Implementing and Optimizing Chemical Phosphorus Removal

Alyssa Mayer, PE

Agenda

- Drivers for Phosphorus Removal
- Phosphorus Removal Mechanisms
- Chemical Phosphorus Removal
  - Principals
  - Design Considerations
  - Optimization of Chemical Feed with EBPR
- Case Study: Upper Mill Creek
- Case Study: Fairfield

Drivers for Phosphorus Removal

Eutrophication and Hypoxia

Under natural conditions, phosphorus (P) is a limiting nutrient, which restricts the growth of algae and/or aquatic plants

Eutrophication:

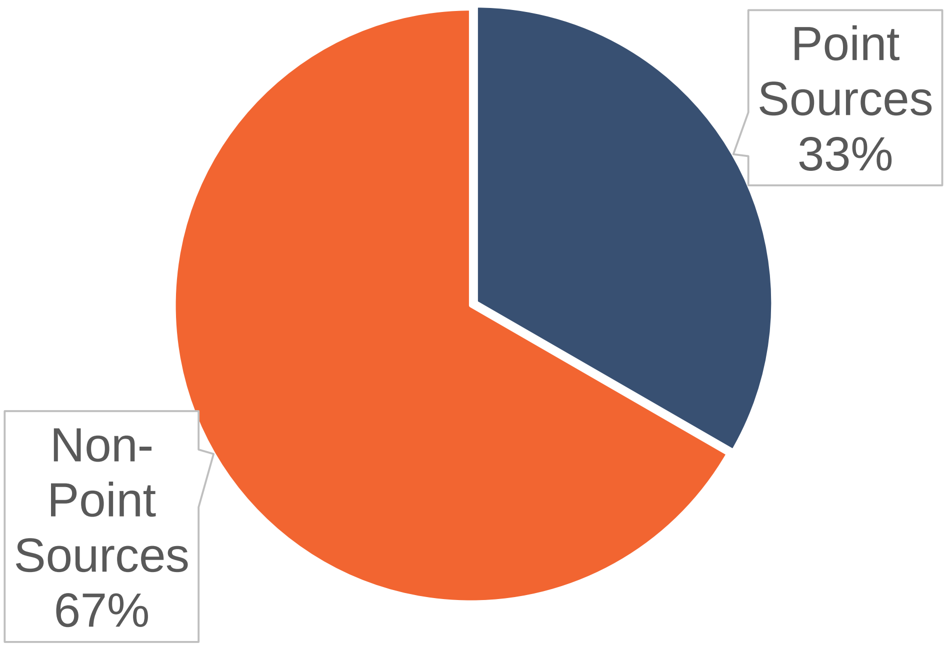
- Excess nutrients (either N or P, depending on the water body) lead to an overgrowth of aquatic plants (i.e. algae)

Hypoxia:

- Low DO conditions in a water body (<2 mg/L O_2)
- Leads to physiological stress/death of aquatic organisms

Phosphorus Loading to Lakes and Rivers

- Human activities have resulted in excessive loading of phosphorus into receiving water systems, promoting algae growth.
- Impacts on water quality have led regulatory agencies to require phosphorus removal in some WWTPs



Phosphorus Loading to Water Bodies

Ohio Phosphorus Removal Feasibility Studies (Senate Bill 1)

Who: Publicly Owned Treatment Works (POTW) with design flow greater than 1 MGD with no phosphorus limit as of July 3, 2015

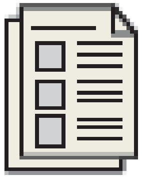
What: Conduct a study evaluating the technical and financial capability of the existing facility to meet an effluent TP limit of 1 mg/L through:

– Source reduction measures

– Operational changes

– Treatment process changes

Begin monitoring by Dec. 1, 2016



Submit study by Dec. 1, 2017

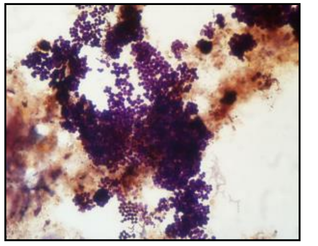
Phosphorus Removal Mechanisms

Phosphorus Historically leaves the WWTP in Two Ways

Effluent

Solids

Phosphorus Removal Mechanisms



Biological removal

Enhanced Biological Phosphorus Removal (EBPR)

