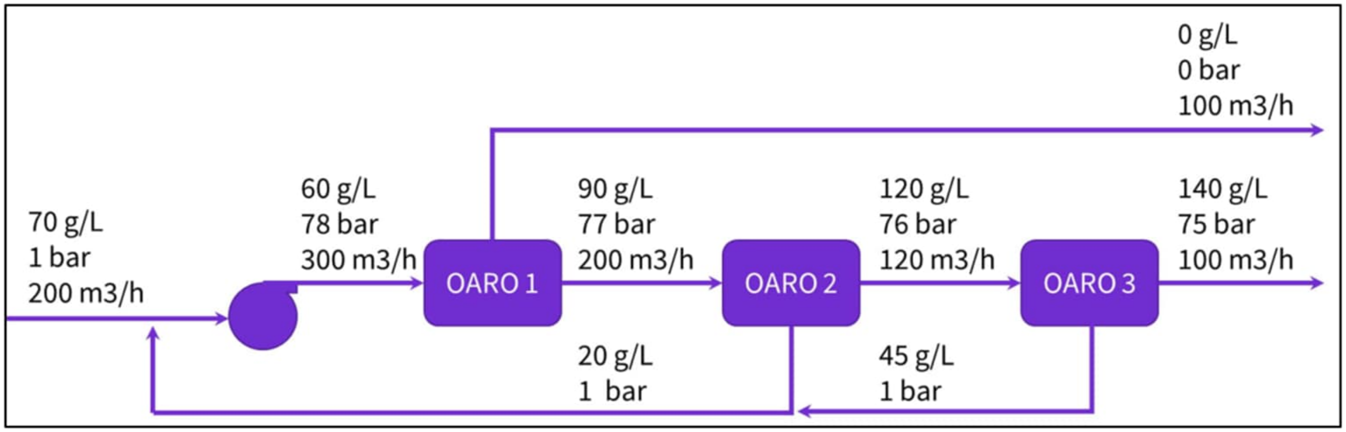


OARO is also limited by the osmotic pressure …

(113+80)/2 - (50+32)/2 = 55 g/L

OARO by Gradiant

Osmotically-Assisted RO Process



Ref: Stover. R. and Boyd, M. (2023). Don't Throw that Brine Away! Desalinate it with OARO, IWC 23-62

- Several Patents (2016)
- CFRO (Counter Flow RO)
- Full Scale OARO plant operating in Saudi Arabia since ???
- Several papers at IWC 23-62, 22-??

INTERNATIONAL WATER CONFERENCE

SAWACO (Water Utility in Saudi Arabia)

BRINE, NOT WASTE: UNLOCKING BRINE'S POTENTIAL WITH SAWACO'S CFRO SOLUTION. By Eng. Nizar Kammourie, CEO, SAWACO Water Group.

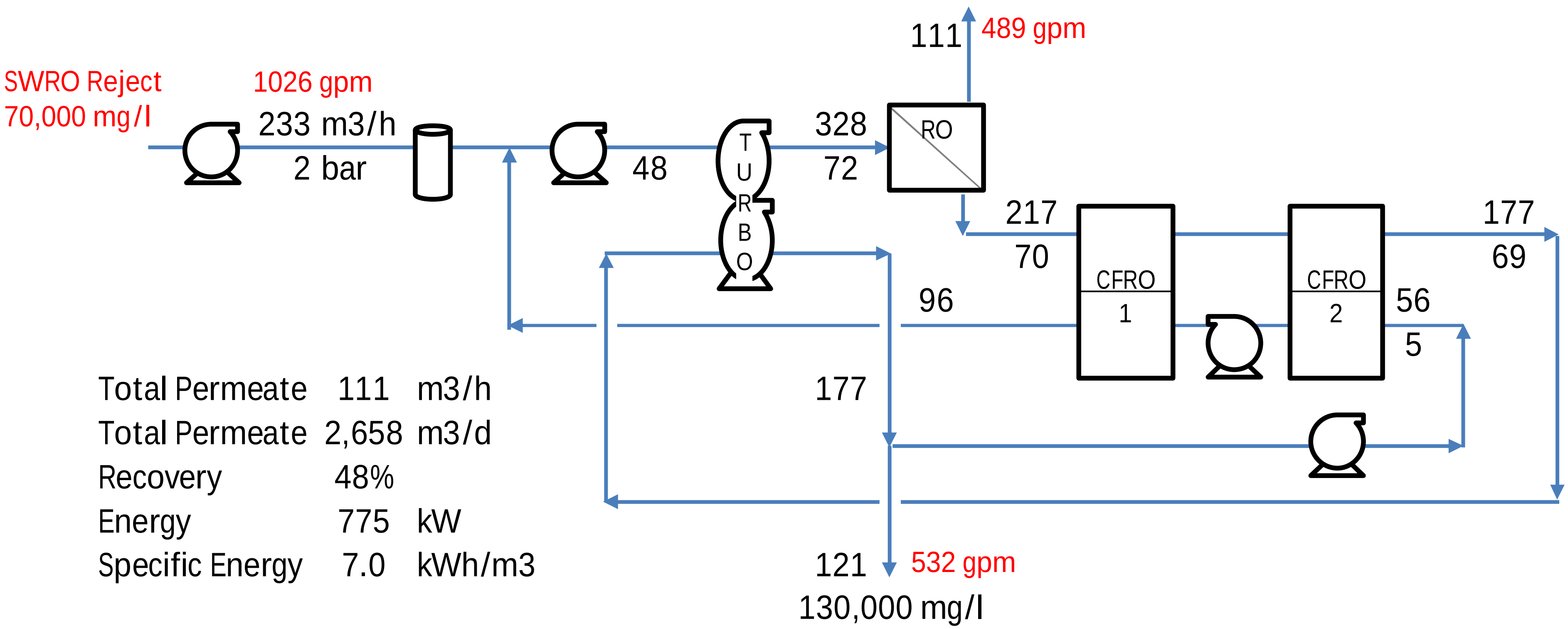
As the world faces the impending crisis of water scarcity, the demand for pioneering and efficient methods of producing fresh water is on the rise. The World Health Organization predicts that by 2025, half of the world's population will be experiencing water shortages due to the changing climate. This dire prediction has put the spotlight on the RO desalination process, which has the potential to meet the freshwater needs of entire countries.

SAWACO, a leading provider of potable water in Saudi Arabia, has collaborated with Gradiant to bring the new CFRO technology solution to seawater desalination. This innovative Cascade Flow Reverse Osmosis technology (CFRO) provides a sustainable approach to freshwater production.

For more details about CFRO Technology, please click this link..

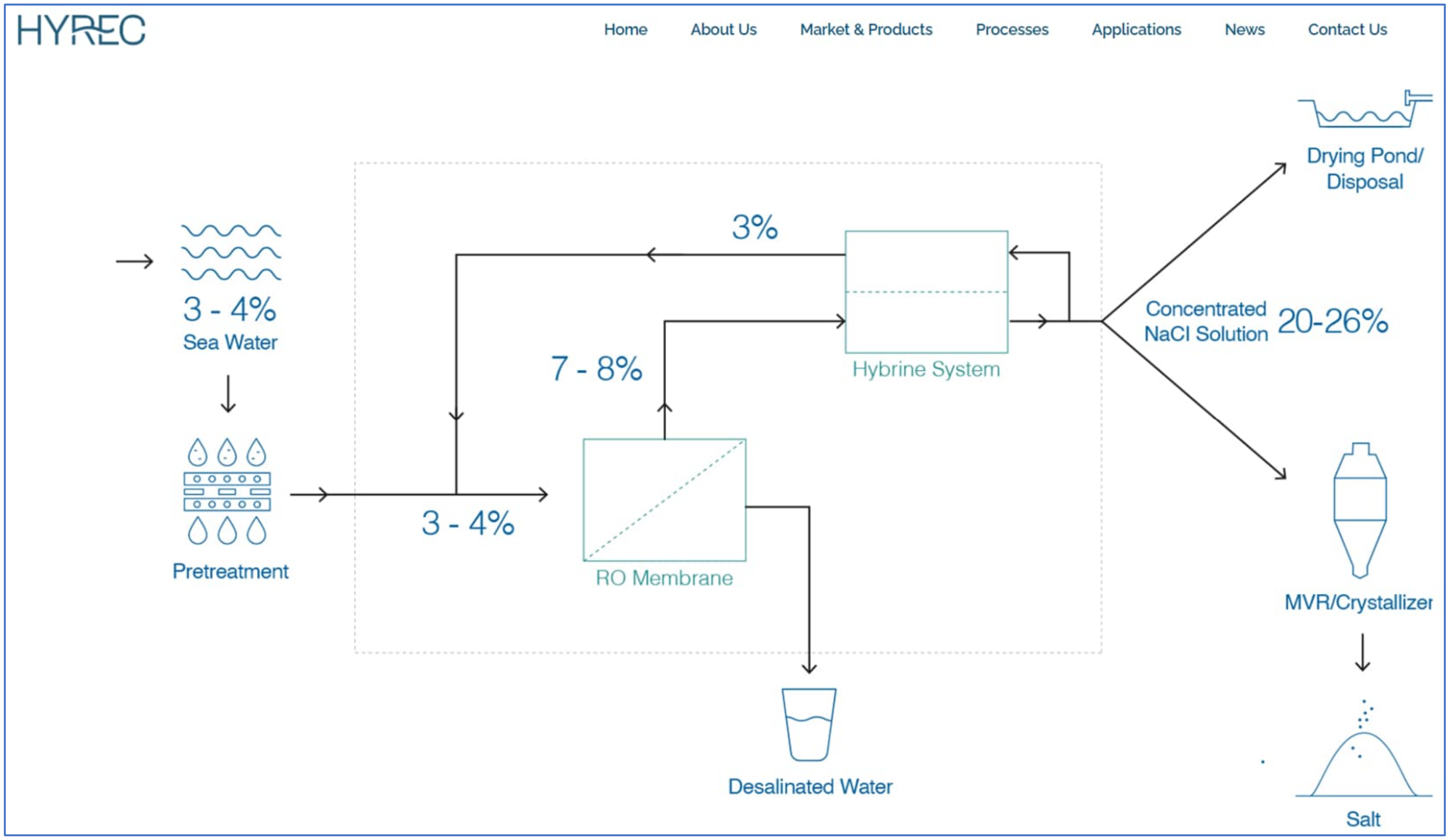
Ref. https://www.sawaco.com/Home/DisplayAllNews

Gradiant – SAWACO



Total Permeate	111	m3/h
Total Permeate	2,658	m3/d
Recovery	48%	
Energy	775	kW
Specific Energy	7.0	kWh/m3

OARO by HYREC

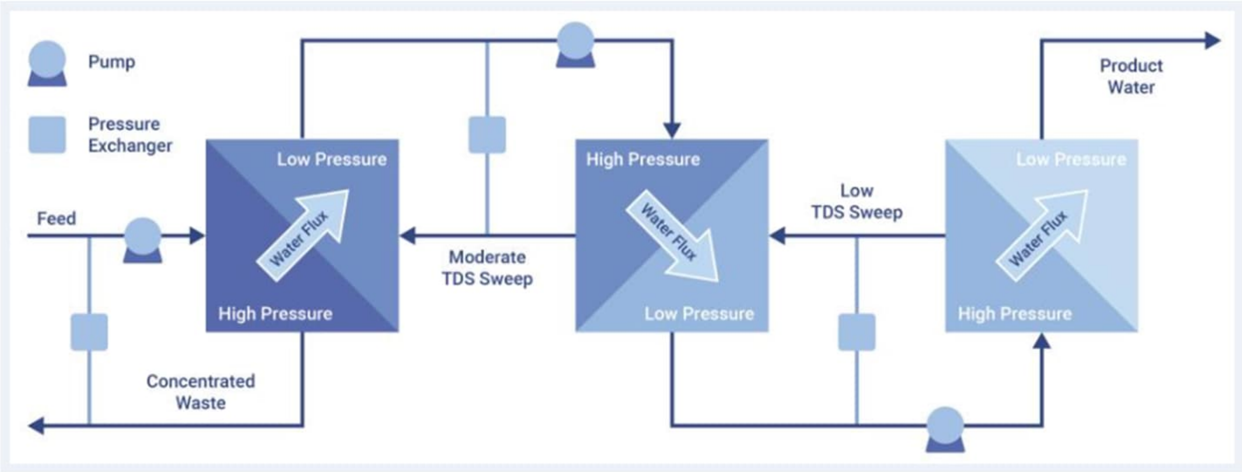


Hyrec-Maven

The first OARO Plant in the world is under construction in Indonesia to be completed by Q1 of 2023. The plant will produce 25,000 m3/day of desalinated water and 220,000 tons per year of food grade sea salt. Hyrec started working on this project in 2018.

ref: https://hyrec.com/processes/

OARO by Steritech



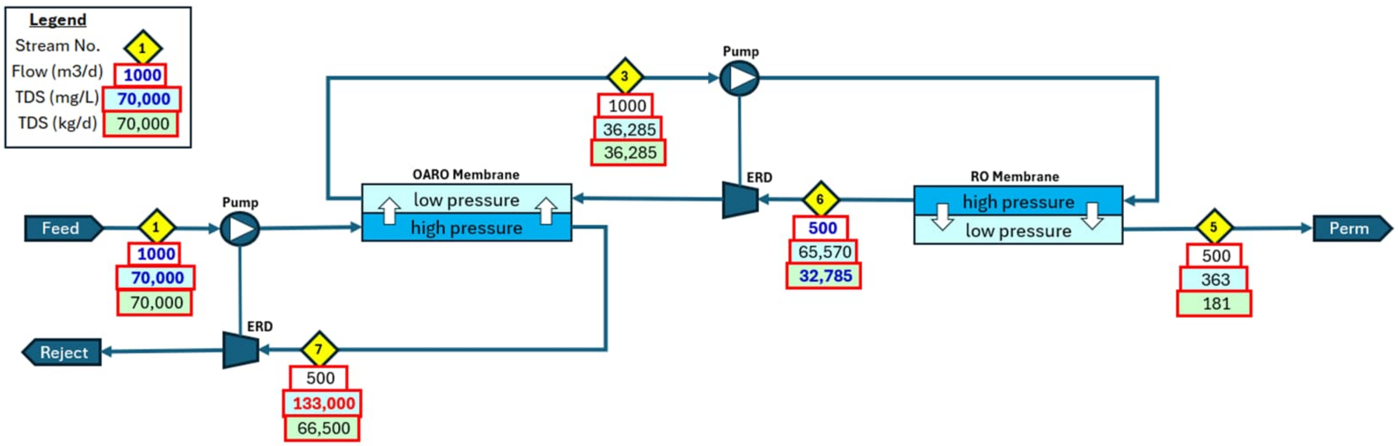
- Partnered with Aquatech
- Piloting in North America

https://www.sterlitech.com/blog/post/osmosis-assisted-reverse-osmosis-a-promising-brine-desalination-technology?srsltid=AfmBOooWkrvUPcG1M2GVbNu8cji0iMgPgZKaxEMNhqo3gRbjrQ8wlsaC

OARO by Steritech

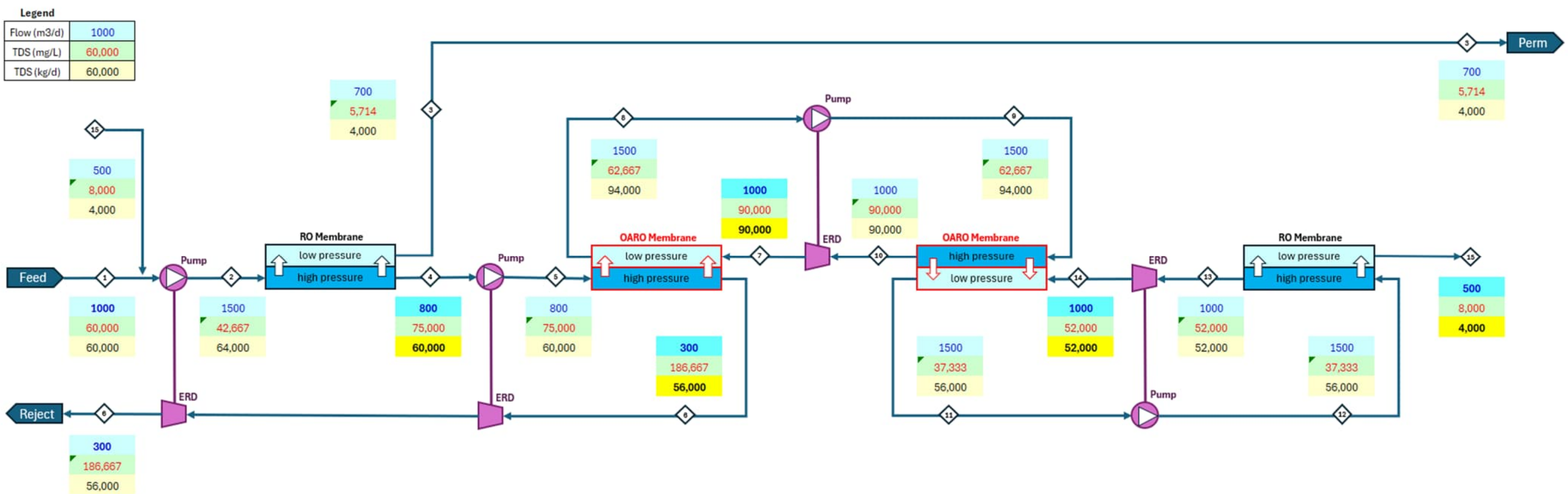
- https://ftsh2o.com/fluid-technology-solutions-fts-h2o-completes-delivery-of-innovative-osmoarotm-system-to-standard-lithium-ltd/

OARO Water / Mass Balance



Water/Mass Balance		1	2	3	4	5	6	7		
Stream		OARO Feed	OARO Flux	RO Feed	RO Flux	RO Perm	RO Reject / Sweep	OARO Reject	Total In	Total Out
Flow	m3/d	1000	500	1000	500	500	500	500	1000	1000
TDS	mg/L	70,000	7,000	36,285	363	363	65,570	133,000		
TDS	kg/d	70,000	3,500	36,285	181	181	32,785	66,500	70,000	66,681
Recovery			50%		50%					
Rejection			90%		99%		Balance			
Ave Feed/Reject TDS			101,500		50,928		500			
Ave Perm/Sweep TDS			50,928		363		72,207			
Ave Difference in TDS			50,573		50,565		36,104			

OARO Water / Mass Balance



Balance	
Total In	1000
Total Out	1000
Total In	60,000
Total Out	60,000

	RO Membrane	OARO Membrane	OARO Membrane	RO Membrane
Recovery	47%	63%	33%	33%
Rejection (M)	93.75%	93.33%	95.74%	92.86%
Rejection (C)	86.61%	89.33%	87.23%	78.57%
Flux (Flow)	700	500	500	500
Flux (TDS)	5,714	8,000	8,000	8,000
Flux (Mass)	4,000	4,000	4,000	4,000
HP TDS	58,833	130,833	76,333	44,667
LP TDS	5,714	76,333	44,667	8,000
Diff TDS	53,119	54,500	31,667	36,667
Osmotic P	1,062	1,090	633	733
Pump P	1,262	1,290	833	933

Results of a Recent Study: UHPRO vs. OARO

Recovery, Product Quality and Pretreatment

- OARO systems achieve significantly higher recovery but may require more intensive pretreatment and are challenged to meet product water requirements

Parameter	Goal/Criterion	UP-RO		OARO		
		Dupont	Hydranautics	FTSH2O	Hyrec	Gradiant
No. of OARO stages	--	--	--	7	4	7
Recovery, %	Maximize	59.4	61.3	78.7	79.6	75.9
Brine TDS, g/L	Maximize	114	125	230	230	247
Product TDS, mg/L	≤400	18	63	9	<400	66
Product Boron, mg/L	≤1.0	0.5	0.7	Not provided		1.3
Pretreatment	--	GMF or UF		UF Only		GMF or UF

AMTA

Ops Complexity, Technology and Safety Risk

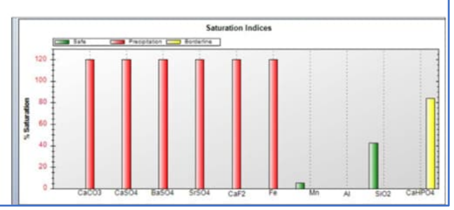
- OARO systems have higher operational complexity and greater technical risk (limited full-scale systems)
- UHP-RO systems represent greater safety risk (greater operating pressure in UHP stage)
- OARO systems are proprietary; dependent on a single supplier

Parameter	UHP-RO	OARO
Operational Complexity	Low to Moderate	High
Technology Risk	Low to Moderate	High
Safety Risk	Higher	Lower

AMTA

OARO Brine Precipitation Management

- OARO use has been focused on treating low-scaling brines
  - Brine mining concentrating monovalent rich streams produced by nanofiltration
  - Lithium concentration
- In OARO brine (~80% recovery), several salts are supersaturated
- Brine must be stored for up to 5 days prior to barging
- AWC tested candidate scale inhibitors on the simulated brine
  - Successfully ID'd a product that inhibited for 48 hours
  - At high dose, possibly could inhibit for required 5 days of storage
  - **Considered a major process risk**



Summary

- Unique project requirements necessitated the need to maximize desalination system recovery
- UHP-RO and OARO systems were evaluated for this purpose
- Although OARO systems can achieve significantly higher recoveries, other factors over-ride their consideration for this project, including space requirements, technology maturity and concerns meeting product quality
- UHP-RO recommended for implementation
- Inhibition of mineral precipitation during brine storage could be a significant issue; exacerbated by OARO increased recovery

AMTA

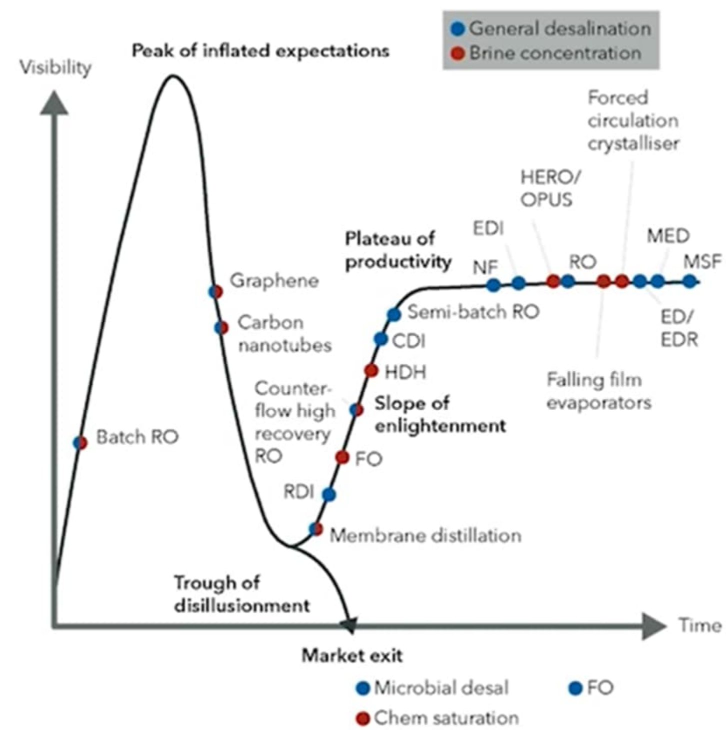
ref: AMTA 2024 J. Lozier

GWI | DESALDATA

Overview

- This schematic of a technology's journey towards commercialisation charts the initial excitement that surrounds a new technology, followed by disillusionment as practical difficulties set in, before a final move towards commercialisation and mainstream acceptance.
- Brine management is currently a key driver of adoption. Almost all of the technologies making the slow ascent to mainstream use are primarily used in brine concentration, with the notable exception of semi-batch reverse osmosis.
- The time needed to create reliable and affordable manufacturing methods for materials such as graphene and carbon nanotubes, means that these are among the slowest technologies to mature. However, 'operational R&D' such as semi-batch or counter-flow reverse osmosis system configurations are likely to take off much more quickly.

Commercialisation of new technologies in desalination & brine concentration




KEEP
CALM
AND
REUSE
WATER

INDUSTRIAL WATER REUSE

LESSONS LEARNED

IWC 24 - W03

Case Study

Who: Navajo Refining Co. (NRC) (100,000 bbl/d complex)
When: 2015 Design, 2016 Startup
Where: Artesia New Mexico … a very arid region

Why Water Reuse:

- Water scarcity → Site needed to improve water footprint
- Pressure to become a ZLD site → Wastewater was either irrigated onsite (high TDS), sent to POTW (high COD) or injected into a disposal well (hazardous)
- Regulatory pressure to stop irrigation → Disposal options were complex/costly

Challenges for Water Reuse:

- Groundwater supply was high in TDS, silica and hardness
- Existing well water RO system was struggling

2017 Paper Selected "Best of IWC"

IWC 17-18

A Unique High Recovery Secondary RO to Resolve Refinery Source Water and Brine Disposal Issues

ED GREENWOOD, P.ENG.
Amec Foster Wheeler
Cambridge, Ontario

SCOTT DENTON
The HollyFrontier Companies
Artesia, New Mexico

JOHN CHRISTIANSEN, P.E.
Amec Foster Wheeler
Houston, Texas

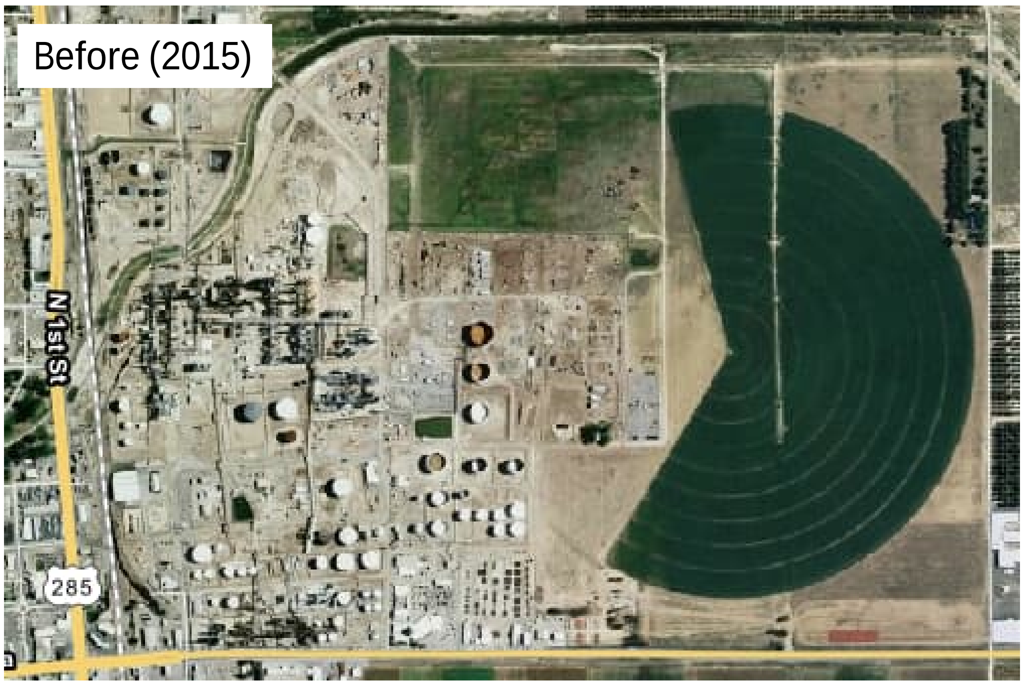
DAN KWIECINSKI, P.E.
Amec Foster Wheeler
Albuquerque, New Mexico

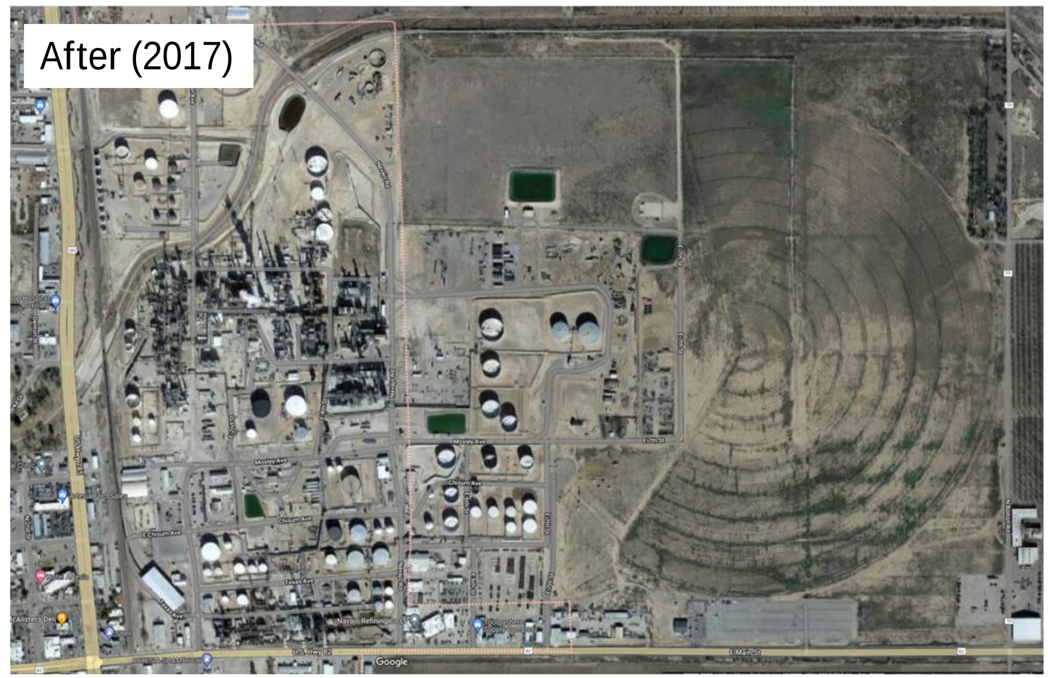
ROBERT KIMBALL, P.E.
Amec Foster Wheeler
Denver, Colorado

Abstract: Wood Environment and Infrastructure designed and constructed a unique high recovery Secondary RO system at a Refinery in New Mexico to resolve source water and wastewater disposal limitations. The new system is directly coupled to the Primary RO System and operates beyond the solubility limits for Silica and Calcium Sulfate by using a unique high recovery three stage array with both permeate and concentrate recycle loops to optimize performance.

