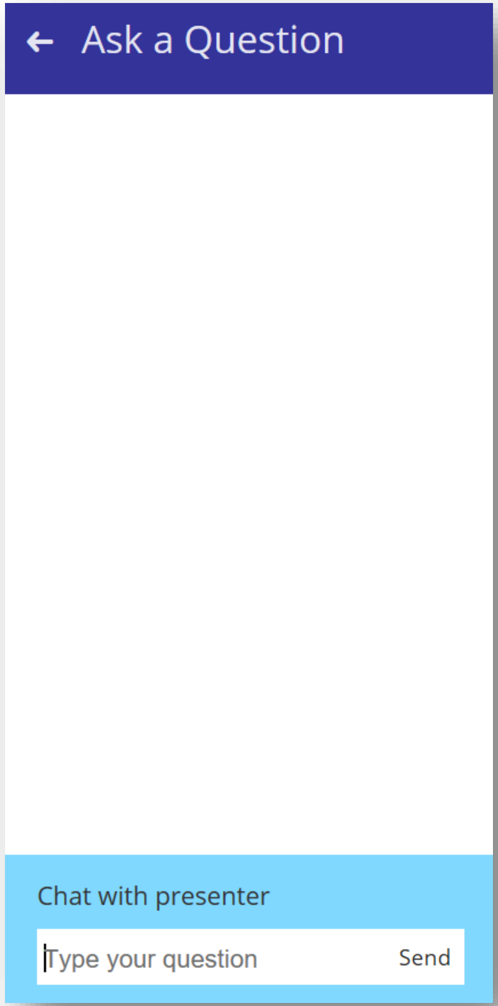
Membranes 101: The Basics and Beyond

September 26, 2019

WateReuse Webcast Series

A Few Notes Before We Start…

- Today’s webcast will be 60 minutes.
- There is one (1) Professional Development Hour (PDH) available for this webcast.
- A PDF of today’s presentation can be downloaded when you complete the survey at the conclusion of this webcast.
- If you have questions for the presenters please send a message by typing it into the chat box located on the panel on the left side of your screen.



WATEREUSE

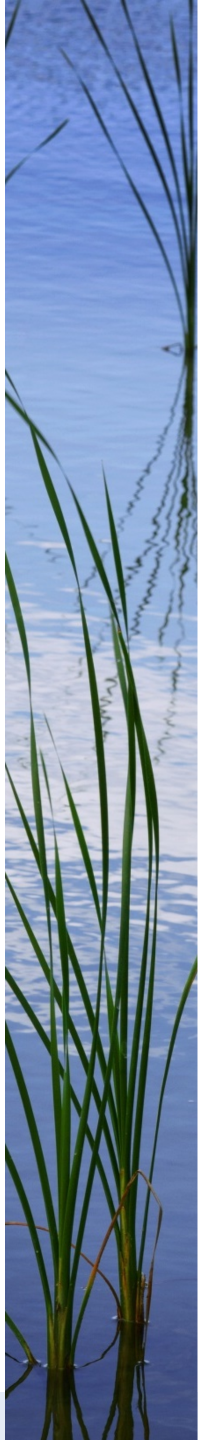
Today’s Presenter

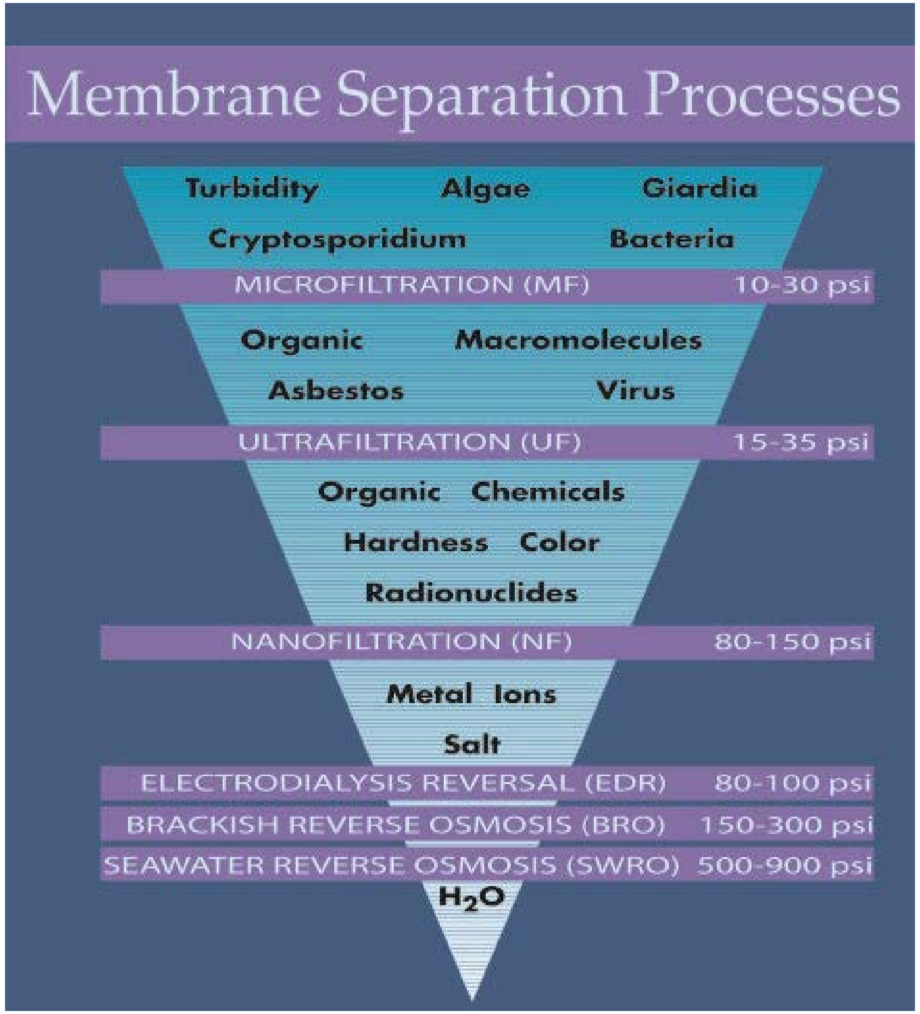
carollo
Engineers...Working Wonders With Water®

Dan Hugaboom
Chief Technologist,
MF/UF Membranes
Carollo Engineers, Inc.

Agenda

- Microfiltration/Ultrafiltration Membranes & Applications
- Membrane Bioreactor applications & Applications
- Desalting Membrane applications & Applications

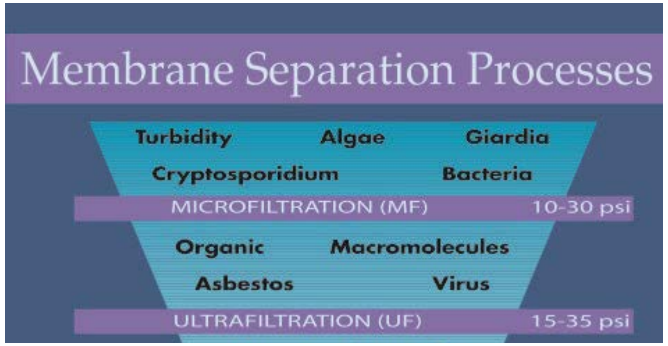




Credit: AMTA
https://www.amtaorg.com/wp-content/uploads/01_Application_of_Membrane_Technologies.pdf

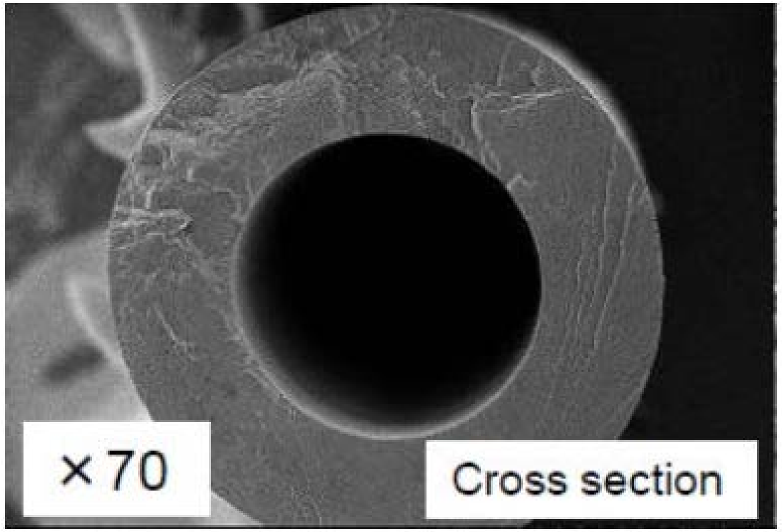
Micro and Ultra filtration (MF/UF) Work on Size Exclusion Principal

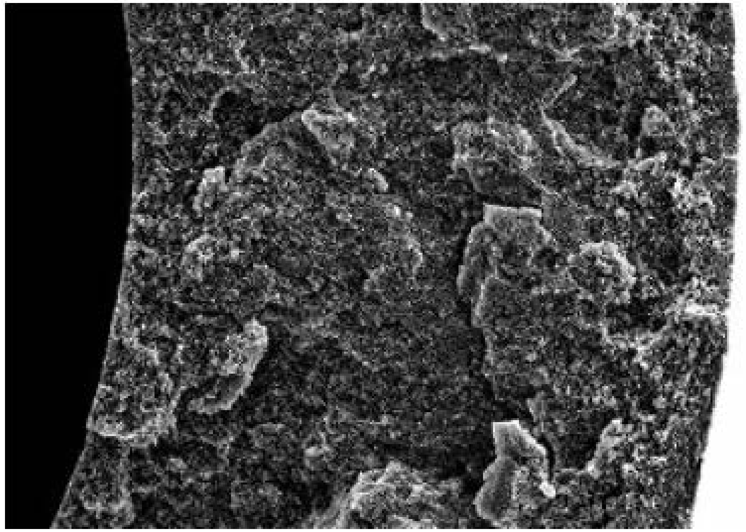
- Membrane Filtration
  - Pressure driven, liquid phase, separation process based on size exclusion utilizing a thin layer of semi-permeable material
  - MF/UF Membranes have distinct pores



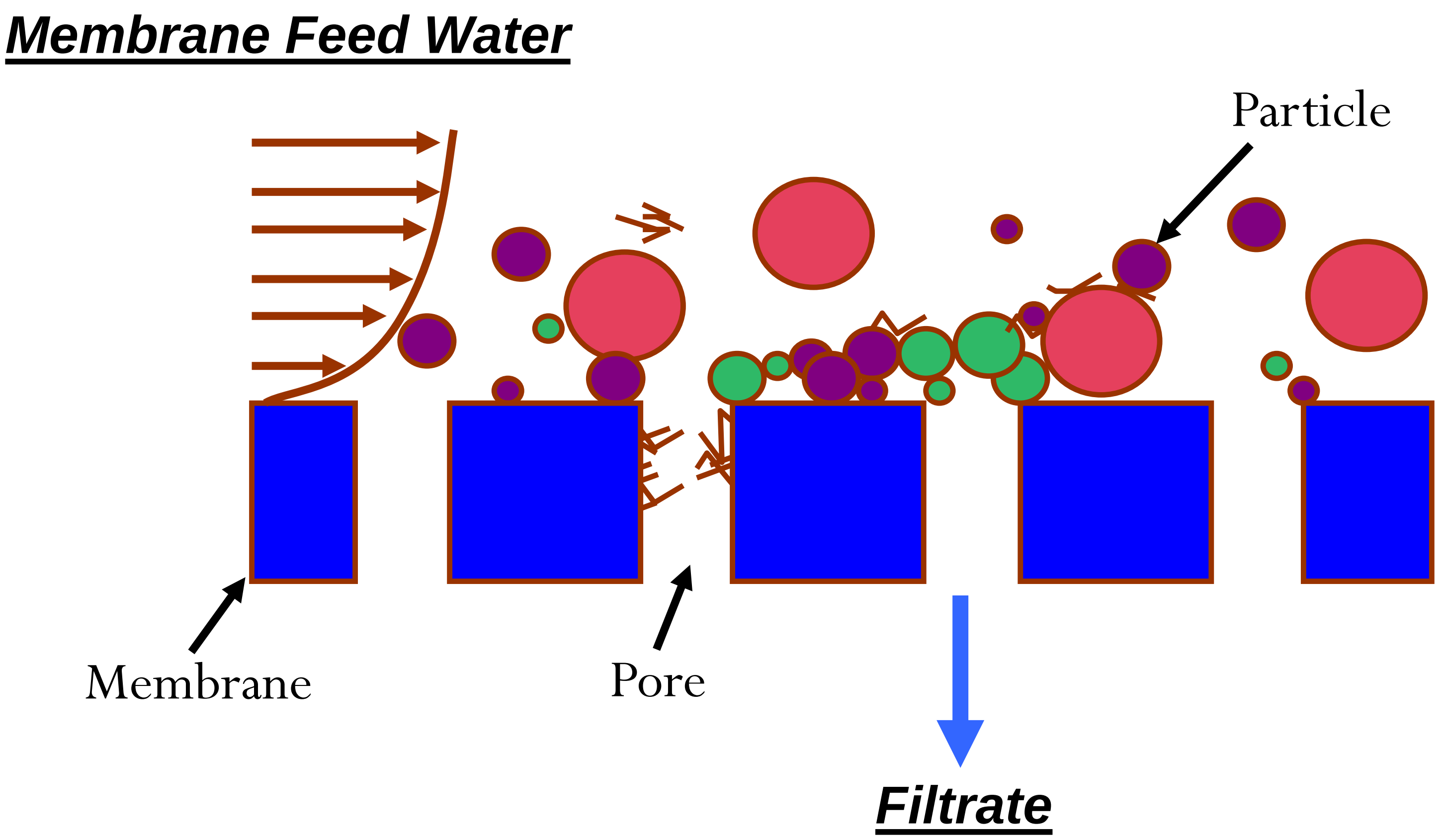
CEI image (1500x) of the filtrate side of a pre clean fiber

MF/UF Membranes have many Forms, but the Most Common is Polymeric Hollow Fiber (HF)

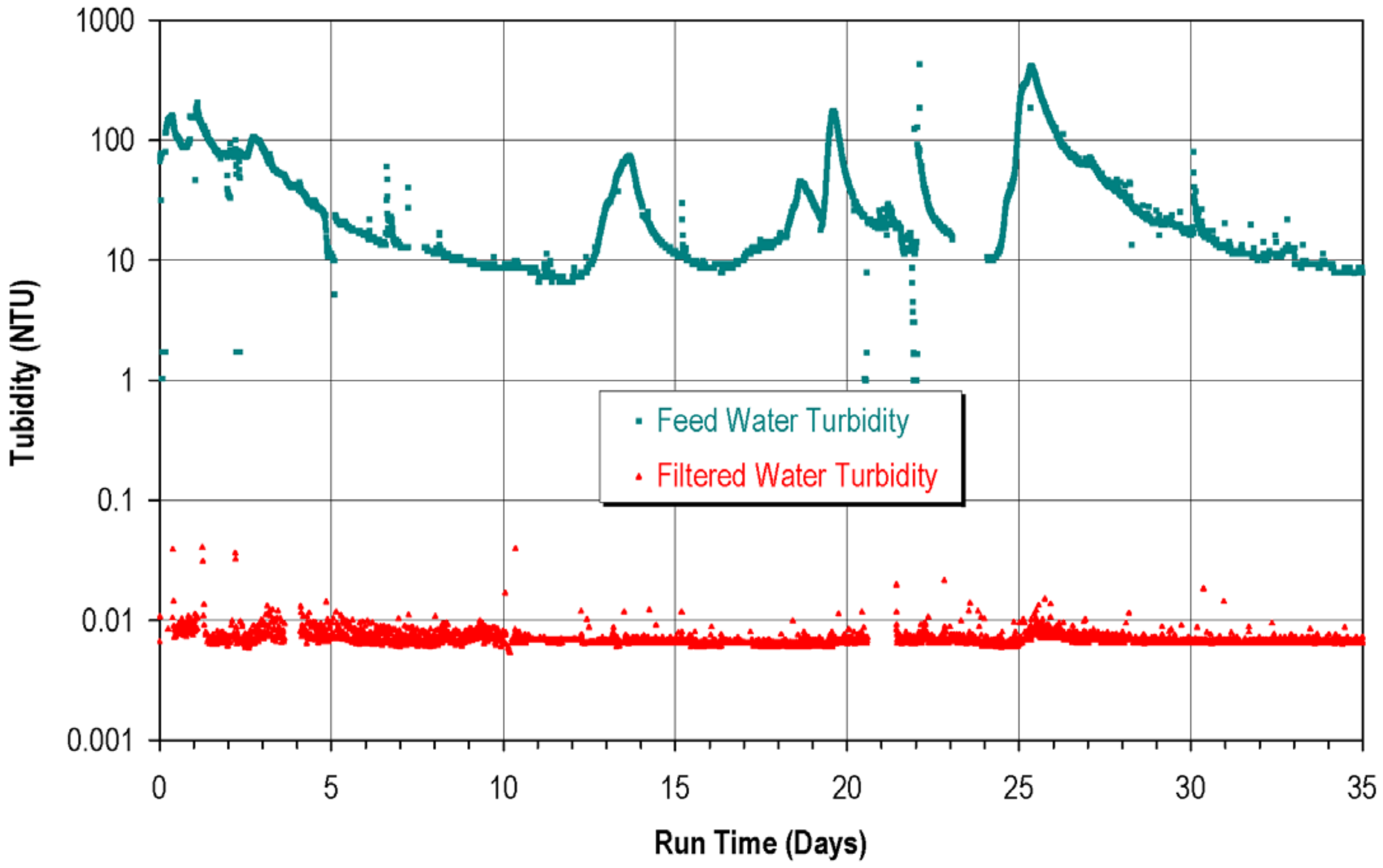




MF/UF Membrane Rack, 1.5 mgd Capacity


Membrane Feed Water
Particle
Membrane
Pore
Filtrate

Solids Removal is nearly Complete as long as the membrane is intact



WATEREUSE

MF/UF Membranes are also classified in water treatment by rejection characteristics

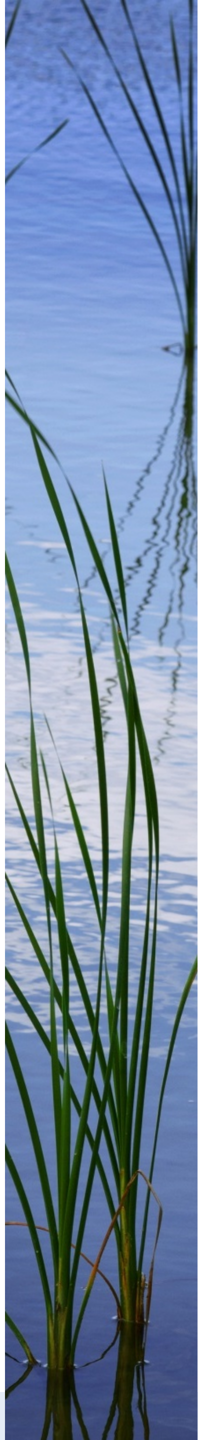
California Surface Water Treatment Rule
Alternative Filtration Technology - Membrane Filtration

California Surface Water Treatment Rule
Alternative Filtration Technology - Membrane Filtration
SWRCB-DDW Water Treatment Committee - June 2018