Chemical removal

Addition of metal salts to promote precipitation

Physical removal

Settling in a solids separation unit

Filtration

Also…

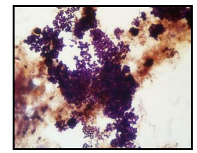
Recovery

Intentional formation of a P product for reuse

Wastewater Phosphorus Speciation & Removal Methods

Total Phosphorus

- **Ortho-Phosphate**
- **Poly-phosphate**

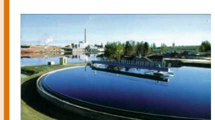


Biological P Removal

Chemical P Removal

Organically Bound

- **Particulate Phosphorus**
- **Biodegradable Soluble**
- **Inert Soluble**



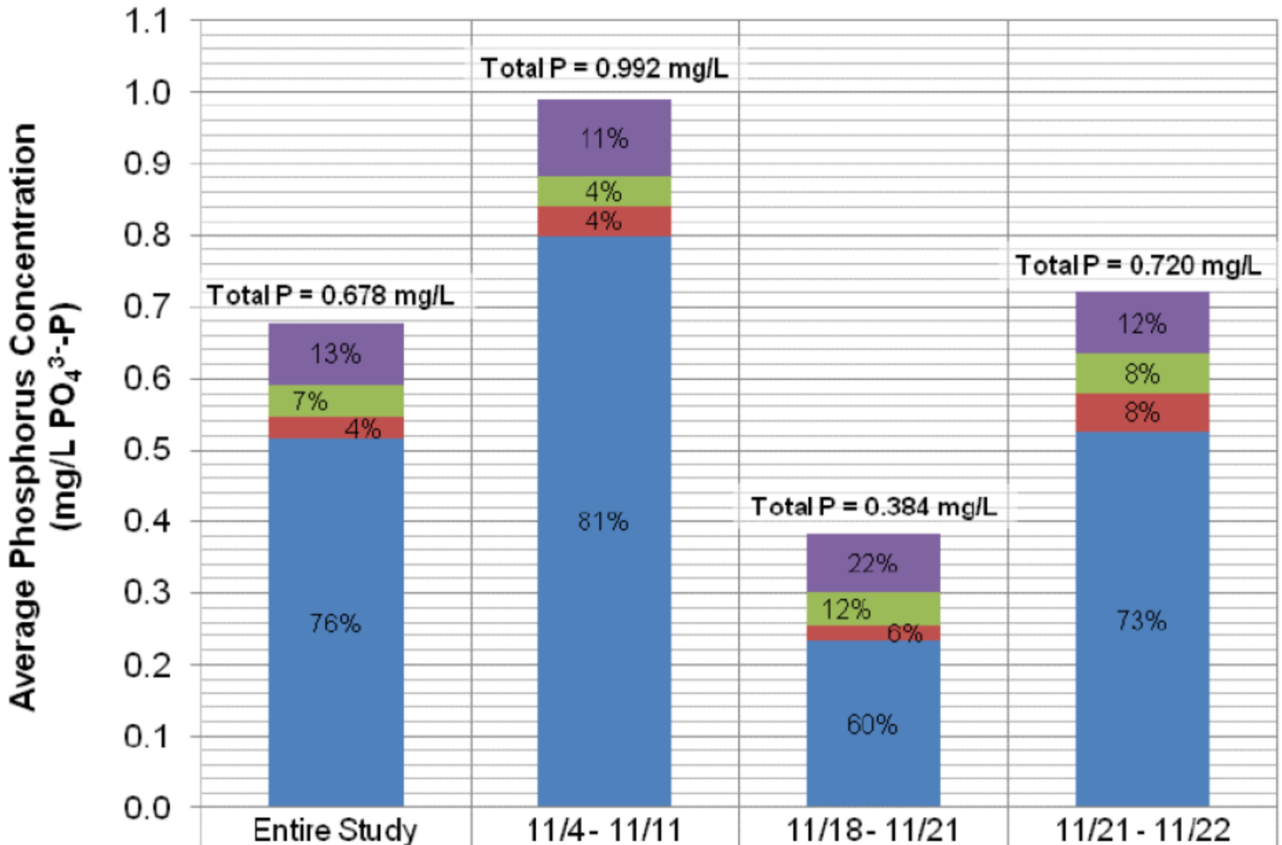
Solids Separation

Chemical Coagulation Adsorption

Cannot Remove

Impact of Phosphorus Speciation

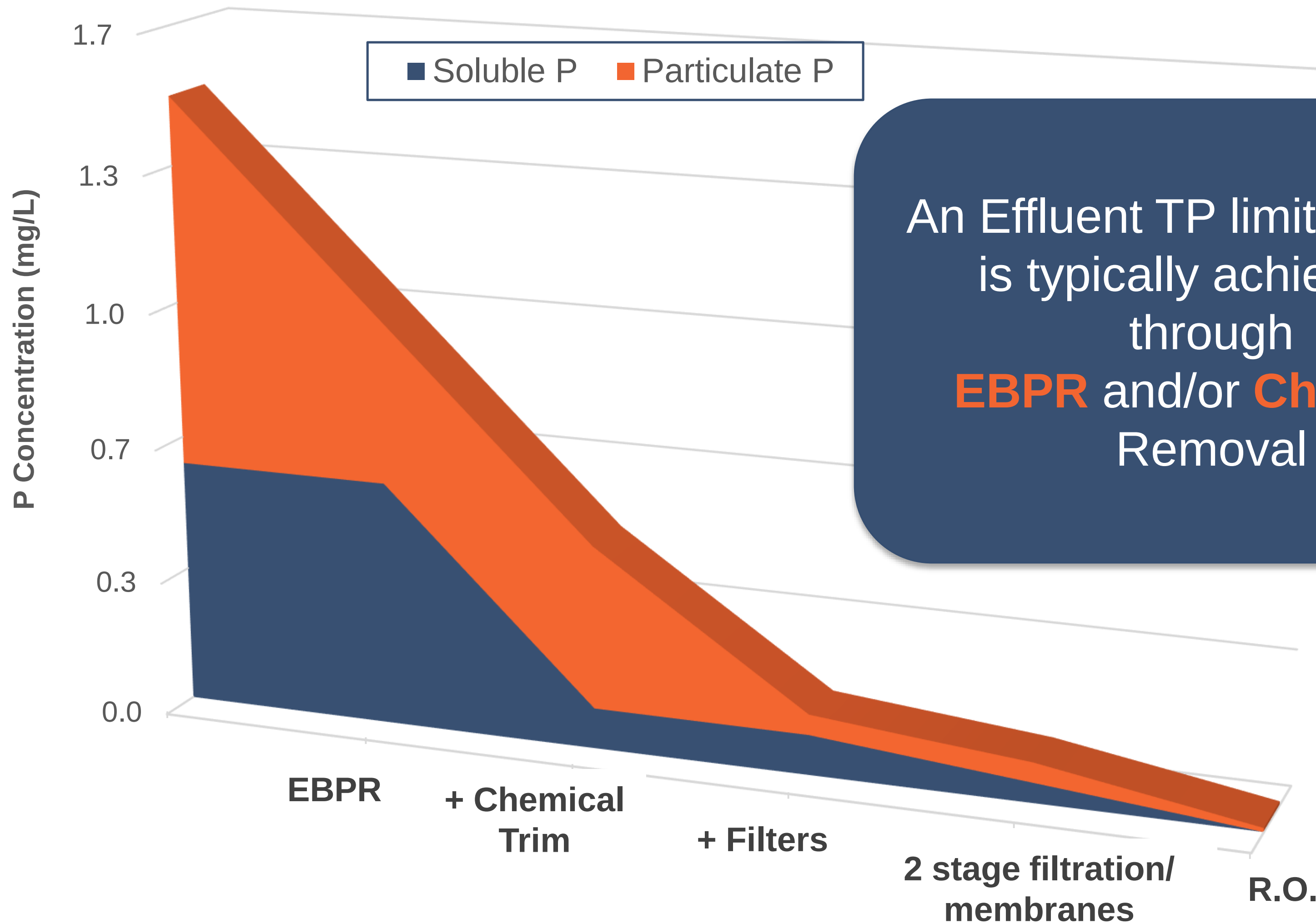
Expected 0.075 mg/L Effluent TP Limit



	Entire Study	11/4 - 11/11	11/18 - 11/21	11/21 - 11/22
Insoluble Non-Reactive	0.087	0.110	0.083	0.085
Insoluble Reactive	0.045	0.040	0.045	0.055
Soluble Non-Reactive	0.030	0.043	0.024	0.055
Soluble Reactive	0.516	0.799	0.232	0.525

Hughes, M.P., et al. (2015) Validating the Reliability of Cloth Media Filtration to Achieve an Effluent Total Phosphorus Less Than 75 ug/L. WEFTEC 2015. Chicago, IL.

Phosphorus Removal Potential



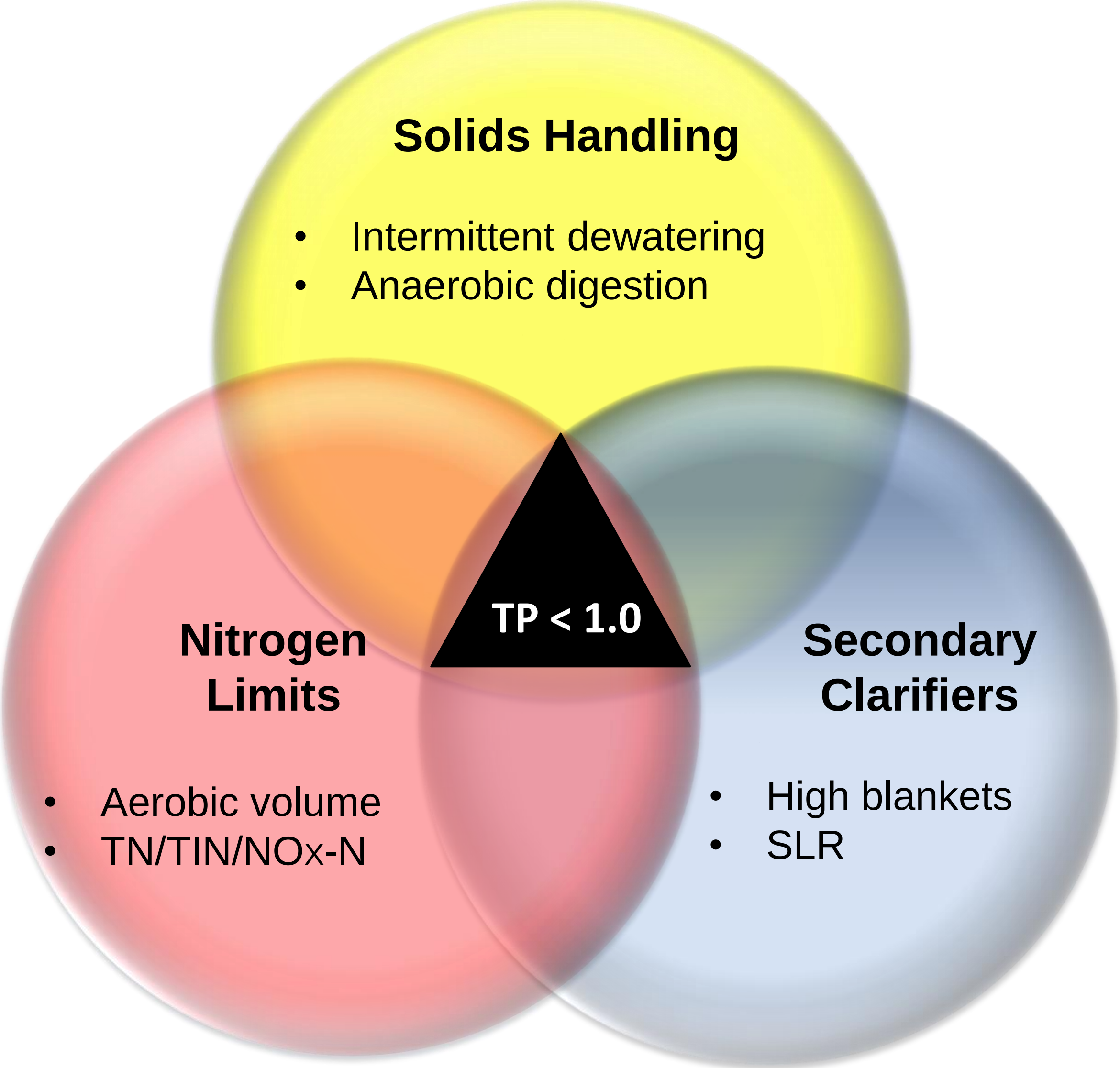
An Effluent TP limit of 1mg/L is typically achievable through **EBPR** and/or **Chemical** Removal

Hierarchy of Treatment Priorities

Nutrient Removal Process	Requirements
Nitrification	- Meet required aerobic SRT - Most effective option (breakpoint chlorination, stripping)
Denitrification	- TN, TIN or NO_x-N limits - Influent org-C for denitrification - Most effective option (add-on processes w/ chemicals)
Phosphorus Removal	- EBPR - Chem-P

Chemical Phosphorus Removal

Chem-P Application “Check List”



Chem-P Removal
Advantages and Disadvantages

Advantages

Not biologically based performance
Reduces sidestream impacts
Particulate removal
Low effluent TP
Low capital costs

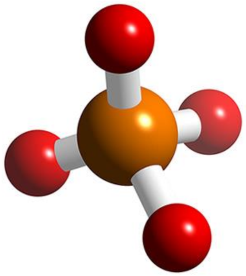
Disadvantages

Higher solids production
Impacts to digestion VSR
Alkalinity consumption
Potential overdosing
Higher operational costs

Principles of Chemical Phosphorus Removal

Principles of Chemical Phosphorus Removal

Classical approach – precipitation of $MePO_4$



$Me^{3+} + PO_4^{3-} \leftrightarrow MePO4_{(S)}$

No longer thought to be primary mechanism in WW treatment

Updated theory – Surface Complexation Model (SCM)

PO_4-P adsorption to metal oxides/hydroxides dominant mechanism for chemical P removal

Potential for direct precipitation at high Me and P concentrations, and low pH conditions

Chem-P Removal Mechanism

1. Dose chemical
2. Rapid mix to disperse chemical
3. Hydrous metal oxide (HMO) particles form
4. PO_4 binds to HMO particles
5. HMO floc form
6. HMO floc trap additional PO_4
7. PO_4 surface adsorption to HMO floc
8. Solids settle in clarifier

Common Chem-P Removal Chemicals

- Typically, Al or Fe metals

Aluminum Based	Iron Based
Aluminum sulfate $Al_2(SO_4)_3 \bullet 14H_2O$	Ferric chloride $FeCl_3$
Sodium aluminate $Na_2Al_2O_4$	Ferrous chloride $FeCl_2$
Poly-aluminum chloride (PACL,PAX) $Al_nCl_{(3n-m)}(OH)_m$	Ferrous sulfate Fe (SO_4)

What are all of these values?

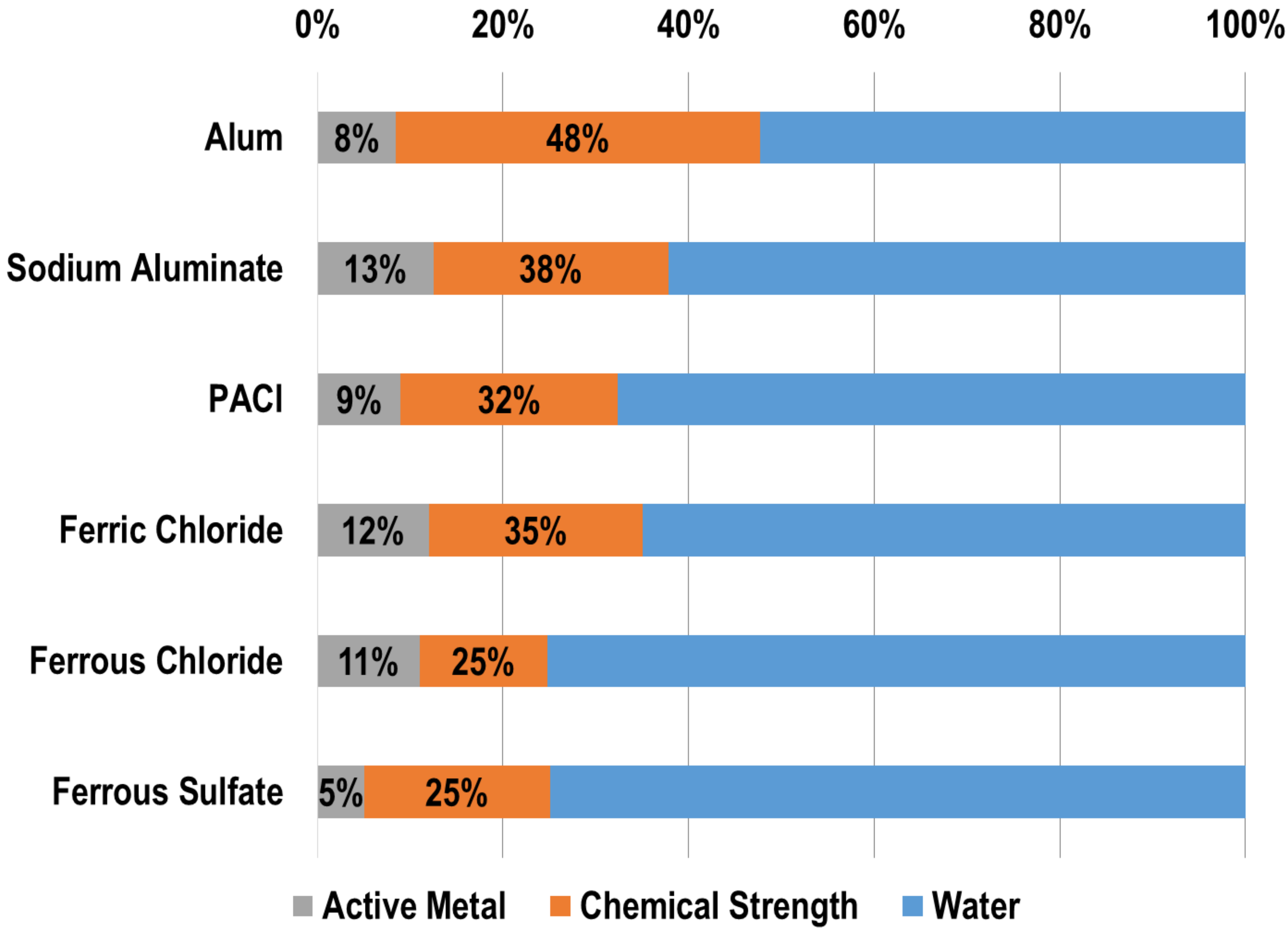
Stoichiometric Example

$$\mathbf{1}FeCl_3 + \mathbf{1}PO_4^{3-} \leftrightarrow \mathbf{1}FePO_{4(S)} + 3Cl^-$$

