Introduction to Phosphorus Removal

NEWEA 2019 Specialty Conference and Workshop Series: Perspectives on Phosphorus Removal in the Sudbury-Assabet-Concord Watershed

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Agenda

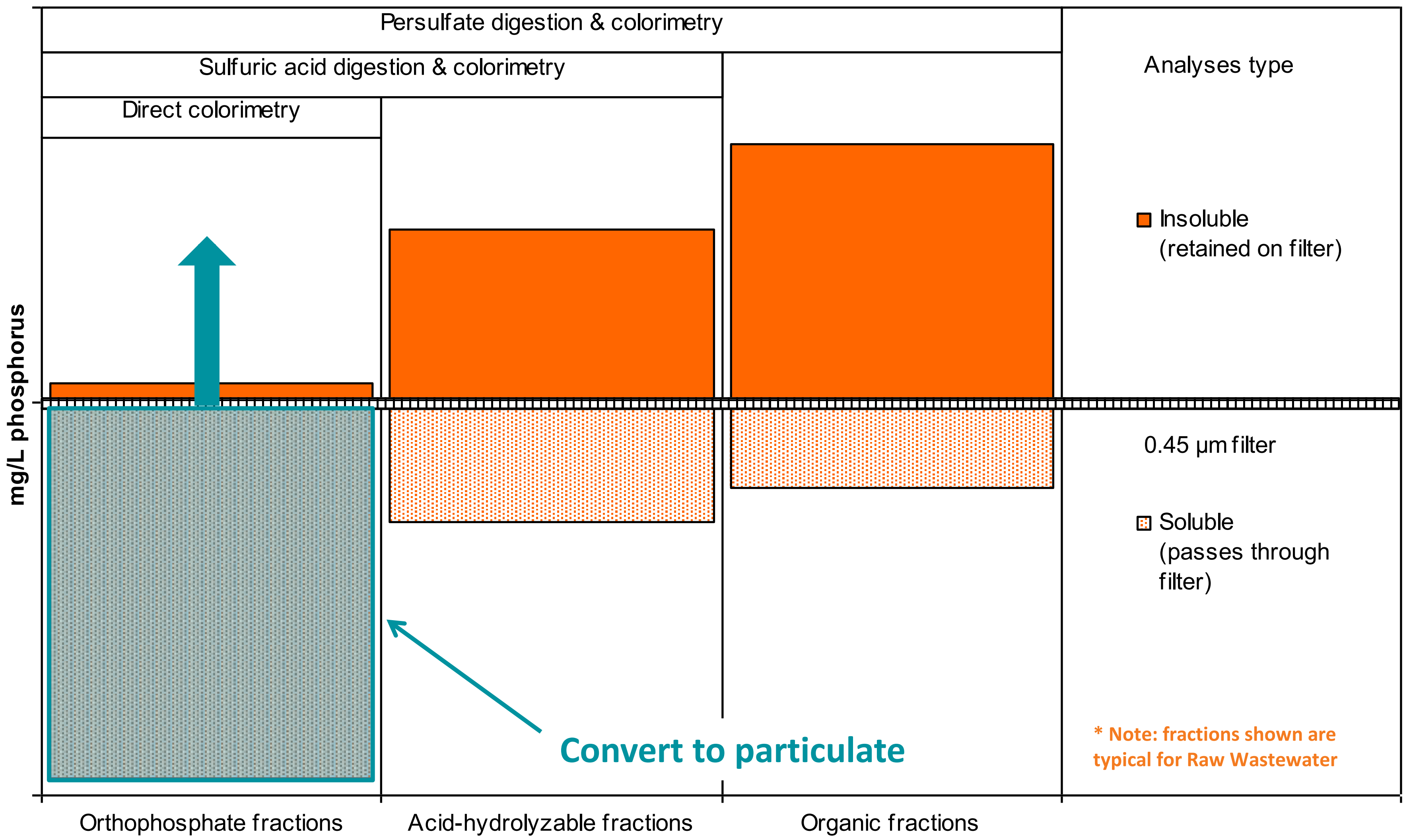
- Phosphorus Removal Overview
  - How Phosphorus Removal is Achieved
  - Biological Phosphorus Removal
  - Chemical Phosphorus Removal
- Technologies to Achieve TP < 0.2 mg/L
  - Add-on Processes
  - Integrated Processes
- Compliance Considerations for Achieving < 0.2 mg/L
  - Soluble Non-Reactive Phosphorus
  - Permit Reporting Methodologies
  - On-line Analyzers

Phosphorus Removal Overview

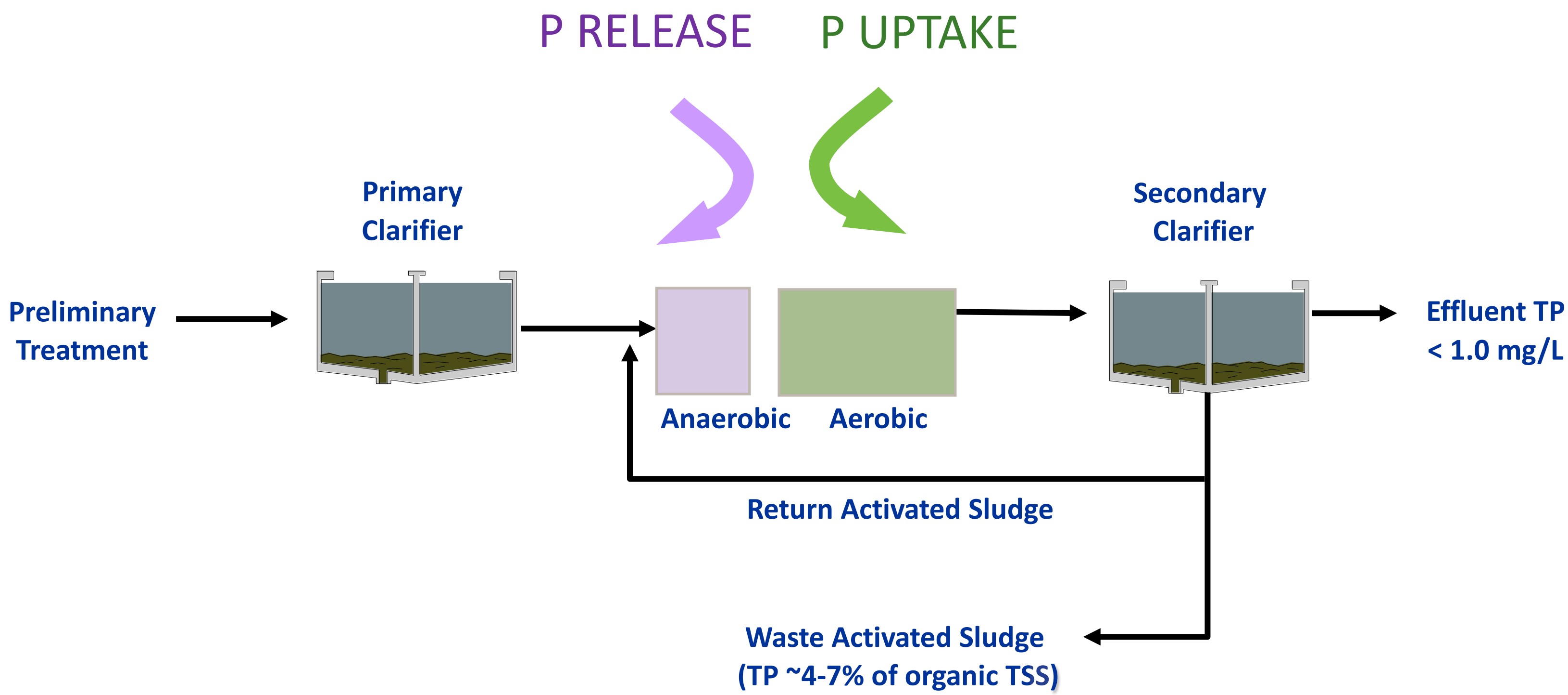
How is Phosphorus Removal Achieved?

- Convert soluble orthophosphates (reactive P) to a solid
- Remove solid
  - Biological solid (microorganism)
  - Chemical solid (precipitate and adsorbed)

Phosphorus Fractionation

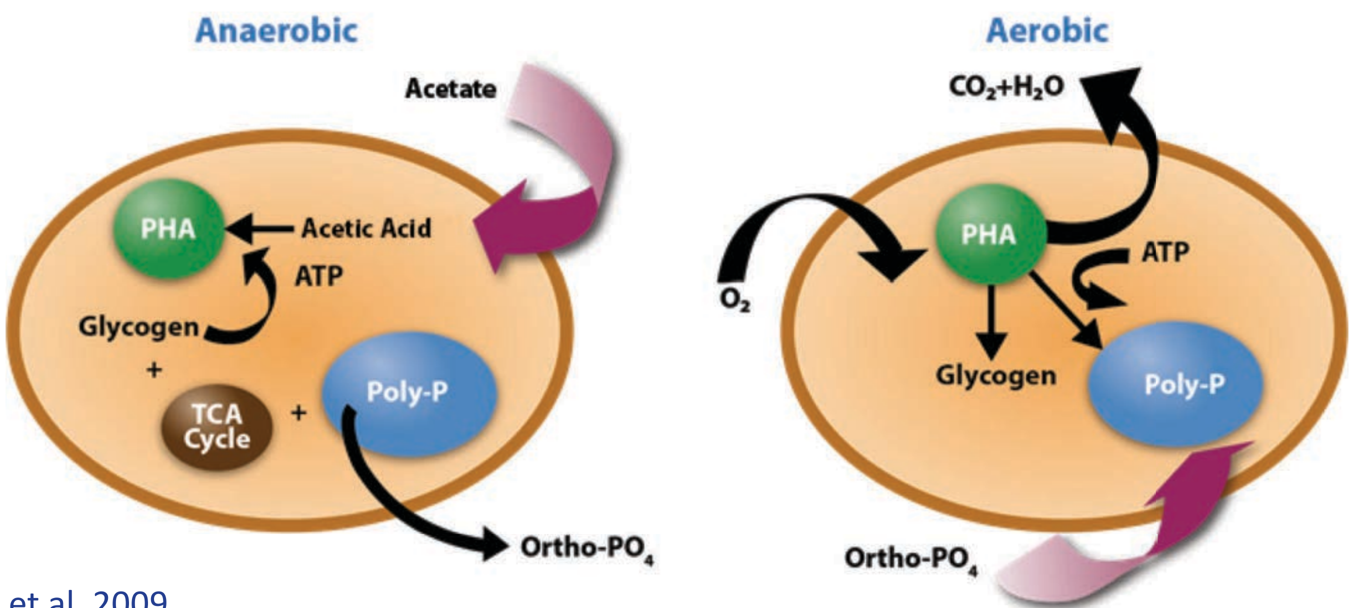


Biological Phosphorus Removal (EBPR)



