CornellEngineering
Civil and Environmental Engineering

CEE 4540

Sustainable municipal drinking water treatment

2018 Fall Course Review

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Class #25 11/28/2018 2:55 – 4:10pm

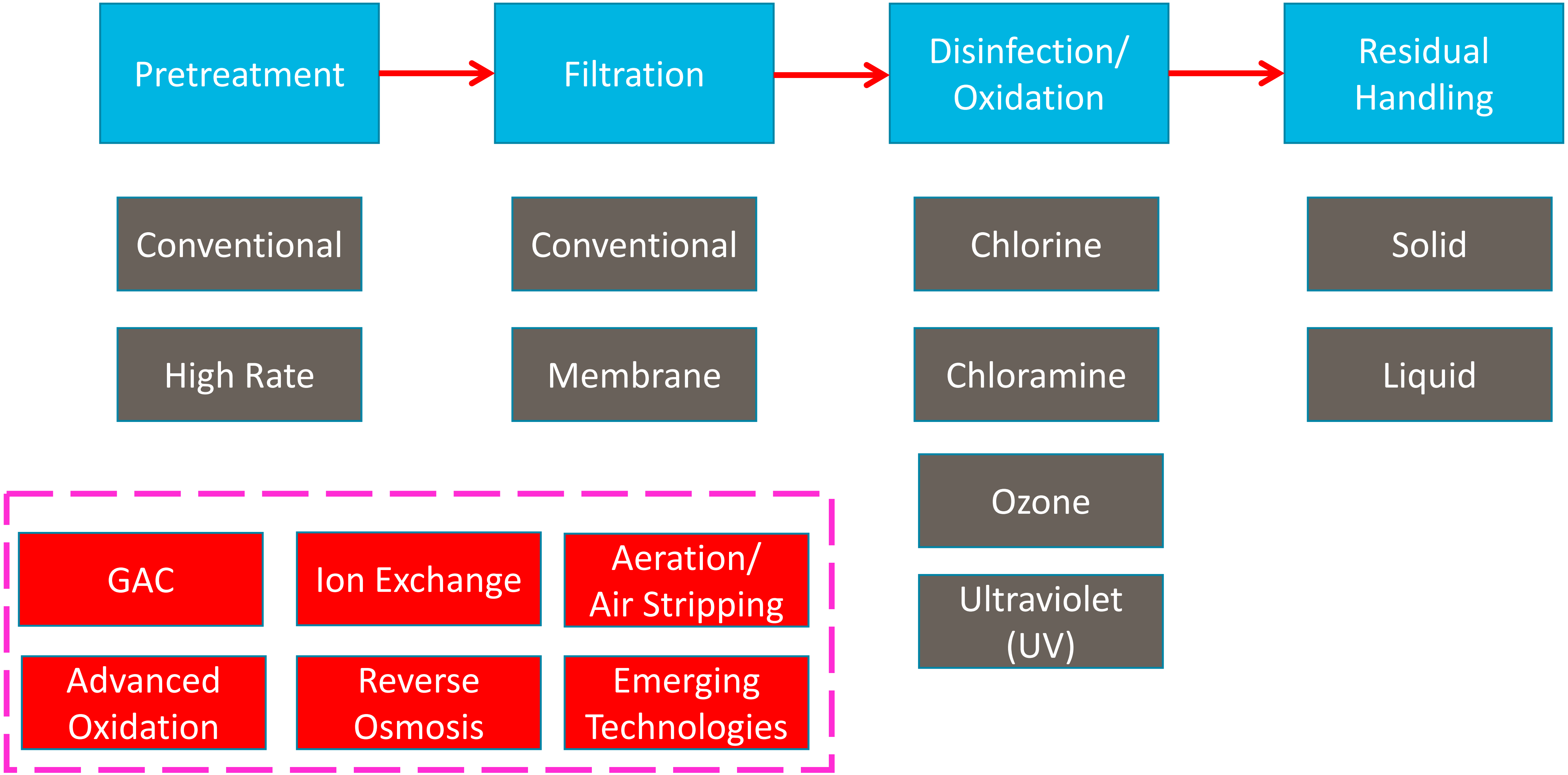
Final Design Project Presentation

- December 3rd Monday
- Please arrive at 2 pm
- First team will start presentation at 2:10
- Second team will star at 3:10
- Each team will have
  - 30 min Presentation
  - 15 min Q&A

Final Exam

- Similar format as the Prelim
- Proper time management should be considered (up to 2 hours testing time)
- Coverage will be after the Prelim

Major Building Blocks for Water Treatment Process

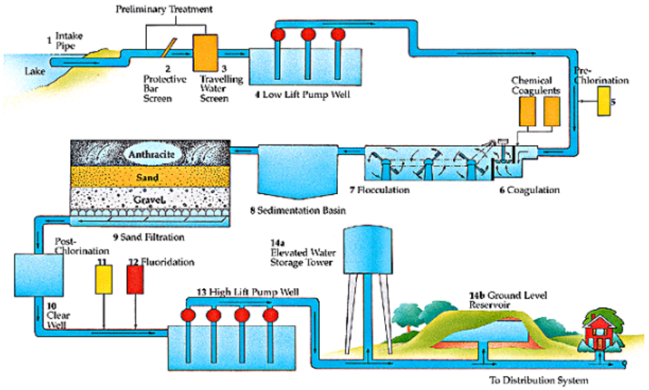


Class #2: Drinking Water Regulations & Design Project

- USEPA Safe Drinking Water Act
  - Primary MCL
  - Secondary MCL
- Design Project Requirements
  - Basis of Design
- Chemical concentration units
  - mg/L (normally used at WTP, a.k.a., Parts, short form of ppm)
  - Molarity, Normality, Molar Fraction

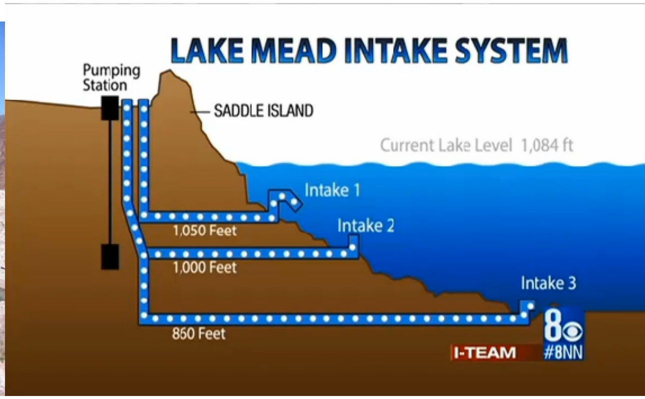
Stanislaus Regional Water Supply

- Stanislaus County
- East Stanislaus Regional Water Management
- Turlock Irrigation Distrtict



Class #3: Intake Structure & Coagulation

- Raw water intake structure and its function
- Various types of coarse screens
- Coagulation/Flocculation mechanisms
- Ferric and Aluminum based coagulants
- Coagulant aid/polymer



Class #4:Flocculation & Sedimentation

- Mechanism of flocculation
- Jar Testing for coagulation/sedimentation optimization
- Enhanced Coagulation for NOM removal and DBP control
- Various types of flocculators

Table 3-3
Required Removal of Total Organic Carbon by Enhanced Coagulation and Enhanced Softening for Step 1 Compliance

Source Water TOC (*mg/L*)	Source Water Alkalinity (*mg/L* as $CaCO_3$) 0–60	>60–120	>120
>2.0–4.0	35.0%	25.0%	15.0%
>4.0–8.0	45.0%	35.0%	25.0%
>8.0	50.0%	40.0%	30.0%

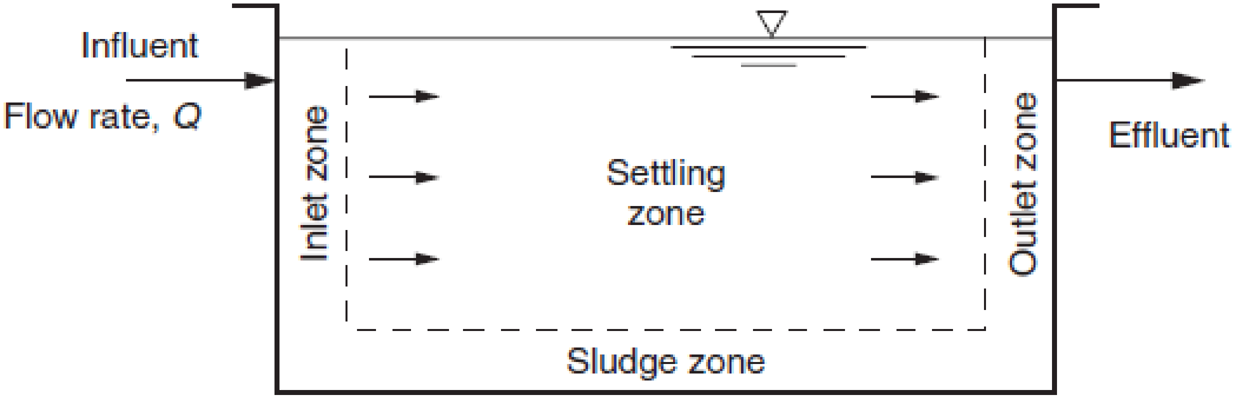
Sedimentations – Conventional Sedimentation

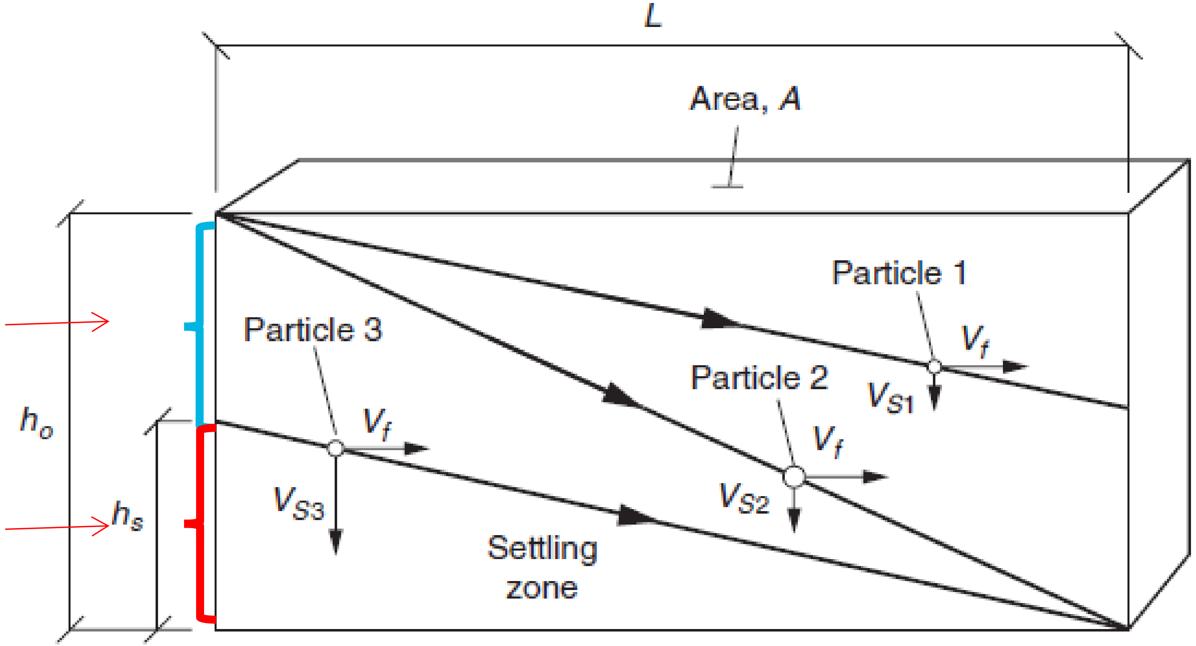
- Particles settling depends on
  - Settling velocity of the particles
  - Where do particles entering the sedimentation basin
  - Length of the settling tank

$$\text{Fraction of particles removed} = \frac{h_s}{h_o} = \frac{h_s/\tau}{h_o/\tau} = \frac{v_s}{v_c} (v_s < v_c) \qquad (10\text{-}18)$$

where h_s = height of particle from bottom of tank at position entering settling zone, m

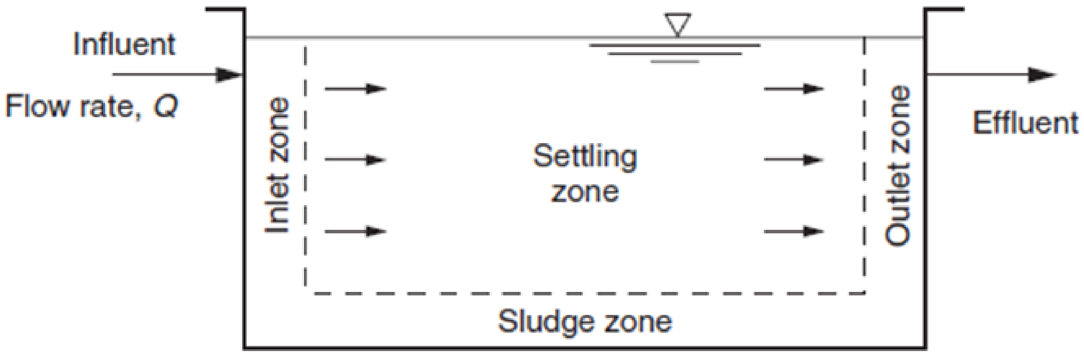
v_s = particle settling velocity smaller than v_c, m/h

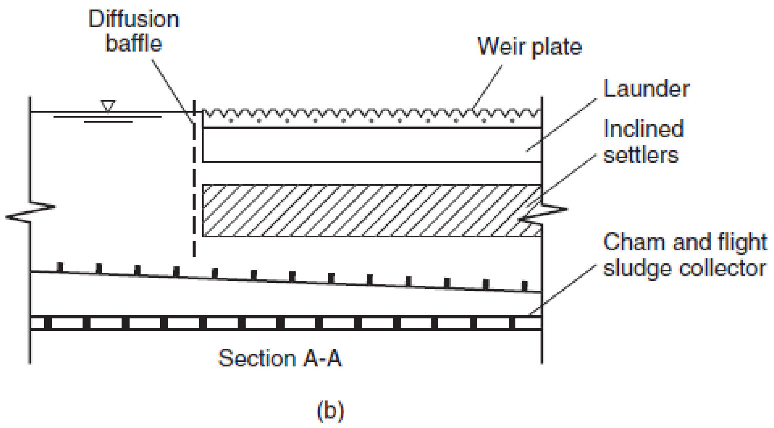


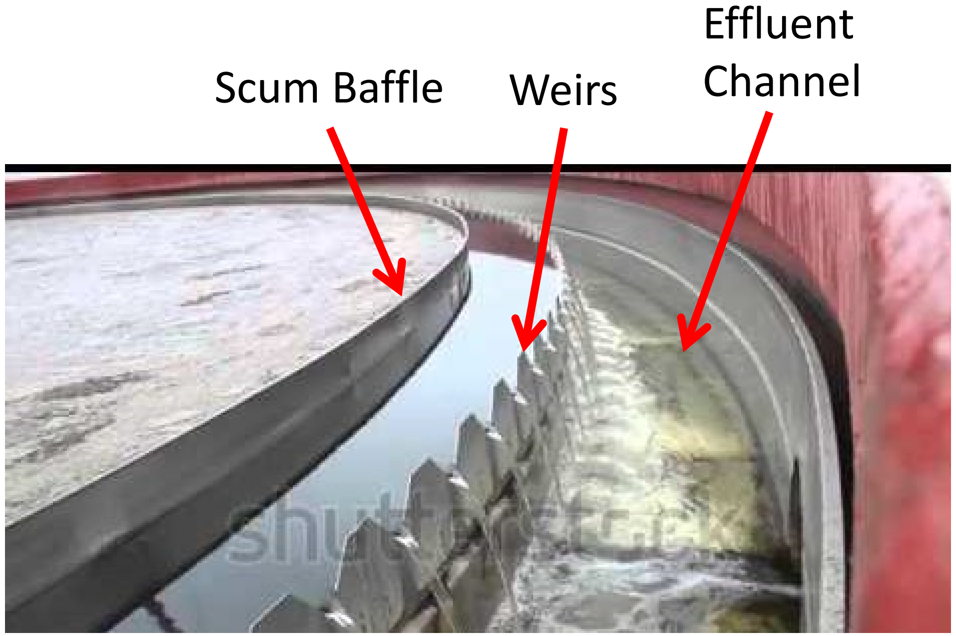


Weirs at a Sed. Basin

- The outlet zone (or Launder) should provide a smooth transition from the sed basin to the outlet without disturbing the flocs
- Weirs installed at the edge of sed basins
- Weirs is used to measure the flow rarte
- Enough length of weirs should be provided
- 20,000 gal/day/ft is the rule of thumb

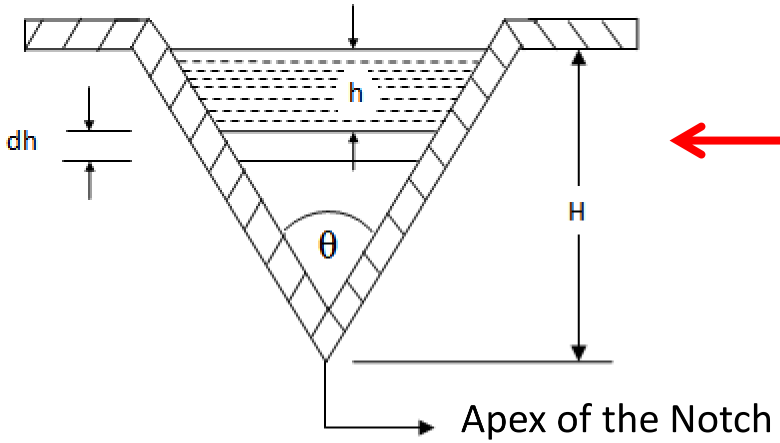


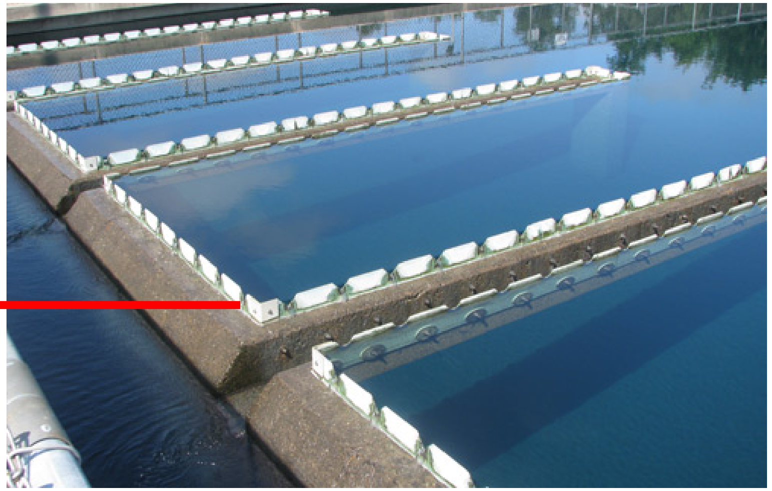




How does weirs work?

