Technology Update
Phosphorus Removal

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Take Home Messages

- Many approaches to reach low effluent P using proprietary & non-proprietary systems
- Generally requires multi-stage treatment entailing some form of clarification, filtration, & chemical addition
- Highly effective solids capture is central
- Removing soluble non-reactive P (sNRP) is most challenging (Typical value ≈ 0.01 mg/L)
- Reverse Osmosis (RO) is effective in removing sNRP but is costly
- Every plant is different. Site-specific testing can be very valuable. CAUTION: Pilot data may not scale up.
- Final technology selection should be based on an unbiased evaluation of available options.

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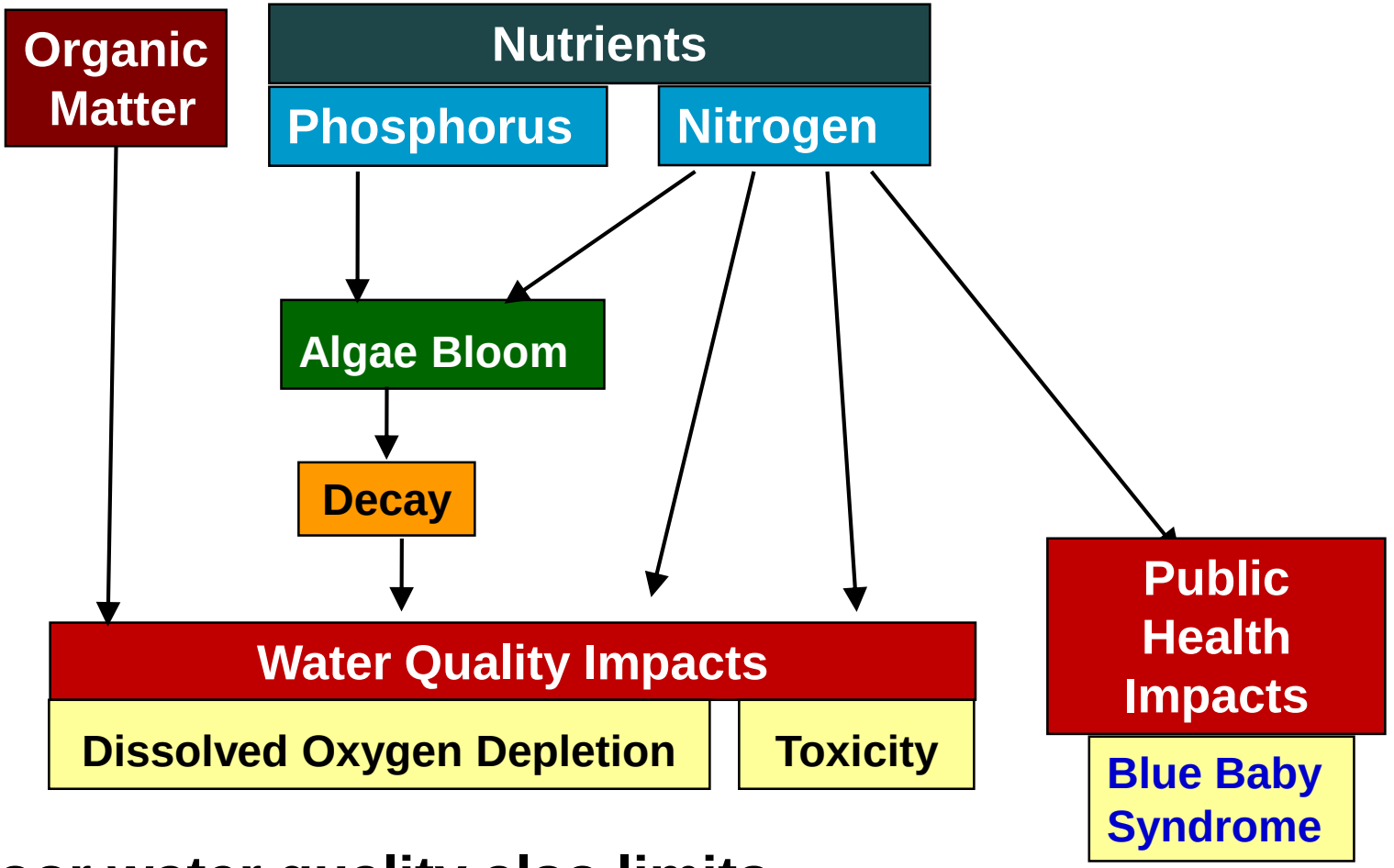
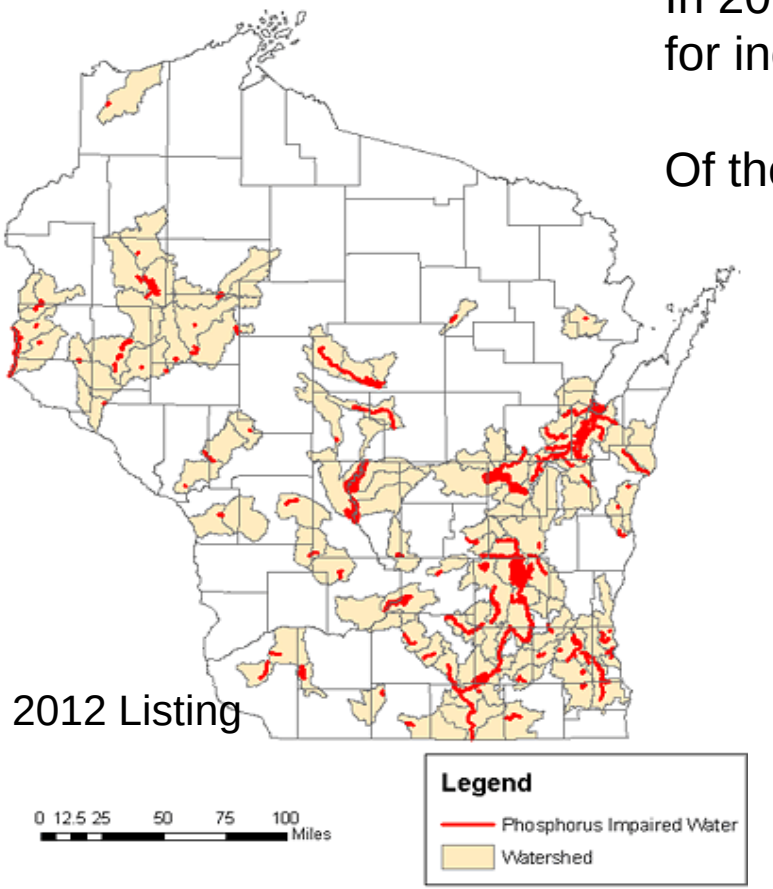
The Need to Control Nutrient Discharges



Poor water quality also limits fishing & recreational opportunities.