*** Net reduction of P when phosphorus-rich sludge is removed in WAS**

Phosphate-accumulating Organisms (PAOs) Cycle between Anaerobic and Aerobic Conditions



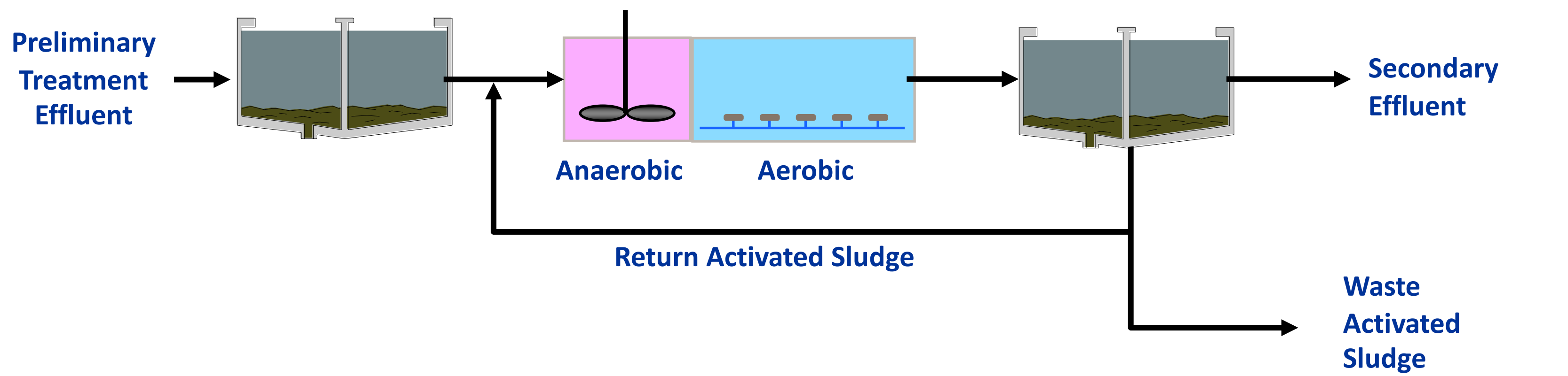
Forbes et al, 2009

Break polyphosphate bonds to take up and store carbon, as poly-β-hydroxyalkanoates (PHAs), and release P

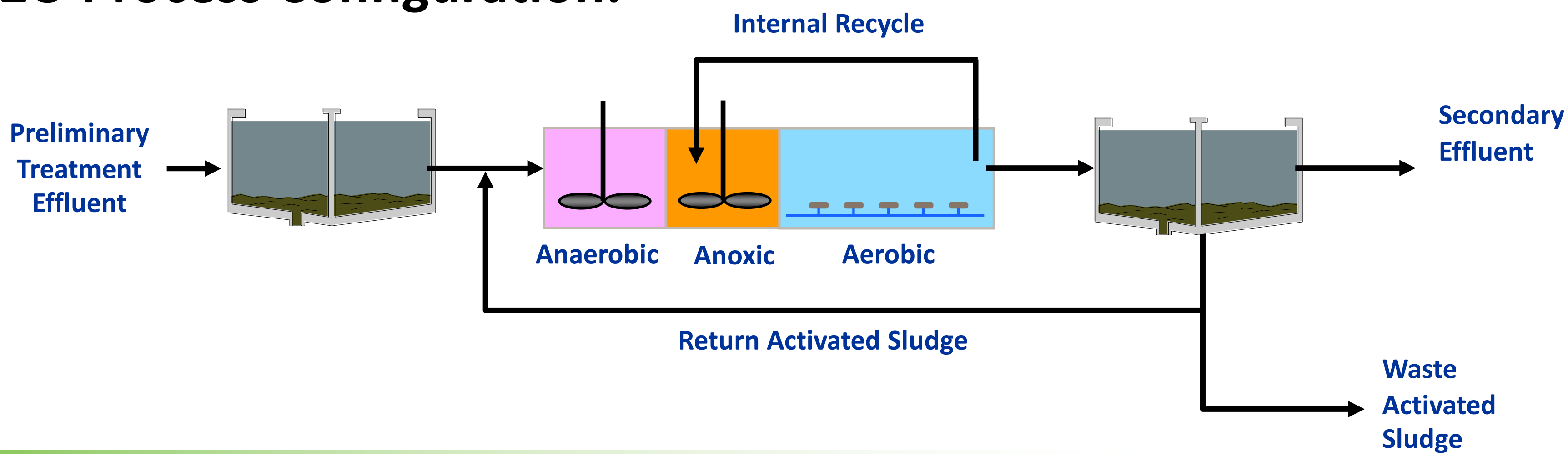
Use O_2 to break down stored carbon (PHAs) to take up large amounts of P, which is stored as polyphosphates, and cell growth

Example EBPR Process Configurations

AO Process Configuration:



A2O Process Configuration:



Challenges for Conventional EBPR Can Cause Process Instability

- Insufficient or inconsistent carbon (volatile fatty acids)
  - Try to overcome with fermentation to generate VFAs
- Too many Glycogen Accumulating Organisms (GAOs)
  - Outcompete PAOs for carbon
- Inadequate anaerobic conditions
  - Too much DO or NO_x in anaerobic zone
- General process instability
  - Maintaining consistent SRT and pH is beneficial

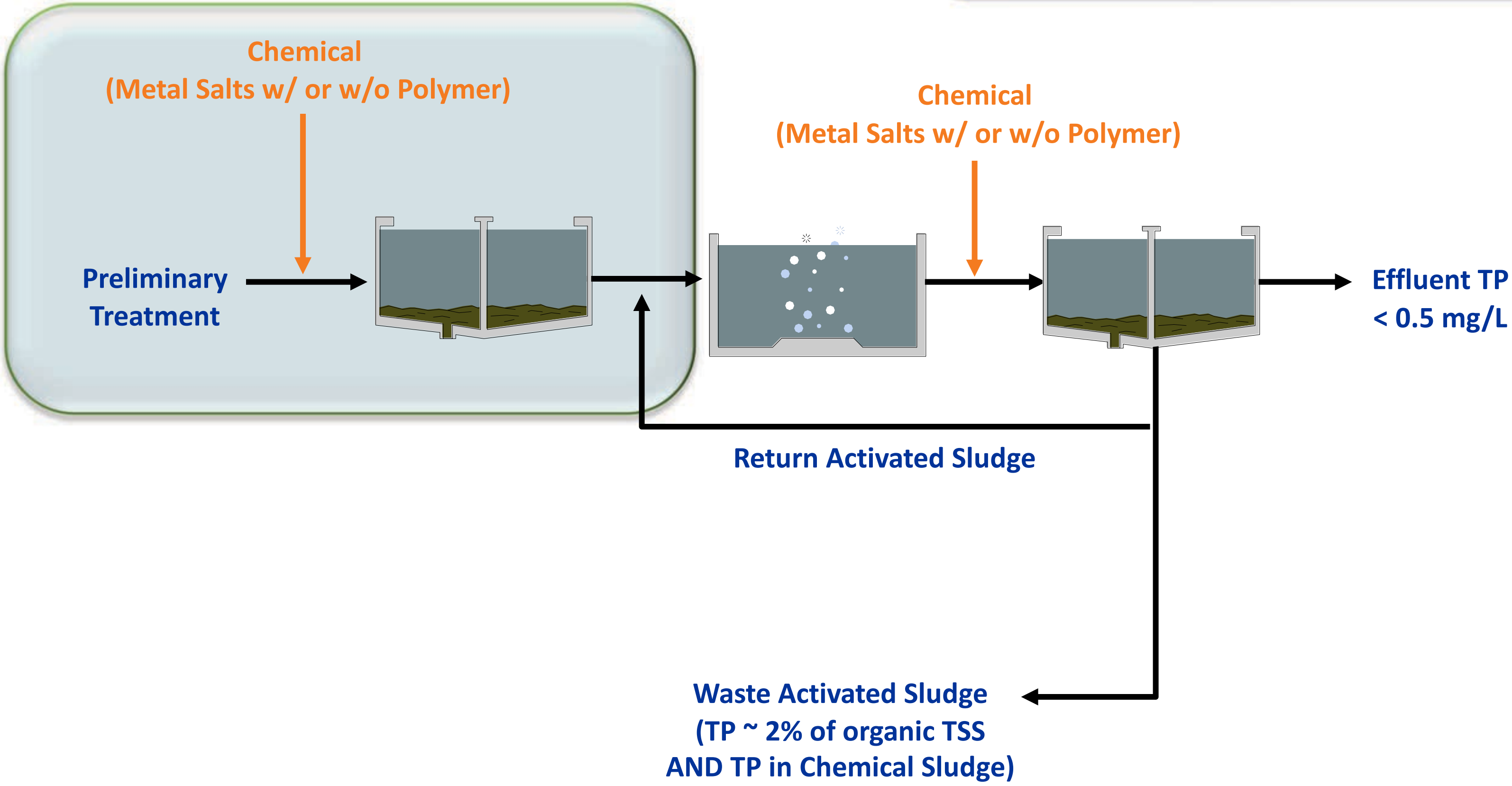
Pros and Cons of Conventional EBPR

- **Pros**
  - Sustainable treatment process
  - Low O&M costs
  - No chemical storage and feed systems
  - Less sludge production
  - Anaerobic selector provides improved sludge settleability
- **Cons**
  - Cannot achieve lower P limits (only 0.75 to 1 mg/L)
  - Phosphorus re-release
  - Subject to upsets and instability (like any biological process)

Chemical Phosphorus Removal

Chemically Enhanced Primary Treatment (CEPT)