- Assuming Triangular Notch
- The outlet zone (or Launder) should



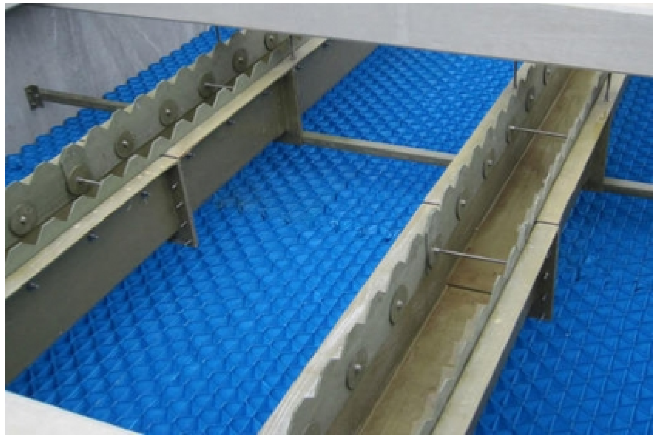


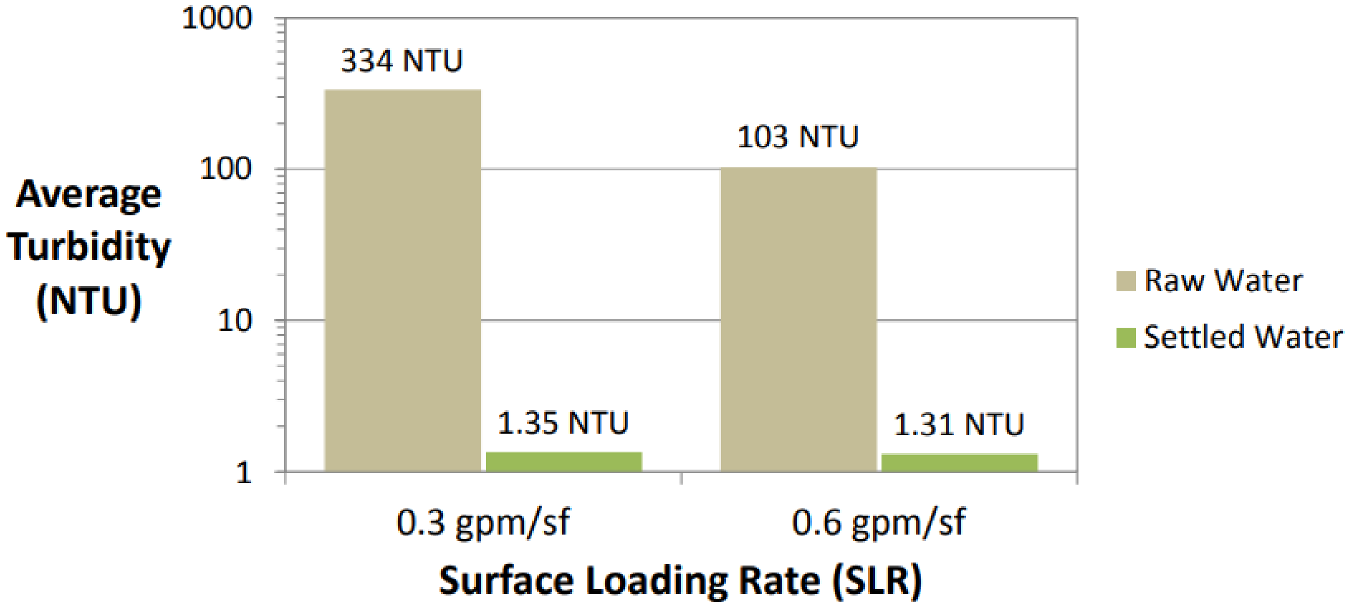
- H = Height of the liquid above the apex of the notch
- θ = Angle of the notch
- C_d = Coefficient of discharge

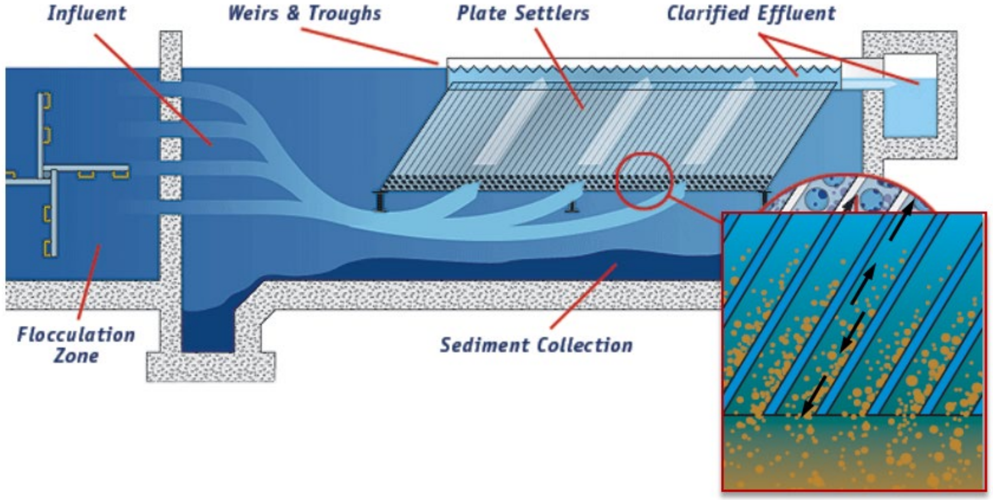
$$Q = \frac{8}{15} C_d \sqrt{2g} \tan\frac{\theta}{2} \times H^{\frac{5}{2}}$$

Sedimentations – High Rate Clarification Processes

- Tube Settler
- Plate Settler
- Dissolved Air Floatation (DAF)
- Actiflo Process

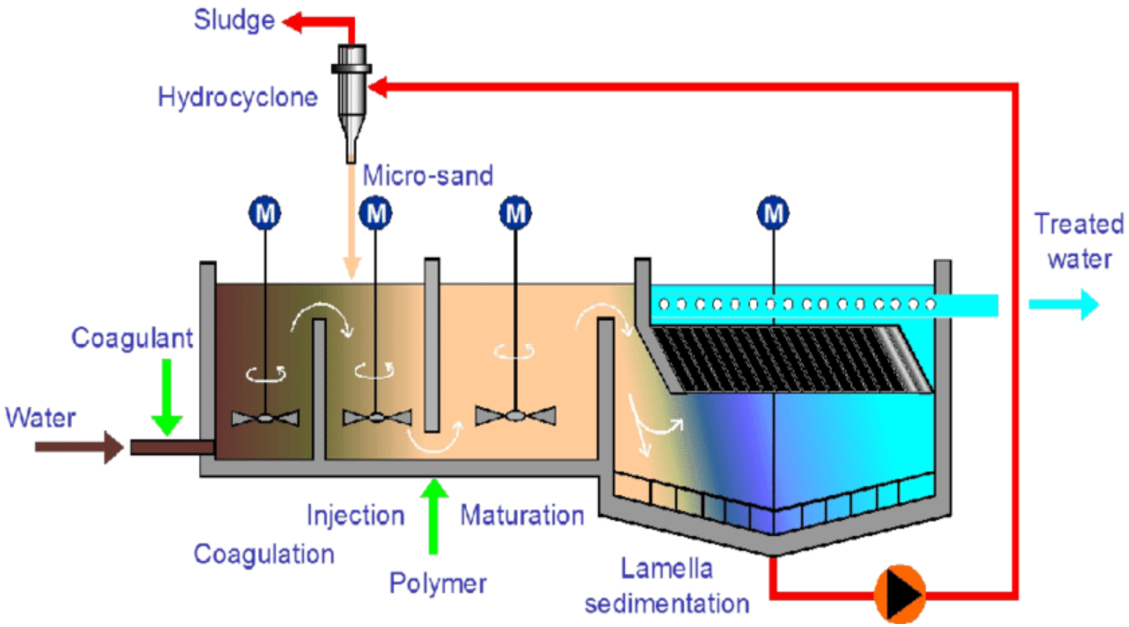


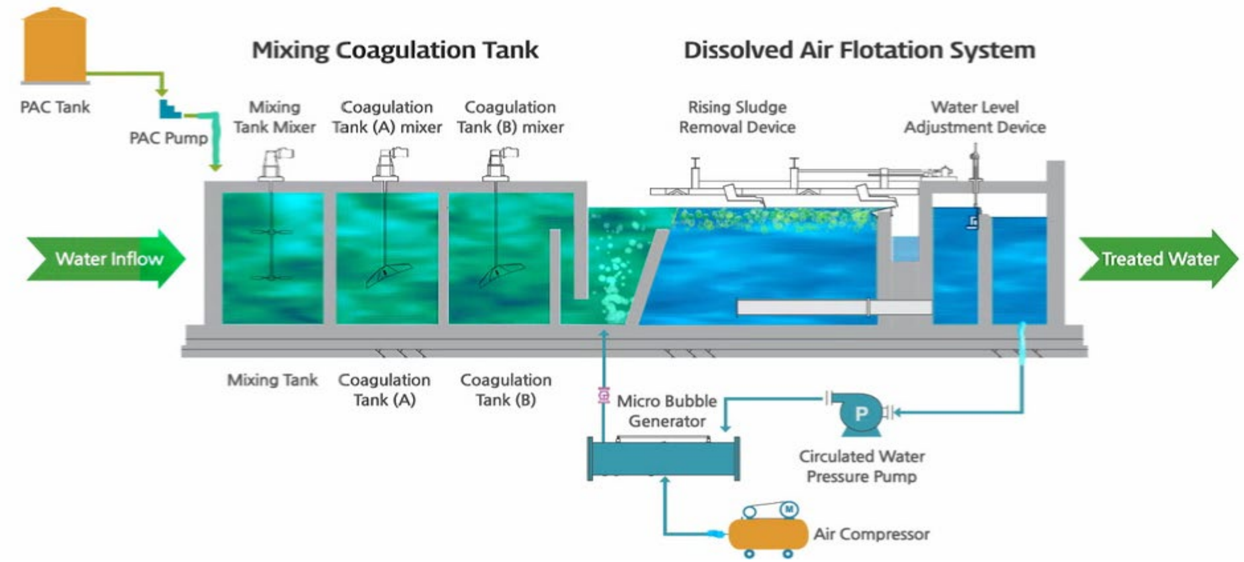




Very High Rate Clarification Process

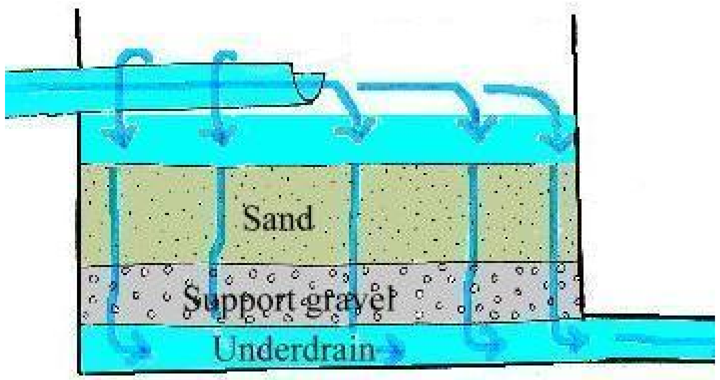
- Increasing surface loading rate from < 1 gpm/ft^2 to > 30 gpm/ft^2
- Actiflo Process (10 to > 30 gpm/ft^2)
- Dissolved Air Floatation (DAF) (3.3 to > 6.6 gpm/ft^2)
- Densadeg



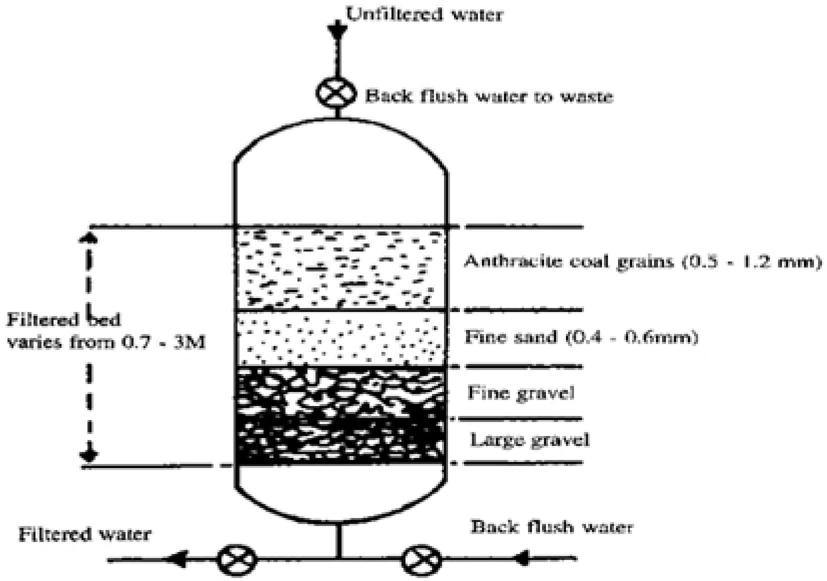


Filtration: A Physical Process for the Removal of Solids

- Strainers (MF/UF)
- Bag Filters
- Cloth Filters
- Cartridge Filters (NF/RO)
- Media Filters
  - Single media filter
  - Multimedia filter
- Membrane Filters
  - Microfiltration (MF)
  - Ultrafiltration (UF)



Filter Basin



Pressurized Filter Vessel

Slow Sand Filtration

- Developed in 1804 in Scottland
- A Slow Sand Filter (SSF) utilizes a very thin layer of “deposits” (a.k.a Schmutzdecke) that consist of inert sand/silt, organics, and biomass to remove particulate in the feed water
- Filtration Rate is very low; but requires very low level of operation and no chemical is needed
- A well-designed and properly maintained SSF can effectively removes turbidity and pathogenic organisms through various biological, physical and chemical processes in a single treatment step.

Rapid Sand Filter

- Predominant Filtration Process for WTP
- Sand, or Media filters can be operated in open/gravity driven basins or in enclosed pressurized filters.

Multi-Media Filter

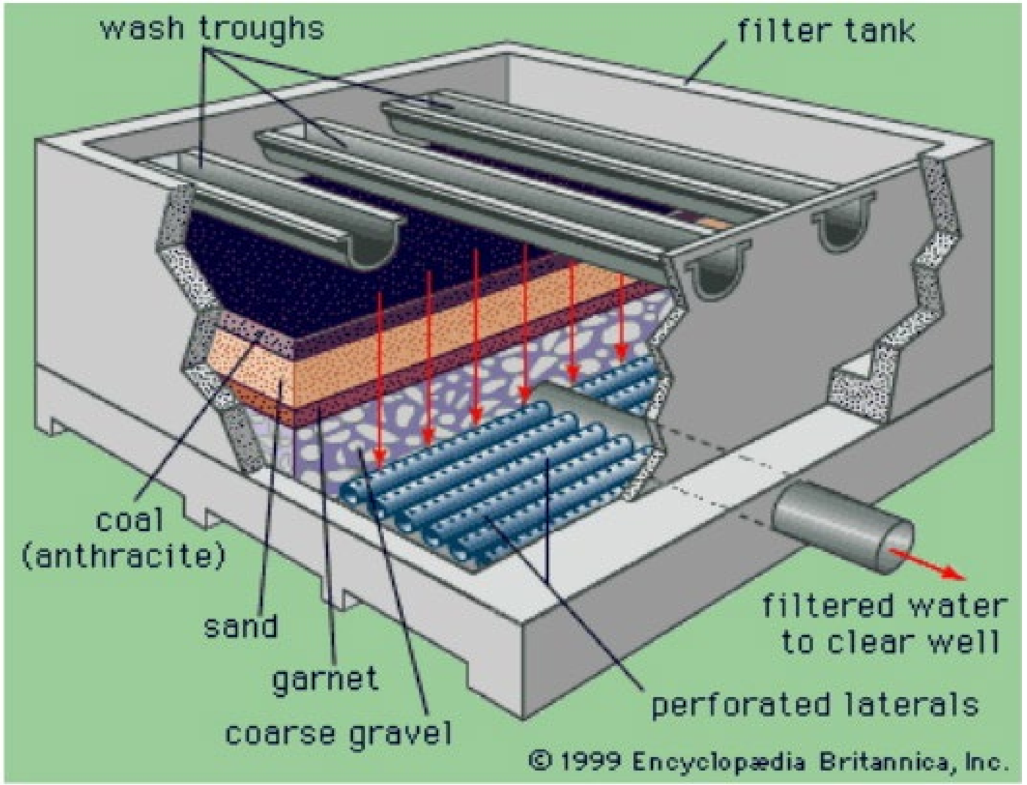
- Filter consists of more than one type of media
  - A: Fine Sand + Corse Sand + Gravels
  - B: Fine Sand + Corse Sand + Garnet Sand
  - C: Anthracite + Corse Sand + Gravels
  - D: GAC + Corse Sand + Gravels