The Wisconsin Scene



In 2014, 192 new waterbodies proposed for inclusion in impaired list

Of these 65% exceed TP criterion

- **No. of discharge permits ≈ 540**
- **Current limit for many plants: 1.0 mg/L TP**
- **>50% of the plants will have limits approaching 0.1 mg/L TP or less**
- Statewide compliance cost estimate
  - Generic: $1.3 to 1.8 billion
  - Accrual site-specific cost reported: 1.1 to 2.4 times

http://www.jsonline.com/news/wisconsin/96995454.html
http://dnr.wi.gov/news/mediakits/mk_phosphorus.asp

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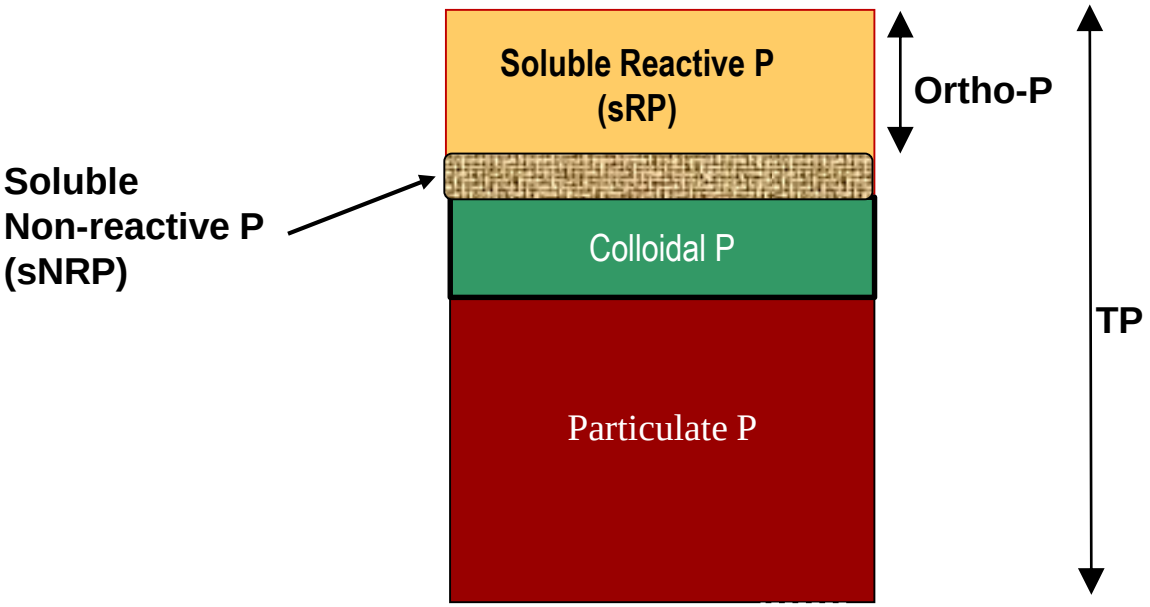
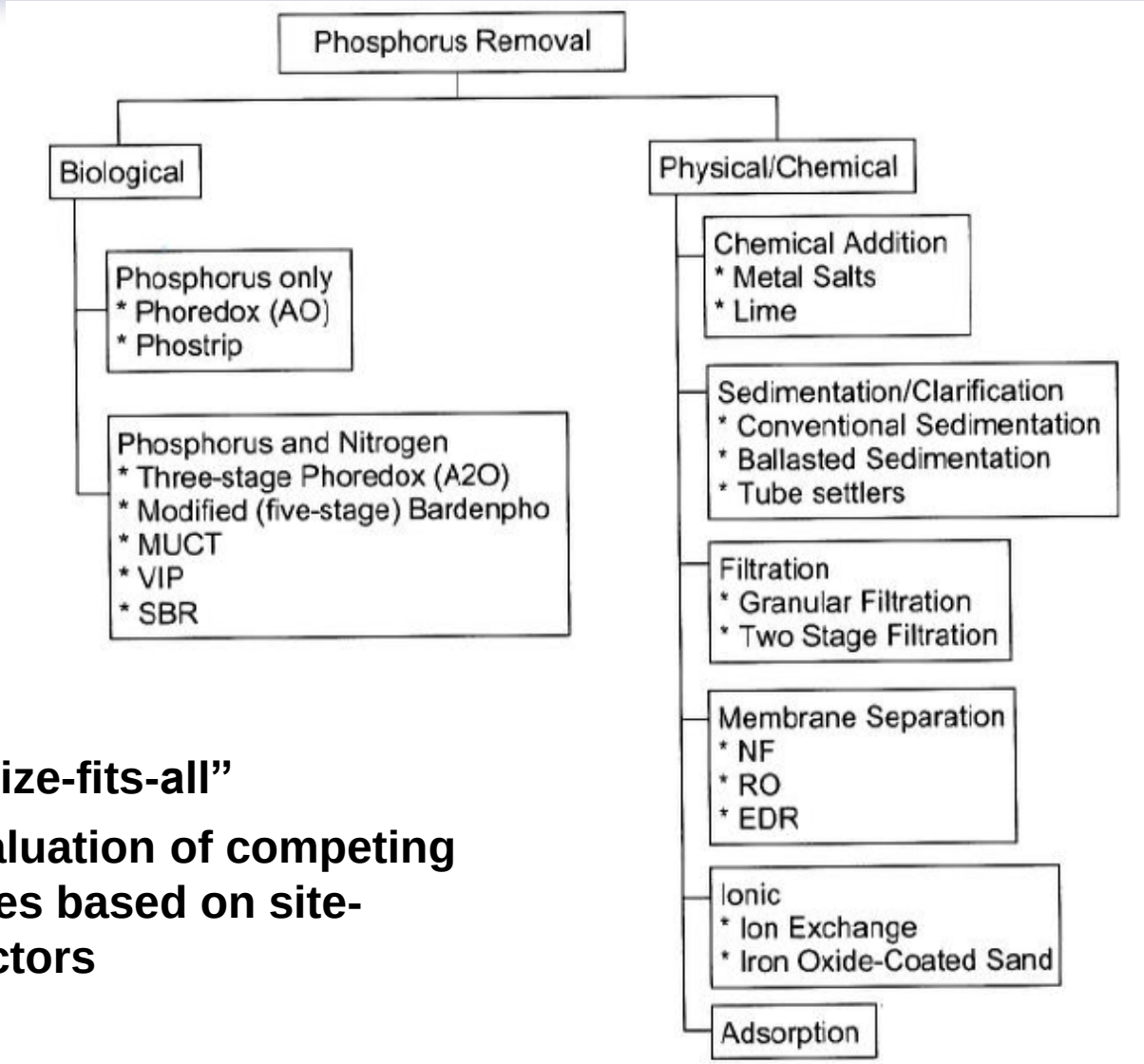
Phosphorus Speciation Terminology



EBPR: Enhanced biological P removal
Chem-P: Chemical P removal

Phosphorus Removal Alternatives



- **No "One-size-fits-all"**
- **Careful evaluation of competing technologies based on site-specific factors**

Phosphorous Removal

Phosphorus removal occurs in all WWTPs due to metabolic requirements;

- Secondary sludge contains about 2% P by weight
- Up to 3 mg/L P removed - inadequate for environmental protection

Two methods available for additional P removal:

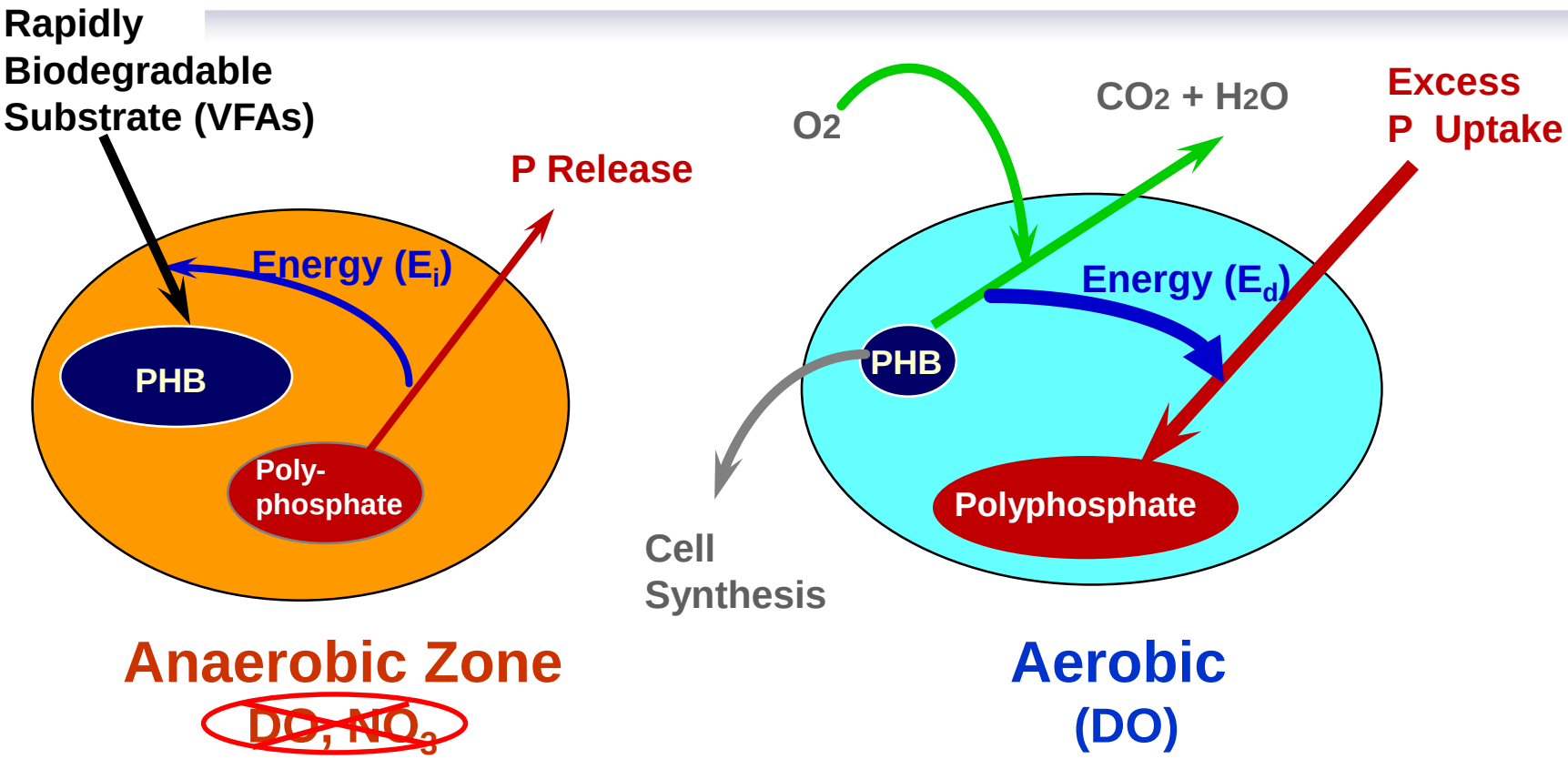
- Chemical
- Biological

Basic concept:

Sol. Reactive P (sRP) → Particulate P ↓

Phosphorus removal occurs when sludge is wasted

Enhanced Biological P Removal (EBPR) Mechanism



Why does *EBPR* work

Energy Investment = E_i

Energy Dividend (E_d)= 24 – 36 x E_i

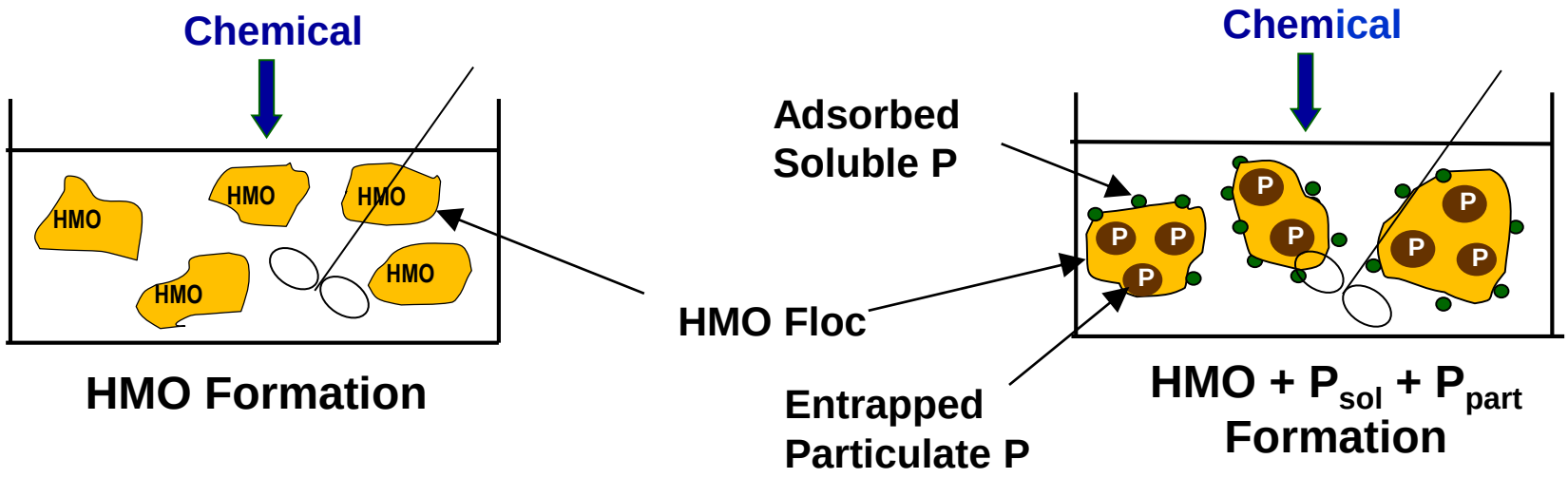
PHB: Poly-β-hydroxybutyrate

Introducing Phosphorus Accumulating Organisms in Person!

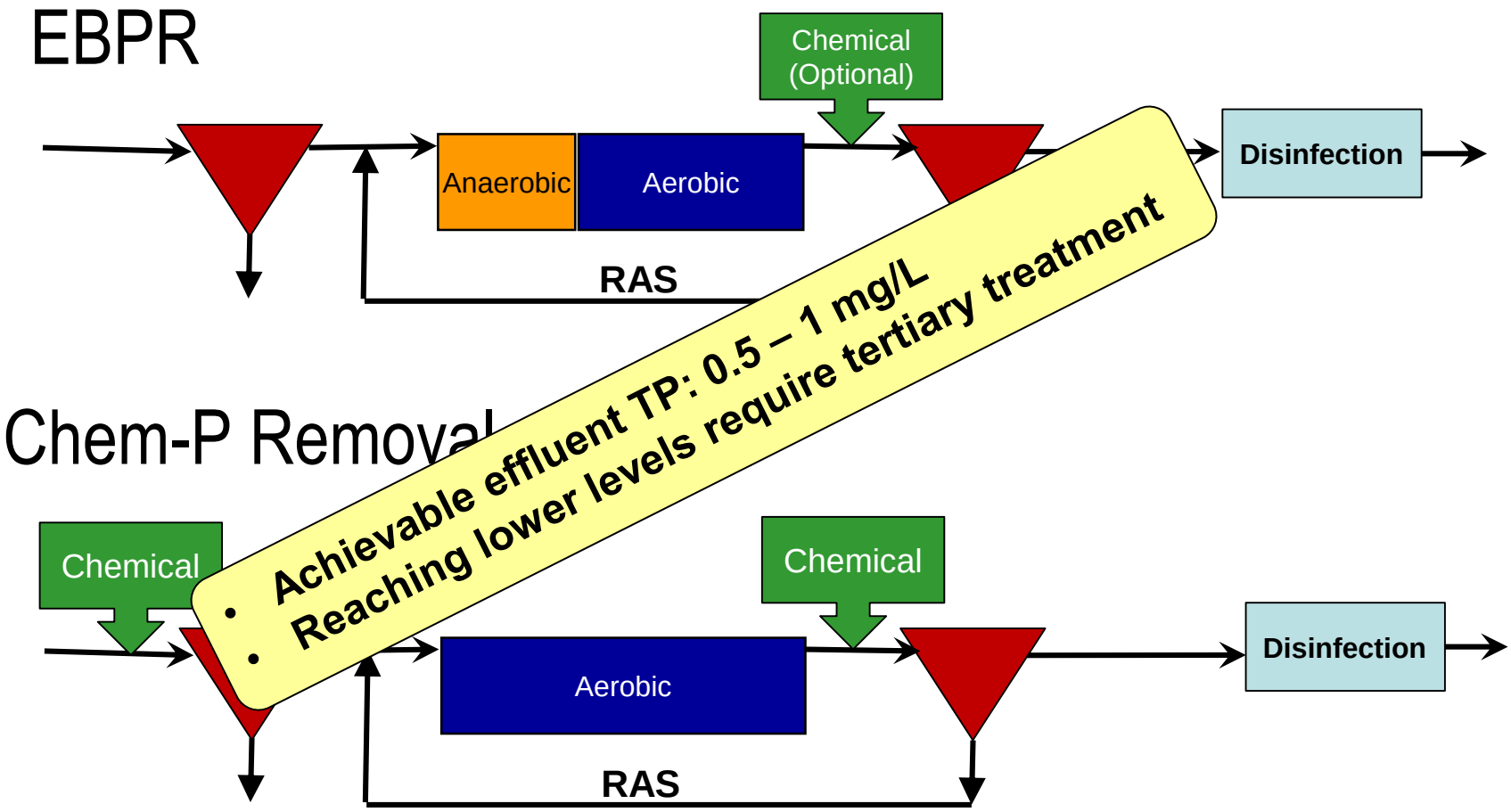
Current Understanding of the Chem - P Removal Mechanism