Criteria	Dose as $FeCl_3$	Dose as Fe^{3+}
Dosing Ratio	$FeCl_3$: P	Fe : P
Mole Ratio	1 : 1	1 : 1
Weight Ratio	5.2 : 1	1.8 : 1
Solution Specific Weight	11.4 lb solution / gal	
Strength	35% as $FeCl_3$	12% as Fe^{3+}
Density	4.0 lb as $FeCl_3$ / gal	1.4 lb as Fe^{3+} / gal
Volumetric Dosage	1.3 gallon solution / lb P removed	

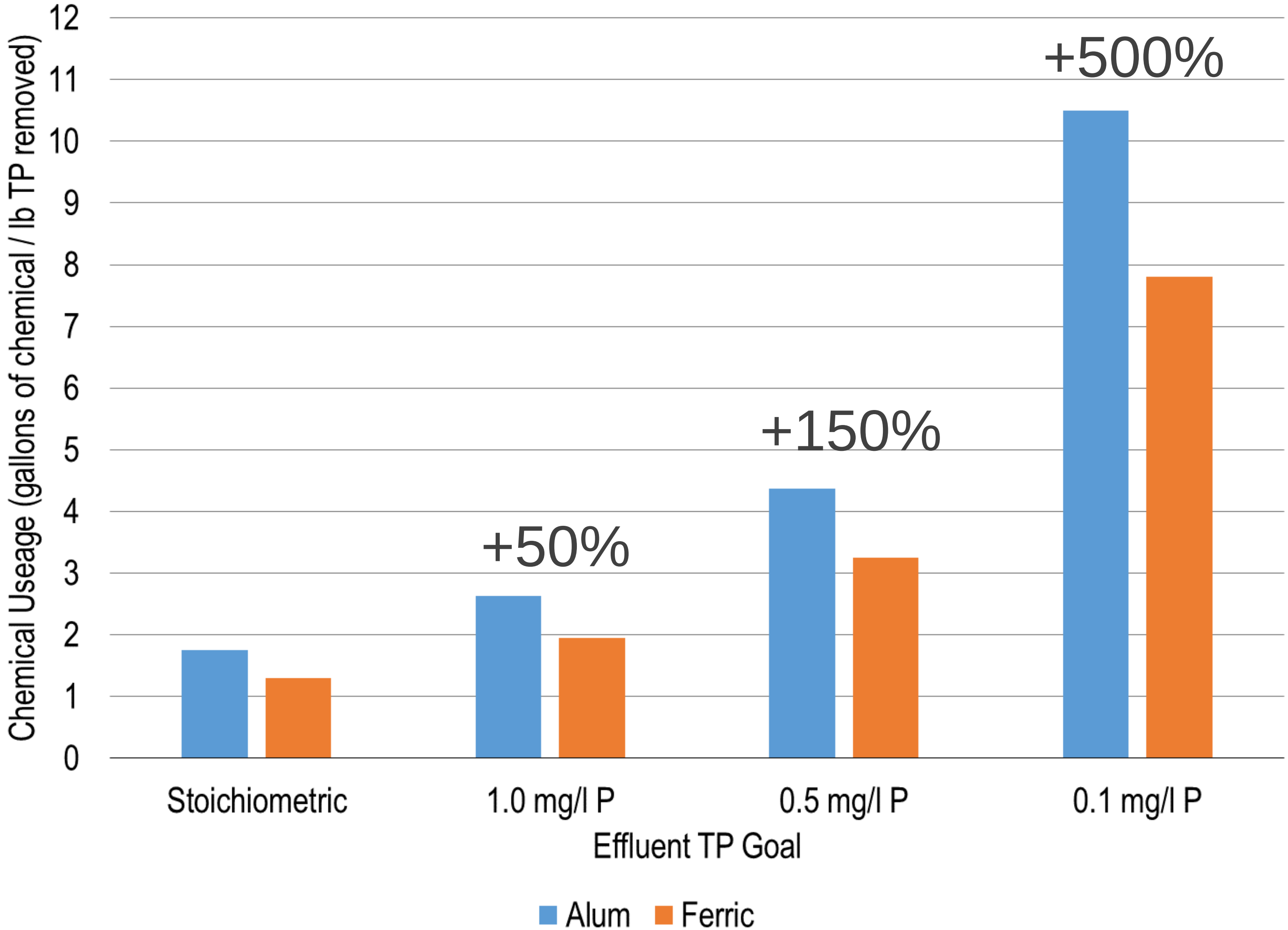
Be consistent as either chemical or metal !!!!!

Typical Chemical Properties



Design Considerations

Typical Chem-P Dosing Requirements



Factors that Increase Dosing Requirement

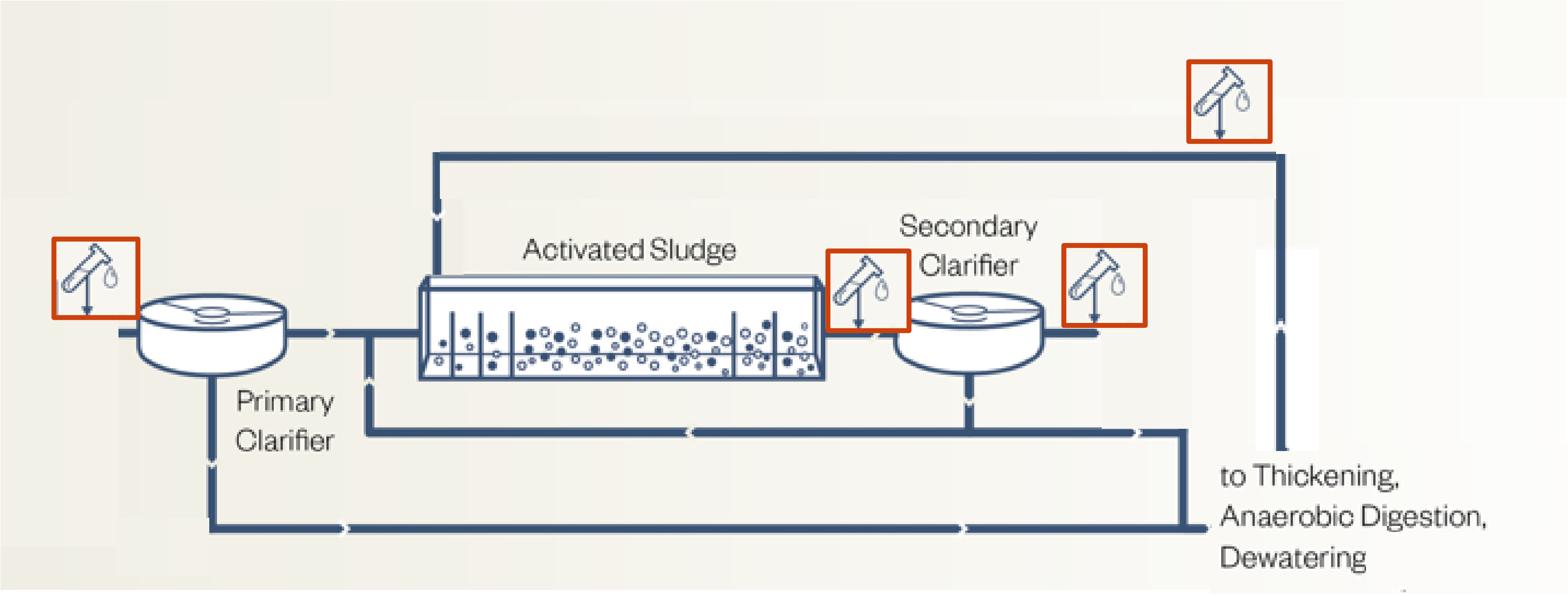
- Presence of organic material
  - Interference with HMO binding sites
- Elevated pH
  - Ideal range 5.5 – 7.0
- High soluble P concentrations
  - More TP to remove
- Mixing intensity
  - Too much – Shear HMO floc and reduces settling
  - Too little – Inadequate dispersion of chemical

Jar Testing

Compare multiple types of coagulant to identify the best fit for specific wastewater.