Dual Point is more efficient than single point addition



Chemicals (Metal Salt Coagulants) Used for Phosphorus Removal

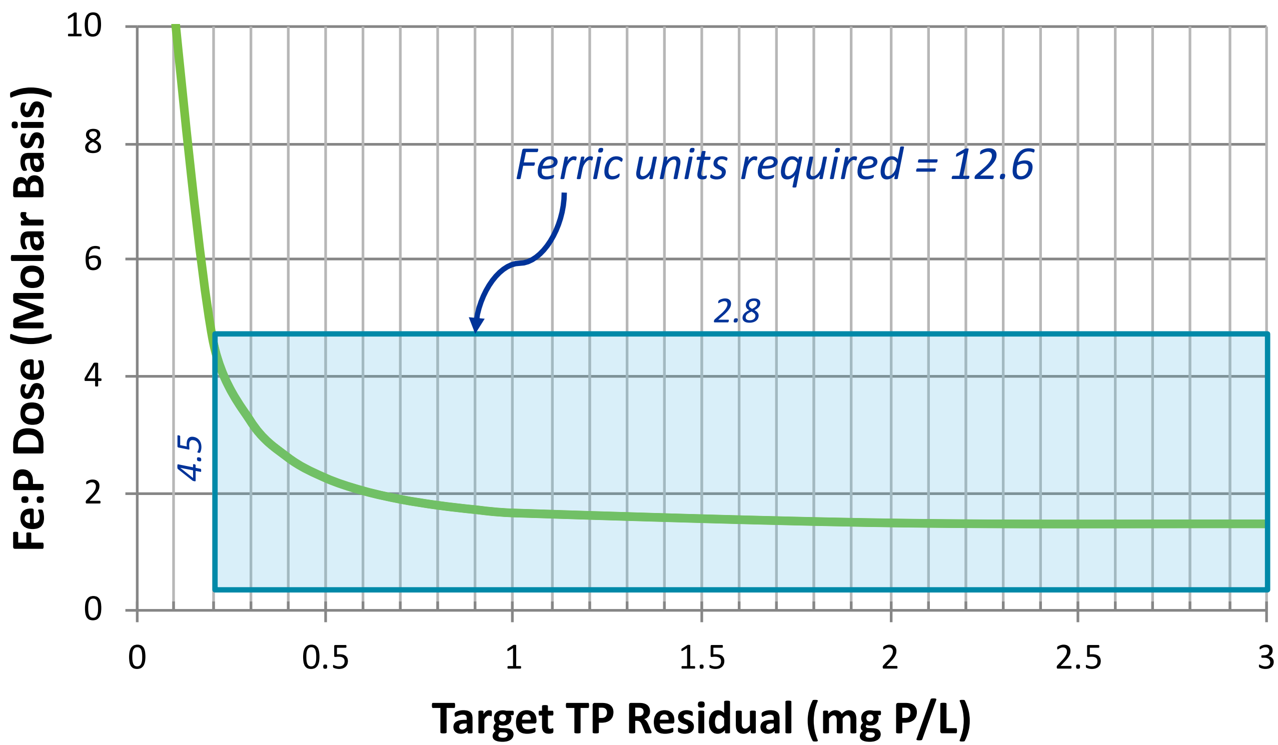
- Iron Salts
  - Ferric Chloride
  - Ferrous Sulfate
- Aluminum Salts
  - Alum (Aluminum Sulfate)
  - Poly Aluminum Chloride (PACl)
  - Aluminum Chloride Hydrate (ACH)
- Calcium Compounds
  - Quick Lime
  - Hydrated Lime
- Rare Earth Salts, e.g. RE-100 or Cerium Chloride

Chemical Phosphorus Removal Considerations

- Precipitation and adsorption of phosphorus occurring with most metal salt coagulants
  - Surface chemistry
- Cerium (rare earth metal) forms a crystalline solid precipitate with phosphorus
  - Forms strong ionic bonds
- Dual point chemical addition more efficient than single point
- Chemicals added will consume alkalinity and drop pH, potentially requiring alkalinity adjustment

Single Point Ferric Chloride Addition

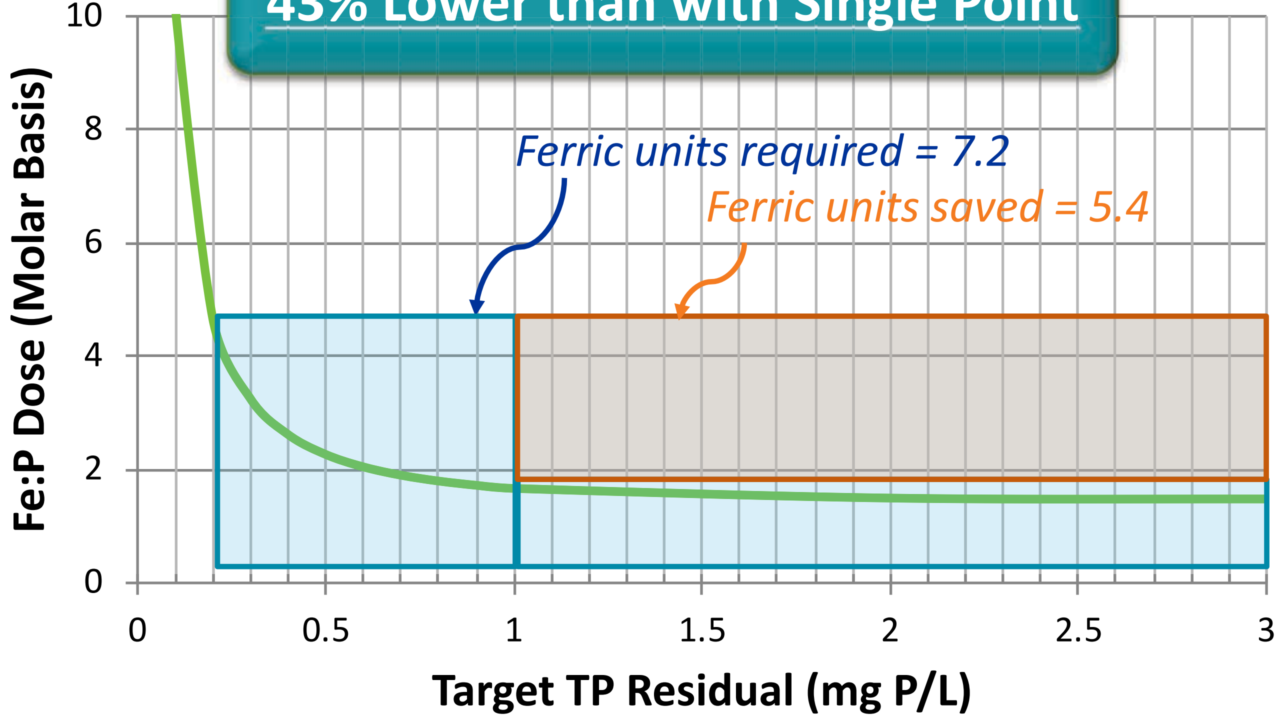
- 3 mg/L TP to 0.2 mg/L TP
- Fe:P dose required ~ 4.5 (molar basis)
- Total Fe "units" required = 4.5 x 2.8 = 12.6



Dual Point Ferric Chloride Addition

- 3 mg/L TP to 1 mg/L TP
  - Fe:P dose ~ 1.8 (molar basis)
  - Total Fe "units" ~ 3.6
- 1 mg/L TP to 0.2 mg/L TP
  - Fe:P dose ~ 4.5 (molar basis)
  - Total Fe "units" ~ 3.6

43% Lower than with Single Point



Pros and Cons of Chemical Phosphorus Removal

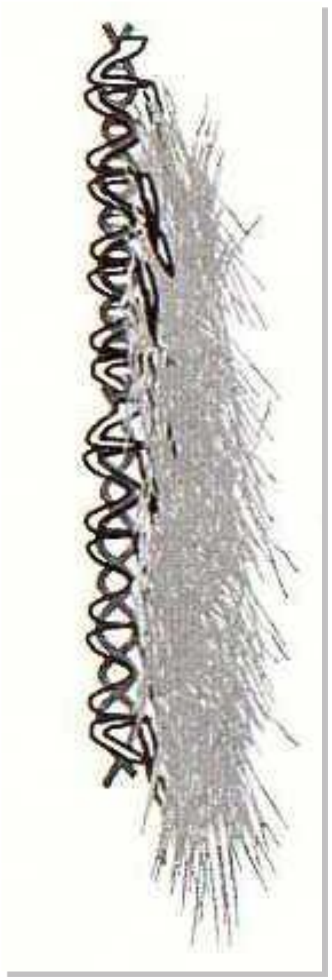
- **Pros**
  - Can achieve < 0.5 mg/L on its own
  - More consistent process
  - No phosphorus re-release
- **Cons**
  - High O&M Cost
  - Increased sludge production and associated disposal costs
  - Sludge more difficult to thicken and dewater
  - Additional chemicals for alkalinity control
  - Not as sustainable

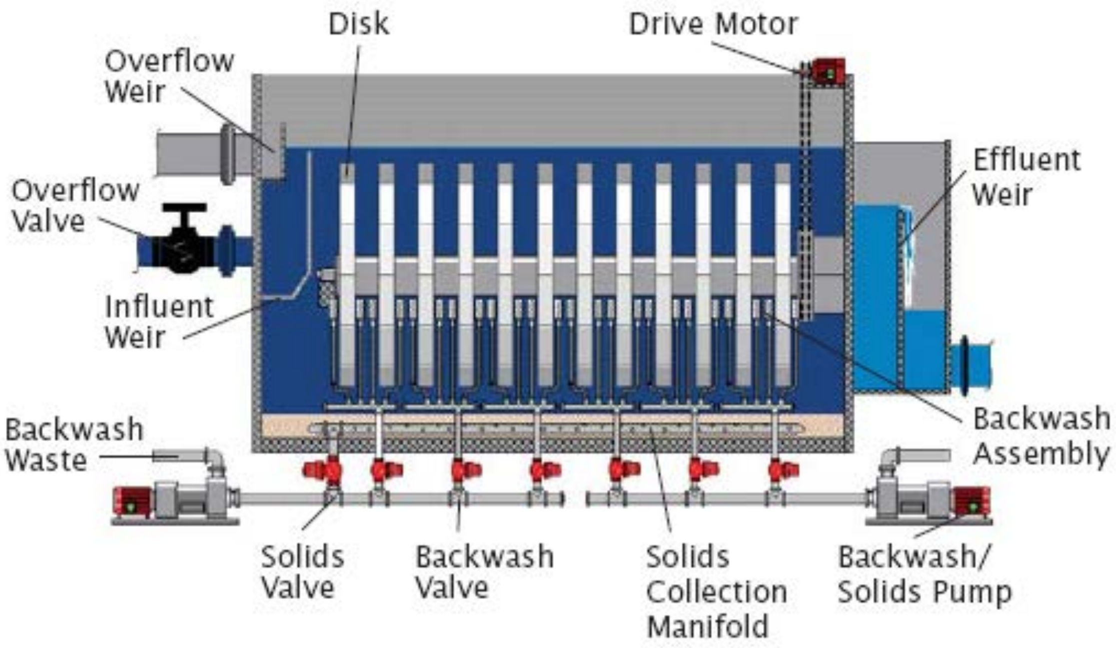
Technologies to Achieve TP < 0.2 mg/L

Physical/Chemical Processes to Achieve Low TP Limits (0.2 mg/L or less)

- Add-On Processes
  - Filtration
    - Cloth media filters
    - Continuous upflow filters
    - Compressible media filters
    - Membranes
  - Ballasted Flocculation
    - ACTIFLO®
    - CoMag®
  - High Rate Clarifier
    - DensaDeg®
    - AquaDAF®
- Integrated Processes
  - BioMag®
  - Membrane Bioreactors (MBRs)
- Other
  - Algae Treatment

