HDR

Fifteen Years of Progressive Membrane Bioreactor Experience in the Pacific Northwest

Patrick Roe

April 27, 2018

HDR

Membrane Bioreactors (MBRs)

- In the last 15 years, MBRs have become common in the Pacific Northwest
- Significant advantages over conventional activated sludge
  - High mixed liquor suspended solids (biomass) allows compact footprint
  - No secondary clarifier
  - Membrane filtration results in high-quality effluent
- Treatment capacity can vary
- Relatively new technology
- Retrofits to facilities operating less than six years
- "Lessons learned" from design and operation
  - Apply to retrofits of an existing facility
  - Considering new MBR plant

01 Membrane Bioreactor Basics

02 Control Influent Debris to Protect Membranes

03 Plan for Membrane Cleaning

04 Control Potential Contaminants

05 Consider Cold Wastewater Impacts

06 Equalize Influent Flow to Improve Performance

07 Configure Membrane Scouring Air System for Variable Supply

08 Assess Control System Maintainability

09 Plan for Membrane Replacement

10 Consider New Membrane Technologies

MBR Lessons Learned – Courtesy of Gordon Culp

- Carefully select the membrane flux rate
  - Membrane filterability varies
  - Cold weather impacts permeability
- Run pilot test
  - City of Coeur d'Alene performed a 20-month test
- Equalize wastewater flow
  - Membrane operate best at constant flow
- Provide right O&M skills
  - MBRs are complex and highly automated
- Talk with other utilities using the same membranes
- Check the membrane warranty
- Plan for what happens when membranes can't keep up

Membrane Bioreactors – Lessons Learned
Gordon Culp, Smith Culp Consulting
Presented at the 2018 Nevada Water Environment Association Conference

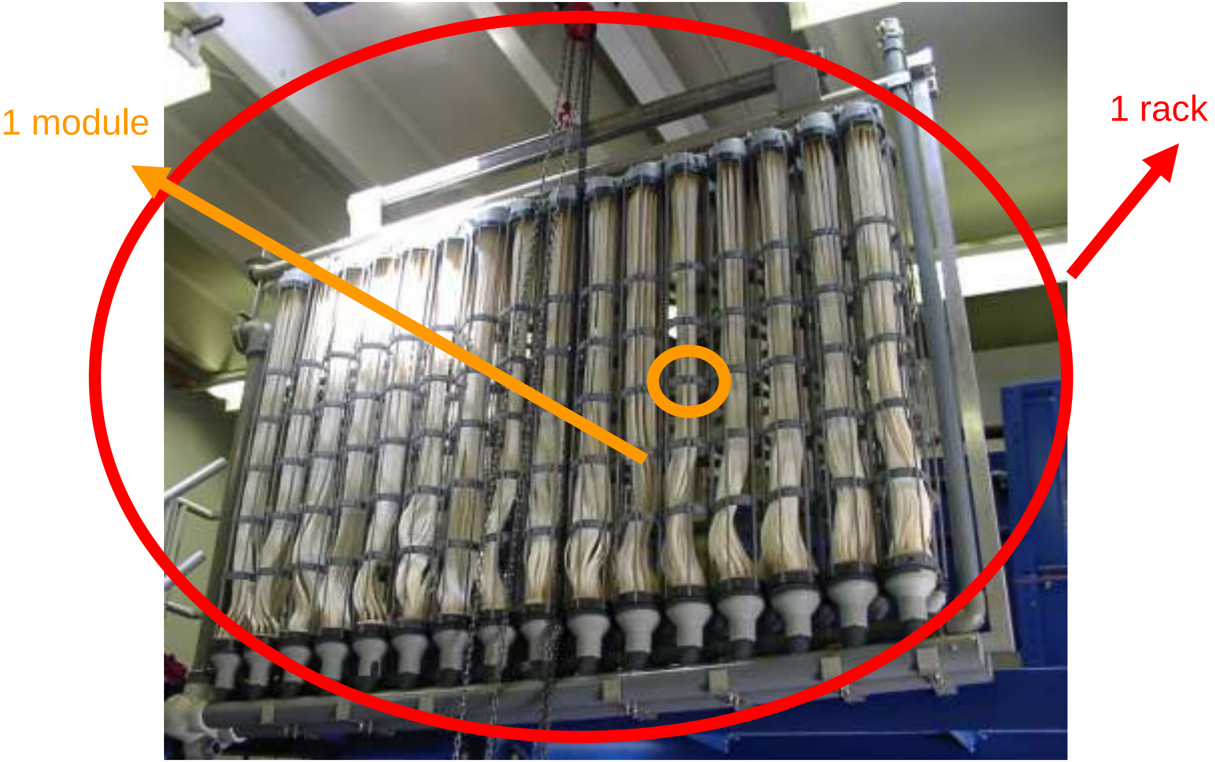
01 Membrane Bioreactor Basics

What is a Membrane?

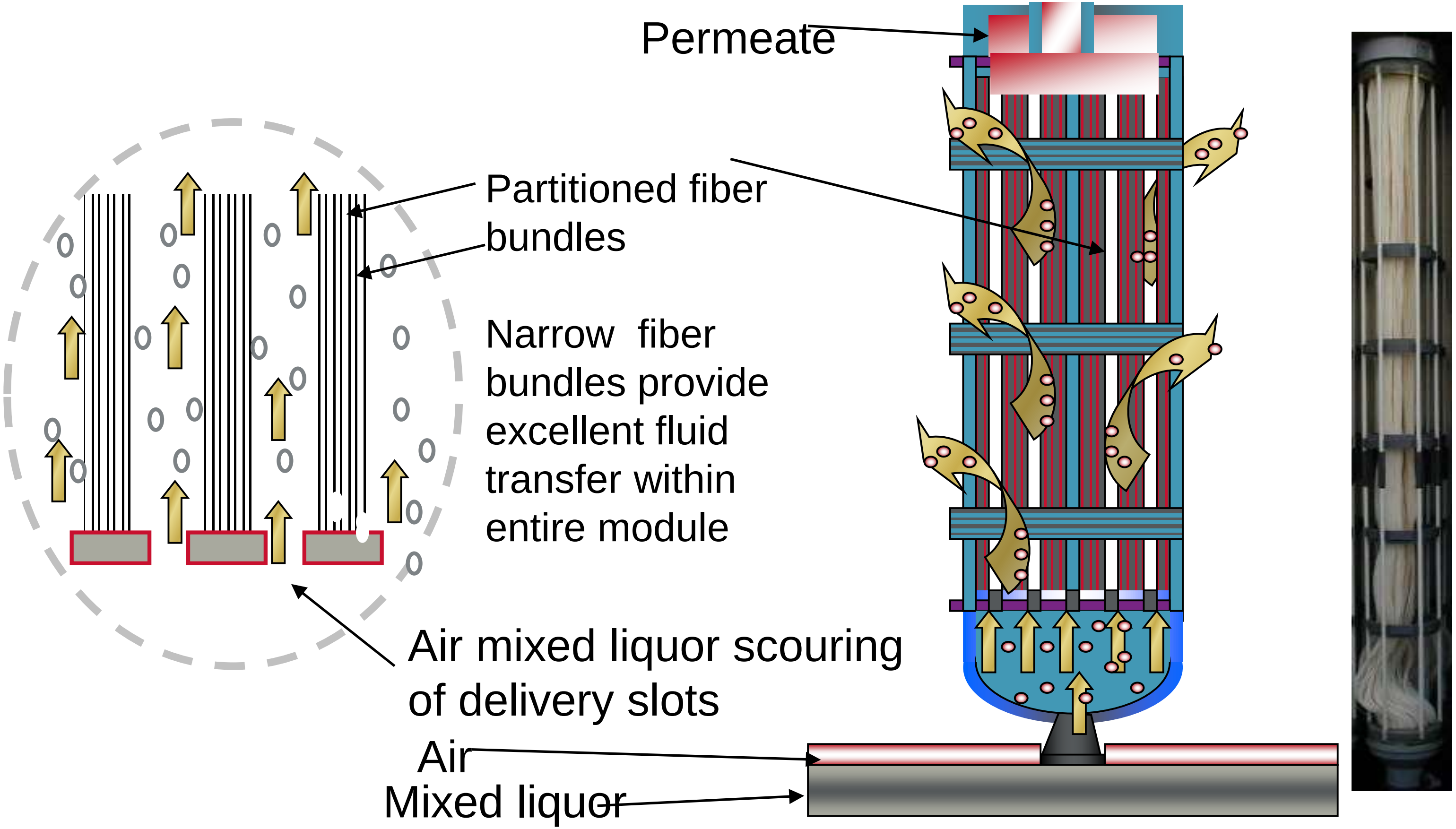
- Separation device like a clarifier to separate suspended solids from the water
- Physical barrier: suspended solids bigger than pore size remain in the process tank

Mixed Liquor	Permeate
MLSS 5,000 – 14,500 mg/L	TSS < 1 mg/l Turbidity < 0.2 NTU

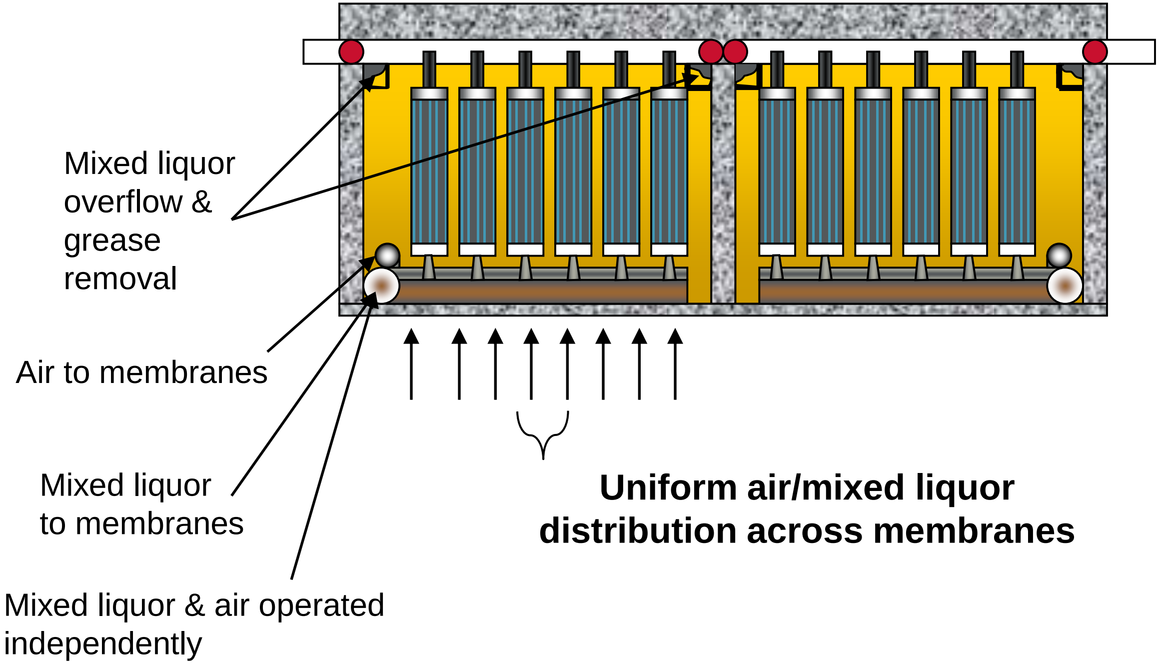
What Does A Membrane Look Like (rack scale)?



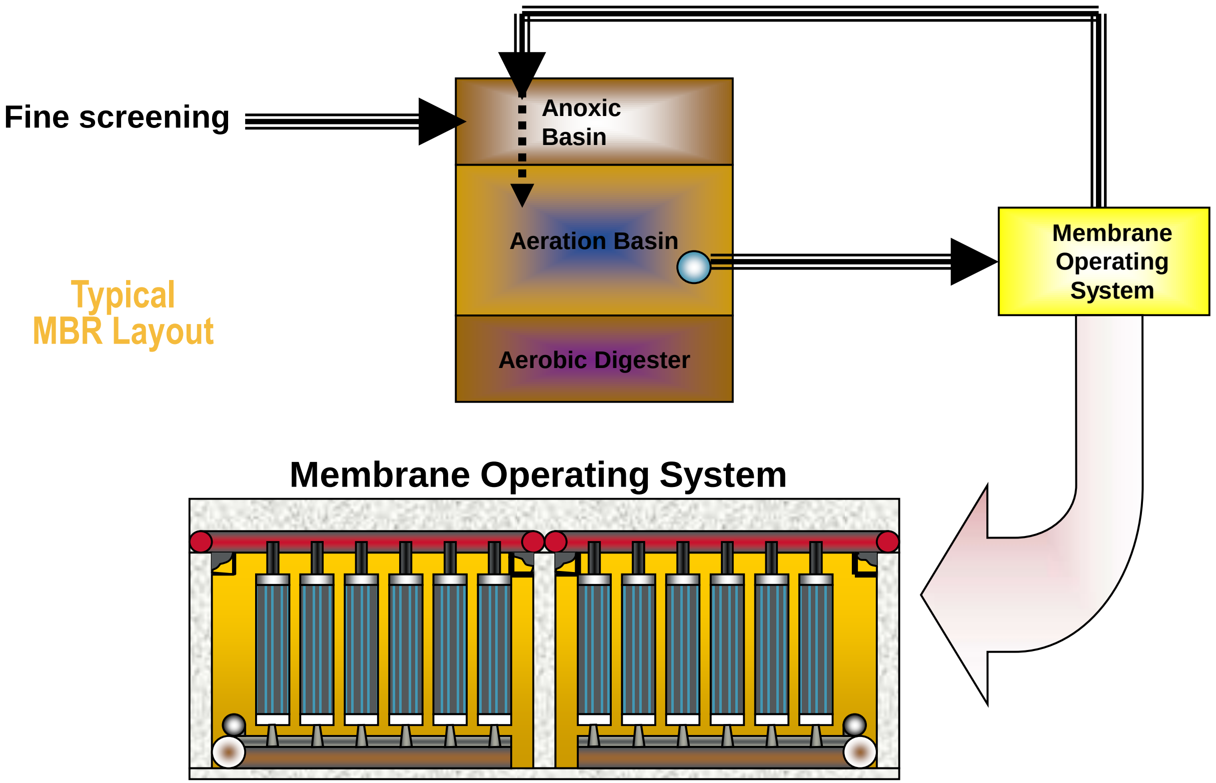
How does it work at the module scale ?



How does it work at the membrane tank scale ?



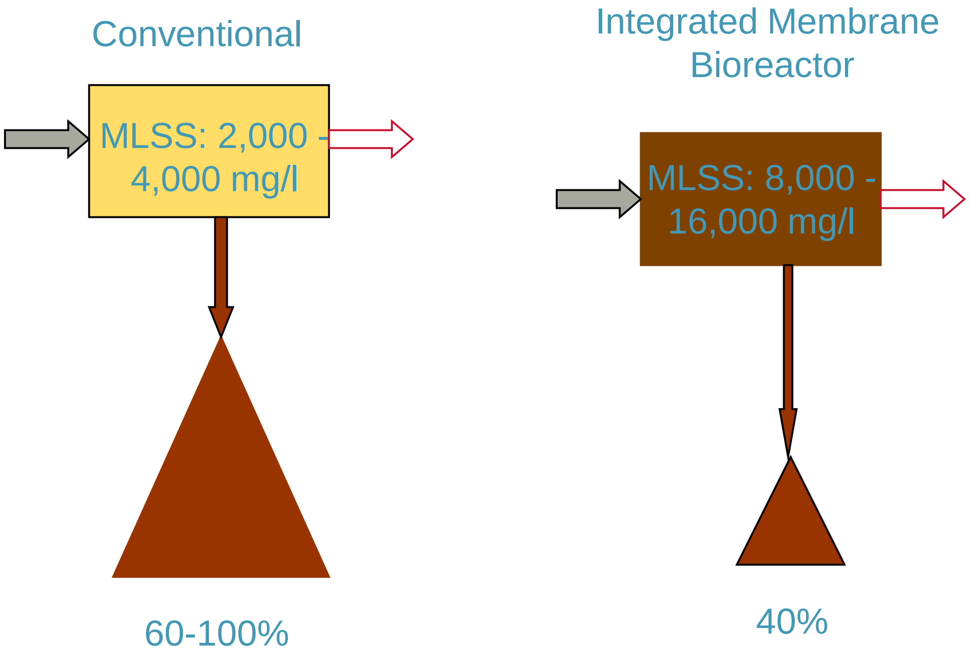
How does it work at the plant scale ?