Manufacturer	Model	Type	Pathogen Removal Standards (log credit)			Turbidity Standards		Conditions During Demonstration	
			Virus	Giardia	Crypto	95% of time	Max	Max Flux Lph/m2 (gfd)	Max TMP (psi)
Aquasource	Advent	UF	4, *	4	4	0.1 NTU	0.5 NTU	136 (80)	29
BASF Inge	D5000	UF	3.5, *	4	4	0.1 NTU	0.5 NTU	156 (92)	29
Dow	UF SFX2860	UF	2.5, *	4	4	0.1 NTU	0.5 NTU	102 (60)	30
Evoqua (formerly Siemens, who acquired US Filter)	Memcor PVdF (S10V, L10V, L20V)	UF	1.5, *	4	4	0.1 NTU	0.5 NTU	88 (52)	22
	PVdF	MF	0.5, *	3.5	4	0.1 NTU	0.5 NTU	85 (50)	29
	L10N, L20N, S10N	UF	1, *	4	4	0.1 NTU	0.5 NTU	263 (155)	22 (L10N, L20N) 12.3 (S10N)
	Polypropylene	MF	0.5, *	4	4	0.1 NTU	0.5 NTU	110 (66.9)	15
	(M10B, M10C, S10T)	MF	0, *	4	4	0.1 NTU	0.5 NTU	160 (93.6)	17
GE Zenon	Homespring UF211	UF	3.5, *	4	4	0.1 NTU	0.5 NTU	93.4 (55)	20
	ZeeWeed 500 series	UF	2, *	4	4	0.1 NTU	0.5 NTU	85 (49.8)	11.8
	ZeeWeed 1000 V2 & V3	UF	3.5, *	4	4	0.1 NTU	0.5 NTU	93.4 (55)	12 (vac)
	ZeeWeed 1000 V4	UF	1, *	4	4	0.1 NTU	0.5 NTU	102 (60)	13
	ZeeWeed 1500 ZeeWeed 1500-600 CPX	UF	1, *	4	4	0.1 NTU	0.5 NTU	170 (100)	45
Hydranautics	HYDRAcap	UF	4, *	4	4	0.1 NTU	0.5 NTU	119 (69.3)	18
Koch	PMPW	UF	4, *	4	4	0.1 NTU	0.5 NTU	173 (102)	35
METAWATER (NGK)	431011	UF	*	4	4	0.1 NTU	0.5 NTU	(175)	55
Norit X-Flow	S 225	UF	*	4	4	0.1 NTU	0.5 NTU	127.3 (75)	31
	SXL-225	UF	*	4	4	0.1 NTU	0.5 NTU	127.3 (75)	31
Pall	Microza USV 6203 Microza USV 5203 Microza UNA 620A	MF	0.5 *	4	4	0.1 NTU	0.5 NTU	203.7 (120)	43.5
	UNA 620A1	UF	4, *	4	4	0.1 NTU	0.5 NTU	102 (60)	51
Seccua	SeccuMem Pro 1000	UF	1, *	4	4	0.1 NTU	0.5 NTU	90 (53)	36
Toray (Torayfil)	HFS-2020	UF	1.5, *	4	4	0.1 NTU	0.5 NTU	202 (120)	29
	LSU-1515	UF	1.5, *	4	4	0.1 NTU	0.5 NTU	83 (49)	10
Toyobo	Durasep (UPF0860, UPF0870)	UF	1.5, *	4	4	0.1 NTU	0.5 NTU	119 (70)	35
WesTech Polymem	120S2	UF	*	4	4	0.1 NTU	0.5 NTU	45 (27)	21

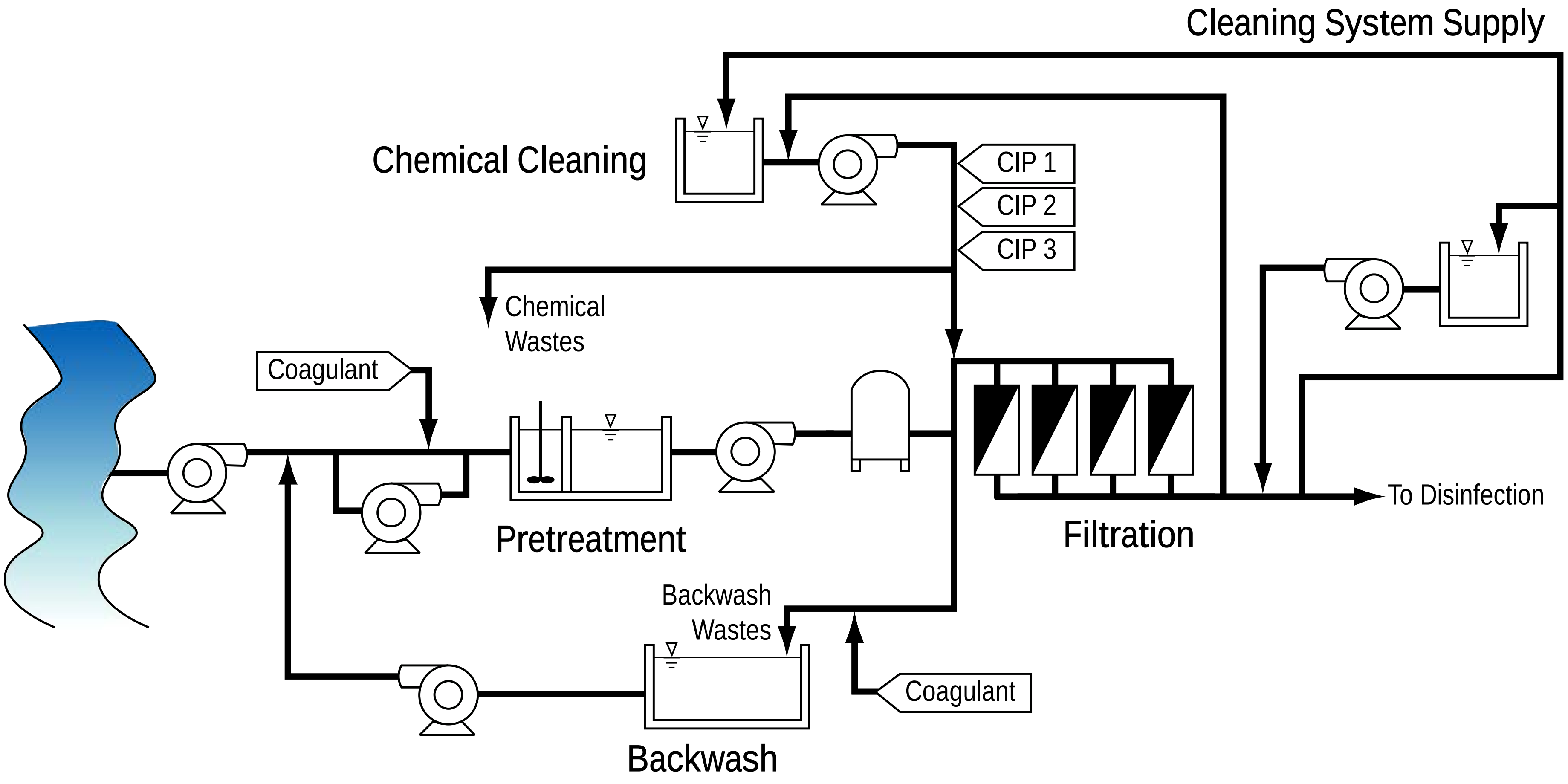
Note *: Although virus removal may have been successfully demonstrated and accepted by DDW in the past, each plant is required to provide a minimum of 0.5-log Giardia and 4-log virus inactivation through disinfection. Credit for virus removal cannot be demonstrated on a daily basis currently via pressure decay testing per the USEPA Membrane Filtration Guidance manual.