Verify site-specific dosing to obtain a more accurate estimate of chemical costs

Multi-Point Chemical Addition

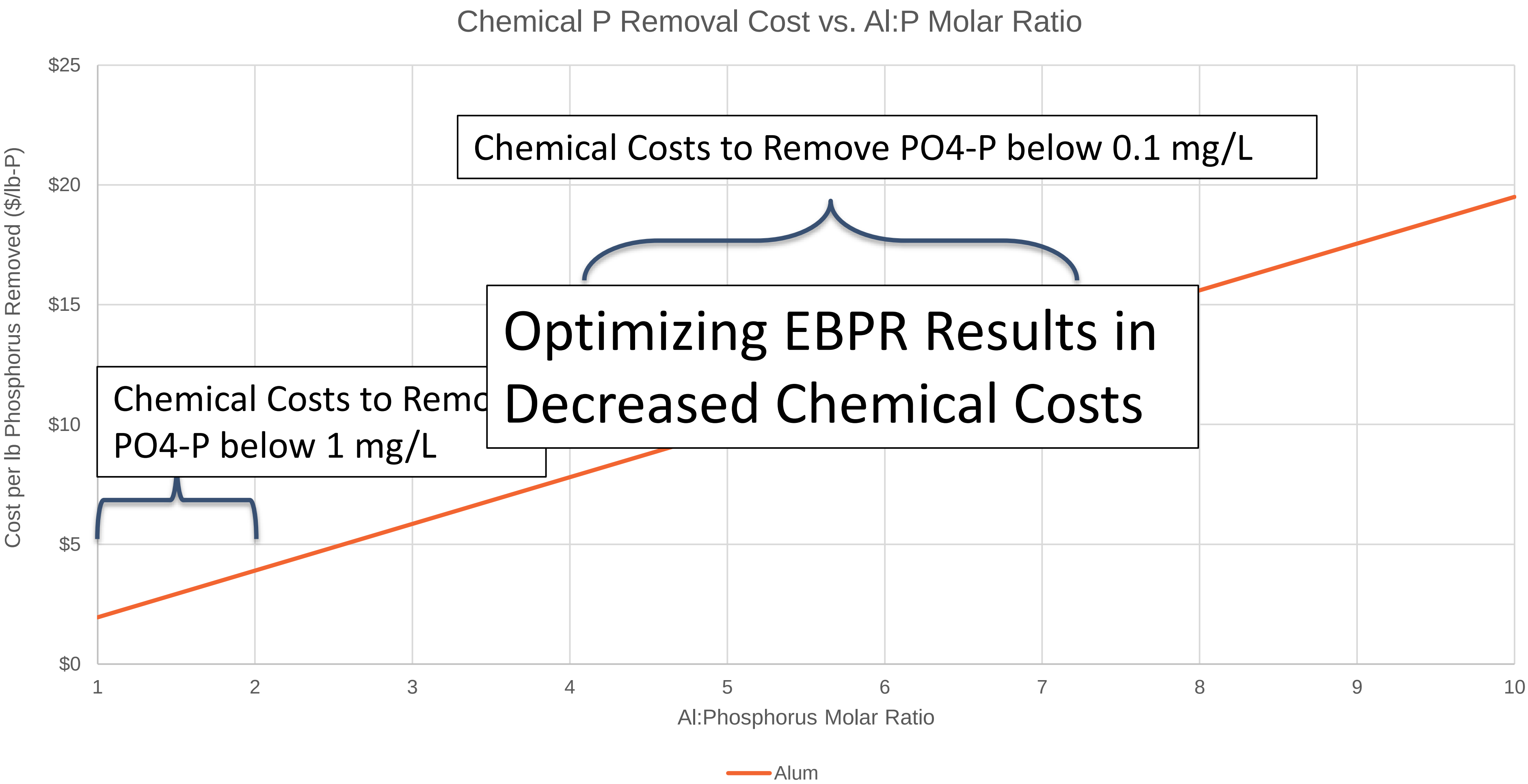


Multi-Point Addition	• Primary clarifiers (dose at Q) • Secondary clarifiers (dose at Q + RAS) • Filters (final polishing) • Recycle streams (dose concentrated load)

Chem-P Removal Design Considerations

Criteria	
Materials of Construction	Most are corrosive (low pH) FRP, plastic and lined steel
Storage Crystallization	May require heated tanks, heat tracing or in building • 35% ferric ~ -42°F • 42% ferric ~ 20°F • 8% alum ~ 32°F
Mixing	G-value > 200 s^{-1}
Pacing	• Peristaltic or diaphragm metering pumps • Flow pacing may overdose (I/I or variable P-conc) • TP pacing at higher cost

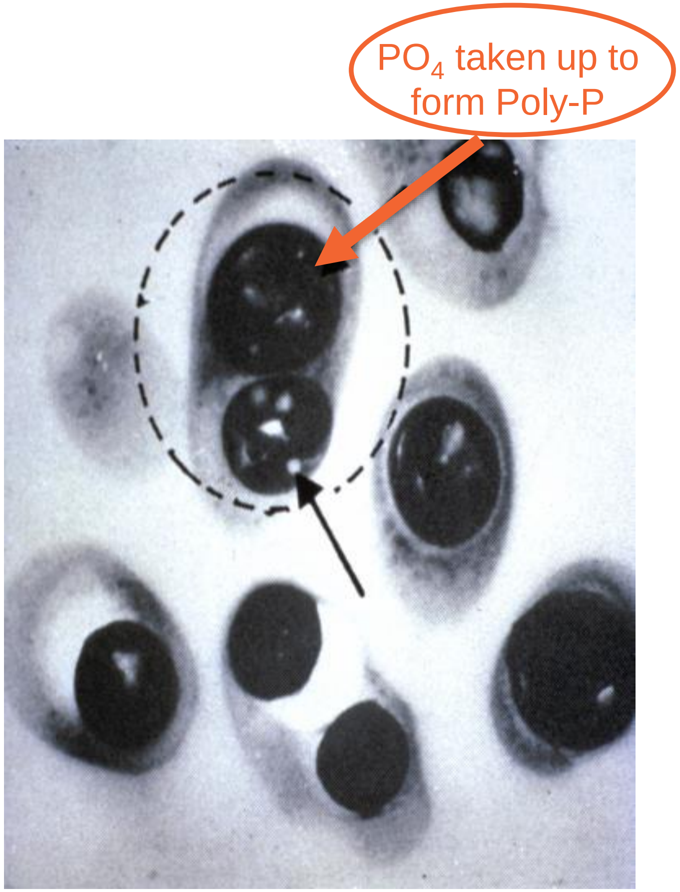
Chemical Costs for P Removal Increase Dramatically as Effluent Limit Decreases



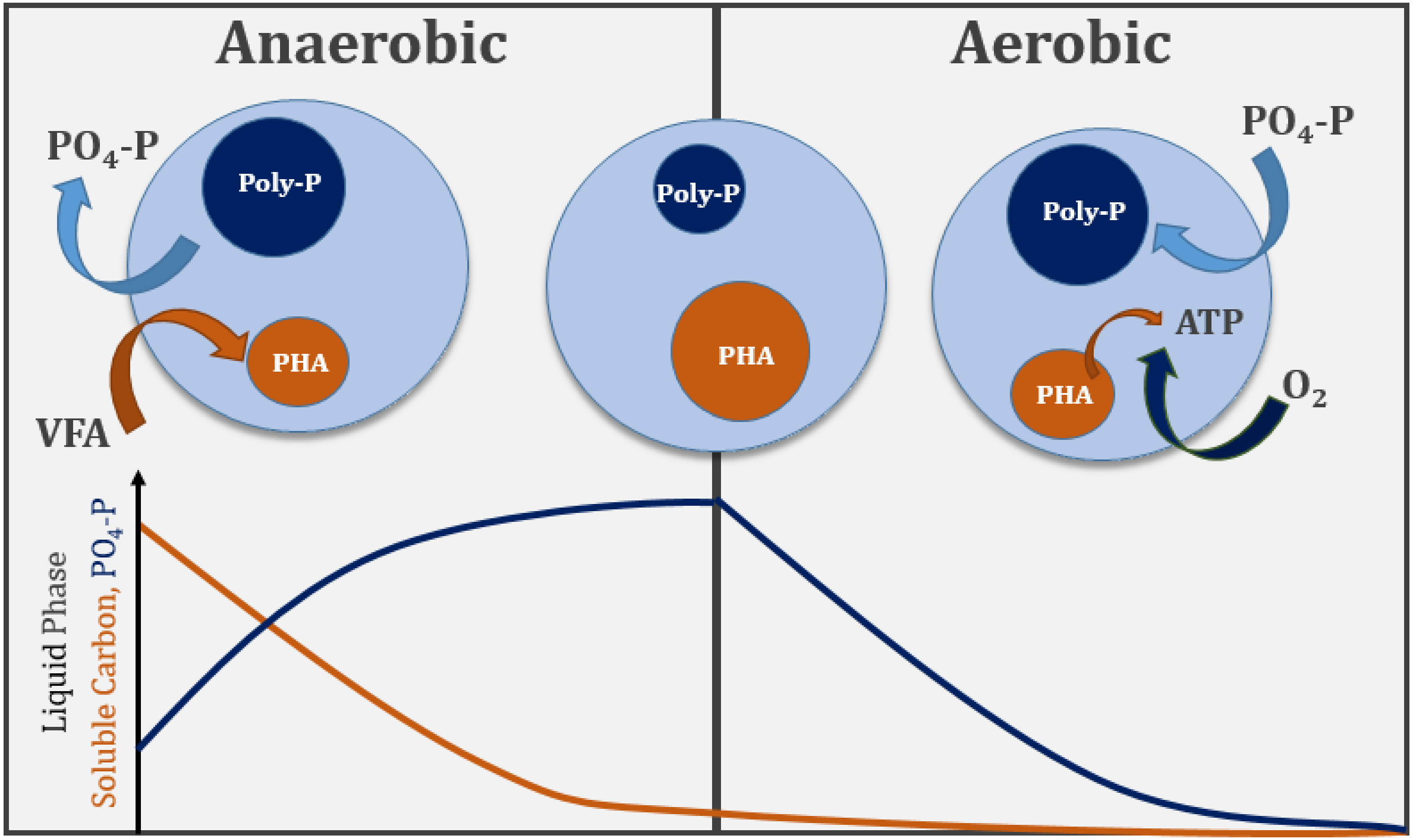
Enhanced Biological Phosphorus Removal

Enhanced Biological Phosphorus Removal

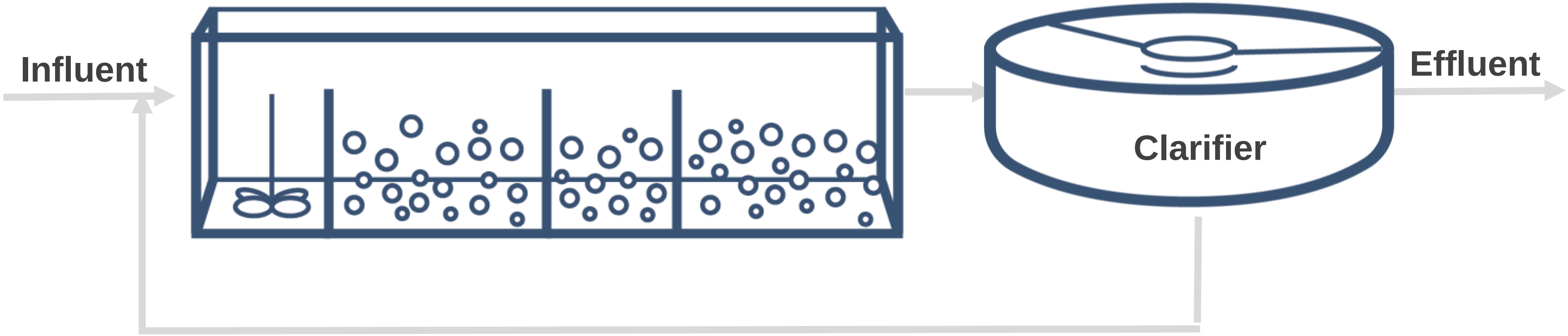
- Specific bacteria (known as **Poly phosphate Accumulating Organisms (PAOs)** can sequester high levels of phosphorus by storing it inside their cell as poly- phosphate (poly-P) when cycled through anaerobic and aerobic conditions
- An EBPR process is designed to **select** for these bacteria and waste them while poly-P content is high (resulting in net removal of phosphorus).