Integrated Membrane Bioreactor Process

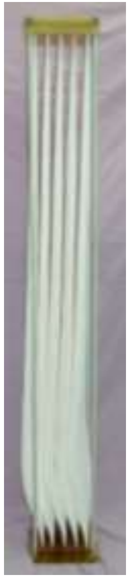
Low Sludge Yield

(Long mean cell residence time)



Compact footprint

Comparison of Manufacturers – Circa 2003

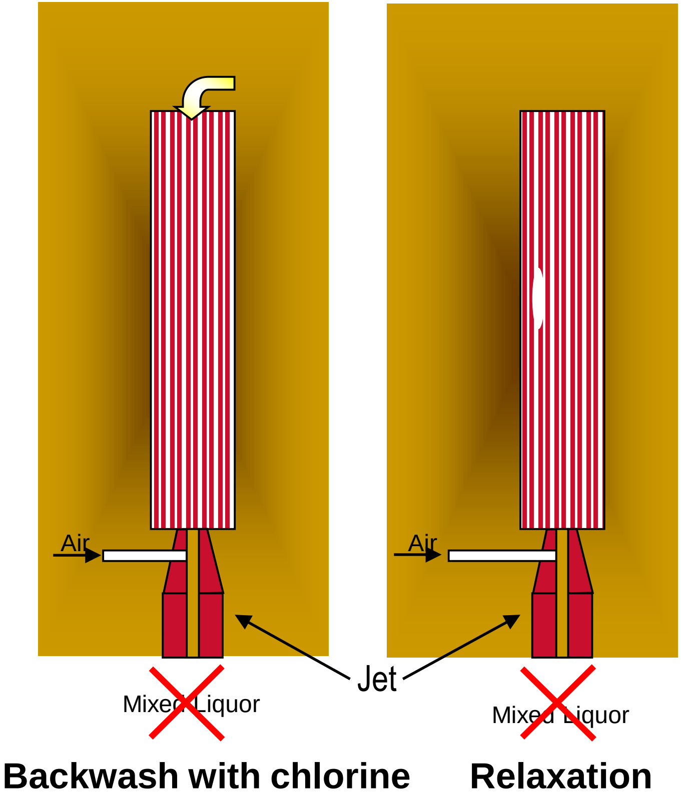
	USFilter	Zenon	Kubota
Type	Hollow Fiber	Hollow Fiber	Flat Sheet
Footprint	Small	Small	Large
			

Managing the Membrane Environment

- Design Needs
  - Fine screening
    - Influent
    - Mixed liquor
    - Post-primary clarifier
  - Fluid transfer control
    - Uniform
    - Continuous
    - Turbulent
- Failure results in:
  - Solids packing around membranes
  - High fluid viscosity around membranes
  - Loss of Permeability (fouling)
  - High Maintenance

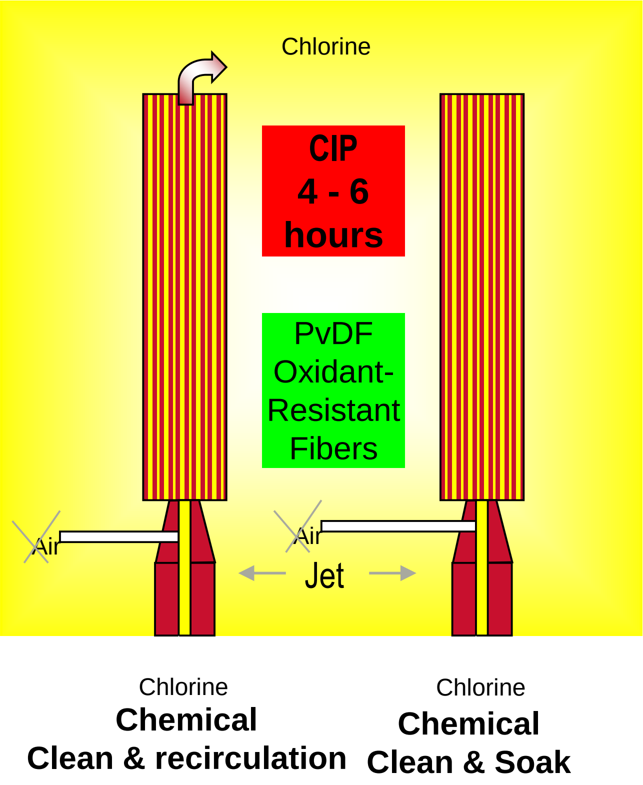
Maintenance Clean

- Completely Automated
- Every 1-2 week(s)
- Air stays ON
- Mixed liquor pump is stopped
- Mixed liquor remains in tank
- Protocol:
  - Backwash with chlorine (200 mg/L) for 2 minutes + priming time
  - Relaxation for 15 minutes
  - 2 times in a row
- 30-40 minutes duration
  - Inhibits biological surface fouling



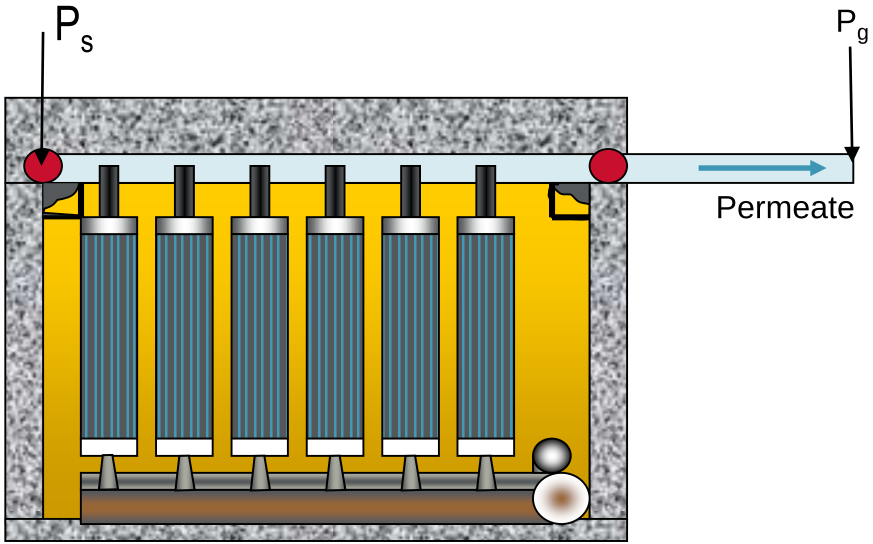
Clean In Place (CIP)

- Automated – no membrane removal
- Every 3 months or if TMP > 35 kPa at average design flux or permeability < 80 LMH/bar
- 4-8 hours per membrane cell
- Mixed liquor is sent back to biological tanks
- Utilizes chlorine at approximately 1,500 mg/L
- Occasional acid cleans for inorganic fouling
- Used CIP solution is wasted or recycled within the plant (job specific)



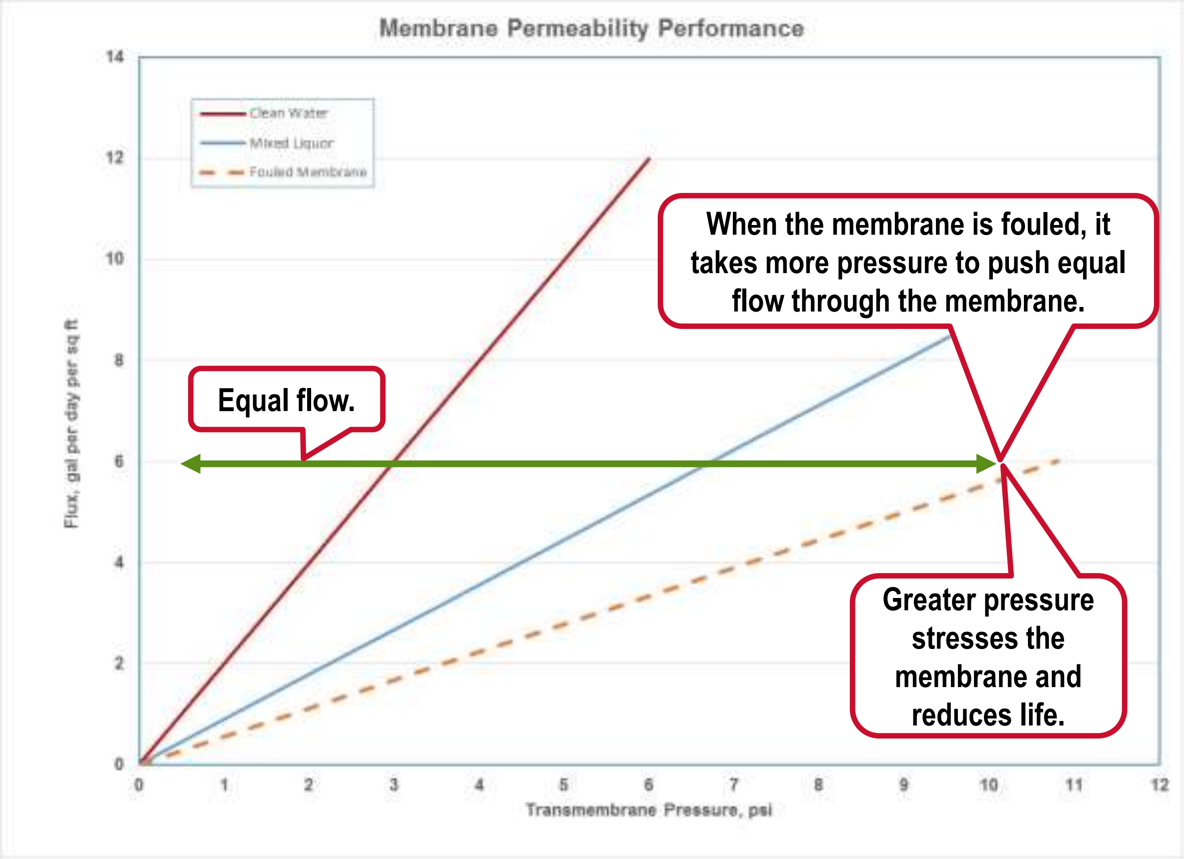
Flux and Transmembrane Pressure

- Flux: Flow across membranes per unit of membrane surface area
- Transmembrane Pressure (TMP): pressure across the membrane surface
  - P_s = static pressure at no flow
  - P_g = Gage pressure during filtration
  - P_l = Losses
  - $P_s - P_g - P_l$ = Transmembrane Pressure



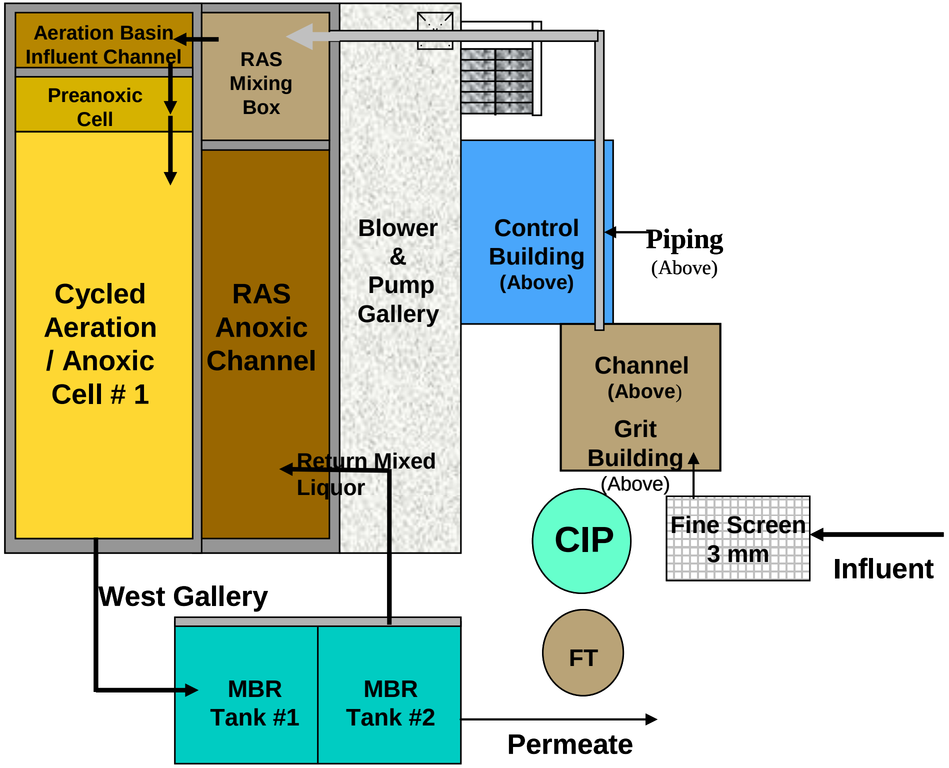
Relationship Between Flux, Transmembrane Pressure and Permeability

- J = P/(μ x R)
  - J = Flux (flow per area)
  - μ = Coefficient
  - P = Transmembrane Pressure
  - R = Membrane resistance
- Once the membrane is fouled, R increases and then the gradient between flux and TMP declines.
- Gradient is called permeability



02 Control Influent Debris to Protect Wastewater

LOTT Clean Water Alliance
Reclaimed Water Plant – 2 x 1 mgd



LOTT – Martin Way Water Reclamation Plant

- Satellite facility
- Provides reclaimed Water to City of Lacey
- Ground water recharge

MBR Design Characteristics

Parameters	Phase I	Phase II
Average Daily Flow, mgd	1.0	2.0
Peak Flow, mgd	1.0	2.0
Number of Membrane Tanks	2	4
Average Flux @ 20 °C, LMH	19	19
Peak Flux @ 20 °C, LMH	19	19
Minimum Temperature, °C	12	12

Main Equipment Provided (Phase I: 1.5 mgd)

- 2 membrane tanks with 11 racks per tank
- Two 1,760 gpm mixed liquor recirculation pumps
- Two 924 cfm blowers
- Three 880 gpm filtrate pumps with VFD (one installed spare)

What Happened in the MBR Facility ?