WATEREUSE

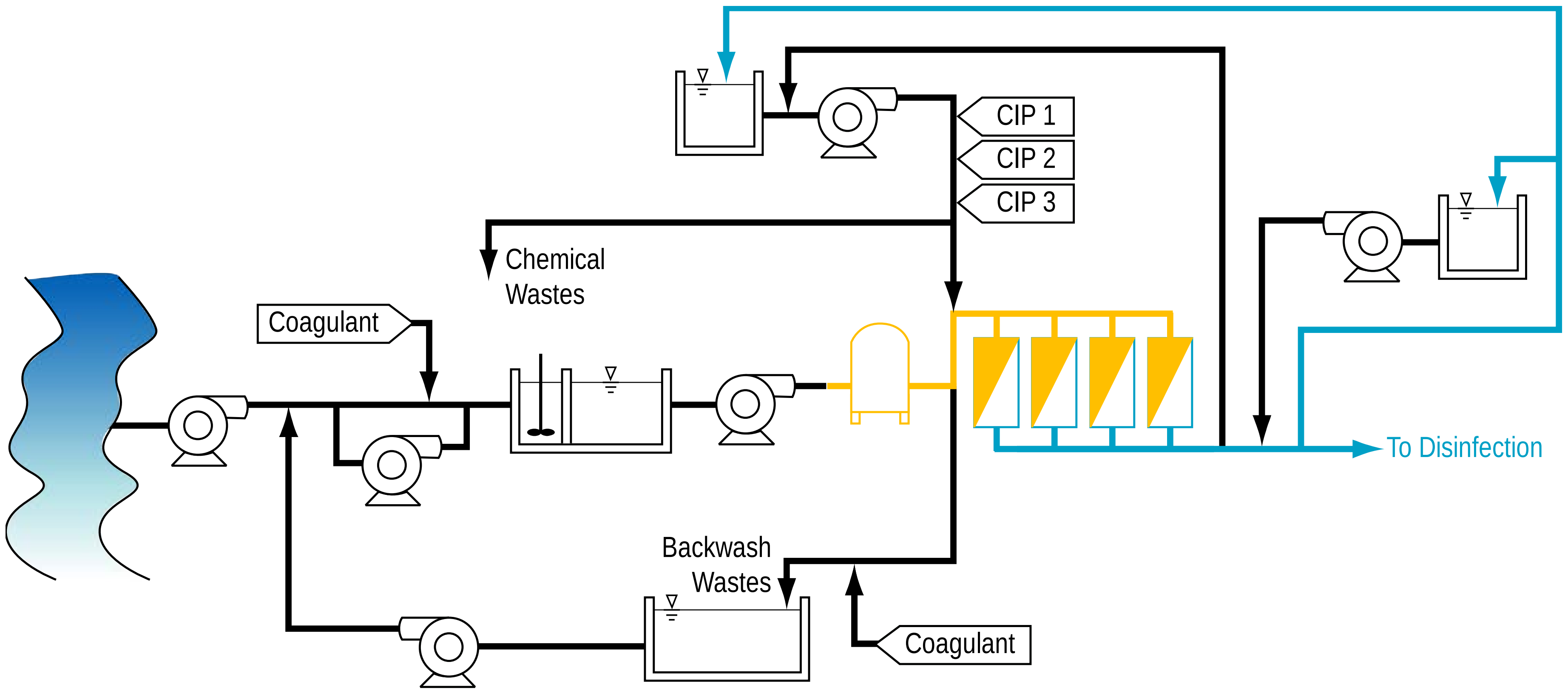


The Operational Challenge is Not Water Quality its Production

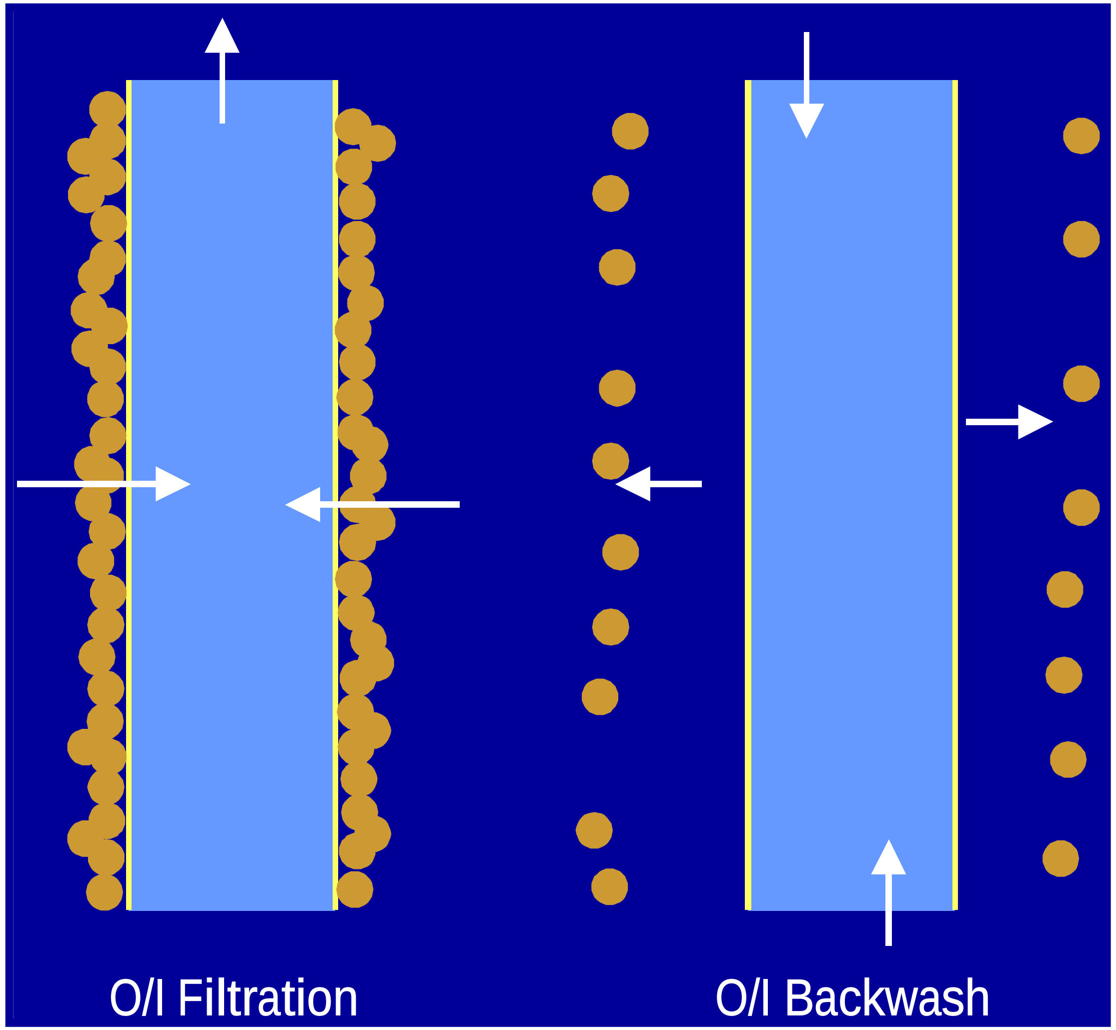
Process Flow Diagram



Process Flow Diagram - Filtration

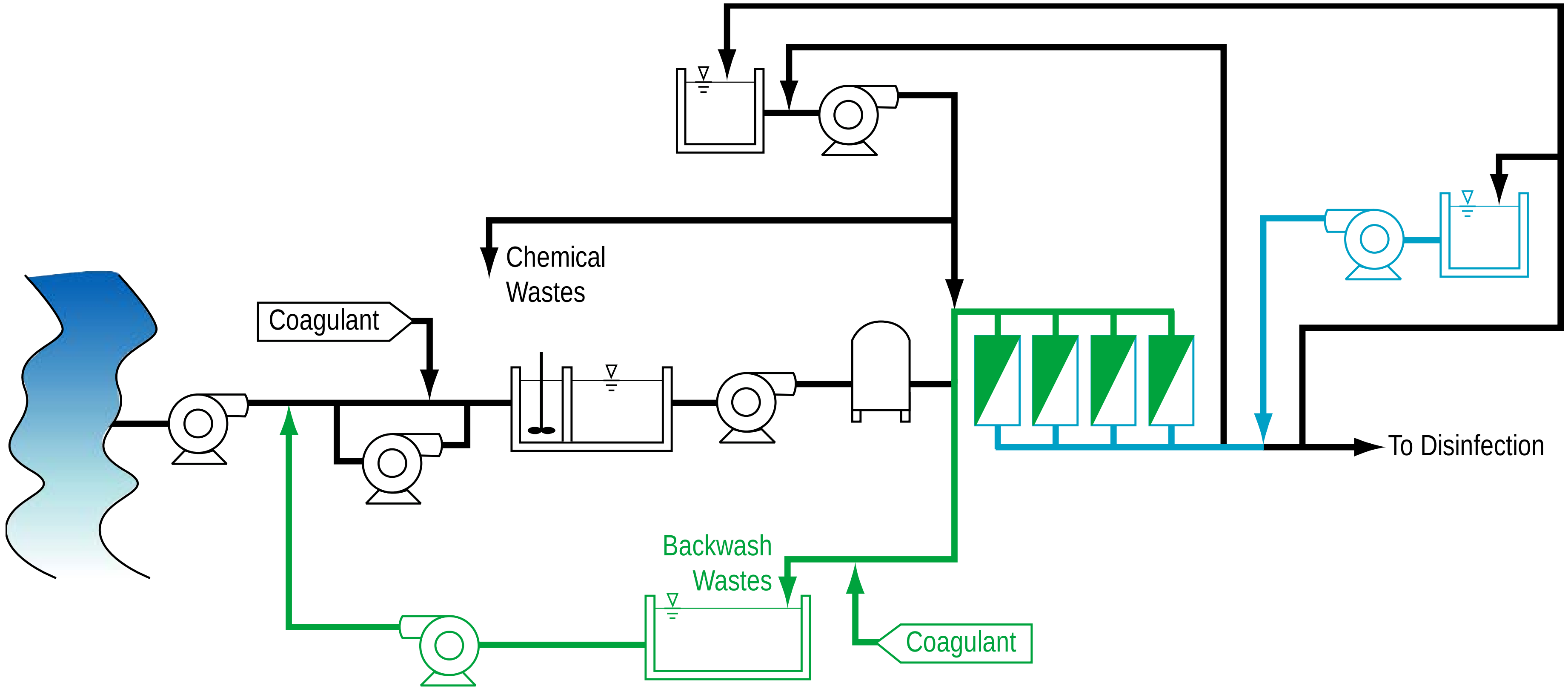


Flow of Water in an *Outside to Inside* Flow Membrane Fiber

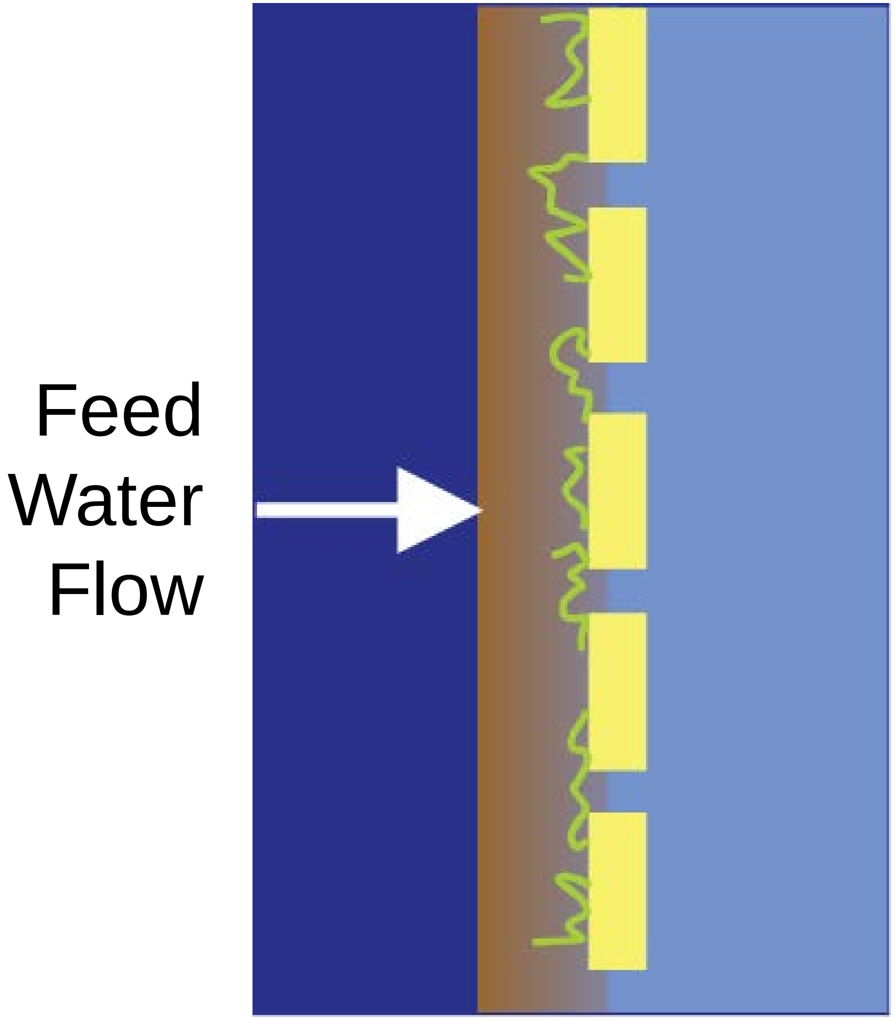


WateReuse

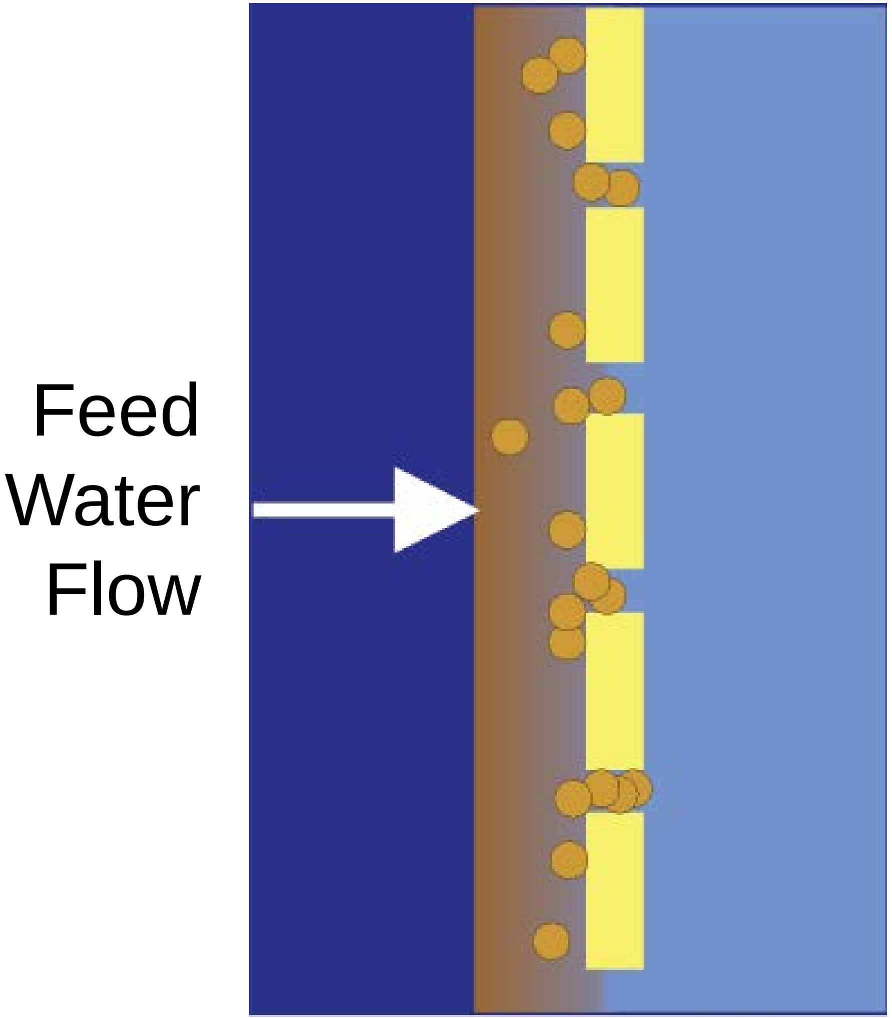
Process Flow Diagram - Backwash



Some Causes of Irreversible Fouling – NOM Adsorption

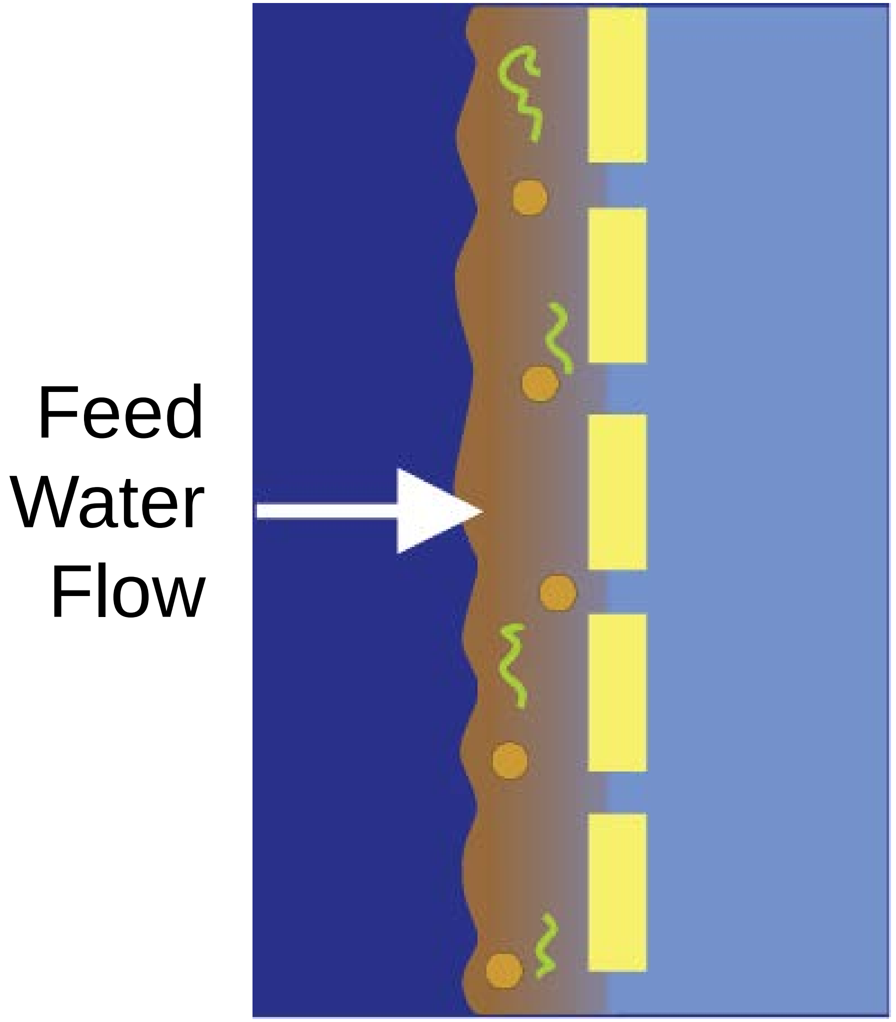


Some Causes of Irreversible Fouling – Pore Penetration

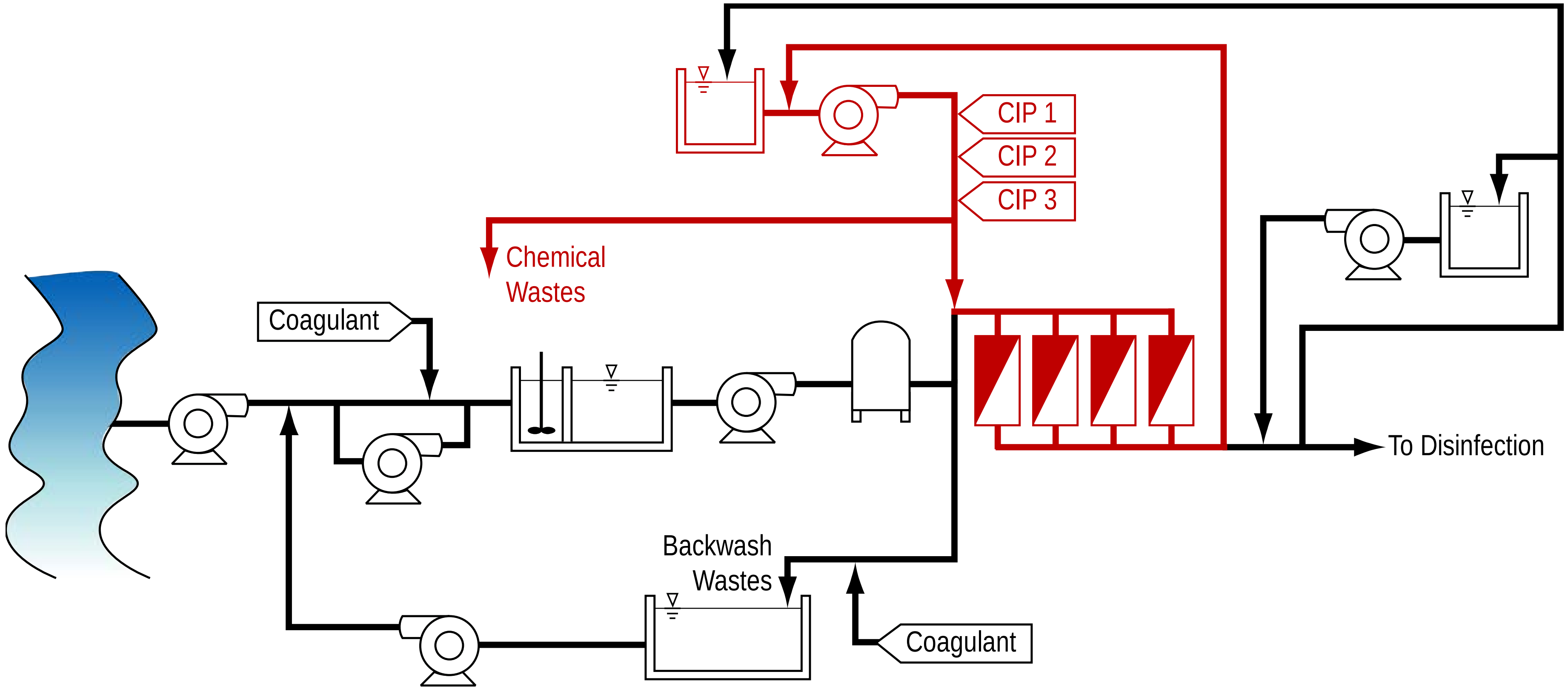


WATEREUSE

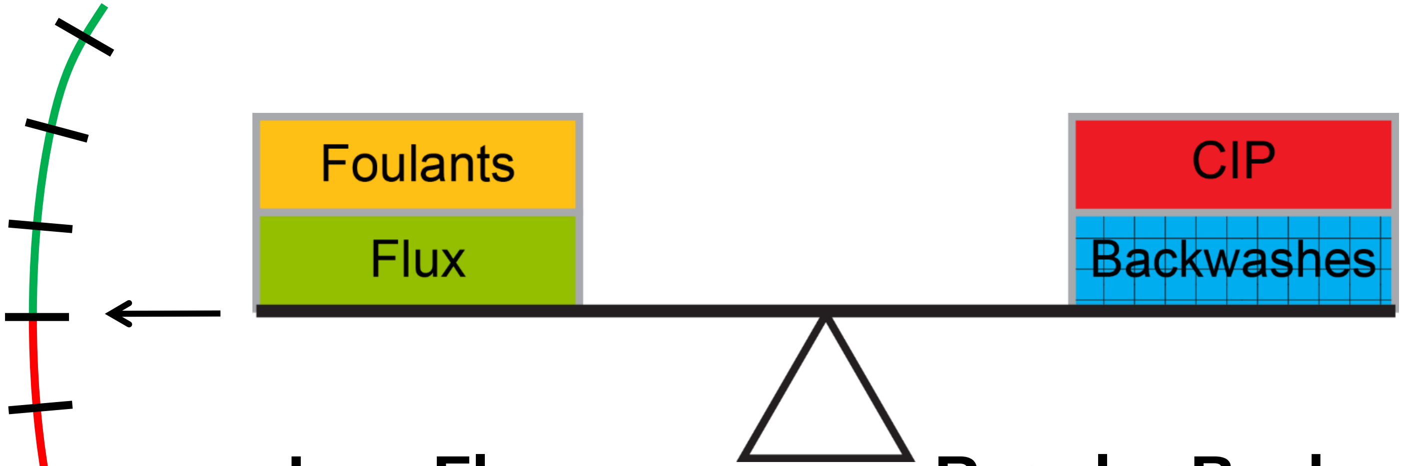
Some Causes of Irreversible Fouling – Cake Formation



Process Flow Diagram – Chemical Cleaning



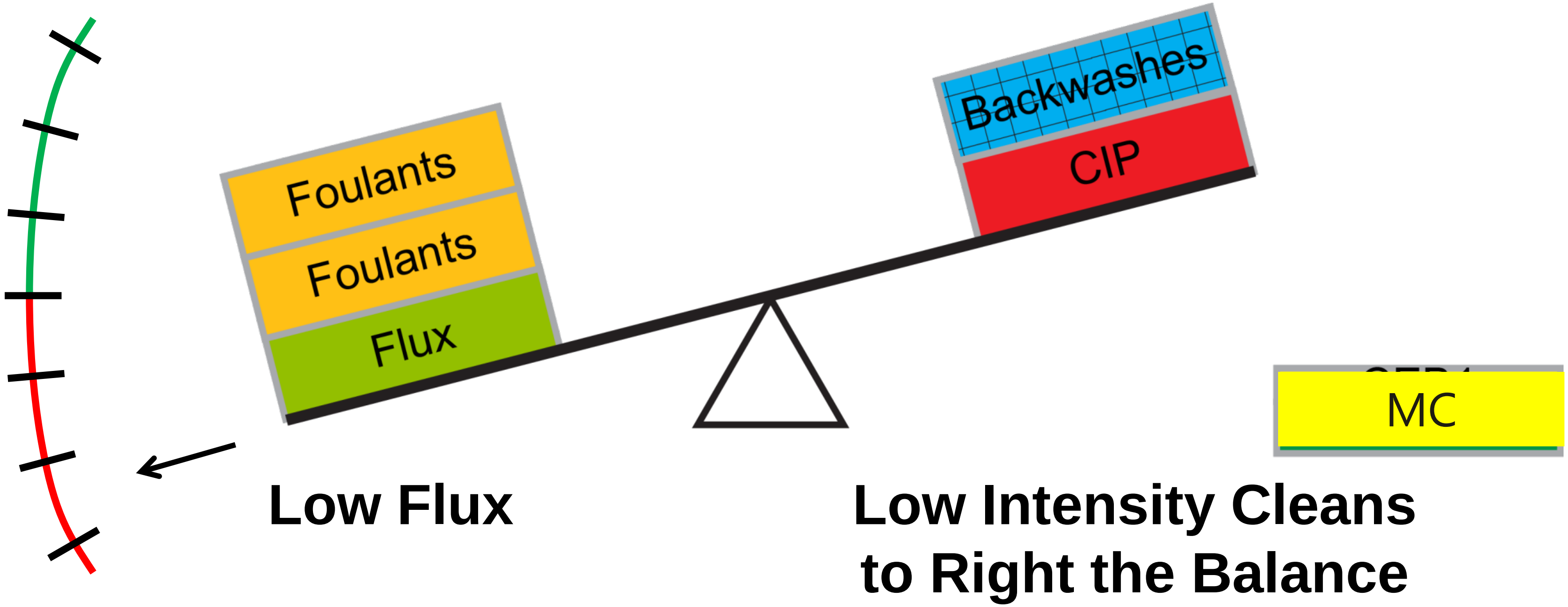
Low Flux & Properly Matched Membrane System = Balance with Minimal Cost



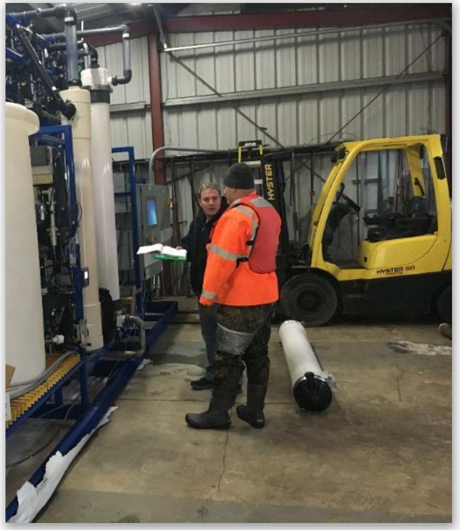
Low Flux

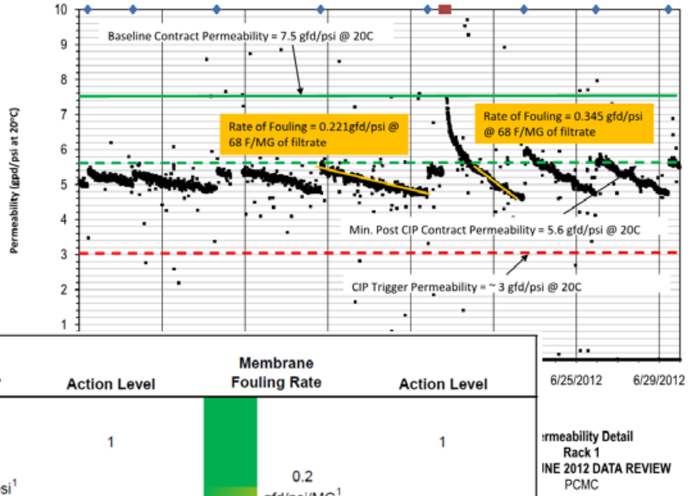
Regular Backwashes and Monthly CIPs

Feed Water Quality Upsets Can put you out of Balance



Pilot Testing Reduces Uncertainty by Defining the Right Balance

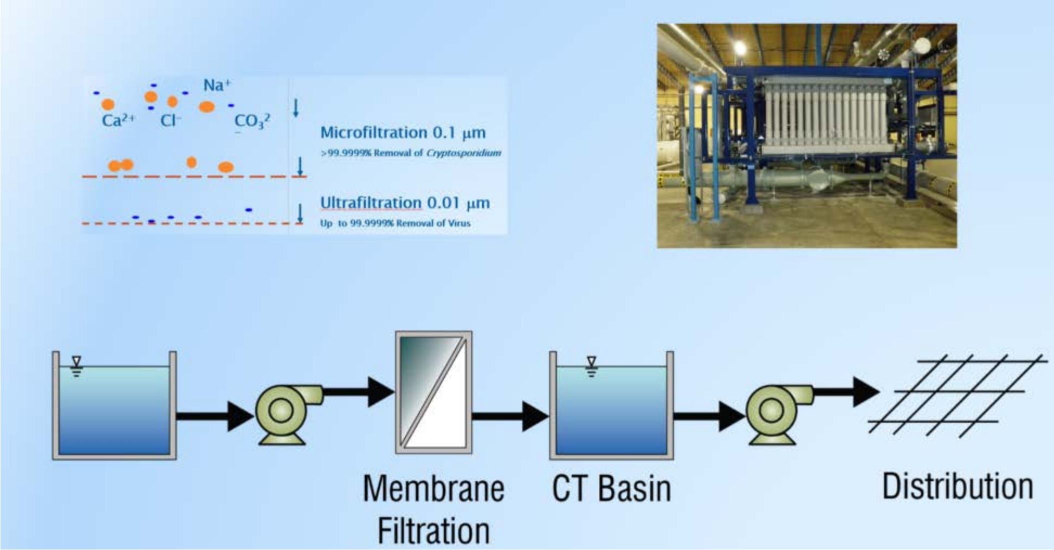




Minimum Permeability	Action Level	Membrane Fouling Rate	Action Level
	1		1
6.3 gfd/psi[1]		0.2 gfd/psi/MG[1]	
	1		1
4.7 gfd/psi[2]		0.6 gfd/psi/MG[2]	
	2		2
3 gfd/psi[3]		0.8 gfd/psi/MG[5]	
	3		3
1 gfd/psi[4]			