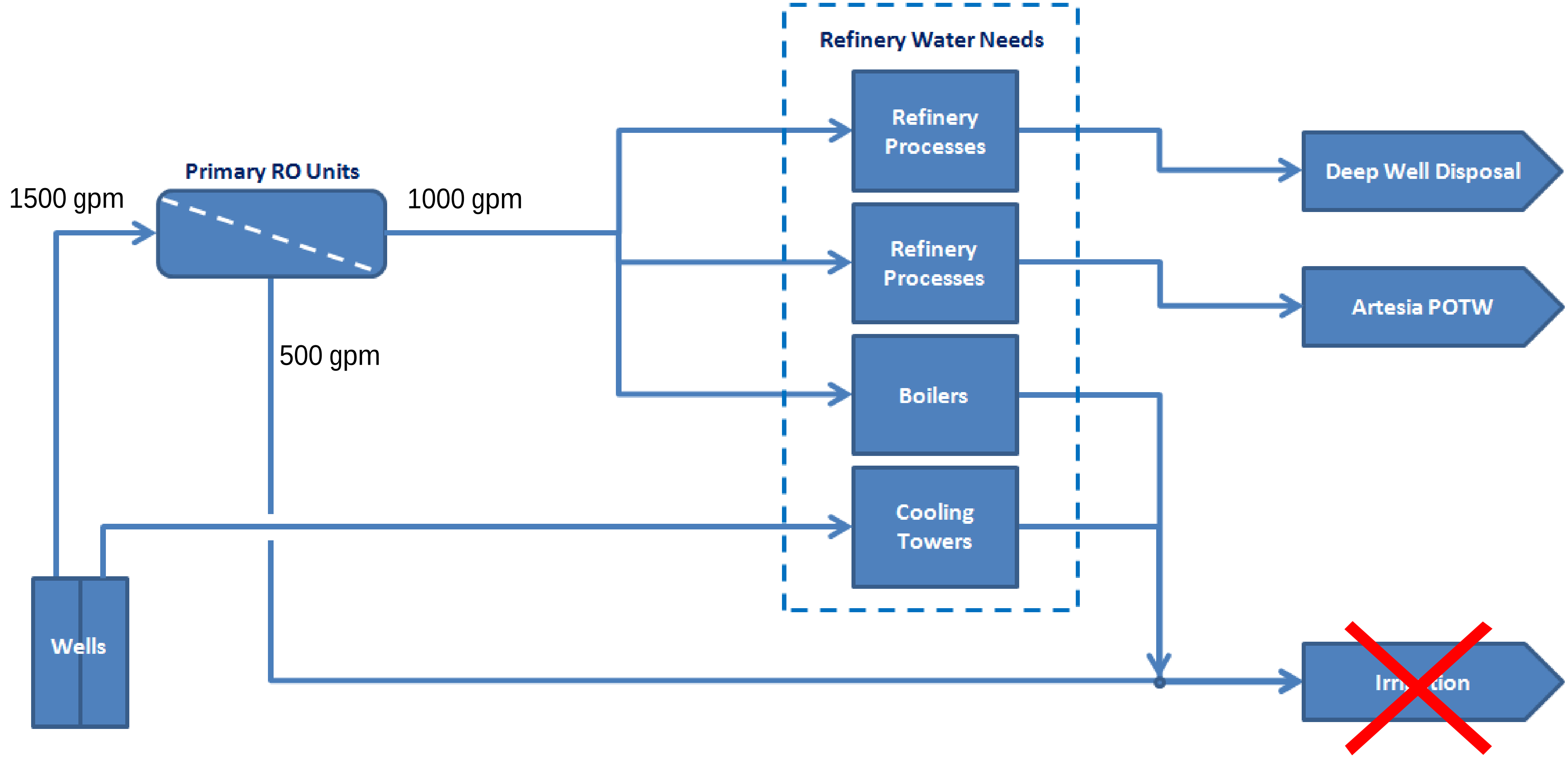
Wastewater Disposal is Complex

- Salty wastewater (RO Reject) was irrigated onsite
- Oily wastewater is treated by Refinery's WWTP then discharged to the City
- Other more challenging wastewaters are pumped into deep disposal wells

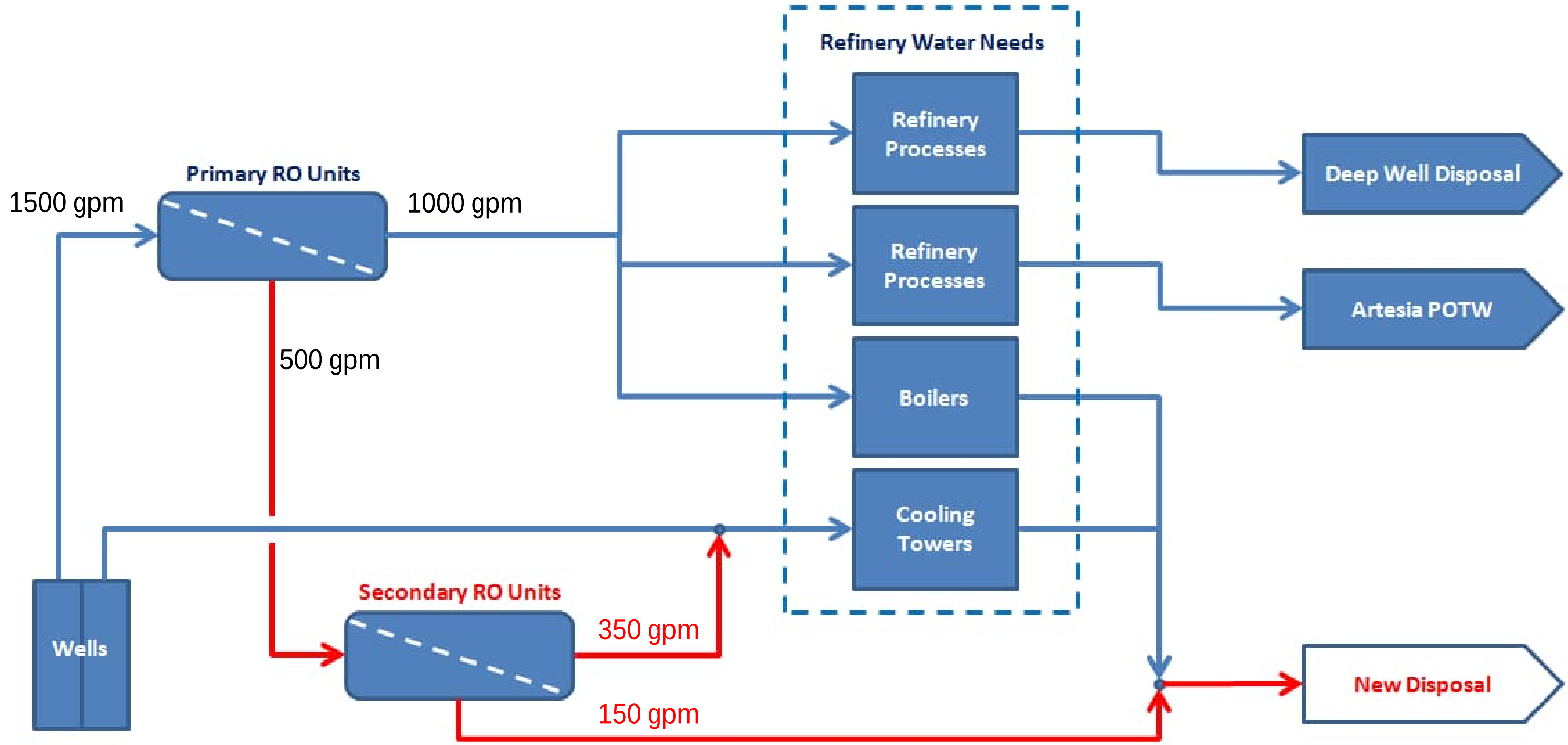




Water Balance



The Solution



Design Basis – Integration with the Existing Equipment

- Recovery of the Primary RO limited to between 60% – 75%
- Fluxrates were ok, however, feed flows were low and stages were unbalanced with respect to concentration polarization
- Pretreatment of the Feed was limited (pH Control)
- O&M issues with corrosion of the permeate piping
- Post treatment of the Permeate was limited (FDD)

Overall the performance was acceptable
… because the RO Reject was irrigated

Site Layout

Existing Primary RO Building

New Primary RO Building

Hydrocarbon Tank

Hazardous Location
Class 1, Div. 1, Group D

Water Quality

Primary RO Reject (Secondary RO Feed)			
Flow	gpm	500	
TDS	mg/L	4864	
Calcium	mg/L	692	High
Magnesium	mg/L	219	High
Sodium	mg/L	424	
Bicarbonate	mg/L	1027	High
Chloride	mg/L	454	
Sulfate	mg/L	1963	High
Silica	mg/L	43	High
pH		7.8	

Obstacles for Treatment and Reuse

Understanding Scaling

- Calcium Carbonate
- Calcium Sulfate
- Silica

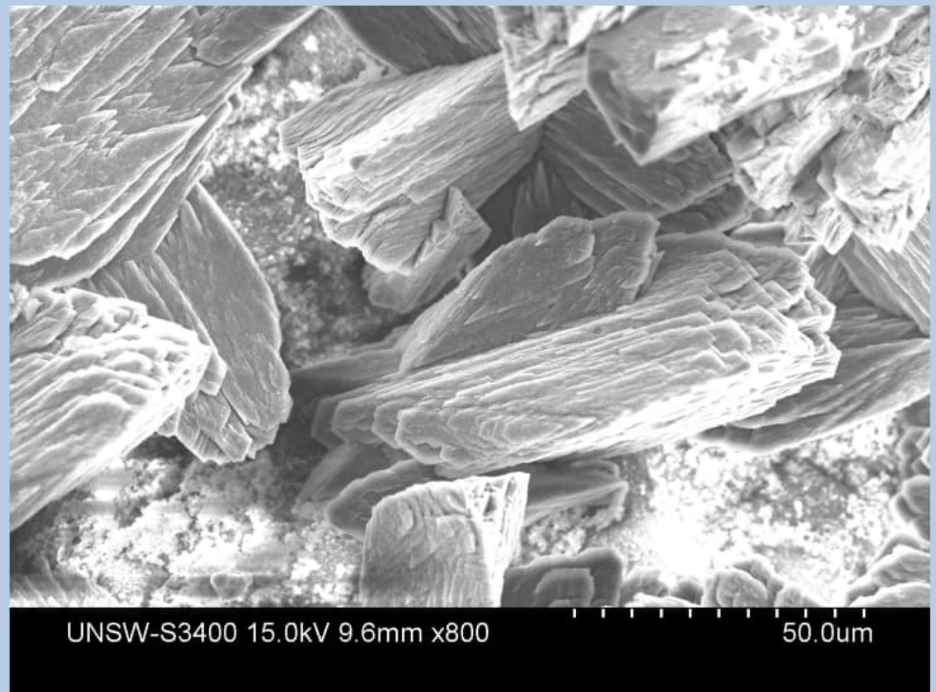
Calcium Carbonate Scaling

Effective methods of control:

- pH Adjustment
- Antiscalant addition

→ Adjust the pH until the Langlier Saturation Index (LSI) is negative. Shift equilibrium away from $CaCO_3$ precipitation

$Ca^{++} + HCO_3^- \leftrightarrow H^+ + CaCO_3$



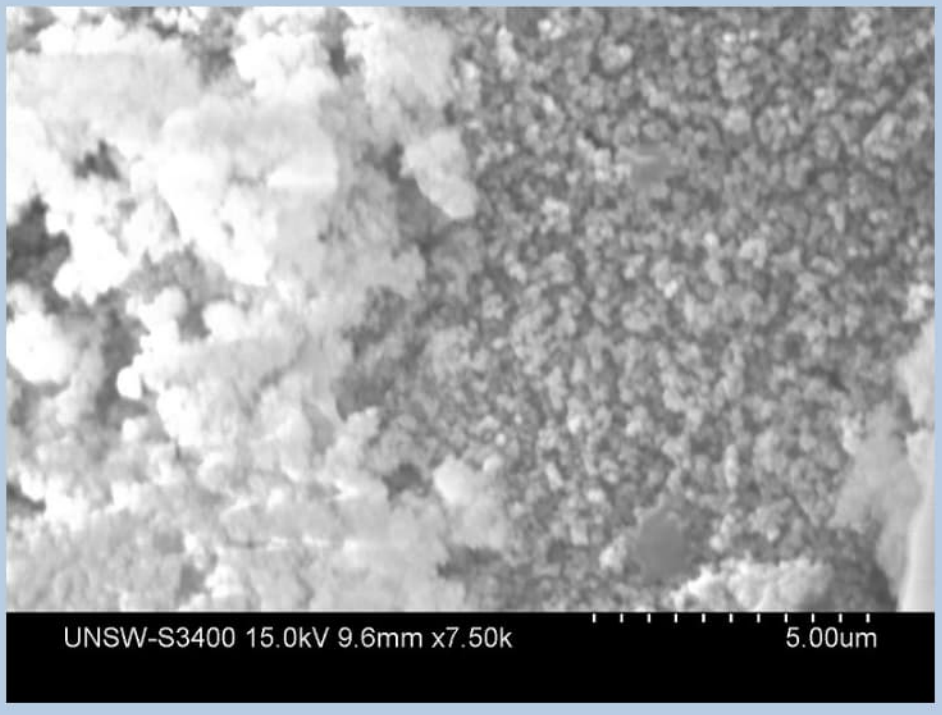
Rhomboidal calcium carbonate crystals with underlying silica fouling.

Silica Scaling

Silica is present in two forms:

- Non-reactive / Colloidal / Particulate
- Reactive / Soluble

→ Optimized Antiscalant selection and use



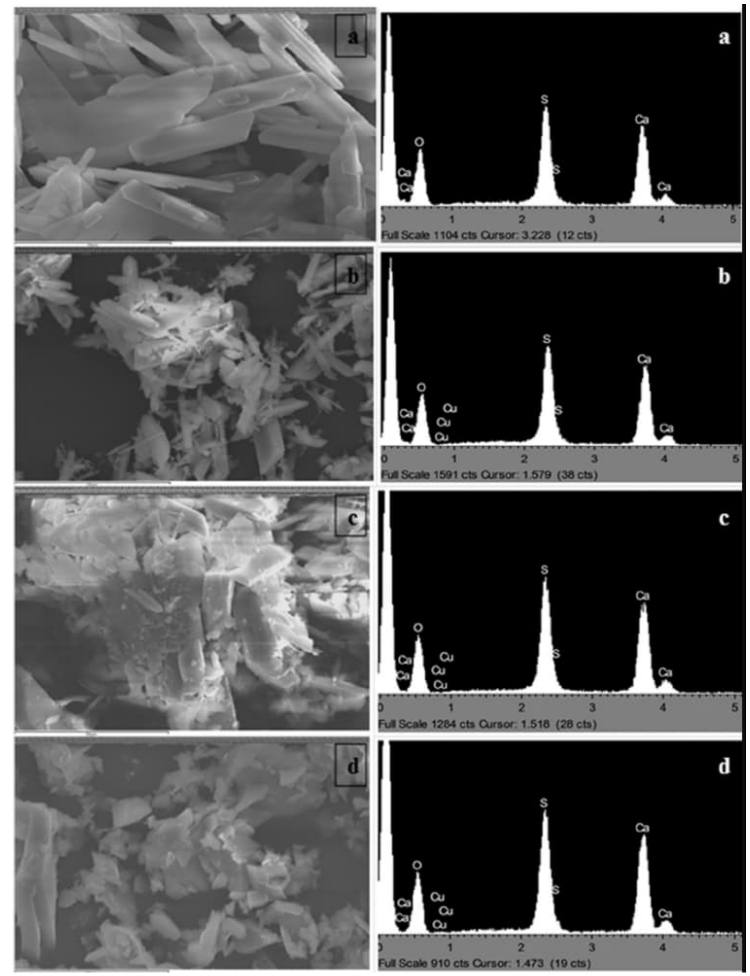
Silica fouling.

Calcium Sulfate Scaling

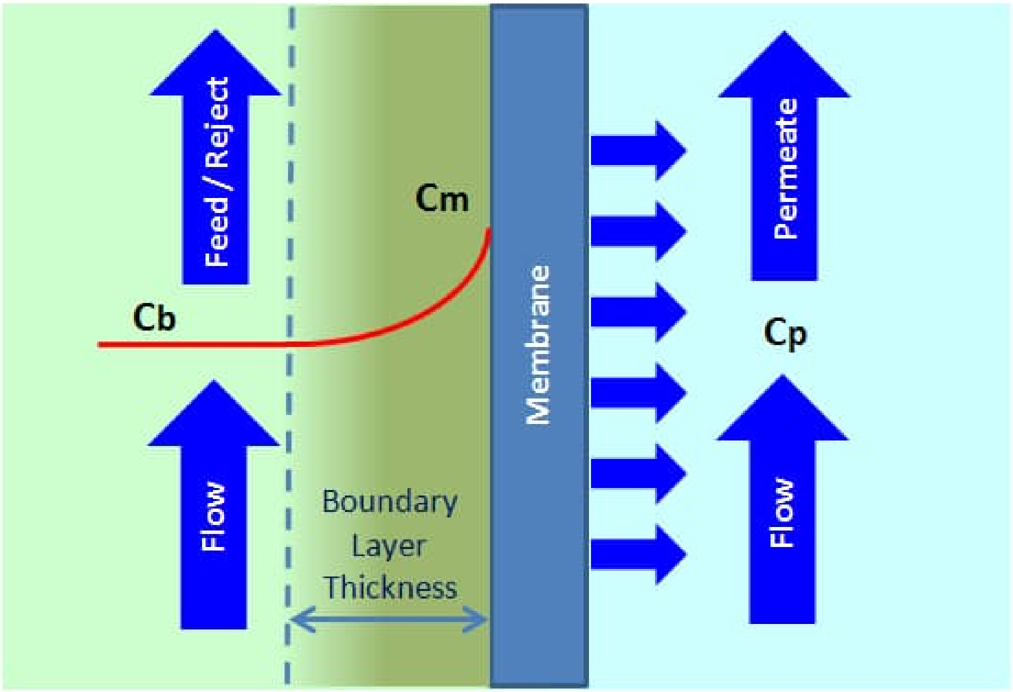
Background:

- Generally not pH dependent
- Antiscalants may have limited effectiveness
- Relatively slow rate of precipitation

→ Optimize design to minimize concentration polarization / maximize cross flow velocity



Issues with Concentration Polarization



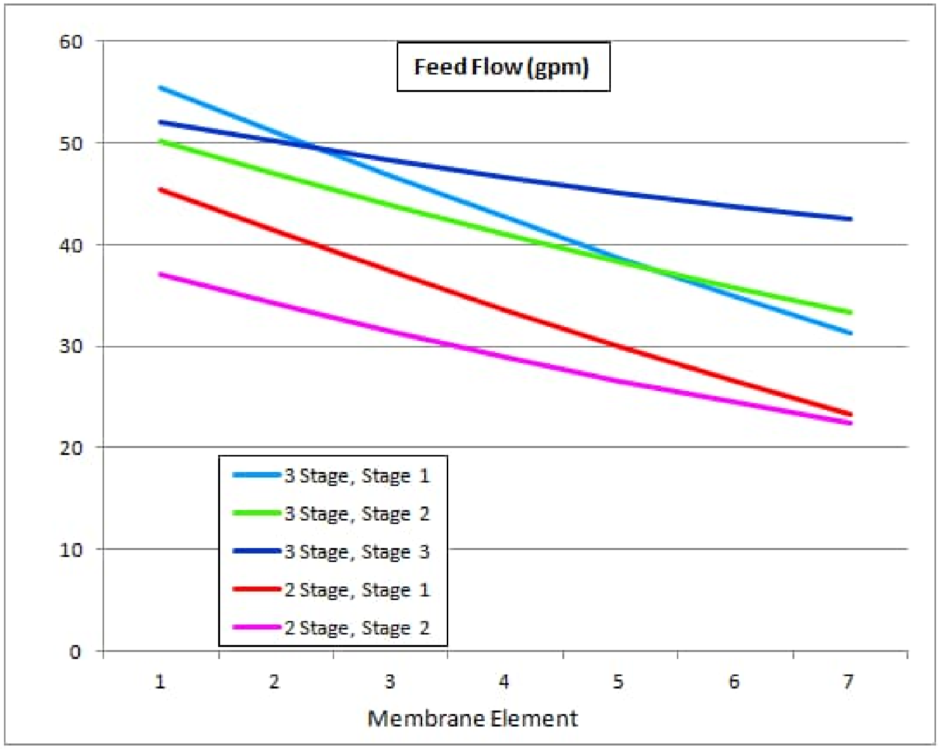
$$\text{Concentration Polarization} = \frac{Cm - Cp}{Cb - Cp}$$

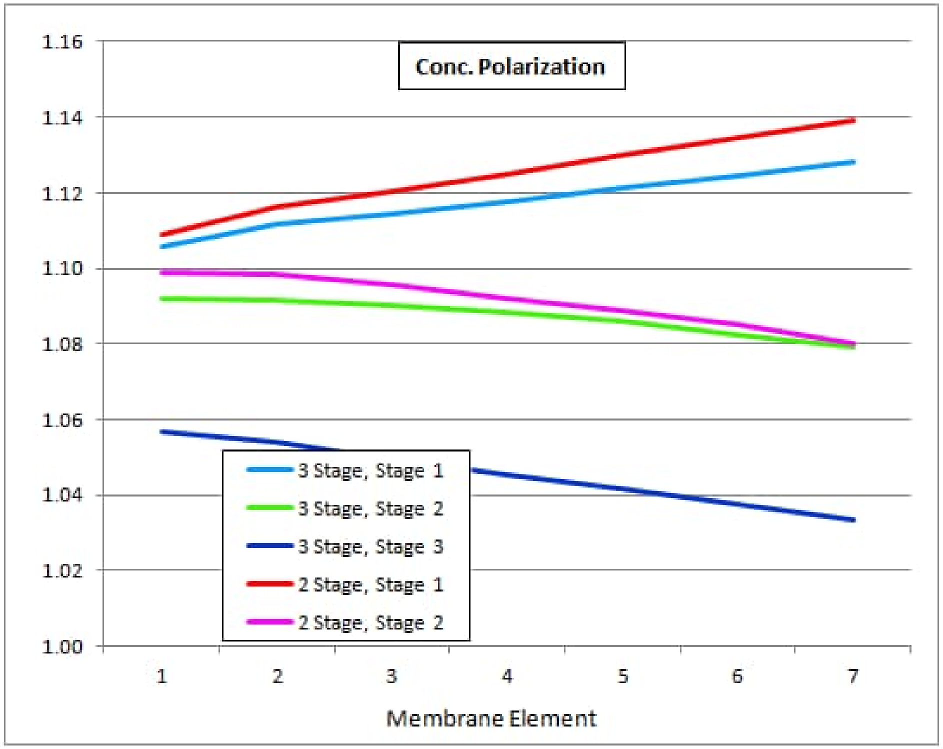
Cb = Solute Conc. in Bulk Solution
Cm = Solute Conc. at Membrane Surface
Cp = Solute Conc. in Permeate

Technology Selection

Options	Standard Brackish Water RO with 2 stages Standard Brackish Water RO with 3 stages High Efficency RO (HERO) Closed Circuit RO (CCRO) Counter Flow RO (CFRO)
Selection	Standard Brackish Water RO with 3 stages
Primary Reasons Why	Reliable Cost Effective In 2015 CCRO was less proven

Comparing Options (2 Stage vs. 3 Stage)





3 Stage RO Design Selection

- A robust three stage SRO system was added (PRO+SRO total 5 stages) with focus to minimize concentration polarization
- Automated feed pH control to control CaCO3 scaling
- Optimized membrane antiscalant to control Silica and CaSO4 scaling (PWT SpectraGuard)
- Low fouling membranes specifically selected for Navajo SRO → ESPA2-LD
- 34 mil feed spacer
  - Lower pressure drop
  - Greater resistance to colloidal fouling
  - Higher turbulence / Lower concentrate polarization

Chart 1: Flux and Delta P element comparison of 34-mil LD spacer to 28-mil spacer

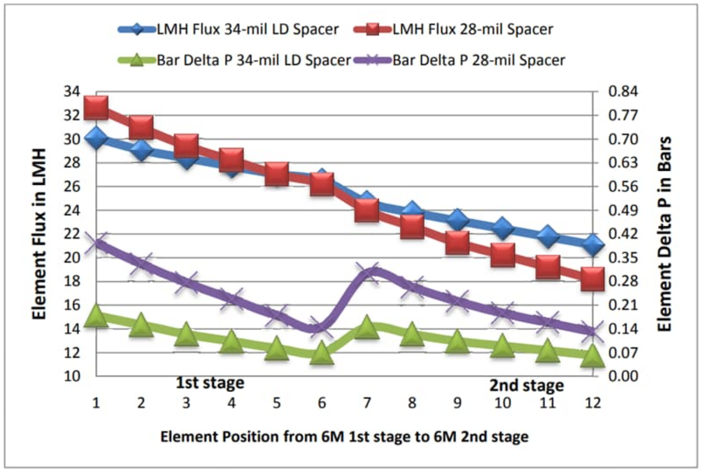
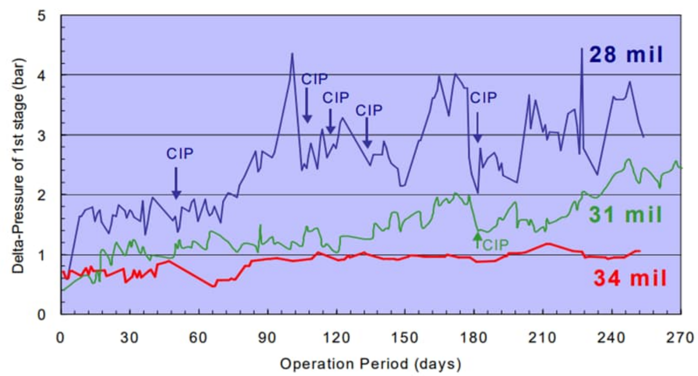
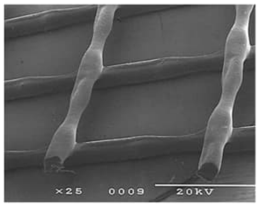


Chart 2: Colloidal Fouling CIP cleaning frequency for various size feed spacers



Photograph 1: LD Feed Spacer



Picture and Charts ref. paper by Bates, Bartels

3 Stage RO Design Selection

Custom RO Design Features (not included in standard RO designs)

- ► Permeate recycle for continuous operation and feed pressure balancing
- ► Concentrate recycle for recovery optimization
- ► Interstage flux balancing valves for optimization of transmembrane pressures and crossflow velocities
- ► Enhanced instrumentation and control features for monitoring interstage performance
- ► Fully-automated permeate flush sequence
- ► Fully-automated CIP system with temperature control
- ► Performance analysis and monitoring tools

Results – Water Reuse Project

Project Execution:	☑ On Budget ... ($6M)
	☒ On Schedule ... Delays with Permitting
Water Quality:	☑ Product water quality requirements
Challenges:	☑ RO scaling issues resolved with custom design approach
	☑ Wastewater flow for disposal to injection well reduced from 500 gpm to 150 gpm

Pictures

Startup Results

	SRO Reject	SRO Reject
Source File	SRO Design Basis	SRO Start-up Cardinal Labs
pH	7.5	7.5
Temp	25	25
TDS, mg/L	14123	7240
Ca, mg/L	2446	1120
K, mg/L	15	10
Mg, mg/L	744	408
Na, mg/L	596	455
Sr, mg/L		17.6
Cl, mg/L	1216	1050
CO_3, mg/L	0	0
HCO_3, mg/L	2697	646
F, mg/L	12	7
SO_4, mg/L	6558	4060
SiO_2, mg/L	170	115

Lessons Learned

- Robust Designs are difficult to procure if equipment buying decisions are based on low price – The best technical solution won't win a competitive bid
- Equipment vendors shy away from performance guarantees
- Cost reduction is a necessary task on every project. If a design feature that adds reliability also adds cost it is often not implemented.

Understand all the risks … and the options.

If you don't the result could be an unreliable (or under designed) system.

INTERNATIONAL WATER CONFERENCE

Questions?