Debris Accumulation in Membranes

- Impaired membrane capacity
- Required excessive, hands-on labor for cleaning

First Barrier In the Treatment Process

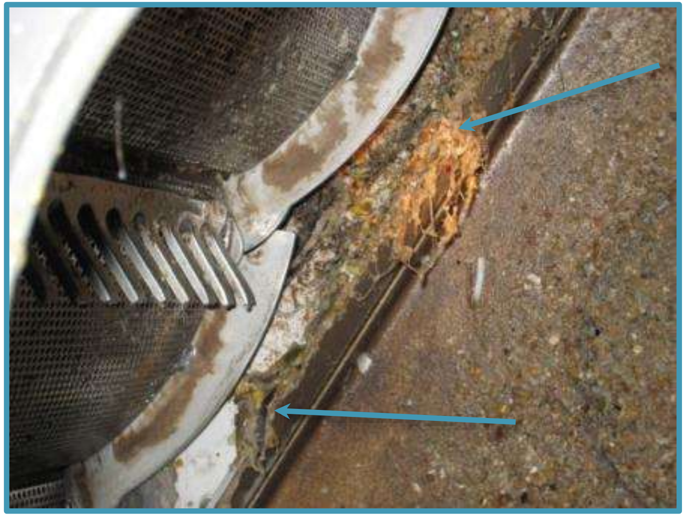
- Influent Screen
- 3 mm Perforated Plate
- Water Spray and Brush Cleaning

Cleaning Mechanism

Brush and Water Spray

Debris Carryover From Brush and Water Spray

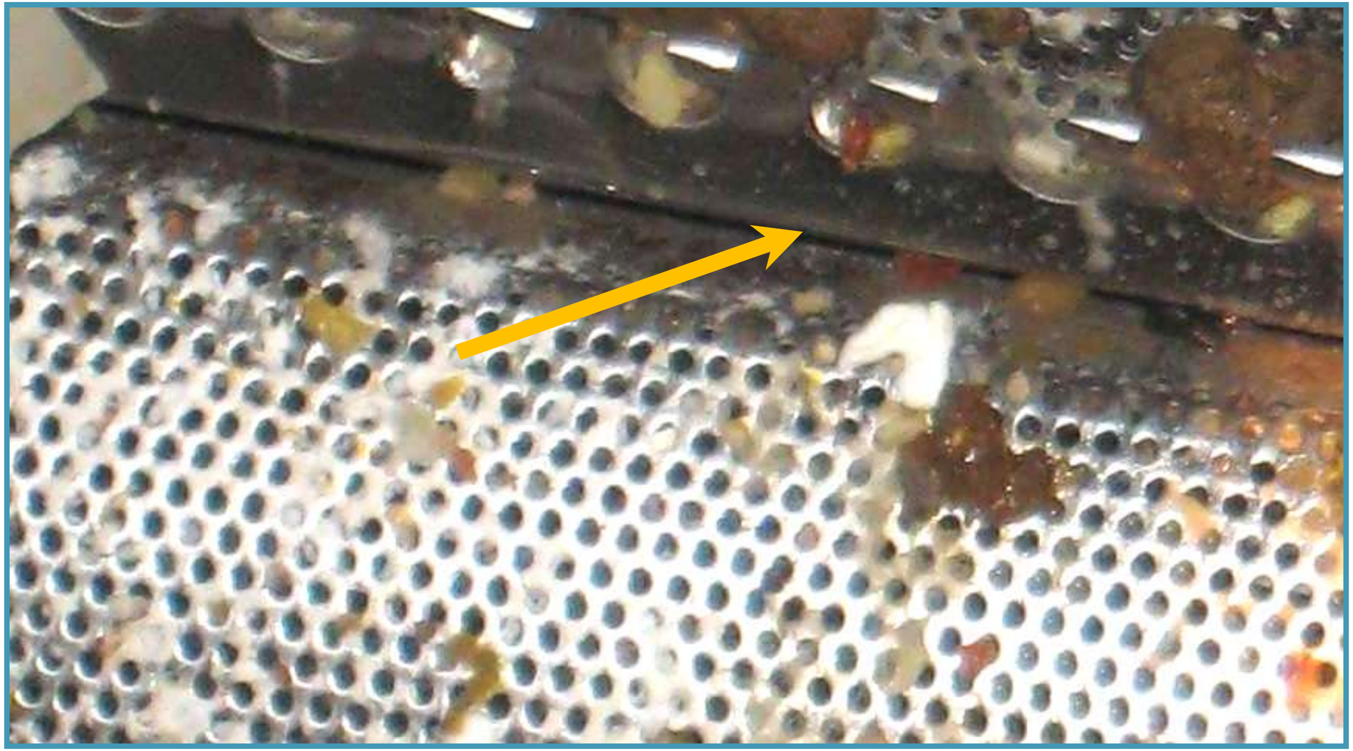
Debris That Passes Around 3 mm Screen



Passage Around Edges of Plates and Frame

Contractor Forgot To Completely Grout between Frame and Channel

Gaps Between Plates



Gaps between perforated plate panels

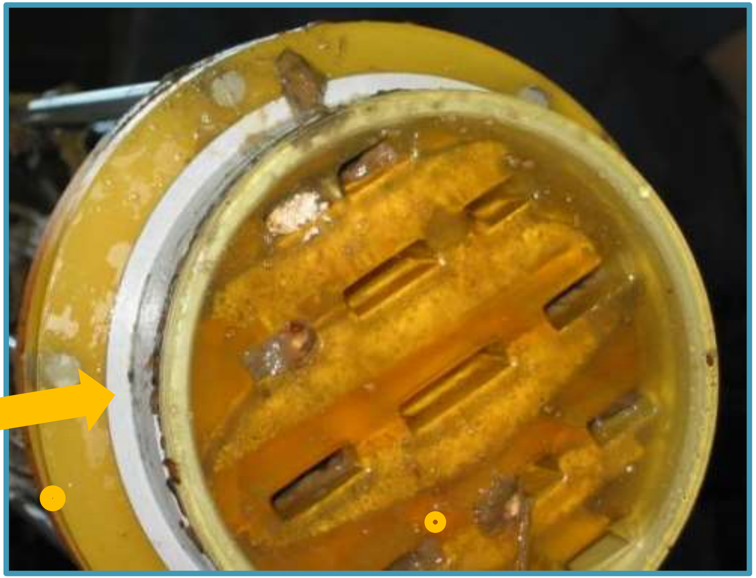
How Much Debris Really Gets By The 3 mm Screen

After 2 hours in the screened wastewater

After 18 hours in the screened wastewater

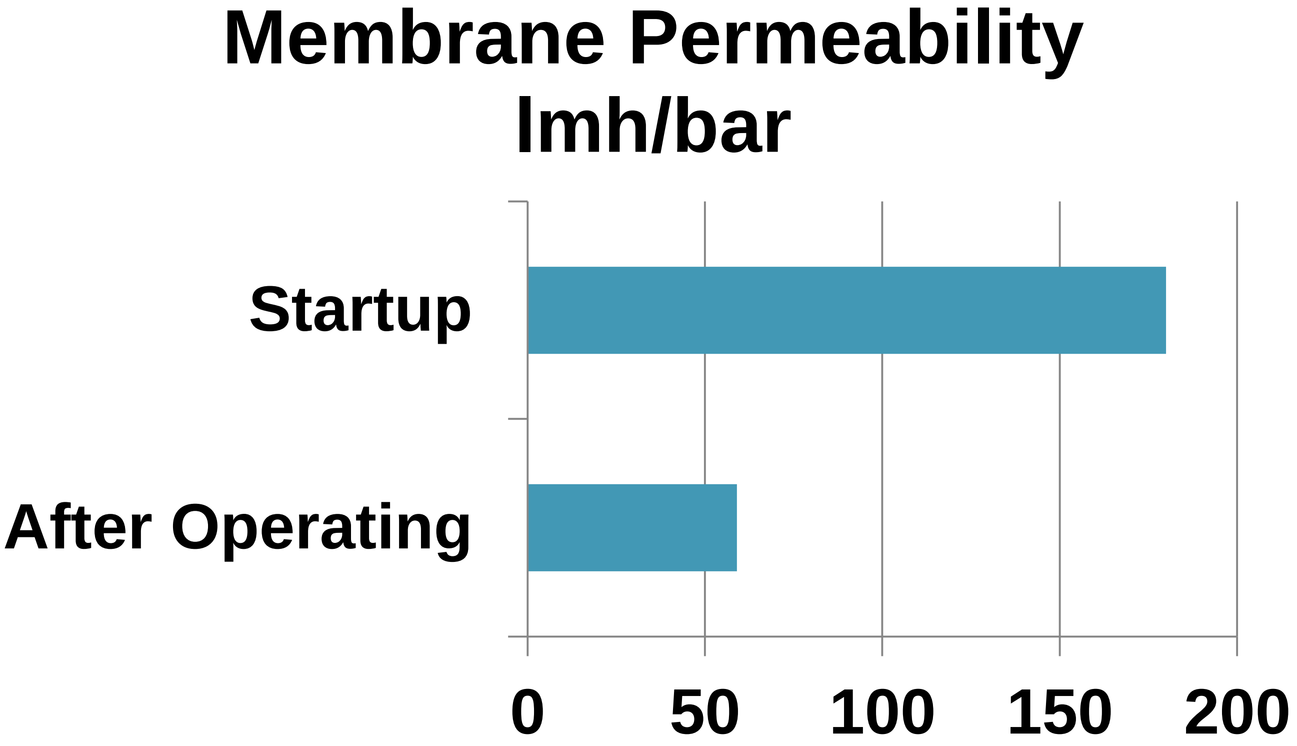
Fouled Membrane Modules

Top of Membrane Clover



Rack End of Module

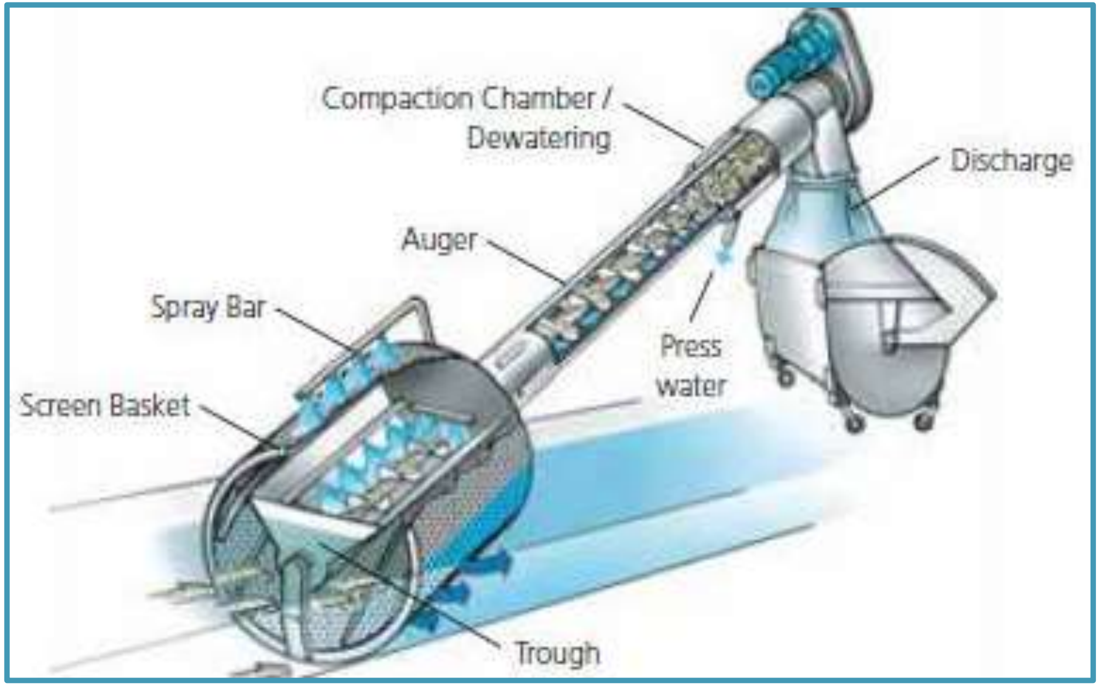
Loss of Performance



Resolution to Membrane Fouling

Basket Screen

Huber Technology Rotomat Fine Screen



Screen Installation in Progress

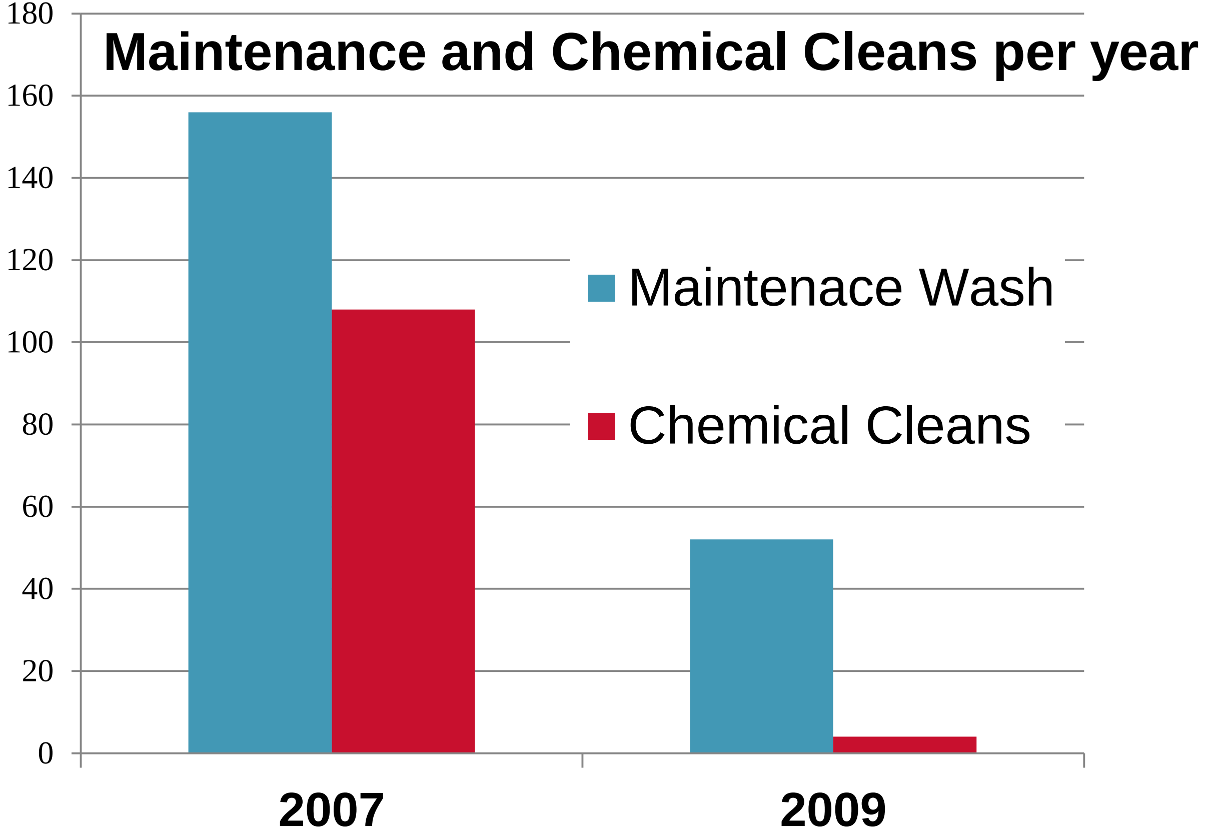
Screen Effluent

Screen Influent

Completed Screen Installation

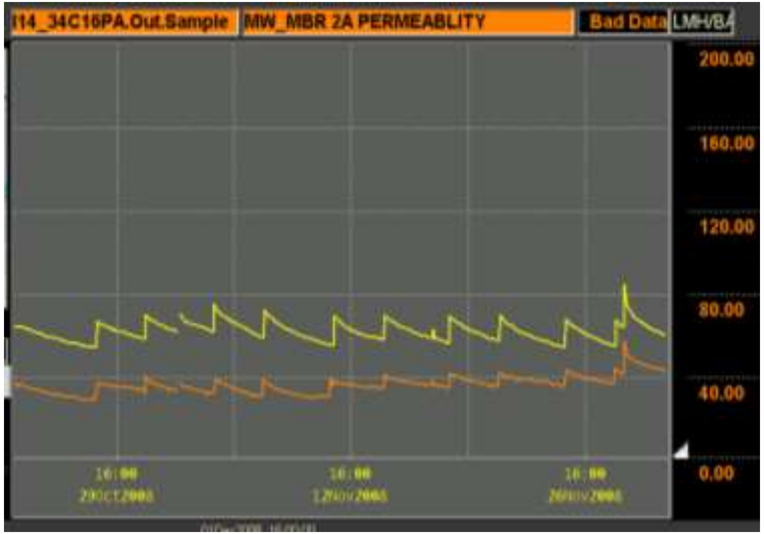
Excessive CIP's

Screen Operational July 2008



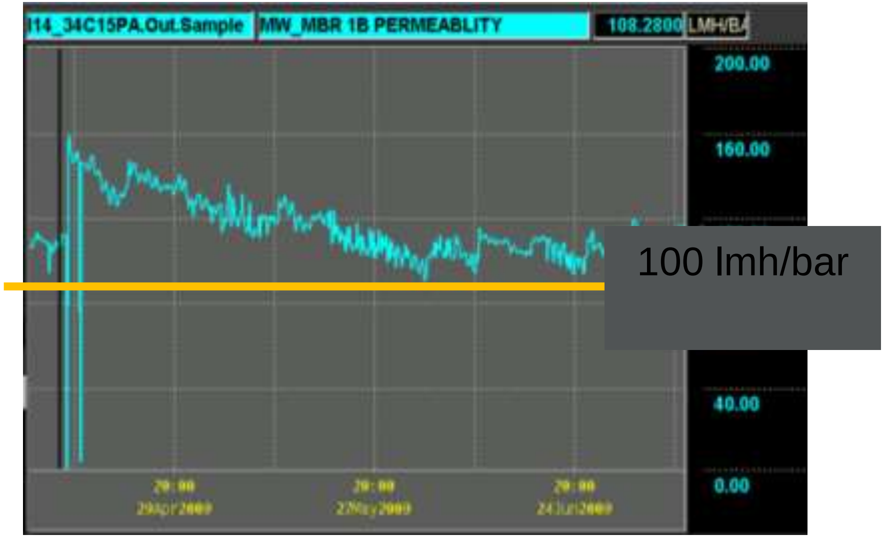
Increased Permeability and Fewer Cleaning Events After Screening Upgrade

pressure across the membrane surface



Before

- **Maintenance washes 2-3 times per week**
- **After new screen installation, permeability starts to increase**