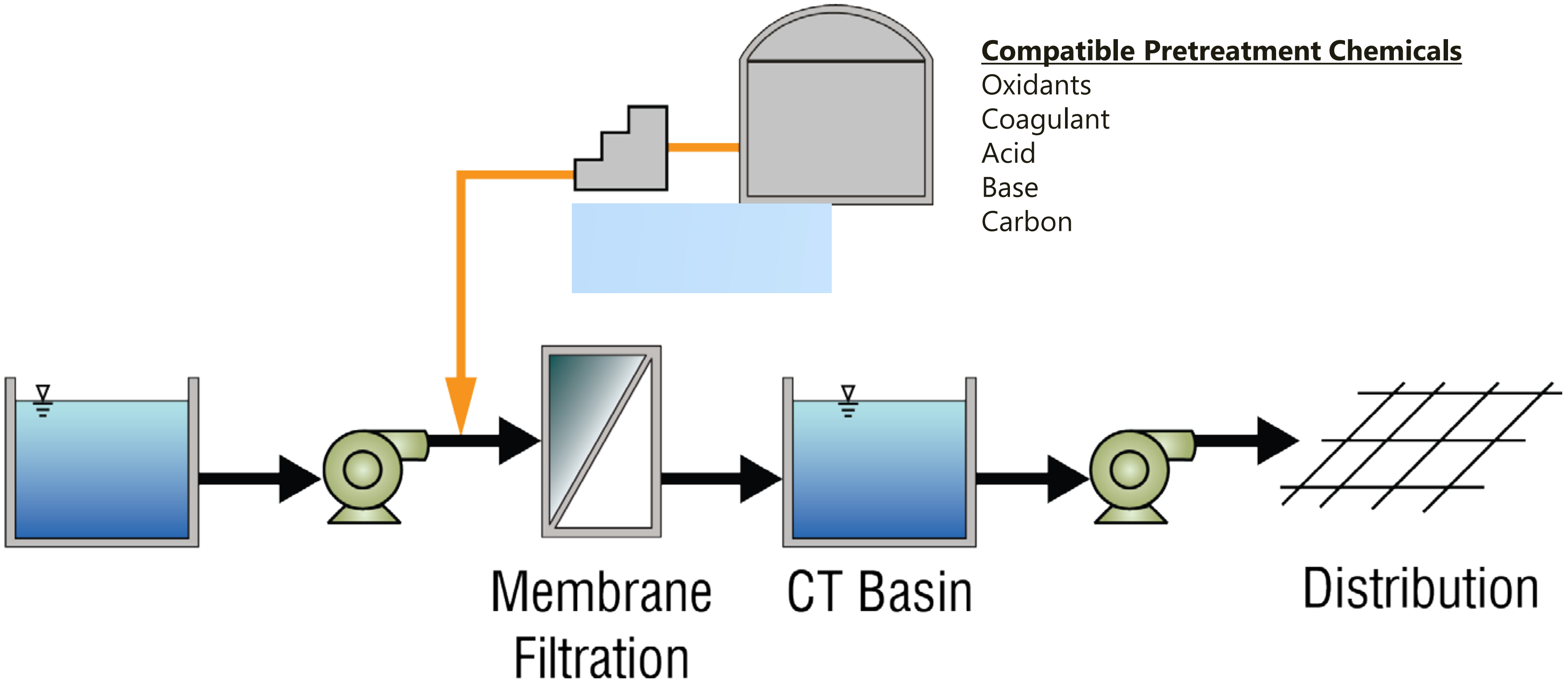
MF/UF Applications in Drinking Water

Treatment Objective	Regulation	Standard
Surface Water Filtration	Surface Water Treatment Rule	<0.3 NTU
Cryptosporidium	LT2	2.5 to 5.5 log removal
GWUDI Filtration		<0.3 NTU



WATEREUSE

MF/UF Membranes Can be Combined with Pretreatment Chemicals to Target Specific Contaminants



Compatible Pretreatment Chemicals

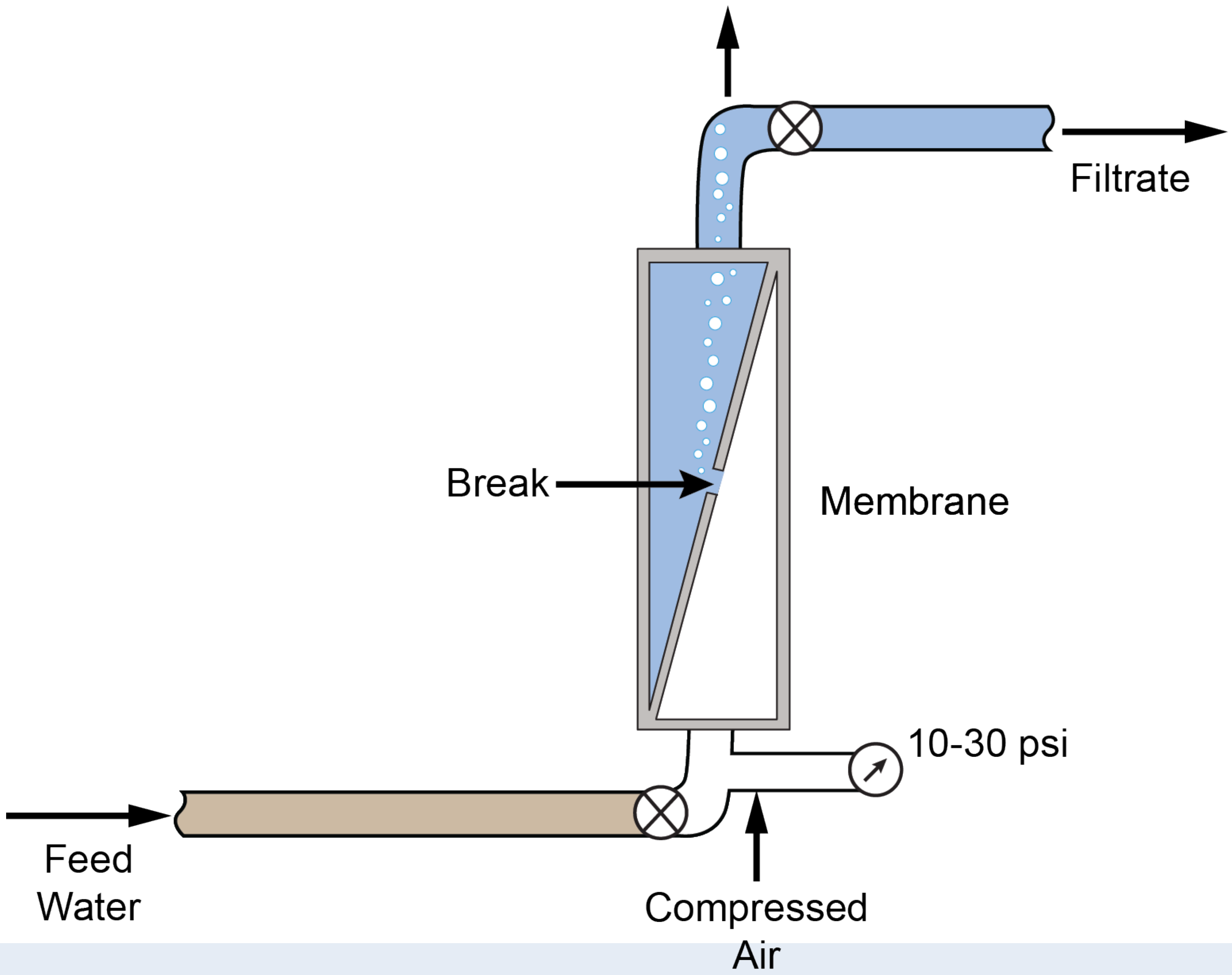
Oxidants
Coagulant
Acid
Base
Carbon

Key Considerations – Integrity Testing as Required by the USEPA MFGM

- Direct Integrity Testing - A direct integrity test is defined as a physical test applied to a membrane unit in order to identify and isolate integrity breaches.

- Indirect Integrity Testing - indirect integrity monitoring is defined as monitoring some filtrate water parameter that is indicative of the removal of particulate matter

Direct Integrity Test Example – Pressure Decay Tests



WATEREUSE

Pressure Decay Test Results Tell us about the condition of the membrane

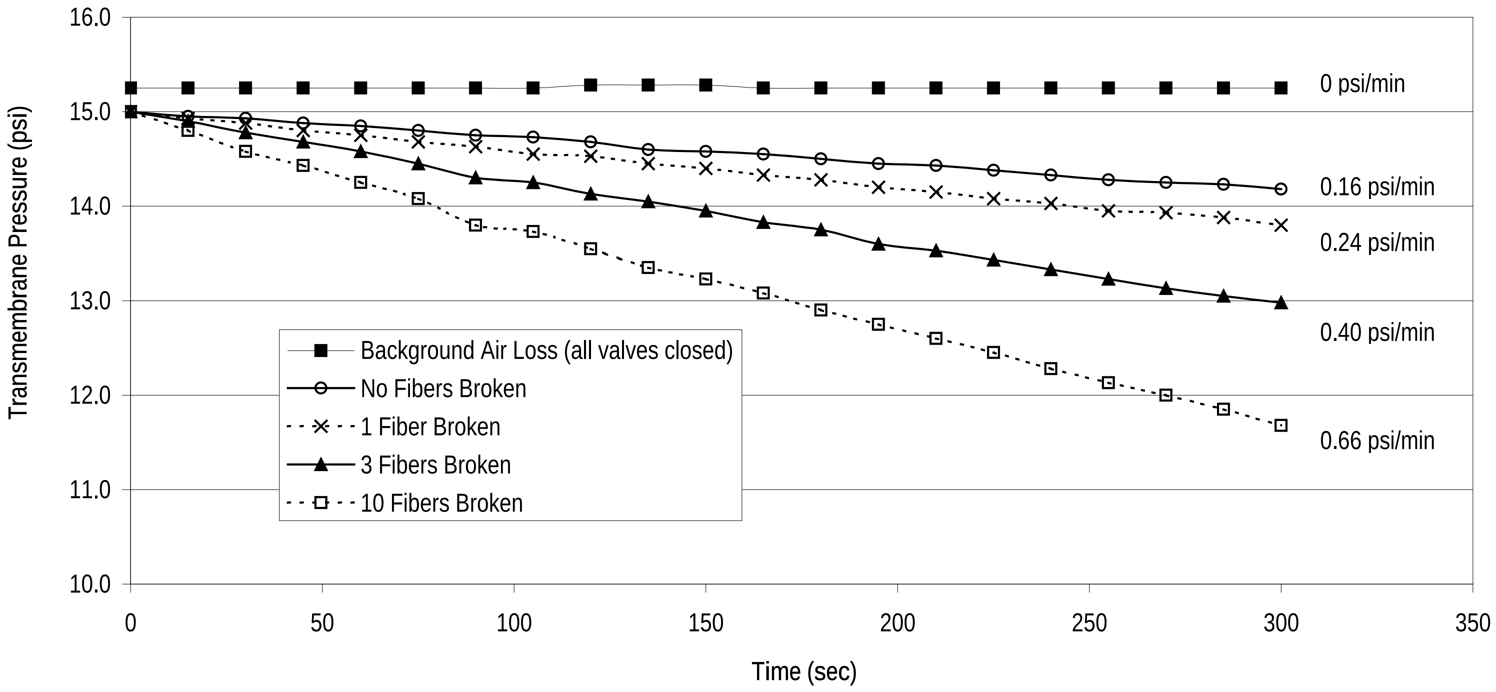


Figure 5.13
PRESSURE DECAY TESTS - PERIOD 3
CDHS CERTIFICATION STUDY - POLYMEM UF120S2
WESTECH/POLYMEM

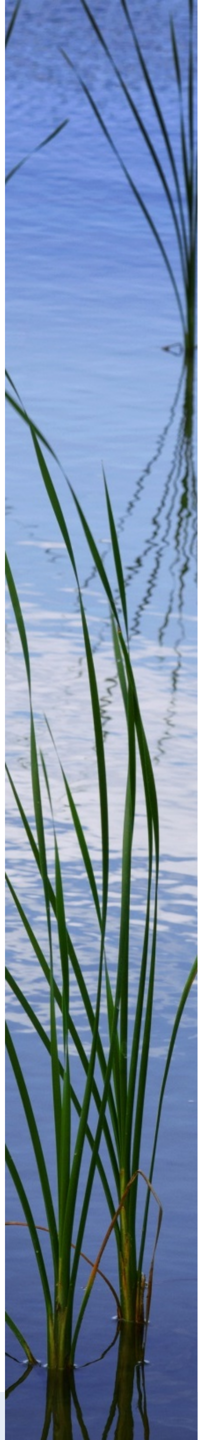
WATEREUSE

The PDT Result (psi/min) is Used in an Equation to Estimate the Amount of water Bypass Treatment and Log Removal – Pencils Down… Its done in the Control System

$$LRV_{DIT} = \log\left(\frac{Q_p \bullet ALCR \bullet P_{atm}}{\Delta P_{test} \bullet V_{sys} \bullet VCF}\right) \qquad \text{Equation 4.9}$$

Where:

LRV_{DIT}	=	direct integrity test sensitivity in terms of LRV (dimensionless)
Q_p	=	membrane unit design capacity filtrate flow (L/min)
ALCR	=	air-liquid conversion ratio (dimensionless)
P_{atm}	=	atmospheric pressure (psia)
ΔP_{test}	=	smallest rate of pressure decay that can be reliably measured and associated with a known integrity breach during the integrity test (psi/min)
V_{sys}	=	volume of pressurized air in the system during the test (L)
VCF	=	volumetric concentration factor (dimensionless)

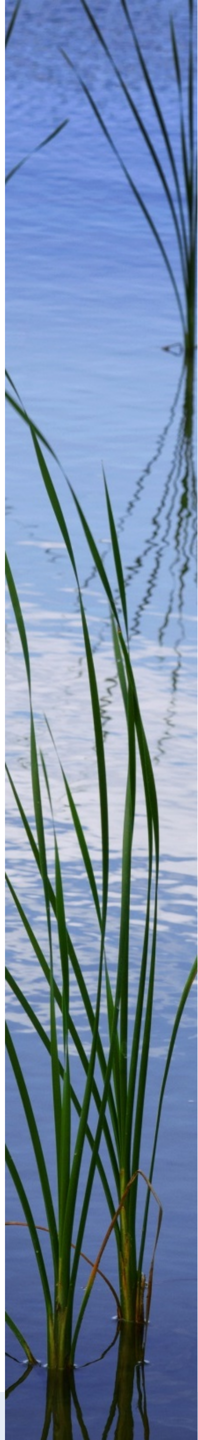


Indirect Integrity Testing Methods

- <u>**Turbidity monitoring**</u>
- Particle counting
- Particle monitoring

Membranes in Tertiary Applications – Key Considerations

- Water Quality
  - Seasonal variations in secondary effluent quality
    - TSS
    - TOC
    - BOD
    - Phosphorus Concentrations and Speciation
  - WWTP characteristics, especially SRT
  - FOG pretreatment

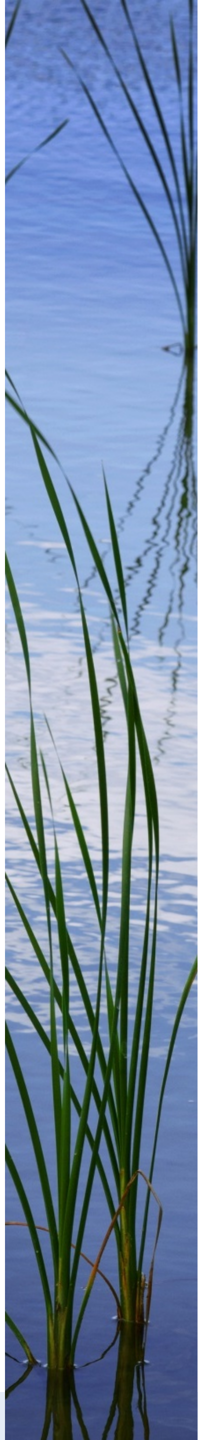


Key Considerations in WW Applications – Solids Residence Time and Flux

May need pretreatment to control fouling.

Examples:

- Coagulation
- Ozone
- Biological filtration
- Ozone/Biological Filtration



WATEREUSE

MF/UF Membranes are Used in Tertiary Filtration Applications

Non – Potable Reuse

Typical Filtration Goal:

Filtrate Turbidity <0.2 NTU

WATEREUSE

MF/UF Membranes are Used in Tertiary Filtration Applications

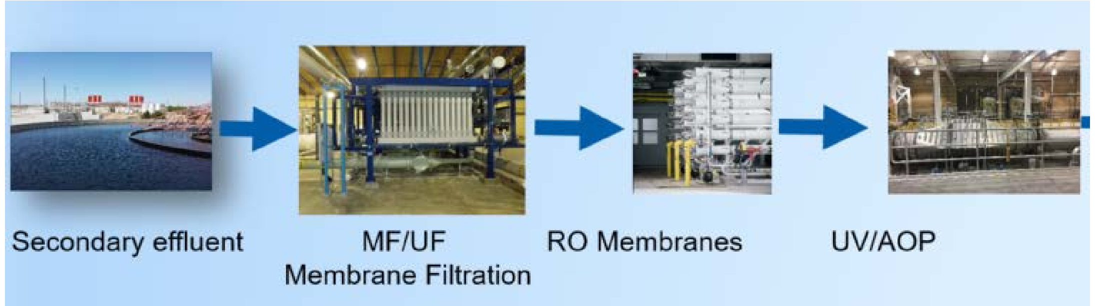
Low Phosphorus Discharges

<u>Typical Filtration Goals:</u>

0.1 mg/L without coagulant
0.02 mg/L to 0.05 mg/L with coagulant

MF/UF Membranes are Used in Tertiary Filtration Applications

Potable Reuse

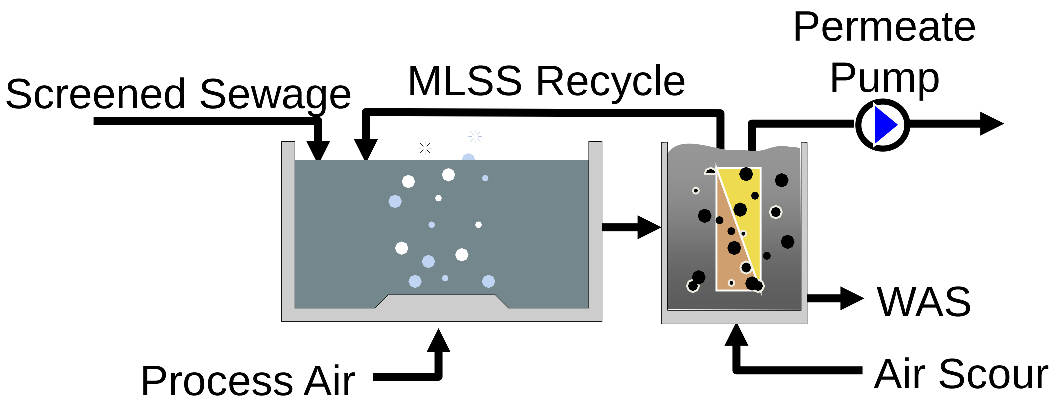


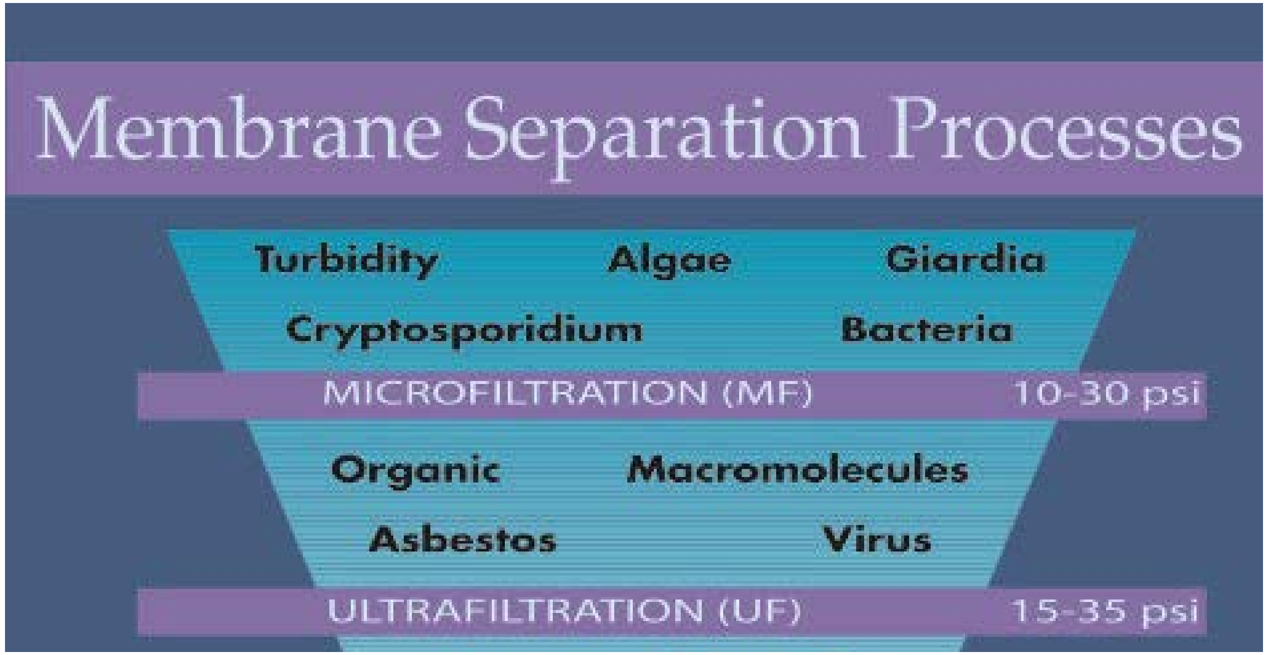
<u>Typical MF/UF Filtration Goals:</u>

RO pretreatment - SDI<3
Cryptosporidium Removal – 4 Log
Giardia Removal – 4 log

The Membrane Bioreactor (MBR) Process

- **Membrane bioreactor process** - An activated sludge biological treatment process that uses membrane filtration rather than secondary clarification for solids separation and conventional filtration