Required Conditions for Enhanced Biological Phosphorus Removal (EBPR)



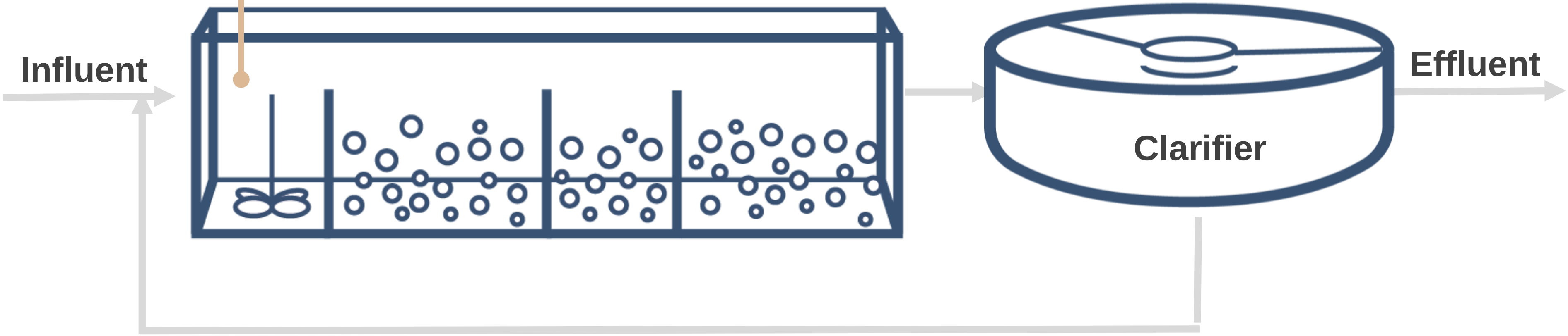
EBPR Process Design Considerations



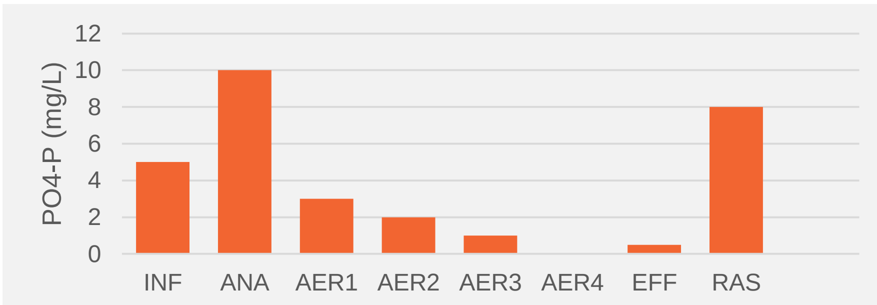
Anaerobic Zone Sizing

Anaerobic Zone

- Selects for PAOs
- HRT 1 – 3 hours

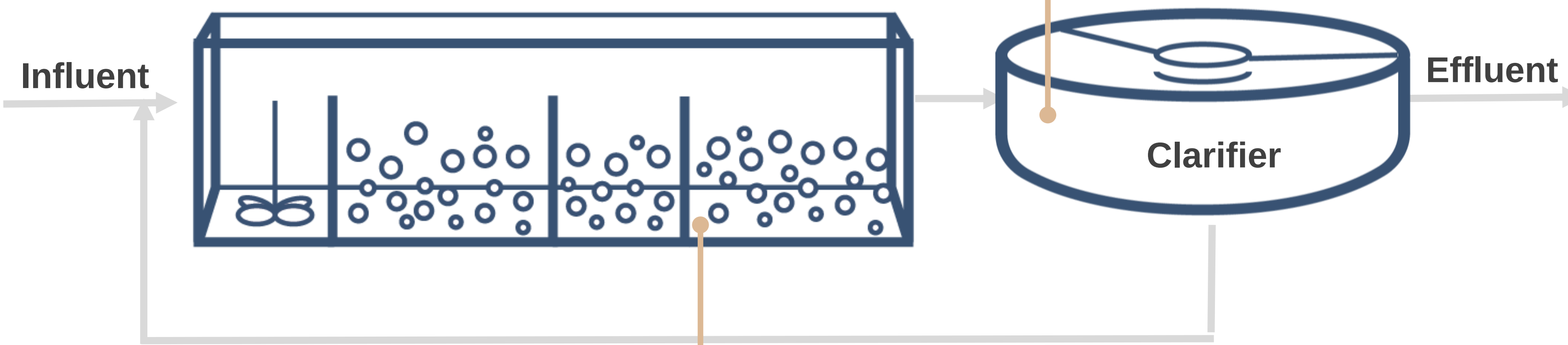


Aeration Control and Prevention of Secondary Phosphorus Release



Sludge Blanket Depth Control

- Anaerobic conditions in sludge blankets can result in P release in the clarifiers



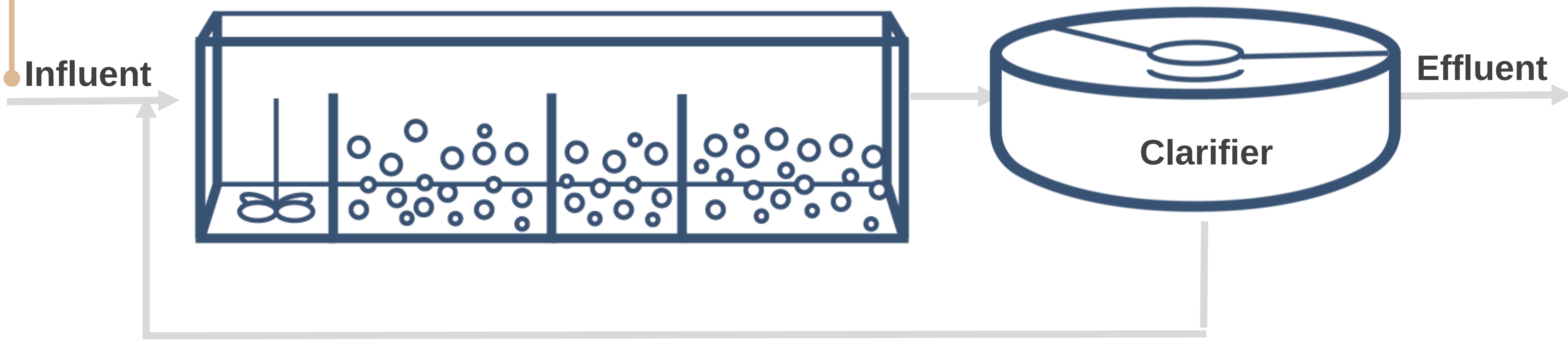
Aeration Control

- Sufficient aerobic HRT necessary to allow for complete removal of PO4-P
- DO control to match diurnal loading fluctuations

Influent Characteristics

Influent Characteristics
- Influent TP fractions
- Influent Carbon: Phosphorus Ratio
- Volatile Fatty Acid (VFAs) required

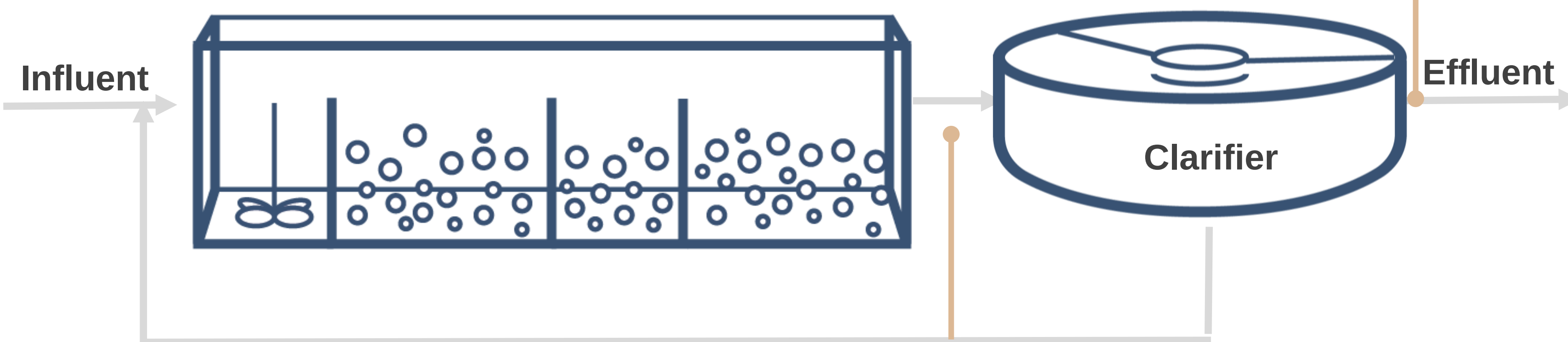
Influent Ratios favorable for EBPR
- BOD:TP > **25**
- rBCOD:TP >**16**

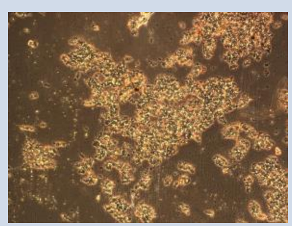


Solids Removal

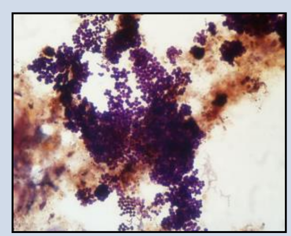
Solids Removal

- Solids removal drives ability to achieve low TP limits
- Tertiary filtration typically not necessary to meet Effluent TP of 1 mg/L; but recommended for limits below 0.5 mg/L





Non-EBPR biomass is approximately 1.5% to 2% phosphorus



PAO biomass can be as high as 8%-12% phosphorus

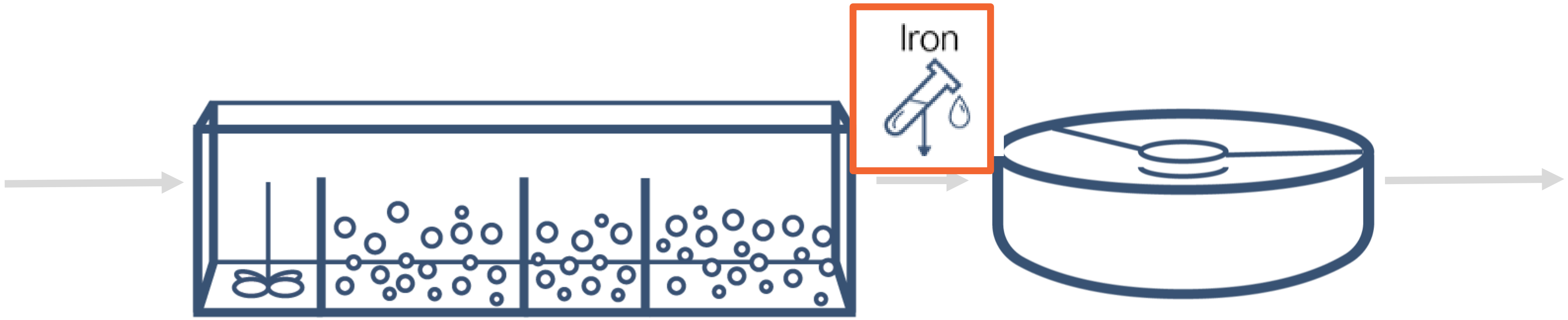
Chemical Trim

Facilities with EBPR processes should include provisions to remove P by chemical addition

Achievable effluent concentrations

- Typically 0.5 mgP/L (without tertiary filtration)
- Can be lower with optimized addition and solids separation