KEEP
CALM
AND
REUSE
WATER

INDUSTRIAL WATER REUSE

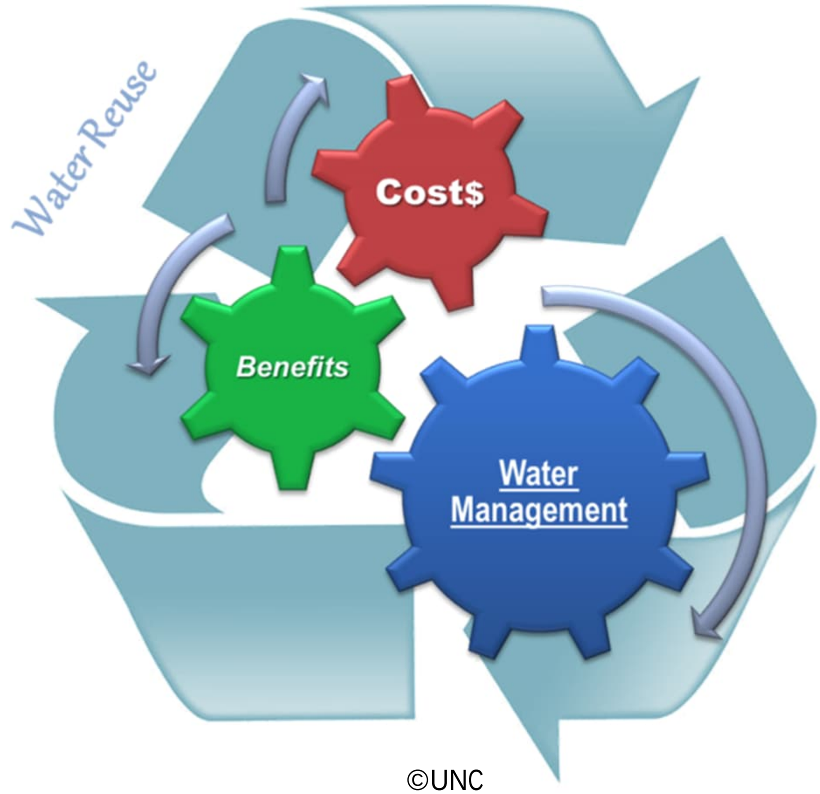
LESSONS LEARNED

IWC 24 - W03

Case Studies – Reuse Complications & Solutions

- Case Study #1:
  Cheese manufacturing facility implementing irrigation reuse

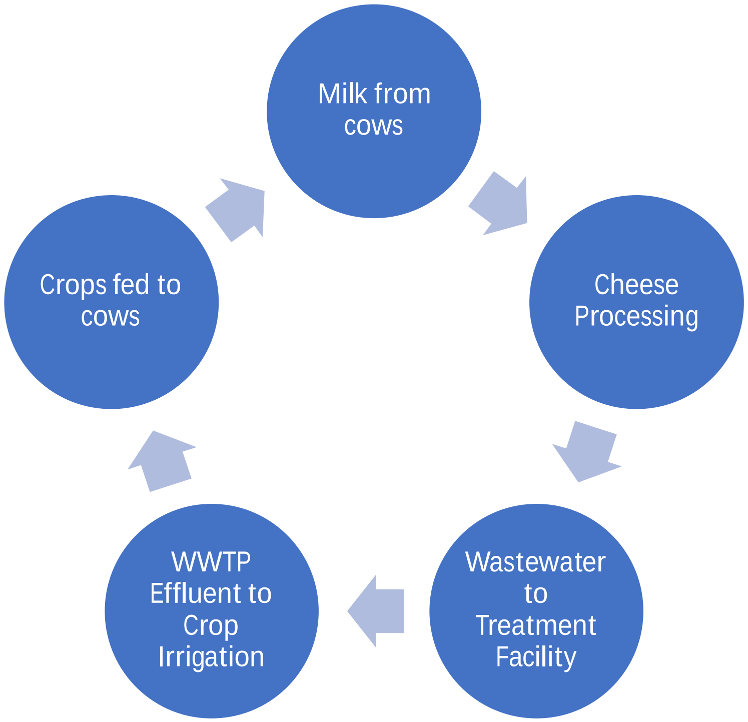
- Case Study #2:
  Sugar cane manufacturing facility implementing process reuse



©UNC

Case Study #1: Cheese Manufacturing Facility

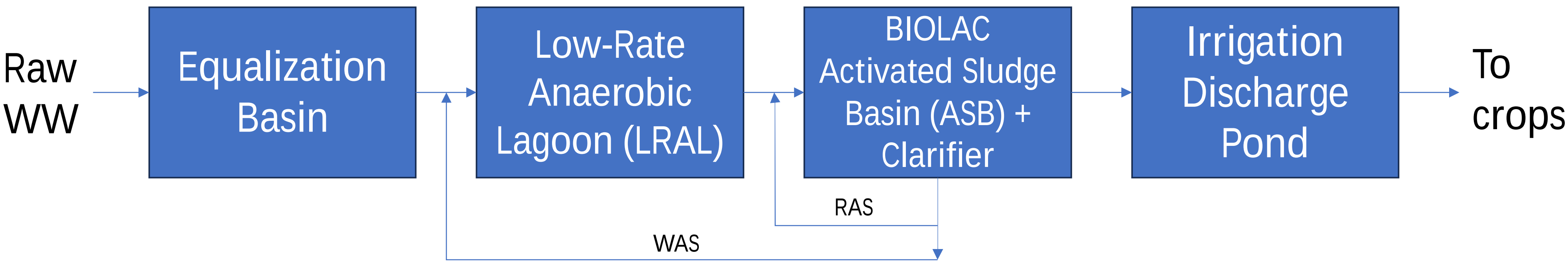
- Facility located in water scare area of Idaho
- Dairy can be a water-intensive process
- Getting pressure from stakeholders to reduce freshwater usage to achieve sustainability goals
- Facility decided to use treated process wastewater for irrigation of feed crops
- Installed new WWTP and discharged effluent for irrigation



Case Study #1 – Great idea, but…

- Effluent quality was not meeting discharge goals
- Poor effluent quality caused issues with:
  - Blinding off surface due to high BOD and high TSS loading resulting in stormwater issues (inadequate infiltration)
  - Odor issues – formal complaints from neighbors
  - Nitrate concentration increasing in the groundwater
- So, what went wrong?

Case Study #1 – Let's take a closer look



Parameter	RAW WW	LRAL Effluent	ASB + Clarifier Effluent	Target Effluent
Flow (MGD)	1.4			
COD (mg/L)	5,140	1,413	100	25
TSS (mg/L)	1,000	605	80	25
Nitrate (mg/L as N)	-	200	180	10

Case Study #1 – Evaluation of existing WWTP

- Problem #1: Variable water quality sent to LRAL
  - Equalization Basin appears to have adequate volume for flow equalization
  - Minimal quality equalization due to significant short circuiting in basin due to close proximity of influent and effluent pipes
  - Insufficient water quality equalization resulted in variable pH and organic loading being sent to LRAL

Recommendations:

- Relocation of effluent piping in EQ Basin
- Addition of aerators in EQ Basin to provide adequate mixing

Case Study #1 – Evaluation of existing WWTP

- Problem #2: No sludge wasting from system
  - The LRAL was designed to have only manual campaign style sludge removal (expected annually)
  - The system generated more sludge than expected when denitrification occurred in the BIOLAC. WAS was sent to the LRAL causing thermal stratification of sludge and upset conditions
  - Since no ability to waste sludge from the entire system, solids build up in the causing process upsets in LRAL and BIOLAC systems

Recommendations:

- Install a new sludge wasting and management system to remove WAS from BIOLAC and manage MLSS in BIOLAC

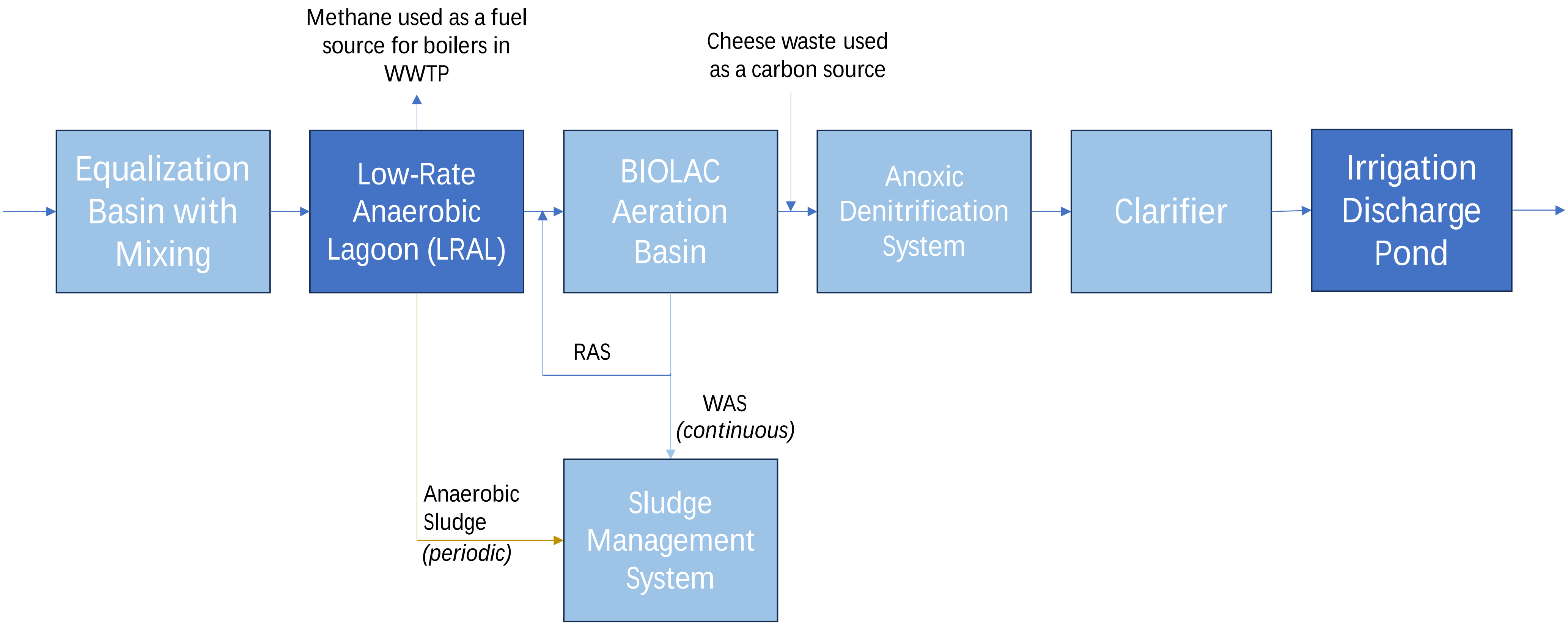
Case Study #1 – Evaluation of existing WWTP

- Problem #3: Insufficient capacity for denitrification and clarification
  - The BIOLAC system was designed to operate with aerobic and anoxic zones for complete denitrification however undersized for nitrogen load and complete denitrification did not occur in the BIOLAC system.
  - Insufficient area for denitrification in the BIOLAC system and an oversized clarifier caused denitrification to occur in the clarifier causing solids to lift resulting in TSS issues

Recommendations:

- Operate BIOLAC system aeration only ASB
- Addition of anoxic system after BIOLAC for complete denitrification
- Addition of new properly sized clarifier after denitrification for improved TSS removal

Case Study #1 – Updated Design

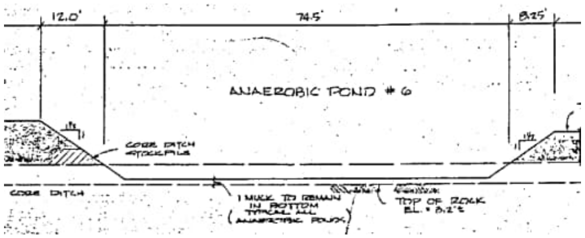


Case Study #1 – Lessons Learned

- Original system did not consider a conservative and complete design basis
- System saw higher values of BOD, TSS, and nitrogen
- Able to update the system to achieve the discharge goals and successfully reuse water
- Used waste stream from cheese manufacturing process and feed into denitrification step for carbon source – reuse waste stream and saved on chemical costs
- Captured methane from digestor to fuel WWTP boilers
- Upgraded system operational system 2009 and successfully achieving irrigation limits and helping achieve their sustainability goals

Case Study #2 – Sugar Cane Processing Facility

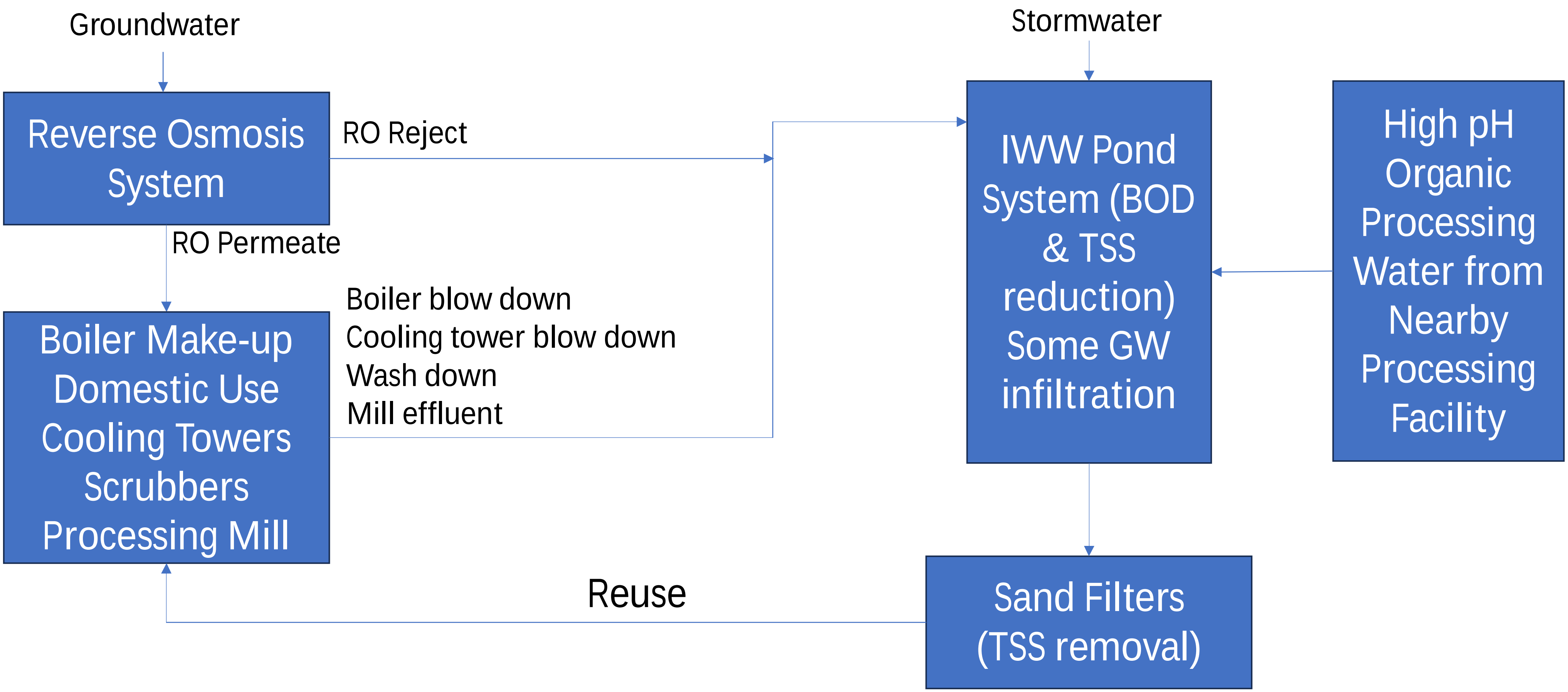
- Sugar cane processing facility located in Florida
- Surplus of water onsite to manage
- Driver for Reuse: Reduce fresh water supply and eliminate surface water discharge
- Original water management and reuse plan designed in 1970s
- Water usage has increased and surplus of water due to recent storm events

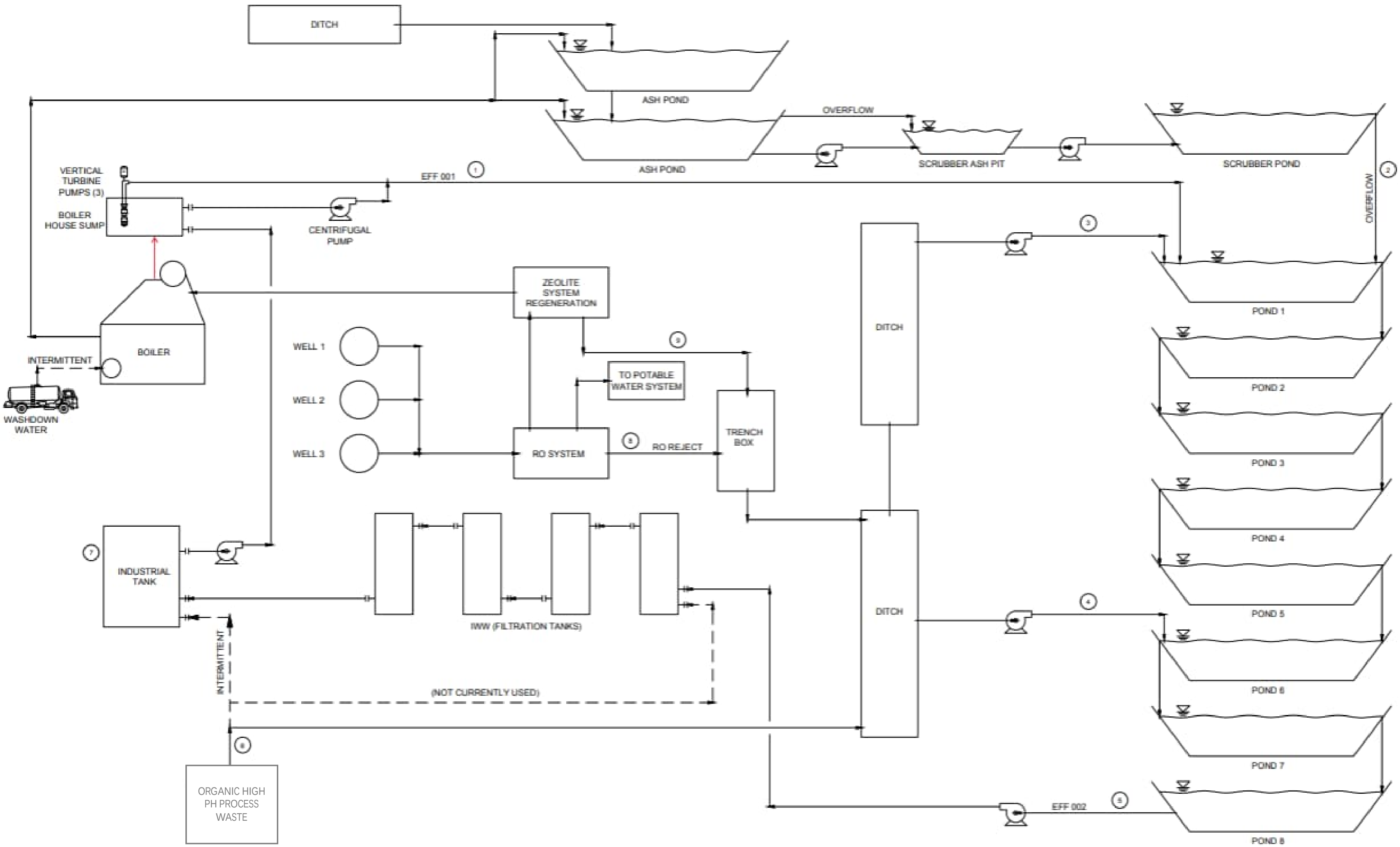


Case Study #2 – Water Reuse Evaluation

- Project Goals:
  - Continue to reuse water with no surface water discharge
  - Achieve groundwater limits at compliance well
  - Increase water management system to handle higher than 0.3 MGD (up to 3 MGD)
- Evaluation included:
  - Design basis development including site wide sampling and characterization over a 1-year period
  - Groundwater modeling
  - Alternatives analysis
  - Design for selected alternative (currently in design and permitting stage)

Case Study #2 – Water Reuse



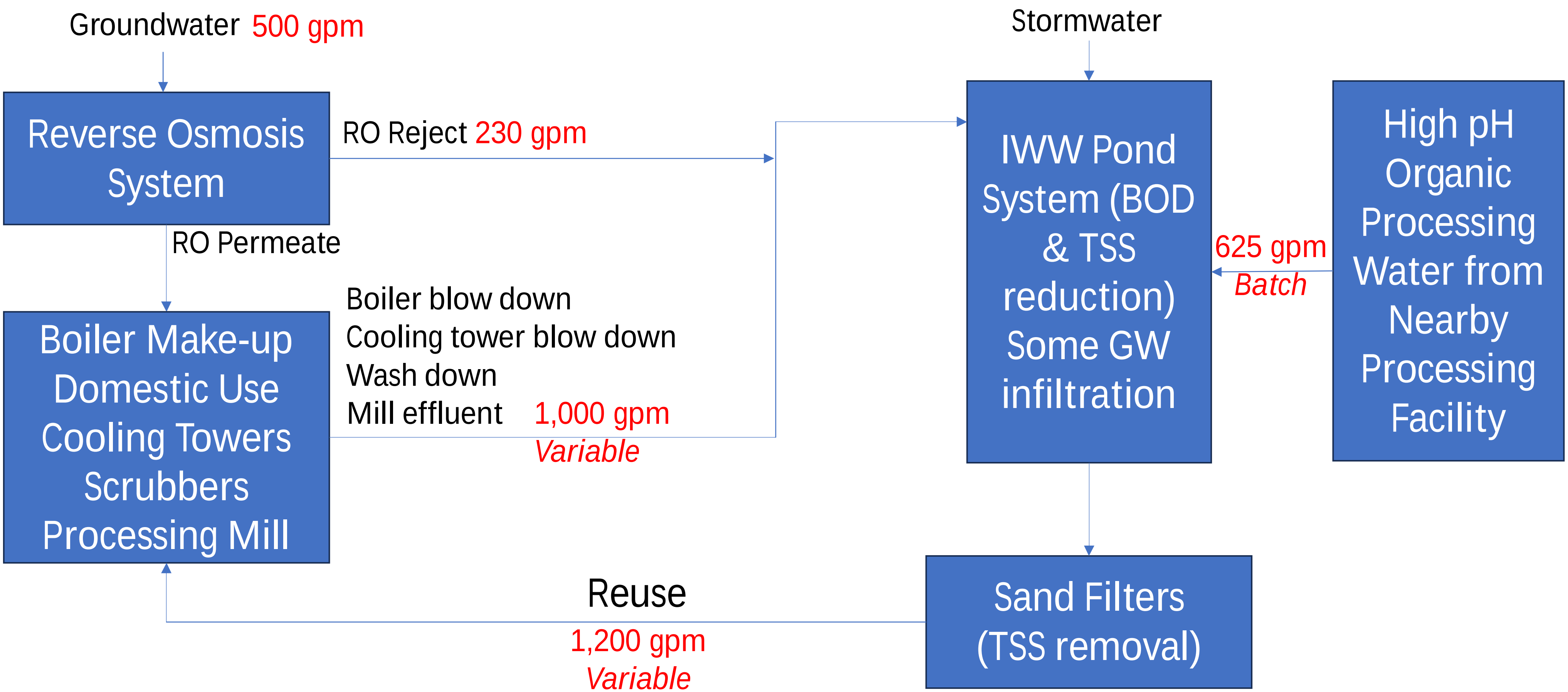


DITCH
ASH POND
ASH POND
OVERFLOW
SCRUBBER ASH PIT
SCRUBBER POND
VERTICAL
TURBINE
PUMPS (3)
BOILER
HOUSE SUMP
EFF 001
1
2
OVERFLOW
CENTRIFUGAL
PUMP
3
DITCH
POND 1
ZEOLITE
SYSTEM
REGENERATION
BOILER
INTERMITTENT
WASHDOWN
WATER
WELL 1
WELL 2
WELL 3
9
TO POTABLE
WATER SYSTEM
RO SYSTEM
8
RO REJECT
TRENCH
BOX
POND 2
POND 3
POND 4
7
INDUSTRIAL
TANK
IWW (FILTRATION TANKS)
DITCH
4
POND 5
POND 6
INTERMITTENT
(NOT CURRENTLY USED)
6
POND 7
ORGANIC HIGH
PH PROCESS
WASTE
EFF 002
5
POND 8

Case Study #2 – Design Basis

- Flow Data:
  - Discharge Monitoring Reports (DMRs) provided monthly flow data for Mill Effluent (sent to Pond 1) and IWW Pond Effluent
  - Other source flows from flow monitoring and estimations based on site water balance
- Water Quality Data:
  - DMRs provided monthly water quality data for Mill Effluent and IWW Pond Effluent
  - DMRs provided quarterly data for GW monitoring and compliance wells
  - Created Sampling & Analysis Plan (SAP) for sources around the site as well as Ponds 1, 5, 6, and 8 (5 sampling events)
- Treatment Goals:
  - Original plant reuse goals
  - Groundwater compliance

Case Study #2 – Flows



Case Study #2 – Design Basis – Ponds

Parameters	Units	Mill Effluent	Pond 1	Pond 5	Pond 6	Pond 8	Pond Effluent	Effluent Reuse Goal
Sodium	mg/L	274	716	645	700	528	400	
TSS	mg/L	859	4,414	141	113	72.5	59	50
pH	s.u.	6.4	5.10	7.31	7.68	7.88	7.9	
TDS	mg/L	2,921	4,304	3,350	2,923	2,298	1,844	
Total Phosphorus	mg/L	14	27.0	24.8	20.0	13.5	12	
TKN	mg/L	79	59.5	32.0	31.9	24.1	28	
Nitrate	mg/L as N	NS	0.440	0.425	0.425	0.350	NS	
Nitrite	mg/L as N	NS	0.440	0.425	0.425	0.350	NS	
BOD	mg/L	5,120	2,143	171	139	79.0	236	50
COD	mg/L	NS	6,105	737	606	487	NS	
TOC	mg/L	NS	1,458	164	146	117	NS	

"NS" indicates not sampled

Case Study #2 – Design Basis – Ponds

Parameters	Units	Mill Effluent	Pond 1	Pond 5	Pond 6	Pond 8	Pond Effluent	Effluent Reuse Goal
Sodium	mg/L	274	716	645	700	528	400	
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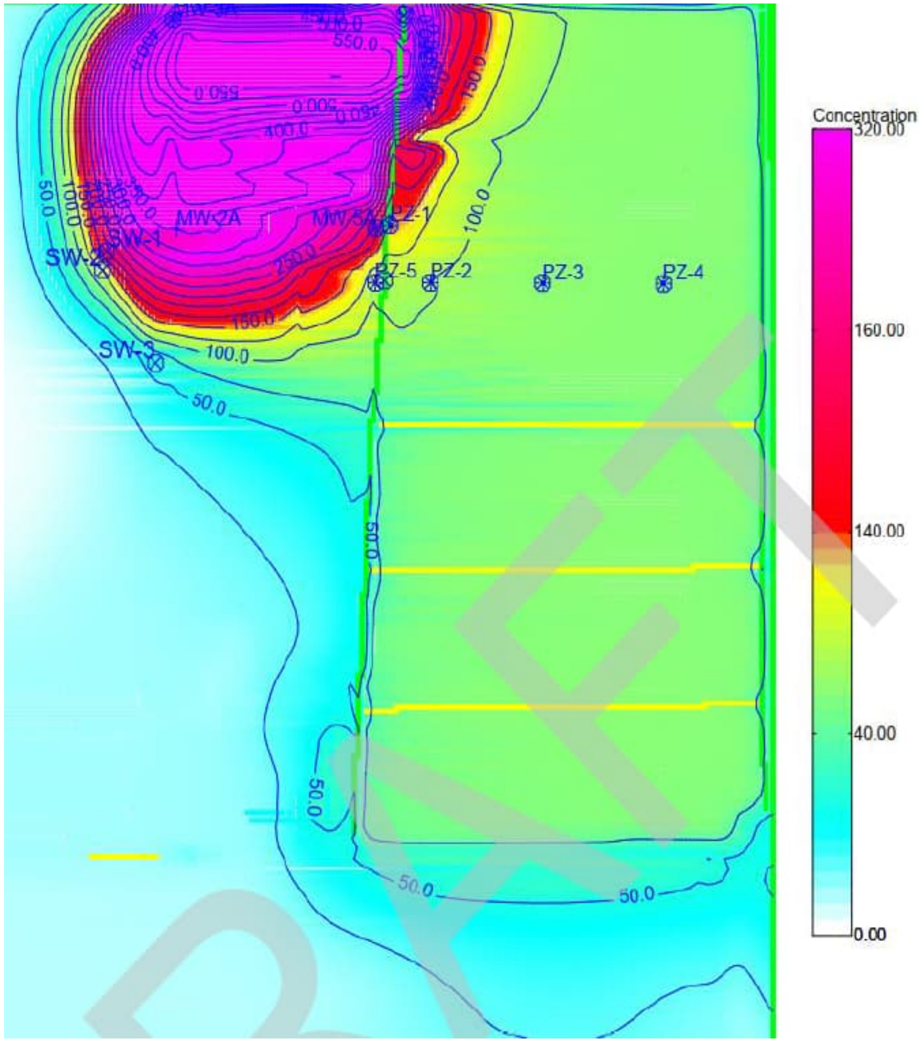
pH	s.u.	6.4	5.10	7.31	7.68	7.88	7.9	
TDS	mg/L	2,921	4,304	3,350	2,923	2,298	1,844	
Total Phosphorus	mg/L	14	27.0	24.8	20.0	13.5	12	
TKN	mg/L	79	59.5	32.0	31.9	24.1	28	
Nitrate	mg/L as N	NS	0.440	0.425	0.425	0.350	NS	
Nitrite	mg/L as N	NS	0.440	0.425	0.425	0.350	NS	
BOD	mg/L	5,120	2,143	171	139	79.0	236	50
COD	mg/L	NS	6,105	737	606	487	NS	
TOC	mg/L	NS	1,458	164	146	117	NS	