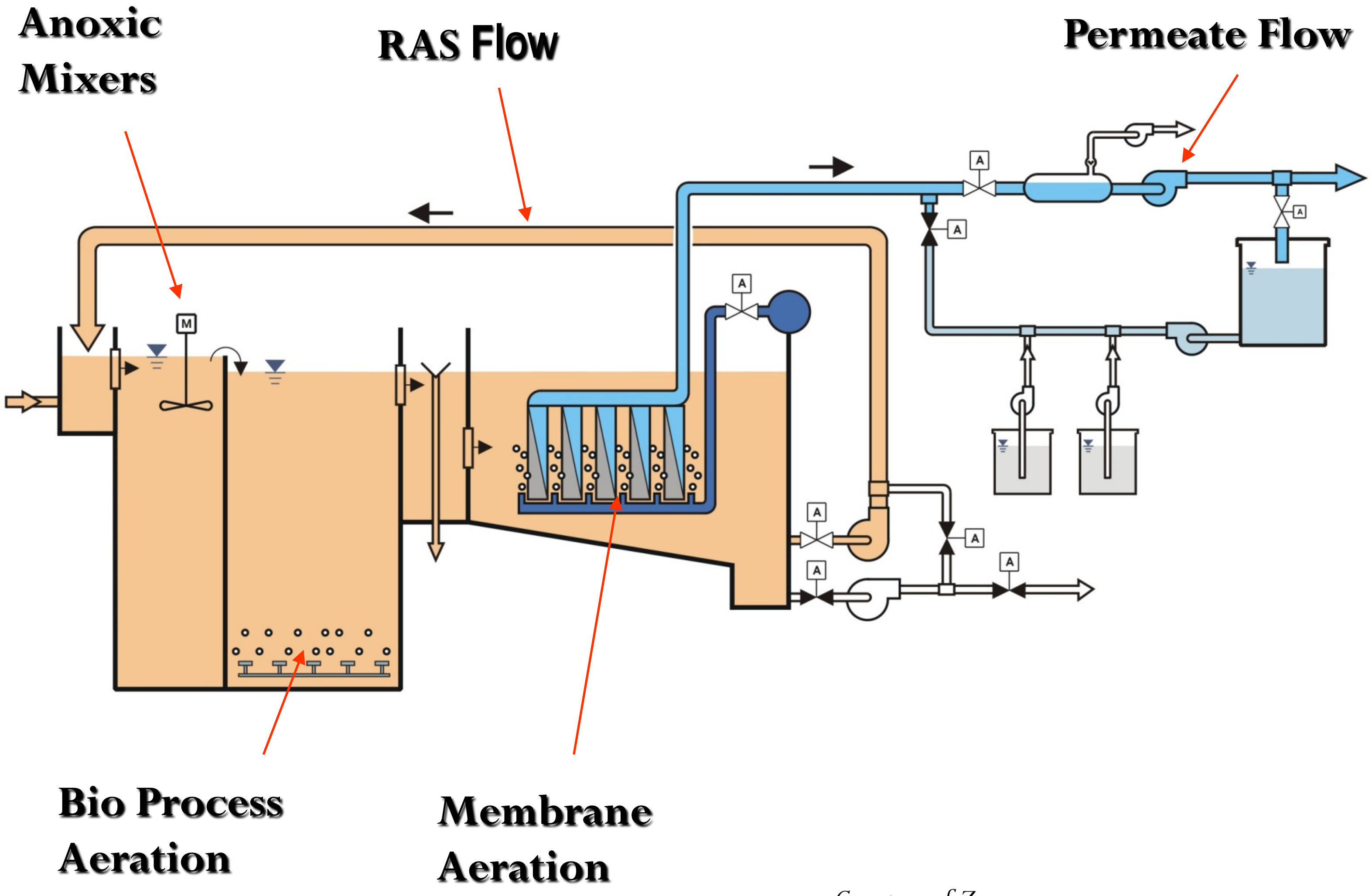



Membrane Separation Processes
Turbidity
Algae
Giardia
Cryptosporidium
Bacteria
MICROFILTRATION (MF)
10-30 psi
Organic
Macromolecules
Asbestos
Virus
ULTRAFILTRATION (UF)
15-35 psi

MF and UF Membranes are used in MBR Applications, in Hollow Fiber and Flat Sheet Forms

Groups of modules are connected to Filtrate Piping by Small Diameter Pipe and/or Hoses

MBR Schematic – A Little More Detail



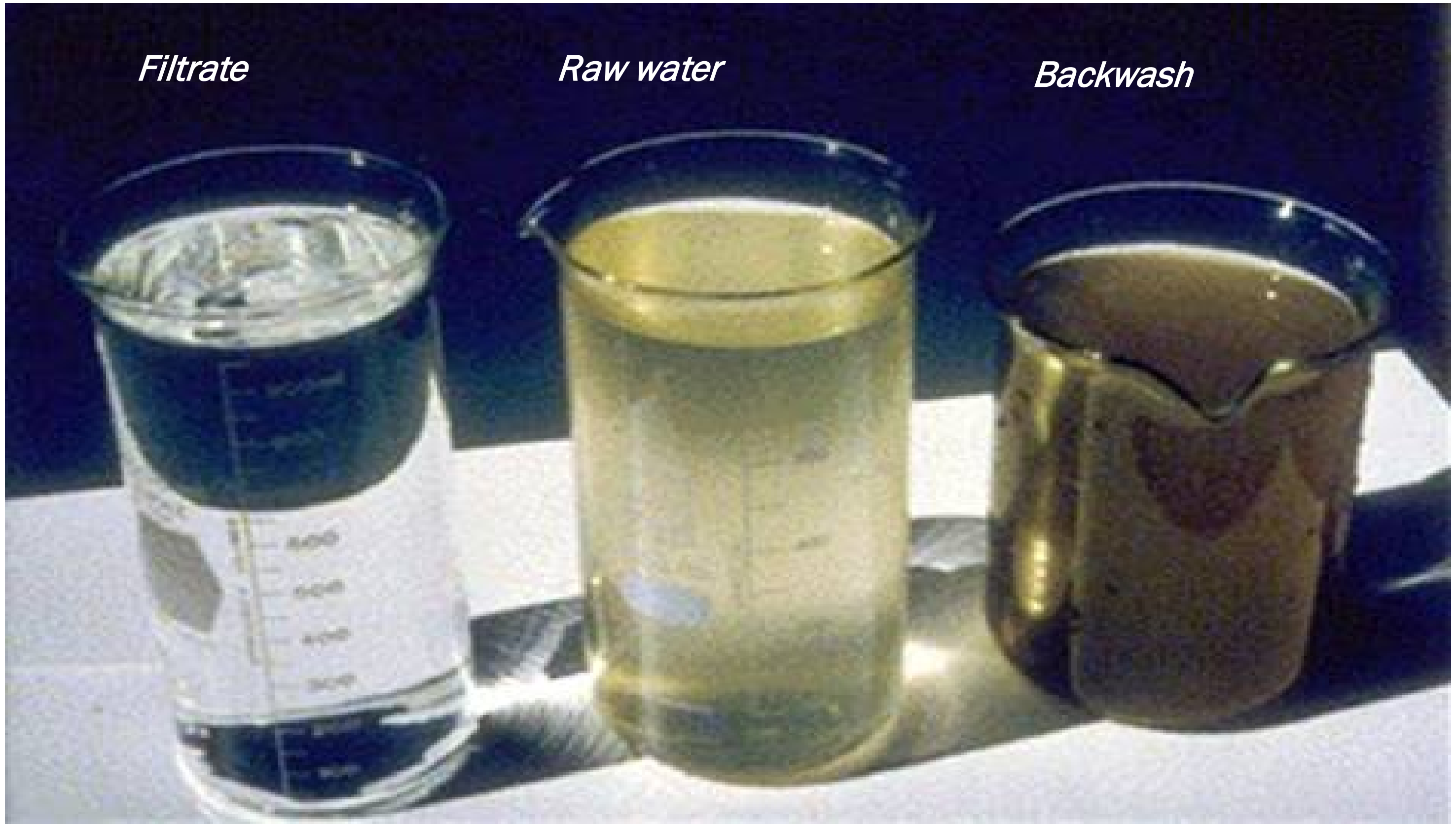
Courtesy of Zenon

WATEREUSE

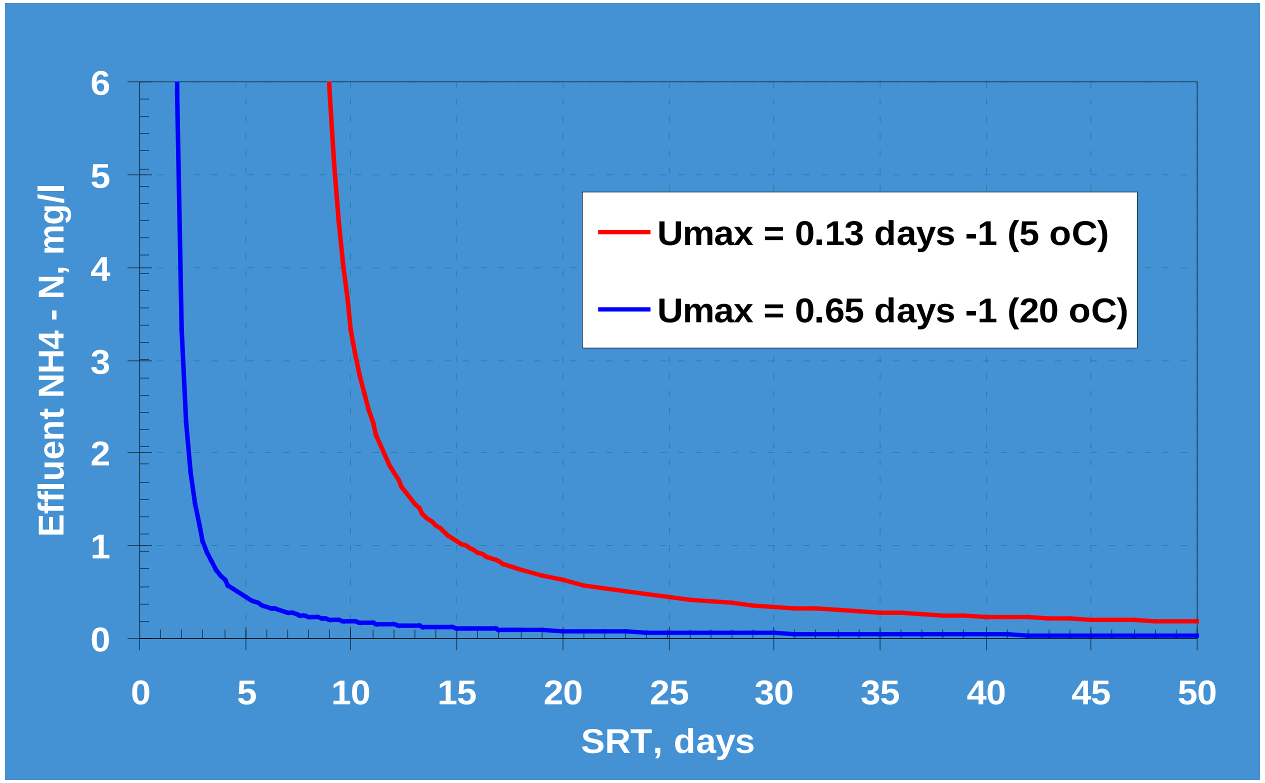
Key Elements of an MBR

- Use of membrane filtration to separate biomass from effluent
- Higher MLSS concentrations in aeration basins
- High solids recycle rate from membrane tank to aeration basin
- Membranes scoured with air
- Biological elements remain essentially the same

MBRs Provide Reliably Low Effluent TSS

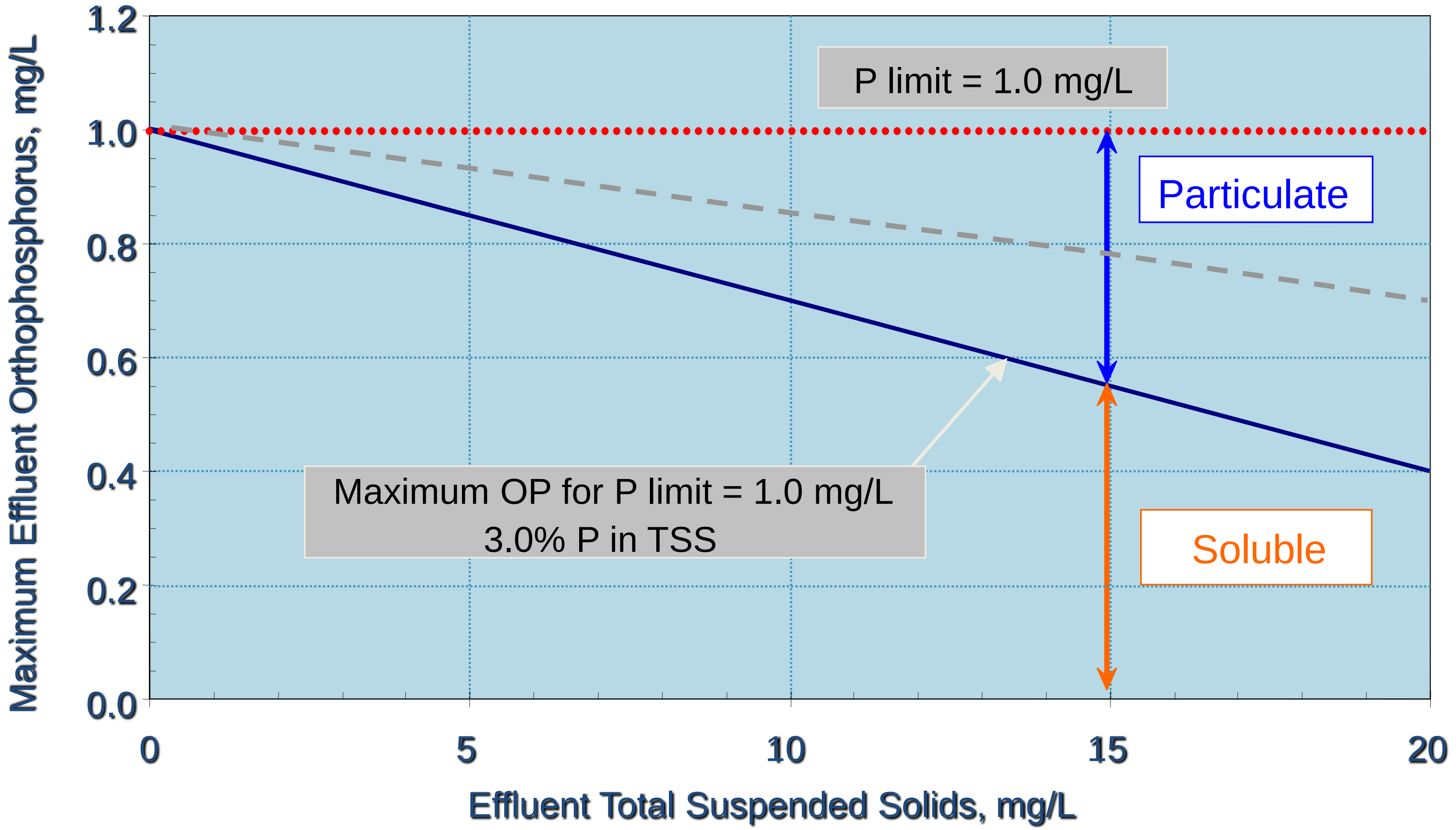


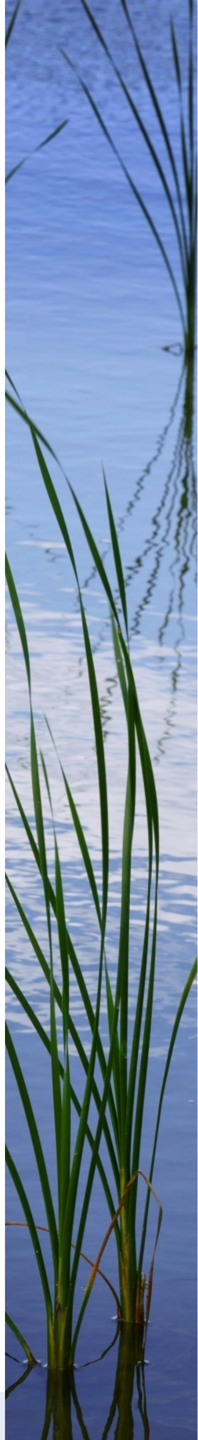
MBR Applications: Long SRTs and Low Effluent Ammonia Concentrations



WATEREUSE

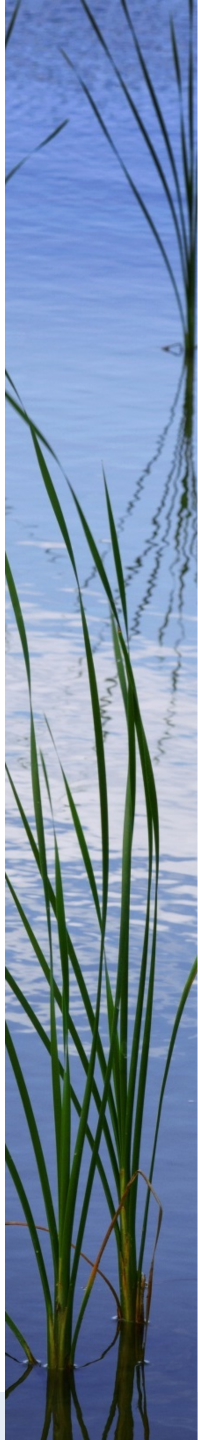
MBR Applications: Low effluent Phosphorus Due to Solids Separation Capabilities