A B C D

Example of a Multimedia Filter Bed

– Composition of a 60” (5 ft) multimedia filter bed

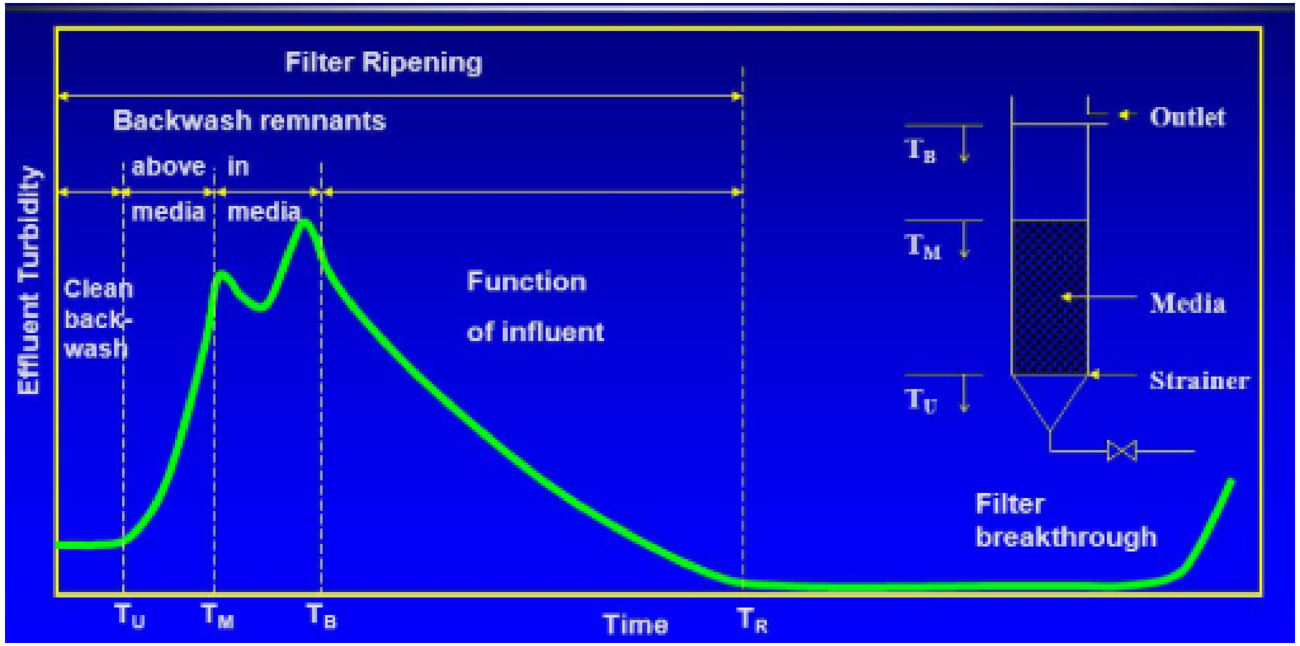
Material	Layer	Particle Size
Anthracite coal	28”	1-1.2 mm
Silica sand	15”	0.4-0.5 mm
High-density sand	5”	0.2-0.3 mm
Garnet gravel	3”	90-100 % 0.476 mm 0-10% 1.41 mm
Silica gravel	3”	1/4” – 1/8”
Silica gravel	3”	1/2” – 1/4”
Gravel	3”	3/4“ – 1/2”

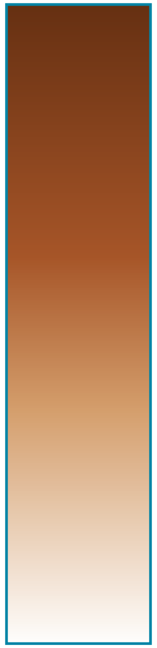


Multi-media filter

Typical Operation Cycles for Media Filters

- Filter to waste (with turbidity > 0.3 NTU)
- Filtration
- Surface Scouring (if equipped)
- Backwash
- Filter to waste
- Potential Filter Problems
- Channeling
  - Air binding
  - Mud balls
  - Excessive loss of media





Clean-Bed Hydraulic Head Loss: The Ergun Equation

– Based on Navier-Stokes Equation with 2 assumptions
  - Filter medium & fluid are homogeneous in isotropic
  - Thermodynamic & chemical effects are small and negligible

Ergun Equation
$$h_L = \kappa_V \frac{(1-\varepsilon)^2}{\varepsilon^3} \frac{\mu L v}{\rho_w g d^2} + \kappa_I \frac{1-\varepsilon}{\varepsilon^3} \frac{L v^2}{g d} \quad (11\text{-}13)$$

where κ_V = head loss coefficient due to viscous forces, unitless
κ_I = head loss coefficient due to inertial forces, unitless

Data compiled from 640 experiments covering Reynolds numbers between 1 and 2,000; proposed $\kappa_V = 150$ and $\kappa_I = 1.75$

Recommended Values for Parameters

– Ergun equation and proposed coefficients are reasonable for spherical glass beads

Table 11-3
Recommended parameters for use with Eq. 11-13[a]

Medium	κ_V	κ_I	ε_I,
Sand	110–115	2.0–2.5	40–43
Anthracite	210–245	3.5–5.3	47–52

[a]When effective size as determined by sieve analysis is used for the diameter.

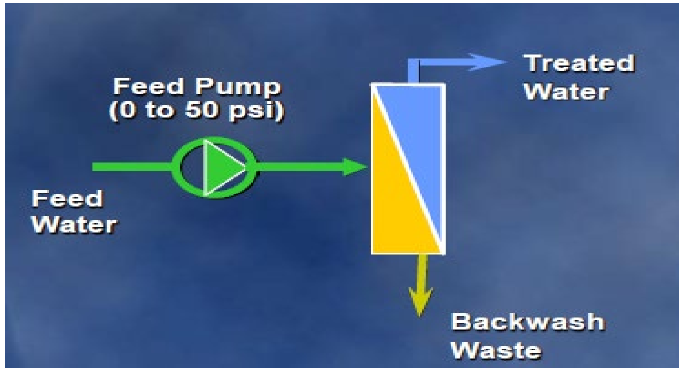
Basic Filter Production Calculation

- UFRV (Unit Filter Run Volume)
- UBWV (Unit Backwash Volume)
- UFWV (Unit Filter-to-Waste Volume)
- Recovery

Membrane Filtration

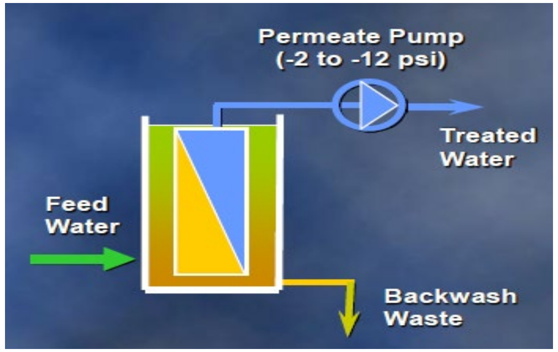
Pressurized Membrane System

A system where membranes are encased in a housing and pressure us used to force water through the membranes to produce a permeate



Submerged Membrane System

A system where membranes are immersed in a basin. Usually a vacuum is applied to produce filtrate



Fouling Material & Cleaning Chemicals

For Fouling Material	Cleaning Chemical
Biological; NOM; Synthetic polymers	NaOCl
Inorganic deposits	Acids (HCl, H_2SO_4, Citric Acid)
NOM	NaOH
Reducible metals (Fe, Mn)	Sodium bi-sulfite (SBS)
NOM	H_2O_2
Metals	EDTA

Monitor Your Membrane Performance: Key Operating Parameters

- **Flux:** Filtration rate per unit surface area (gfd, lmh)
- **Transmembrane pressure (TMP):** Pressure difference across the membrane, driving force for filtration
- MIT: Membrane Integrity Testing (psi/min; kpa/min)
- Permeability: Temperature corrected specific flux (gfd/psi, lmh/kpa)
  - Permeability is a normalized parameter that takes into the consideration of operating flux, pressure, and temperature
  - Permeability can serve as an unbiased indicator of membrane health

$$Permeability = \frac{Flow\ Rate\ \left(\frac{gal}{day}\right) \times Water\ Viscossity\ (cP)}{Membrane\ Surface\ Area\ (ft^2) \times TMP(psi)}$$

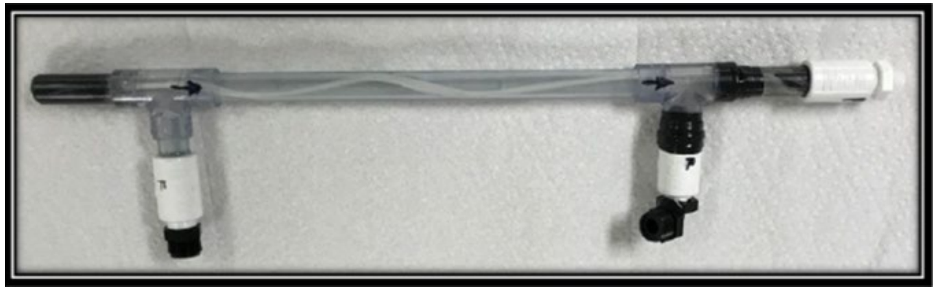
- *A normalized parameter that takes into the consideration of Flux, TMP, Temp*
- *An unbiased indicator of membrane heath*

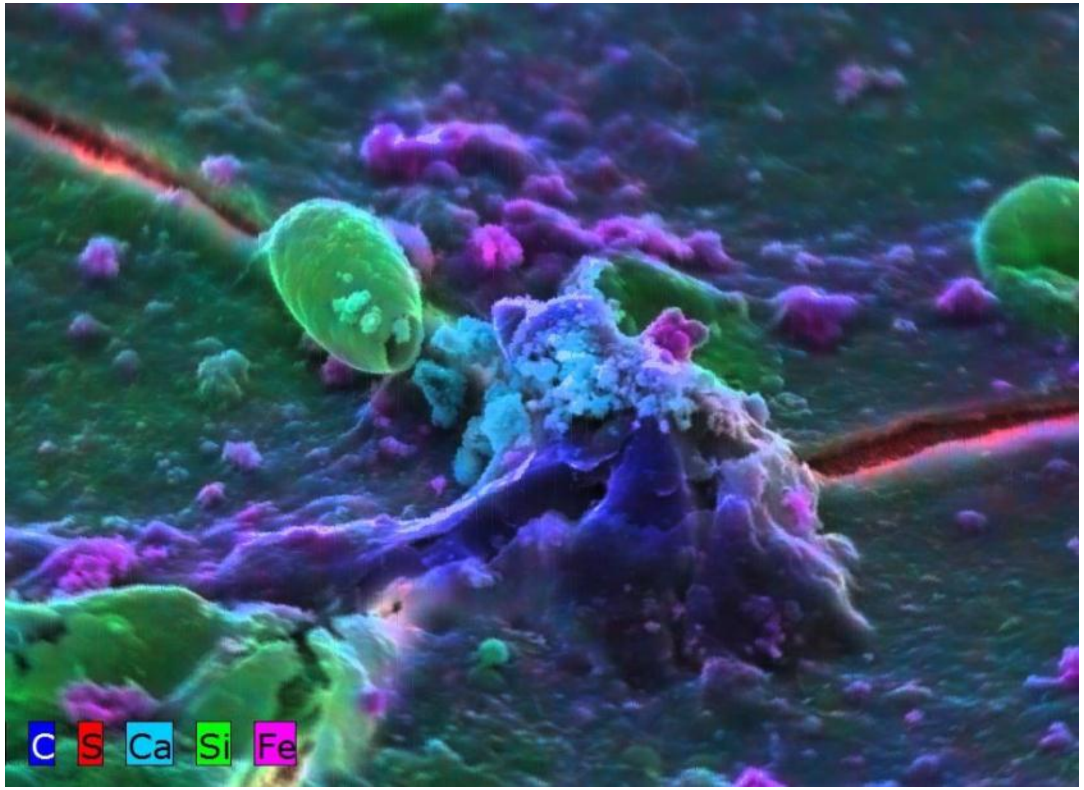
Membrane Integrity Monitoring

- On-Line Turbidity Monitoring
  - 0.08 NTU 95% of the time, 0.1 NTU max.
- On-Line Particle Count (not common anymore)
  - Baseline establishment (< 50 particles/mL)
  - Could be affected by air bubbles
  - Sensitivity: Not sensitive enough (yet) for the detection of a 3 μm breach
  - Too easy for false alarms
- Pressure Holding Test (Air integrity testing)
  - Direct Integrity Testing is required by EPA
- Virus Seeding Test (UF)
  - Only for initial product verification, cannot be used for continuous monitoring

Membrane Forensic Studies & Performance Optimization

- Mini Module Testing
- Chromatic Elemental Imaging (CEI)

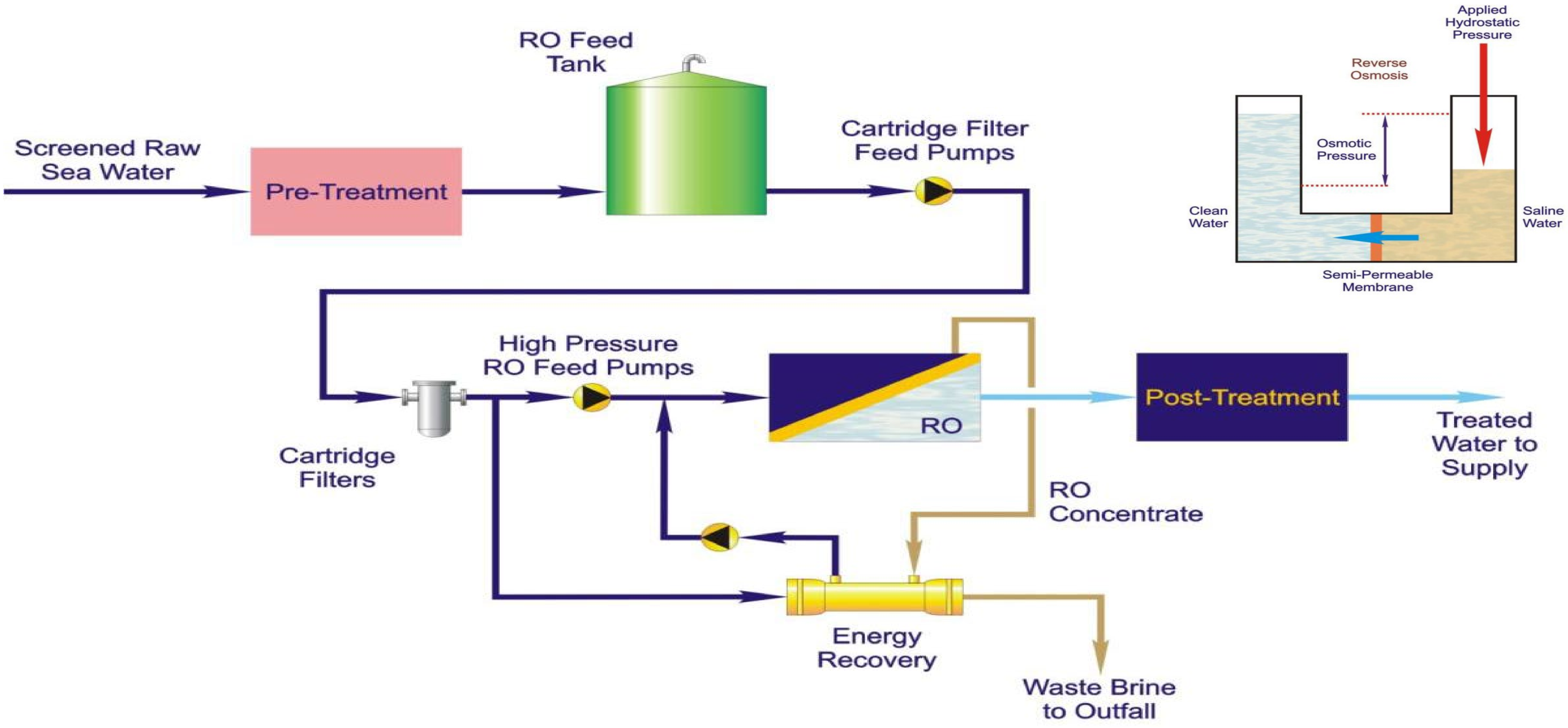




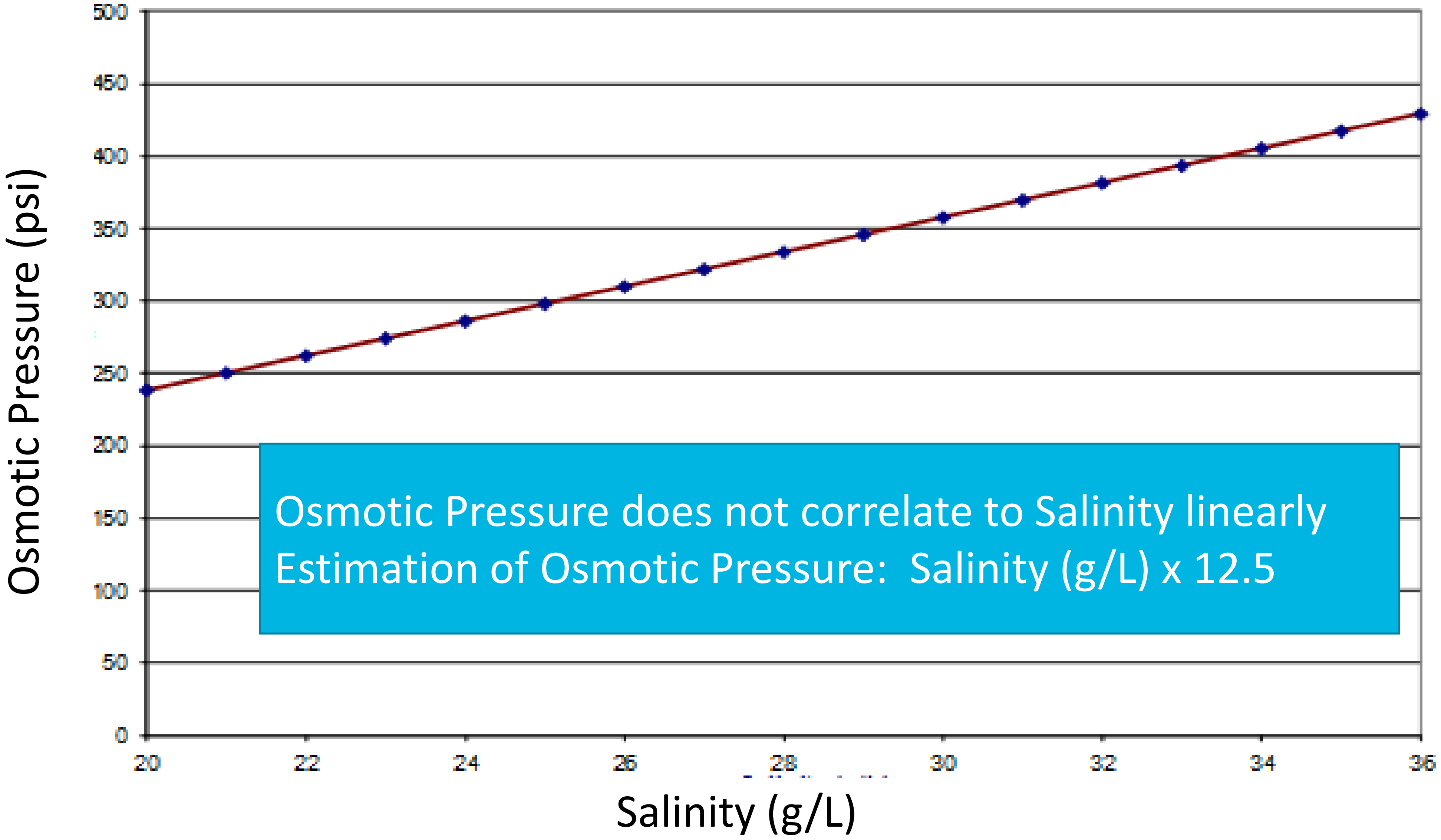
Membrane Process Design Considerations

- Make sure adequate membrane surface area is acquired to provide firm capacity regardless of water temperature
- Adequate safety factors should be included to account for membrane aging issues
- Monitor membrane permeability rather than TMP
- Adequate pretreatment should be included to accommodate potential raw water quality changes
- Overall plant hydraulics and flow balance should be evaluated: constant flow or constant flux