"NS" indicates not sampled

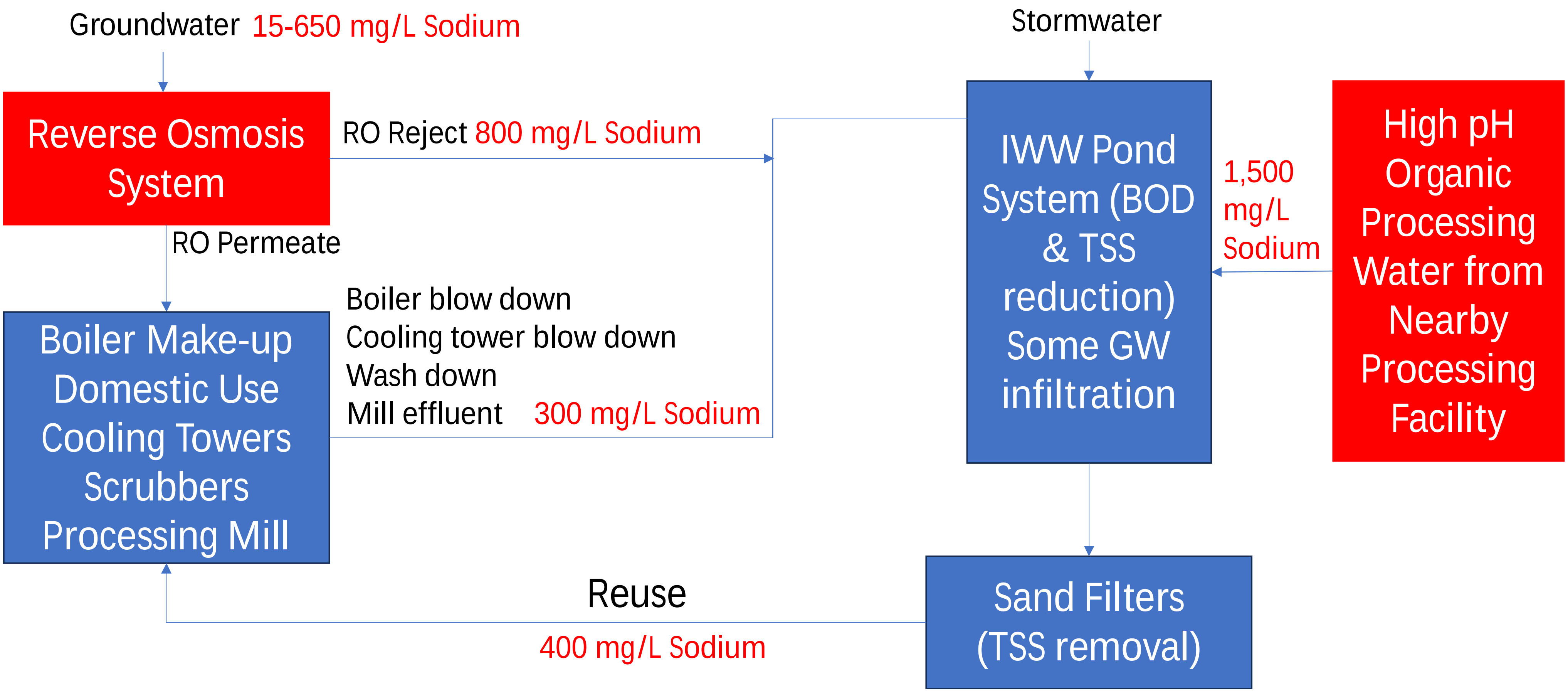
Case Study #2 – Sodium

- Groundwater infiltration occurs in the IWW impacting groundwater and groundwater is used as process makeup water
- Closed loop system with no monovalent management which created high sodium concentrations in reuse water as well as groundwater

- GW Limit = 160 mg/L



Case Study #2 – Sodium



Case Study #2 – Design Basis Conclusions

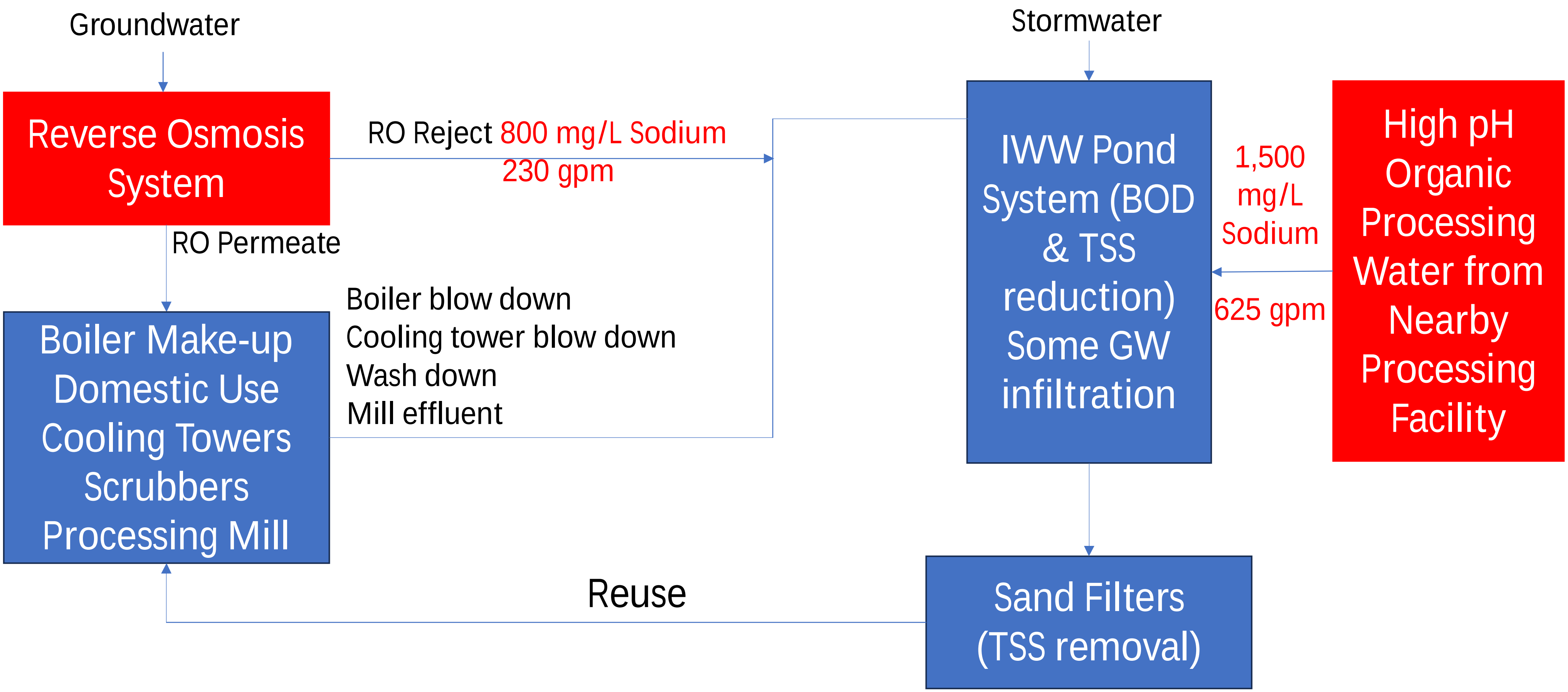
- Created a closed loop reuse with no management of monovalent ions
  - → Sodium issue
- IWW Ponds are now undersized. Originally designed for 0.3 MGD, now sends 1.5-3.0 MGD to IWW Ponds
  - → Insufficient retention time and reduced BOD/TSS removal
- IWW Ponds originally designed as a series of 6 anaerobic ponds followed by 2 aerobic ponds for bulk BOD reduction however, aerators have not been operational in over a decade
  - → Limited BOD reduction

Case Study #2 – Alternatives Analysis Goals

- Goal #1: Point source treatment/management of high sodium streams

- Goal #2: Increase IWW Pond System hydraulic capacity or decrease flows sent to the IWW Pond System

Case Study #2 – Sodium Management



Case Study #2 – Sodium Management

- Five Alternatives Evaluated
  - Alternative 1: Offsite Disposal
    → Not logistically feasible: Greater than 1,000,000 gal/day liquid waste and not feasible for transportation
  - Alternative 2: Enhanced Evaporation Pond
  - Alternative 3: Pretreatment + RO + Brine Management
  - Alternative 4: Vibratory Shear Enhanced Processing (VSEP) Membrane System + Brine Management
  - Alternative 5: Deep Well Injection

Case Study #2 – Enhanced Evaporation

Sprayers – floating or on berm

Sprayerless

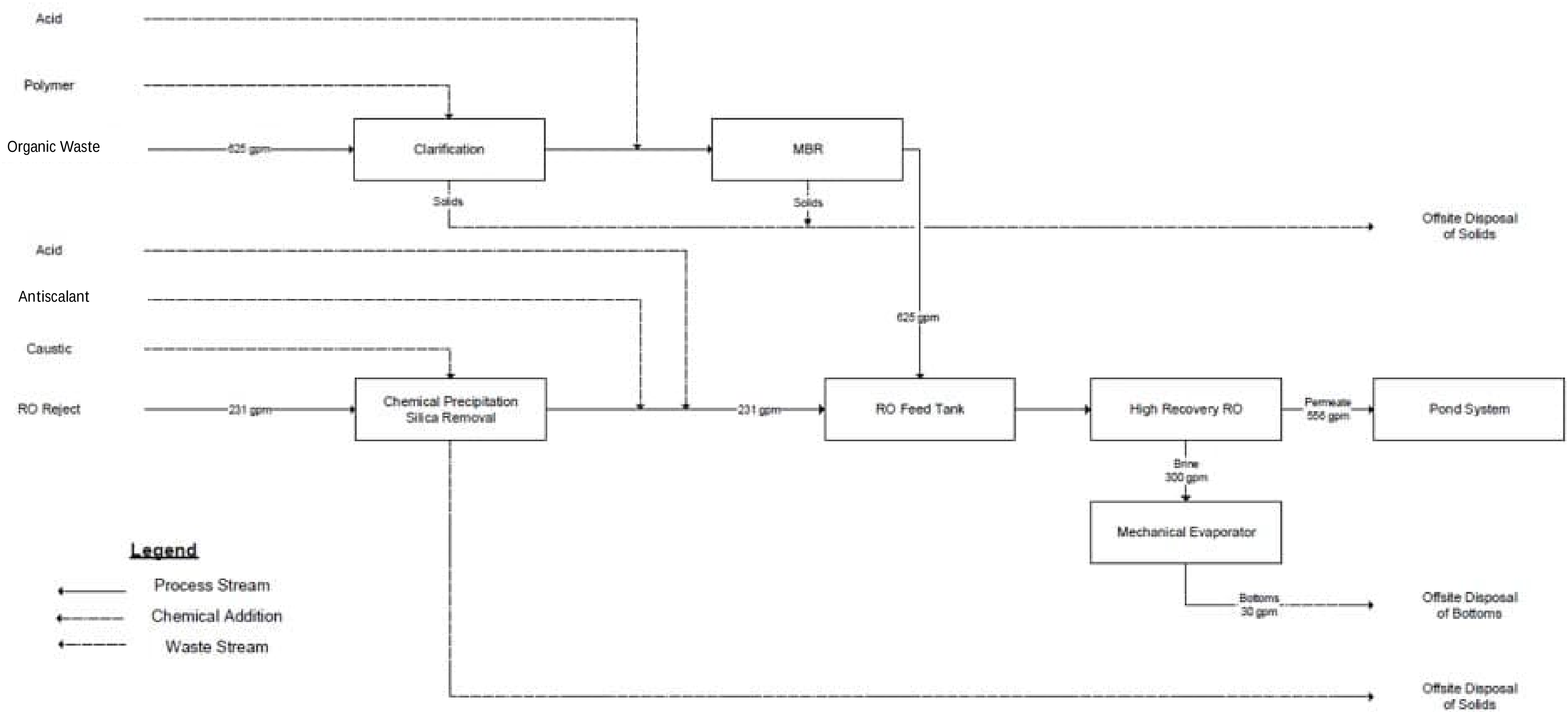
ECOVAP

Wind aided intensified evaporation (WAIV)

Advantages: Highly automated, low operating cost

Disadvantages: Wildlife risk and overspray exposure, public perception, large area requirement, scaling, salt management, Florida climate not optimal for evaporation

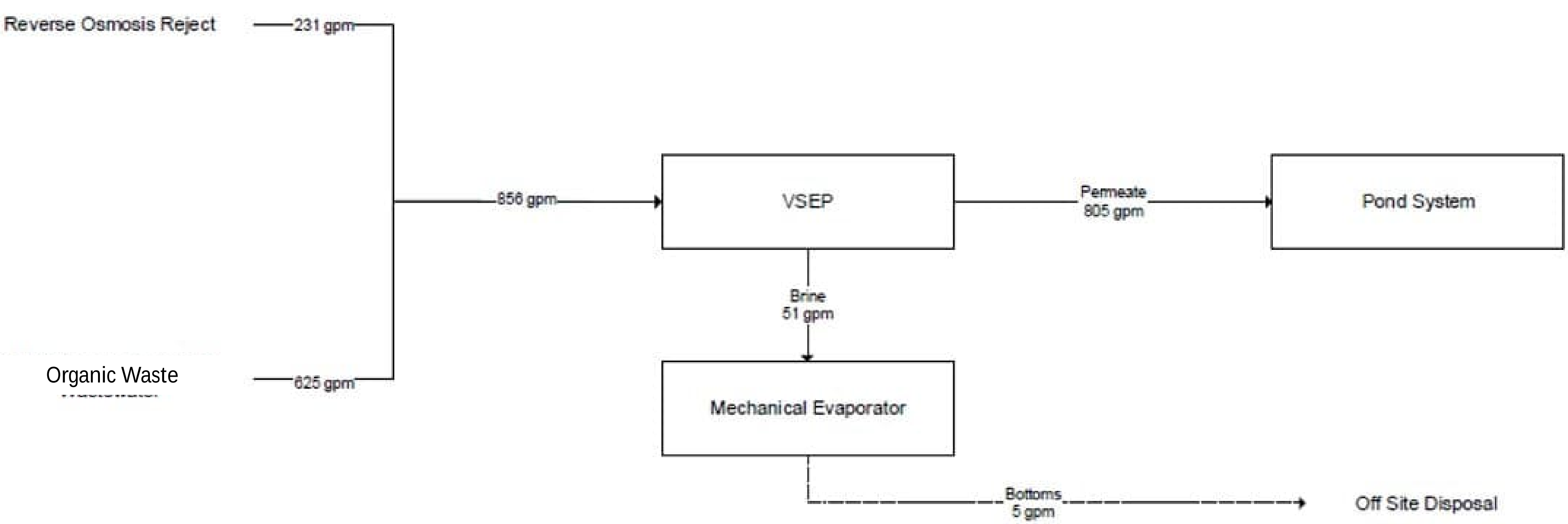
Case Study #2 – RO



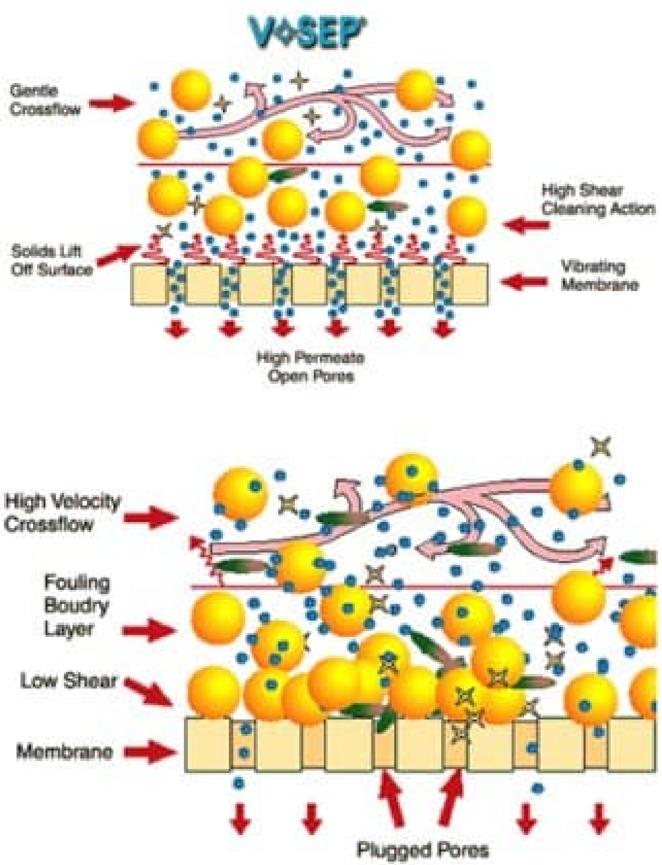
Case Study #2 – RO

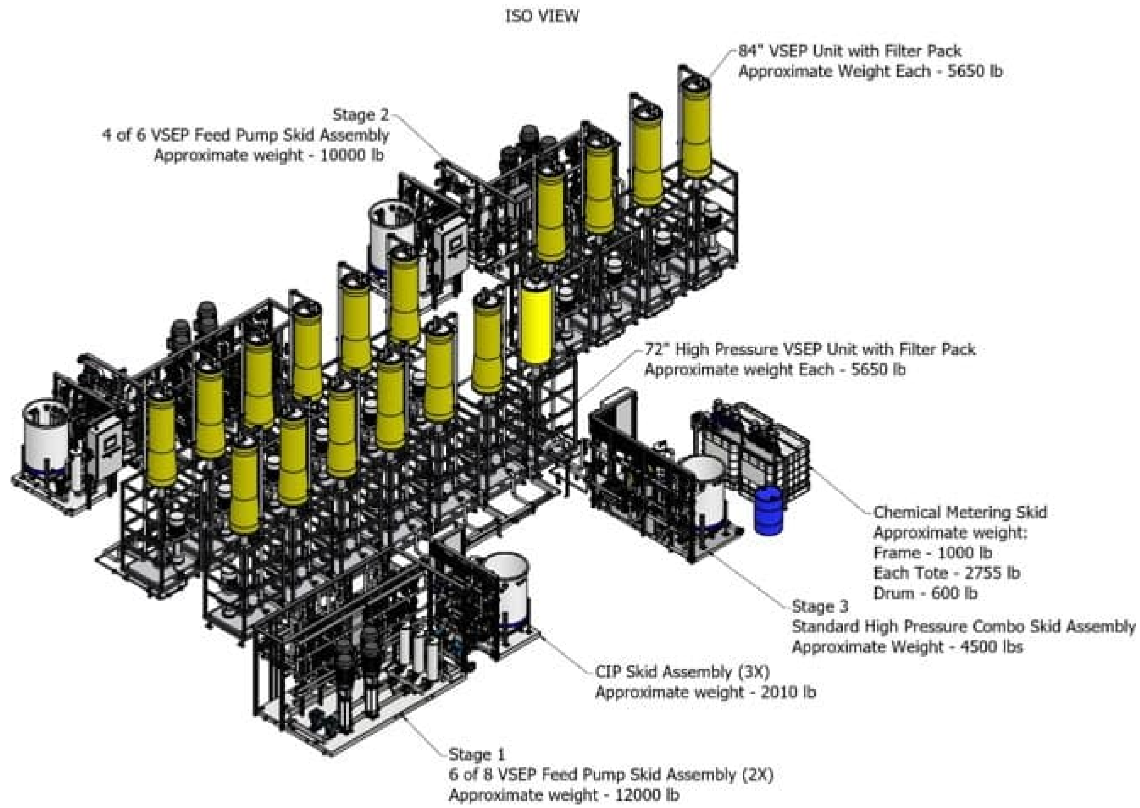
- Advantages:
  - Continuous operation at design flows regardless of climatic conditions
  - No risk to wildlife or public perception issue
  - Smaller footprint than evaporative technology
  - Produces high quality effluent
- Disadvantages:
  - High capital cost
  - Requires sludge disposal and disposal of liquid secondary waste
  - High labor cost
  - High power requirements

Case Study #2 – VSEP



Case Study #2 – VSEP



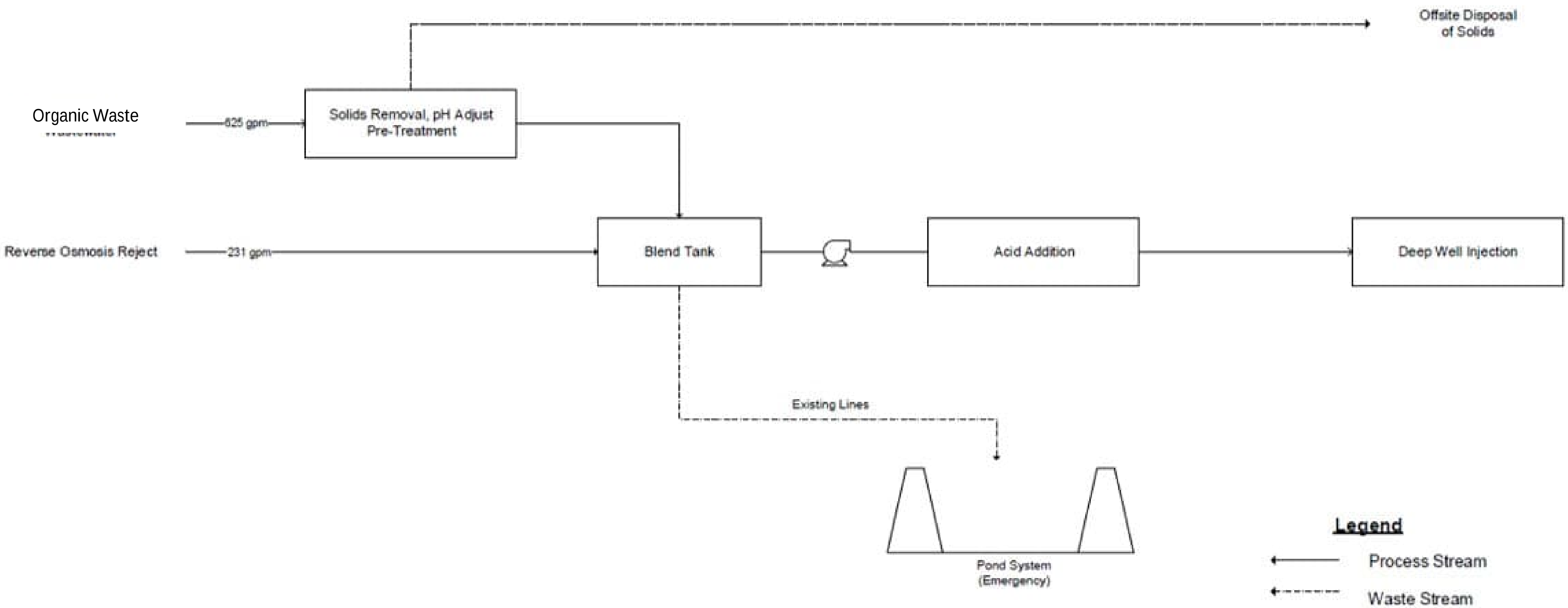


Case Study #2 – VSEP

- Advantages:
  - Continuous operation at design flows regardless of climatic conditions
  - No risk to wildlife or public perception issue
  - Smaller footprint than evaporative technology
  - Produces high quality effluent
  - Limited to no pretreatment required

- Disadvantages:
  - High capital cost
  - Requires sludge disposal and disposal of liquid secondary waste
  - High labor cost
  - High power requirements
  - Emerging technology
  - Requires treatability and pilot testing

Case Study #2 – Deep Well Injection



Case Study #2 – Deep Well Injection

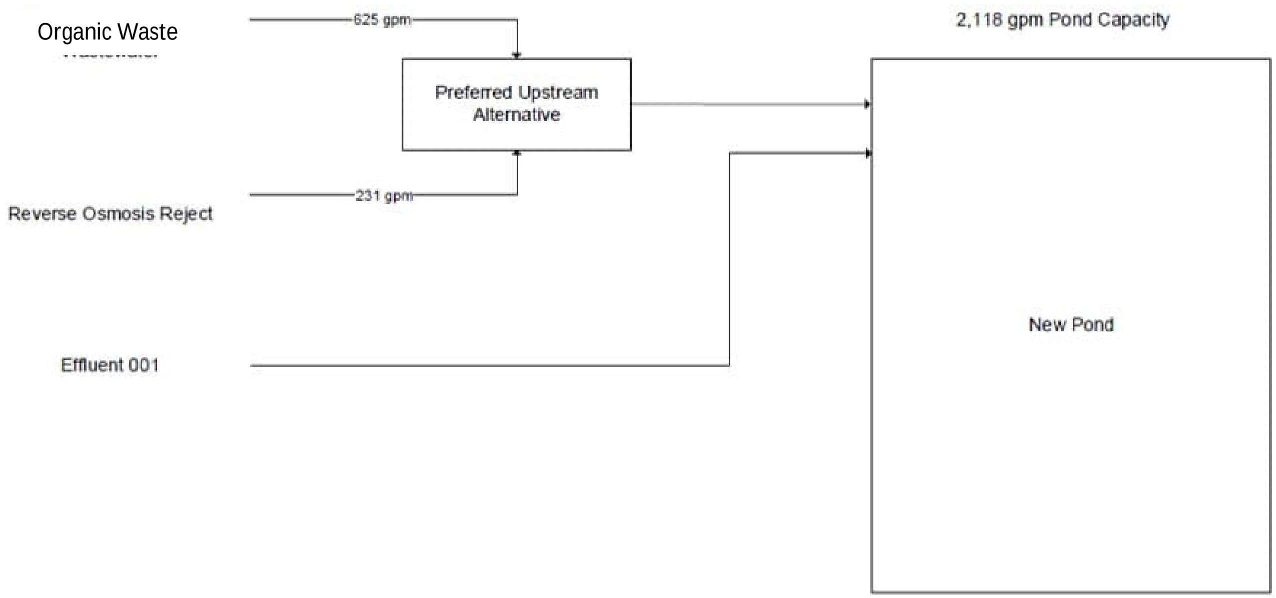
- Advantages:
  - Removes high sodium streams from management system
  - Highly automated - limited operator intervention required
  - Small footprint
  - Nearby facilities demonstrated success with injection wells
  - Lower capital cost than RO alternatives

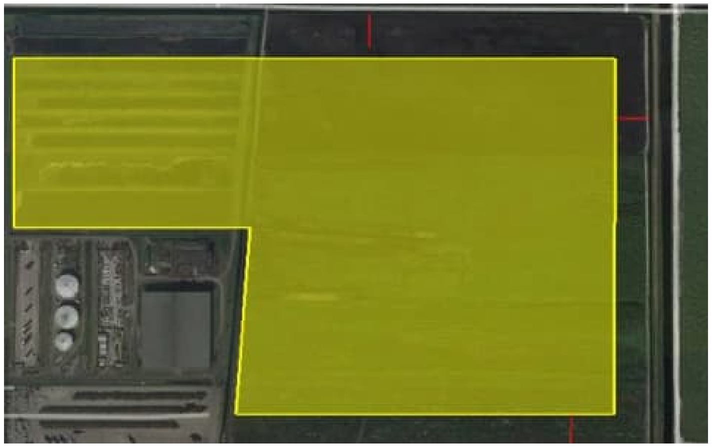
- Disadvantages:
  - Requires sludge disposal
  - Dual-zone monitoring required

Case Study #2 – Increased Hydraulic Management

- Three Alternatives Evaluated
    - IWW Pond Expansion
    - New Pond Construction
    - Deep Well Injection

Case Study #2 – Increased Hydraulic Management



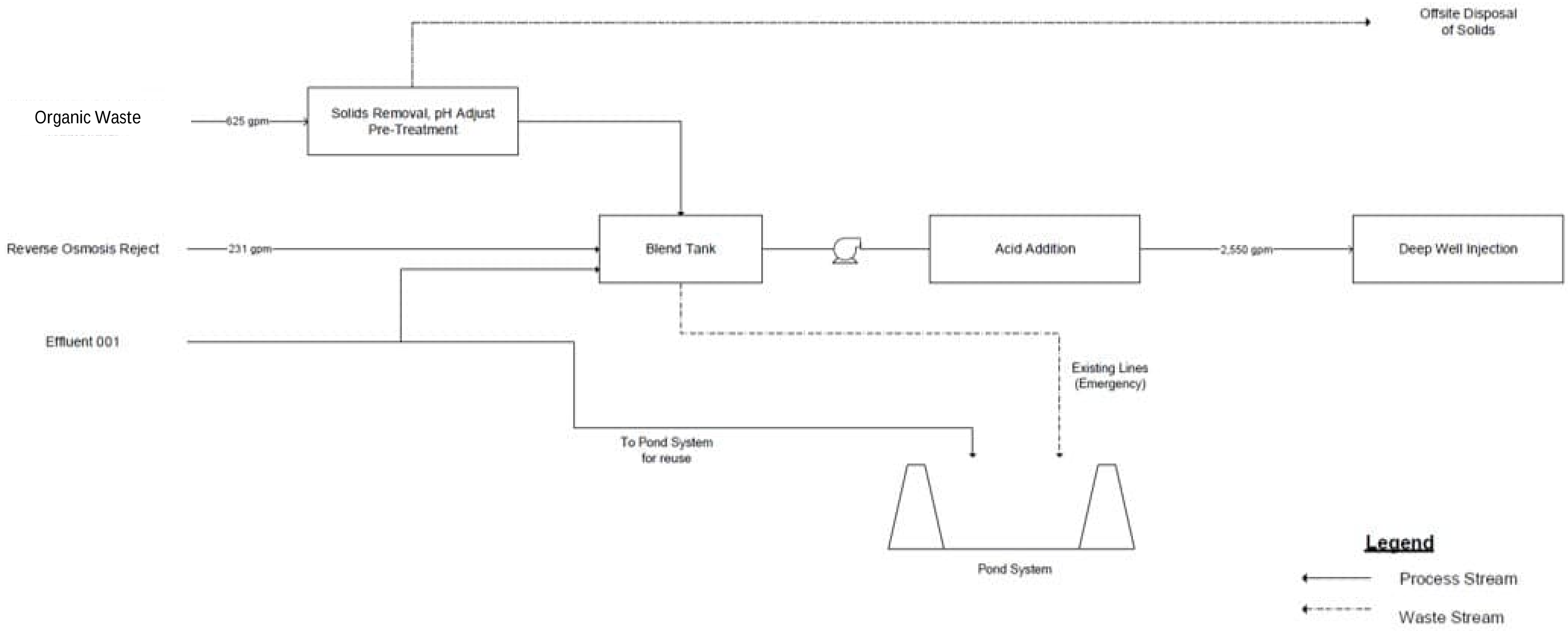


Footprint: 146 acres

Advantages: Low cost, low power requirements, can manage additional stormwater

Disadvantages: Large footprint, larger wildlife exposure risk

Case Study #2 – Deep Well Injection



Case Study #2 – Deep Well Injection

- Advantages:
  - Removes high sodium streams from management system
  - Highly automated - limited operator intervention required
  - Small footprint
  - Nearby facilities demonstrated success with injection wells
  - Allows additional flexibility for water management onsite
  - Additional cost to increase injection well size minimal compared to pond expansion

- Disadvantages:
  - Requires sludge disposal
  - Dual-zone monitoring required

Case Study #2 – Alternatives Screening

Evaluation Criteria Definitions
Hydraulic Capacity – Hydraulic capacity for the system.
Treatability Testing Requirements – Length and duration of treatability testing, extent of and complexity of bench and pilot testing required, amount of water required and other impacts to schedule and budget for process testing.
Maintainability and Operability – Ease of inspectability, readily accessible maintenance points, process monitoring and troubleshooting, availability of required spares, preventative maintenance requirements, downtime for routine and nonroutine maintenance; process complexity, operational and maintenance labor requirements (time and skill levels), capability to for continuous operations (24/7) attended or unattended.
Footprint Required – Area needed for treatment system.
Sustainability – Power requirements and usage, chemical usage, sludge/residuals generation, and ecosystem impacts; hazards related to chemical reagent shipments onsite storage and use, secondary waste characteristics and volume; impacts with regard to public exposure and wildlife exposure, or environmental impacts from treatment system.
CAPEX – Capital costs associated with the design, construction, and physical assets (i.e., equipment, building) required for treatment installation.
OPEX – Annual operation and maintenance costs for power, chemical usage, operations and maintenance allowance. Labor is not included.
Secondary Waste – Volume of secondary waste (salt, sludge, RO brine, etc.) that requires offsite disposal.
Safety – Personnel safety hazards such as low clearances, trip hazards, noise, pinch points, elevated platforms, space-constrained walkways/work areas. Process hazards such as extreme (high or low) process temperatures or pressures, risk of exposure to electrical or mechanical energy, chemical hazards (corrosivity, volatility, fumes).