Warning: Overfeeding chemical can shut down PAOs



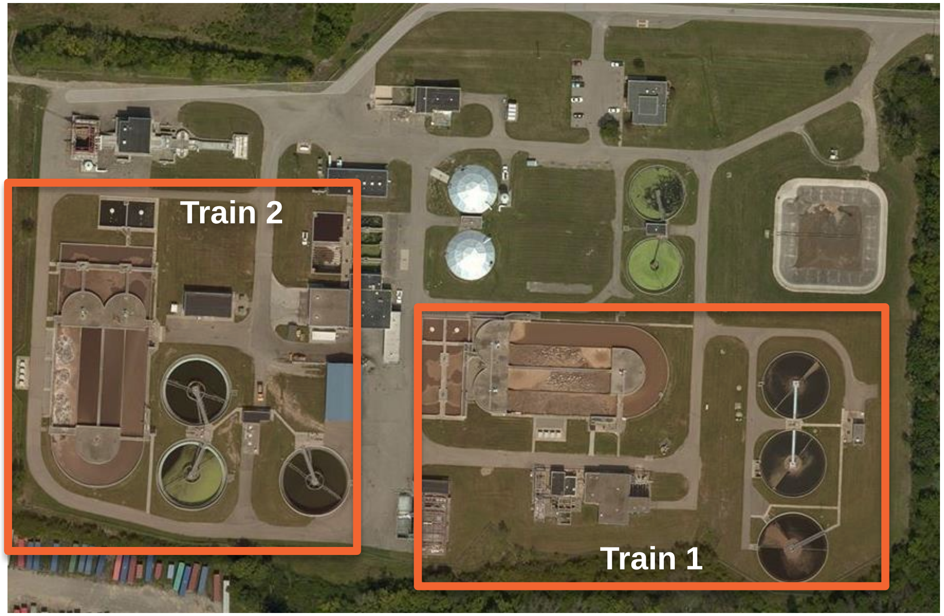
Case Study –
Upper Mill Creek

Plant Overview

Capacity: 16 mgd

Two Oxidation Ditch Trains

Biological Nitrogen and Phosphorus Removal with Chemical Trim



Current effluent nutrient limits:

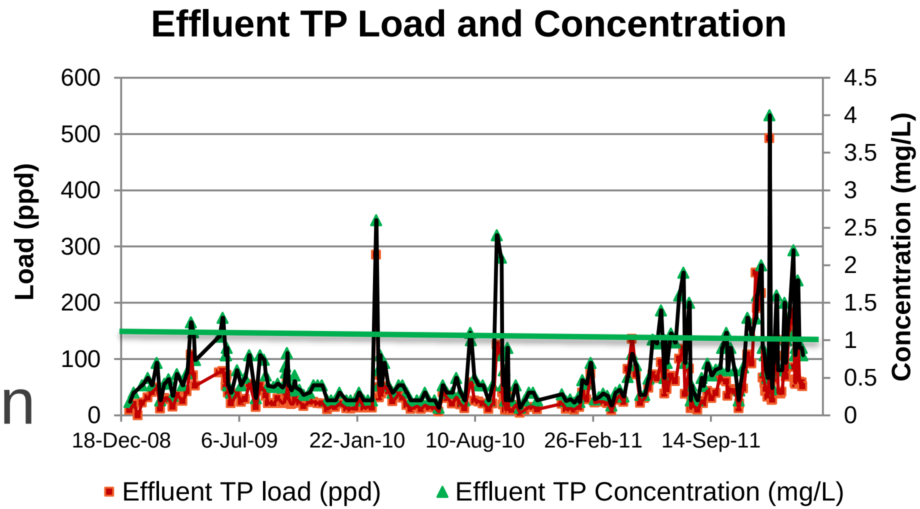
- 1 mg/L NH3-N (summer), 3 mg/L (winter)
- 5 mg/L NOx-N
- 1 mg/L TP

Phosphorus Removal Optimization Study

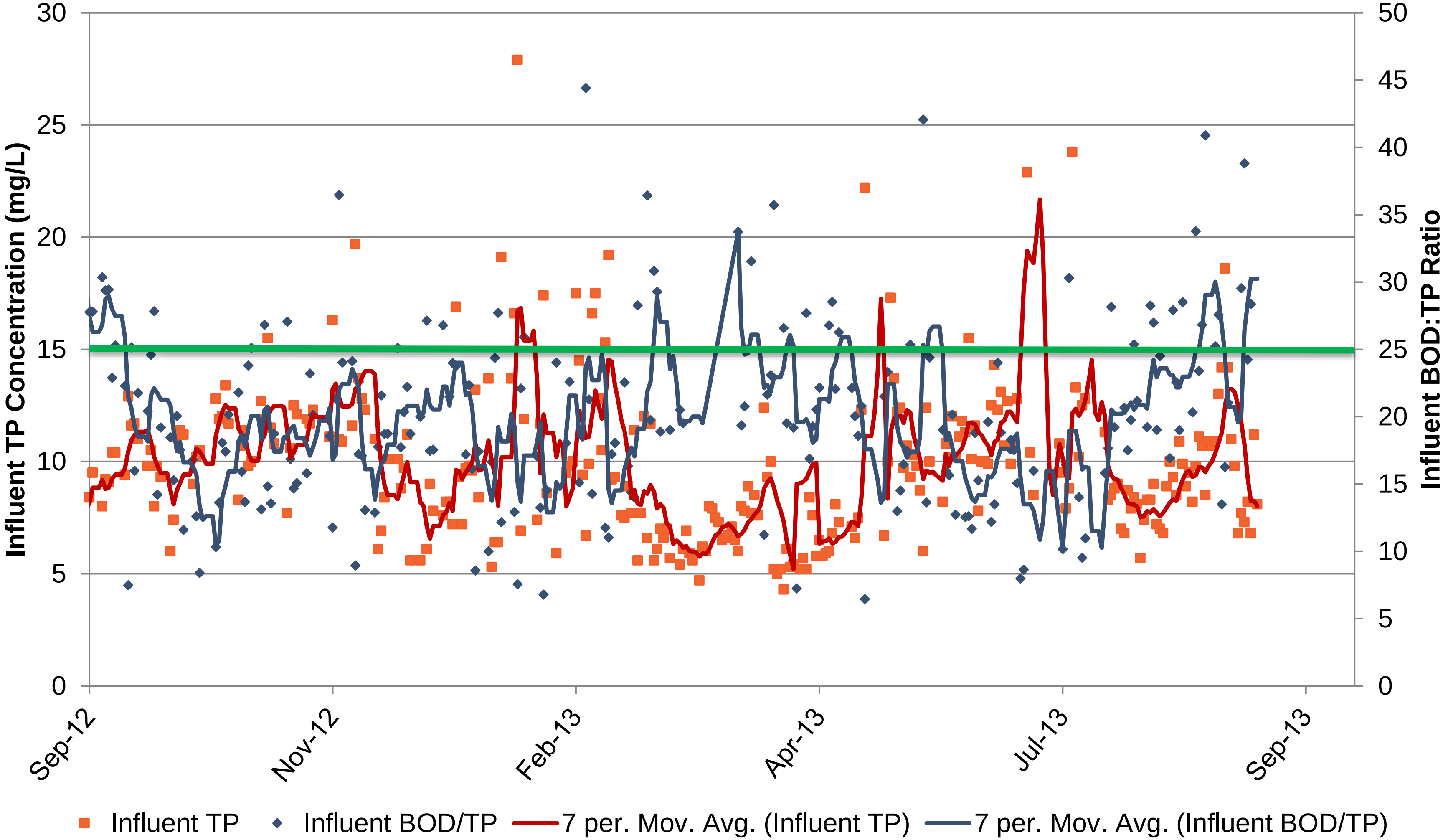
Inconsistent Bio-P performance resulted in effluent phosphorus excursions in 2010-2012.

Optimization Study initiated in 2012

- Historical Plant Data Review
- Industrial Discharger Data Review
- Detailed Sampling and Bench Scale Testing
- Process Model Development



Historical Data Revealed Variable Influent Phosphorus Loading and Marginal Carbon

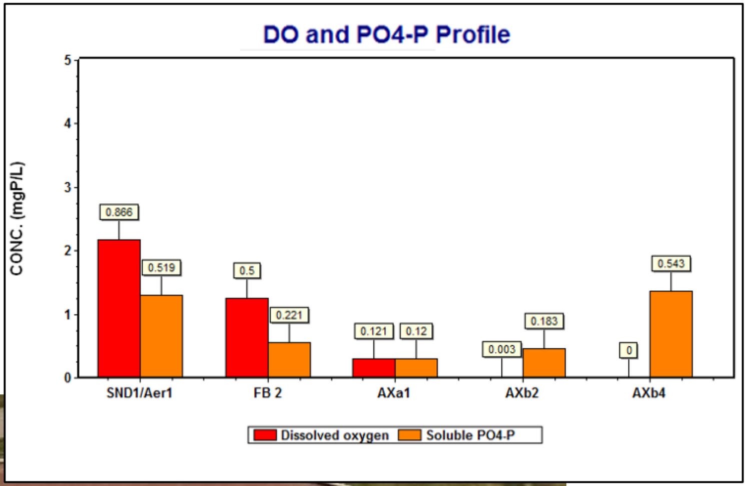


Hazen

Sampling and Modeling Revealed Operational Optimization Opportunities

Overfeeding Chemical Results in shut down on PAOs

DO sag under high loading period results in P release



Summary of Recommendations

Influences

Variable influent P from industries

Variable influent P from sidestreams

Periods of low COD:TP

DO sags in Ox. Ditches during high demand

Over/under with sodium aluminate

Optimization Suggestions

Work with SIUs to reduce phosphorus discharges

Increased process control sampling

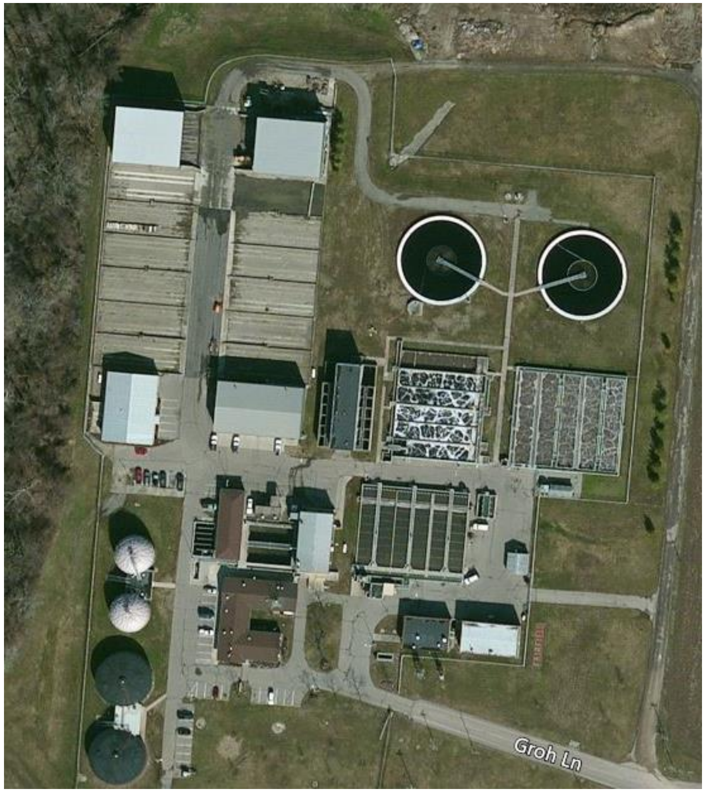
Higher capacity sodium aluminate feed

Move sampling location for sodium aluminate prior to feed

Case Study – Fairfield

Plant Overview

Unit Process	Description
Permitted Capacity	10 mgd
Primary Clarifiers	Yes
Treatment	CAS
Stabilization	Anaerobic Digestion
Dewatering	Belt Press