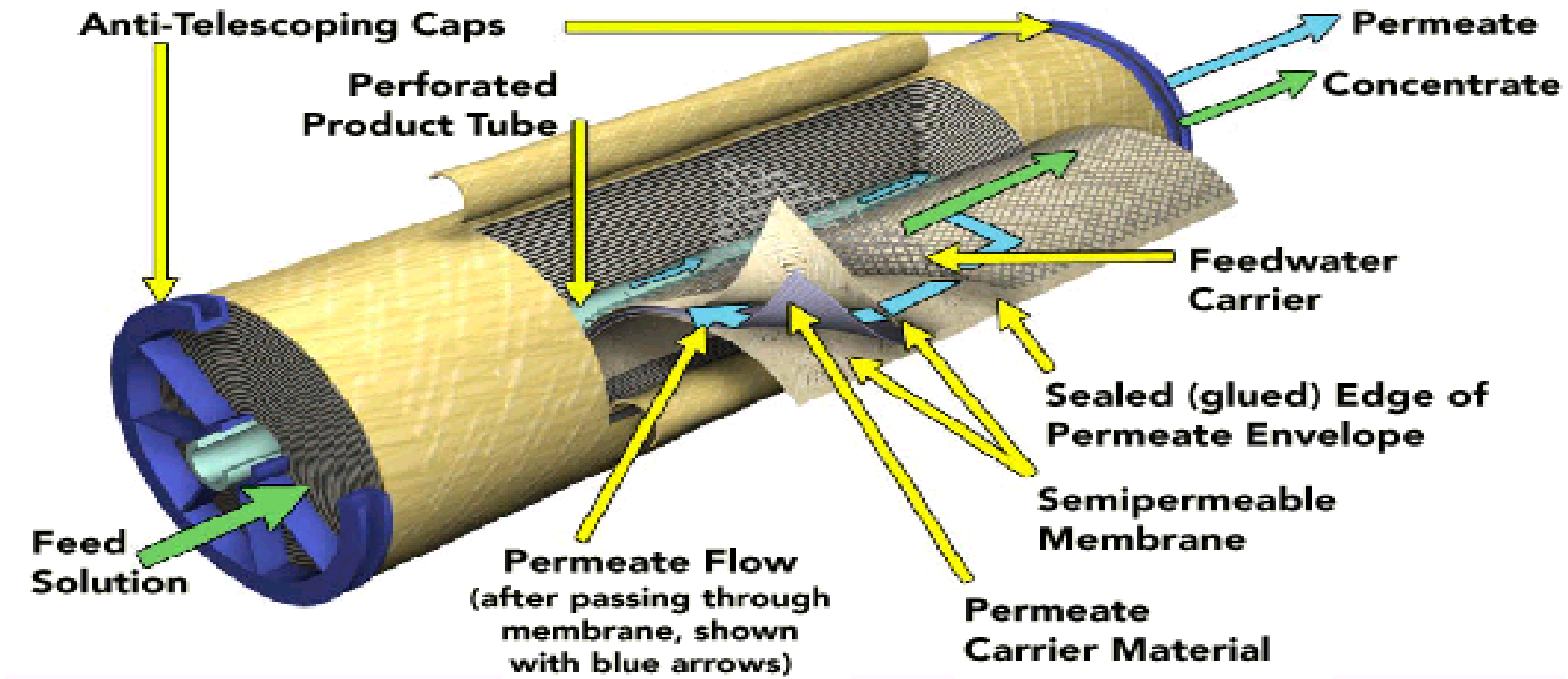
Typical PFD for Seawater Reverse Osmosis (SWRO)



Equation for Salinity vs. Osmotic Pressure



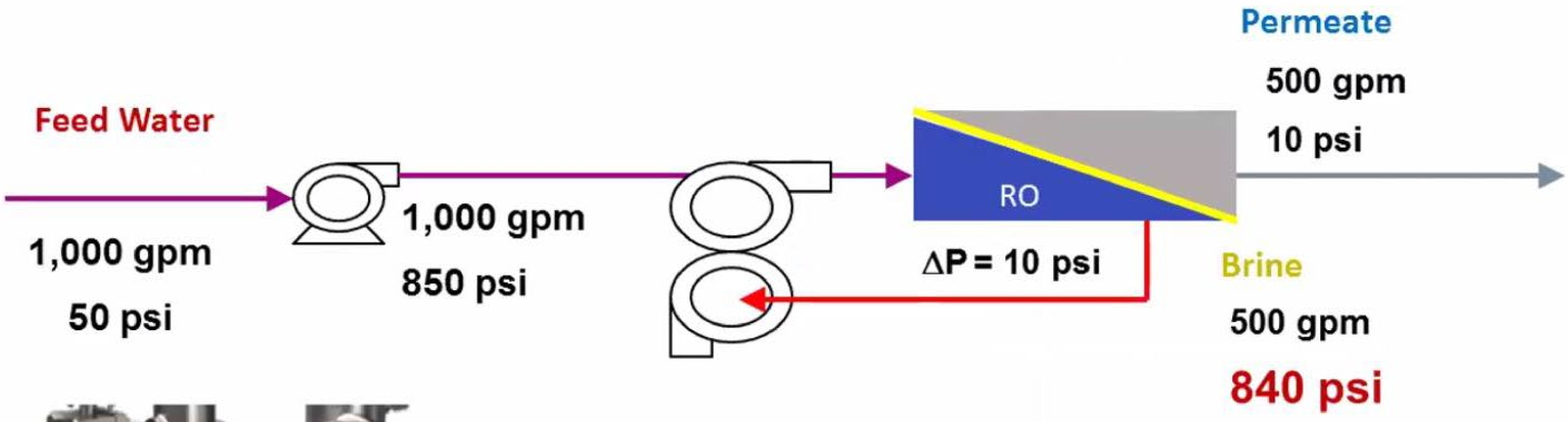
Membrane element Arrangement



Pressure Required for Seawater Desalination

- Theoretical Minimum Energy: 1.02 kWh/m^3
  - Consider osmotic pressure only
- Practical Minimum Energy: 1.52 kWh/m^3
  - Assuming all pumps, valves, piping head-loss, Energy Recovery Devices all work perfectly
- Best Operated SWRO Plant: 2 – 2.5 kWh/m^3

RO Energy Recovery Devices (ERD)

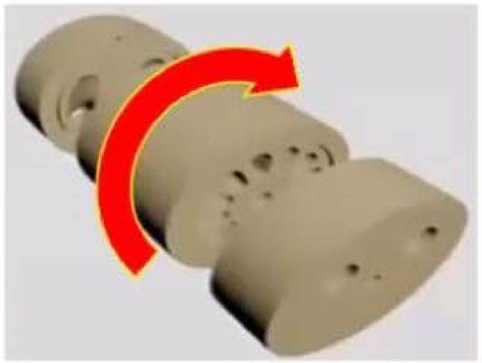


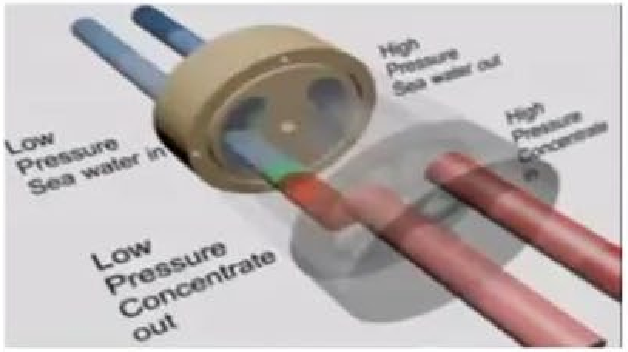
Hydraulic → Mechanical → Hydraulic

Energy Recovery Efficiency ~ 80%

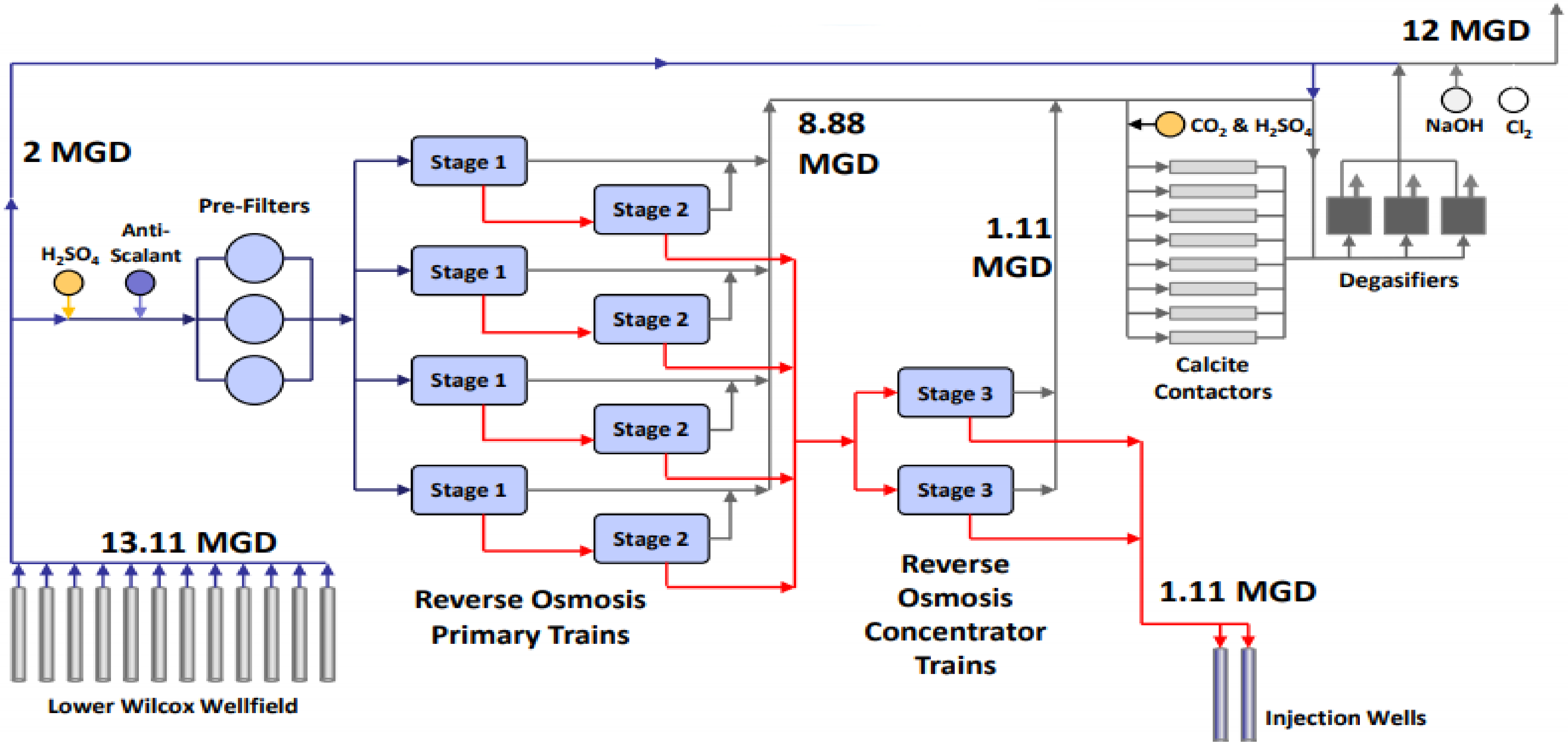
High Efficiency Energy Recovery

- Isobaric devices (95-99%)
  - Piston style (DWEER by Flowserve)
  - Rotary pressure exchangers (PX by ERI)





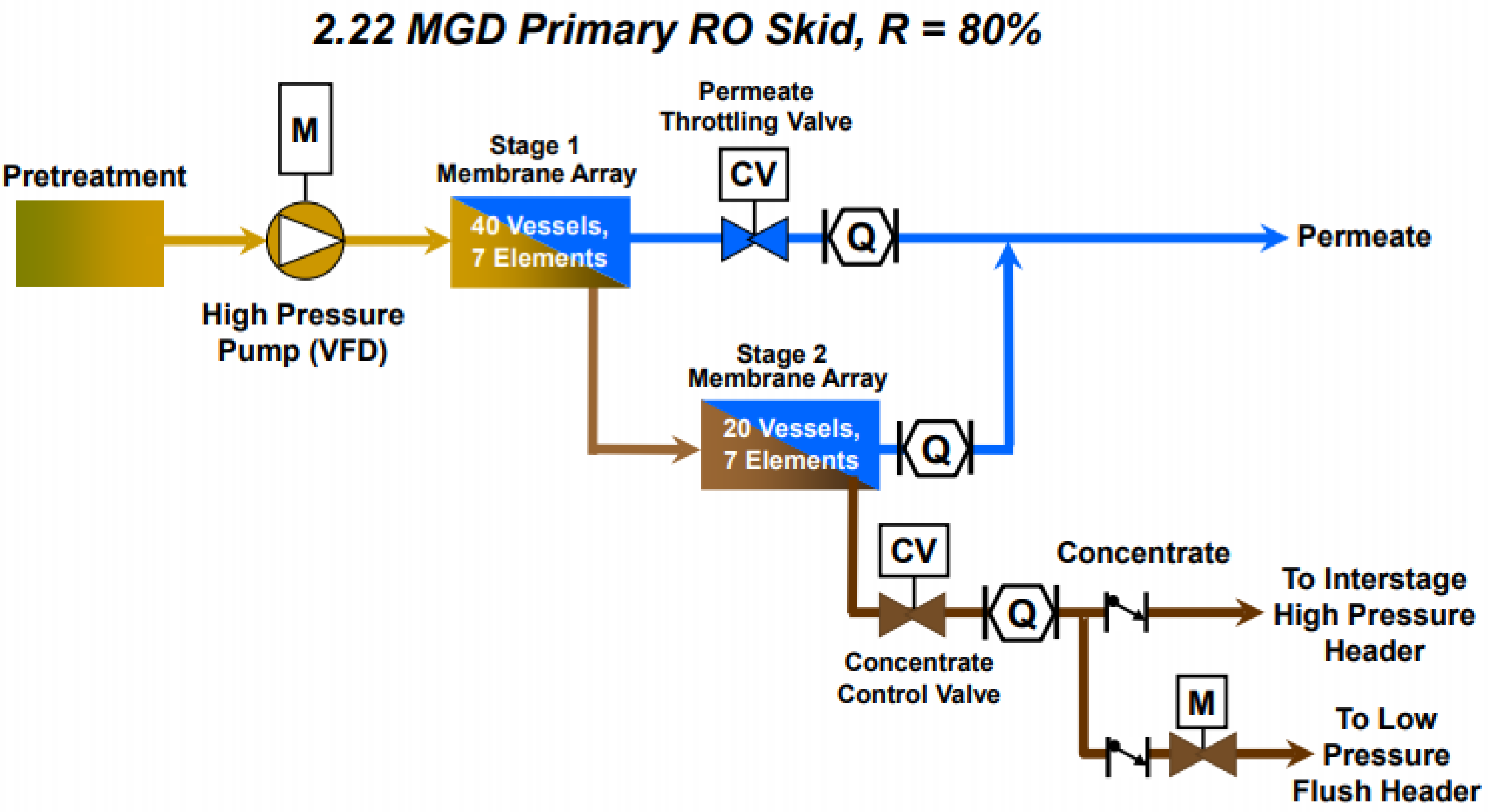
Brackish Water Desalination (3-Stage BWRO)