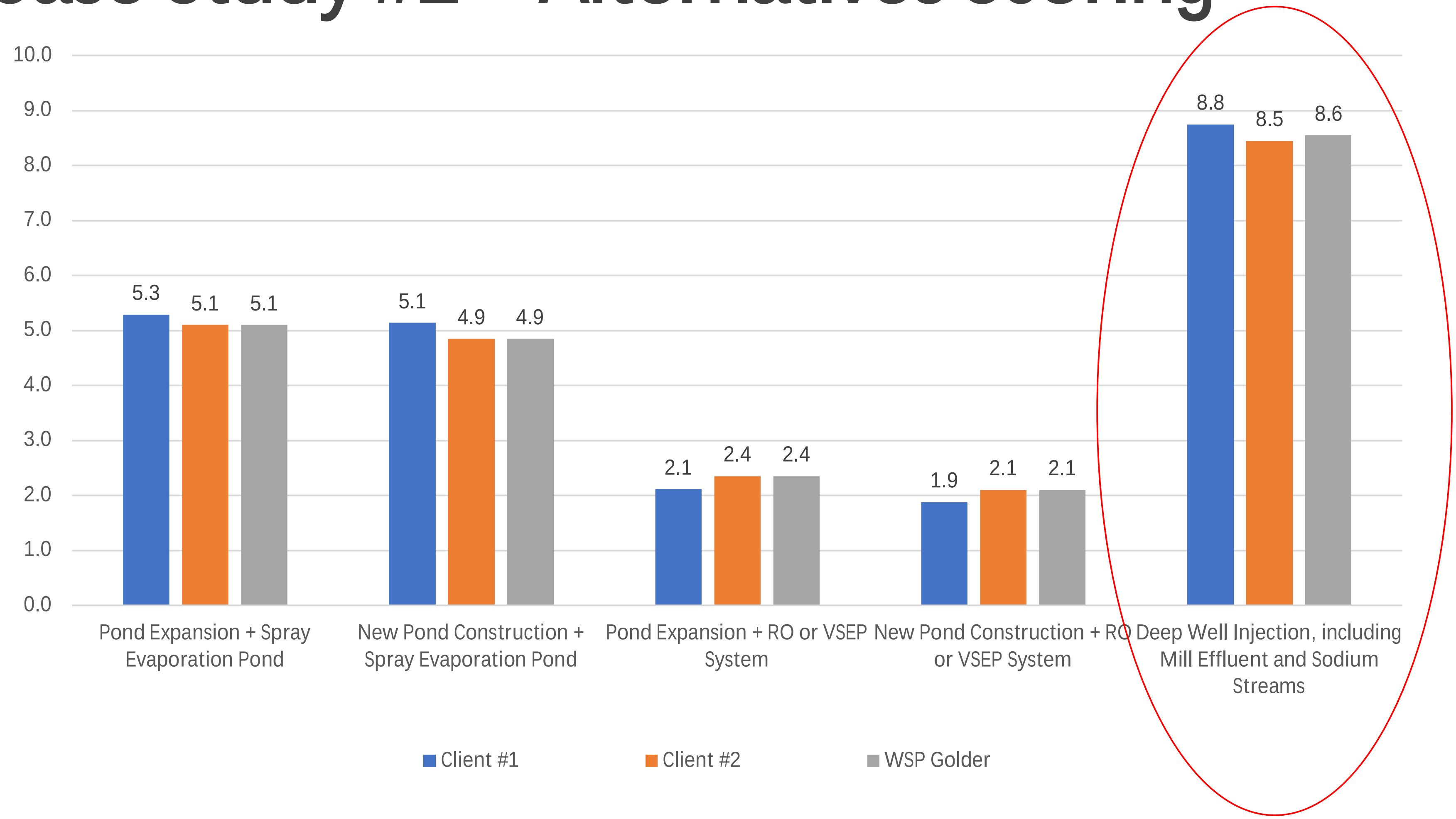
Case Study #2 – Alternatives Screening

Criteria	Scoring	Guidance
Hydraulic Capacity **(10% Weighting)**	8 to 10	Highest hydraulic capacity
	5 to 8	Ranking relative to low and high ratings
	0 to 5	Lowest hydraulic capacity
Treatability Testing Requirements **(5% Weighting)**	8 to 10	Testing not required or can be accomplished in a relatively simple one-to-two-week bench test. Proven models available so that testing is not typically required.
	5 to 8	Testing required and can be accomplished in 3 months or less.
	0 to 5	Testing required and typically bench testing followed by pilot testing. Testing requires more than 3 months.
Maintainability & Operability **(15% Weighting)**	8 to 10	No unusual components, ready availability of spares, maintenance required on minimal components (such as only a pump or two) with low level of mechanical maintenance, minimal downtime for maintenance and cleaning cycles, easily accessible maintenance points. No more than intermittent operator attention required. Treatment complexity low and does not require speciality skilled operator.
	5 to 8	No unusual components, ready availability of spares, standard level of mechanical maintenance, minimal downtime for maintenance and cleaning cycles, easily accessible maintenance points. Treatment system has multiple unit ops and requires full-time operator(s).
	0 to 5	System requires speciality equipment for maintenance, has multiple unit ops, and requires full-time speciality operator(s).
Footprint Required **(15% Weighting)**	8 to 10	Low footprint. May be able to install in existing facility. Less than 20,000 sq. ft.
	5 to 8	Ranking relative to low and high ratings.
	0 to 5	Large footprint. Greater than 100,000 sq. ft.

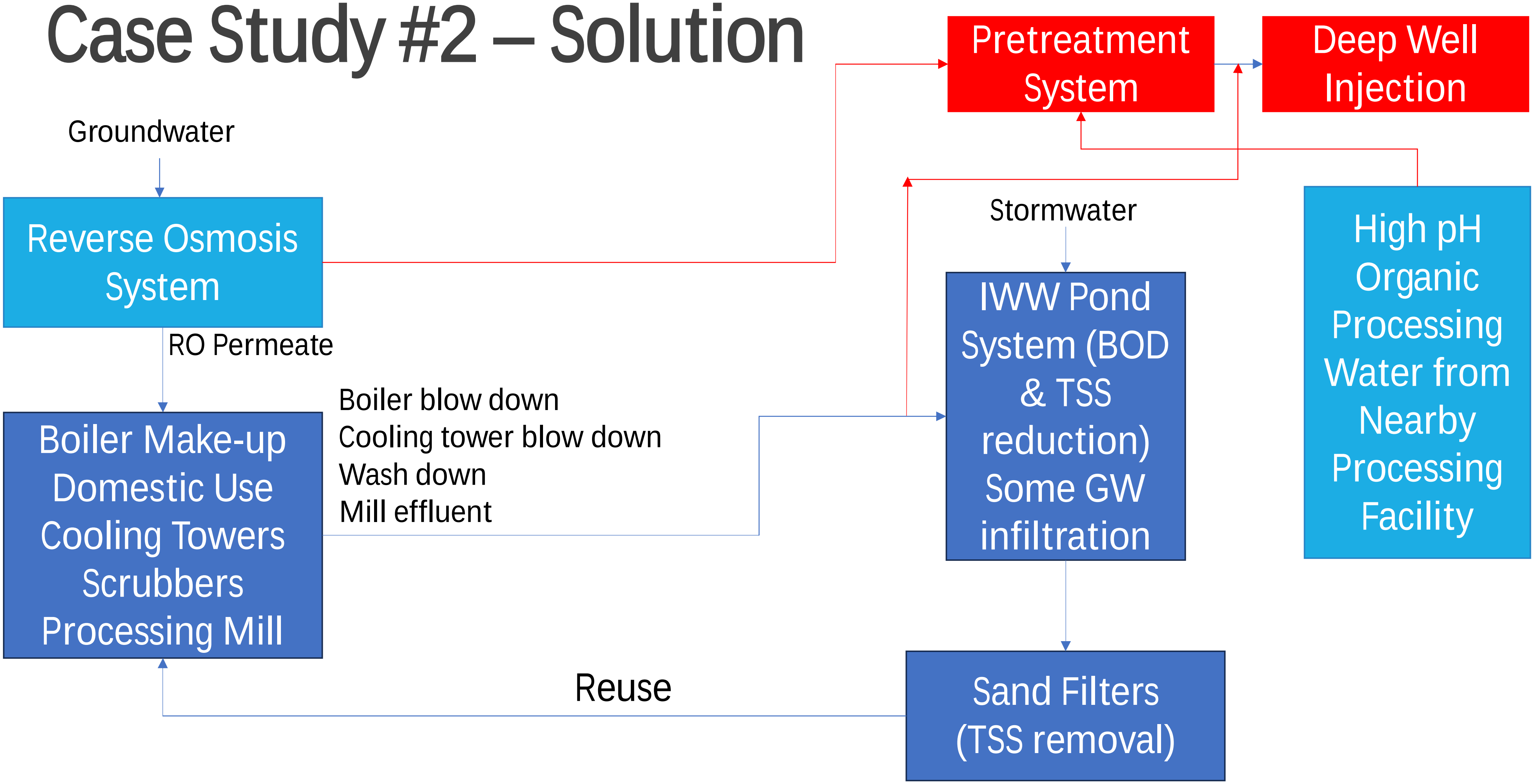
Case Study #2 – Alternatives Screening

Criteria	Scoring	Guidance
Sustainability **(5% Weighting)**	8 to 10	Net negative carbon footprint due to low or no power, no chemicals, no sludge, environmentally pleasing layout, reduces impact at site.
	5 to 8	Ranking relative to low and high ratings. May have one element that is higher or another element that is lower. For example, a high power usage, but no chemicals are needed.
	0 to 5	High power requirements and usage, high chemical usage, high sludge/residuals generation, potential hazards related to chemical reagent shipments onsite storage and use, potential impacts with regard to public exposure and wildlife exposure, or environmental impacts from treatment system.
CAPEX **(15% Weighting)**	10	Lowest capital costs
	2 to 8	Scored based on capital cost ranking
	0	Highest capital costs
OPEX **(15% Weighting)**	10	Lowest estimated annual operating cost
	2 to 8	Scored based on annual operating cost
	0	Highest operating cost
Secondary Waste **(15% Weighting)**	10	Lowest volume of secondary waste that requires offsite management
	2 to 8	Score based relative to the highest and lowest volume of secondary waste
	0	Highest volume of secondary waste that requires offsite management
Safety **(5% Weighting)**	8 to 10	Minimized risk of personnel injury - noise, pinch points, low clearances, elevated platforms, space-constrained work areas/walkways, reduced impact to public, wildlife and environment from treatment process, chemicals, and residuals. Minimized process-related hazards - chemical hazards (corrosivity, fumes, volatility), extreme process temperature or pressure, confined space entry, electrical and mechanical hazards
	0 to 8	Ranked relative to top scorer and the standards for "10" score

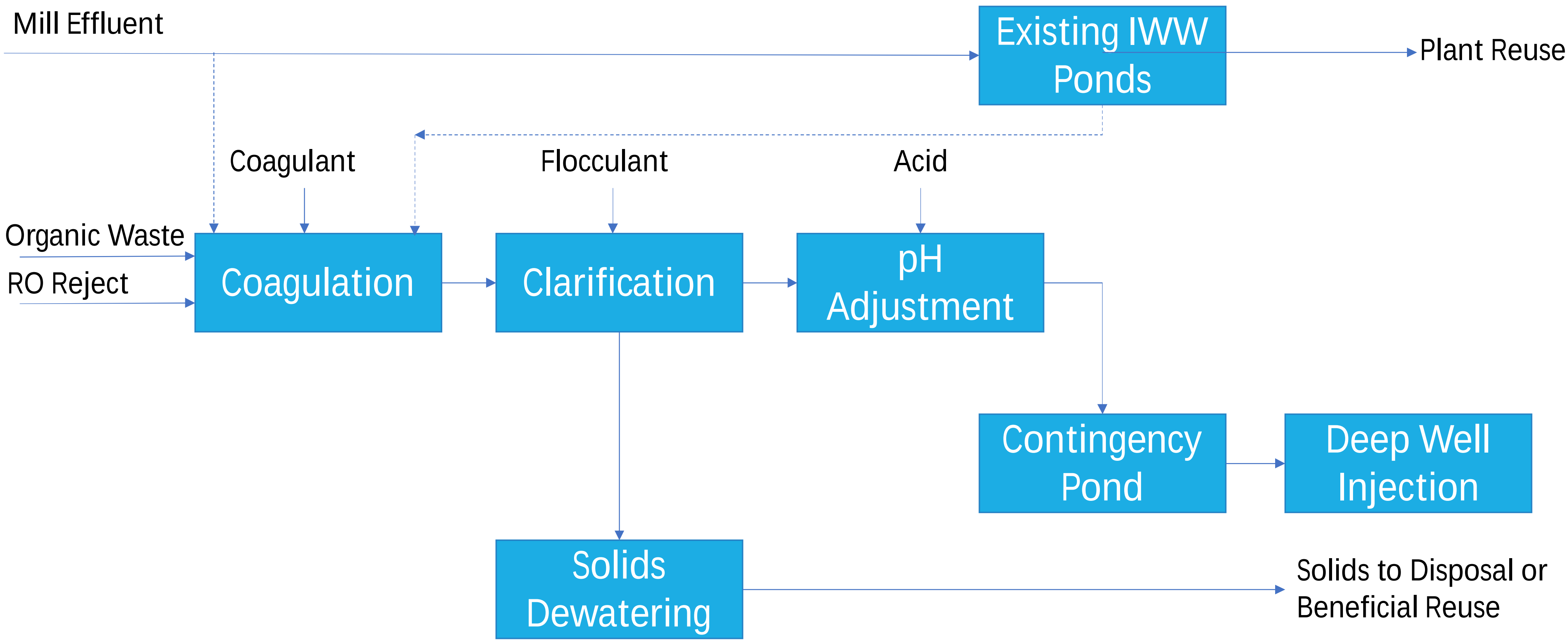
Case Study #2 – Alternatives Scoring



Case Study #2 – Solution



Case Study #2 – Solution




KEEP
CALM
AND
REUSE
WATER

INDUSTRIAL WATER REUSE

LESSONS LEARNED

IWC 24 - W03

Case Study

Who: McCain Foods Mehsana

When: 2014

Where: Gujarat, India … a very arid region

Why Water Reuse:

- Severe water scarcity → Aquifer was drying up
- A true ZLD site → No surface water in the area → No where to discharge effluent
- Population Growth → Increased Demand for McCain's Products → Plant Expansion

Challenges for Water Reuse:

- Even with water reuse it would be difficult to support the site's need for clean water. Target RO Recovery ~~75%~~ increased to 87% - Every Drop Counts
- Production Required a Reliable Source of Clean Water

2018 Paper

IWC 18-09

**A Case Study of Industrial Water Reuse and ZLD:
Four Years of Operation and Lessons Learned**

ED GREENWOOD, P.ENG., BCEE
Wood plc
Cambridge, Ontario

BILL MALYK, P.ENG., BCEE
Wood plc
Cambridge, Ontario

Abstract: One food processor rose to the challenge of water scarcity with a unique high recovery water reclamation plant. To meet the needs of production the RO system was designed with a water recovery rate of 87%. A few years later the RO was upgraded to over 93%. Since then, operators have dealt with a major wastewater treatment plant upset, issues with brine management and several other plant expansions and upgrades. Four years of operating data and lessons learned are presented in this paper.

Case Study

Who: McCain Foods Mehsana

When: 2015

Where: Gujarat, India … a very arid region

Why Water Reuse:

- Severe water scarcity → Aquifer was drying up
- A true ZLD site → No surface water in the area → No where to discharge effluent
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Challenges for Water Reuse:

- Even with water reuse it would be difficult to support the site's need for clean water. Target RO Recovery ~~75%~~ increased to 87% - Every Drop Counts
- Production Required a Reliable Source of Clean Water

McCain Foods – DESIGN BASIS

- Flowrates:

Parameter	Units	Secondary Clarifier Effluent	RO Feed Flow	RO Permeate Flow
Flow with All Trains in Operation	m3/d	1500	1350	1181

Influent Water Quality (Secondary Clarifier Effluent):

Parameters	Units	Average	Design Basis
Temperature	°C	28.0	30.0
Residual Chlorine	mg/L	0.2	0.3
TOC	mg/L	77.0	100
DOC	mg/L	31.7	50
Turbidity	NTU		100
COD	mg/L	216	300
BOD	mg/L	27	40
TSS	mg/L	115	300
TDS	mg/L	3485	4000
Ortho-Phosphate	mg/L		10
Total Phosphorus	mg/L		10
Cyanide (as CN)	mg/L	<0.005	<0.005
pH	pH units	7.7	7.7
Conductivity	ms/cm	9.2	2.5

Parameters	Units	Average	Design Basis
Total Hardness (as CaCO3)	mg/L	263	300
Carbonate (as CaCO3)	mg/L	1338	10
Bicarbonate	mg/L	0.0	1100
Chloride	mg/L	573	610
Fluoride	mg/L	0.5	0.5
Nitrates (as NO3)	mg/L	<0.1	300
Sulphate (as SO4)	mg/L	75	100
Sulphide (as H2S)	mg/L	<0.05	0.05
Calcium	mg/L	44	50
Magnesium	mg/L	37	40
Potassium	mg/L	300	350
Silica (as SiO2)	mg/L	19.3	25.0
Aluminum	mg/L	<0.02	<0.02
Barium	mg/L	<0.5	<0.5

Parameters	Units	Average	Design Basis
Boron	mg/L	<0.05	<0.05
Copper	mg/L	<0.04	<0.04
Iron	mg/L	<0.08	<0.08
Lead	mg/L	<0.005	<0.005
Manganese	mg/L	<0.02	<0.02
Mercury	mg/L	<0.0005	<0.0005
Selenium	mg/L	<0.001	<0.001
Zinc	mg/L	<0.01	<0.01
Sodium	mg/L	387	400
Strontium	mg/L	<0.05	<0.05
Bromide	mg/L	<0.1	<0.1
Oil & Grease	mg/L	1.05	2.00
Soluble Phosphorus	mg/L		1.00
TKN	mg/L		1.00
Ammonia-N	mg/L		1.00

McCain Foods – DESIGN BASIS

Product Water Quality (Equivalent to Potable)

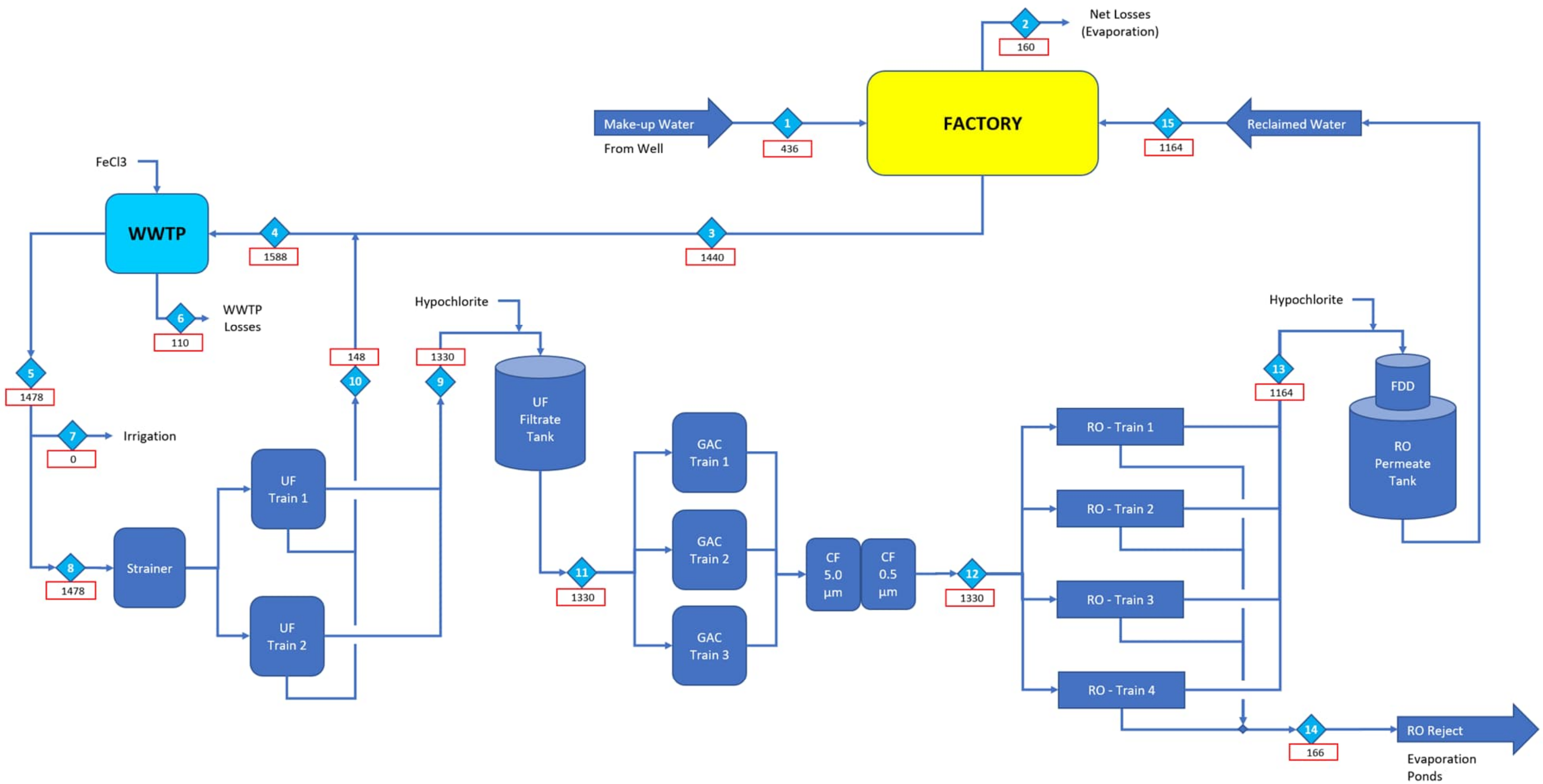
Parameter	Units		Comments
Colour	TCU	< 15	Performance Requirement
Turbidity	NTU	< 0.1	Performance Requirement
pH	-	8.2 - 9	Performance Requirement
Total Hardness (as CaCO3)	mg/L	< 5	Performance Requirement
Chlorides (as Cl)	mg/L	< 250	Performance Requirement
TDS	mg/L	< 100	Performance Requirement
Calcium (as Ca)	mg/L	< 75	Performance Requirement
Magnesium (as Mg)	mg/L	< 30	Performance Requirement
Manganese (as Mn)	mg/L	< 0.05	Performance Requirement
Sulphate (as SO4)	mg/L	< 500	Performance Requirement
Nitrate (as NO3)	mg/L	< 45	Performance Requirement
Fluoride (as F)	mg/L	< 1.5	Performance Requirement
Potasium (as K)	mg/L	< 15	Performance Requirement
P Alkalinity (as CaCO3)	mg/L	0	Performance Requirement
M Alkalinity (as CaCO3)	mg/L	< 100	Performance Requirement
Total Alkalinity (as CaCO3)	mg/L	< 100	Performance Requirement
Boron (as B)	mg/L	< 5	Performance Requirement
E.Coli	/100mL	0	Performance Requirement
Total Coliform	/100mL	0	Performance Requirement

McCain Foods – DESIGN BASIS

Secondary Clarifier → **Screening** → **Filtration** → **Disinfection / Organic Carbon Removal** → **Desalination** → **pH Neutralization** → **Disinfection** → **Reuse Water Storage**

	Screening	Filtration	Disinfection / Organic Carbon Removal	Desalination	pH Neutralization	Disinfection
Options	Self Cleaning Strainer Rotary Drum Screen	Sand Filtration Multimedia Filtration (MMF) Microfiltration (MF) Ultrafiltration (UF)	Sodium Hypochlorite Dosing Ozone Activated Carbon (GAC)	Reverse Osmosis (RO) Ion Exchange (IX)	Caustic Dosing Forced Draft Decarbonator (FDD)	Sodium Hypochlorite Ultraviolet System (UV)
Selection	Self Cleaning Strainer	Ultrafiltration (UF)	Sodium Hypochlorite and Activated Carbon (GAC)	Reverse Osmosis (RO)	Forced Draft Decarbonator (FDD)	Sodium Hypochlorite
Primary Reasons Why	Low solids/trash loading was expected Small footprint Low capital cost	Positive Barrier to Coliforms Higher solids loading Reliable filtrate quality Reliable performance during upsets	Ozone was too expensive Footprint for a future Ozone System was included in the building design	Positive barrier to Coliforms Low capital cost	Easy to operate and control	Client was comfortable with Hypochlorite Dosing Low capital cost

Note: Evaporation Ponds were installed in 2013 and were used to collect and store the RO Reject. For the first 2-3 years of the Water Reclamation Plant operation the ponds gradually filled up with RO Reject. However, the Evaporation Ponds were too small to be a permanent solution.



Stream No.		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15		
Stream Name		Make-Up Well Water	Production Losses (Evap)	Raw Wastewate	WWTP Influent Total	Secondary Clarifier Effluent	WWTP Losses	Irrigation Water	UF Feed	UF Filtrate	UF Reject	GAC Feed	RO Feed	RO Permeate	RO Reject	Product Water For Reuse	Total In	Total Out
Flow	m3/d	**436**	**160**	1440	**1588**	1478	**110**	0	**1478**	1330	148	1330	1330	1164	166	1164	1478	1478
TDS	mg/L	**150**	**150**	**4000**	**4000**	**4000**	4000	4000	4000	4000	4000	4000	4000	46	31680	46		
TDS	kg/d	65.4	24	5760.8	6352	5912	440	0	5912	5320.8	591.2	5320.8	5320.8	53.208	5267.592	53.208	5912	5912
SiO2	mg/L	**25**	**25**	**25**	**25**	**25**	25	25	25	25	25	25	25	0.3	**198**	0.3		
SiO2	kg/d	10.9	4.0	36.0	39.7	36.95	2.75	0	36.95	33.3	3.7	33.3	33.3	0.3	32.9	0.3	37.0	37.0
RO Recovery										**90.0%**				**87.5%**				
RO TDS Rejection														**99.0%**				

McCain Foods
Mehsana Water Balance
Block Flow Diagram &
Simplified Water/Mass Balance

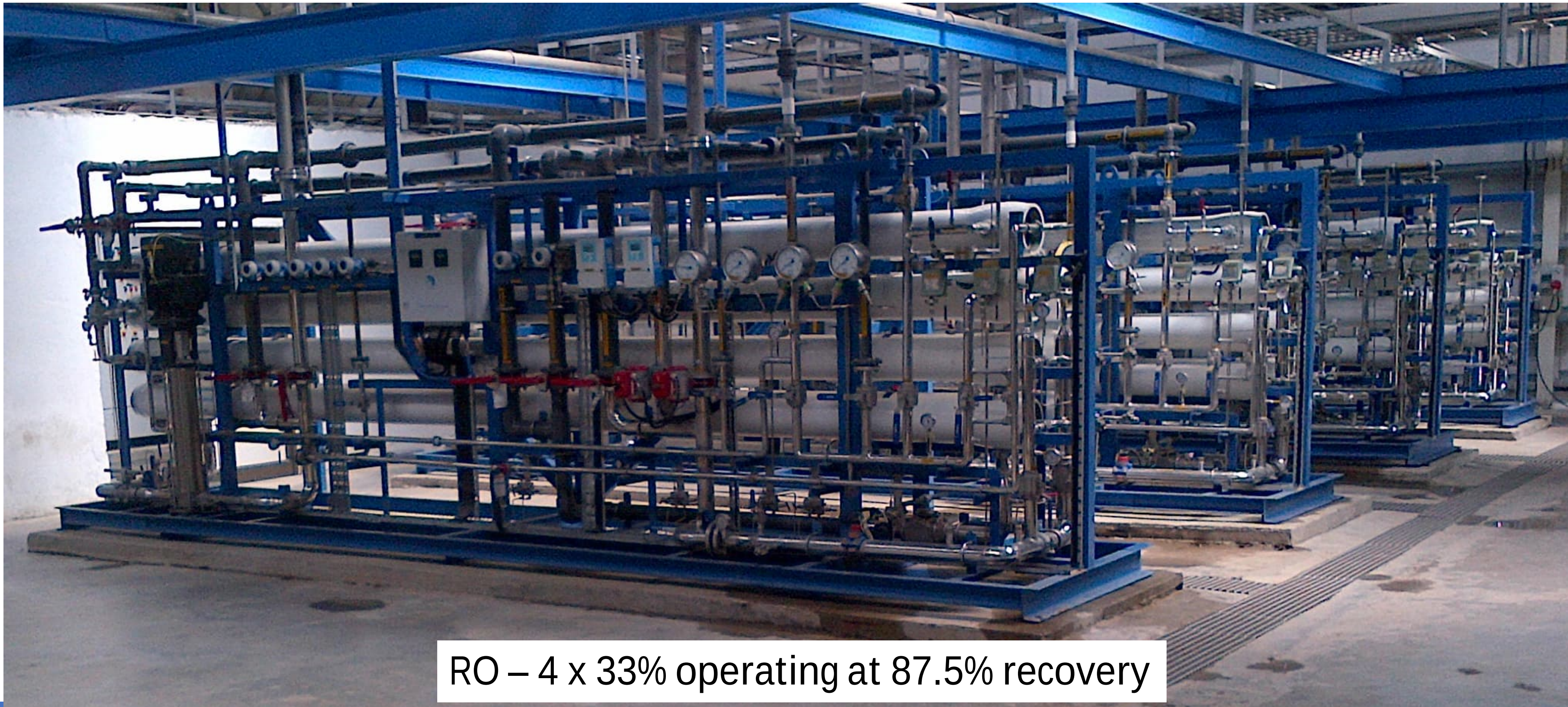
2014 - Original Design Condition

Technology Selection

Treatment Technologies

Tertiary MF/UF verse MBR			
	Tertiary MF/UF	MBR	Comments
Description	Reuse existing biological treatment and secondary clarifier with minimal or no changes	Upgrade biological treatment and replace secondary clarifier	Tertiary MF/UF is usually less expensive because less changes are required. If WWTP remains the same less training is required.
Biological Treatment	No changes - if flow and loading remains the same	Potential for higher MLSS Higher RAS flow	If flow or loading increases MBR can be less expensive (smaller bioreactor) MBR with higher MLSS has potential to handle upsets better than clarifier
Solids Separation	Clarifier does most of the work UF/MF polishes secondary effluent	MF/UF does all the work (higher solids loading)	Tertiary MF/UF will have lower solids loading so it will operate at higher flux and require fewer membranes ... Tertiary MF/UF will therefor be less expensive
Upset	Clarifier upsets (filamentous) can foul MF/UF membranes and impair performance.	MBR upsets are caused be the same conditions (low DO, low nutrients, etc.) as conventional activated sludge process.	Very similar ... MF/UF becomes the bottleneck in both processes. Severe upsets can damage membranes in both (depends more on membrane than process)


UF – 2 x 100%
GAC – 3 x 50%



RO – 4 x 33% operating at 87.5% recovery

Lessons Learned

1) During the Start-Up period (1-2 months) the WRP feed water quality was off-spec (TSS 40-200 mg/L). The UF handled the upset with no impact to performance.