- Currently no TP limit (eff TP 2 – 3 mg/l)
- Proactively evaluating improvements for 1 mg/l TP

2014 Bio-P Evaluation Summary

BioWin Model developed to evaluate phosphorus removal options:

Both EBPR and Chemical Addition were considered viable options to meet an effluent TP of 1 mg/L

EBPR

- Higher Capital Cost
  - New Anaerobic Tank
  - New Pump Station
- Significant contribution of filtrate P due to digestion requires chemical trim
- Anaerobic selector results in improved settling, addressing a current capacity limitation

Chemical Addition

- Higher operating cost
  - Sodium Aluminate
  - Increased sludge production

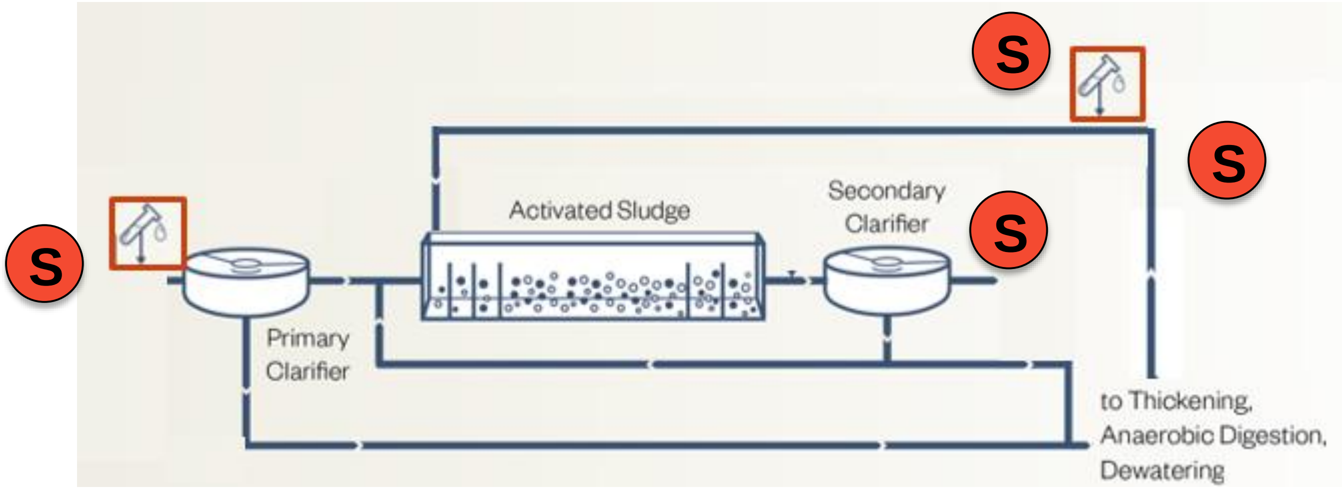
2015 Full Scale Chemical P Removal Pilot

Fairfield conducted chem-P study with Sodium Aluminate

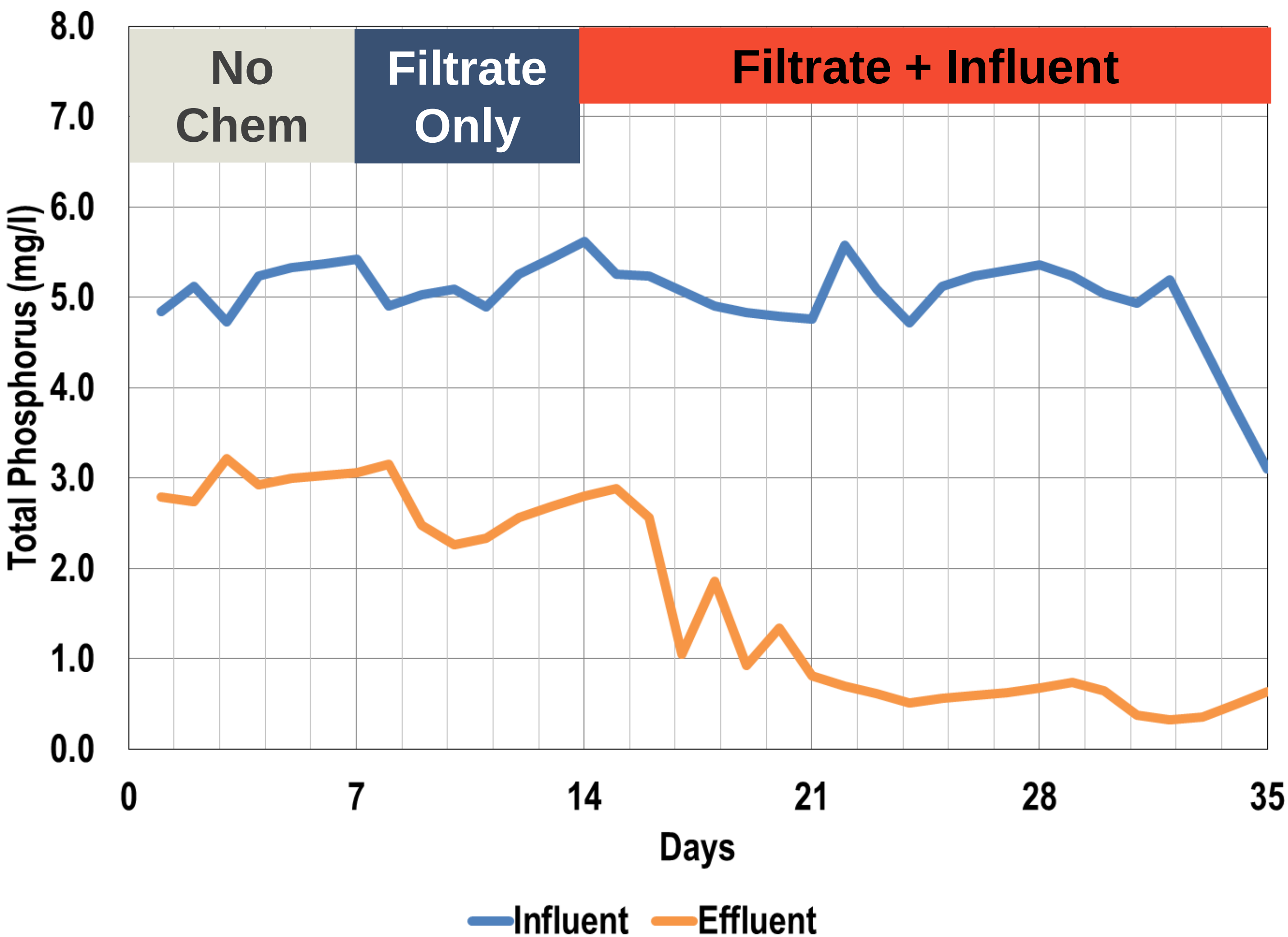
Feed locations: Raw Influent, Belt Press Filtrate

Sample locations: Influent, Effluent, Filtrate (Pre- & Post-chem add.)

Sample type: Unfiltered and 0.45-micro filtered



Chem-P Pilot Results



Chem-P Pilot Results

Location	Dosage (lb Al^{3+} / lb TP removed)	Overall Chemical Efficiency
Theoretical	0.87	100%
Filtrate	2.74	32%
Influent	1.65	52%
Total	1.85	47%

- Filtrate efficiency lower than typical (inadequate reaction time)
- Influent efficiency higher than typical (filtrate underestimation)

Summary

Chemical phosphorus precipitation can reduce effluent phosphorus concentrations below 1 mg/L

Dosage could be optimized across the two feed points.

But significant capital and operating costs.

Questions?

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Bullpen

Chemical Properties of Common Coagulants

Chemical	Alum	PACl	ACH	Sodium Aluminate	Ferric Chloride
Typical solution strength	48%	32%	45%	38%	35%
Solution strength as % Al^{3+} or Fe^{3+}	4.4%	9.0%	13.9%	12.5%	12%
Typical solution density, lb/gal	11.1	10.8	11.1	12.7	11.4
lb Me^{3+}/gal solution	0.49	0.97	1.55	1.59	1.37
Alkalinity consumed, g $CaCO_3$/ g chemical	0.51	0.52	0.29	(-) 0.61	0.92
Alkalinity consumed, g $CaCO_3$/ g Me^{3+}	5.6	1.9	0.93	(-) 1.9	2.7

Steps to Evaluate Feasibility

Phosphorus Monitoring

Historical Data Review (Carbon, Phosphorus Loading, if available)

Wastewater Sampling

- Influent Characterization
- Effluent
- Sidestreams

Look for Optimization Strategies with Existing Infrastructure

Influent source control (industry)

Create anaerobic zones within existing tanks?

P release in storage tanks?

Major sidestream loads that could be reduced?

Can your facility meeting 1mg/l right now, without major capital upgrades? – IF YES, then DONE

Evaluate Improvements to Reduce P

EPBR – Anaerobic Zone Addition

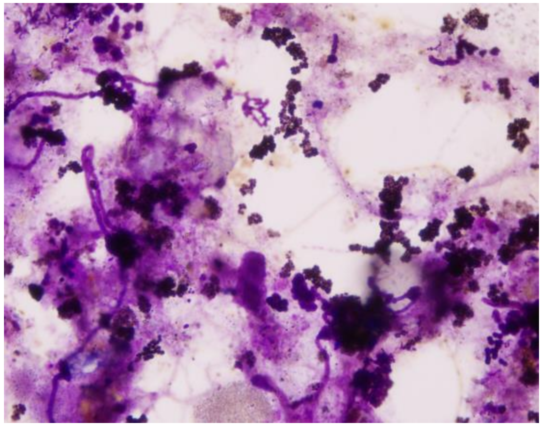
- HRT ~1-3 hours
- Create within existing tanks?
- Build new tanks?