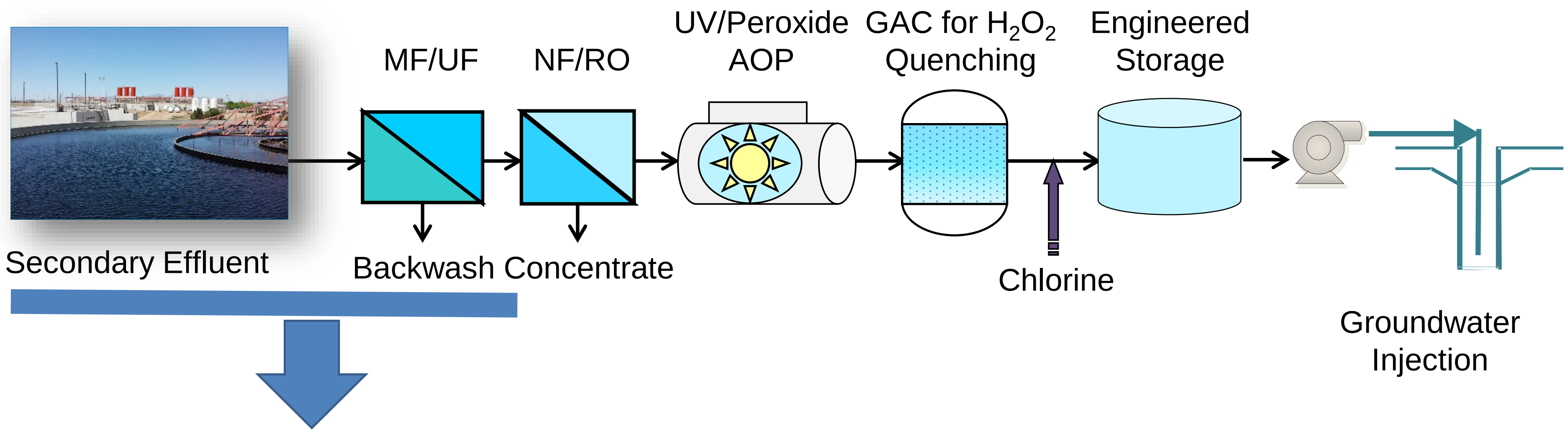
Example Effluent Phosphorus Concentrations at Operating Full-Scale MBR Plants

Plant	Permit Limit (mg/L)	Typical Effluent TP (mg/L)
Cauley Creek, GA	0.13	0.08
Arapahoe County, CO	0.05	0.035
Rubes Creek, GA	0.12	0.10
Traverse City, MI	0.50	0.06 to 0.25
Epping, NH	0.28	0.09
Milton, ON	0.07	0.04



WATEREUSE

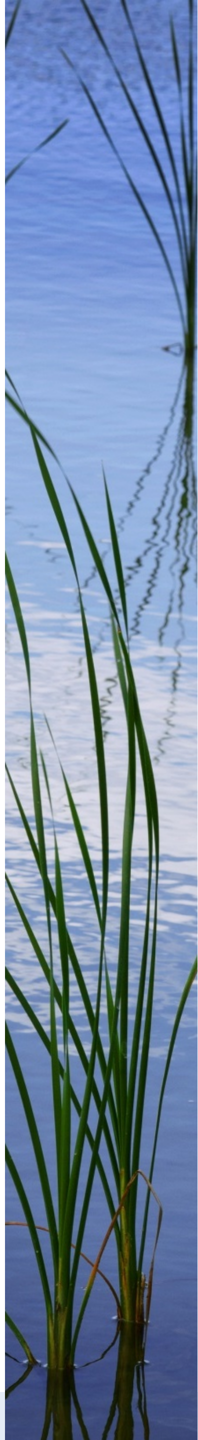
MBRs in Potable Reuse, the Next Frontier?



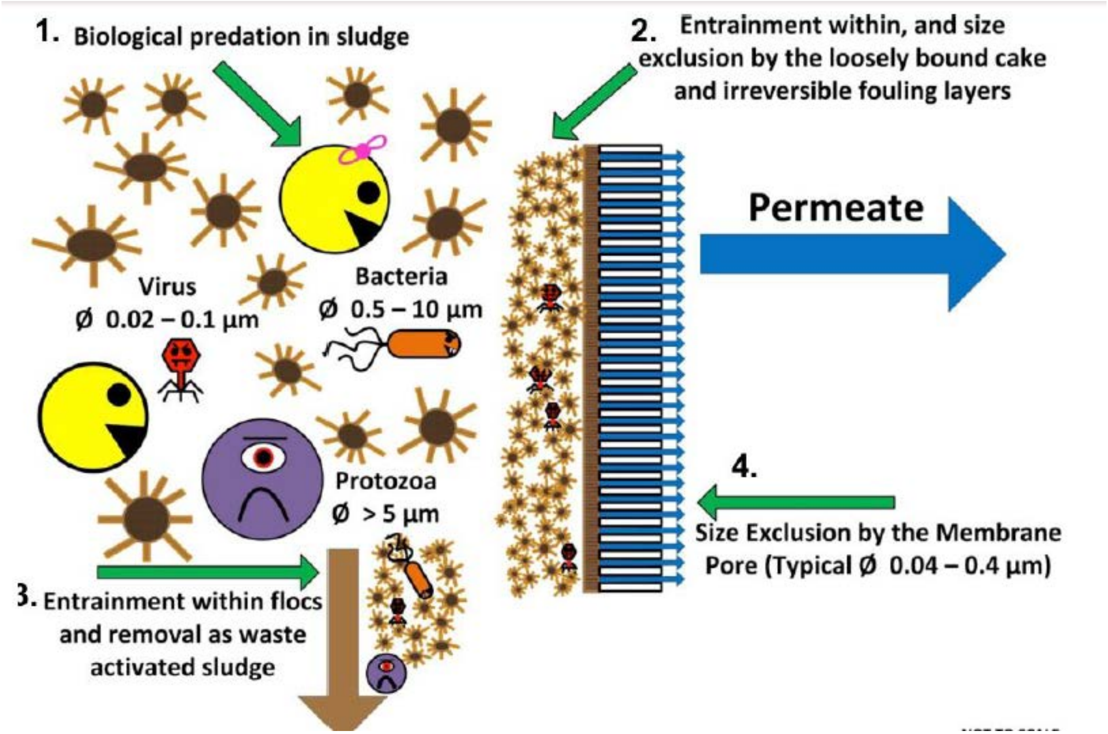
WATEREUSE

A pressure based Direct Integrity test would say No.

	MBR	WTP
System	System 1	System Type 1
Test Start Pressure	5 psi	13 psi
Test End Pressure	3.2 psi	11 psi
Breach Size Resolution[2]	10 micron	3 micron
Pressure Decay Rate	30 psi/min (over 15 sec)	0.186 psi/min
Calculated Log Removal per MFGM Equations	<1.8 log	4 log



Pathogen Rejection in MBR is a Complex Phenomena Not Defined by the Membrane Alone

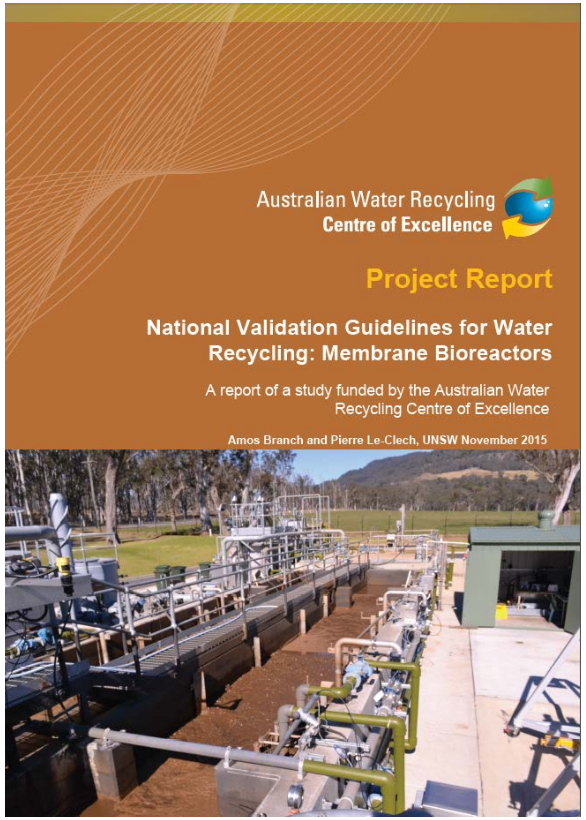


Credit: Branch et al., 2016

WATEREUSE

MBR are Being Considered for Log Removal Credits in Potable Reuse Trains

- No adequate data set was available to correlate influencing factors on LRV through MBR. “MBR removal mechanisms are complex and synergistic, leading to difficulties when applying simplistic modelling approaches”.
- Likelyhood that poor LRV correlates with low HRT, high flux, high permeability, low TMP, high turbidity, low MLSS and high DO, resulting in an “operational envelope”.



Pathogen credit for MF and UF is well understood

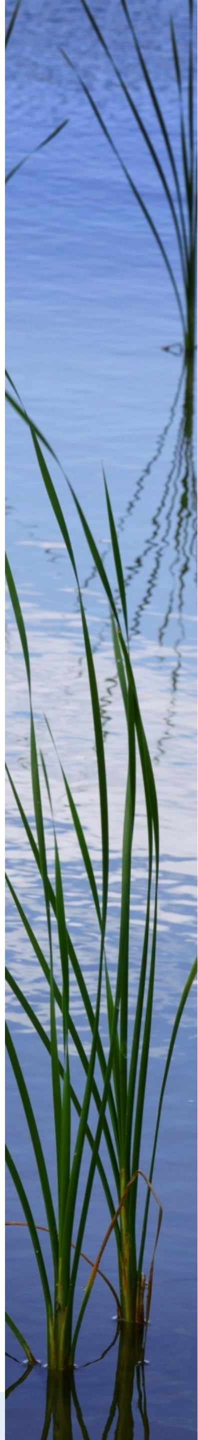
Pathogens	Removal Goal	Primary/ Secondary	MF	RO	UV/ H_2O_2	Subsurface Travel Time	Total Credits
log viruses	12	1.9	0.0	1.5	6	6	15.4
log *Giardia*	10	0.8	4.0	1.5	6	0	12.3
log *Crypto*	10	1.2	4.0	1.5	6	0	12.7

Credits based upon DIT results

MBR-based potable reuse treatment provides insufficient credit for IPR GW injection

Pathogens	Removal Goal	MBR	RO	UV/ H_2O_2	Subsurface Travel Time	Total Credits
log viruses	12	??	1.5	6	6	13.5+
log *Giardia*	10	??	1.5	6	0	7.5+
log *Crypto*	10	??	1.5	6	0	7.5+

Additional 2.5 LRV needed for protozoa



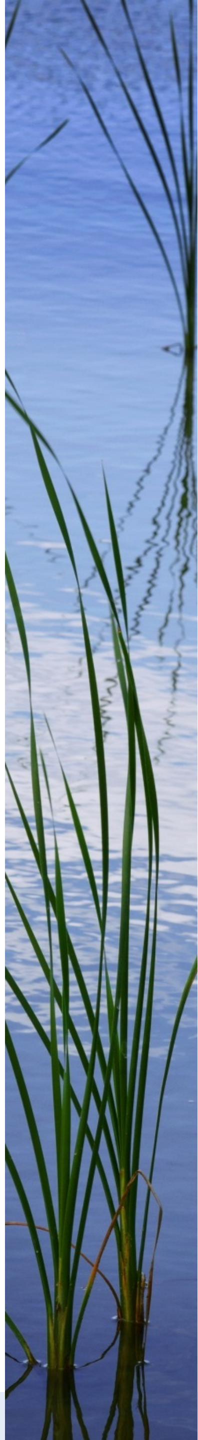
Experimental Evidence (SCVWD, Carollo 2017) shows MBR can achieve Virus & Protozoa Removal

Pathogen Credits for Potable Reuse with Proposed Credits for MBR

Pathogens	Removal Goal (CDPH, 2014)	MBR[1]	RO	UV AOP	Subsurface Travel Time	Total Credits
log viruses	12	3.0	1.5	6	6	16.5
log Giardia	10	3.2	1.5	6	0	10.7
log Crypto	10	3.2	1.5	6	0	10.7

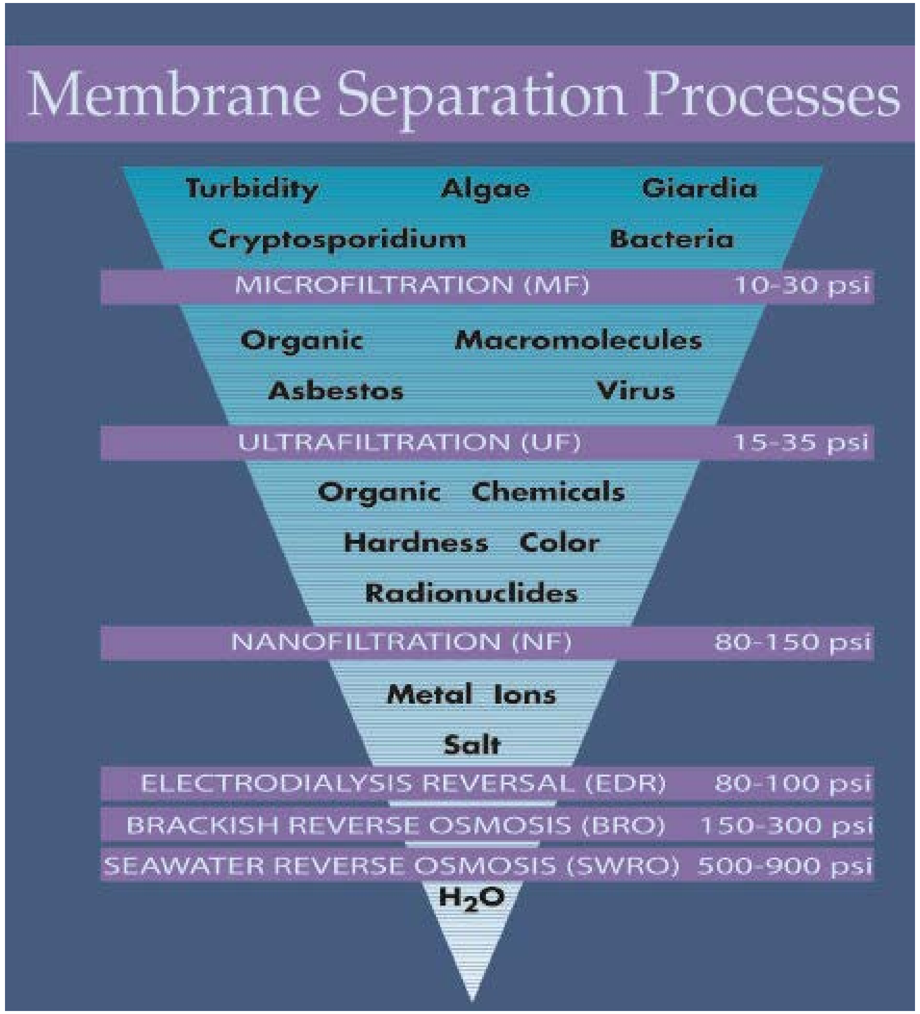
Notes:

1. Proposed log reduction value credits for ≤ 0.2 NTU.



WATEREUSE

Membrane Desalting



Form: Spiral wound, thin film

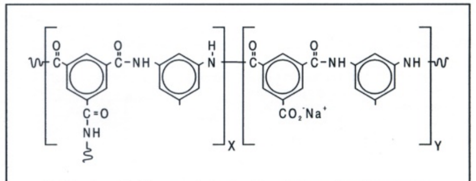
polyamide composite or nanocomposite

NF vs. RO: What’s the Difference?

- Both are membrane processes
- With a similar setup (spiral-wound modules)

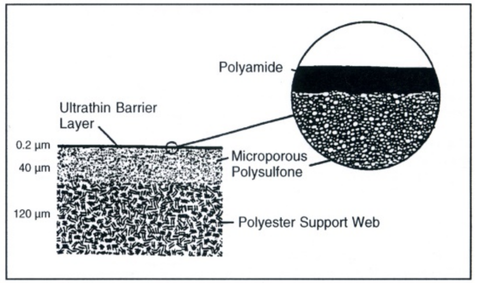
Parameter	NF	RO
Typical equipment cost	high, may be less than RO	high
Typical operating pressure	50-80 psi (lower power demand)	200+ psi
Typical salt rejection	25-75% (less/no brine waste)	99%+

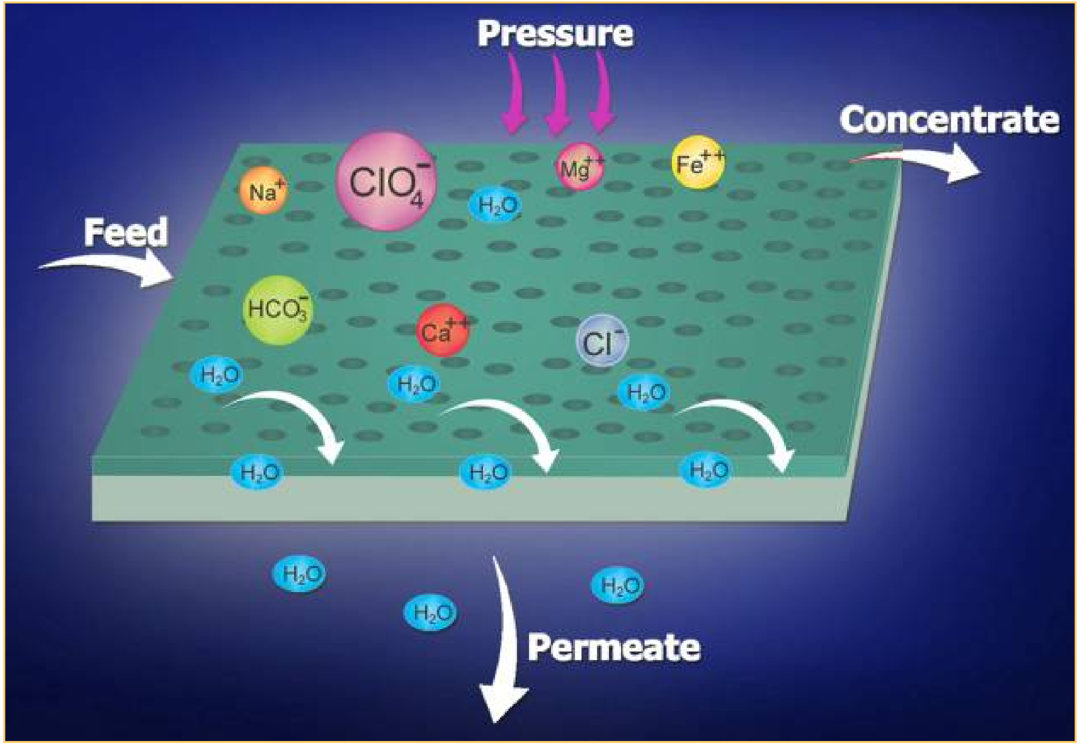
NF/RO Membranes *Do Not Have Pores* - Salt Rejection is Based Upon Diffusion



FT30 polyamide is cross-linked and contains carboxylate groups

FT30 membrane.