After

- **Now CIP every 6 months at 100 lmh/bar**

Dual Stage Screening – Preferred Approach for MBRs

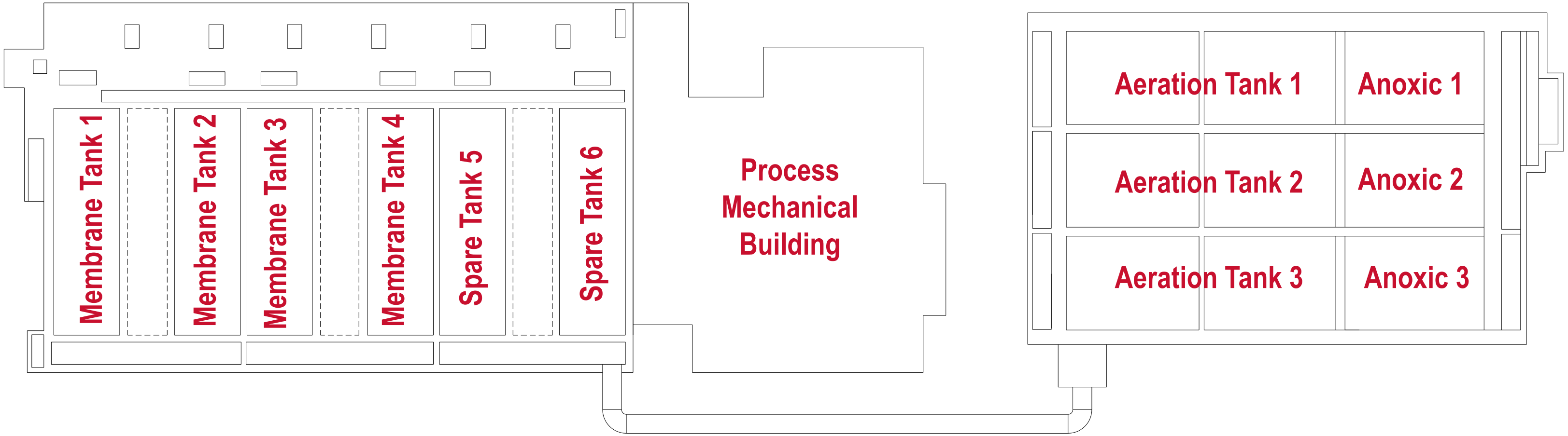
Perforated Plate

Drum Screen

03 Plan for Membrane Cleaning

Alderwood Water and Wastewater District, Picnic Point Wastewater Treatment Facility

Picnic Point Wastewater Treatment Facility



Screens Selected to Accommodate Membranes

Flat-plate Membranes

Band screens with 3-mm perforations

Annual Spring Cleaning Event

Performance Following Cleaning

- Temporary reduction in permeate flow after cleaning
  - Need for improved air venting

Plan for Operator Safety

- Fall Protection
- Confined Space Retrieval
- Slips Trips and Falls
- Engulfment

Plant Safety and House Cleaning

- Lifting Hazards
- Bucket Brigade
- Communication
- Trash and Debris Maintenance

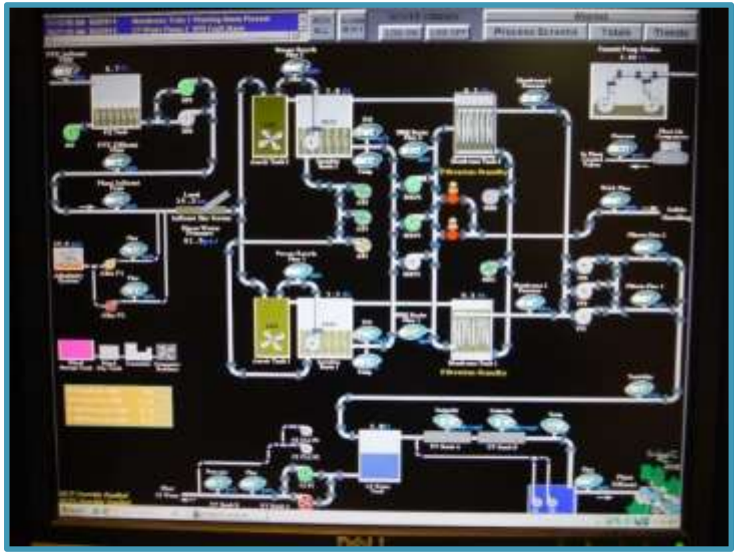
Plan ahead for cleaning access and operator safety!

04 Control Potential Contaminants

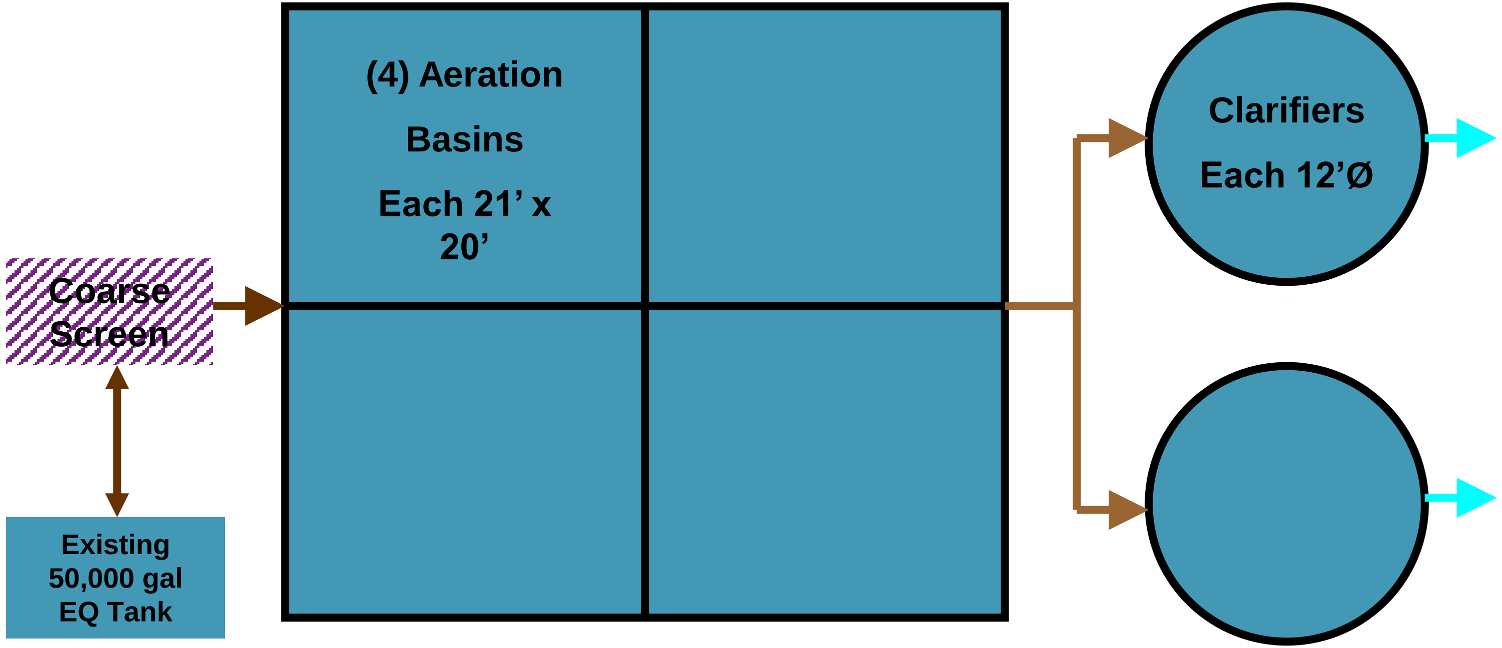
Stevens Pass Sewer District Wastewater Treatment Plant Membrane Bioreactor

Upgraded Plant

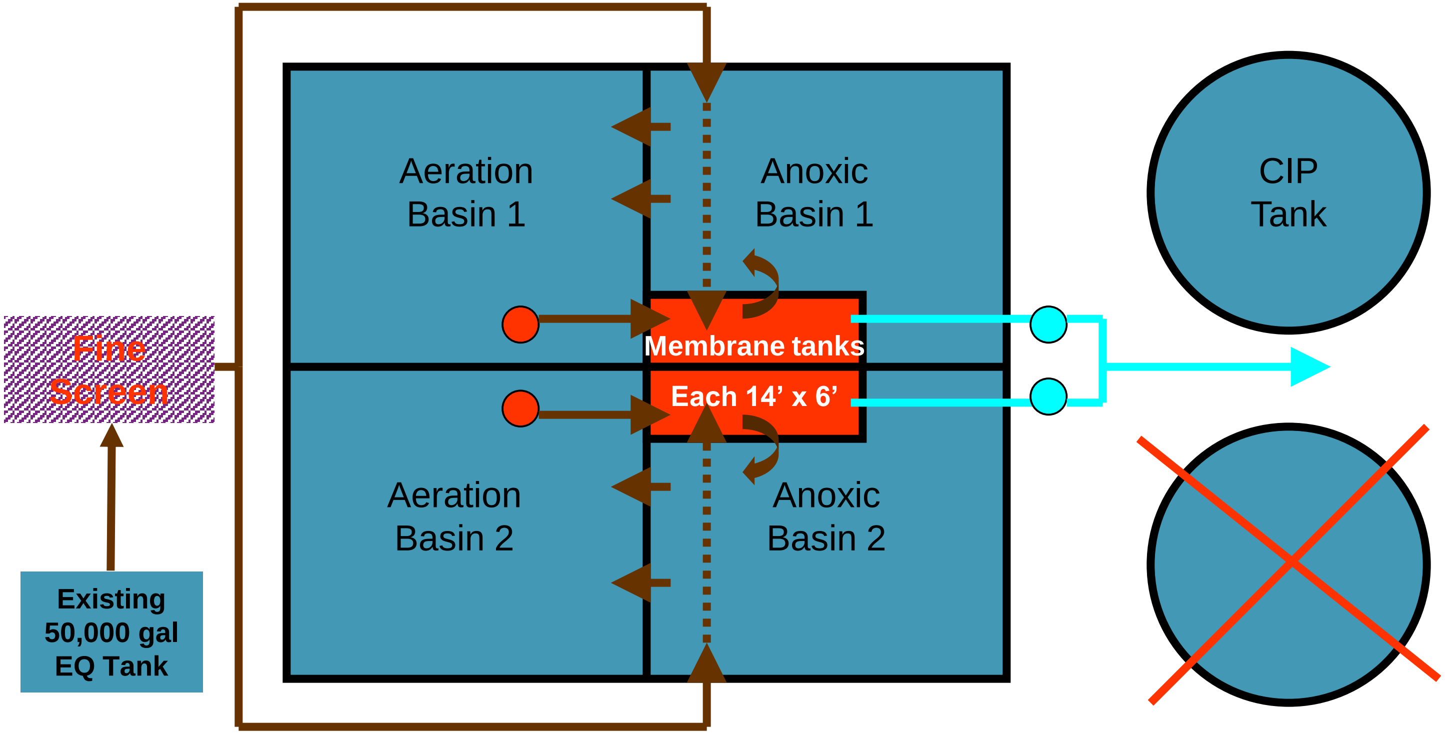
- Upgrade of existing secondary treatment plant
  - Driver for MBR was footprint
- Previous capacity of 80,000 gpd
- Expansion to 213,000 gpd
- Construction completed in summer 2003
- High strength wastewater
  - COD = 1179 mg/l
  - BOD = 261 mg/l
  - TSS = 504 mg/l
  - TKN = 127 mg/l



Previous Plant - 80,000 gpd



Upgraded Plant (213,000 gpd)



Operational Facility

Membrane Recirculation Pumps

Jet Distribution

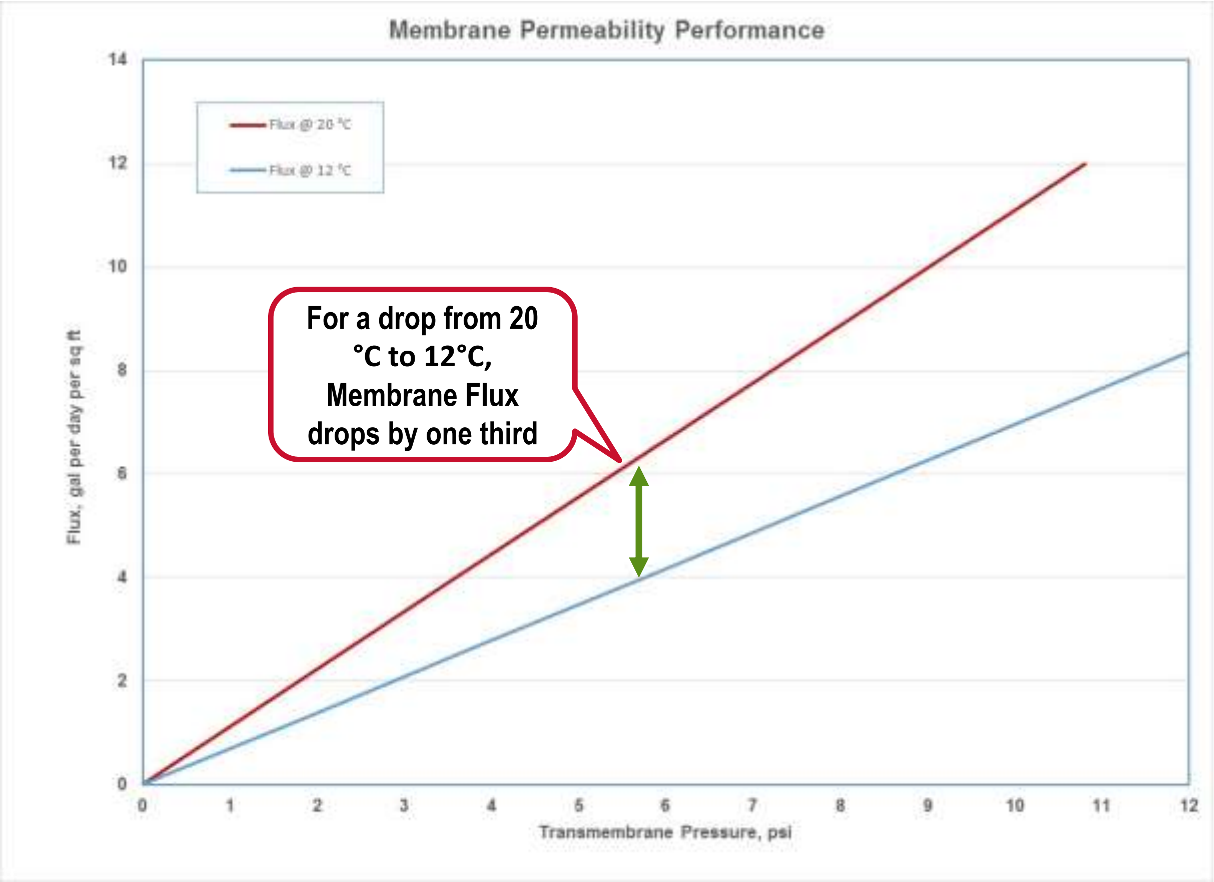
Filtrate Pumps in Background

Operational Challenge

- In winter 2016, hydrocarbon contamination was discovered
- As membranes are impaired by hydrocarbons, manufacturer invalidated warranty
- Membranes were subsequently replaced
  - Insurance claim