2) During the Start-Up period McCain production needed more water for washing/rinsing equipment than what was available from the WRP.

3) During Start-Up both the 5 micron and 0.5 micron cartridge filters following the GAC required <u>very</u> frequent changes. It took much longer than anticipated to rinse the GAC (and much more water).

4) At Start-Up the GAC removed approx. 40-50% of the TOC. TOC removal is 10-30% is typical now and RO membrane life was approx. 8-10 years.

Lessons Learned

5) The UF membranes are 10+ years old (2014 to present).

6) Controlling organic fouling/biofouling is the biggest challenge for operators.

7) In 2017, a major upset in the WWTP occurred. Suspended Solids levels (MLSS) in the feed to the WRP rose to 2000-6000 mg/L for 3-4 weeks. The WWTP upset occurred during a severe flood in the region and was caused by a lack of sludge wasting from the AS process.

→ Once sludge wasting resumed and WWTP upset condition passed both the WWTP and the WRP performance returned to normal without any damage to the WRP membranes. However, during the upset the UF membrane system became a bottleneck for the WRP and significantly reduced the amount of water provided to McCain's Production Plant. For more info see IWC-18-09.

Case Study – Brine Concentration

Who: McCain Foods Mehsana

When: Two Projects … 1st start-up in 2016 … 2nd start-up in 2019

Where: Gujarat, India … a very arid region

Why Brine Concentration:

- Over time the raw wastewater TDS levels have decreased
- Increased demand for McCain's products → Another plant expansion
- Severe water scarcity → Every Drop Counts

Challenges for Water Reuse:

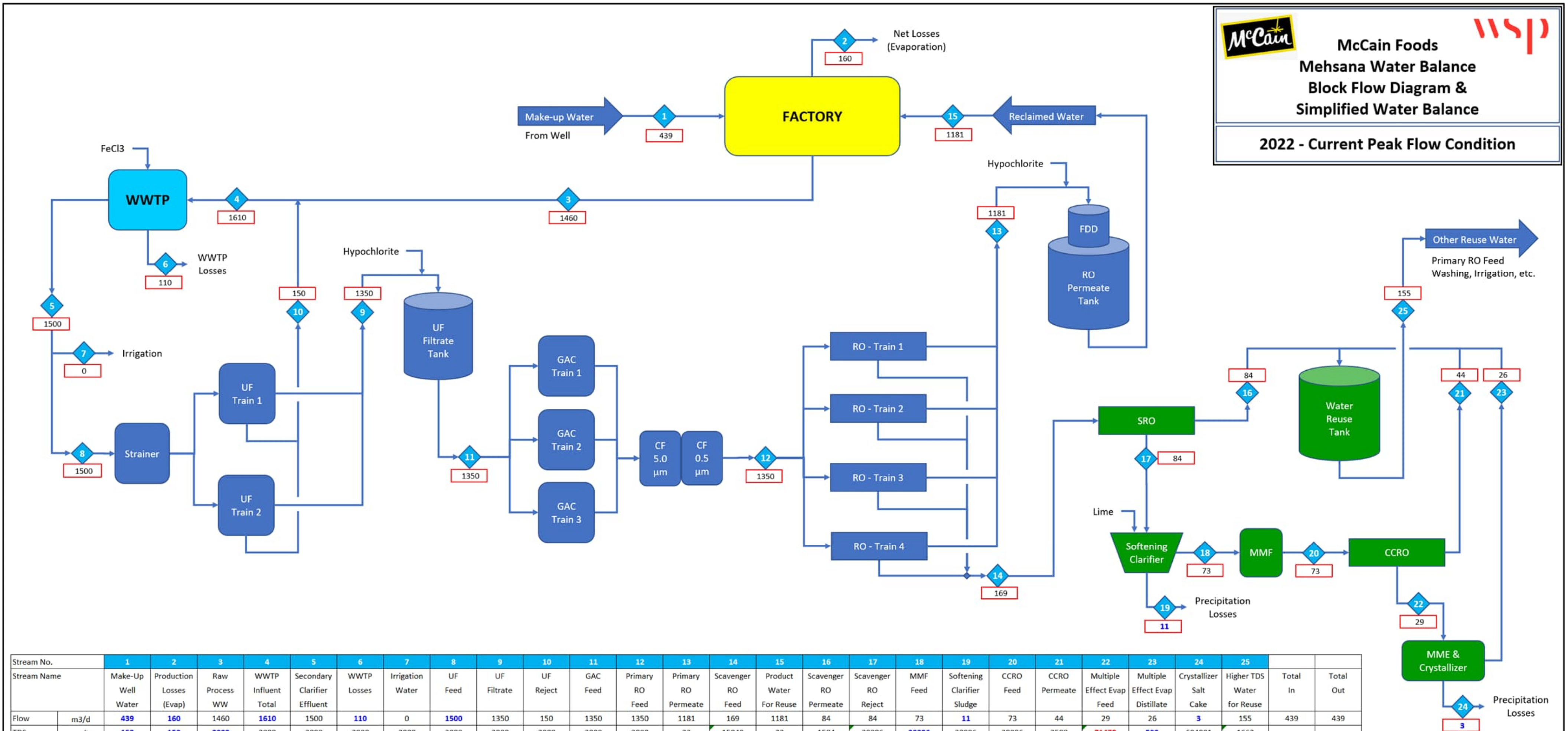
- Production Required a Reliable Source of Clean Water
- Equipment must operate and always perform adequately … even during upsets

Brine Concentration Technology Selection

RO Reject → **Brine Concentration** → **Softening** → **Filtration** → **Brine Concentration** → **Evaporation** → **Crystallization** → **Salt Cake**

	Brine Concentration	Softening	Filtration	Brine Concentration	Evaporation	Crystallization
Options	Seawater RO (1000 psi) Ultra High Pressure RO (1800 psi) Closed Circuit RO (CCRO)	Membrane Softening (NF) Softening Clarifier Ion Exchange	Sand Filtration Multimedia Filtration (MMF) Microfiltration (MF) Ultrafiltration (UF)	Seawater RO (1000 psi) Ultra High Pressure RO (1800 psi) Closed Circuit RO (CCRO)	Multiple Effect Evaporator (MEE) Mech Vapor Compressor (MVR) Spray Dryer Direct Contact Evaporator	Forced Circulation Crystallizer Spray Dryer Direct Contact Evaporator
Selection	Seawater RO (SRO)	Softening Clarifier	Multimedia Filtration (MMF)	Closed Circuit RO (CCRO)	Multiple Effect Evaporator (MEE)	Forced Circulation Crystallizer
Primary Reasons Why	Simple Low capital cost	Client wanted highest possible recovery	MMF is very reliable when operating conditions are stable/constant Low capital cost	Organic fouling is mimized in CCRO by cycling TDS conc CCRO recovery can be optimized after start-up by adjusting cycle times	Low capital cost	Waste heat was not available Low capital cost

Note: In 2015, McCain decided to replace the Evaporation Ponds with a Brine Concentration system, an Evaporation system and a Crystallizer system. The Brine Concentration system is refered to as the Scavenger RO (SRO) and is a simple two stage RO with Seawater RO membranes.
In 2018, McCain decided to install a Softening System and another Brine Concentration step upstream of the MEE and Crystallizer to reduce flow/loading to the evaporation system. This would help with equipment redundancy of the MEE and Crystallizer during maintenance (i.e. HX tube cleaning) and reduce operating costs (evaporator steam consumption).



Stream No.		1	2	3	4	5	6	7	8	9	10	11	12	13
Stream Name		Make-Up Well Water	Production Losses (Evap)	Raw Process WW	WWTP Influent Total	Secondary Clarifier Effluent	WWTP Losses	Irrigation Water	UF Feed	UF Filtrate	UF Reject	GAC Feed	Primary RO Feed	Primary RO Permeate
Flow	m3/d	**439**	**160**	1460	**1610**	1500	**110**	0	**1500**	1350	150	1350	1350	1181
TDS	mg/L	**150**	**150**	**2000**	2000	2000	2000	2000	2000	2000	2000	2000	2000	23
TDS	kg/d	65.85	24	2920	3220	3000	220	0	3000	2700	300	2700	2700	27
SiO2	mg/L	**5**	5	**15**	15	15	15	15	15	15	15	15	15	0.2
SiO2	kg/d	2	1	22	24	23	2	0	23	20	2	20	20	0
RO Recovery										**90.0%**				**87.5%**
RO TDS Rejection														**99.0%**

Stream No.		14	15	16	17	18	19	20	21	22	23	24	25		
Stream Name		Scavenger RO Feed	Product Water For Reuse	Scavenger RO Permeate	Scavenger RO Reject	MMF Feed	Softening Clarifier Sludge	CCRO Feed	CCRO Permeate	Multiple Effect Evap Feed	Multiple Effect Evap Distillate	Crystallizer Salt Cake	Higher TDS Water for Reuse	Total In	Total Out
Flow	m3/d	169	1181	84	84	73	**11**	73	44	29	26	**3**	155	439	439
TDS	mg/L	15840	23	1584	30096	**30096**	30096	30096	2508	**71478**	**500**	694901	1662		
TDS	kg/d	2673	27	134	2539	2208	**1524**	2208	110	2098	13	2085	257		4110
SiO2	mg/L	119	0.2	36	**202**	202	1162	58	15	**123**	15	1080	26		
SiO2	kg/d	20	0	**3**	17	**17**	**13**	4	**1**	4	0	3	4		22
RO Recovery				**50.0%**					**60.0%**						
RO TDS Rejection				**95.0%**					**95.0%**						

Treatment Technologies

Technology Selection

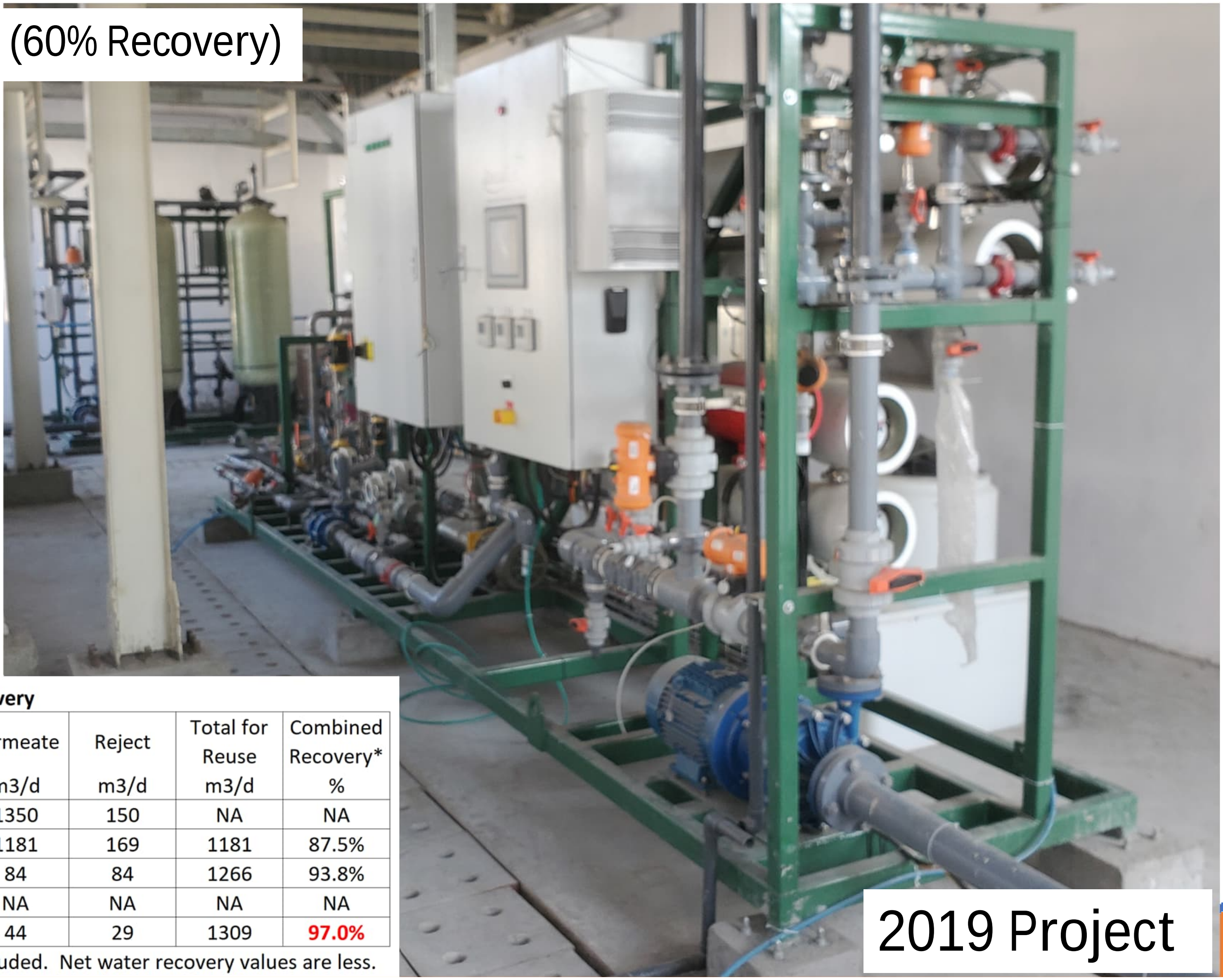
HERO vs. CCRO			
	HERO (IX + high pH RO)	Lime Softening + CCRO	Comments
Description	High Efficiency RO system operates at very high recovery. Includes Ion Exchange softening WAC followed by RO operating at a high pH	High Recovery RO operates in semi batch mode - continuous feed and permeate flowrate with batch RO reject cycling between concentration mode and purge mode. Includes lime softening clarifier.	-
Key Advantages	Operating at high pH: - minimizes silica scaling - silica is very soluble at high pH - minimizes biological fouling - biological cells don't like high pH	Large TDS swinges in feed: - reduce scaling - salts redissolve when TDS drops at beginning of cycle - reduce biological activity - biological cells don't like rapid TDS changes - adjustable recovery (cycle duration) offers ability to "tune" CCRO for varying feed conditions	Both processes have key advantages over conventional RO HERO very effective for high silica CCRO is very attractive if feed water quality is unknown or may change in future
Key Disadvantage	Ion Exchange can be very expensive when TDS and Hardness levels are very high	CCRO is a single stage system with fewer membranes in each housing so they are larger and more expensive systems than conventional RO	HERO less competitive when TDS and hardness is high. CCRO less completive for primary RO.

Scavenger RO 1x100% (50% Recovery)

Multiple Effect Evaporator 1x100%

2016 Projects

CCRO 1x100% (60% Recovery)



RO Membrane Systems - Combined Recovery

System	Feed m3/d	Recovery* %	Permeate m3/d	Reject m3/d	Total for Reuse m3/d	Combined Recovery* %
UF	1500	90%	1350	150	NA	NA
PRO	1350	87.5%	1181	169	1181	87.5%
SRO	169	50%	84	84	1266	93.8%
Clarifer/MMF	84	NA	NA	NA	NA	NA
CCRO	73	60%	44	29	1309	97.0%

*Water used for CIP and rinsing is not included. Net water recovery values are less.

2019 Project

Lessons Learned

1) Evaporators & Crystallizers are very expensive systems and the solution with the lowest capital cost may not always be as robust or reliable.

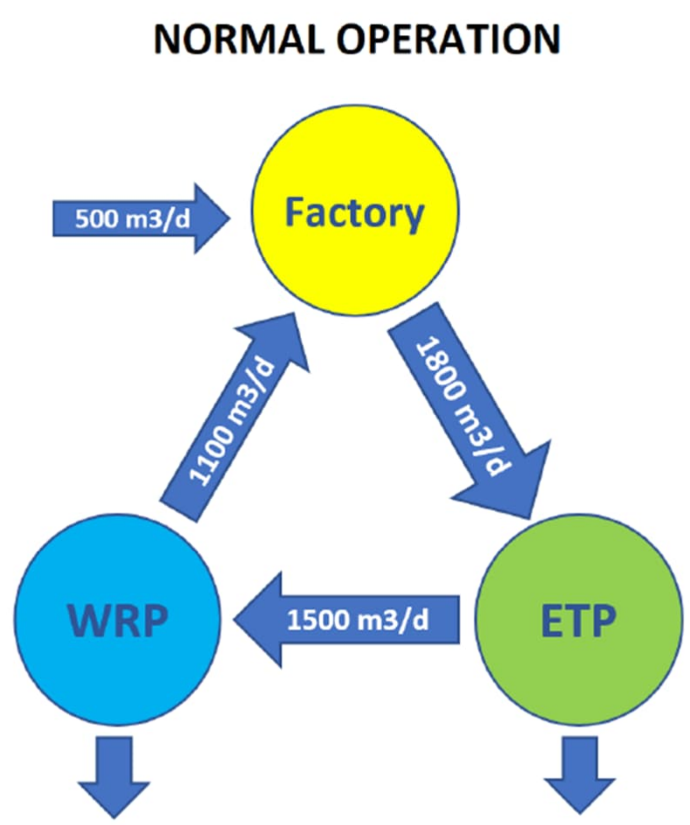
2) Local vendors can provide superior service during start-up and commissioning. Vendors that provide service remotely (from a different country) can require multiple visits and this can cause delays.

3) There are many technologies to concentrate brine. Process designers must understand the differences and be unbiased to select the most appropriate technology for each application.

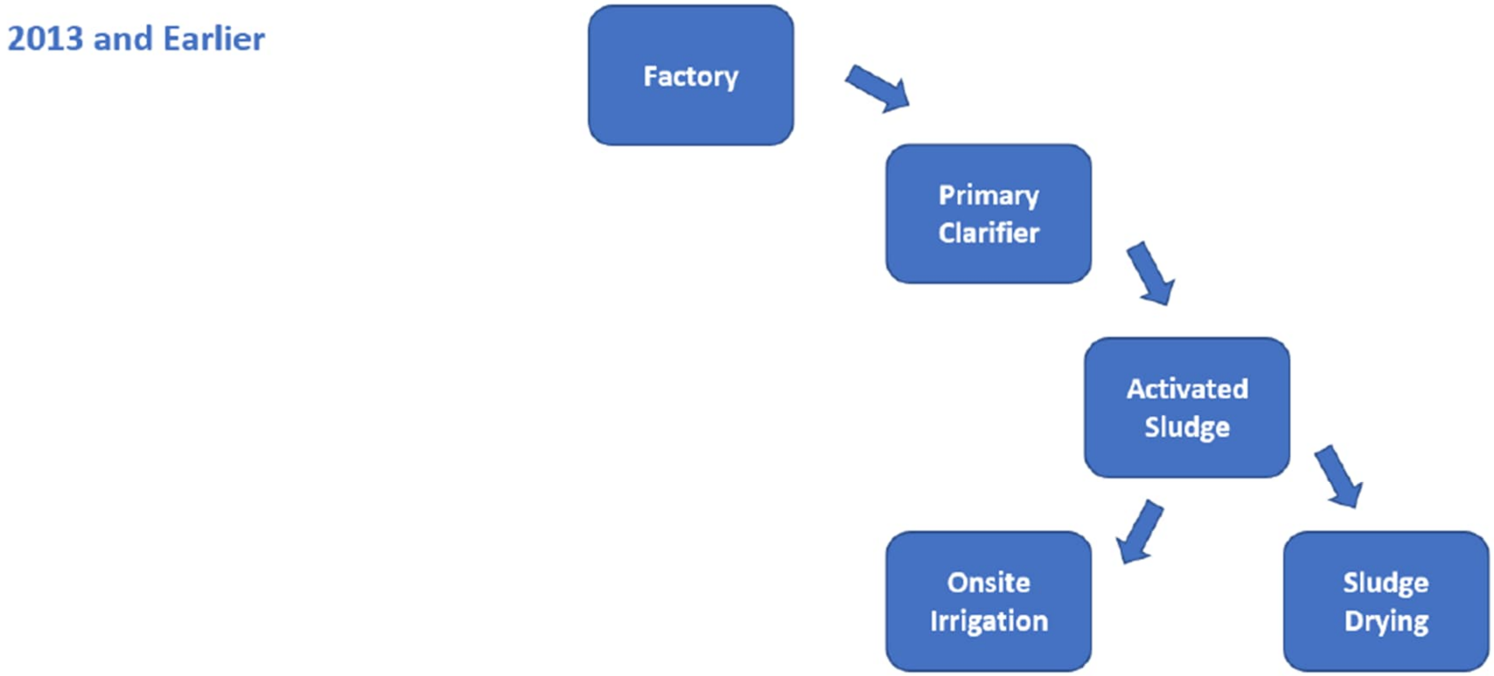
4) Combining separate technologies in one flowsheet may require separate contracts with different vendors … especially if the vendors provide competing technologies.


KEEP
CALM
AND
REUSE
WATER

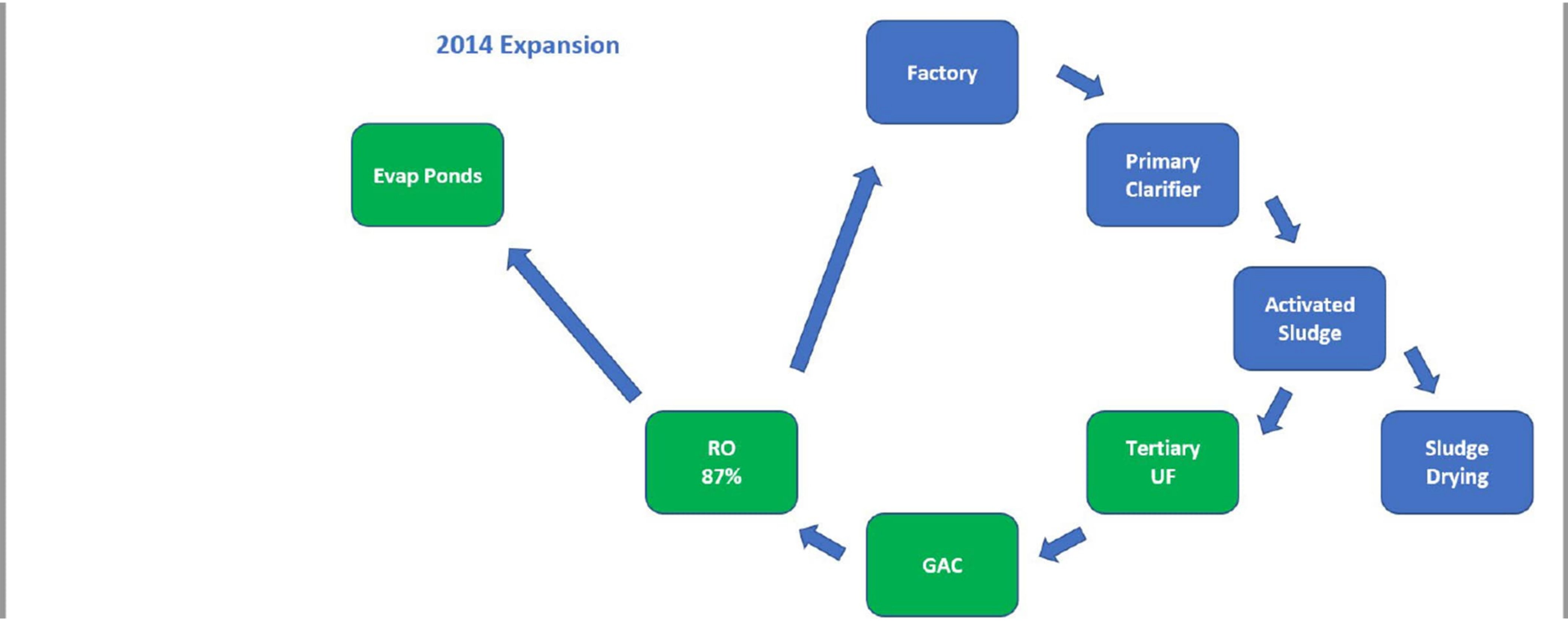
Lesson Learned … 2017 Major Upset



2017 Major Upset



2017 Major Upset



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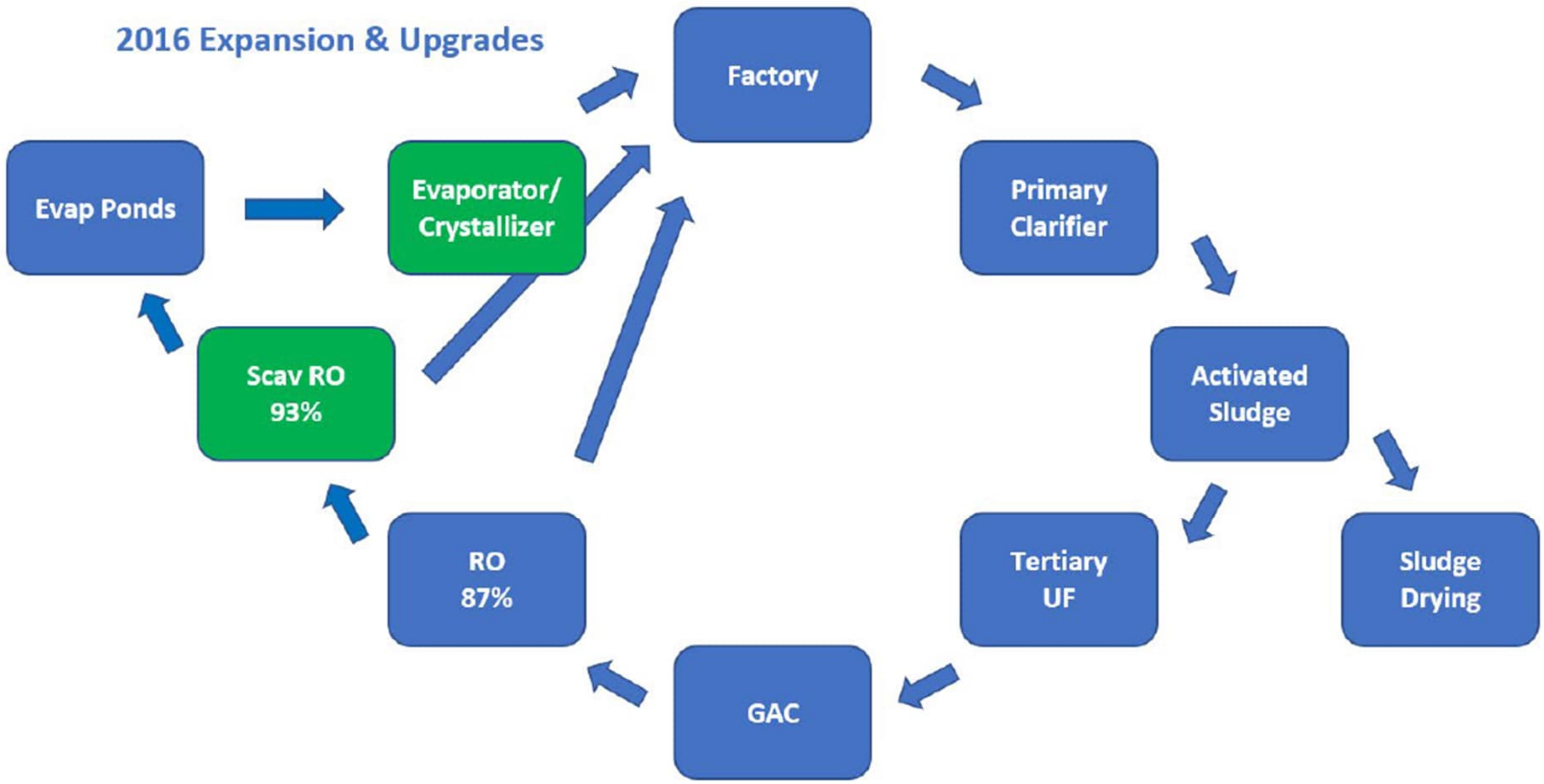
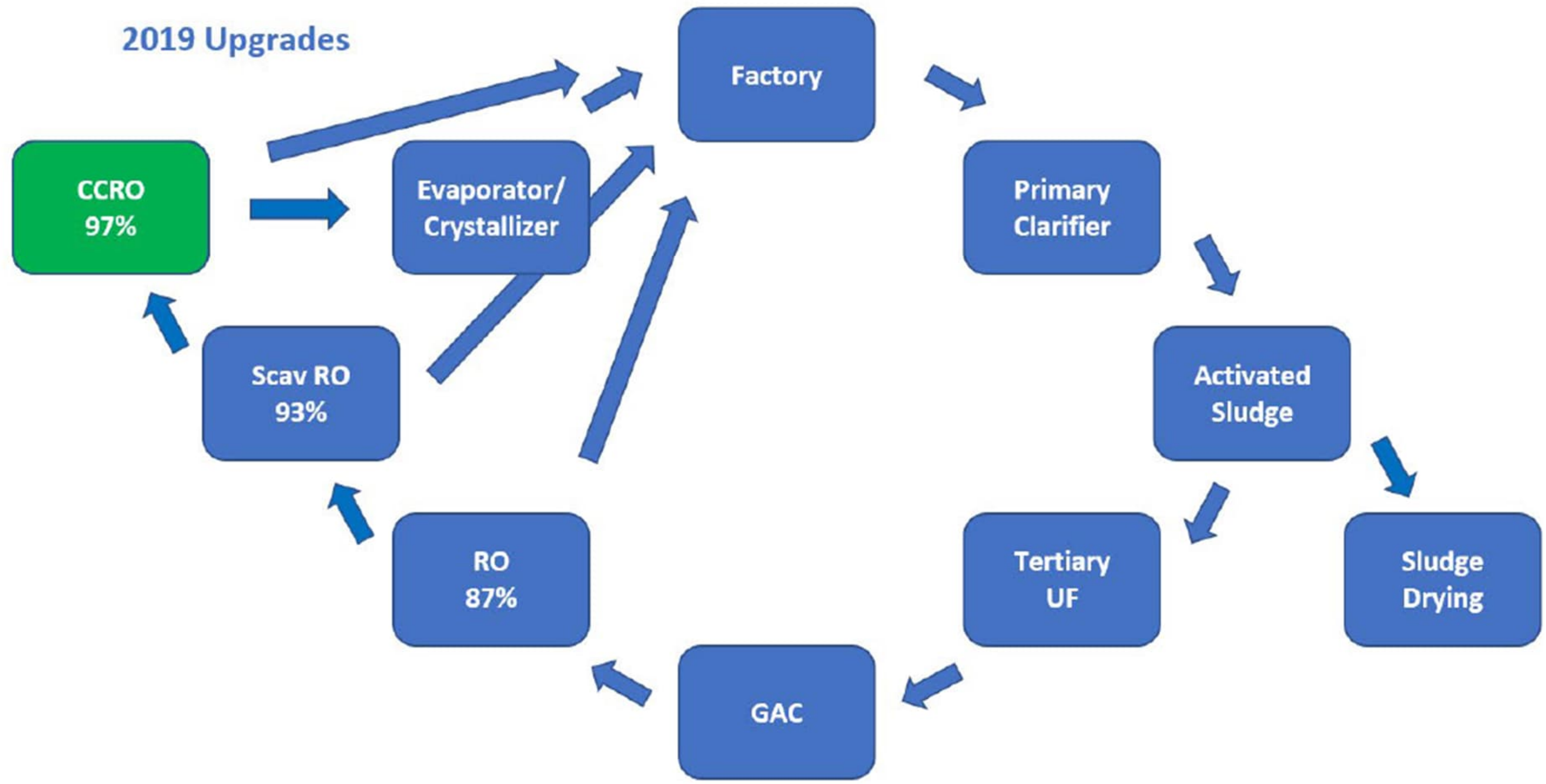