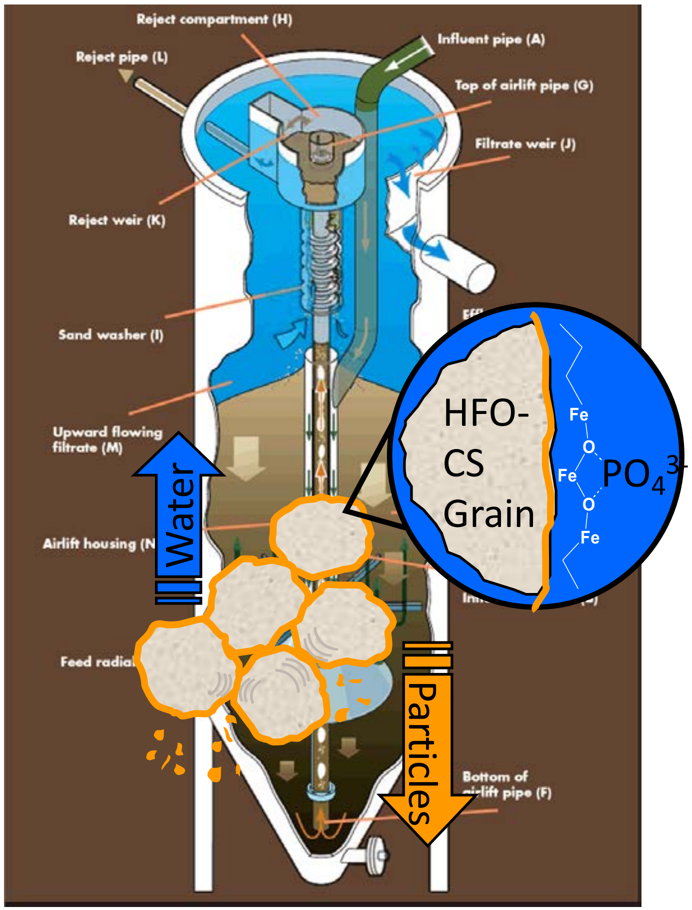
Filtration – Cloth Media



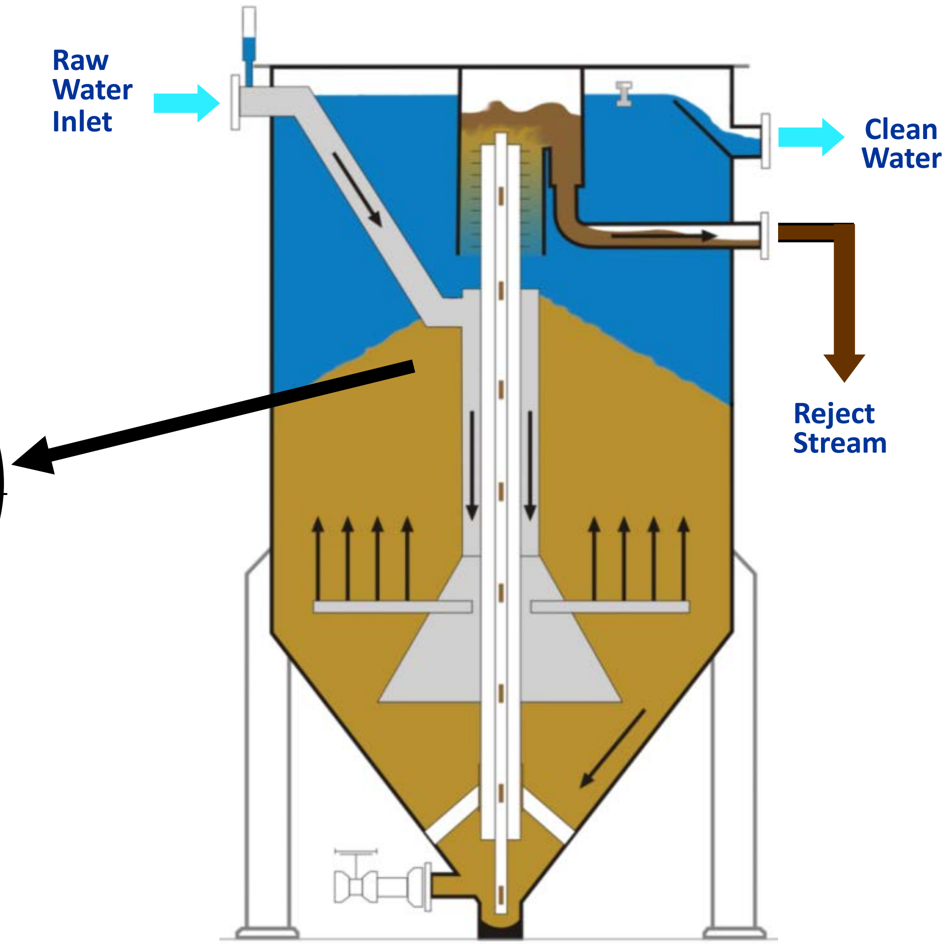


- Aqua-Aerobic Systems system depicted
- Other manufacturers include Kruger and Evoqua

Filtration – Continuous Upflow Sand (Marlborough Westerly)