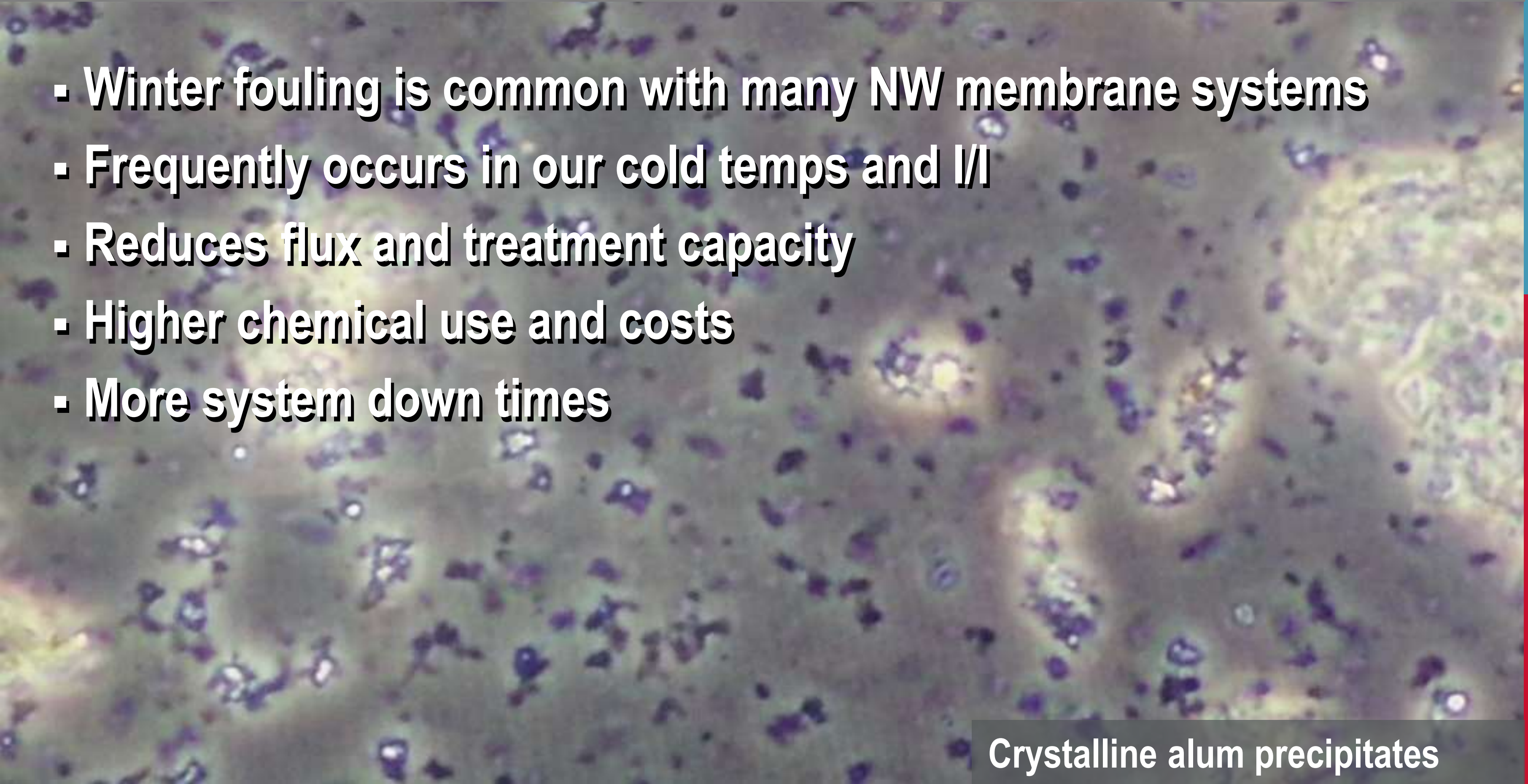
05 Consider Cold Weather Impacts

Cold Water Temperature Impair Membrane Performance



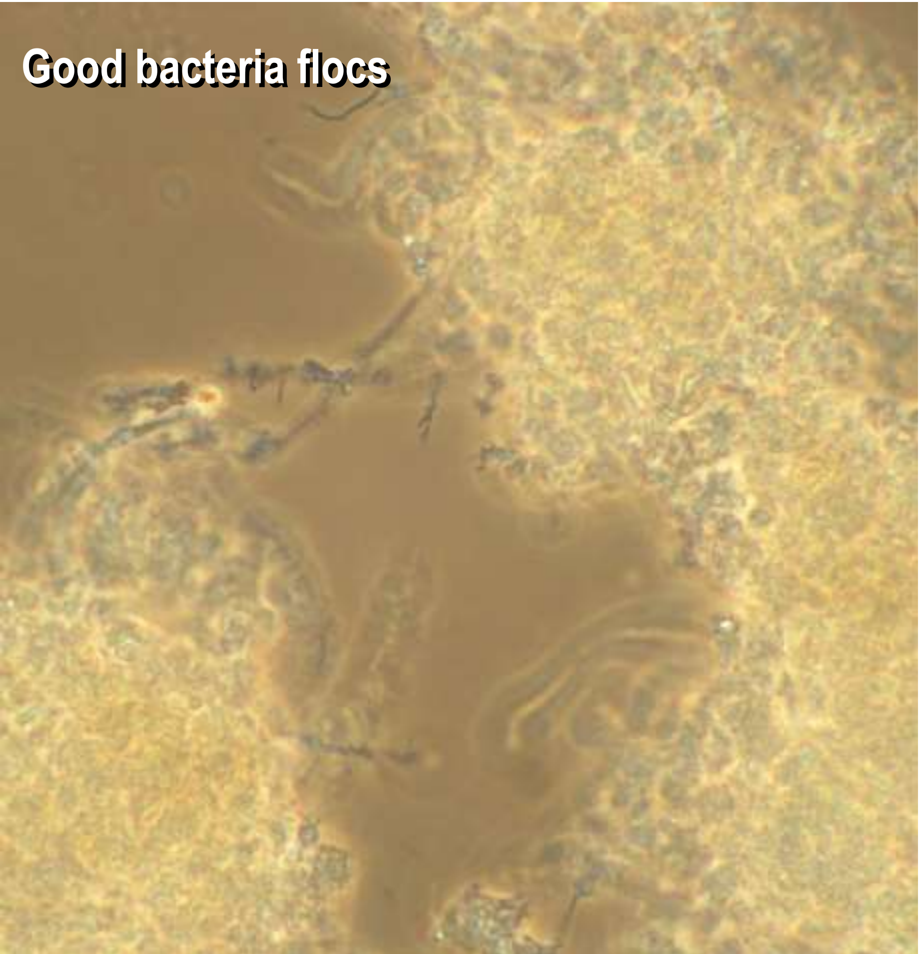
Optimization of Pacific NW membrane installations has led to improved operations

- Winter fouling is common with many NW membrane systems
- Frequently occurs in our cold temps and I/I
- Reduces flux and treatment capacity
- Higher chemical use and costs
- More system down times

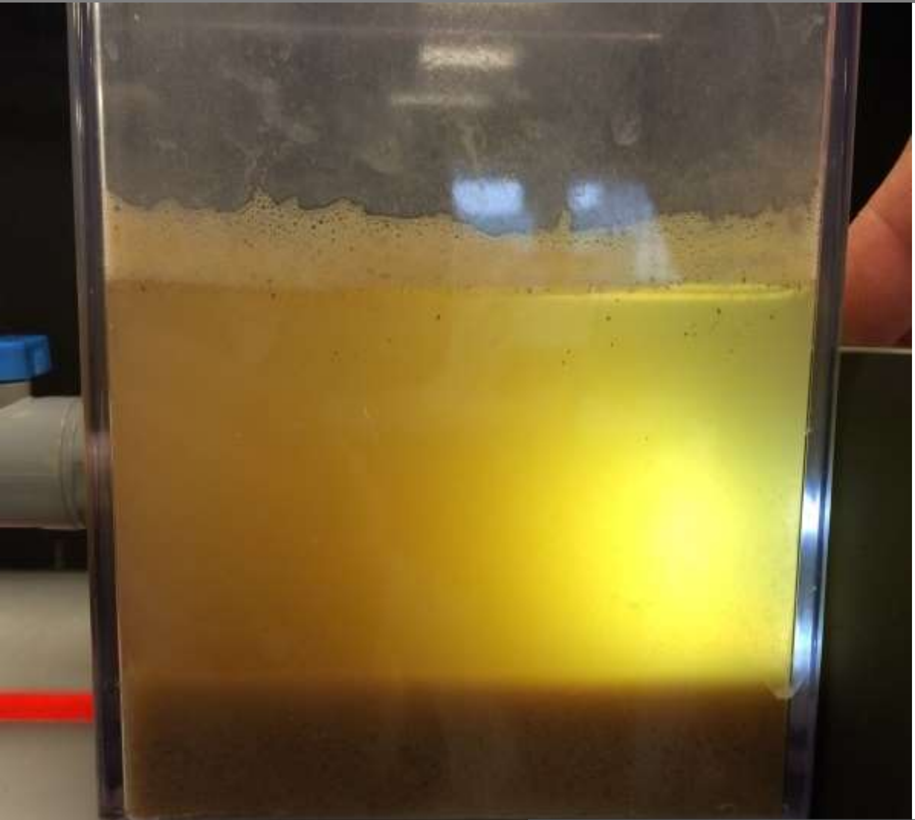


Crystalline alum precipitates

Fixing MBR biology leads to cost-effective solutions



Coeur d'Alene Cold Weather Assessment



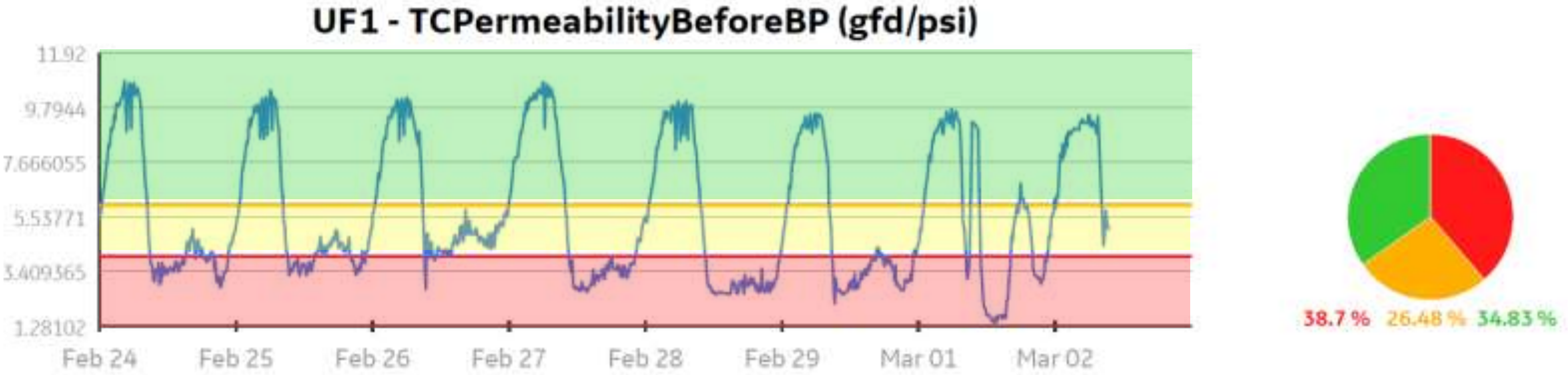
- Foulant characterization
- Jar testing
- Cleaning chemical optimization
- Full-scale testing

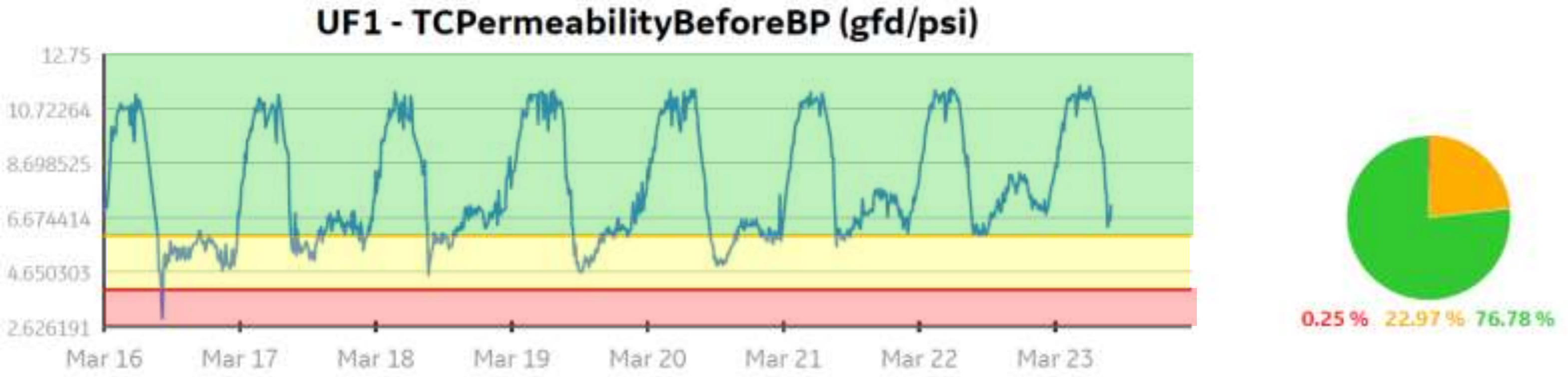
Optimization minimizes capital expenses

- More stable operations
- Higher winter-time flux
- Less cleanings
- Smaller or eliminated EQ basins

Spokane County Regional Wastewater Treatment Facility

Operational tweaks resulted in rapid performance improvements





Success: System Returned Back to Full Operations!