2017 Major Upset

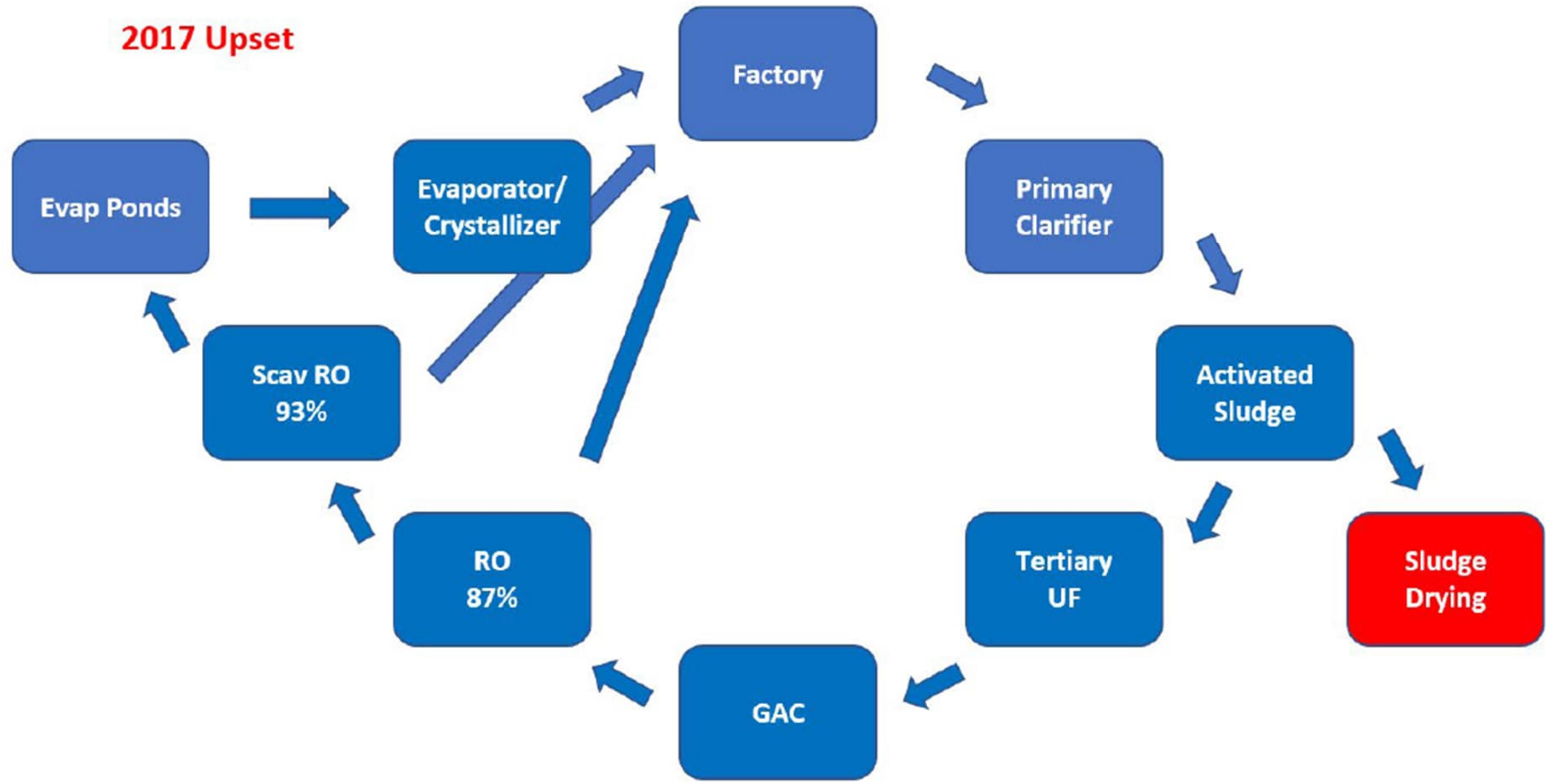


2017 Major Upset

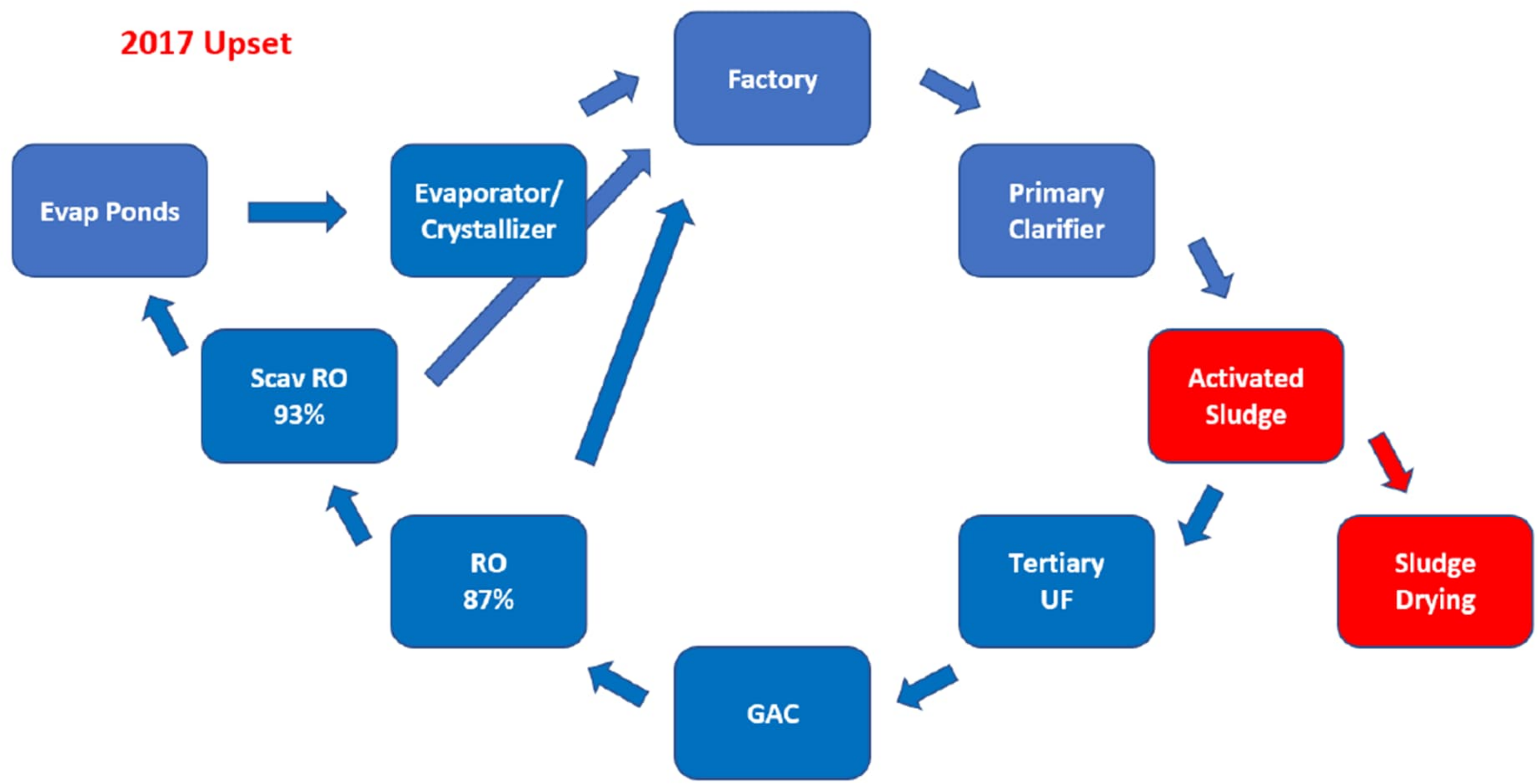
Biological Treatment Upset in late 2017:

- Rainiest monsoon season of the decade
- Reduced sludge wasting to Drying Beds
- MLSS too high
- F:M too low
- Filamentous growth

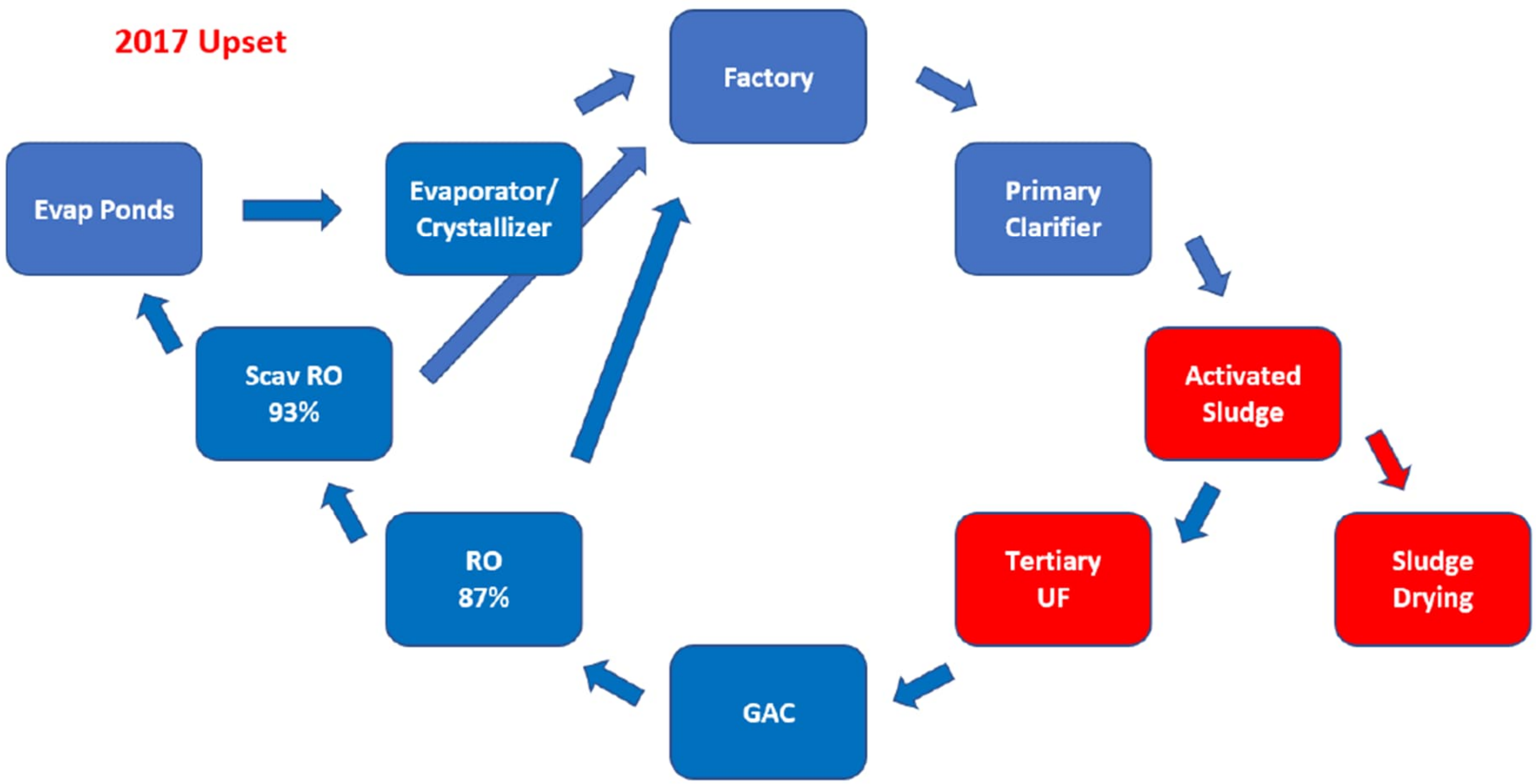
2017 Major Upset – Monsoons & Floods



2017 Major Upset



2017 Major Upset



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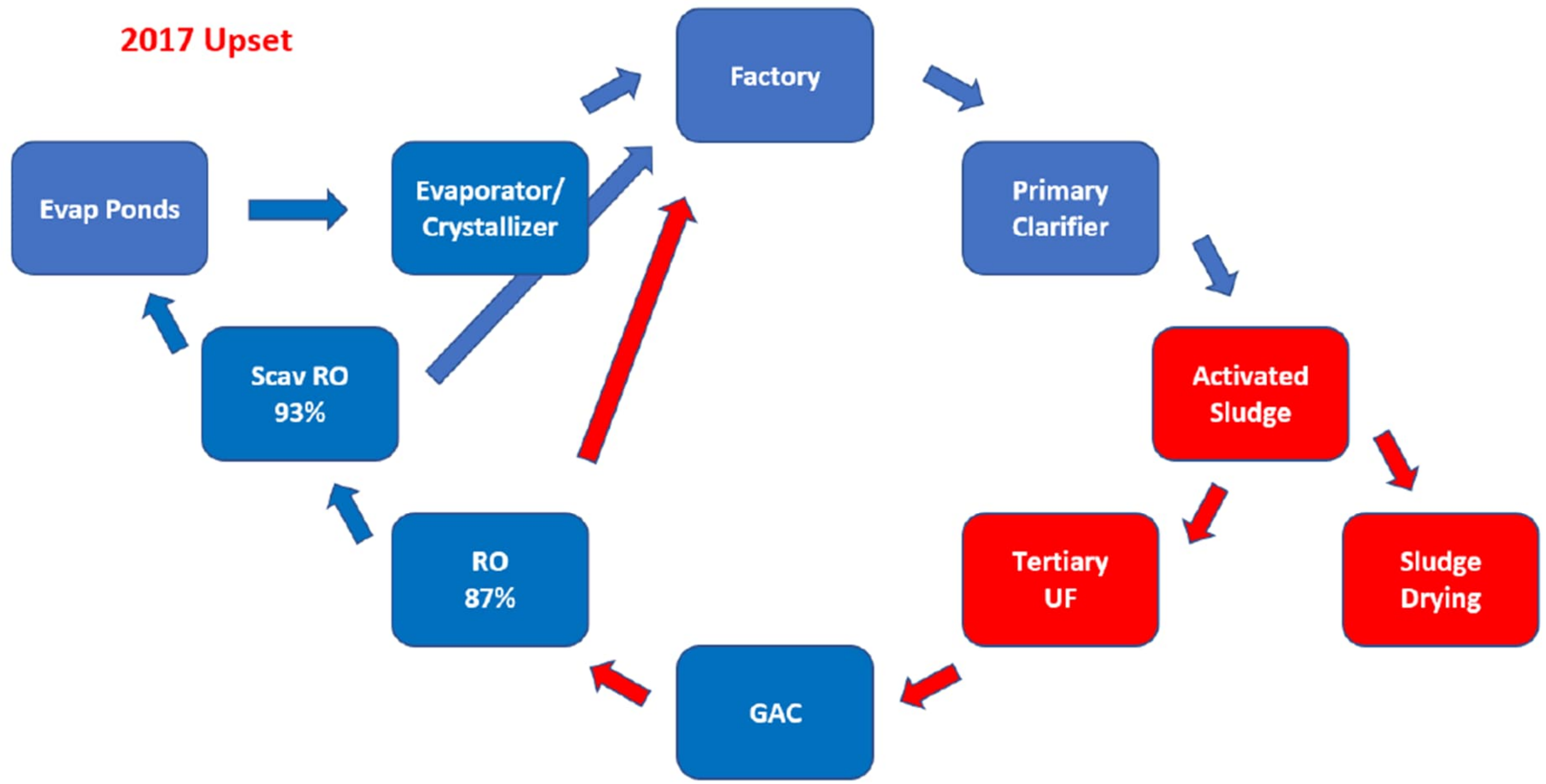
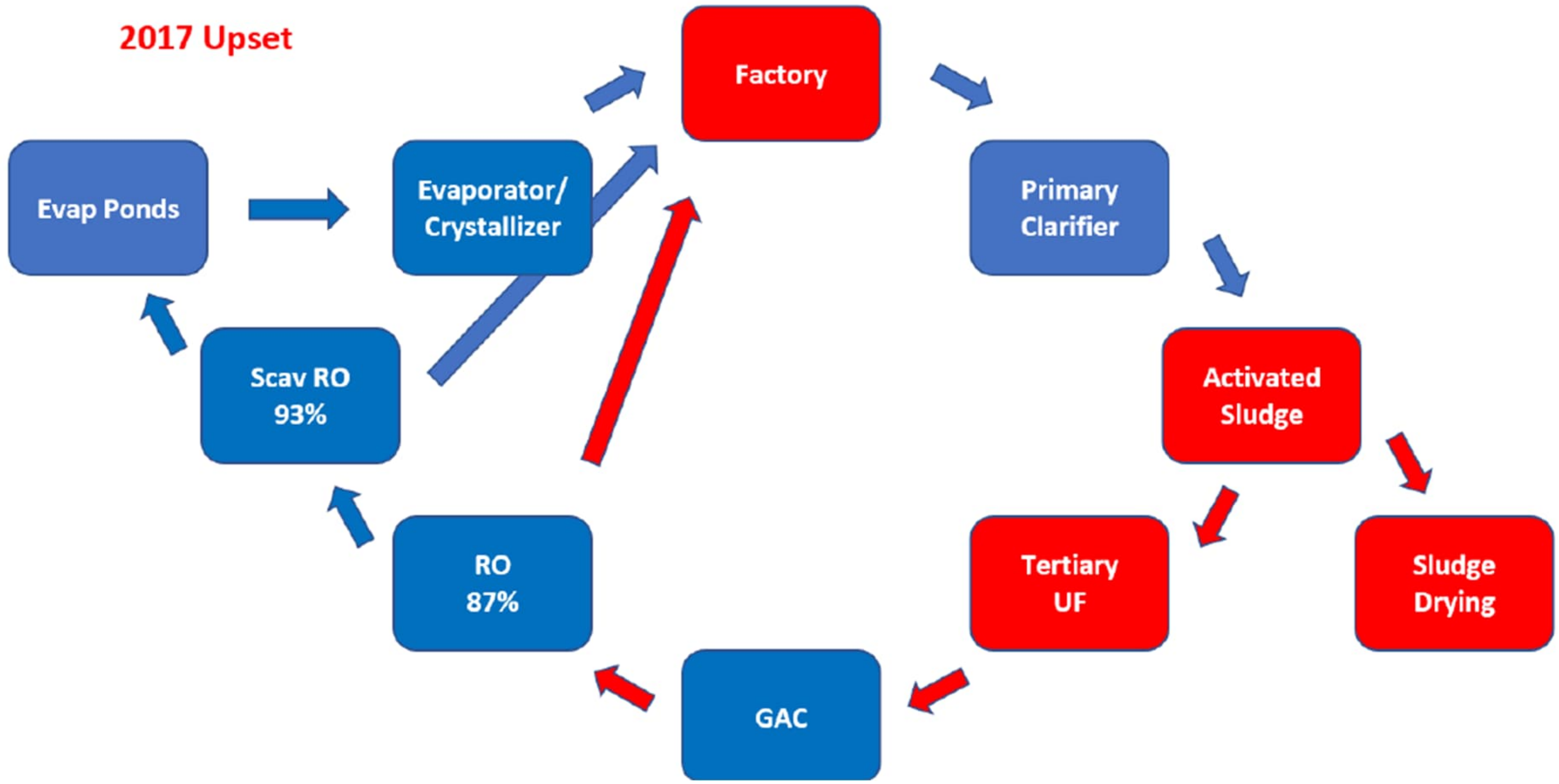


2017 Major Upset



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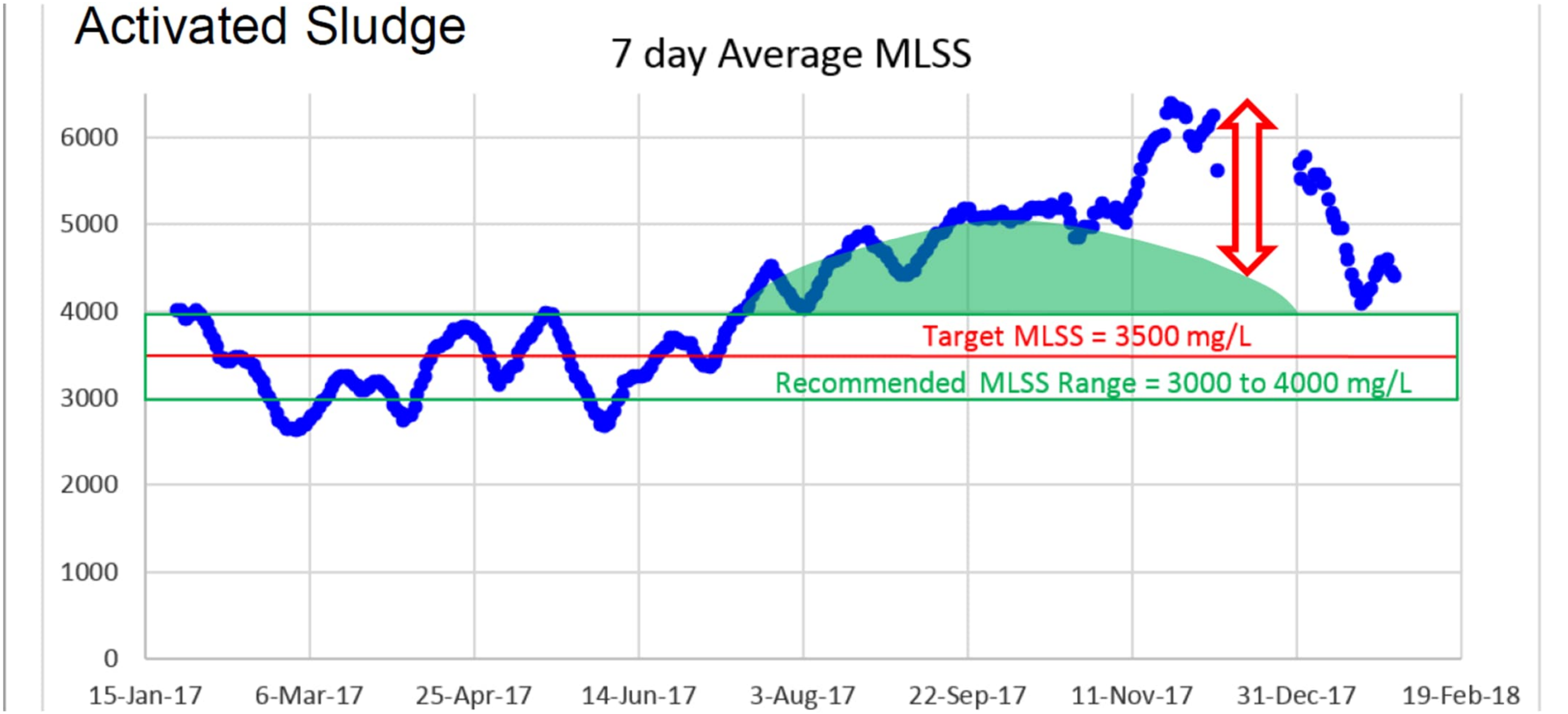

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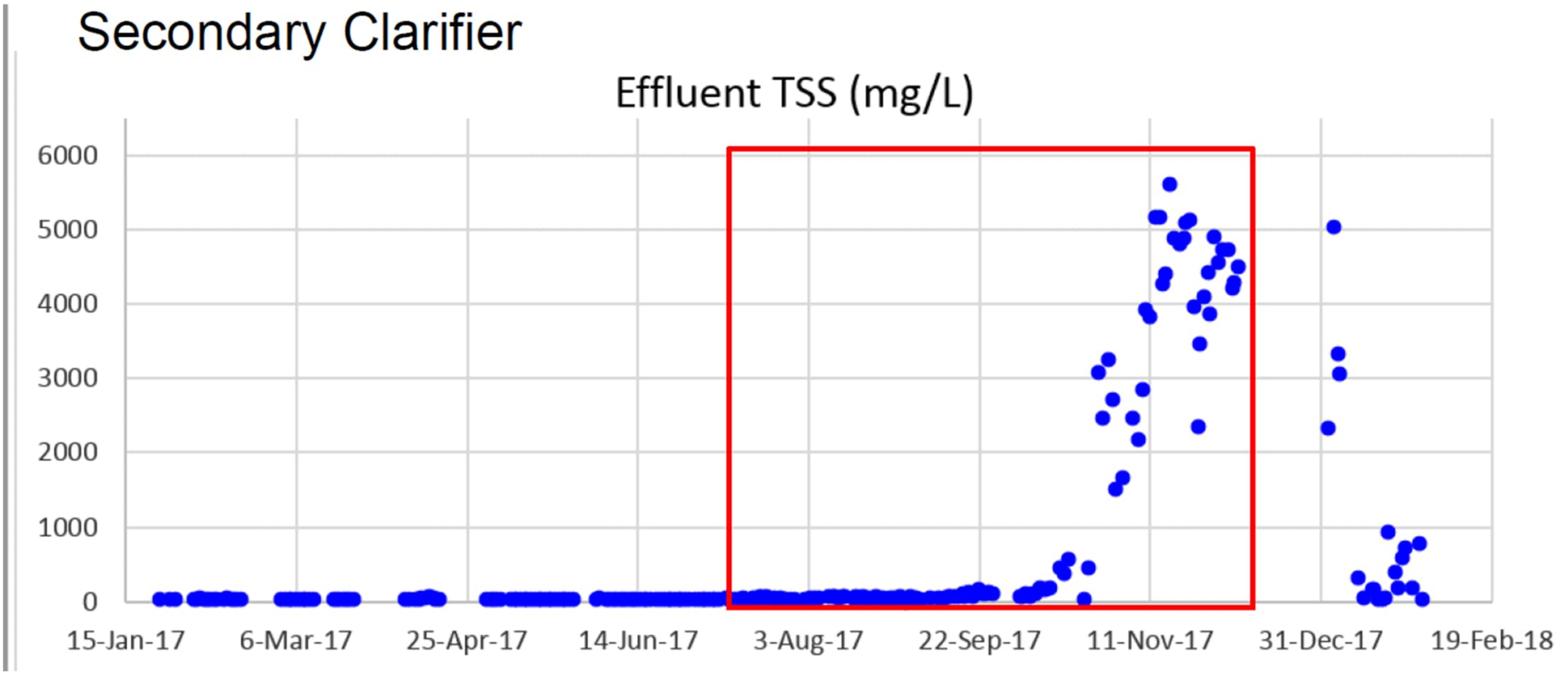