Fe & Al salts are most commonly used.
Recent plant data do not support the long-held view that P is precipitated.
Actual mechanism involves:

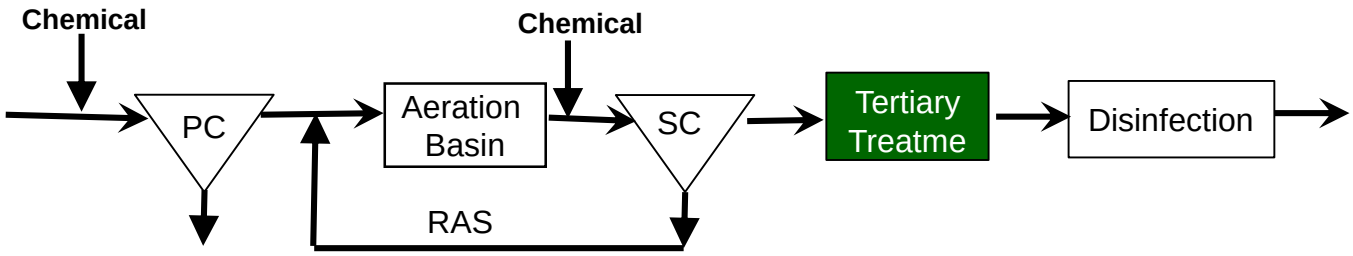
1. Reaction with alkalinity to form hydrous metal oxide (HMO) floc
2. Soluble P adsorbs to HMO reactive sites
3. Co-precipitation: HMO enmeshes colloidal & Particulate P



Conventional P Removal



What is Tertiary Treatment?

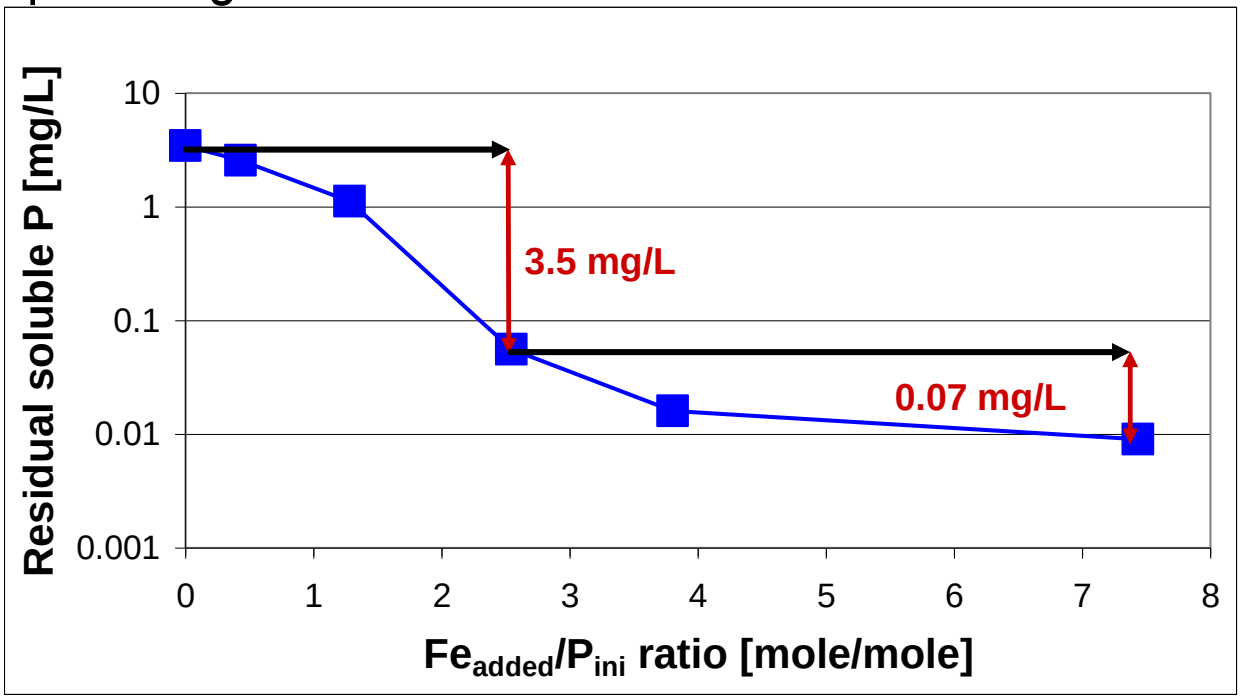


- Tertiary treatment follows final clarifiers & typically entails
  - Clarification
  - Filtration
  - Chemical addition
- Need to understand
  - Chemical reactions involved
  - Effluent P speciation & solids capture
  - Available technologies and their capabilities
  - Integration challenges & plant-wide impacts
  - Wet Weather operations

Achieving Low Effluent P Requires Higher than Stoichiometric Me/P Ratio

In typical wastewater with sufficient mixing and alkalinity:

- Initial rapid reaction; significant P removal. Stoichiometric Me:P ratio
- Removal of the remaining P is more difficult; reaching low effluent P requires high Me:P ratio



*** Szabó, A., I. Takács, S. Murthy, G. T. Daigger, I. Licskó, and S. Smith, "Significance of Design and Operational Variables in Chemical Phosphorus Removal," *Water Environment Research*, 80, 407-416, 2008.**