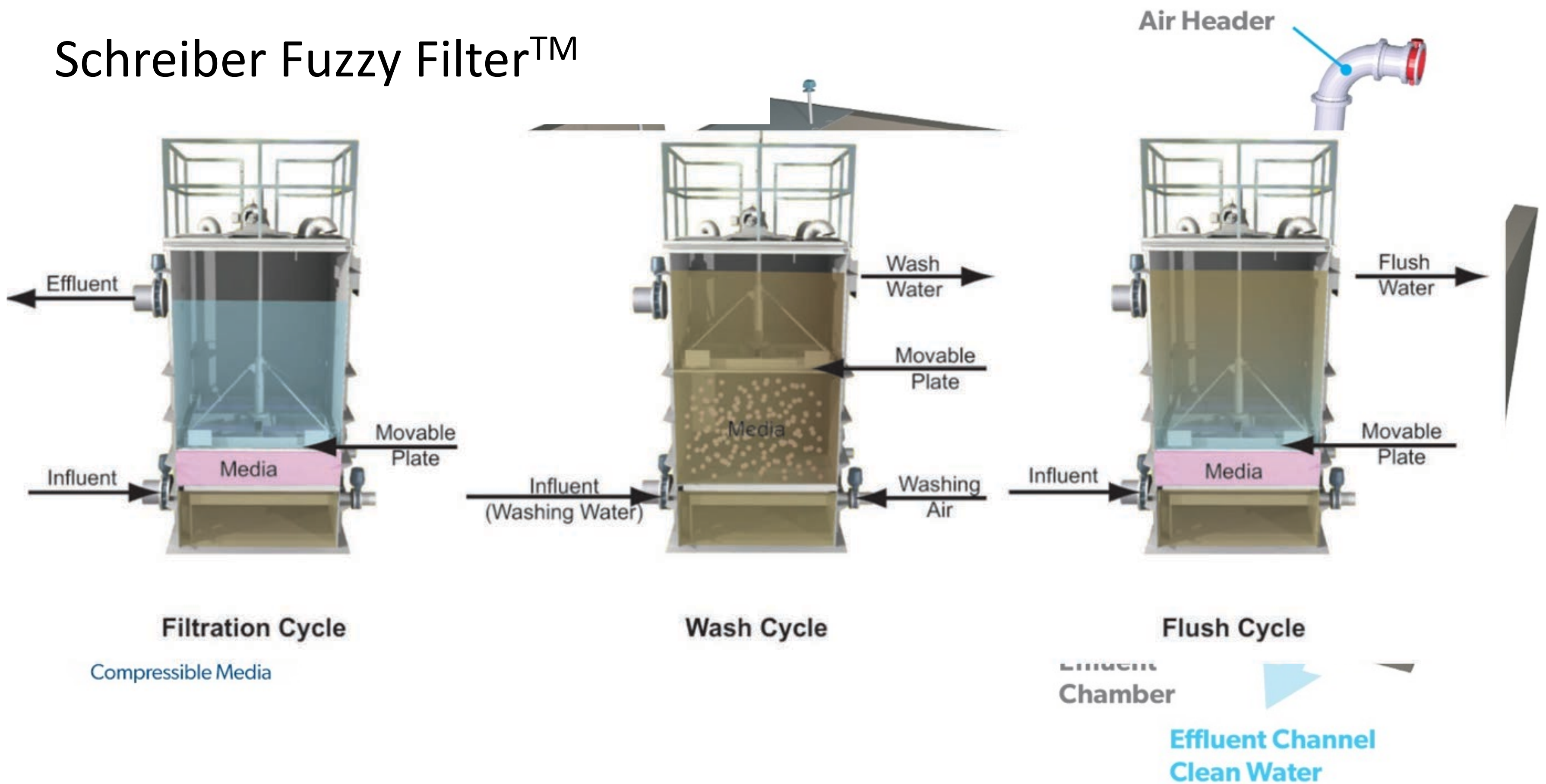
Parkson Dynasand



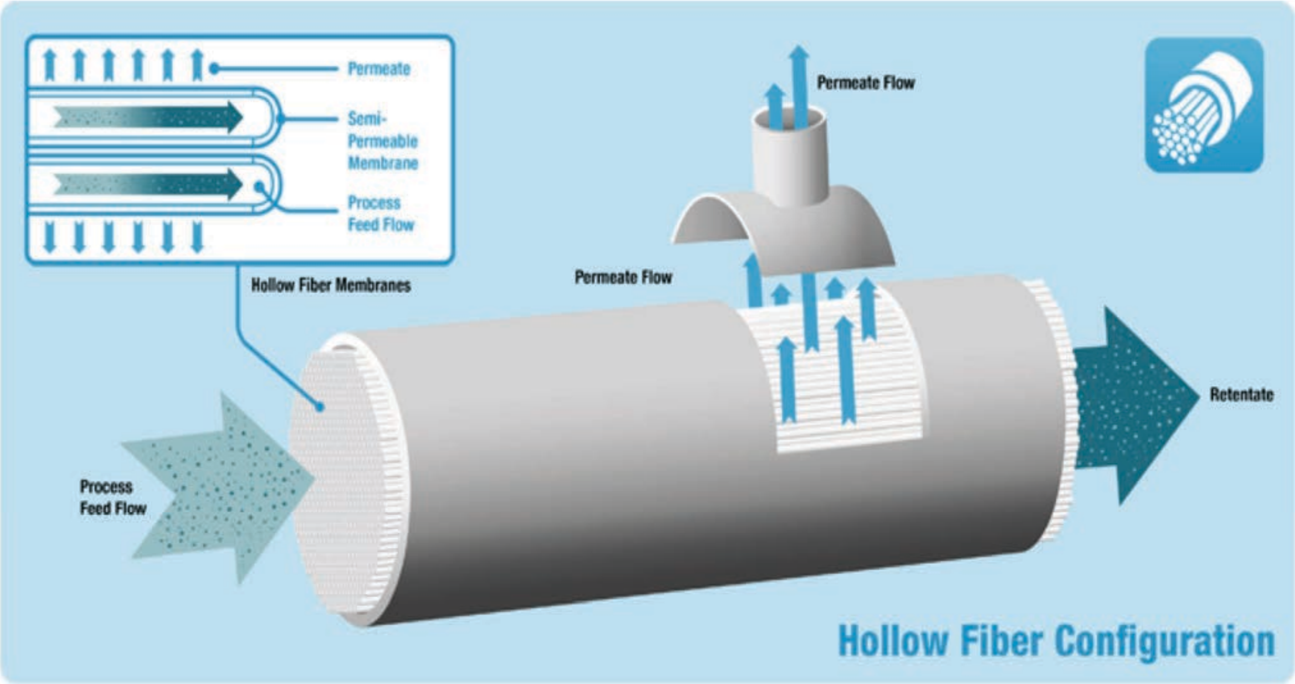
Nexom Blue PRO®

Filtration – Compressible Media

Schreiber Fuzzy Filter™

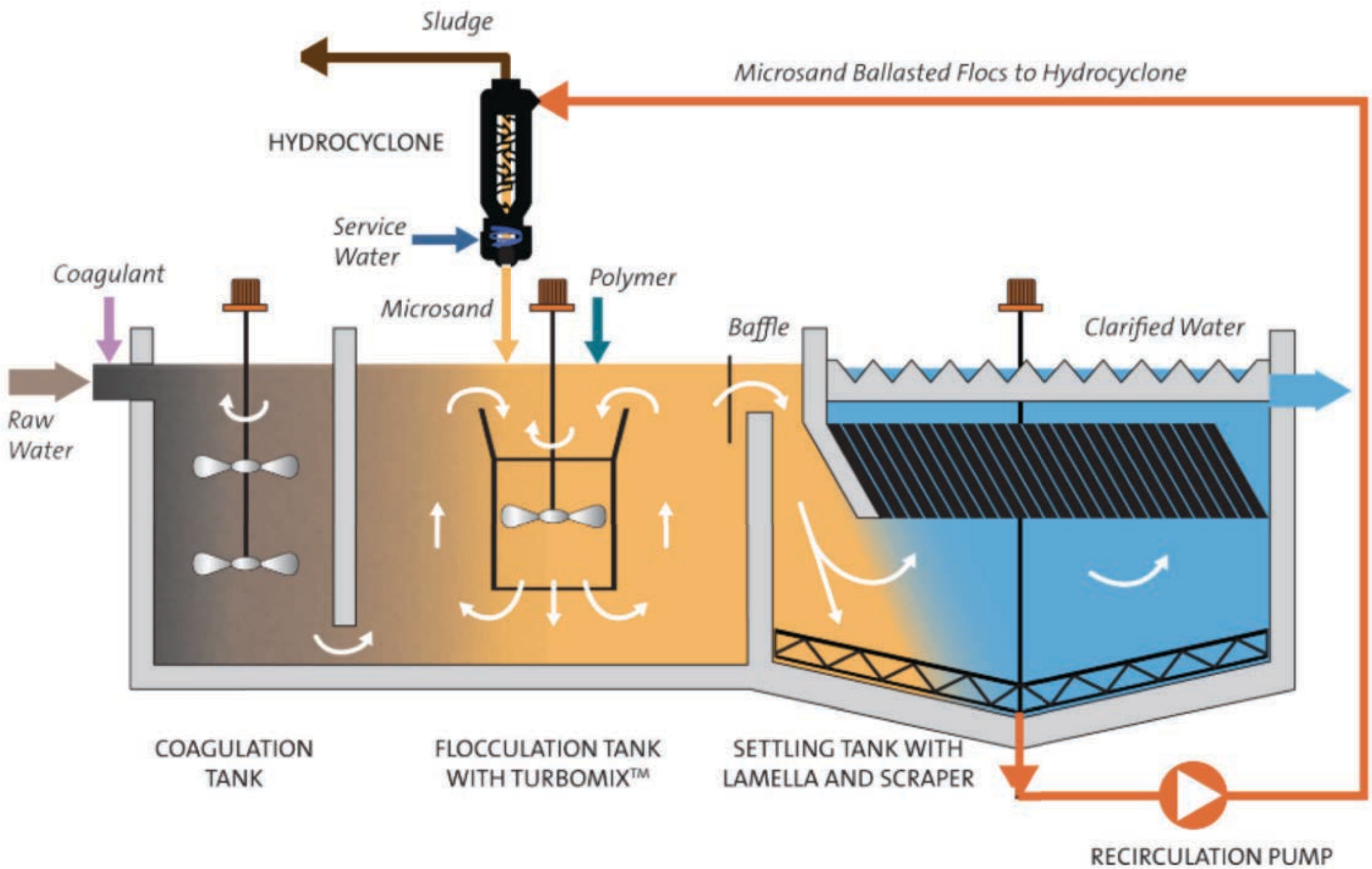


Filtration – Membranes

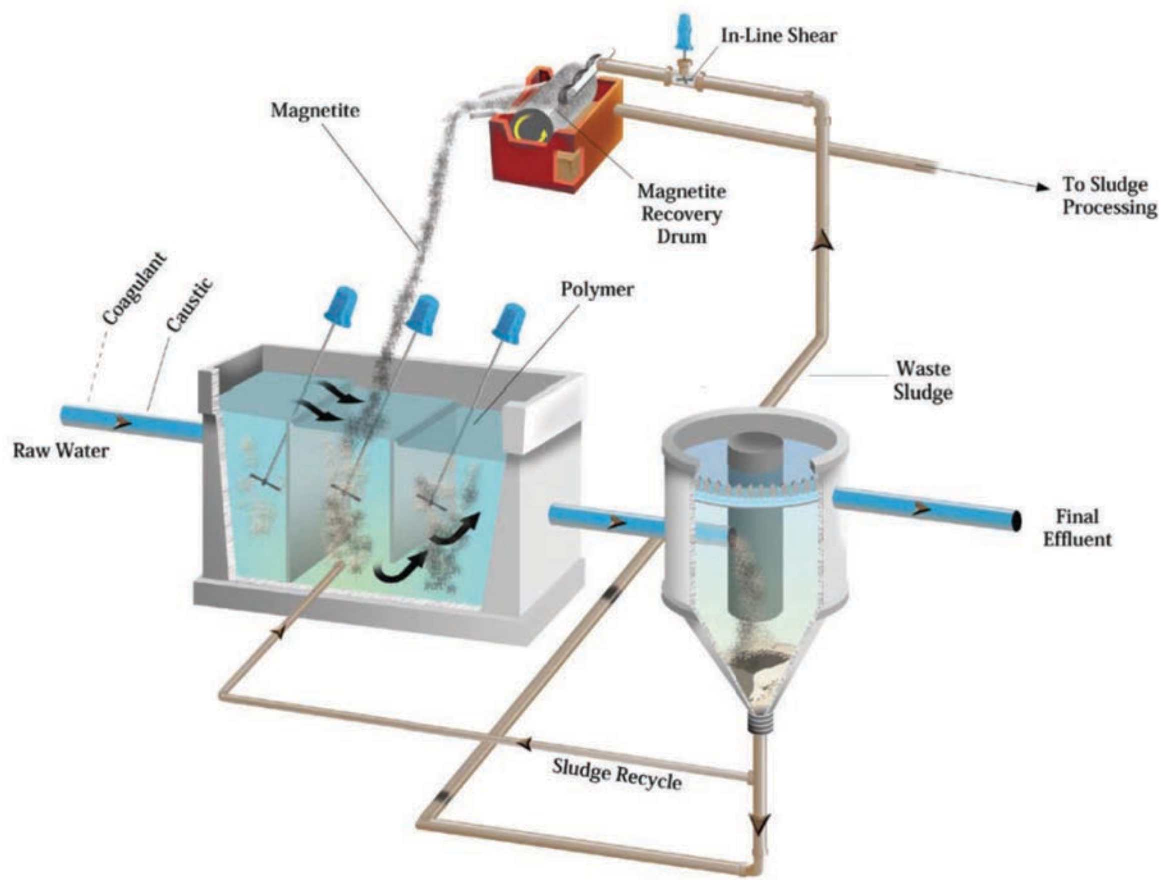


- Hollow fiber Microfiltration
  - Fibers have an inside diameter ranging from 0.4 to 1.0 mm and a wall thickness ranging from 0.07 to 0.6 mm
  - Evoqua, Suez Water, Pall Water

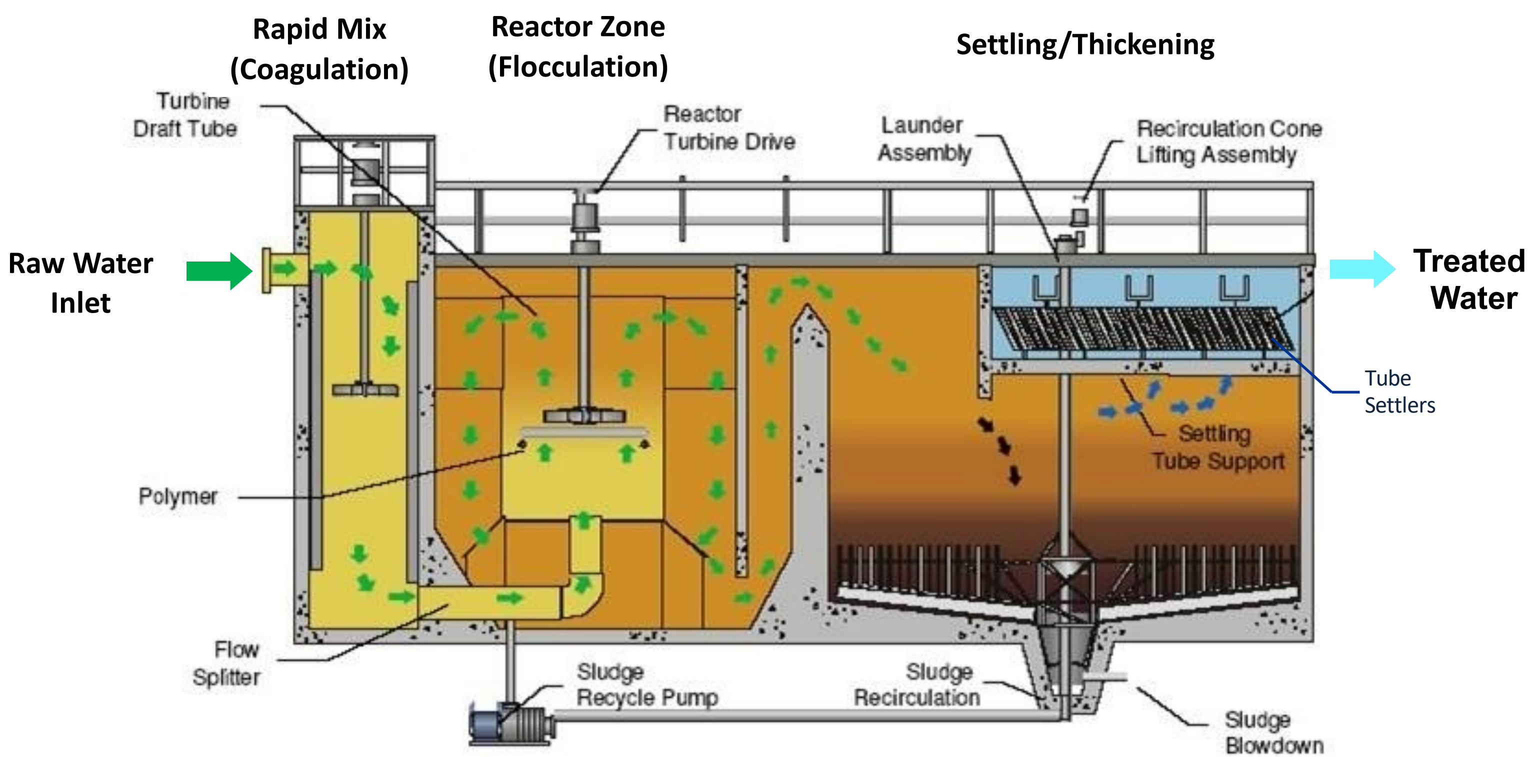
Ballasted Flocculation – Kruger ACTIFLO® (Westborough)