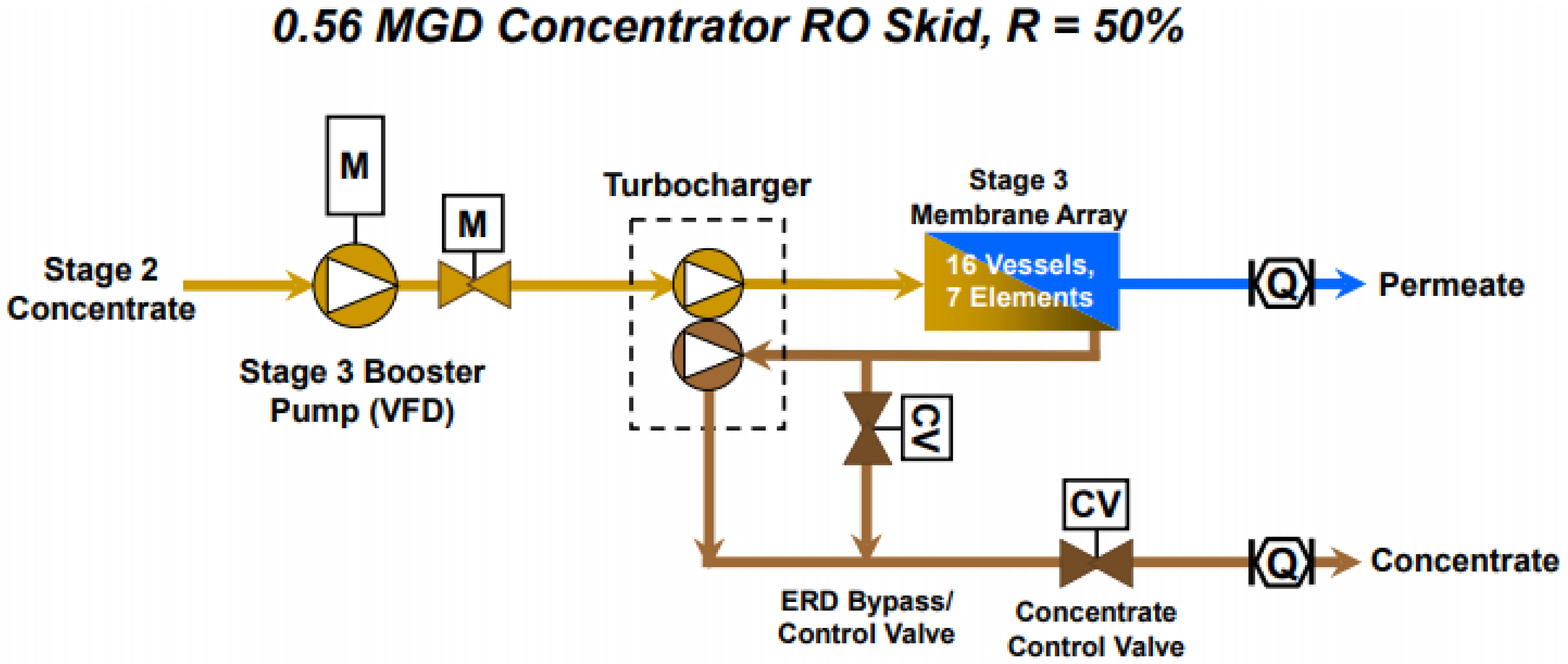
BWRO Pretreatment

- Scale Inhibitor/Anti-scalant
- pH Adjustment - 6.5 using sulfuric acid
- Cartridge Filters
  - 3 x 7.0 MGD units
  - 14.0 MGD with one unit offline
  - 5-Micron nominal polypropylene, string-wound, SOE, 40-inch

Primary RO Skid Configuration



3rd Stage Concentrator RO Skid Configuration



Finished Water Quality

Parameter	Overall Finished Water Quality Goal	BGD Finished Water Parameters
pH, Std Units	7 – 8.5	7.9 – 8.2
TDS, mg/L	< 400	< 320
Alkalinity, mg/L as $CaCO_3$	100 – 300	120- 160
Calcium, mg/L as Ca (mg/L as $CaCO_3$)	40 – 100 (100 – 250)	38 – 46 (95 – 115)
LSI	0.1 – 0.4	> 0.1 (at 25 ^{o}C)
CCPP, mg/L as $CaCO_3$	4 – 10	7 – 12 (at 25 ^{o}C)

Understanding Langelier Saturation Index (LSI)

- An Index that predicts whether calcium-based solids will tend to precipitate, or dissolve in a specific water chemistry

LSI = (pH) + (Temperature) + (Calcium Hardness) + [(Total Alkalinity) – (CYA Correction Factor @ current pH)] – (TDS Factor)

- If LSI > 0, solid tend to precipitate
- If LSI < 0, solid tend to dissolve
- We like finished water having LSI slightly positive to avoid corrosion

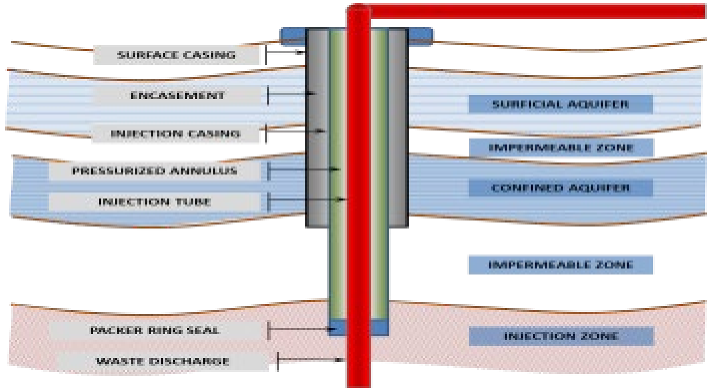
Post RO Treatment

- Calcite Contactors – Calcium and alkalinity addition
- Raw Water Blending – Supplemental alkalinity & hardness
- Degasifiers –Excess CO_2 removal
- Sodium Hydroxide – Final pH stabilization
- Chlorine – Disinfection

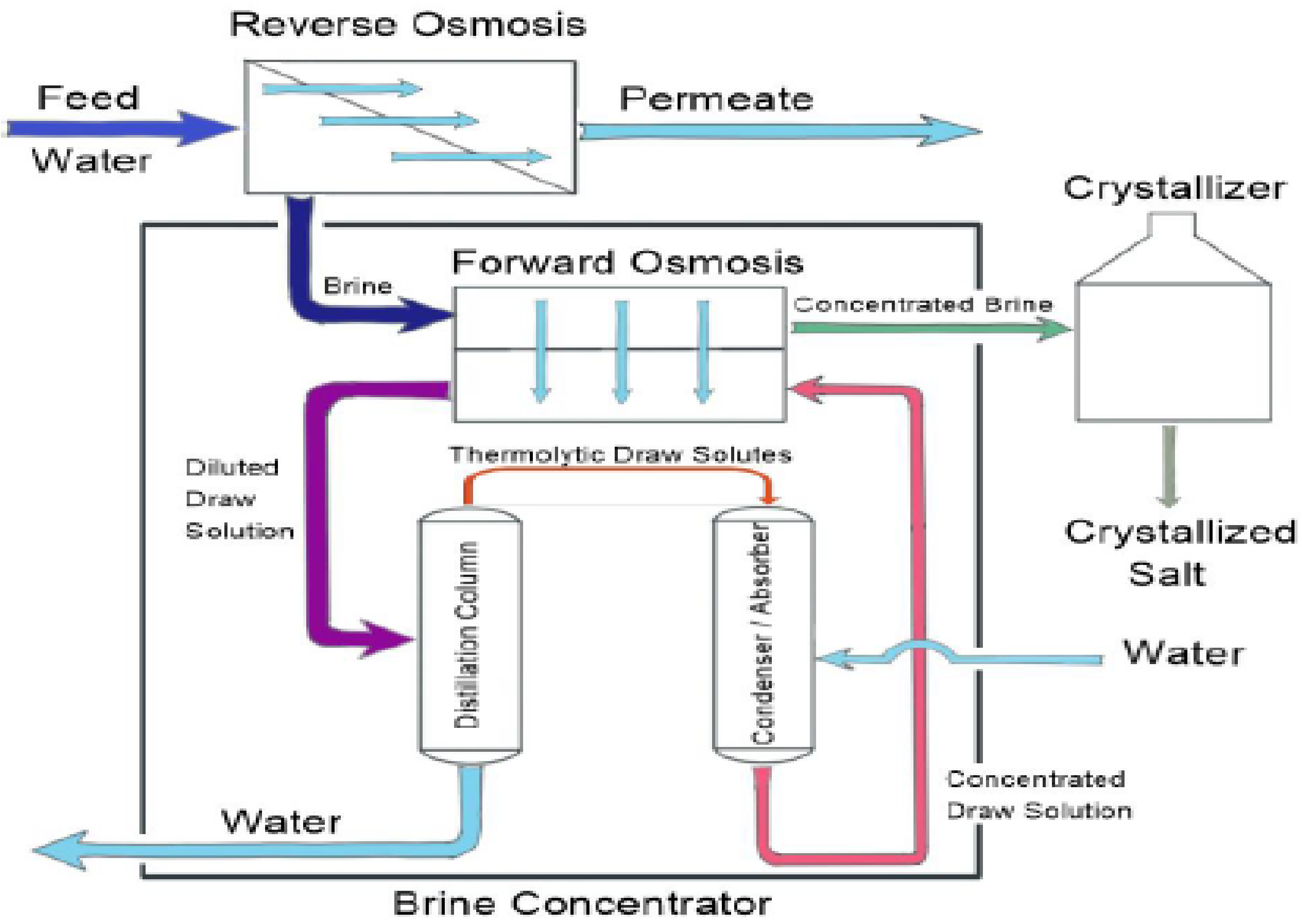
Raw Water Blend (Bypass) Control Valve

Challenges for Brine Discharge Options

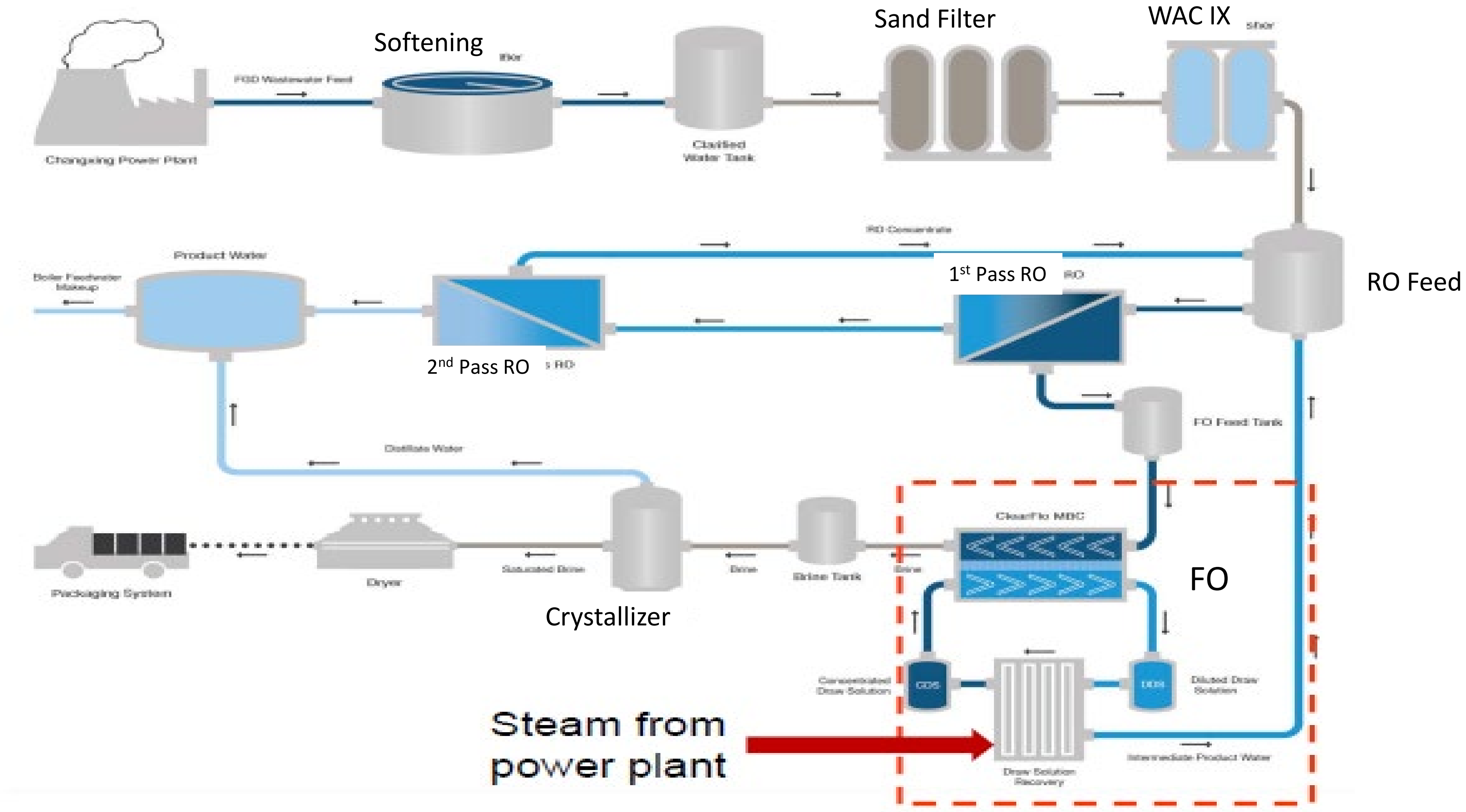
- Sewer line (! ! ! !)
  - Depending on acceptability to WWTP based on brine water quality and impact to WWTP process as well as its discharge permit
- Surface water (! ! ! ! !)
  - Mostly prohibited due to high salinity
- Deep well injection (! ! !)
  - Only available to a few states
  - EPA is tightening up the restrictions
  - Not an option for seismic areas
- Dedicated brine line for ocean discharge (SARI) (! ! ! ! !)
  - Regional effort
  - Close proximity to the ocean
  - High maintenance



FO Zero Liquid Discharge Process Scheme



The World’s First FO-Based ZLD (Oasis USA & China)



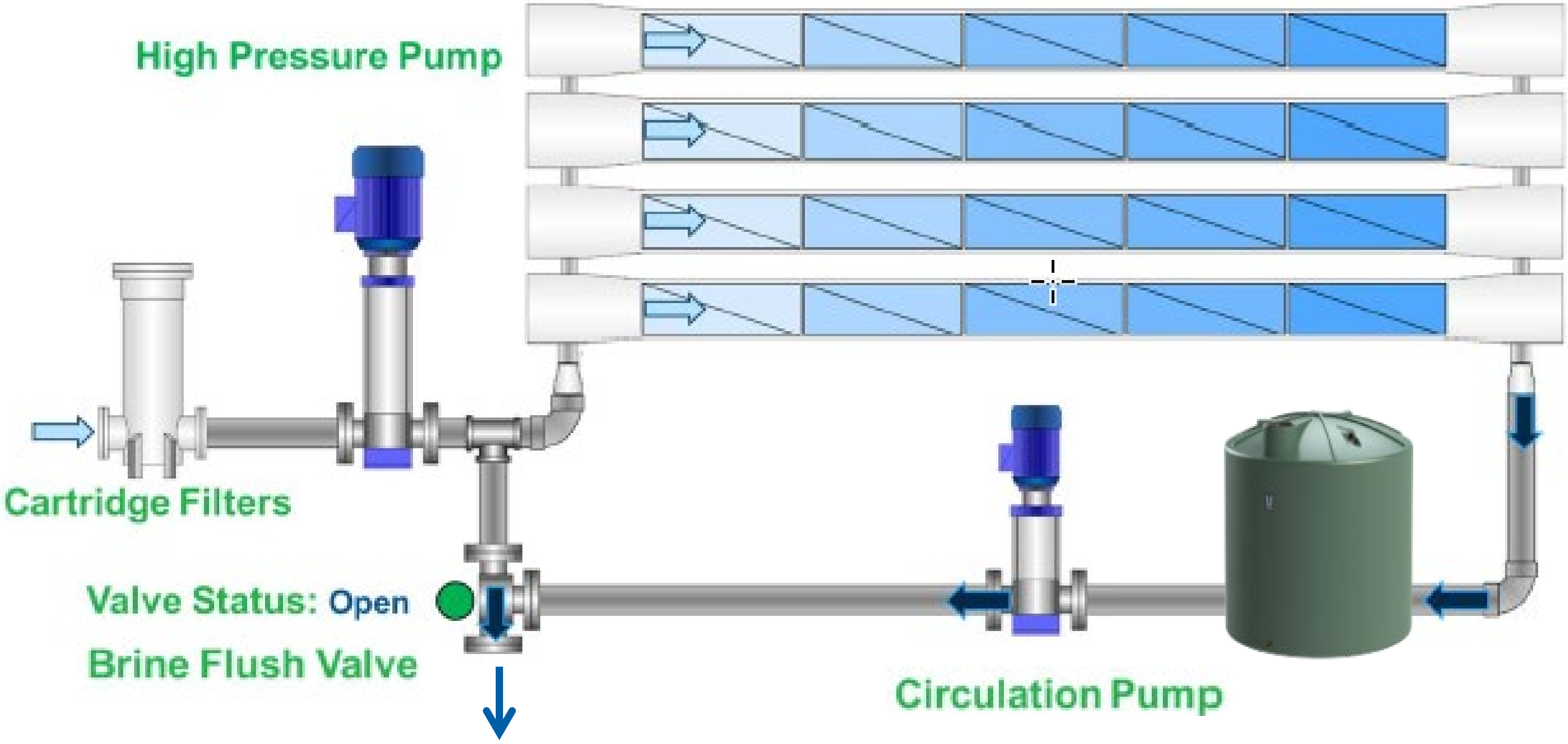
Challenges with ZLD Processes

- Extremely high capital costs
  - Unique proprietary technologies
  - High energy consumption
  - Expensive materials