WATEREUSE

Flat Sheets of Membrane Material and Spacers are Combined into a "Spiral Wound" Membrane Element for Commercial Use

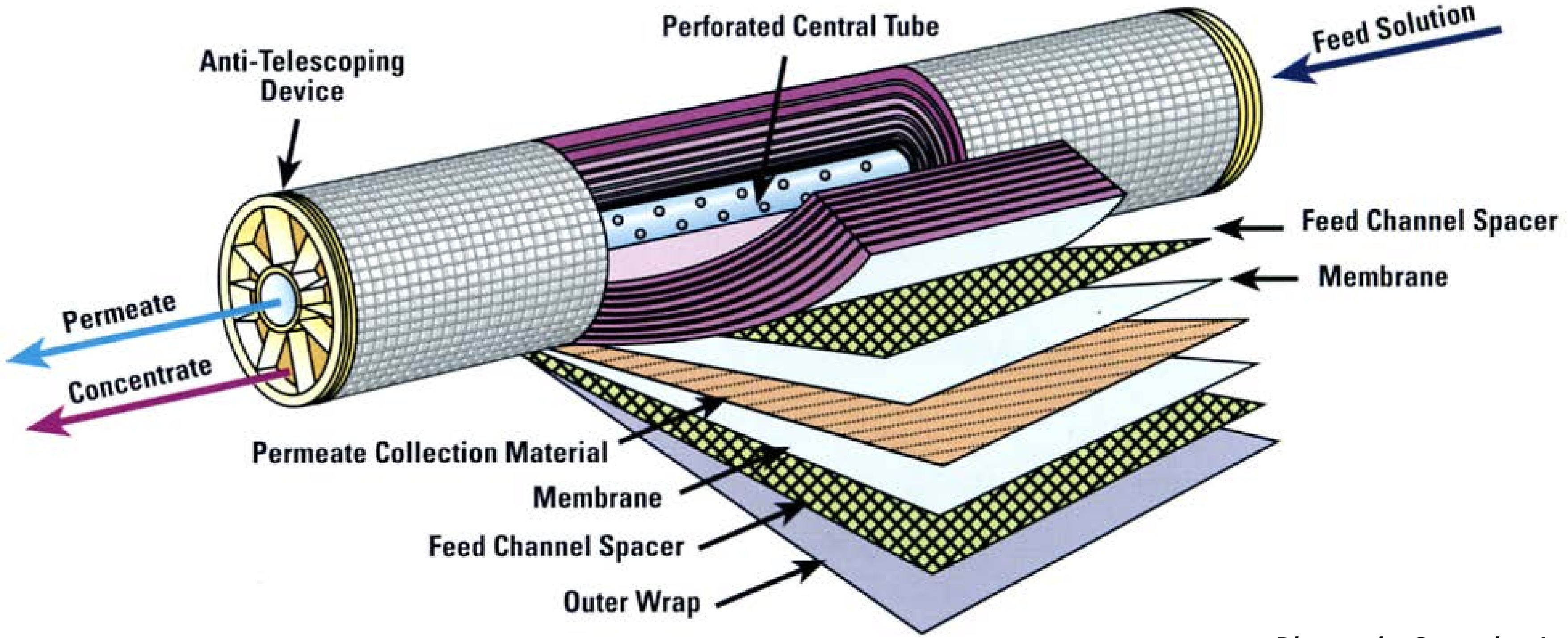
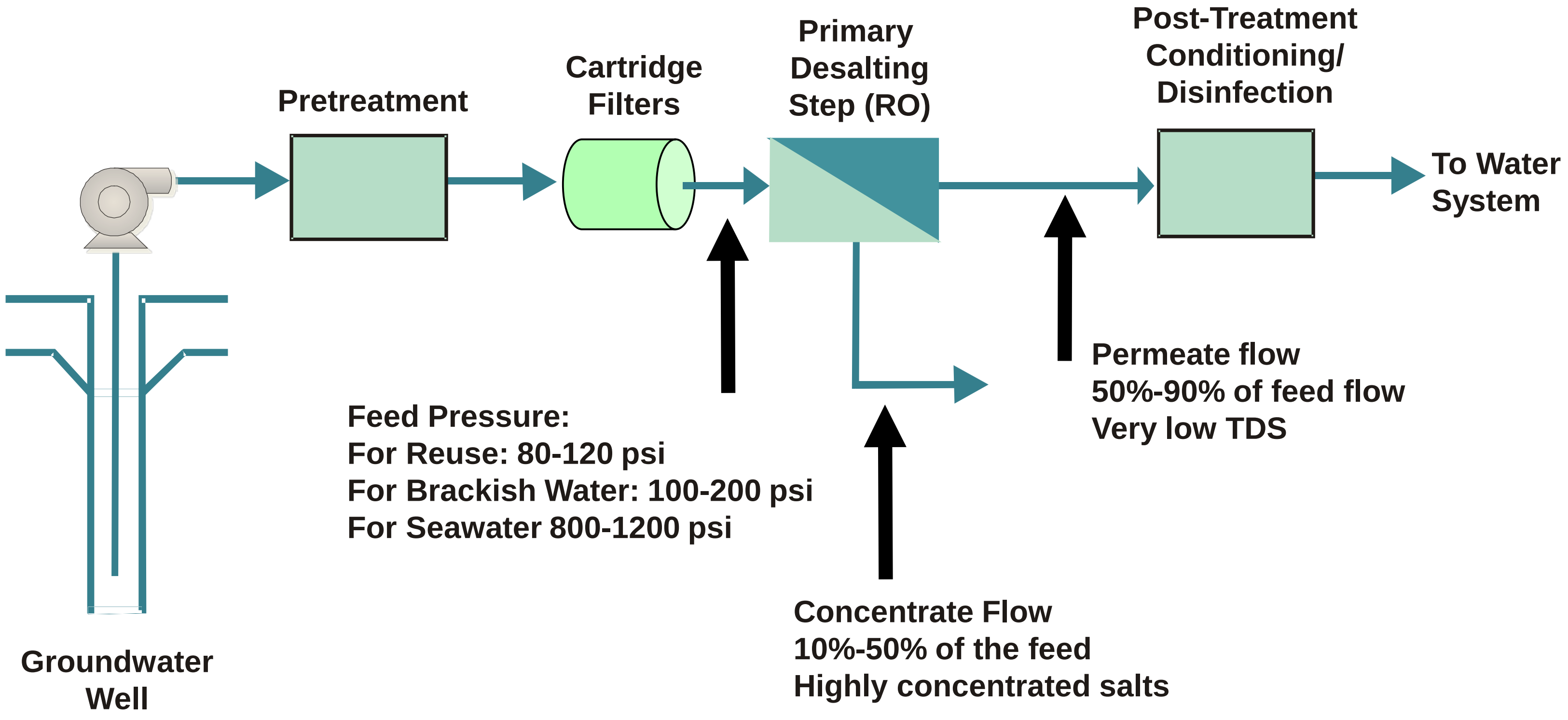


Diagram by Osmonics, Inc.

WATEREUSE

A Primary Desalting RO System has Several Components

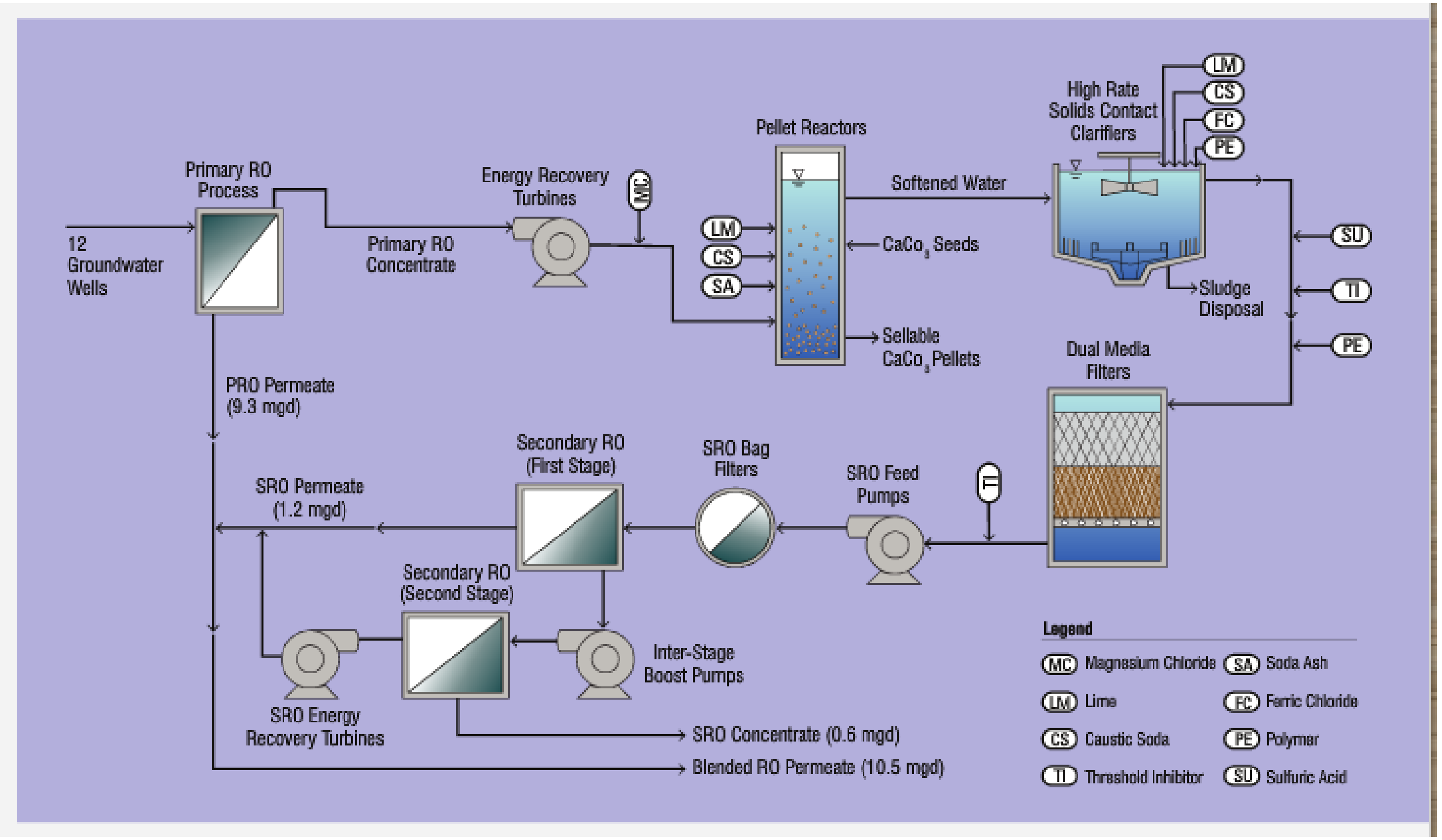
(Example: Groundwater Desalting)



Concentrate Handling Must be a Primary Consideration in the Design of Any RO System

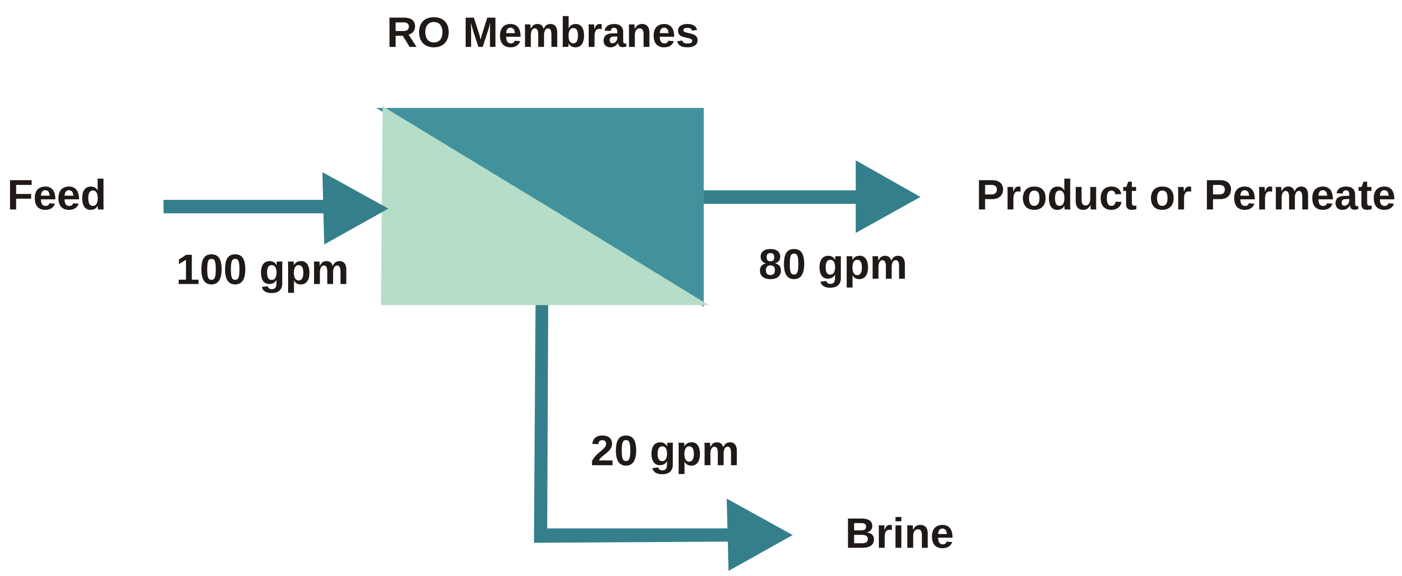
- Disposal options
  - Discharge to Sewer?
  - Ocean Discharge?
  - Surface water discharge ?
  - Injection wells ?
  - Or concentrate reduction……

Concentrate reduction can be simple or complex



WATEREUSE

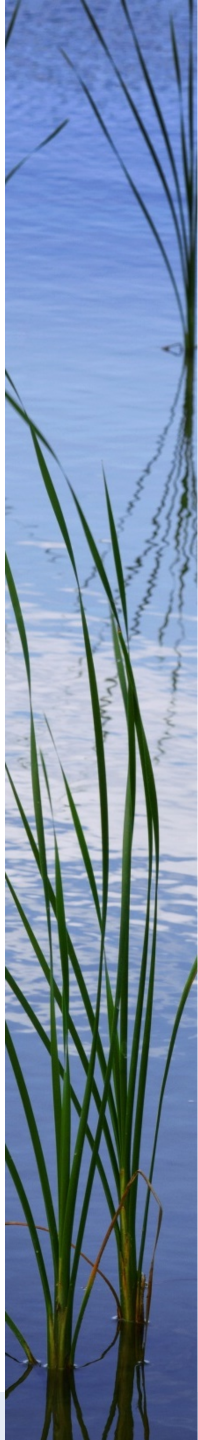
Product Recovery Measures the Percentage of the Feed Stream that Becomes Product



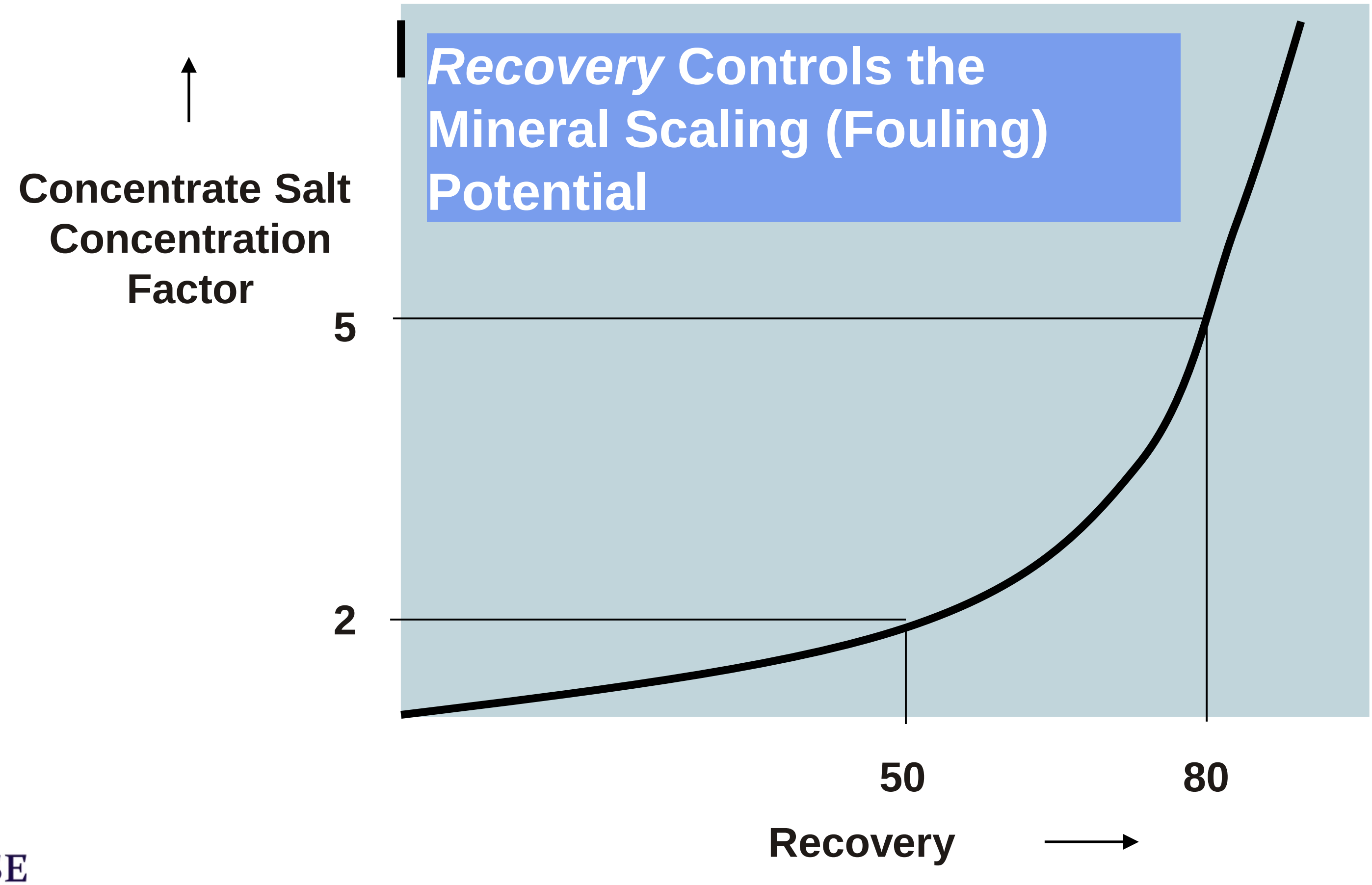
$$\text{Recovery (\%)} = \frac{\text{Product or Permeate Flowrate}}{\text{Feed Flowrate}} \times 100$$

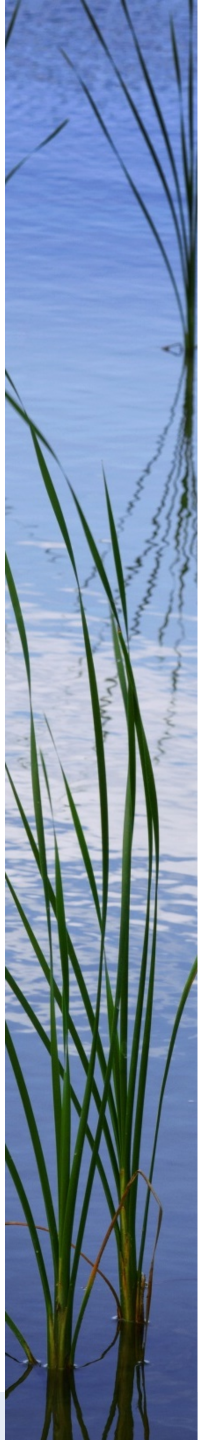
$$= \frac{80}{100} \times 100 = 80\ \%$$

WATEREUSE



As Recovery Increases the Concentrate Salt Concentration Increases Exponentially

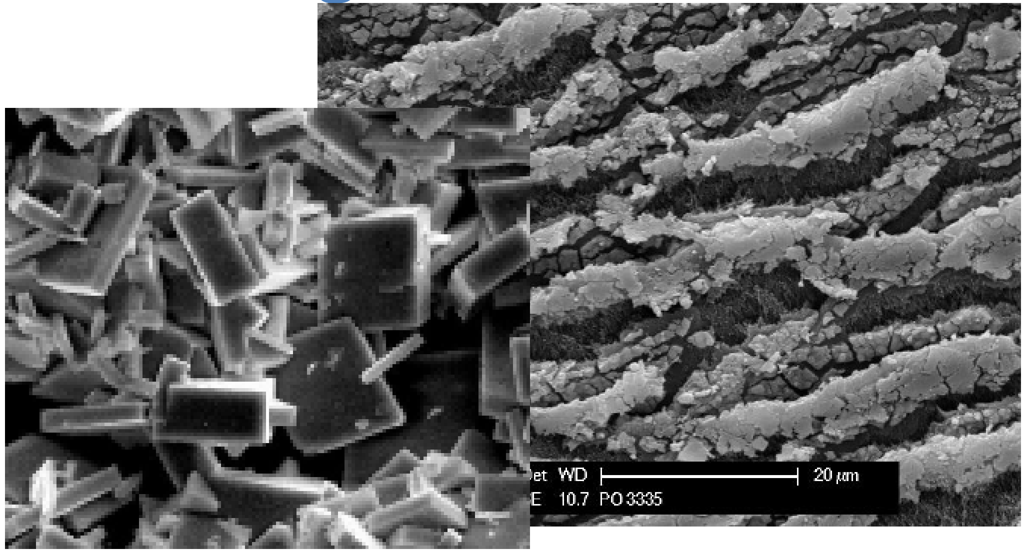




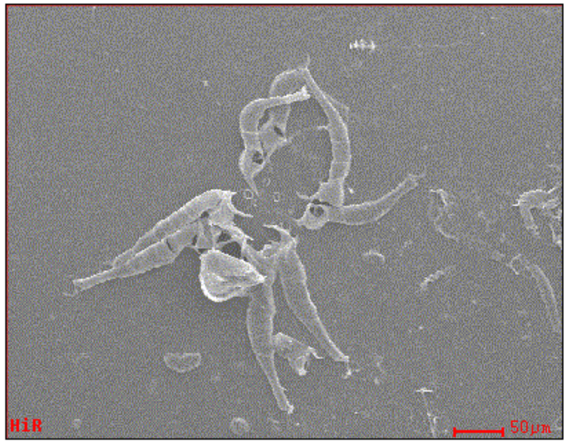
WATEREUSE

Types of Fouling

Biological Foulant



Mineral Scaling



Biological Foulant

Particle (Silt) Foulant

WATEREUSE

How is are process parameters determined?