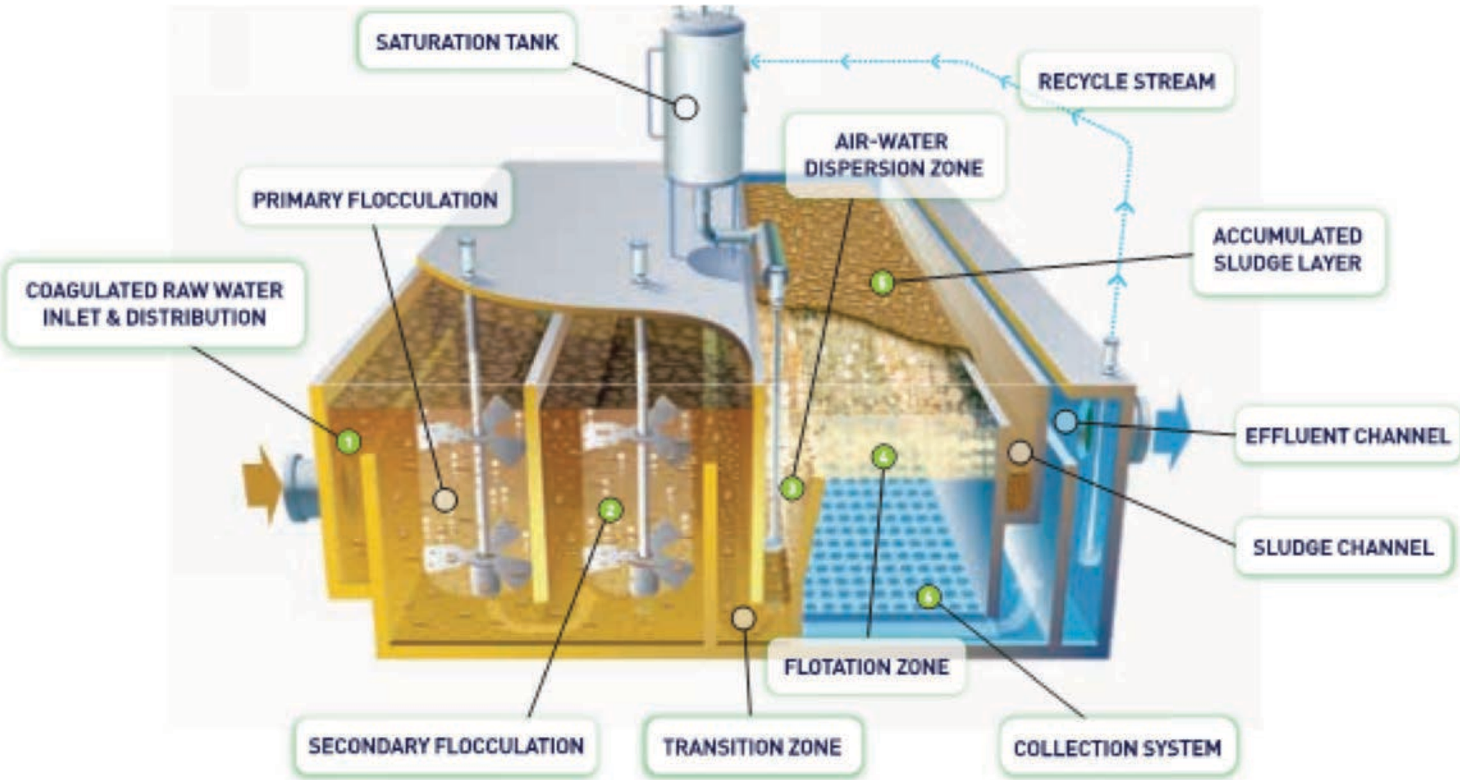
Ballasted Flocculation – Evoqua CoMag®
(Concord, Billerica and Maynard)



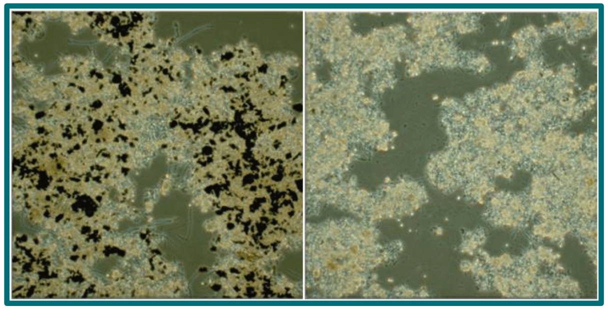
High Rate Clarifier – Suez Water DensaDeg®

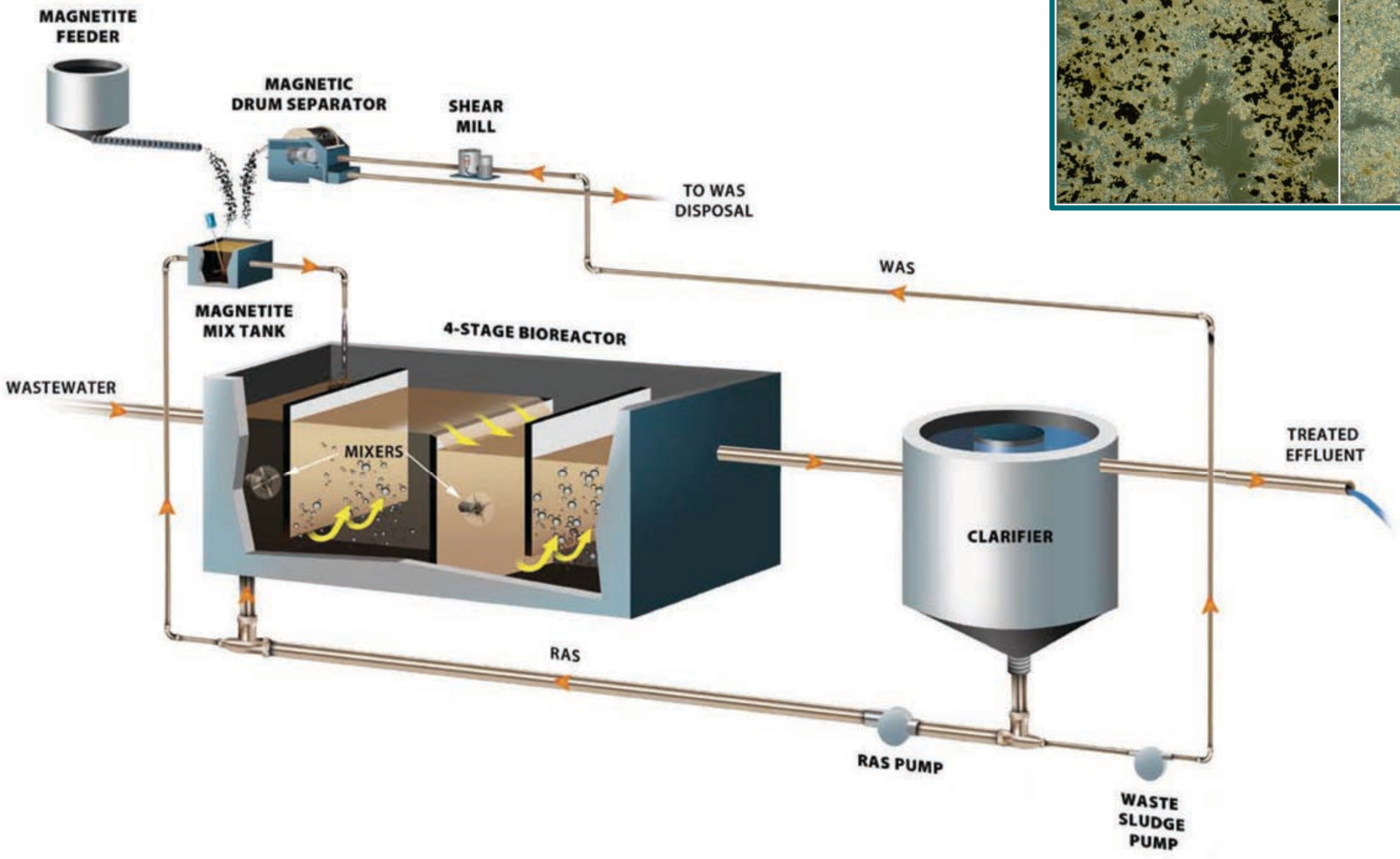


High Rate Clarifier – Suez Water AquaDAF® (Hudson)