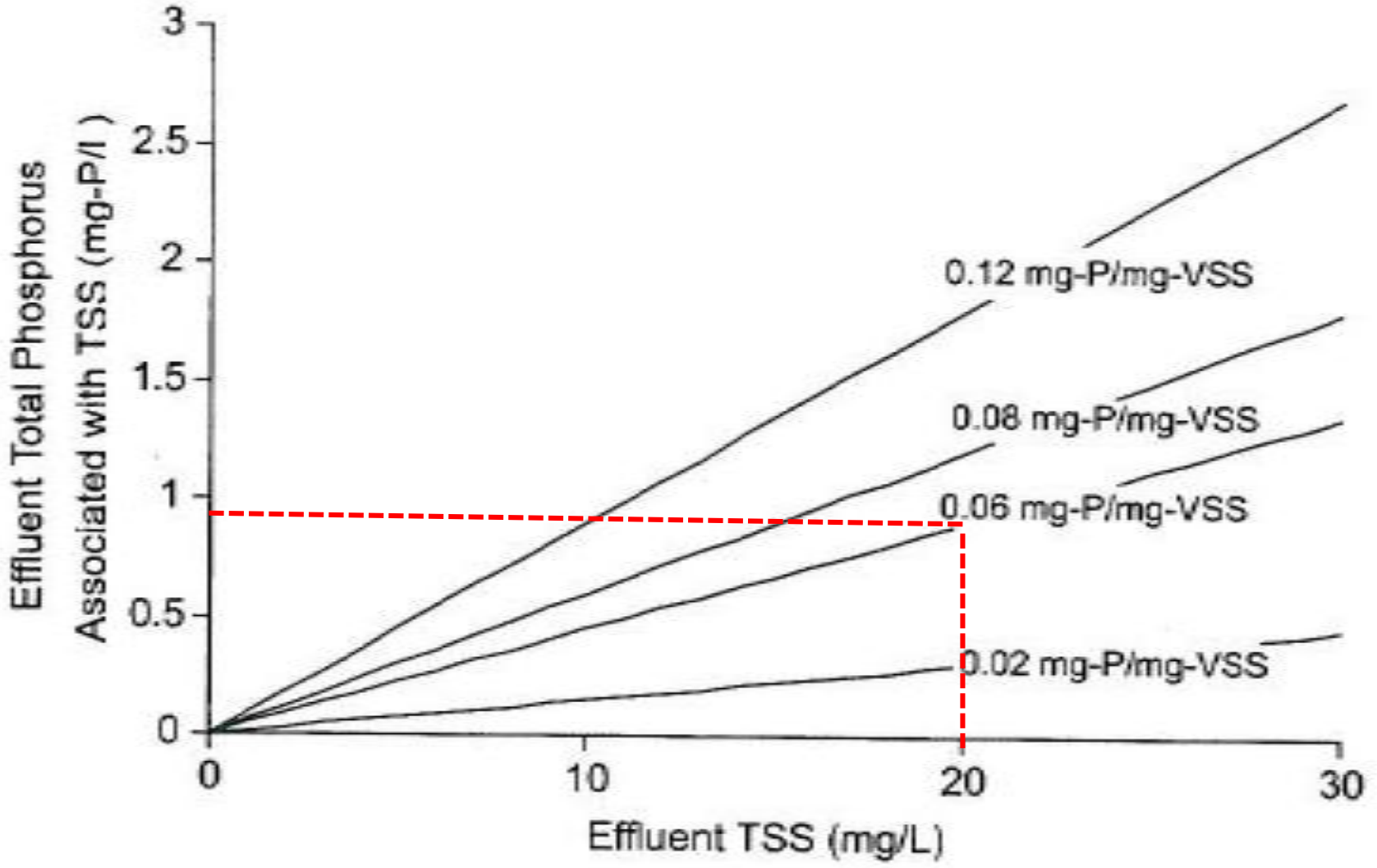
Achieving Very Low Effluent TP Requires Analysis of Constituents

Constituent	Secondary Effluent TP (0.4 mg/L as P)	Limitation	Typical Very Low Plant Effluent TP[1] (0.04 – 0.055 mg/L as P)
Soluble Orthophosphate	0.02	Solubility of Metal Phosphate	0.01-0.02
Particulate	0.3 (at 10 mg/L TSS)	Solids Capture	0.01 (at 2 mg/L TSS)
Colloidal	0.08	Solids Coagulation and Filtration	0.02-0.025

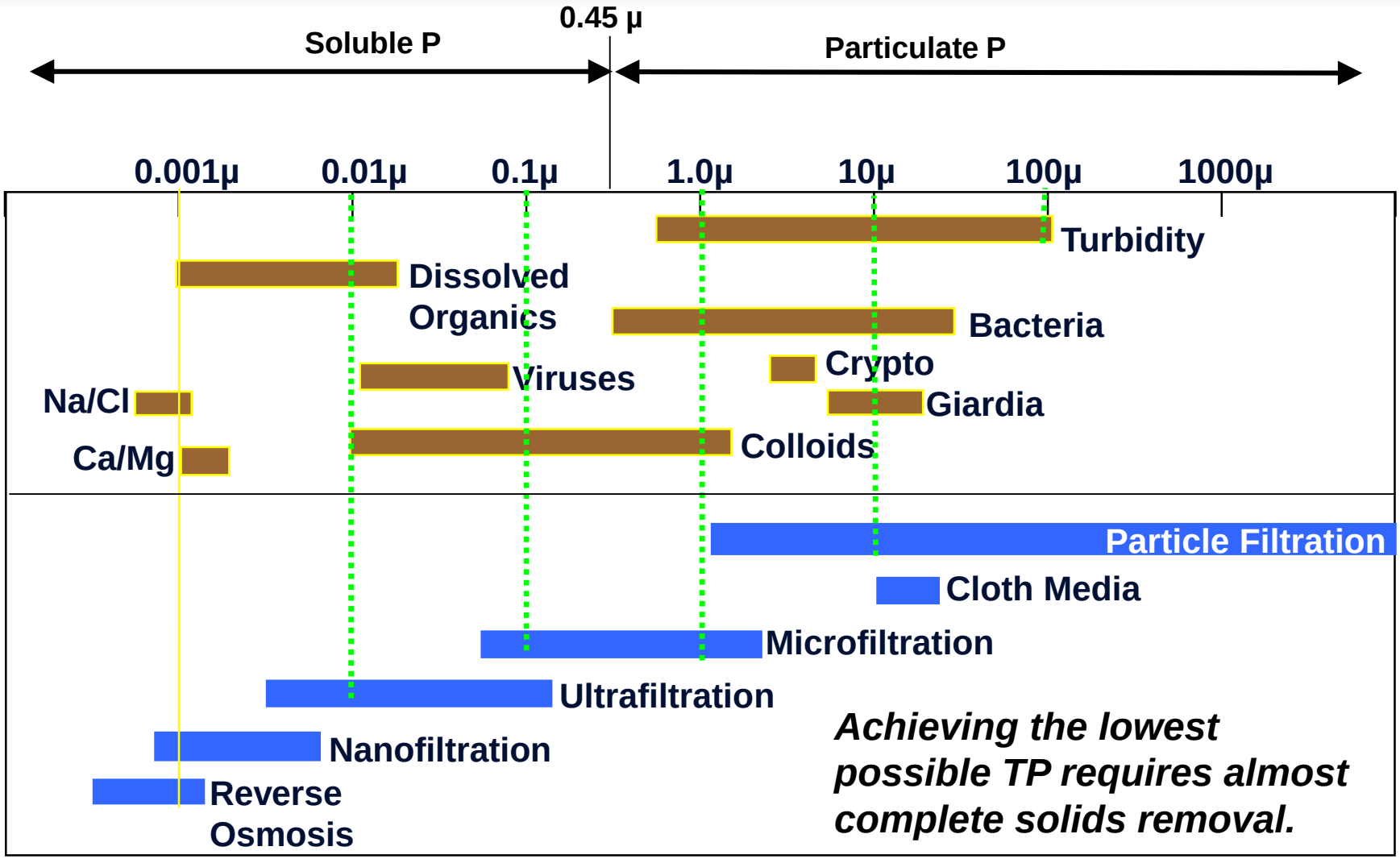
Based on Data From Rock Creek WWTPs

Every plant is unique!