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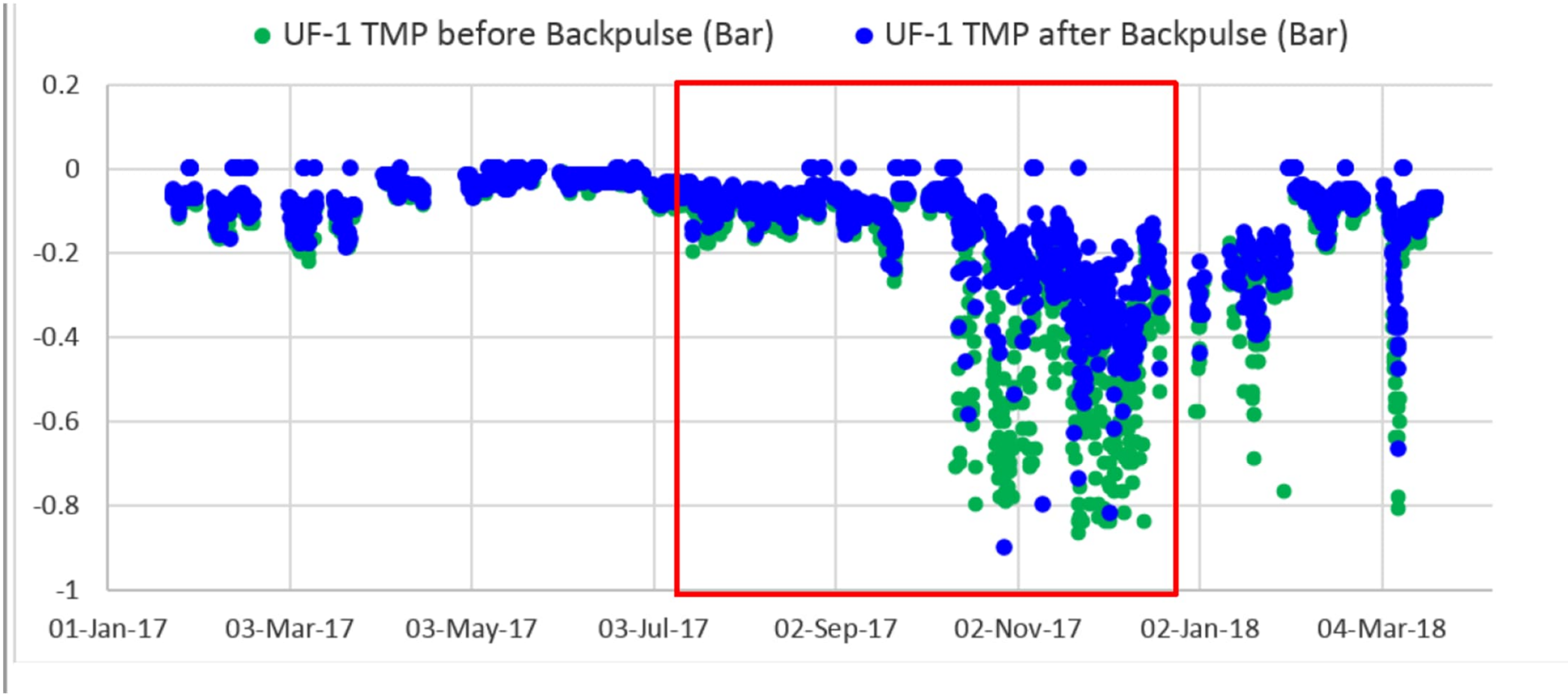
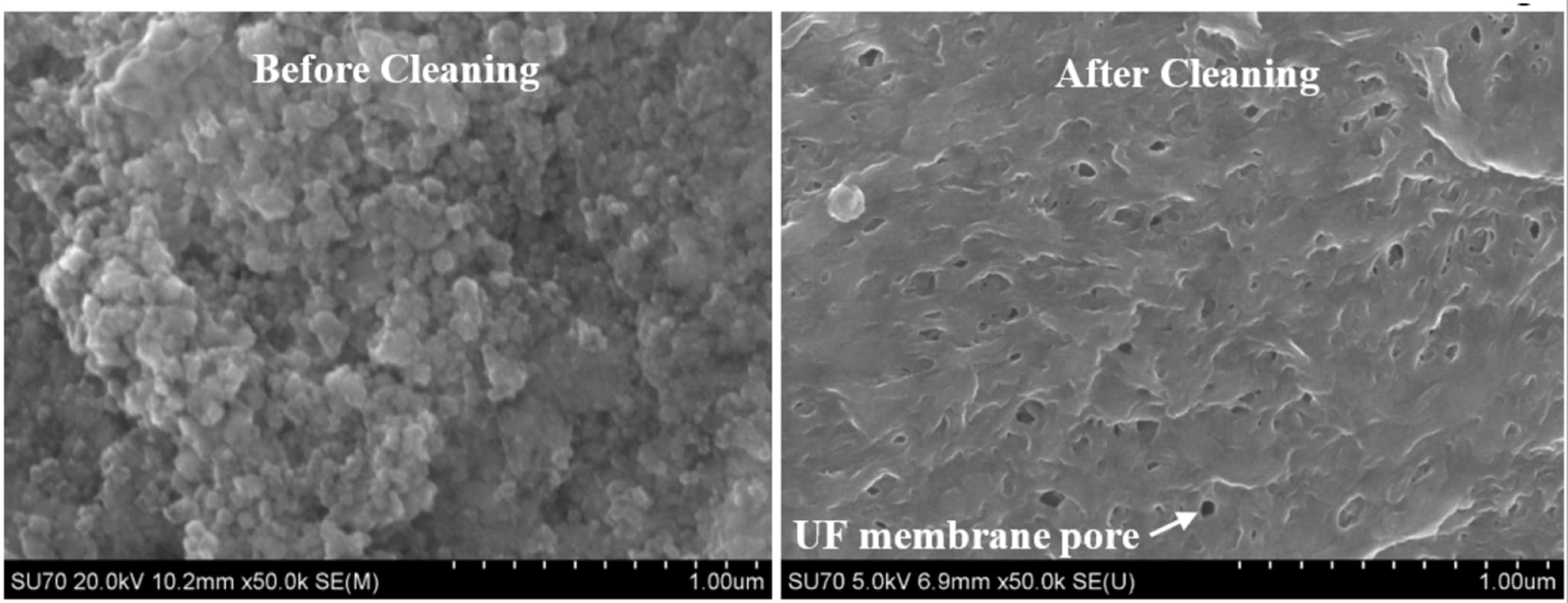


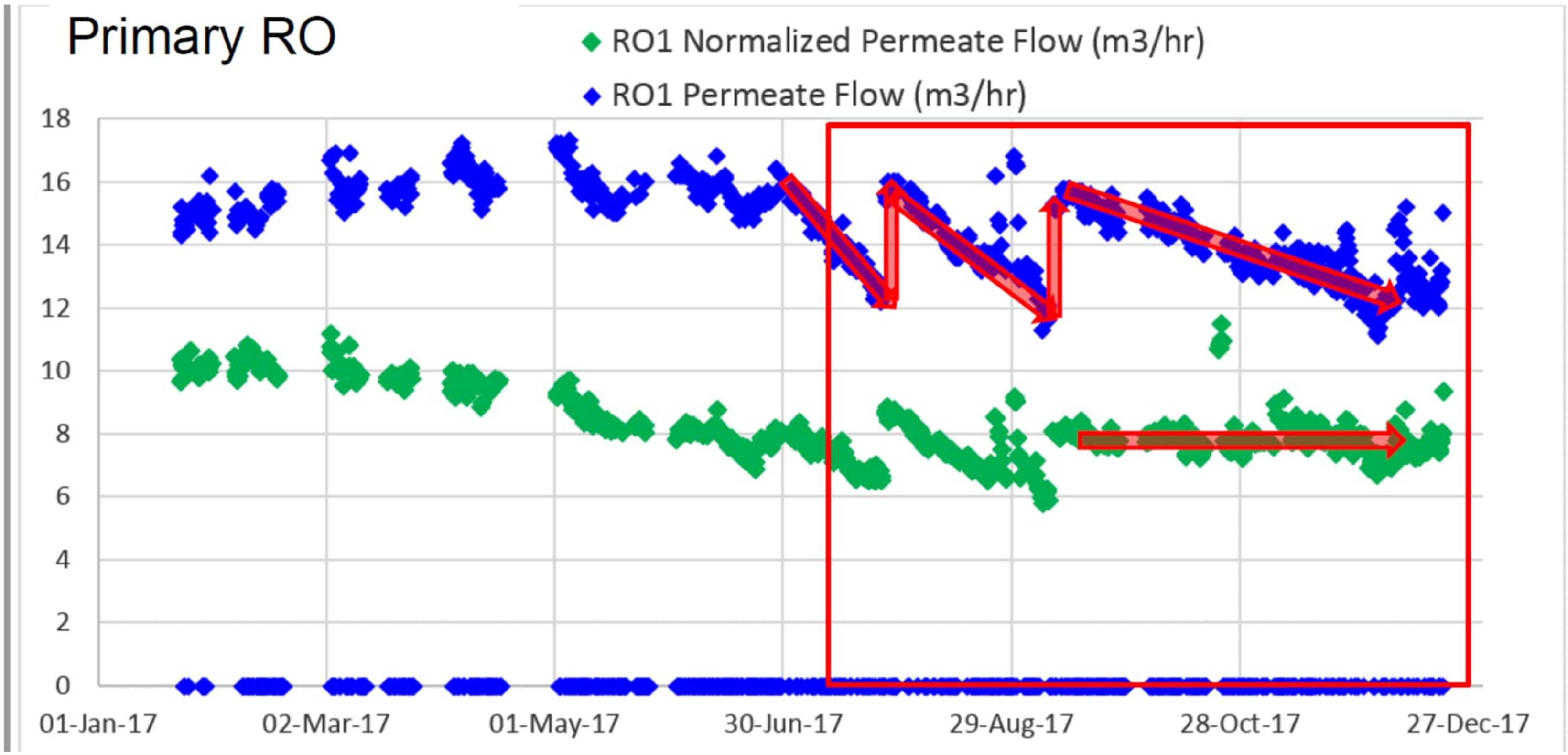
2017 Major Upset

2017 Major Upset

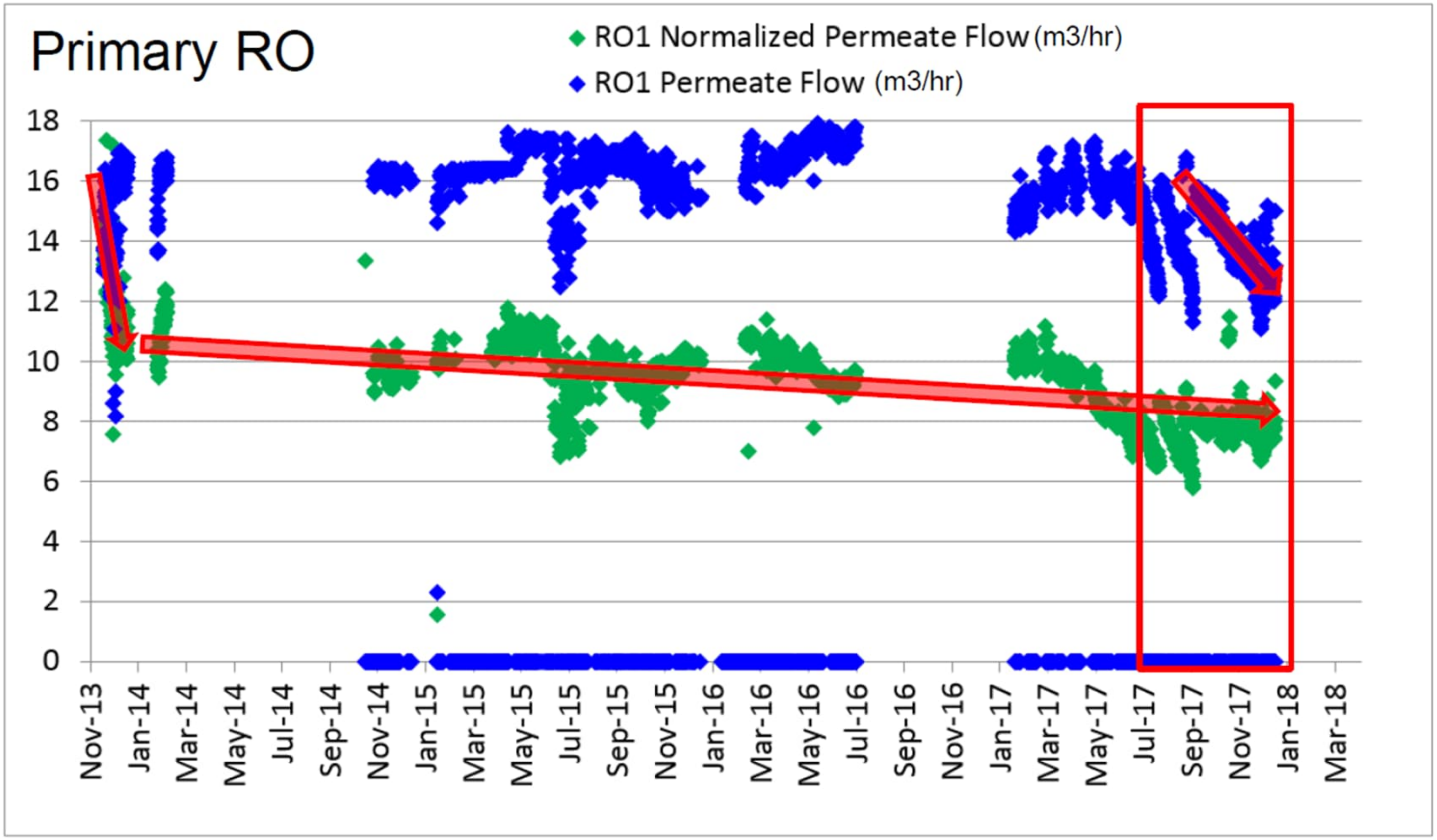
UF - Membrane Autopsy



2017 Major Upset



2017 Major Upset



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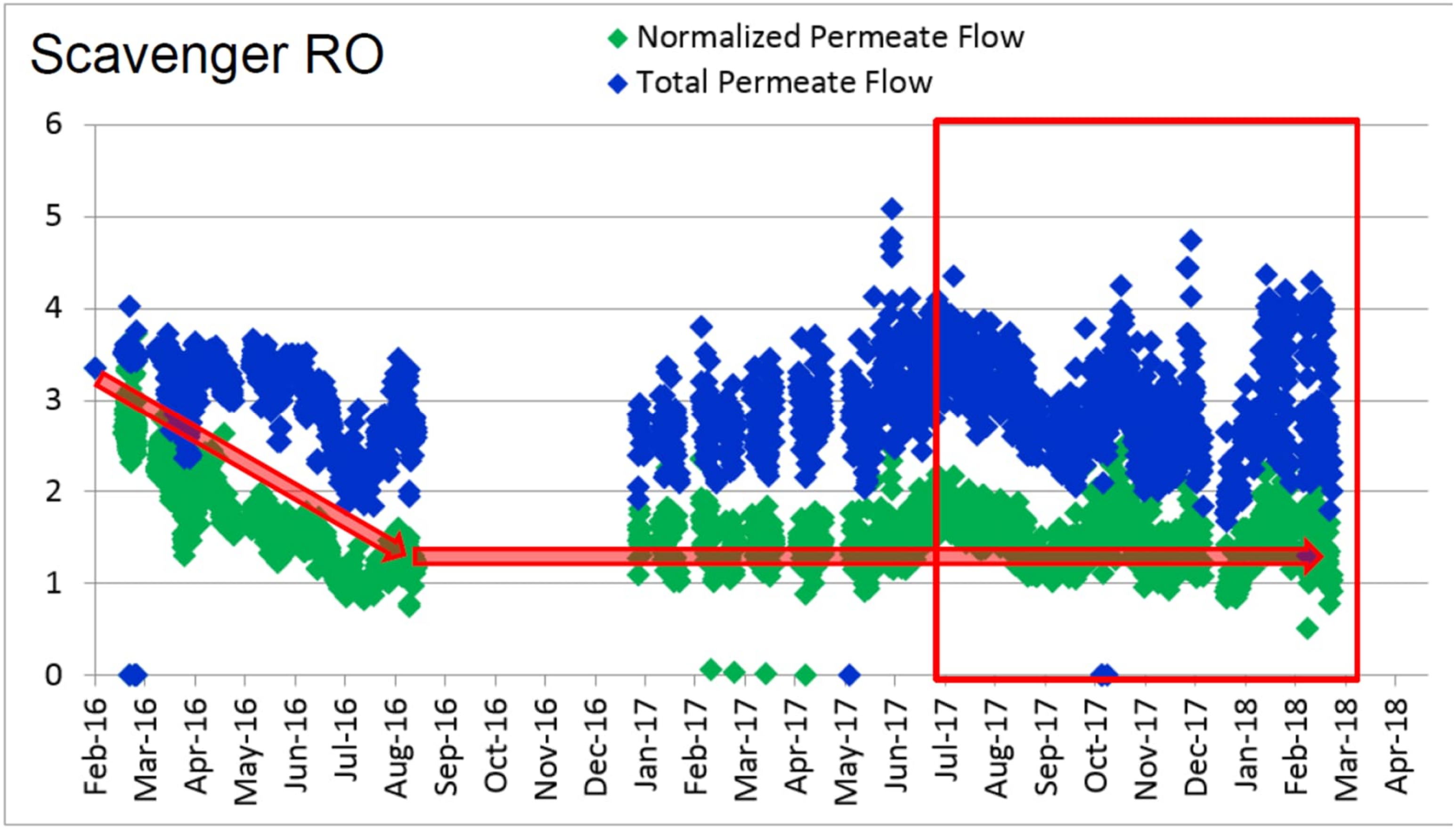


Case Study – WWTP, WRP and ZLD Expansion

Who: McCain Foods Mehsana
When: Startup in 2025
Where: Gujarat, India … a very arid region

Expand All Water and Wastewater Treatment Infrastructure:

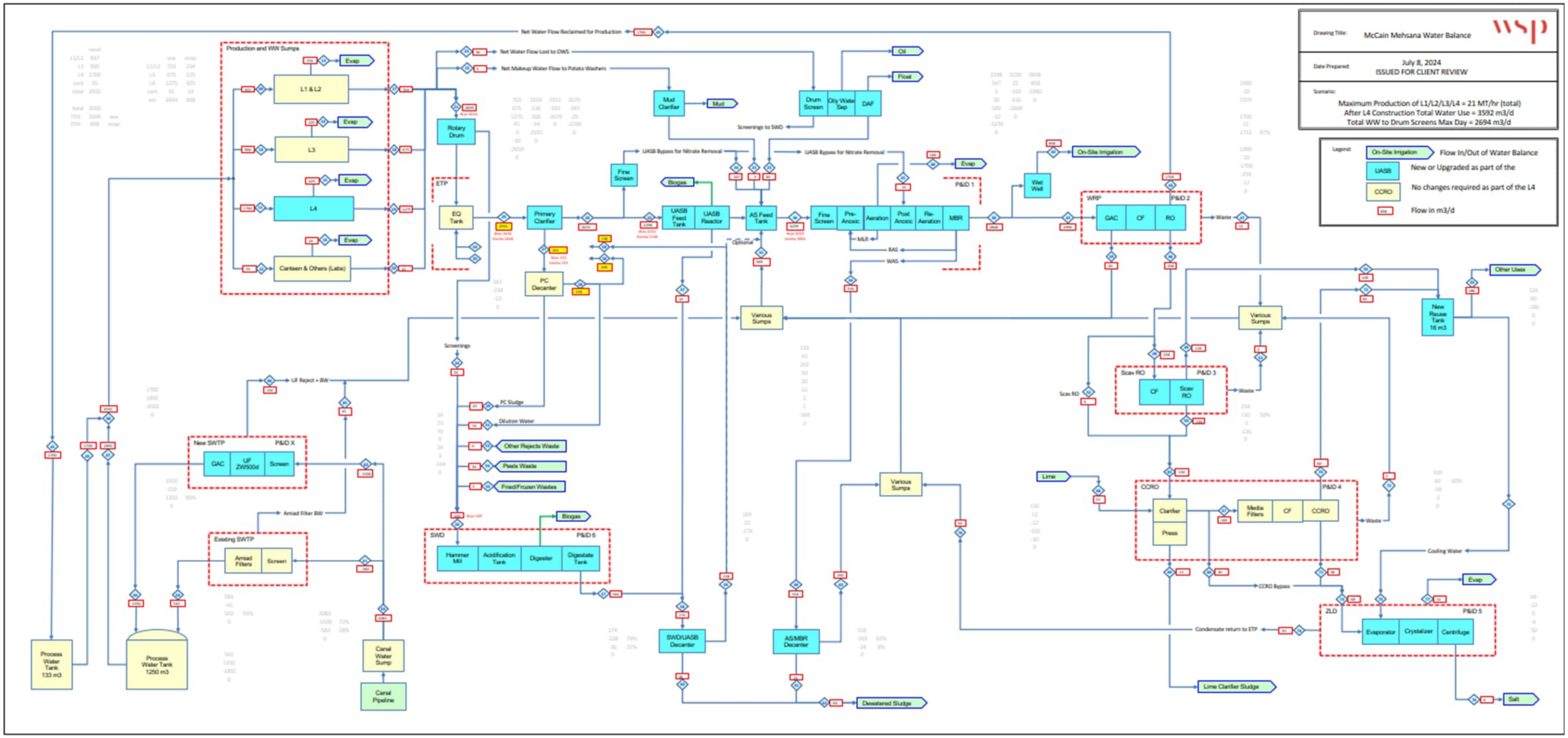
- Increased demand for McCain's products → Another plant expansion (more wastewater created & more reuse water needed)
- Very limited space

Challenges for Water Reuse/Brine Concentration and Evaporation:

- Equipment must operate at all times and always perform well … Even during upsets!
- Space Constraints – Expand everything without a shutdown of the WWTP
- Minimize impact to McCain Foods Production

Major Expansions & Upgrades

- New production line increases process water need. Reuse water need grows from 1180 to 1700 m3/d. Key challenges are the growing water footprint and shrinking space on site.
- New (larger) pretreatment equipment … rotary drum screens and primary clarifier
- New UASB, biogas scrubber and biogas flare
- New activated sludge basin with fine bubble aeration to replace aeration lagoon and secondary clarifier
- New MBR to replace tertiary UF
- Additional trains of GAC, primary RO and secondary RO to expand capacity of WRP
- No changes to Closed Circuit RO (brine concentrator RO)
- New MVR evaporator / crystallizer system to expand on existing MEE treatment capacity
- Other water/wastewater infrastructure systems and equipment (SWD, SWTP, OWS, etc.)



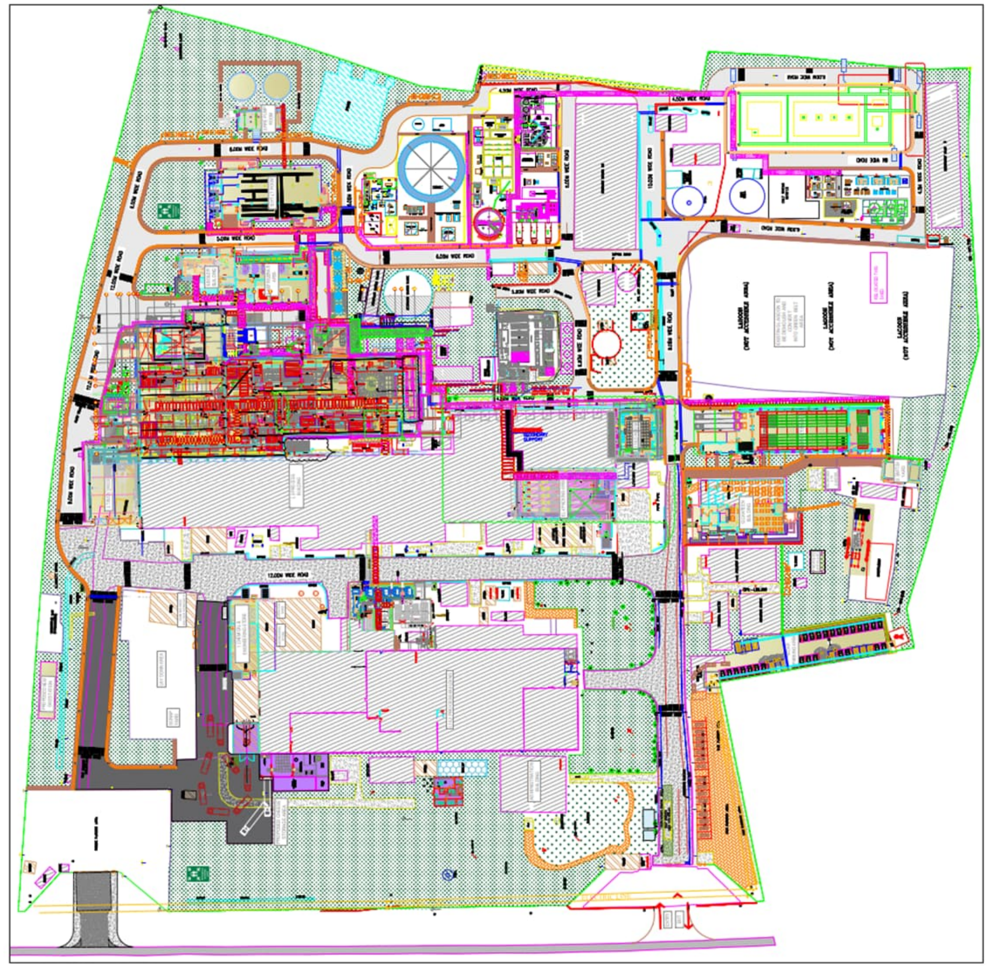
Stream No.		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Description		Canal Water to Exist SWTP	Canal Water to New SWTP	Amiad Filtrate to 1250 Tank	UF Filtrate to 1250 Tank	Amiad Filter BW	UF Reject and BW	Filtered Water to Factory	Process Water to Factory	L1&L2 Feed	L3 Feed	L4 Feed	Canteen & Other	Evap Losses L1&L2	Evap Losses L3	Evap Losses L4	Evap Losses Other	L1&L2 WW	L3 WW	L4 WW	Other WW to EQ Tank
Flow	m3/d	583	1500	542	1350	41	150	1892	3592	937	900	1700	55	234	225	425	14	703	675	1275	41
	gpm	107	275	99	248	7	28	347	659	172	165	312	10	43	41	78	3	129	124	234	8
COD	mg/L																				
	kg/d																				
TSS	mg/L																				
	kg/d																				
TDS	mg/L																				
	kg/d																				

Stream No.		21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40
Description		WW to Drum Screens	Net Water to Mud System	Oily Water System Effluent	Screenings	Screened WW to PC	PC Effluent	PC Sludge to Decanter	PC Decanter Centrate	PC Sludge to HM	PC Decant to EQ Tank	Dilution Water to HM	Feed to UASB	Reuse Water Other Uses	Bypass to AS Feed	Bypass to Post Anoxic	AS Influent	UASB Waste Sludge	MBR Permeate	MBR WAS	Evap Losses from ETP
Flow	m3/d	2659	5	30	34	2931	2670	261	238	23	168	70	2298	186	347	25	3239	10	2848	316	100
	gpm	488	1	6	6	538	490	48	44	4	31	13	422	34	64	5	594	2	522	58	18
COD	mg/L					[illegible]	[illegible]				[illegible]		[illegible]				[illegible]				
	kg/d					21420	9756				672		13806				1457				
TSS	mg/L				[illegible]	[illegible]	[illegible]	2%	[illegible]	20%	[illegible]		[illegible]							1%	
	kg/d				7480	6504	1284	5220	952	4600	672		1735							3160	
TDS	mg/L																				
	kg/d																				

Stream No.		41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60
Description		Sumps to ETP	Irrigation	Feed to WRP	Perm from WRP	GAC BW Waste	RO Reject to Scav RO	RO CIP Waste	Scav RO Feed	Scav RO Perm	Scav RO Reject	Scav RO CIP Waste	Scav RO Bypass	Other Rejects Waste Solids	Peels Waste Solids	Fried/Frozen Waste Solids	SWD Feed	SWD Digestate	SWD Decanter Feed	SWD Decanter Centrate	SWD Decanter Cake
Flow	m3/d	569	858	1990	1700	20	258	12	258	126	130	2	0	0	34	3	164	164	174	138	36
	gpm	104	157	365	312	4	47	2	47	23	24	0	0	0	6	0	30	30	32	25	7
COD	mg/L																			[illegible]	
	kg/d																			276	
TSS	mg/L														[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	kg/d														3740	800	20438	8175	8675	1380	8875
TDS	mg/L			[illegible]	[illegible]		[illegible]		[illegible]	[illegible]	[illegible]										
	kg/d			3781	82		3668		3668	44	3616										

Stream No.		61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	Balance: Total In	Balance: Total Out
Description		MBR WAS Decanter Cake	WAS Decanter Centrate	Dewatered Sludge	Raw Canal Water	CCRO Clarifier Feed	CCRO Bypass	CCRO Feed	Lime & Soda Ash	CCRO Clarifier Sludge	CCRO Perm	CCRO Reject	CCRO CIP Waste	ZLD Feed	Condensate Return to ETP	Cooling Water	Salt Cake from ZLD	Evap Losses from ZLD	Total In	Total Out
Flow	m3/d	24	292	60	2083	130	30	100	12	12	60	38	2	68	50		6	12	2131	2131
	gpm	4	54	11	382	24	6	18	2	2	11	7	0	12	9		1	2	391	391
COD	mg/L																			
	kg/d																			
TSS	mg/L	[illegible]		[illegible]																
	kg/d	3120		2975																
TDS	mg/L					[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]		[illegible]			
	kg/d					3634	834	2780	2400	2400	42	2738		3572	13		3561			

Site Layout – Space Constraints

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