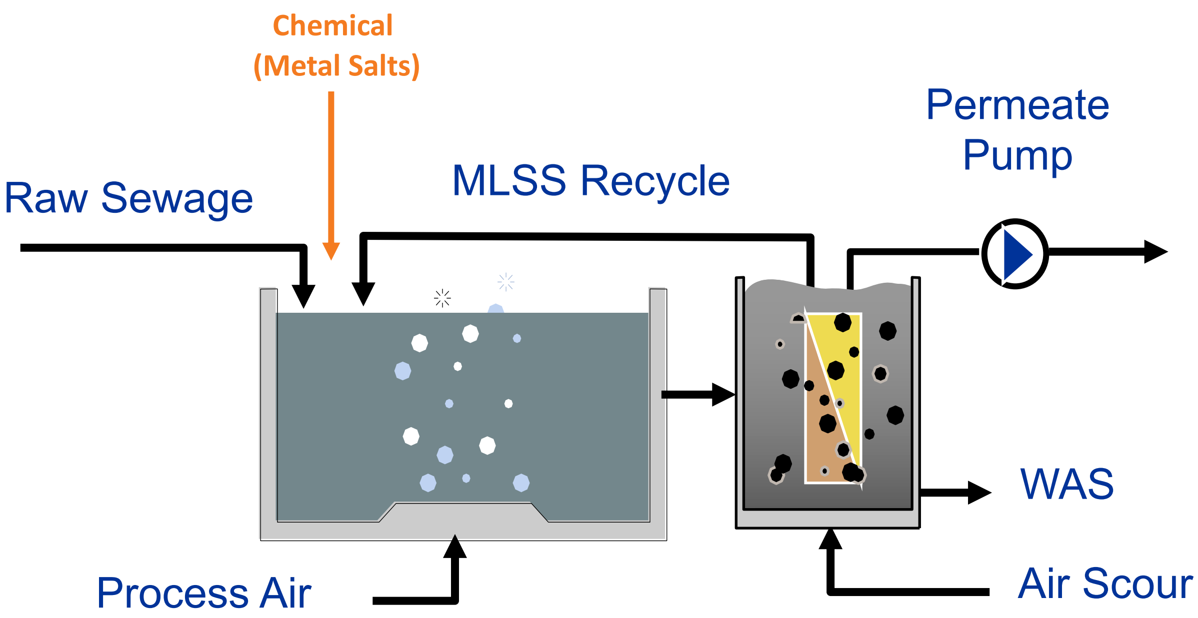


Integrated Process – Evoqua BioMag (Marlborough Easterly)





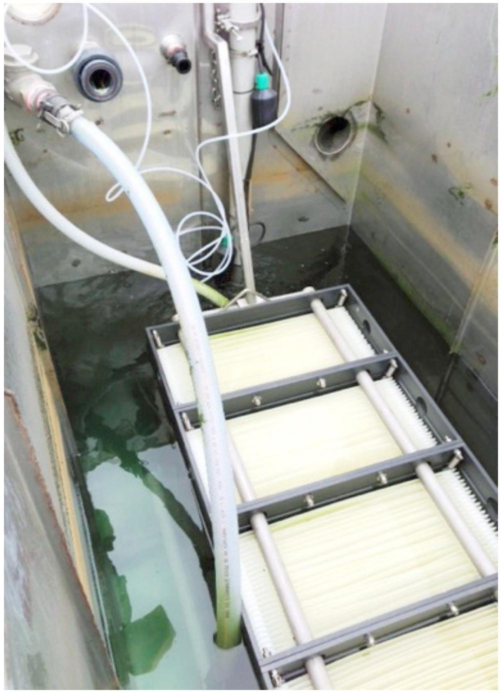
Integrated Process – Membrane Bioreactors