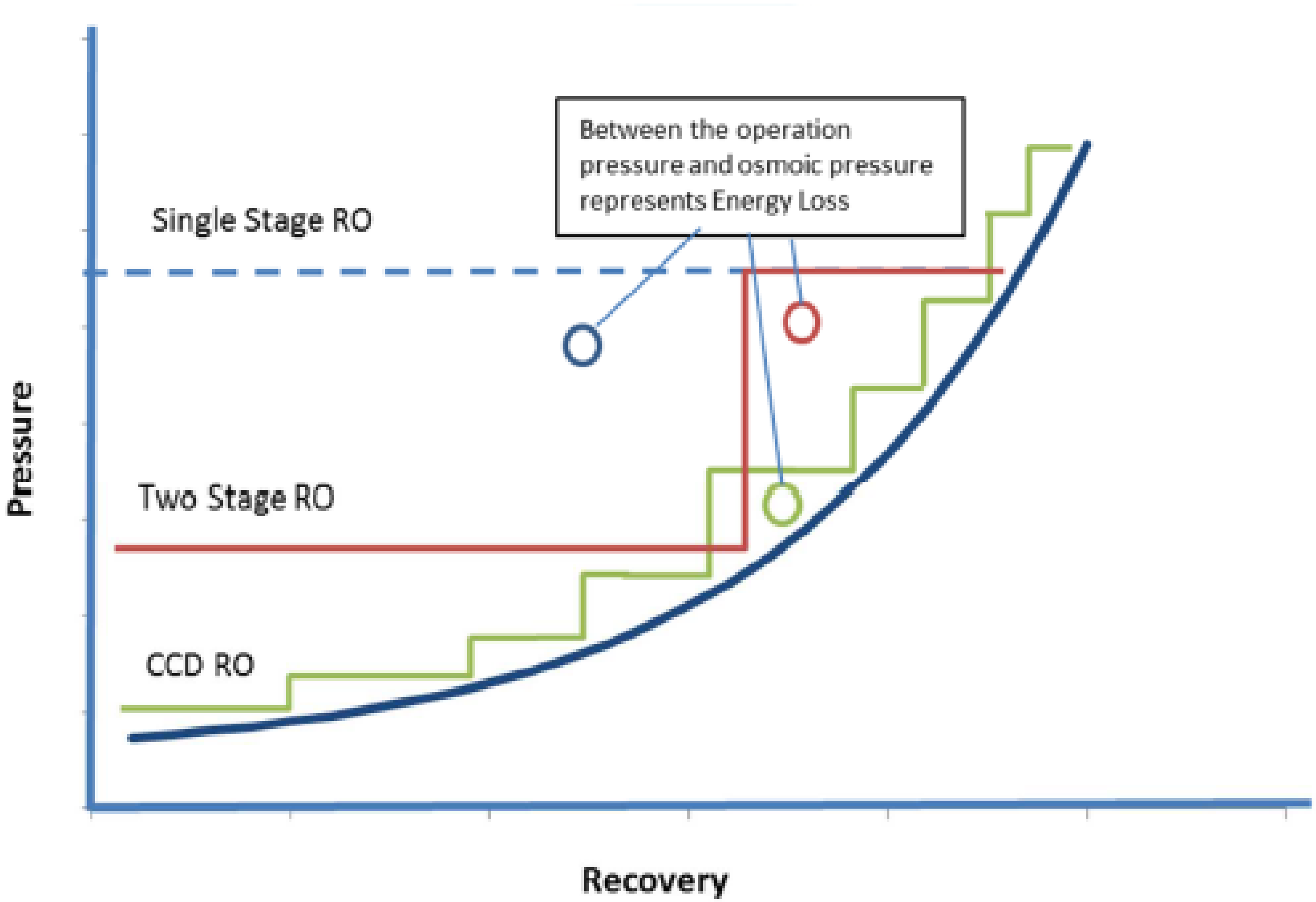
- Operation challenges
  - Sophisticated operations
  - Changes in water quality in the brine
  - Final disposal of salt slurry/solids

Step 2: Plug Flow (1.5 min)

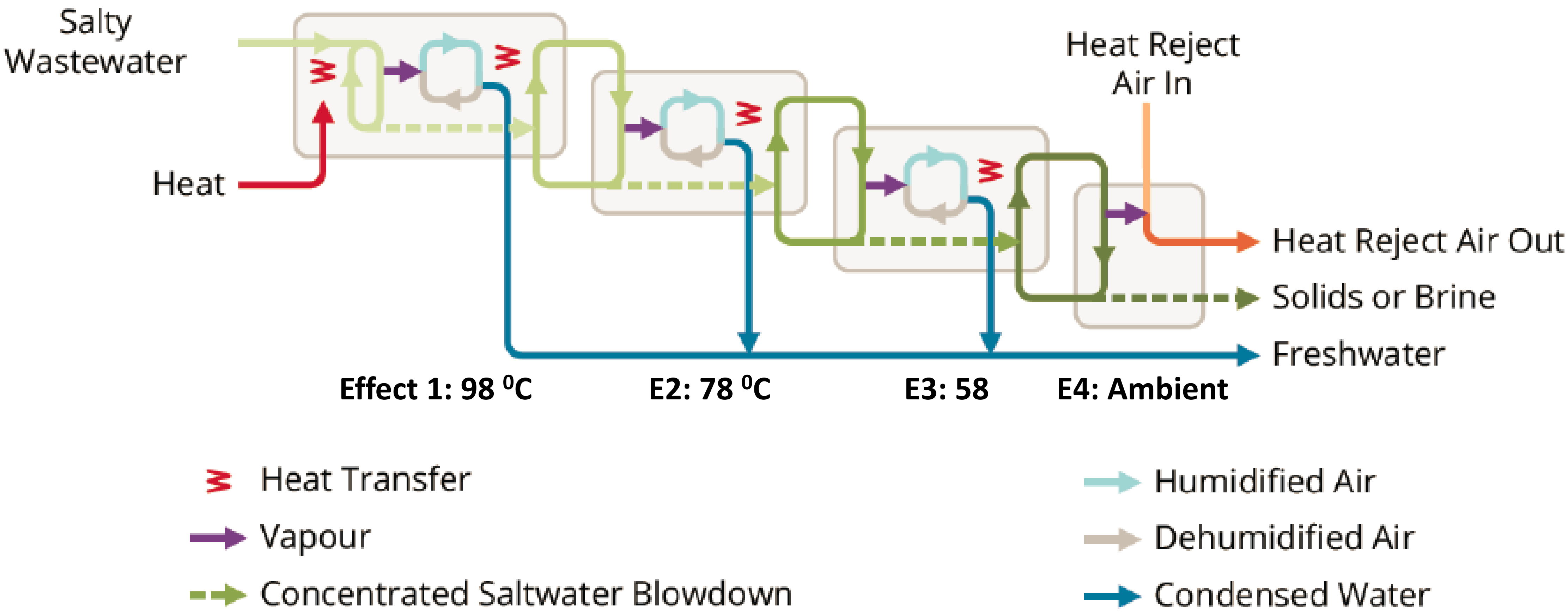
- Brine is discharged just before scaling is about to occur



Energy Efficiency for CCD Process/CCD



Multi-Effect Low Temperature– Saltworks, Vancouver Canada



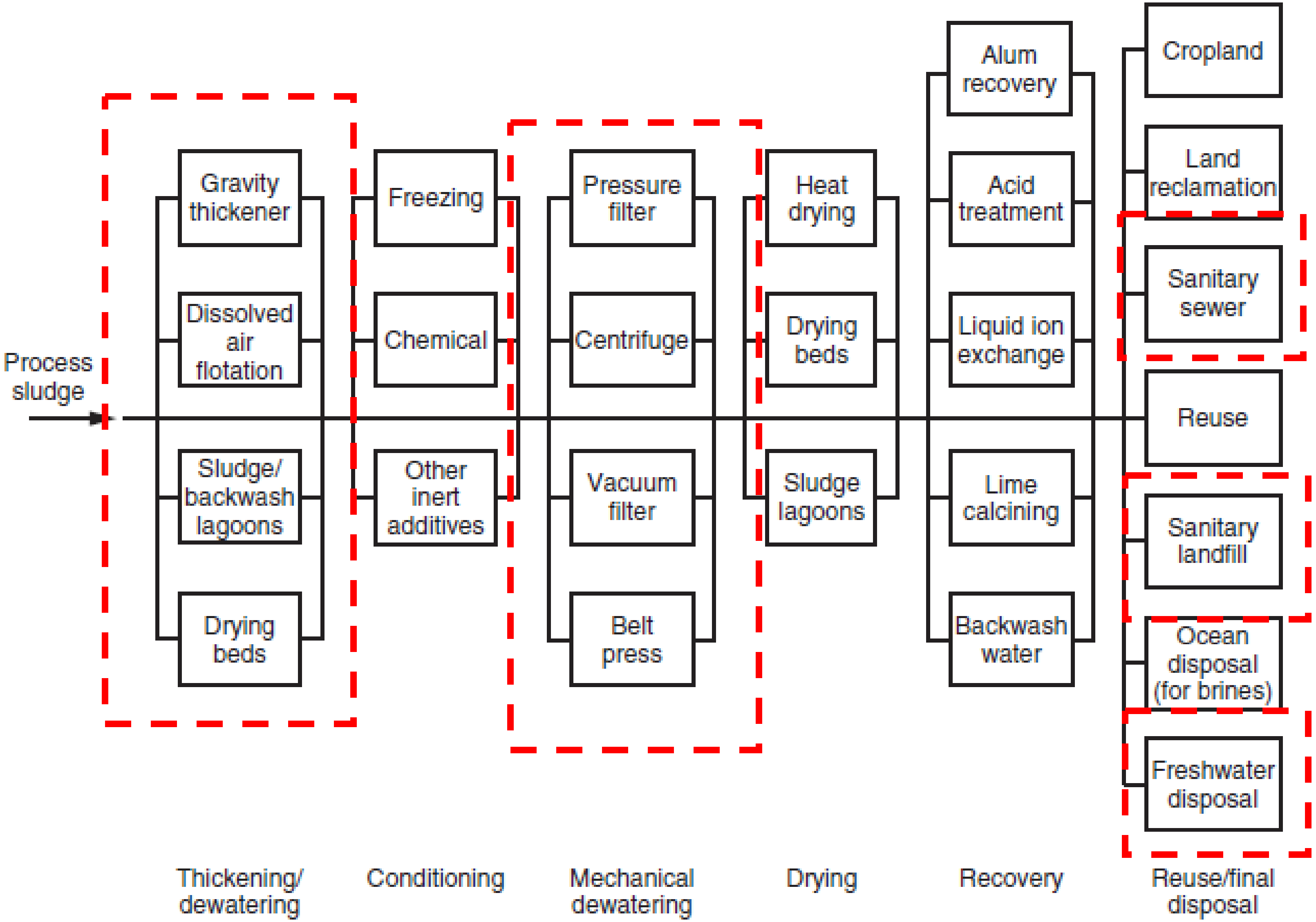
4 - Effects Evaporation & Solid Collection System

Landfill leachate

Oil sands evaporator blowdown

Overview of WTP Sludge Treatment/Disposal

- Physical
- Chemical Conditioning
- Final Disposal
- Beneficial Reuse



Types of Residual from WTP: Liquid Stream

- Liquid waste stream
  - Filter to waste (15 – 60 min)
  - Backwash wastewater (usually containing 10 – 400 mg/L of solids)
  - Chemical cleaning wastewater (needs to be neutralized for pH or oxidation/reduction power)
  - Sludge dewatered wastewater
- Collected liquid wastes stream can be
  - Discharged back to river (downstream of intake)
  - Treated to further increase overall recovery if higher water recovery is desirable

Other Types of Liquid Waste from WTP

- Ion Exchange Resin (IXR) regeneration brine waste
  - Containing substances removed by ion exchange
    - High TDS (Na, Cl, Ca, Mg, SO4 etc.)
    - All other constituents removed by IX, e.g., NOM, and potential contaminants
- Some IXR uses acids or bases for regeneration, therefore the initial treated water immediately following regeneration may contains high or low pH
- MF/UF Membrane Wastewater
  - Backwash wastewater
  - CIP chemical wastewater
- RO Membrane Wastewater
  - CIP chemical cleaning wastewater
  - RO reject brine (covered in SWRO & BWRO), require neutralization of pH and ORP

Types of Residual from WTP: Solid Waste

- Precipitated Salts from softening processes (with the addition of Lime & Soda Ash), typically 80 – 95% of the softening sludge is CaCO3, with remaining solid being MgOH
- Spent adsorptive media, such as Granular Activated Carbon (GAC) and Ion Exchange Resins (IXR)
- Additional Considerations for solid waste disposal
  - Solid waste may contain pathogens removed from the water (pending on local regulations on disposal)
  - Does solid waste contain regulated contaminants?
    - Arsenic, Selenium, Chromium 6+, PFAS, etc.
    - May require certified testing results prior to disposal
      - EPA's Toxic Contaminant Leaching Testing Protocol (TCLP)
      - Regional toxicity testing requirements, such as WET test in CA

Characteristics of Alum Sludge

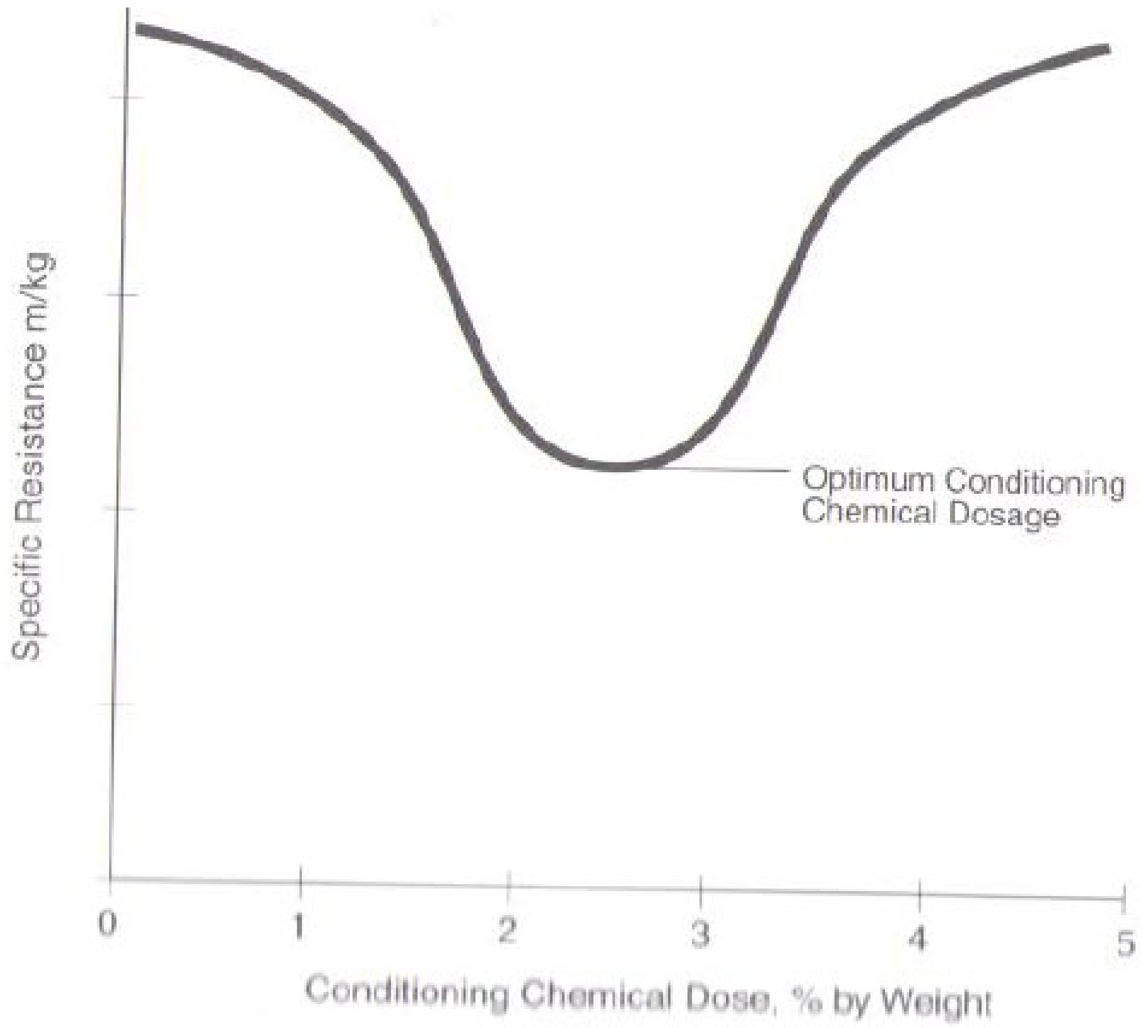
- Quantity of Alum sludge is usually much more than ferric-based sludge due the gelatinous nature of the solid (high water content)
- Typical solid content in alum sludge is only 0.5– 2% (5,000 – 20,000 mg/L)
- Note: Alum: Al2SO4(14 H2O) with MW = 594

$$\text{Solid Production, } S = (8.34Q)(0.44Al + SS + A)$$

S = sludge produced (lbs/day)
Q = plant flow, million gallons per day (mgd)
Al = liquid alum dose (mg/L, as 17.1% Al_2O_3)
SS = raw-water suspended solids (mg/L)
A = net solids from additional chemicals added, such as polymer or powdered activated carbon (PAC) (mg/L)

Conditioning Sludge for Optimum Dewatering

- Sludge's dewatering characteristics can be enhanced by adding polymers
- Higher Molecular Weight Polymers usually work better; but need to watch out for potential handling issues if the viscosity is too high
- Typical polymer dosage:
- 1 g/kg sludge – 10 g/kg sludge