Impact of Effluent TSS



Efficient Solids Capture is Crucial



Conventional Filtration

- Filter Types
  - Granular media
  - Cloth filters
  - Moving bed filters
  - Traveling bridge filters
- Conventional filtration following EBPR or Chem-P removal can achieve **0.1 mg/L T**P
- Often called the Limit of Technology

To reach <0.1 mg/L TP, Tertiary Chemical Addition & Solids Capture Required

- Potential technologies
  - Tertiary clarification + filtration
  - Two-stage filtration
  - Low-pressure membrane filtration
  - Reverse osmosis
  - Adsorption

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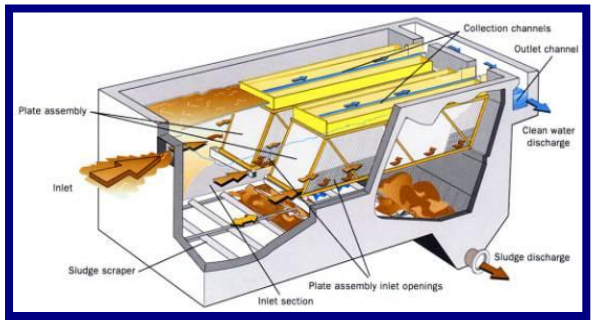
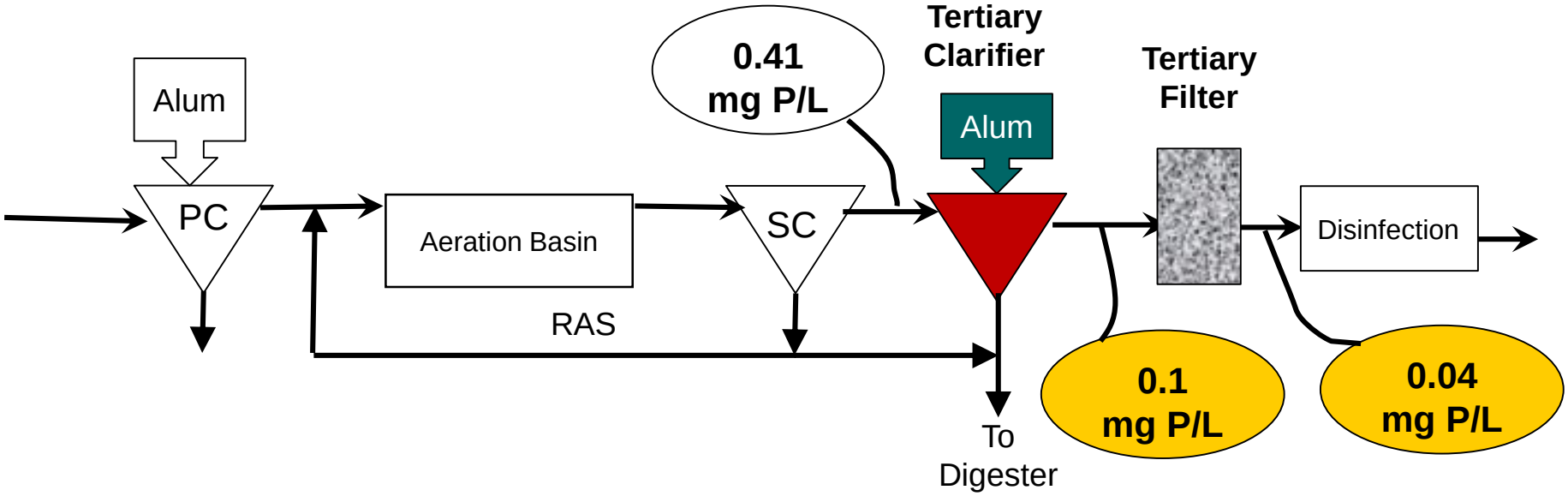
Tertiary Clarification

- What is it?
  - Clarifier operating on secondary effluent
  - Metal salts and polymer
  - Can use Actiflo® or Densadeg®
- What's the benefit?
  - Additional sol. P removal
  - Removal of colloidal P (coagulation/flocculation)
  - Improved particulate P removal, but not for the reasons one might think!
    - TP / TSS ratio is reduced through "dilution" with metal hydroxide floc



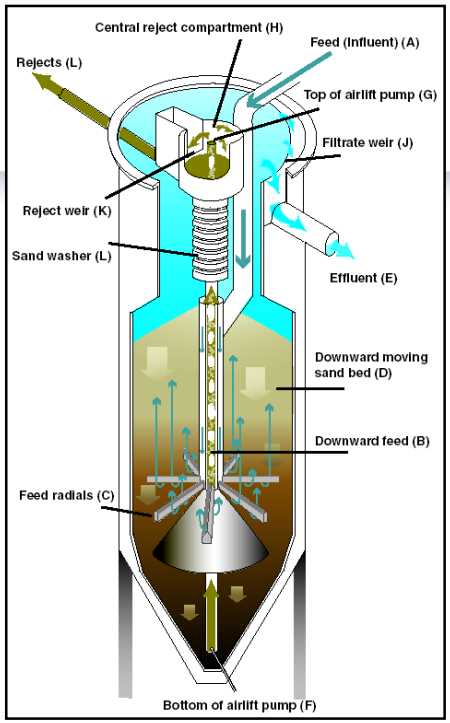
Rock Creek AWTF, Hillsboro, OR
(2-Point Chem. Addition + Tertiary Clarification + Filtration)



- Permit limit: 0.07 mg/L TP (Monthly median)
- Minimum soluble phosphorus: 0.01 to 0.02 mg/L (sNRP)

Tertiary Filtration

- Proprietary & non-proprietary
- Two-stage filtration
  - Granular media
  - Moving bed
  - Continuous-backwash
  - DynaSand® D2 (Parkson)
  - Blue PRO® (Blue Water Technologies)



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Blue PRO™ Reactive Filter

- Sol. P adsorbed by hydrous ferric oxide (HFO) coated sand in a moving bed filter
- HFO & adsorbed P are abraded from the sand & wasted
- Sand re-coated with fresh HFO