- Starts with water quality analysis
- Projection software is used to select products, determine recovery and other design parameters

WATER APPLICATION VALUE ENGINE
DOW WATER & PROCESS SOLUTIONS

RO Flow Table (Stage Level) - Pass 1

Stage	Elements	#PV	#Els per PV	Feed				Concentrate			Permeate			
				Feed Flow (gpm)	Recirc Flow (gpm)	Feed Press (psi)	Boost Press (psi)	Conc Flow (gpm)	Conc Press (psi)	Press Drop (psi)	Perm Flow (gpm)	Avg Flux (gfd)	Perm Press (psi)	Perm TDS (mg/L)
1	SW30ULE-400	78	6	3,761	0.00	211.3	0.0	1,882	186.6	24.6	1,881	14.5	15.0	2.17
2	SW30ULE-400	39	6	1,882	0.00	229.1	47.0	942.0	204.5	24.6	940.2	14.5	15.0	4.18

RO Solute Concentrations - Pass 1

Concentrations (mg/L as ion)

	Feed	Concentrate		Permeate		
		Stage1	Stage2	Stage1	Stage2	Total
NH_4^+	0.00	0.00	0.00	0.00	0.00	0.00
K^+	2.00	3.99	7.93	0.01	0.03	0.02
Na^+	7.27	14.50	28.88	0.04	0.09	0.06
Mg^{+2}	217.0	433.9	866.5	0.13	0.25	0.17
Ca^{+2}	582.0	1,164	2,324	0.33	0.66	0.44
Sr^{+2}	13.40	26.79	53.51	0.01	0.02	0.01
Ba^{+2}	0.00	0.01	0.02	0.00	0.00	0.00
CO_3^{-2}	0.66	2.29	7.57	0.00	0.00	0.00
HCO_3^-	74.00	145.8	284.9	0.35	0.54	0.41
NO_3^-	0.00	0.00	0.00	0.00	0.00	0.00
Cl^-	12.00	23.98	47.86	0.02	0.04	0.03
F^-	3.70	7.38	14.69	0.02	0.05	0.03
SO_4^{-2}	2,200	4,399	8,785	1.16	2.33	1.55
SiO_2	8.30	16.53	32.87	0.07	0.15	0.10
Boron	0.02	0.03	0.06	0.00	0.01	0.01
CO_2	1.65	2.23	3.93	1.66	2.59	1.97
TDS*	3,120	6,238	12,454	2.17	4.18	2.84
pH	7.7	7.7	7.7	5.6	5.6	5.6

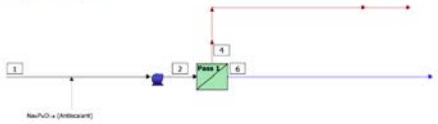
Footnotes:

*Total Dissolved Solids includes ions, SiO_2 and $B(OH)_3$. It does not include NH_3 and CO_2

WATER APPLICATION VALUE ENGINE
DOW WATER & PROCESS SOLUTIONS

RO Summary Report

RO System Flow Diagram



#	Description	Flow (gpm)	TDS (mg/L)	Pressure (psi)
1	Raw Feed to Pump	3,764	3,120	0.0
2	Net Feed to Pass 1	3,761	3,123	214.2
4	Total Concentrate from Pass 1	942.0	12,454	204.5
6	Total Permeate from Pass 1	2,821	2.84	15.0

RO System Overview

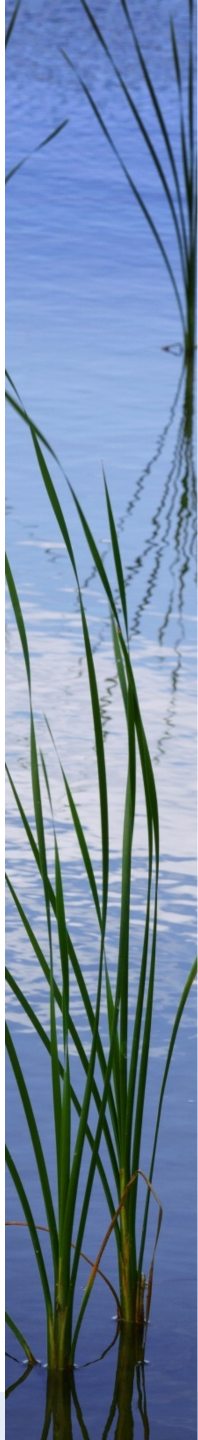
Total # of Trains	1	Online =	1	Standby =	0	RO Recovery	74.9 %
System Flow Rate	(gpm)	Net Feed =	3,764	Net Product =	2,821		

Pass		Pass 1
Stream Name		Stream 1
Water Type		Well Water (SDI < 3)
Number of Elements		702
Total Active Area	(m^2)	26087
Feed Flow per Pass	(gpm)	3,761
Feed TDS*	(mg/L)	3,123
Feed Pressure	(psi)	214.2
Flow Factor		1.00
Permeate Flow per Pass	(gpm)	2,821
Pass Average flux	(gfd)	14.5
Permeate TDS*	(mg/L)	2.84
Pass Recovery		75.0 %
Average NDP	(psi)	163.5
Specific Energy	(kWh/m^3)	0.76
Temperature	(°C)	20.0
pH		7.7 (After Adjustment)
Chemical Dose		3.0 mg/L $Na_6P_6O_{18}$(100%)
RO System Recovery		75.0 %
Net RO System Recovery		75.0%

Footnotes:

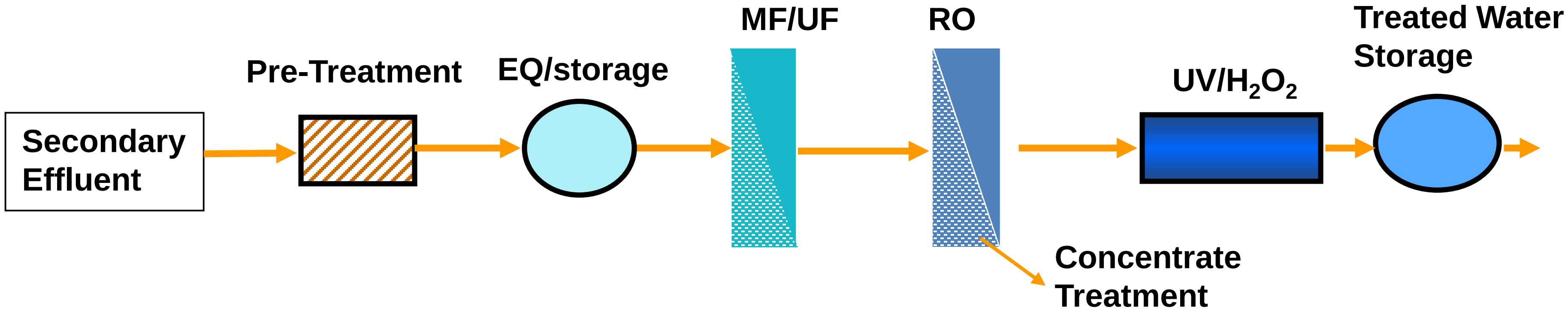
Desalting Membrane Applications are vast in their scope

- Brackish groundwater desalting
- Groundwater and surface water softening applications
- Desalination
- Industrial applications (semiconductor, food, oil & gas, etc)
- Non – Potable Reuse (sodium, boron rejection for irrigation)
- Potable Reuse Applications

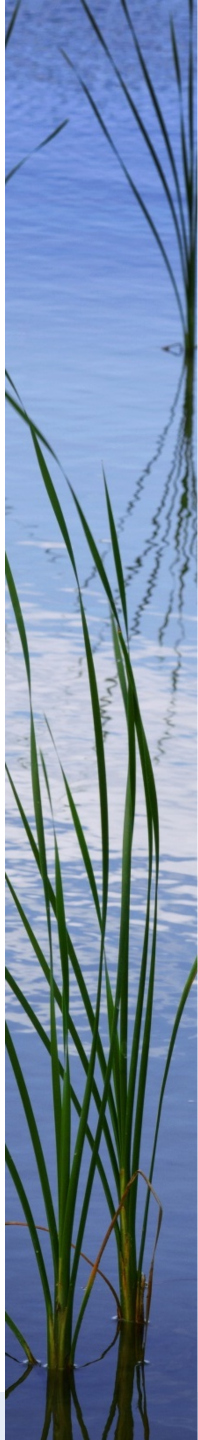


WATEREUSE

Potable Reuse AWT



- Reverse Osmosis (RO) plays a critical role in this process
  - Removes TDS (salt)
  - Removes TOC (0.5 mg/L)
  - Removes Nitrogen (<2 mg/L as NO_3)
  - Removes UV/AOP scavengers (eg alkalinity)
  - Removes most TOrCs



TOrCs Come From Many Sources

(a.k.a. PPCPs, EDCs, COCs, Microconstituents, etc.)

Antibacterial hand soap
<u>triclosan</u>

Birth control pill
<u>ethinyl estradiol (E2)</u>

Coffee
<u>caffeine</u>

Polycarbonate plastic
<u>bisphenol-a (BPA)</u>

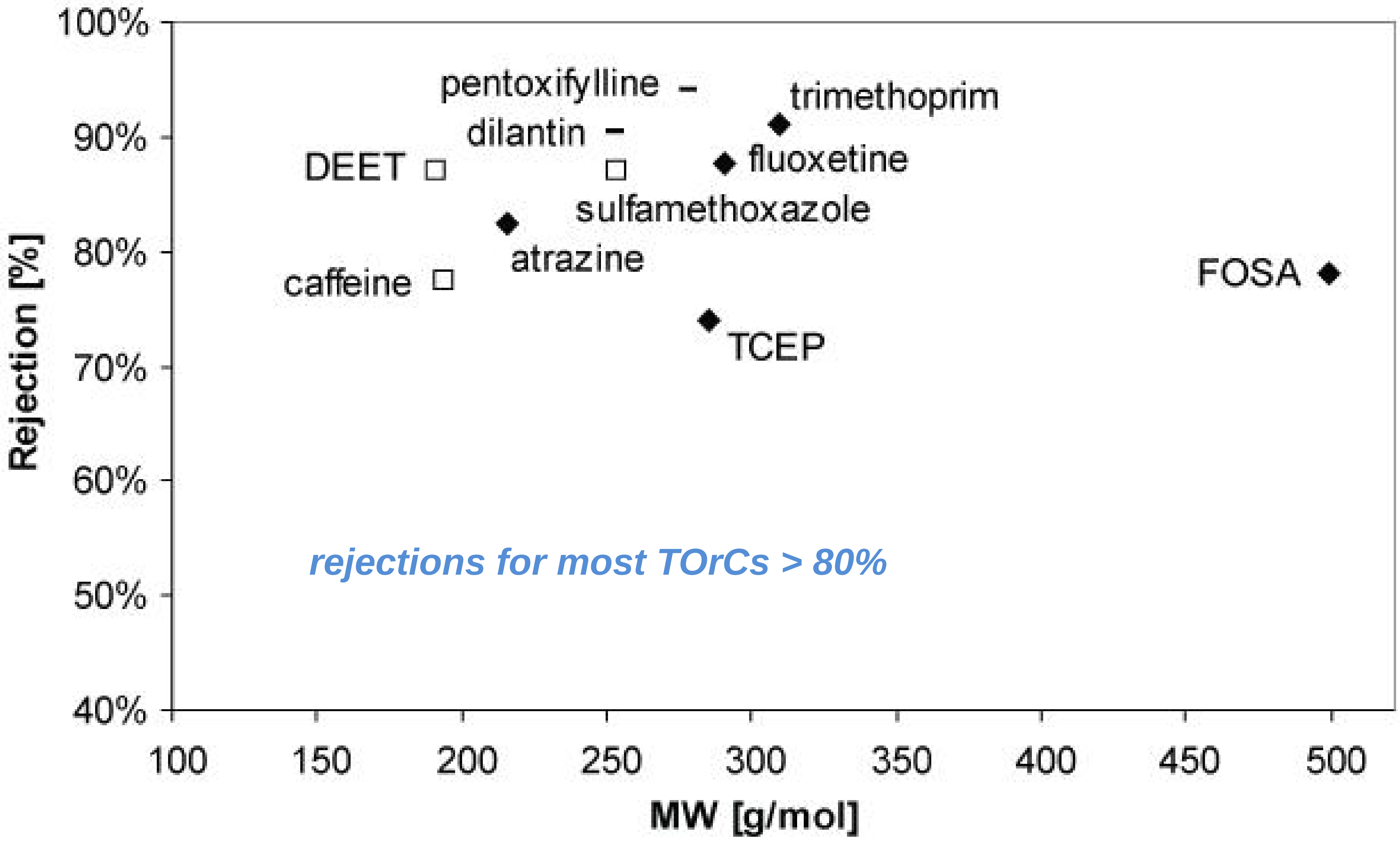
Fire extinguisher
<u>TDCPP, TCEP, TCPP</u>

Insect repellent
<u>DEET</u>

WATEREUSE

Compounds shown represent only a small portion of all compounds analyzed

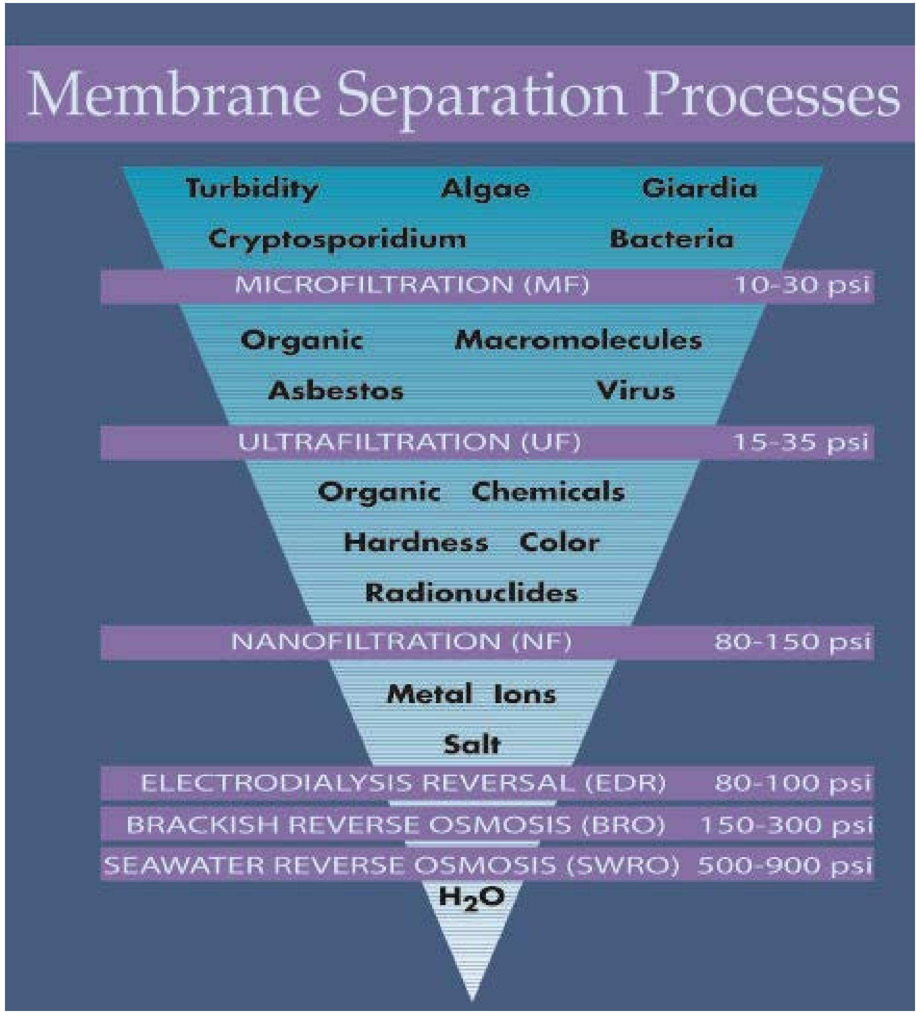
NF Removal of Various TOrCs



WATEREUSE

Experiments with Dow/FilmTec NF270 (a "loose" NF membrane) at only ***50 psi feed pressure***.

Questions?



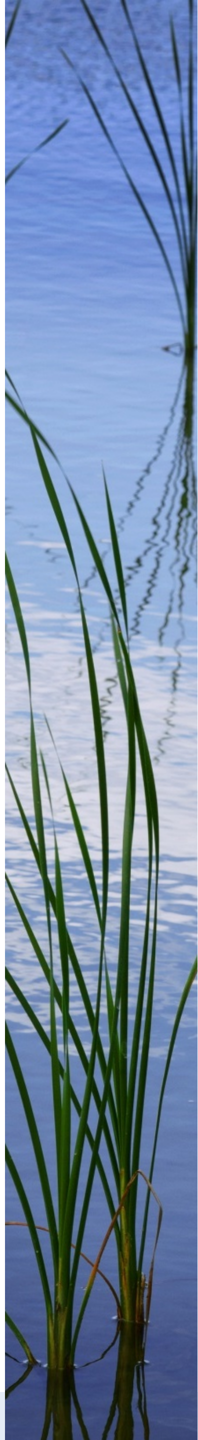
WATEREUSE

Upcoming Webcasts & Events

Enhanced Source Control for Direct Potable Reuse (Webcast)
October 2, 2019
11 am PT | 2 pm ET

Effective Strategies to Mitigate Post Treatment Challenges in Potable Reuse Systems (Webcast)
October 10, 2019
11 am PT | 2 pm ET

2020 WateReuse California Annual Conference
Hyatt Regency San Francisco
San Francisco, California
March 15 – 17, 2020



WATEREUSE