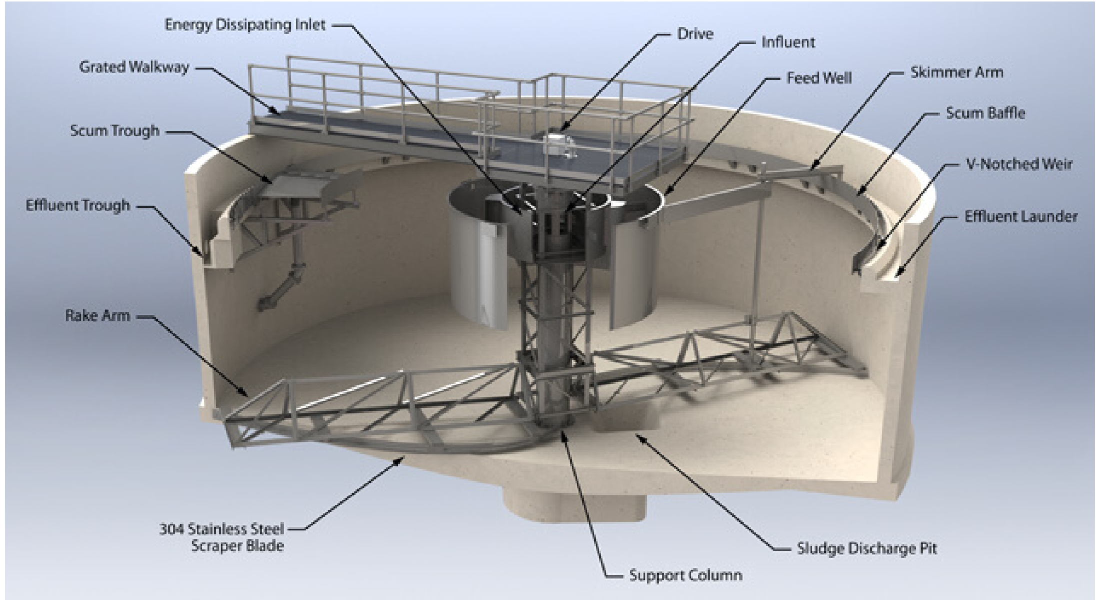


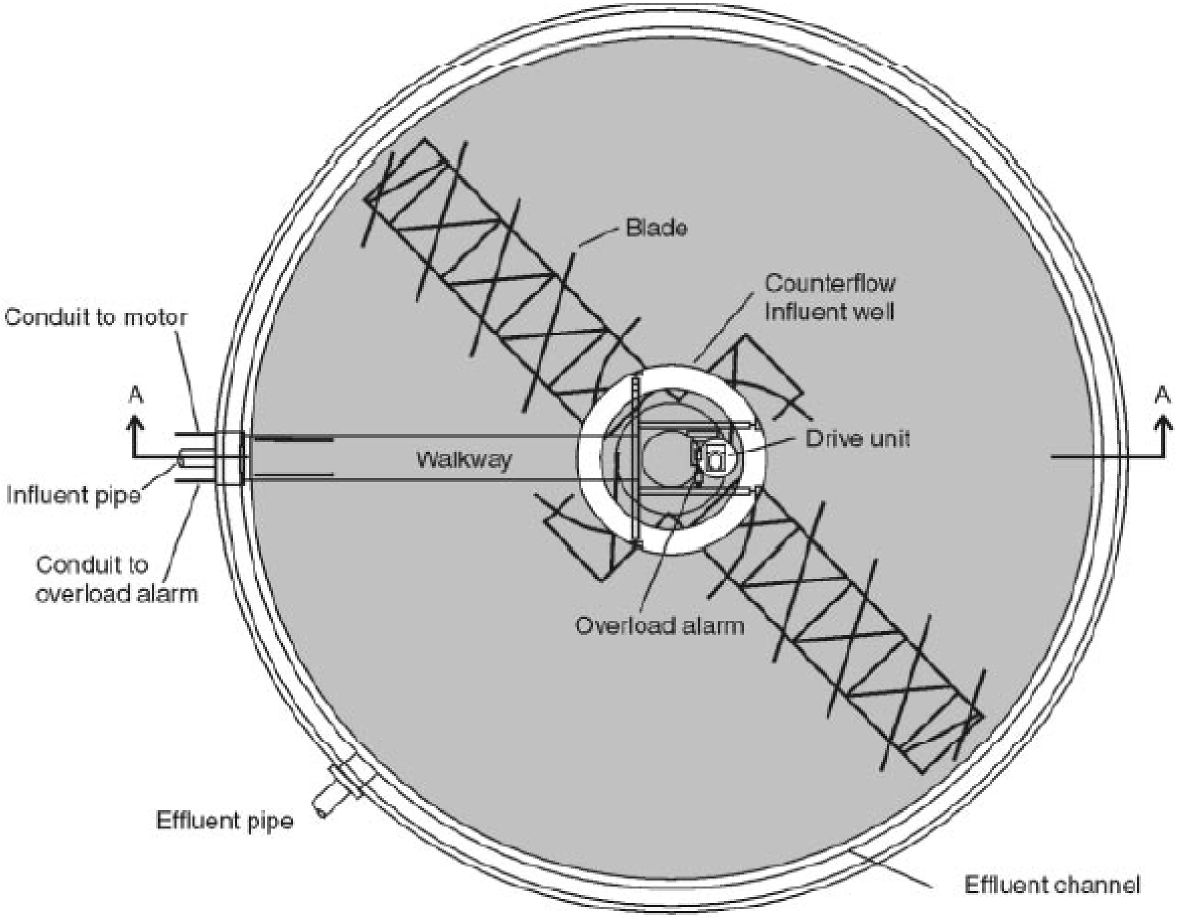
Typical Solid Concentration in Sludge

- Volume of sludge is about 1 – 1.5% of the WTP flow
- Spent Filter Backwash Wastewater Solid: ~ 50 – 400 mg/L
- Ultimate thickened sludge solid: ~6%
- Vacuum Dewatered sludge: 42%

Mechanical Gravity Thickening

- Commonly used for typical WTP and softening plants
- With proper operation solid of thicken sludge can be ~ 2 – 6% for alum sludge and ~ 30% for softening sludge





Sludge Lagoon

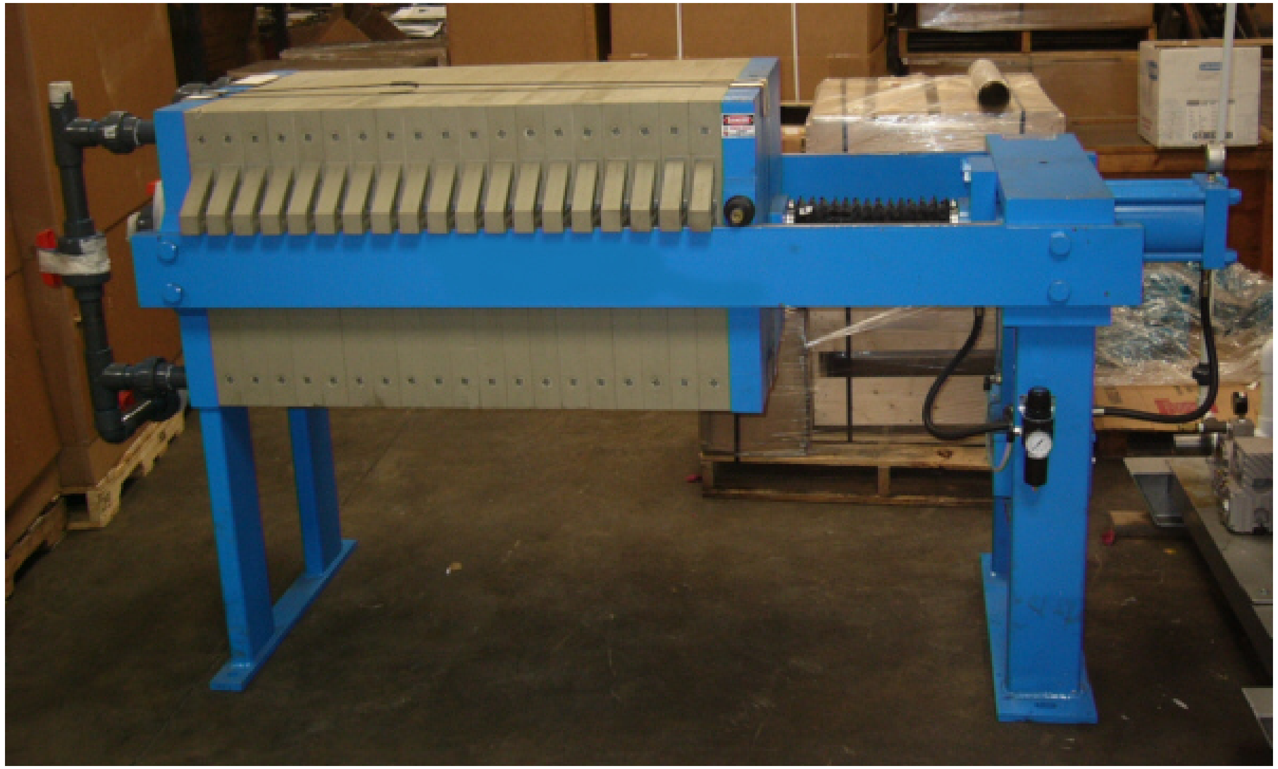
- Non-chemical, conventional and typical sludge thickening process
- Cost effective for sludge thickening, drying and storage, if land is available
- Solid can be increased to 30 – 50%, depending on the types of solids
  - Usually ~ 3 months for filling and another 3 months for drying


Filtration Sludge Lagoon


Softening Sludge Lagoon

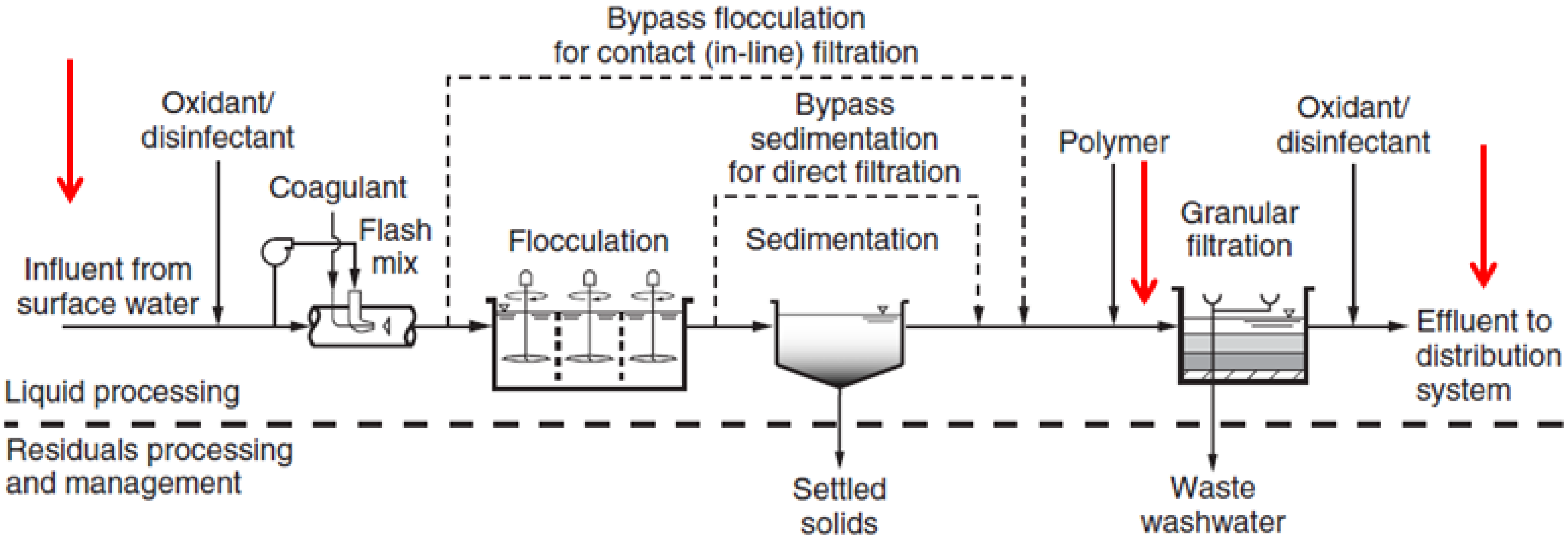
Plate & Frame Filter Press for WTP Sludge Dewatering

- Very commonly seen in small & medium size WTP
- Sludge filled between plates
- Filter cloths attached to each plate
- Plates got pressurized hydraulically to “squeeze” out water from the sludge
- Can achieve 30 – 40% of solids with lime/polymer conditioning



Purpose & Function of Various Disinfectant Injection Locations

- Intake line: To control on algae growth in the intake line & inside the plant
  - Gain extra CT credits
  - Will increase the formation of disinfection by-products (DBPs)
- Prior to granular filters: To control bio/algae growth inside the filters
  - Gain extra CT credits



Disinfection Byproducts

- Disinfection is an oxidation process and will break larger organic molecules (NOM) to smaller molecules, and react with the organics to form Disinfection Byproducts (DBPs)
- DBPs are known carcinogens and are regulated by USEPA
- Regulated Disinfection Byproducts
  - Thihalomethanes (THM) USEPA Regulations: 80 ppb for TTHM
  - Haloacetic Acids (HAAs): 60 ppb for HAA5

TOC Removal Requirements

- TOC removal requirements for DBP control is based on water quality

Source Water TOC (mg/L)	Source Water Alkalinity (mg/L as CaCO3)		
	0 – 60	> 60 – 120	>120 [3]
> 2.0 – 4.0	35.0 %	25.0 %	15.0 %
> 4.0 – 8.0	45.0 %	35.0 %	25.0 %
> 8.0	50.0 %	40.0 %	30.0 %

CT Values Required for Cryptosporidium Inactivation with ClO2

TABLE IV.D–4.—CT VALUES FOR CRYPTOSPORIDIUM INACTIVATION BY CHLORINE DIOXIDE [1] (MG/L × MIN)

Log credit	Water temperature, °C										
	≤0.5	1	2	3	5	7	10	15	20	25	30
0.25	159	153	140	128	107	90	69	45	29	19	12
0.5	319	305	279	256	214	180	138	89	58	38	24
1.0	637	610	558	511	429	360	277	179	116	75	49
1.5	956	915	838	767	643	539	415	268	174	113	73
2.0	1275	1220	1117	1023	858	719	553	357	232	150	98
2.5	1594	1525	1396	1278	1072	899	691	447	289	188	122
3.0	1912	1830	1675	1534	1286	1079	830	536	347	226	147

UV Disinfection for Cryptosporidium & Giardia

- UV is not very effective for viruses

TABLE IV.D–5.—UV DOSE REQUIREMENTS FOR CRYPTOSPORIDIUM, GIARDIA LAMBLIA, AND VIRUS INACTIVATION CREDIT

Log credit	Cryptosporidium UV dose (mJ/cm^2)	Giardia lamblia UV dose (mJ/cm^2)	Virus UV dose (mJ/cm^2)
0.5	1.6	1.5	39
1.0	2.5	2.1	58
1.5	3.9	3.0	79
2.0	5.8	5.2	100
2.5	8.5	7.7	121
3.0	12	11	143
3.5	15	15	163
4.0	22	22	186

Challenges with WaterVal Protocol for Reuse Applications

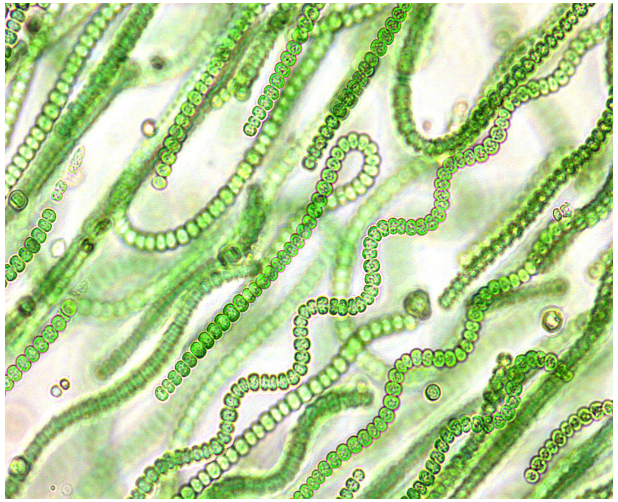
- Terms and conditions are not clearly defined
- Conditions (temperature, flux, HRT) may not be met at all time
- SRT and temperature relationship is missing

	MBR	RO	UVAOP	Free Chlorine	Total	Minimum LRV for GWR via Injection
Cryptosporidium	2	1.5-2	6	0	9.5-10	10
Giardia	2	1.5-2	6	0	9.5-10	10
Virus	1.5	1.5-2	6	5	14-14.5	12

Algae Induced T&O and Algal Toxins

$$\text{TON} = \frac{(\text{Sample Volume} + \text{Dilution Water Volume})}{\text{Sample Volume}}$$

- **TON is a dilution number**
- Usually only one analyst performs the test
- EPA Secondary Standard TON = 3
- Current version published in 1965, 12th ed. *Standard Methods*



Typical Oxidation Process in Water Treatment

- Hydroxyl radical is the most powerful oxidant in common water treatment
- While ClO2 is a strong oxidant, it's application is limited to chlorite concentration limit in the fila finished water (1 ppm)

$$HO\bullet > O_3 > H_2O_2 > HOCl > ClO_2 > KMnO_4 > Cl_2 > O_2 \qquad (8\text{-}64)$$

Commonly Seen AOP Processes (in the order of commonality)

- UV + H2O2 (UV-Peroxide)
- Ozonation
- Ozone + Peroxide (PerOzone)
- UV + TiO2 Catalytic Oxidatiton
- Fenton’s Reactions
- UV/Chlorine AOP (fairly new)
- Electrode Oxidation (new to water treatment)

Liquid Oxygen (LOX) Tank for Ozone Generator

Note: While conventional disinfectant such as chlorine and chloramine are also oxidants, their oxidation power is not enough to oxidize organic synthetic chemicals

Concept of EE/O; Electrical Efficiency per Log Order Reduction (UV)

- 1 EE/O = 90% Reduction; 2 EE/O = 99% Reduction
- EE/O describe the required energy (in kWh) for 1-log reduction of contaminant for 1,000 US Gallon (3,785 L)

$$\mathrm{EE/O} = \frac{P \times t}{V \times \log\left(C_i/C_f\right)} \tag{8-129}$$

$$\mathrm{EE/O} = \frac{P}{Q \times \log\left(C_i/C_f\right)} \tag{8-130}$$

where EE/O = electrical efficiency per log order reduction, $\mathrm{kWh/m^3} = 3.785\ \mathrm{kWh}/10^3\ \mathrm{gal}$

P = lamp power output, kW

t = irradiation time, h

V = reactor volume, $\mathrm{m^3}$

C_i = initial concentration, mg/L

C_f = final concentration, mg/L

Q = water flow rate, $\mathrm{m^3/h}$

UV Lamp Output will reduce over time

AOP Will Generate “Food” for Biological Growth

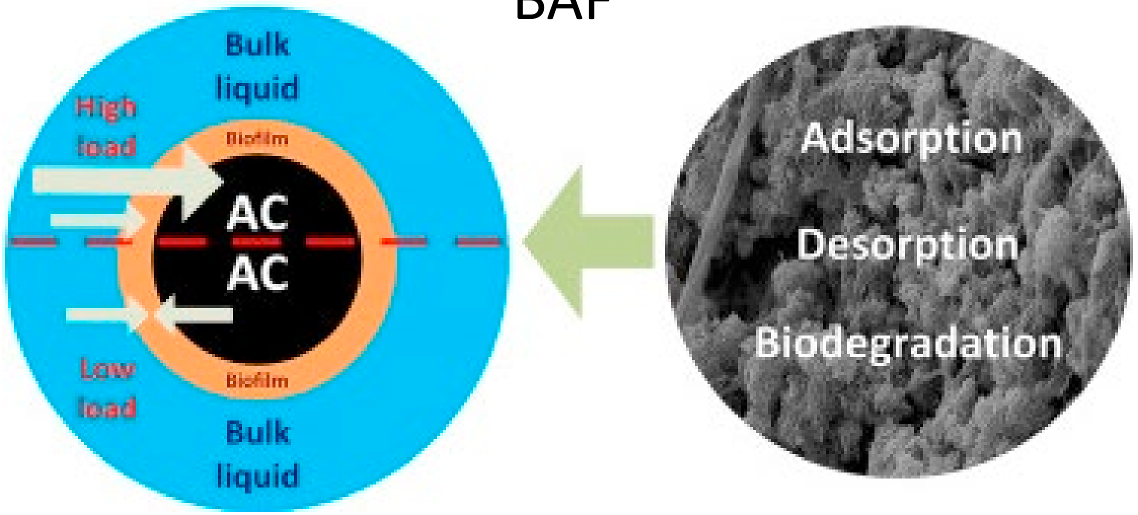
- Produce oxidation by-products that can be assimilated by microbes
  - Assailable Organic Carbon (AOC) or Bio-Degradable Organic Carbon (BDOC)
    - Present in micrograms per litter (μg/L)
    - Causing excessive biological growth in the distribution system