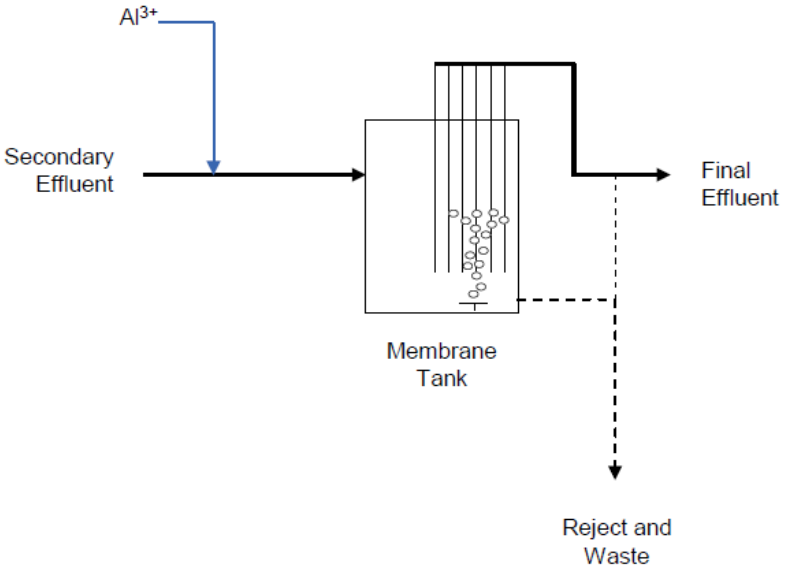
Sand Grain

HFO Coated Sand

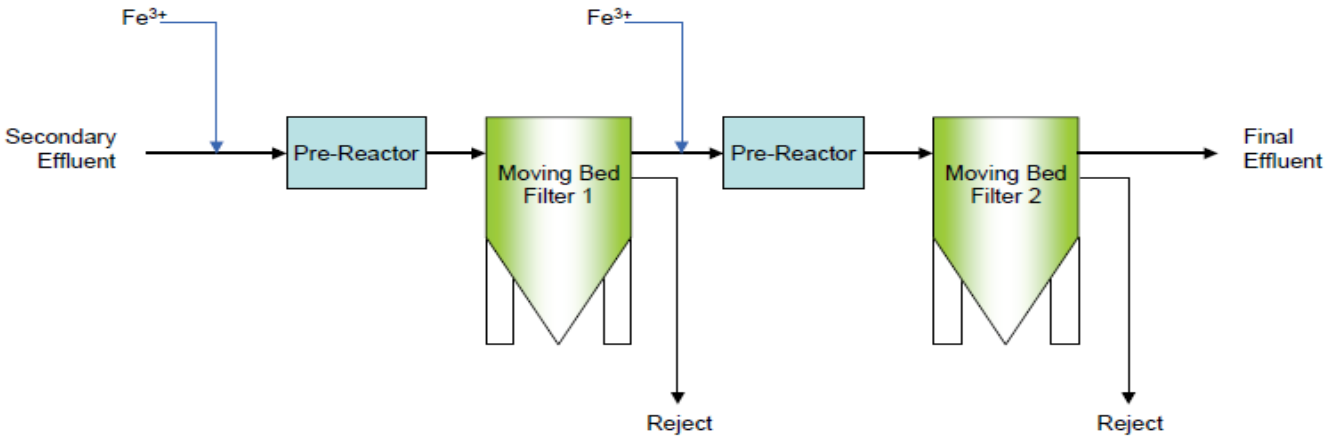
Hayden, ID Pilot Testing

- Average results:
  - Influent 0.69 mg/L TP
  - Effluent 0.011 mg/L TP

Side-by-Side Comparison of Four Technologies



Zenon Zeeweed 500 UF membrane



Dual Stage Blue PRO

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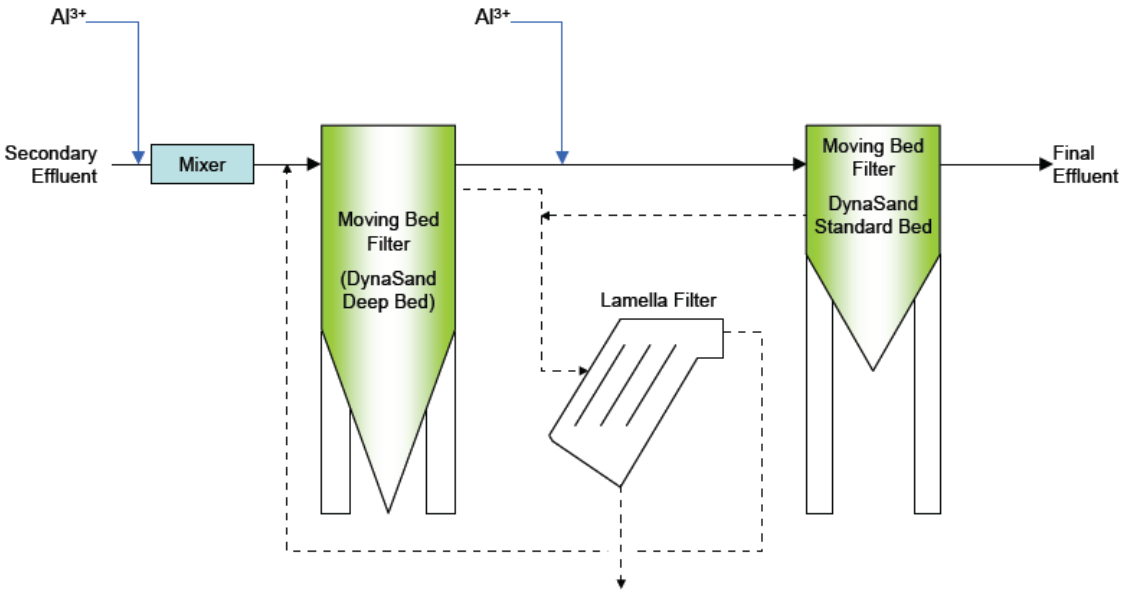
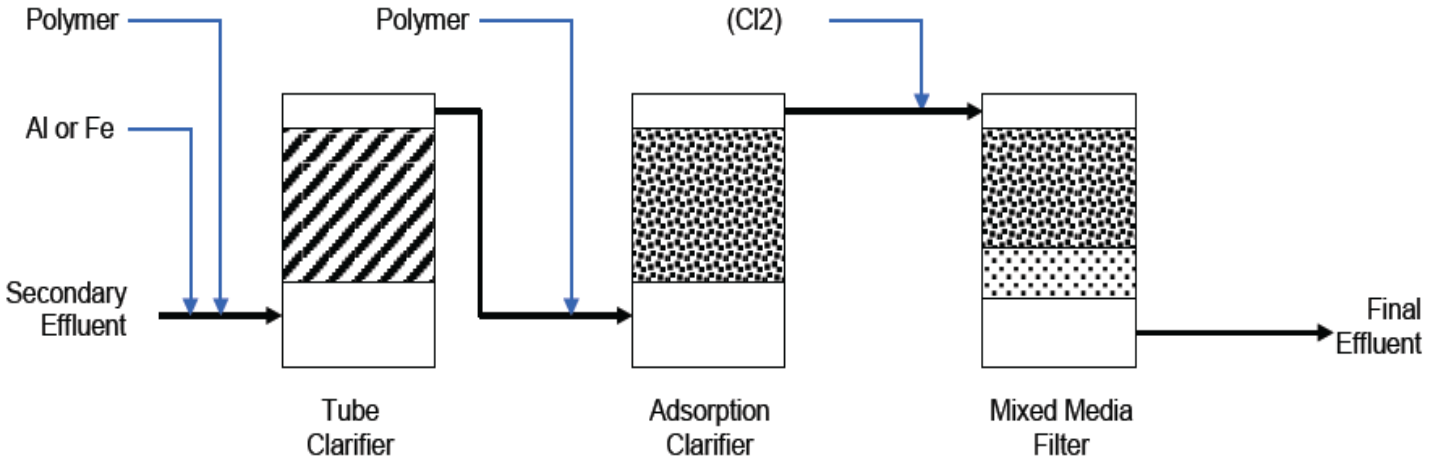