06 Equalize Influent Flow to Improve Performance

Equalization Can Improve MBR Performance and Decrease Stress

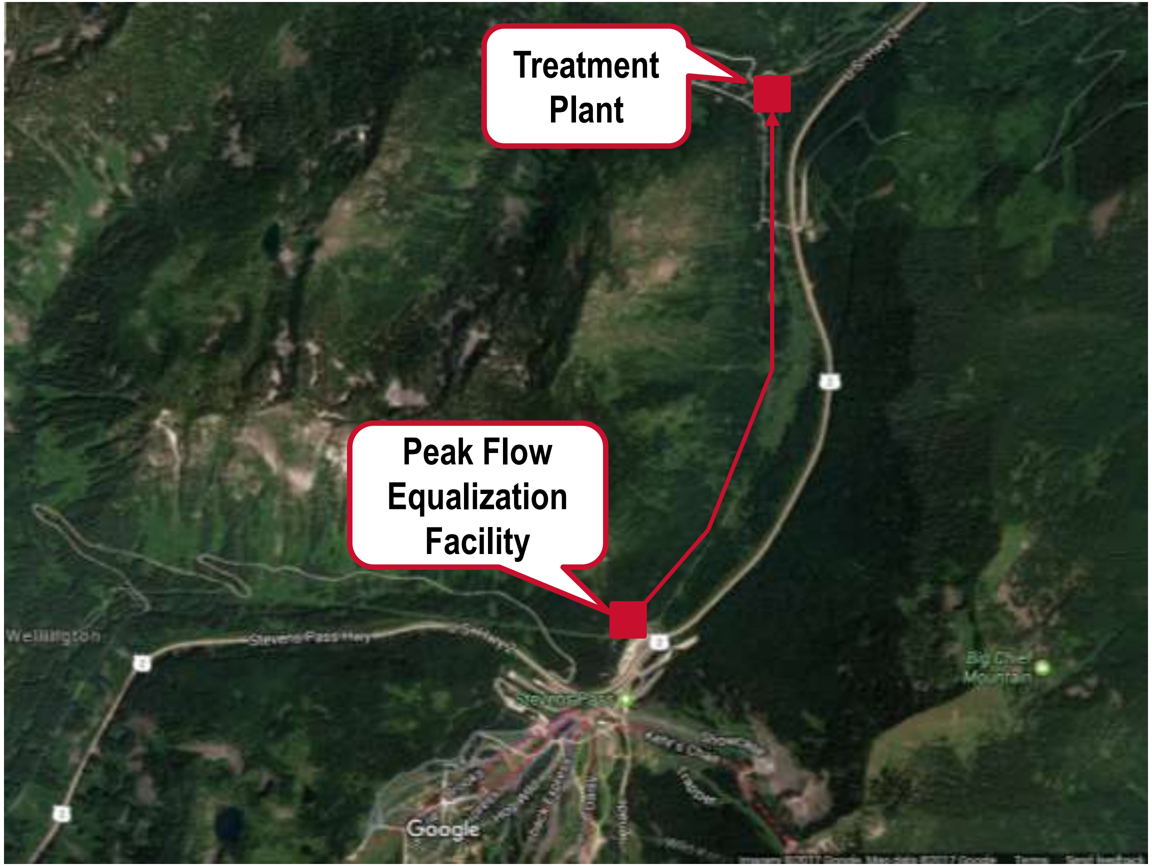
- Wastewater flow is inherently variable
  - Diurnal variation in response to customer habits
  - Impacts from wet weather sewer system infiltration and inflow
- Membranes prefer constant flow
  - Improves performance
  - Reduces membrane stress, potentially extending life

Equalization Approaches

- Two approaches
  - Process equalization
    - Attenuate plant loading, particularly nitrogen, to improve removal
    - Example
      - LOTT Clean Water Alliance – Martin Way Reclaimed Water Plant
      - Equalization Evaluation
  - Wet weather equalization
    - Attenuate plant flow to reduce membrane stress
    - Limit range of required membrane permeability
    - Example
      - Alderwood Water and Wastewater District – Picnic Point Wastewater Treatment Facility
      - Equalization evaluation

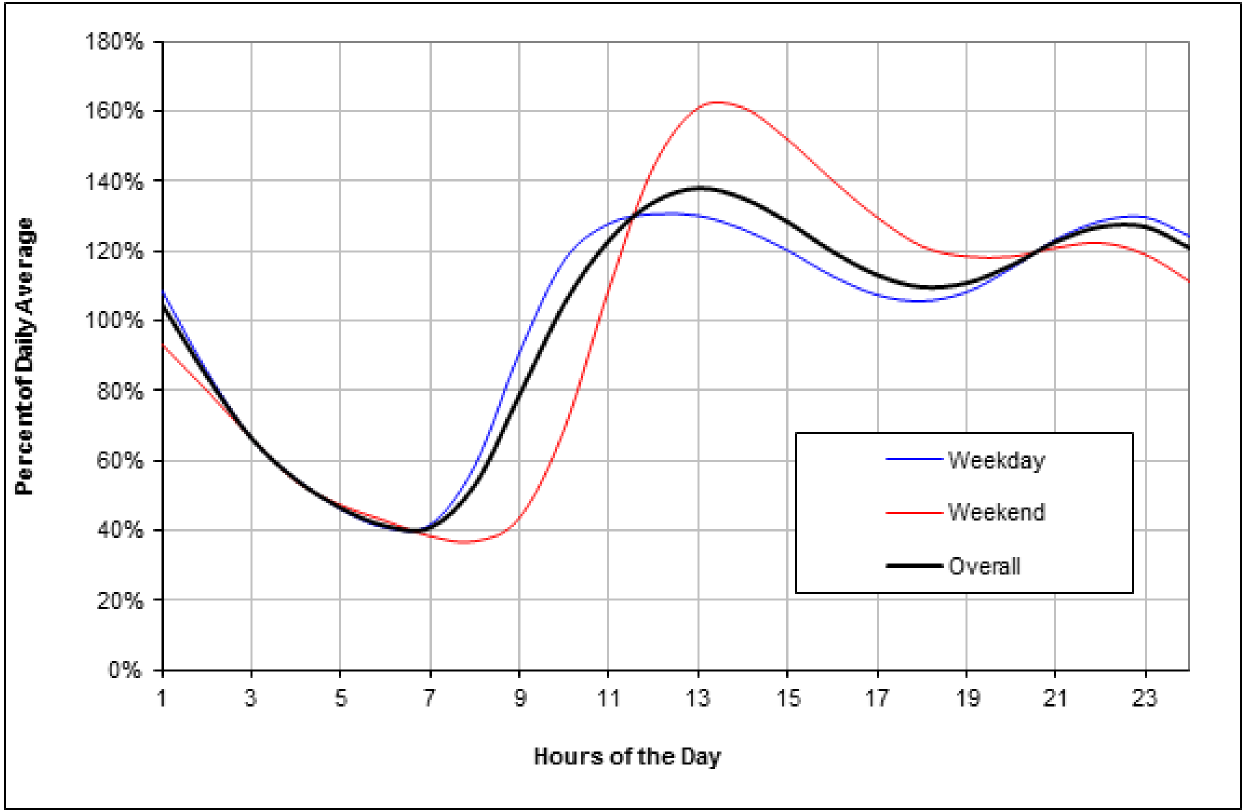
Stevens Pass Equalization

- Large flow variation from ski resort
- 50,000 gallon flow equalization facility
- Equalization has contributed to successful operation of the MBR plant



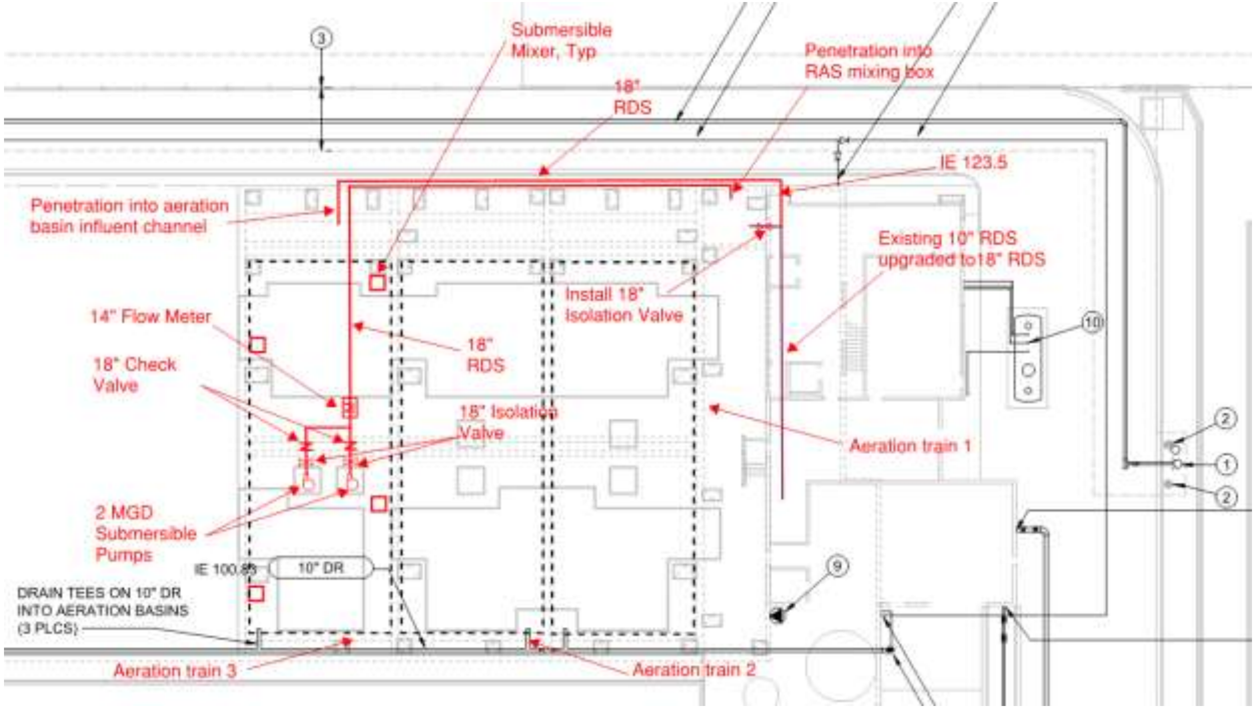
LOTT Martin Way Equalization

- Process equalization to improve nitrogen removal
- Evaluated conversion of spare aeration basin tank to an in-line equalization facility



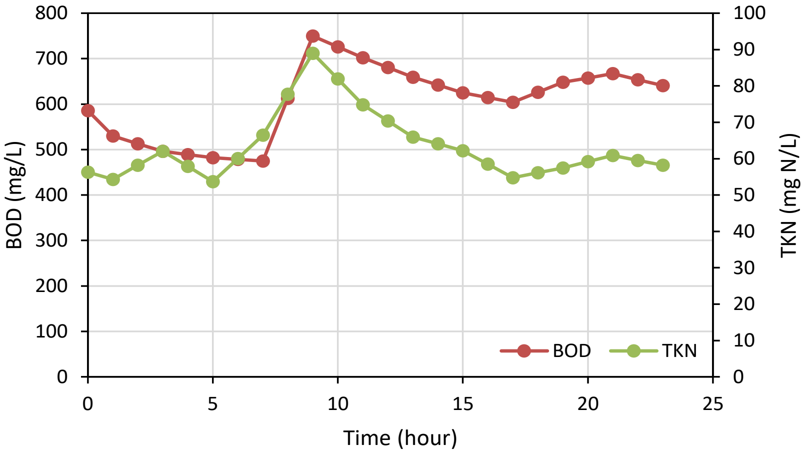
Martin Way Satellite Plant

- Add pumping system to unused aeration tank (Aeration Tank 3)
- Pump flow at constant rate into active aeration basins



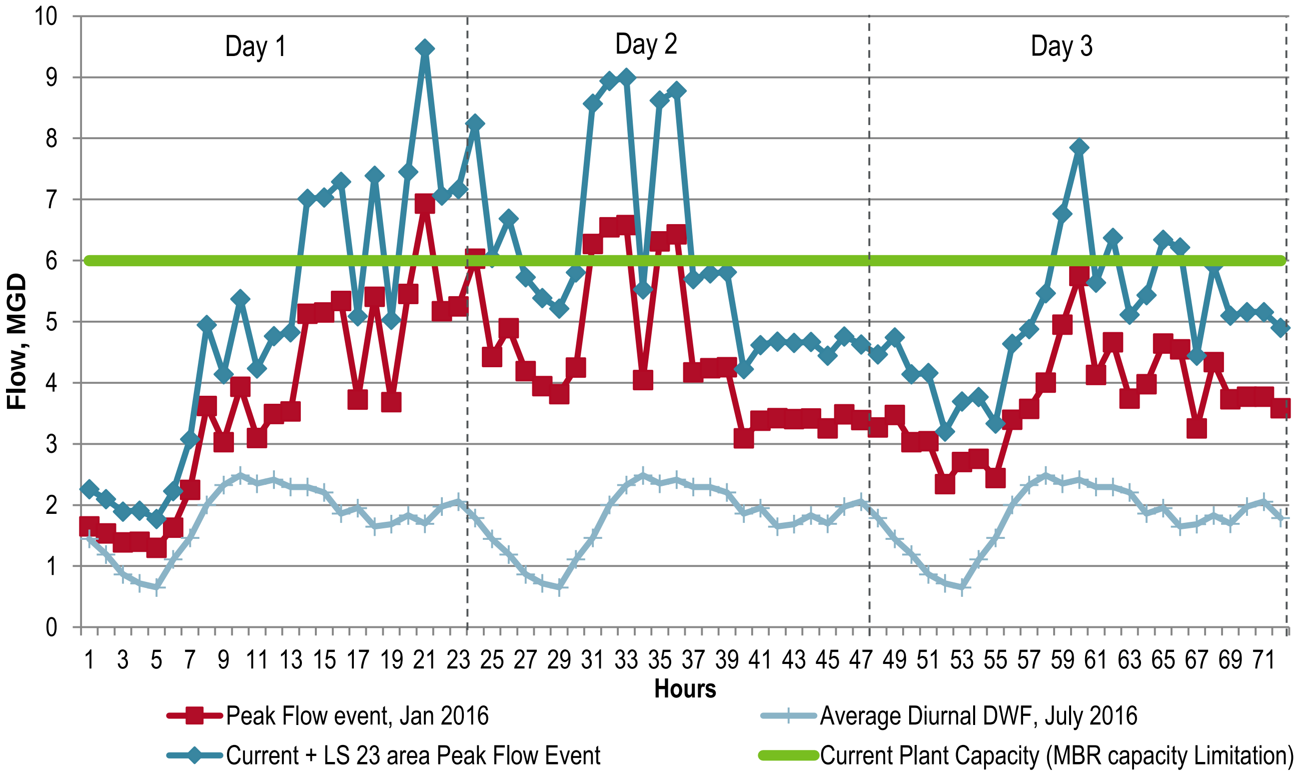
Findings

- Equalization would divert up to 200 lbs per day of nitrogen from Puget Sound
  - Increase nitrogen loading to plant during peak times
  - Improve nitrogen removal through plant
- Life cycle costs with and without equalization were similar
  - Produced more reclaimed water
  - But equalization had an estimated capital cost of $1.7M
- Decided not to move forward with equalization at this time