- Usually require additional treatment processes to remove these small organic molecules
    - Using Biologically Active Filters (BAF) downstream is a common practice, which requires substantial experience in design and operation to maintain a healthy BAF

Biologically Active Filter (BAF)

- Use GAC or Anthracite to serve as breeding ground for biofilms
- GAC can adsorb contaminants and incur a high surface concentration of contaminants
- Bacteria grow on the surface of subtracts and utilize adsorbed contaminants as food source
- BAF requires special system design and operation/maintenance in order to maintain proper performance

BAF



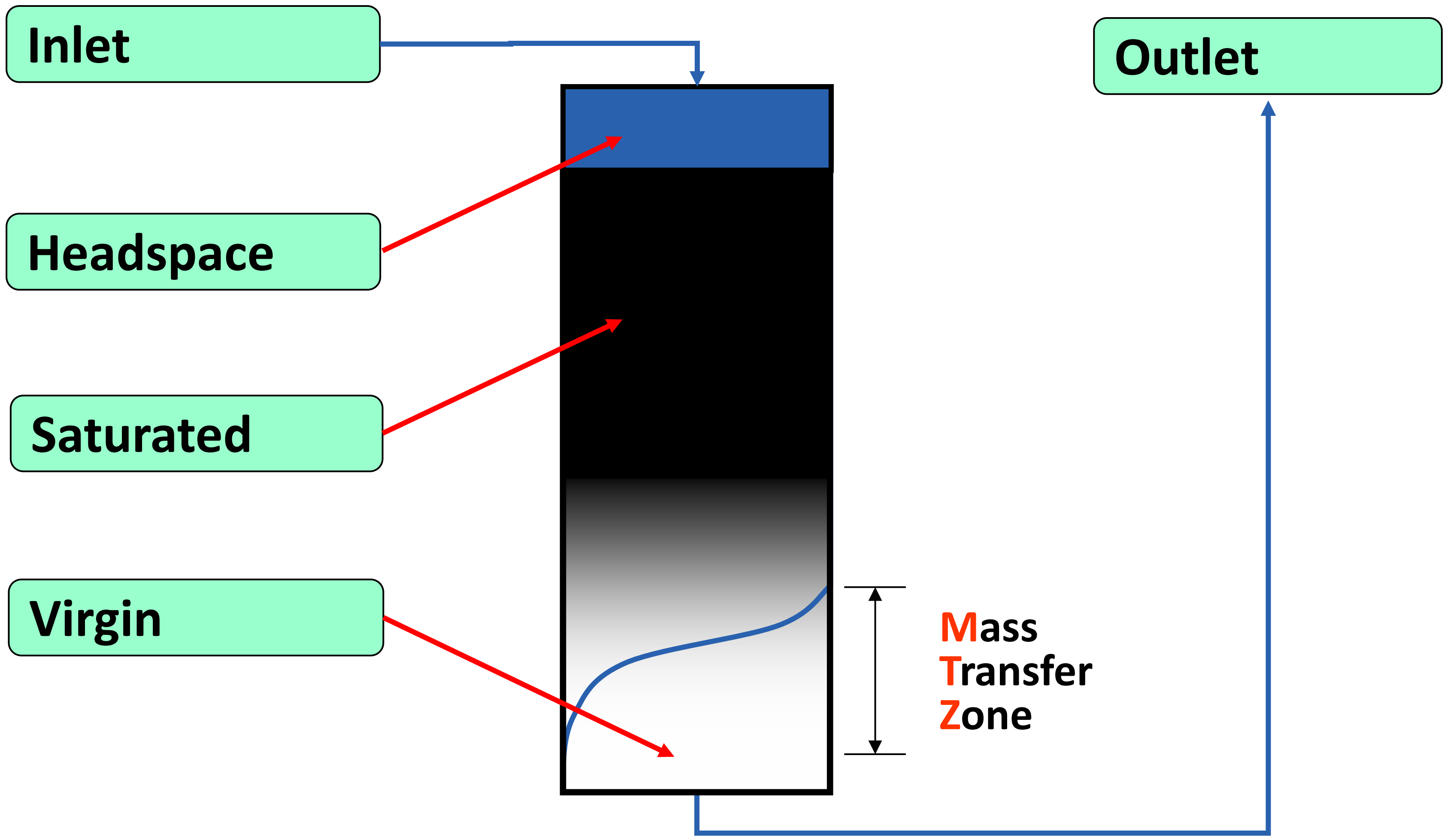
Design Considerations for a Biological Filter

- Select proper filter media, either GAC or Anthracite (maximizing surface area for biological growth
- Potential nutrient feeding system (e.g., acetic acid) for low organic season to maintain biological activity
- Occasional backwashing with low-Cl concentration to control excessive bio growth
- Proper underdrain design to avoid clogging by sloughed-off biomass
- Filter media sampling for occasional microbial speciation

Class #24: Adsorption (GAC)

- Drinking Water
  - Taste & Odor
  - Halogenated organics & their precursors (NOM & disinfection byproducts)
  - Groundwater treatment for VOC or other organic contaminants
- Industrial Applications
  - Toxic organic compounds
  - Color removal
- Polishing of treated municipal wastewater (for reuse applications)

Down Flow Adsorption Breakthrough



Design Considerations

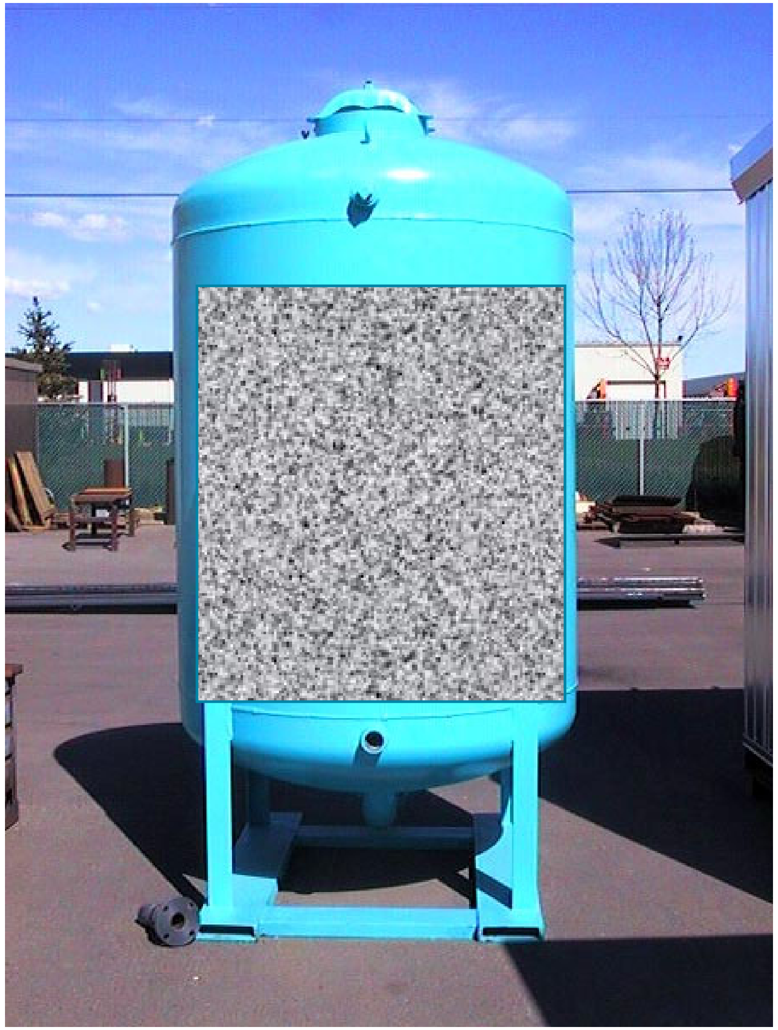
- Bench Scale Rapid Small Scale Colum Testing (RSSCT)
  - Days to breakthrough
  - Require good knowledge and hands-on skills to construct RSSCT columns and conduct testing procedure properly
- Pilot Testing
  - Months to breakthrough
  - Hard to mimic actual plant operating condition
    - Flowrate varies depending on water demand
    - Synchronizing pilot flowrate requires additional planning and control instrumentation
    - Data interpretation could be a challenge
- GAC Adsorption Breakthrough Monitoring

Empty Bed Contact Time (EBCT)

- **Empty Bed Contact Time** (EBCT) A measure of the **time** during which a water to be treated is in **contact** with the treatment medium in a **contact** vessel, assuming that all liquid passes through the vessel at the same velocity.
- EBCT is equal to the volume of the **empty bed** divided by the flow rate.

  EBCT = V $(m^3)/(m^3/min)$, or
  EBCT = V (gal)/(gal/min)

- V (entire bed volume) includes the volume of media and void space in the bed



Typical GAC System Design

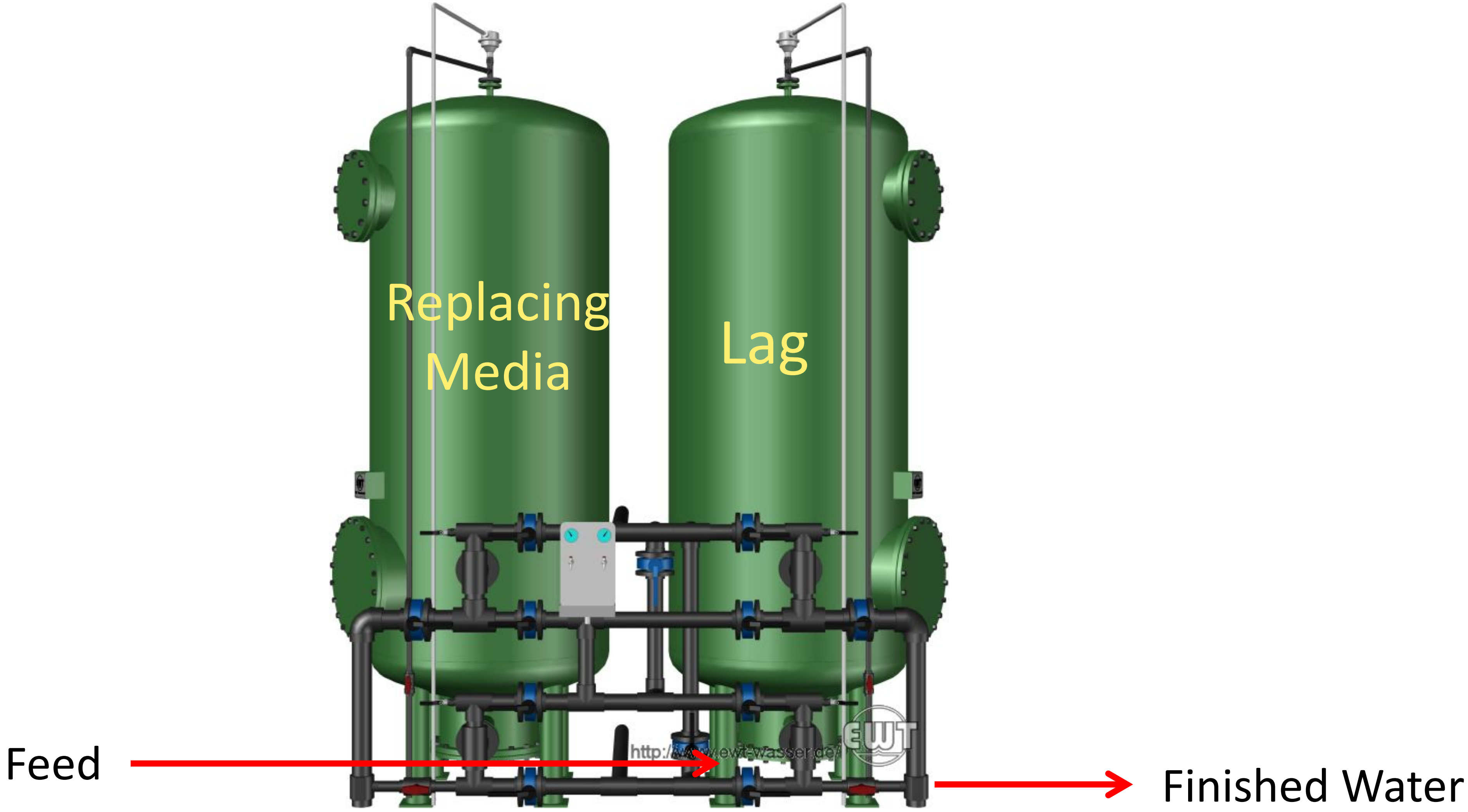
- Loading rate at 1.5 – 3.5 L/s-m^2
- Lead-Lag Operation
- Empty Bed Contact Time (EBCT): 10 – 15 min (prefer 15 min)
  - Ensure adequate reaction time for adsorption to take place (allow time for solutes to migrate further into the micro pores and be adsorbed
  - Need to balance performance with costs
- PAC is usually dosed in with coagulants in conventional WTP
  - Particles containing PAC are much heavier and tend to settle much faster
  - There will be carried over PAC and will be captured by downstream filtration process (impact of membranes?)

GAC Lead-Lag Operation: Normal Operation

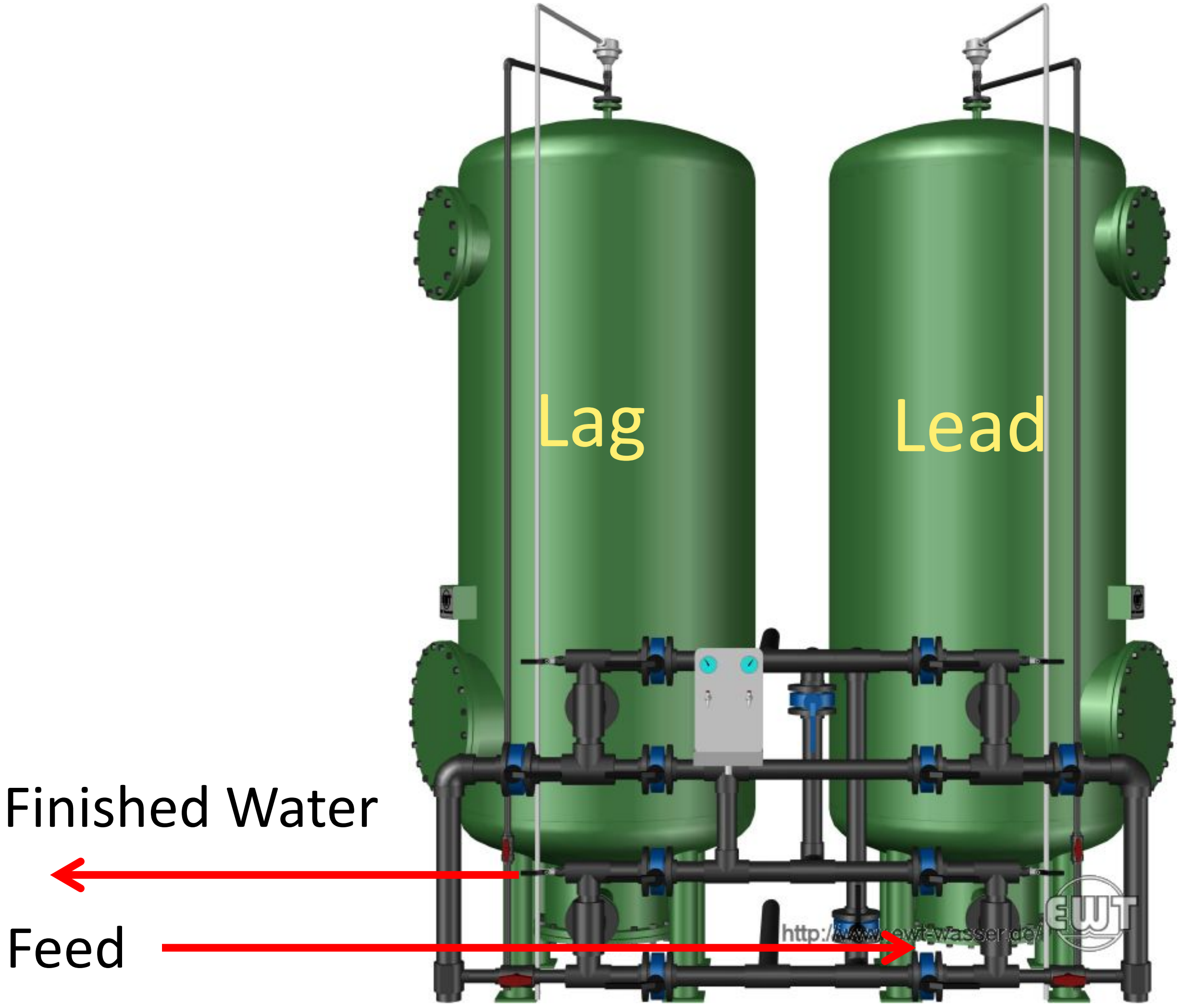
Feed

Finished Water

GAC Lead-Lag Operation: Media Replacement



GAC Lead-Lag Operation: Reverse Lead-Lag



GAC System Design Considerations: Selecting the Right GAC

- Not all GAC are created the same
  - Coal based vs. Coconut Shell based
  - Adsorption Isotherm only tells you the equilibrium concentration, not the useful life of GAC
  - Pilot Testing is recommended (3 – 6 months)
  - Adsorption Capacity for specific compounds varies and it could vary from batch to batch
- Use Performance Based Criteria for selecting the right GAC, rather than just based on costs
- Consider the need for on-site backwashing GAC prior to first use
  - How to get rid of the backwash wastewater that might contain arsenic, heavy metals, particulates, etc.
- Consider water production at WTP varies from season to season; how to maintain adequate EBCT for GAC

A Few Words for IXR

- The principal & design concept is very similar to GAC
- The major deviations are:
  - Select different types of IXR for specific ion removal
  - IXR can be regenerated onsite (vs. GAC needs to be reactivated off-site)
  - IXR regeneration brine needs to be disposed properly (usually discharge to sewer line)
  - IXR could remove trace radionuclides (such as uranium) unintentionally, which could turn the entire media bed into hazardous material)