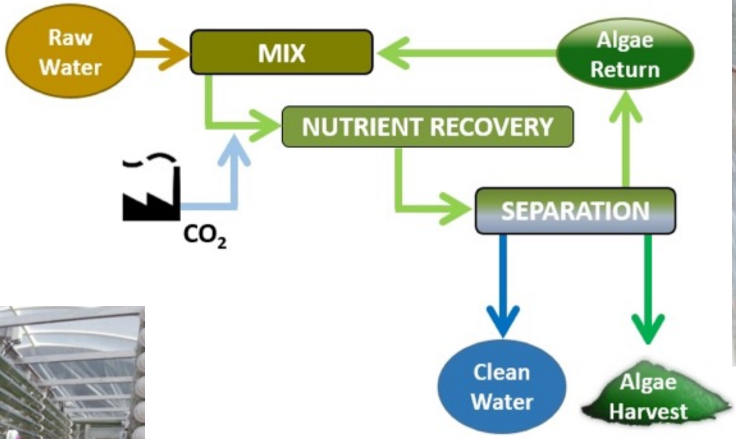


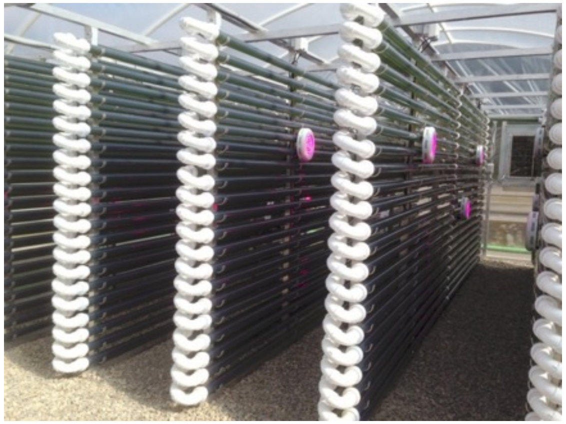
Other – Clearas Algae Treatment

Pre-Filtration and Mix Tank

Membrane Separation Tank

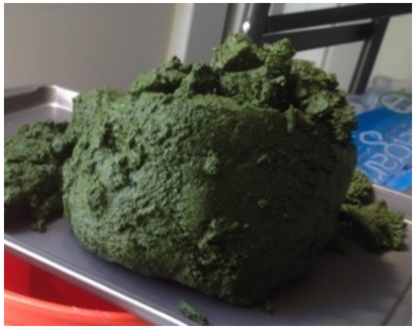




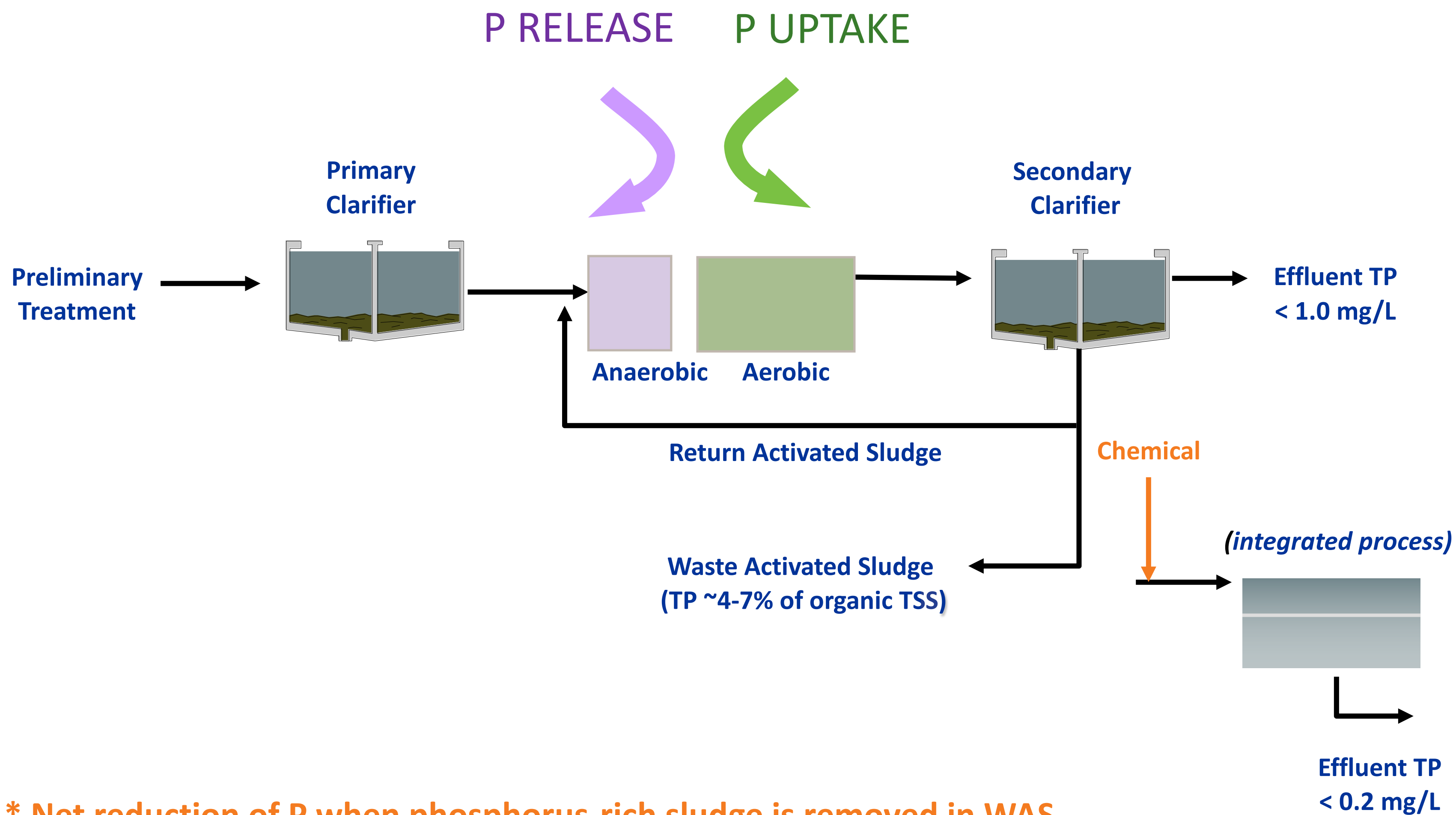


CO_2 Addition and Photobioreactor with LED Lights

Harvested Algae



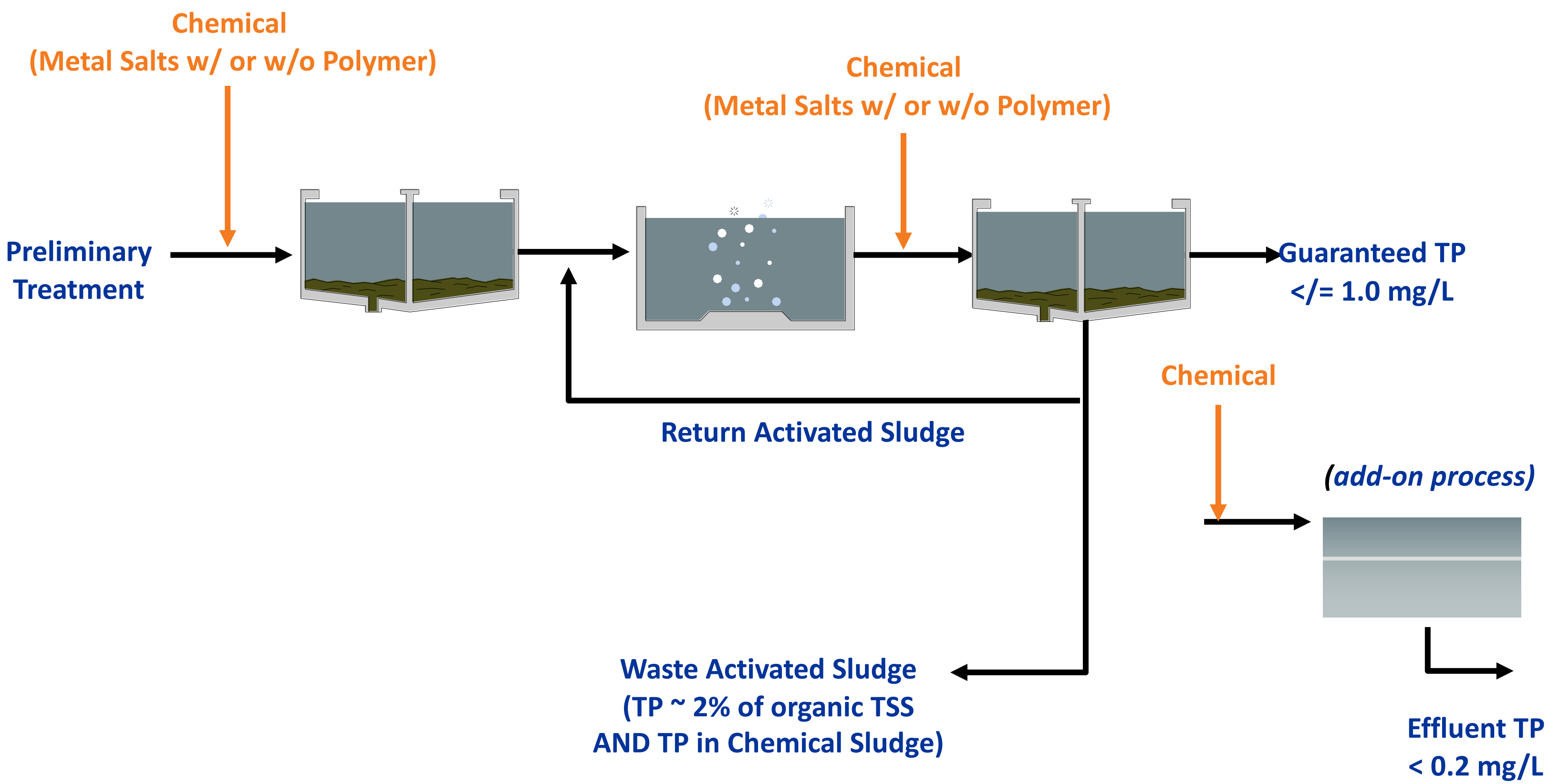
Biological Phosphorus Removal (EBPR)



* Net reduction of P when phosphorus-rich sludge is removed in WAS

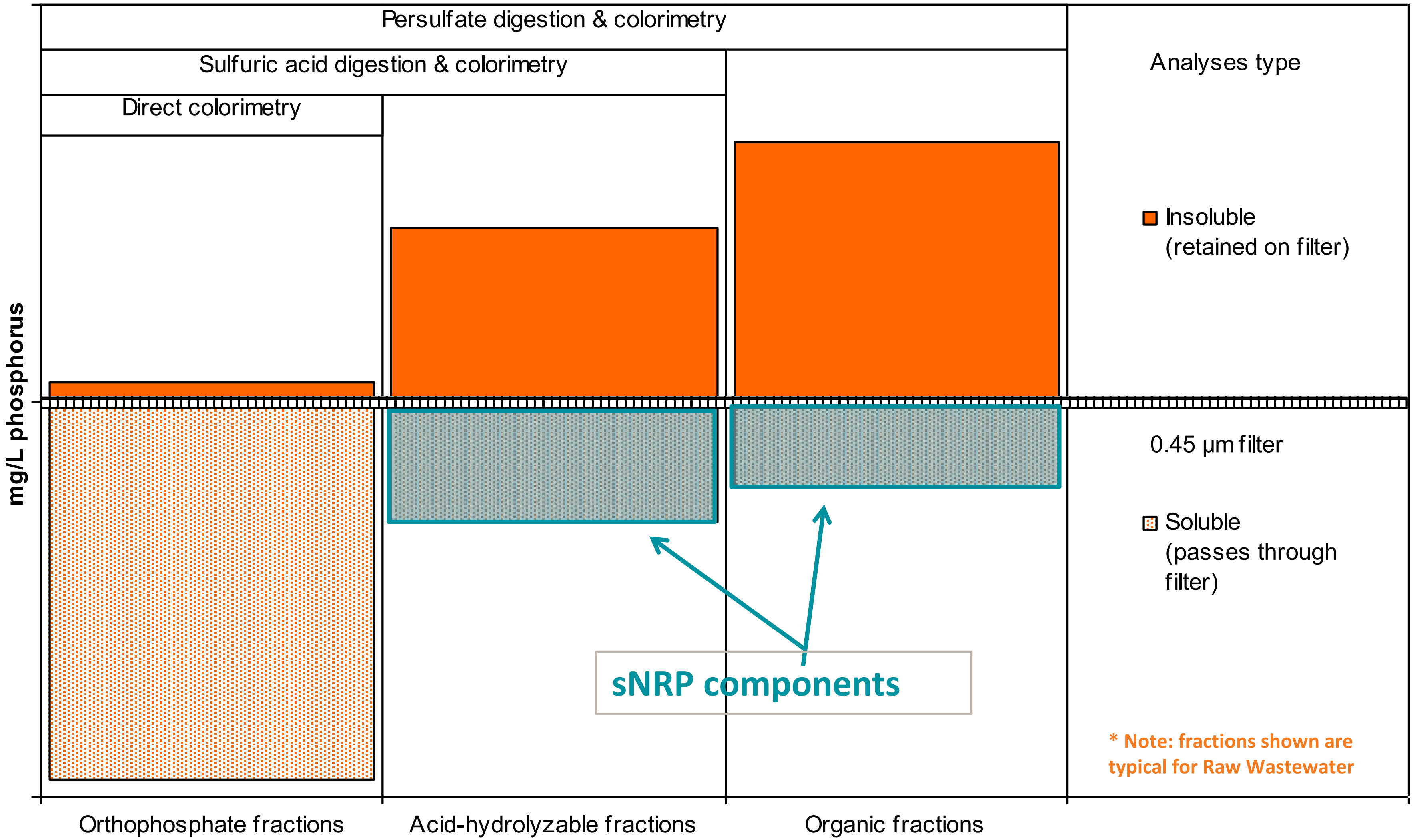
Chemical Phosphorus Removal

Dual or Multi Point addition is more efficient than single point addition



Compliance Considerations for Achieving TP < 0.2 mg/L

Phosphorus Fractions: Ability to Achieve Low Level TP Dependent on Soluble Non-Reactive P



Reporting Methodologies: Ability to Achieve Low Level TP Impacted by Permit Methodologies

- Seven permit reporting methodologies for concentration & load considered
  - Monthly Average (arithmetic mean)
  - Maximum of 60-day Rolling Average
  - Seasonal Average (April – October)
  - Annual Average
  - Monthly Median
  - Seasonal Median (April – October)
  - Annual Median

EBPR Reporting Methodology Example

Year	Month	Monthly Average	Max 60-day Rolling Avg	Seasonal Average	Annual Average	Monthly Median	Seasonal Median	Annual Median
2012 (mg/L)	January	0.37			0.42	0.26		0.30
	February	0.57			0.42	0.45		0.30
	March	0.41			0.42	0.33		0.30
	April	0.75	0.75	0.48	0.42	0.63	0.32	0.30
	May	0.59	0.66	0.48	0.42	0.37	0.32	0.30
	June	0.45	0.66	0.48	0.42	0.50	0.32	0.30
	July	0.22	0.51	0.48	0.42	0.18	0.32	0.30
	August	0.19	0.33	0.48	0.42	0.17	0.32	0.30
	September	0.76	0.47	0.48	0.42	0.63	0.32	0.30
	October	0.41	0.58	0.48	0.42	0.31	0.32	0.30
	November	0.17			0.42	0.15		0.30
	December	0.19			0.42	0.18		0.30

Shaded cells indicate compliance with 0.45 mg/L TP limit

Ballasted Flocculation Reporting Methodology Example

Year	Month	Monthly Average	Max 60-day Rolling Avg	Seasonal Average	Annual Average	Monthly Median	Seasonal Median	Annual Median
2012 (mg/L)	January	0.48			0.25	0.50		0.20
	February	0.79			0.25	0.73		0.20
	March	0.82			0.25	0.79		0.20
	April	0.24	0.24	0.19	0.25	0.24	0.18	0.20
	May	0.21	0.23	0.19	0.25	0.22	0.18	0.20
	June	0.18	0.22	0.19	0.25	0.19	0.18	0.20
	July	0.20	0.21	0.19	0.25	0.19	0.18	0.20
	August	0.13	0.19	0.19	0.25	0.14	0.18	0.20
	September	0.21	0.17	0.19	0.25	0.22	0.18	0.20
	October	0.14	0.18	0.19	0.25	0.14	0.18	0.20
	November	0.20			0.25	0.16		0.20
	December	0.35			0.25	0.32		0.20

Shaded cells indicate compliance with 0.2 mg/L TP limit

Reporting Methodologies for Phosphorus Limits Can Have Significant Impact on Compliance

- 60-day rolling average results in highest values
  - (One outlier can impact 3 months of reportable values)
- Medians generally lower than means
  - (Applies to monthly, seasonal, and annual values)
- Processes with more variation/outliers benefit from median limits
- Longer averaging periods increase compliance
- Compliance higher with load-based limits at facilities operating below permitted flow

On-Line Analyzers: Can Assist Plant Operators to Meet Low Level TP Concentrations

- On-line Orthophosphate analyzers have been used successfully
  - ChemScan and Hach are most common
  - Endress + Hauser and YSI also have analyzers
- Turbidity analyzers used as a surrogate
- Many plants choose to run lab analyses using spectrophotometer and test kits instead

Hach Phosphax w/ Filtrax

- Filtrax pulls samples from designated location
- Phosphax measures orthophosphate concentration
  - Wet chemistry colorimetric method
  - Requires consumable reagents
- Range & Accuracy:
  - 1.0 – 50 mg/L PO_4-P at ± 2% + 1.0 mg/L PO_4-P
  - 0.05 – 1 mg/L PO_4-P at ± 2% + 0.05 mg/L PO_4-P
- Performance and Maintenance:
  - If cell not cleaned regularly, measurements trend low
  - Tubing requires acid cleaning/replacement (particularly if installed in anoxic/anaerobic before aerobic)
  - Tubing freezes at extreme cold temps

Hach Ultralow LR5000sc

- Pumps pull samples from designated location
- Measures orthophosphate concentration
  - Wet chemistry colorimetric method
  - Requires consumable reagents
- Range & Accuracy:
  - 0 – 1000 µg/L PO_4-P (i.e. 0-1 mg/L PO_4-P) at Greater of ± 4 µg/L PO_4-P or ± 4% of reading
- Performance and Maintenance:
  - Sample filtration very important
  - Reagents more numerous and expensive than Phosphax
  - Beneficial for effluent monitoring

Questions?