Picnic Point Hydraulic Analysis

- Focus on wet weather control
- Design for future conditions

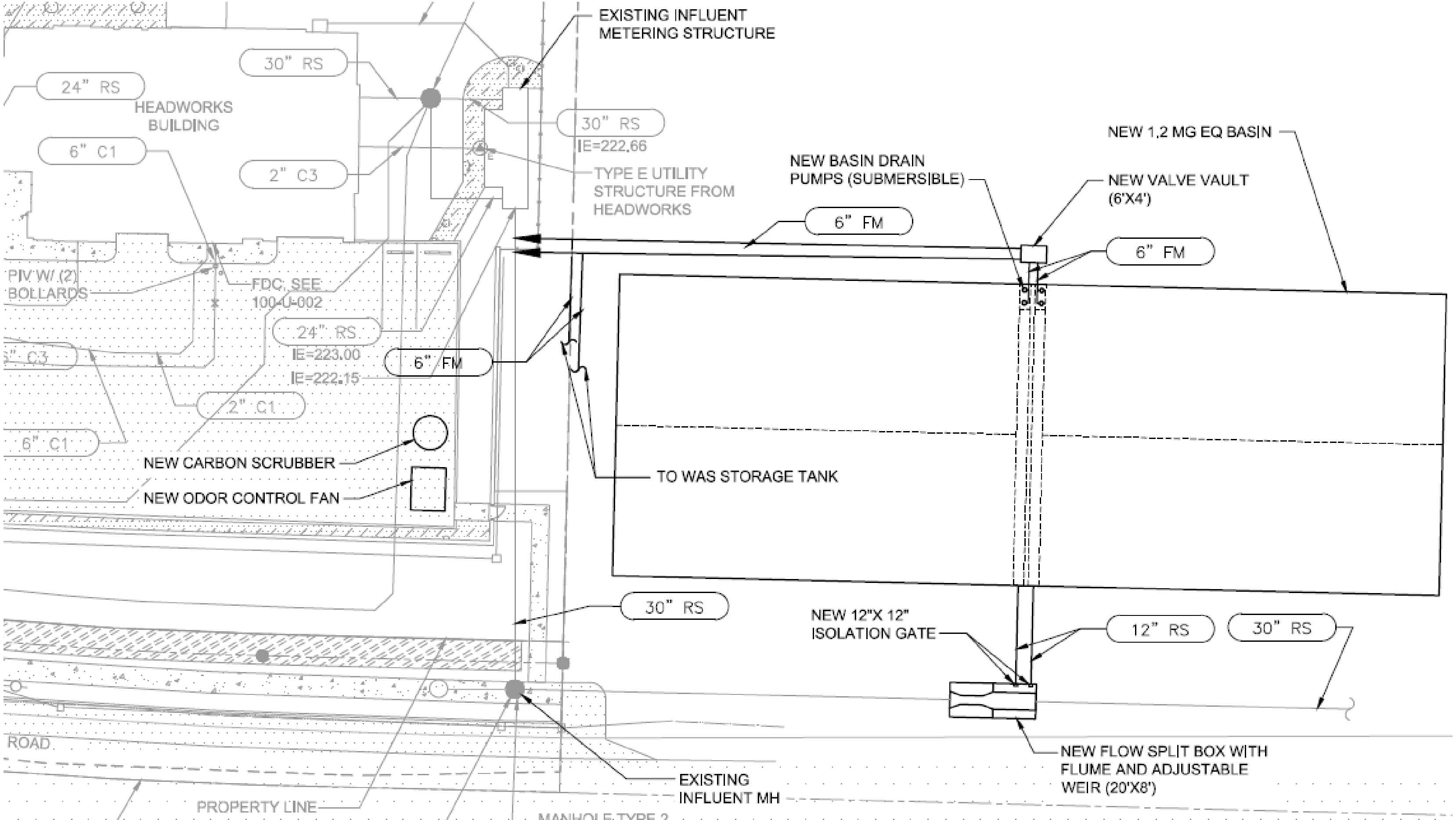


Picnic Point Equalization – Membrane Warranty Approach

Scenario	Parameter	Existing (2016) (With LS 23 Service Area)	2026 (With LS 23 Service Area)	2040 (Build-out) (With LS 23 Service Area)	Risk
Alternative 1 - Membranes with **no equalization.** Membrane flux limited to **220% of Average Daily Flux.**	Limiting Condition	5 mgd maximum month flow, 11 mgd peak hour flow	6 mgd maximum month flow, 13.2 mgd peak hour flow	6 mgd maximum month flow, 15 mgd peak hour flow	Membranes would be configured to treat existing and future peak flow, the same as the current design concept.
	Membrane Configuration	5 tanks - Flat Plate	6 Tanks - Flat Plate	High Rate Membranes	
	Storage, mil gal	**0.00**	**0.00**	**0.00**	
Alternative 2 - Membranes with **Moderate equalization.** Membrane flux limited to **150% of Average Daily Flux.**	Limiting Condition	6.0 mgd Peak Hourly Flow to membranes.	9.0 mgd Peak Hourly Flow to membranes.	10.6 mgd Peak Hourly Flow to membranes.	Membranes would be operated a maximum flux not exceeding 150% of the design Average Daily Flux.
	Membrane	4 Tanks - Flat Plate	6 Tanks - Flat Plate	High Rate Membranes	
	Storage, mil gal	**1.20**	**0.60**	**1.20**	
Alternative 3 - Membranes with **Large equalization.** Membrane flux limited to **130% of Average Daily Flux.**	Limiting Condition	5.2 mgd Peak Hourly Flow to membranes.	7.8 mgd Peak Hourly Flow to membranes.	9.6 mgd Peak Hourly Flow to membranes.	Membranes would be operated a maximum flux not exceeding 130% of the design Average Daily Flux.
	Membrane	4 Tanks - Flat Plate	6 Tanks - Flat Plate	High Rate Membranes	
	Storage, mil gal	**2.20**	**2.80**	**2.80**	

Site Reconnaissance

Equalization Alternative 2 (no shoring)



08 Configure Membrane Scouring Air System for Variable Supply

Plan for Adjustable Membrane Scouring Air Supply

- Membrane scouring air may vary
  - Number of tanks in service
  - May require blowers to start and stop
- Turbo blowers
  - Now common in wastewater treatment
  - But on/off nature of supply may not be compatible with turbo units
- Aeration supply control valves
  - Consider control valve sizing
- Picnic Point
  - Add two additional blowers
  - Modify to operate in idle mode
  - Replace control valves to allow better modulation

08

Assess Control System Maintainability

MBR Control System Issues

- MBRs are complex systems
- Multiple ‘moving parts’
  - 40 valves or more in an MBR system
- Most manufacturers have adopted Ethernet-based control systems
  - Challenging to implement ‘hard-wired’ systems with large number of devices
- Ethernet-based systems more difficult to trouble-shoot
  - Requires a control system technician in addition to normal staff

MBR Control Systems – Plan for Maintenance or Upgrade

- **Staffing:** Plan for staffing to maintain control system
- **Upgrades:** May need to upgrade or replace control system to maintain plant functionality

MBR Control System Status – Replacements Underway

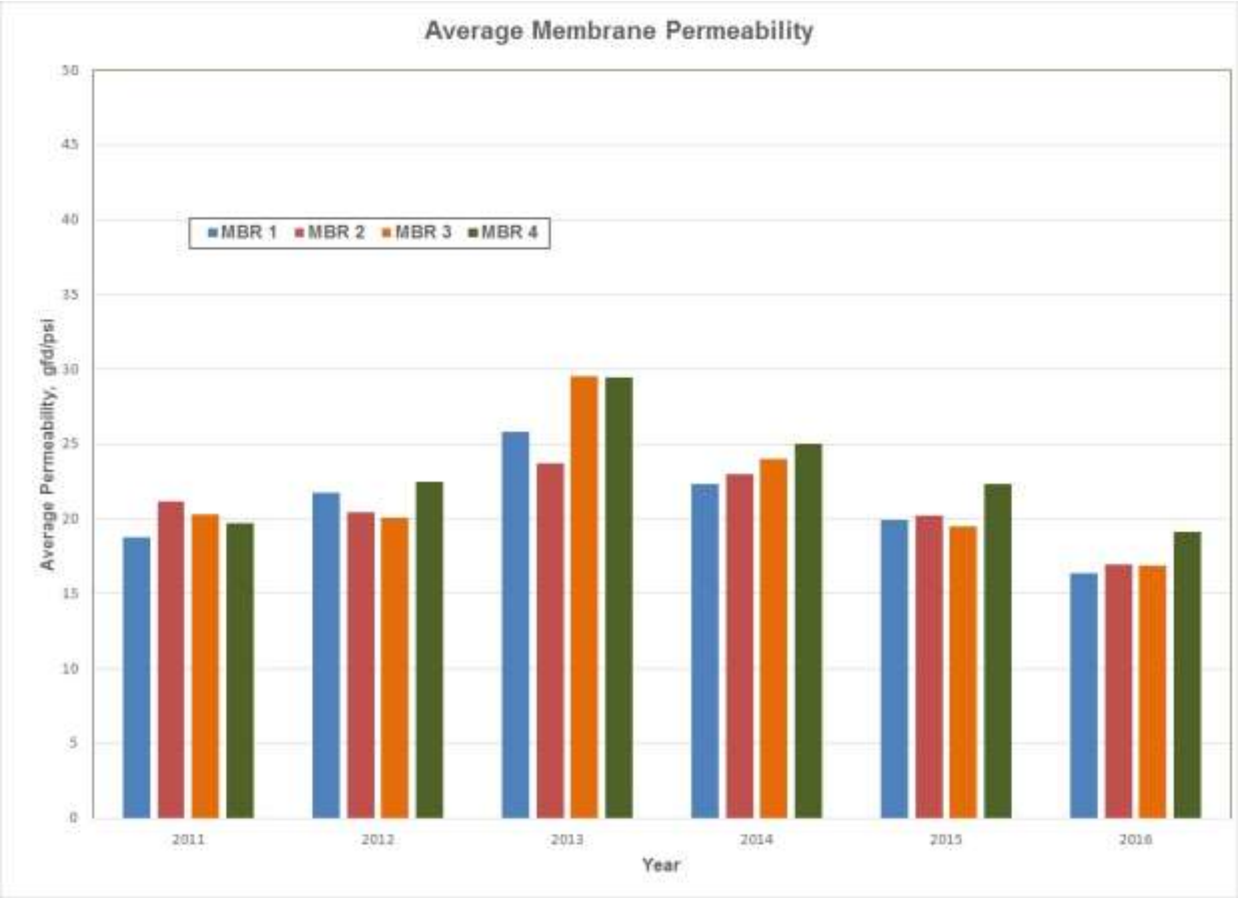
Owner	Alderwood Water and Wastewater District	Stevens Pass Sewer District	LOTT Clean Water Alliance
Facility	Picnic Point Wastewater Treatment facility	Wastewater Treatment Plant	Martin Way Reclaimed Water Plant
Nominal Rated Capacity, mgd	6	0.1	2
Membrane Type	Kubota Flat Plate	Siemens Memcor	Siemens Memcor
Year Plant Commissioned	2011	2003	2006
Main Network-related challenges	Foundation Fieldbus	DeviceNet-controlled valves are failing and no longer available.	DeviceNet–controlled valves are difficult to replace.
Motor Control Center and Variable Frequency Drive Connections	DeviceNet	Hard-wired	DeviceNet
Status of Control System Modifications	**Project for replacement of Foundation Fieldbus network has finished the design stage and is entering the implementation phase. DeviceNet is not being replaced.**	Plant-wide control and SCADA upgrade completed. **DeviceNet-controlled valves have been replaced with “hard-wired” controls.**	Replacement design of DeviceNet valves and VFDs in progress.

09 Plan for Membrane Replacement

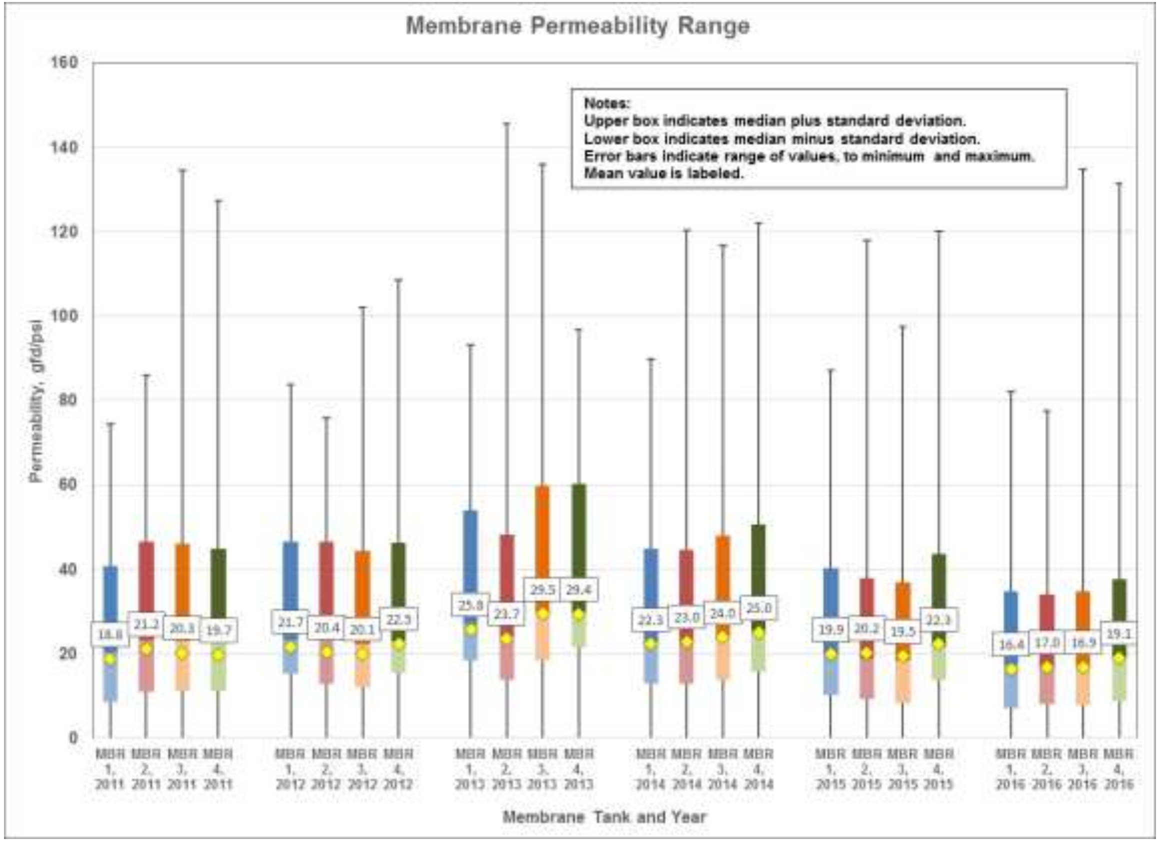
Plan for Membrane Replacement

- Typical membrane life is about 10 years
  - Need to plan for membrane replacement
- Emerging trend is to consider replacement with an alternate vendor’s product
- LOTT replaced Martin Way membranes in 2012, after 6 years of operation
  - Upgraded technology
  - Plan to conduct condition assessment

Picnic Point Membrane Performance Data



Picnic Point Membrane Performance Data



Conclusion: Move ahead with membrane replacement.

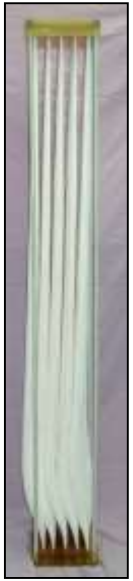
Picnic Point Membrane Replacement Strategy

Divide into multiple contracts and avoid replacing all in a single year?