Chemical P Removal

- Identify the best chemical for your facility
- Rule of Thumb feed rates (ie Ferric 1.3 gal/lb P removed)
- Chemical storage / feed

Bench Scale Testing – The Next Level

Chemical Phosphorus Removal Jar Tests



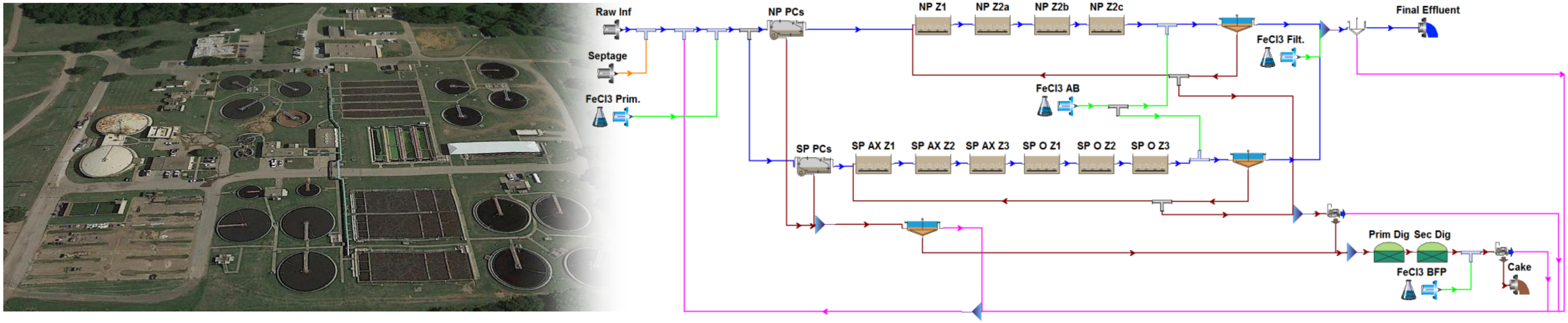
Microscopic Analysis

Biological Phosphorus Release and Uptake Testing

If You Want to Go Further with Evaluation- Process Modeling

Model can be used to evaluate:

- Feasibility of Enhanced Biological Phosphorus Removal (EBPR)
- Energy optimization opportunities
- Impacts of chemical phosphorus removal on entire plant



Determine Costs for Alternatives

Capital

1. New tankage and equipment
2. Chemical storage and feed equipment

O&M (expressed as monthly cost for OEPA form)

1. Chemicals
2. Energy
3. O&M changes

Funding Available for Nutrient Removal Projects

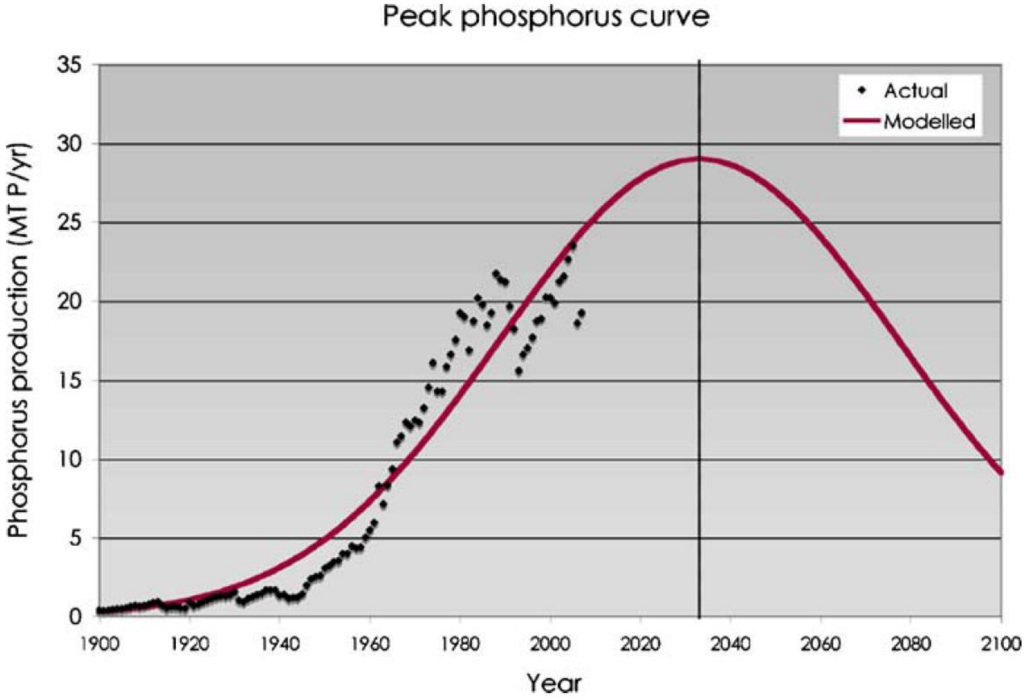
- Funds cover the project portion related to nutrient reduction
- Priority is given to the Lake Erie Watershed or other

OEPA-identified watersheds with excessive nutrients

- Nominations may be submitted through the end of 2017
- A Nutrient Reduction Project Addendum must be submitted with WPCLF application

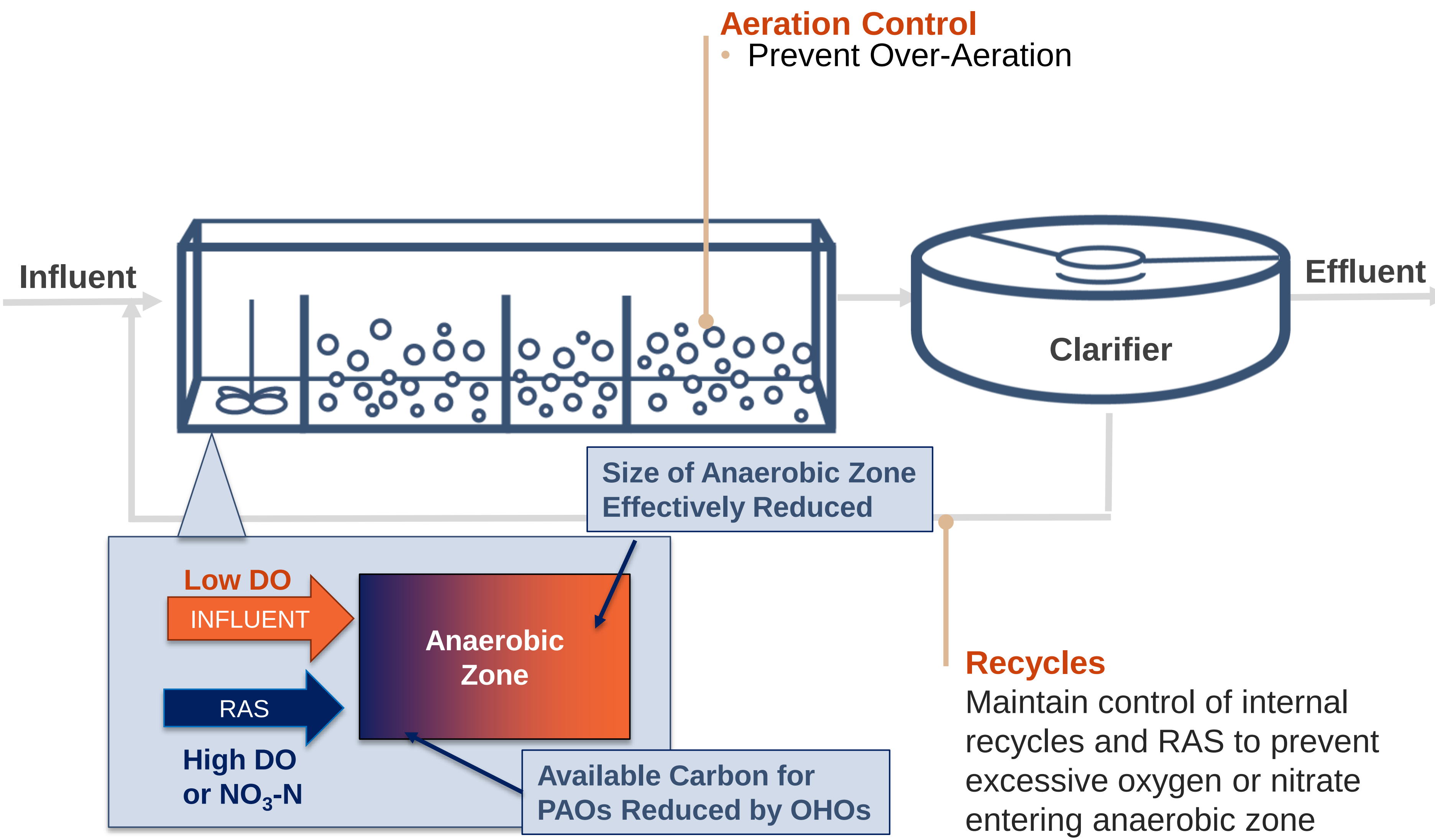
Phosphorus Recovery and Reuse

- Phosphorus is a non-renewable resource
- Natural P-ore diminishing due to growth in last 65 years.
- Price of fertilizer has skyrocketed in past 5 years

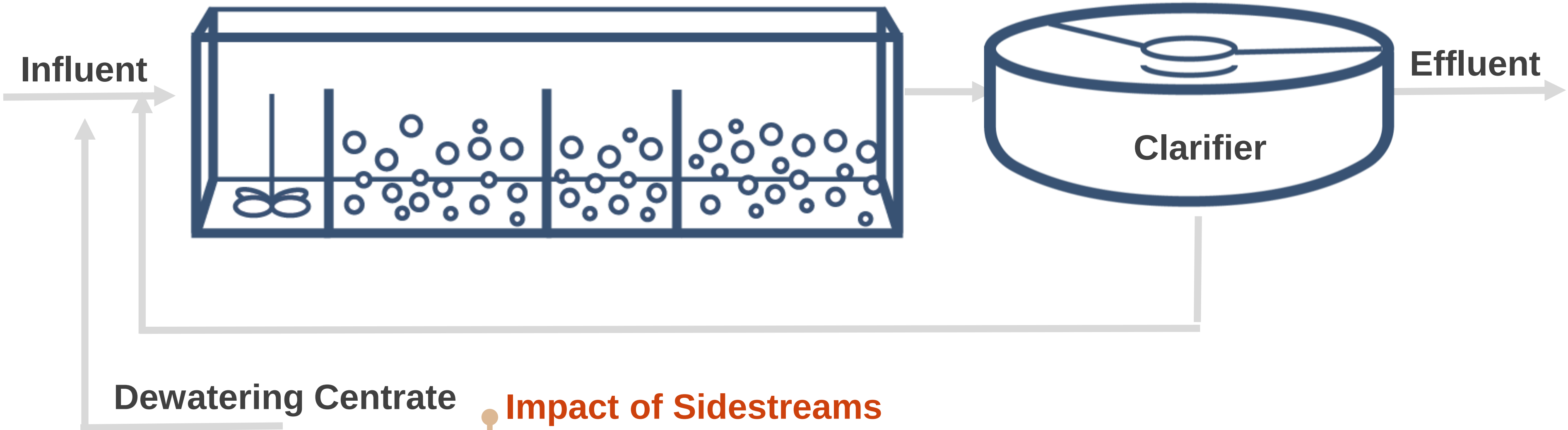


(Jasinski, 2006; European Fertilizer Manufacturers Association, 2000)

Limit NO_3 and DO Recycle to Maintain Anaerobic Zone



Increased Load from Sidestreams



Impact of Sidestreams

- Digestion or Anaerobic storage results in phosphorus release
- High TP, Low BOD
- Can contribute up to **50%** phosphorus load back onto process