- Common to install membranes at one time
- Exception is when spare tanks are constructed
  - Had an opportunity at Picnic Point
- Replacement
  - Most common to replace all membranes at one time
  - Fewer construction disruptions
  - Retain same model throughout system
- Future approach
  - Replace portion of next membrane set early
  - Pilot test new membranes

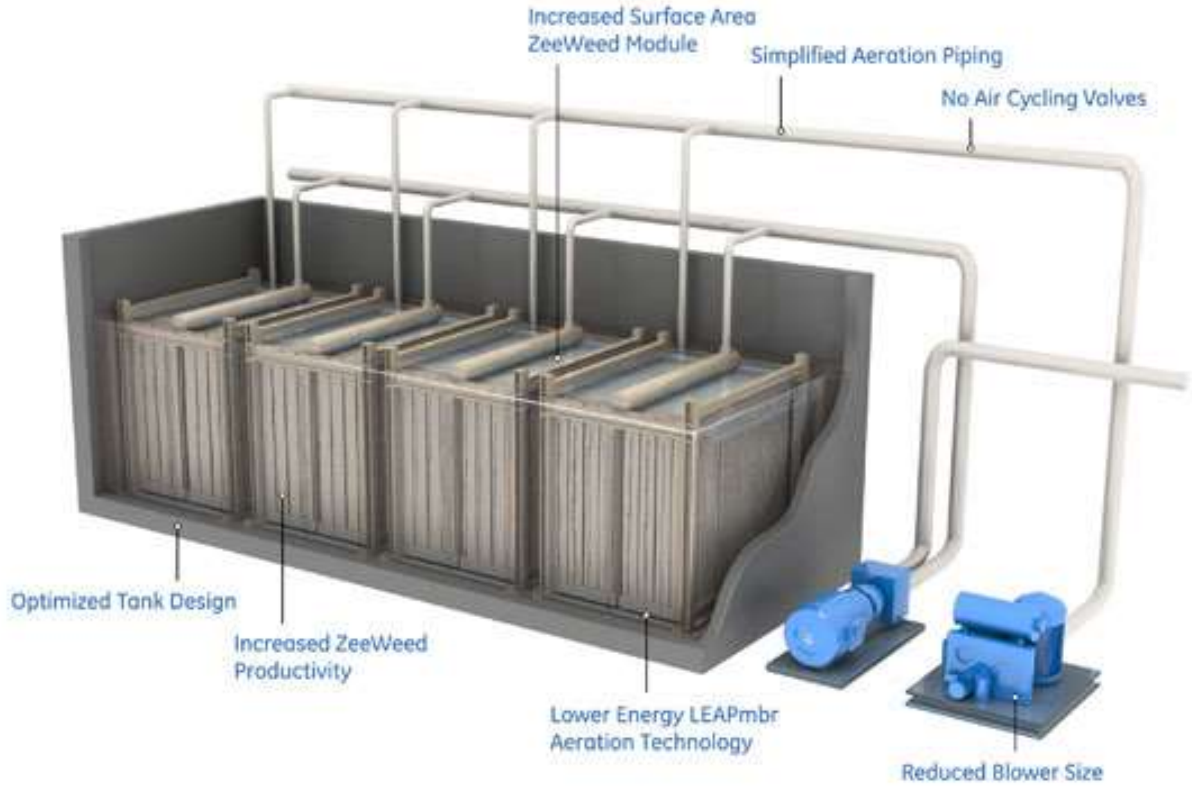
10 Consider New Membrane Technologies

Comparison of Current Products

Mfr	Evoqua/ Memcor	GE/ Zenon	Ovivo/ Microdyn	Anaergia/ Fibracast
Type	Hollow Fiber	Hollow Fiber	Flat Sheet	Hollow Fiber/ Flat Sheet
				

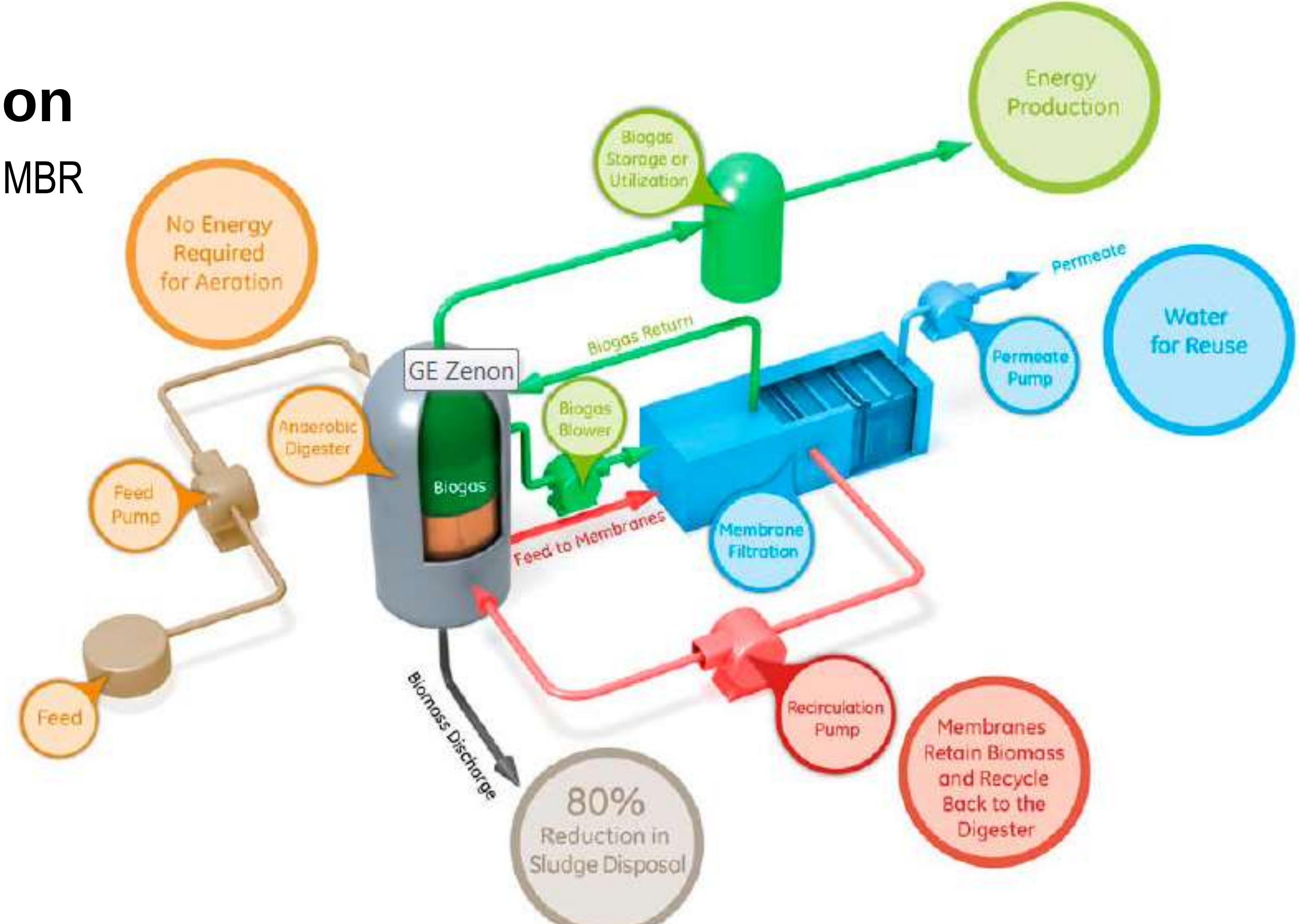
GE Zenon

LEAPmbr



GE Zenon

- Anaerobic MBR



Evoqua

- MemPulse aeration generates random rapid pulses at each MBR module
- Continuous air flow without use of valve or moving parts at base of module which draws mixed liquor into the bottom of the module through airlift effect
- Air bubbles blend with mixed liquor providing scour energy and fluidization of membrane surface which prevent solids drying/accumulation

- Cross flow air pattern that prevents solids accumulation at the surface and reduce air scour requirements



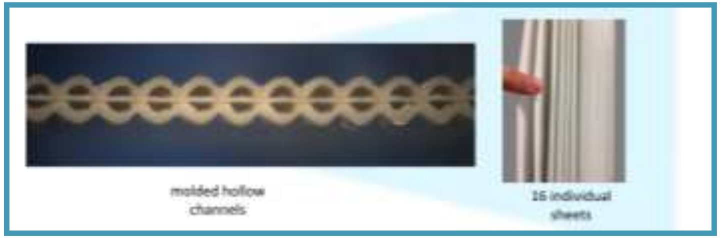

Ovivo

- Microdyn
- Similar operation as Kubota
- Microdyn flat sheet from Germany
- 0.04 micron
- “Self healing”
- Medium bubble scour using Aerostrip non clogging diffuser
- PES membrane
- Planning on building a manufacturing facility in Texas




Anaergia

- Fibracast
- Hollow fiber sheet
- Polyethylene terephtalate support with PVDF membrane
- 0.04 micron
- Tank fed at bottom and overflow on top
- Continuous but variable air scour
- Cleanings
- Backwash at same filtration flow
- Maintenance cleans
- Recovery cleans

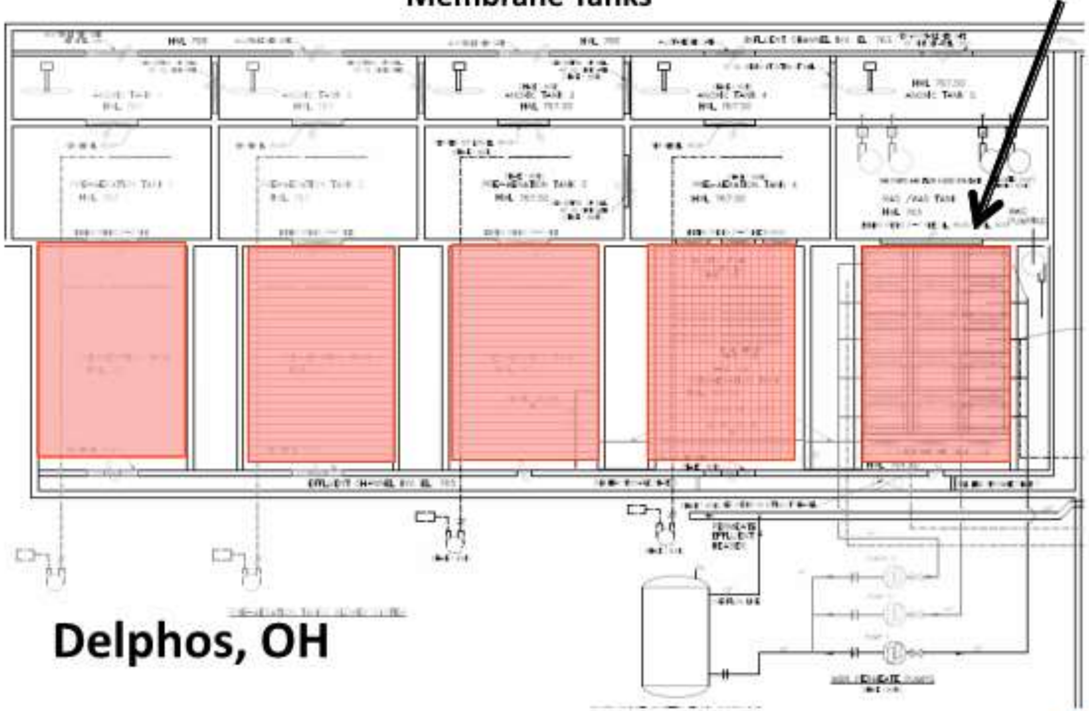


Largest Awarded MBRs using Fibracast

Project	Date	ADF (mgd)	MDF (mgd)
Delphos, OH, USA	2015	3.8	7.7
Victovalley Wastewater Reclamation, CA, USA	2014	2.0	
Aldeno, Italy	2014	0.1	

Applications: Retrofitting a Kubota Flat Plate Membrane Plant

Existing Kubota Membrane Tanks



- Low packing density membranes require 5 membrane tanks

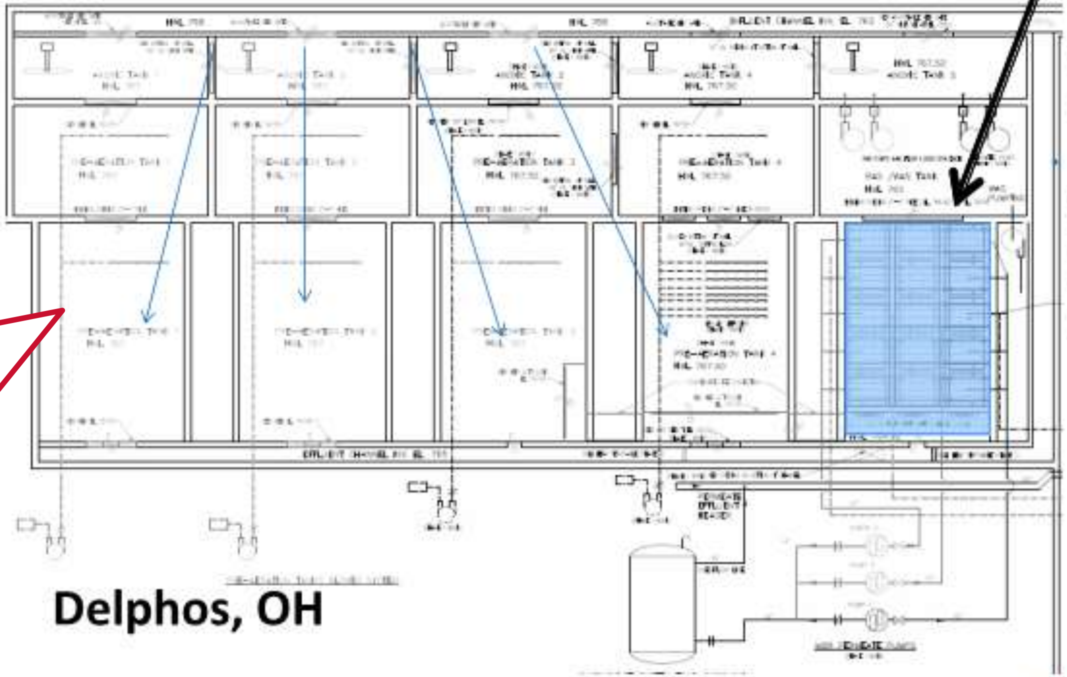
Delphos, OH

FIBRACAST

Applications: Retrofitting a Kubota Flat Plate Membrane Plant

Old Kubota membrane tanks can be used for aeration tanks

May need to retain former membrane tanks for dissolved oxygen transfer

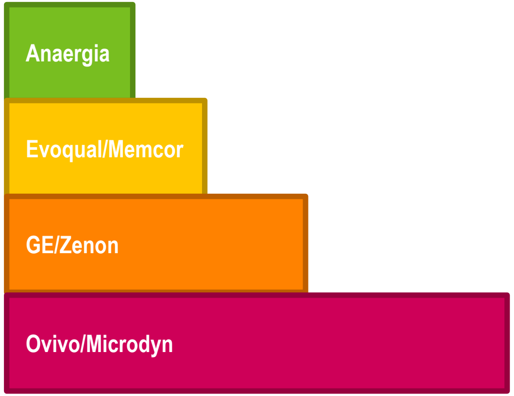


- 1 FibrePlate™ Tank replaces 5 Kubota tanks with same capacity
- Extra tankage can be used to increase aeration tank capacity

Delphos, OH

FIBRACAST

Relative Footprint of Four Membrane Systems




Irvine Ranch Water District MBR Facility


City of Healdsburg MBR Facility

Comparison of Current Products – O&M

	Evoqua/ Memcor	GE/ Zenon	Ovivo/ Microdyn	Anaergia/ Fibracast
Cleaning every 12 minutes	Relax	Backwash	Relax	Backwash
Backwash Capability	Yes	Yes	No	Yes
Maintenance Clean Capability	Yes	Yes	No	Yes
Recovery Clean Capability	Yes	Yes	Yes	Yes
Pressurized Integrity Test	Yes	Yes	No	Yes

Summary

- Improved our understanding of MBRs over last 15 years
- Incorporate lessons learned from previous facilities into design and operation
  - Plan for variable capacity
  - Must control debris and contaminants
  - Cold weather aspects must be considered during design
  - Consider flow equalization
  - Plan for membrane replacement
  - Provide the right mix of O&M skills
- Vendors keep improving their technology for cost and energy efficiency