Parkson DSD2 Advanced Filtration System

USFilter Trident HS 1



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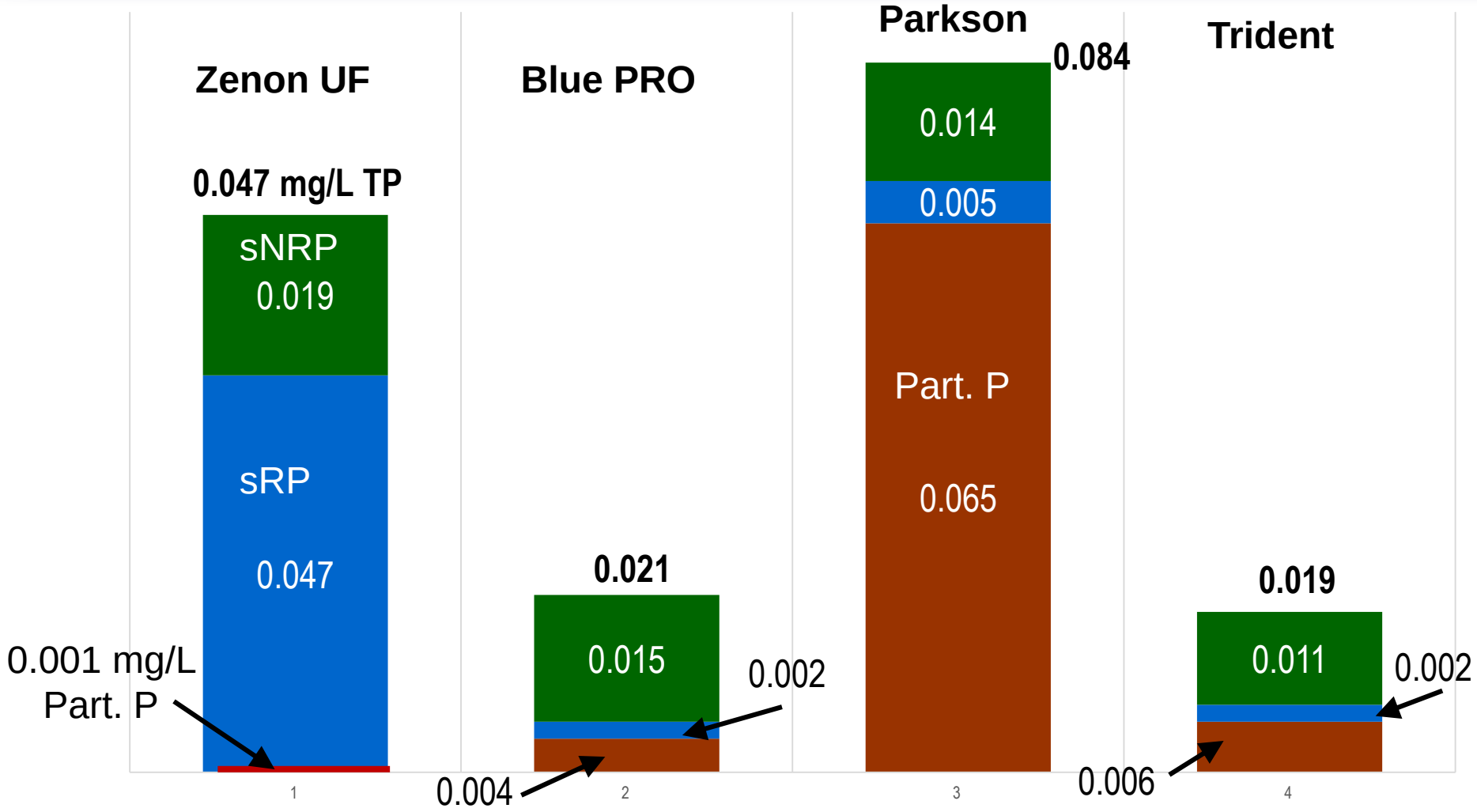
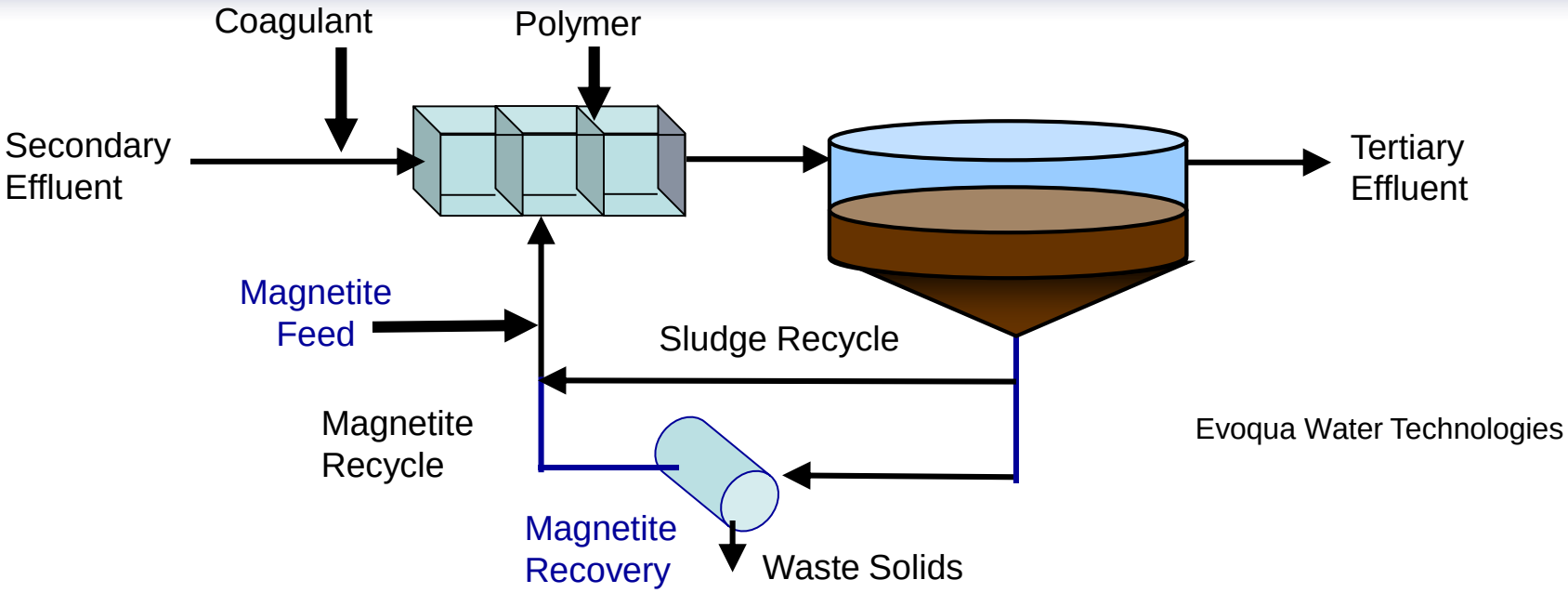


Innisfil, Ontario Pilot Testing

- Head-to-head pilot testing
  - ZENON tertiary ultrafiltration (UF)
  - Blue PRO reactive filtration
  - ACTIFLO
  - Parkson DynaSand D2

Component mg/L	Zenon UF	Blue PRO	Actiflo	DynaSand
TP	0.015	0.015	0.031	0.022
Sol. P	0.012	0.013	0.018	0.016
Part. P	0.003	0.002	0.013	0.006

Co-Mag™ Magnetite Ballasted Technology



Magnetite

- Fully oxidized iron ore (Fe_3O_4)
- Doesn't rust or degrade
- Inert
- Non-abrasive (10 - 30 microns)

Favorable Properties

- Spec. gravity: 5.2
- Hydrophobic: affinity to embed in floc
- Magnetically retrievable
- Readily available ~30¢/lb

Effl. TP achievable ~ 0.02 mg/L
Magnetite consumption: < 10 lb/mgd

What About Membrane Bioreactors?

- Activated sludge with membrane solids separation
- Metal salt added to remove P
- Low-pressure membranes (MF or UF) block biomass and precipitates
- Fine line between removing all ortho-P and leaving just enough for bacterial metabolism
- ZENON MBR pilot system averaged 0.021 mg/L TP (range 0.013 to 0.029 mg/L TP)

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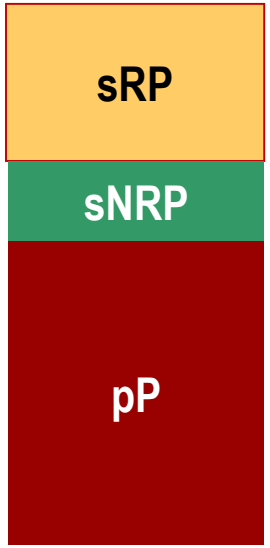
Comparison of Tertiary Treatment Technologies (0.01 mg/L Effl. TP)

WERF



Unit Process	sRP	sNRP	pP
Metal salt addition	+++	+	++
Sedimentation & Ballasted sedimentation	-	-	+
Direct filtration	-	-	++
Sedimentation-filtration	-	-	+++
2-stage filtration	-	-	++++
Reactive filtration (Fe oxide coated sand)	+++	?	+++
Membrane filtration	-	-	+++
Reverse osmosis	++++	+++	++++

Operational Aspects

- Impact on UV disinfection
- Increased sludge production
- Alkalinity consumption
- Good upstream treatment is essential:
  - Management of recycle loads (e.g. nutrient recovery)
  - Additional clarification capacity
- Wet weather operation – unpredictable wastewater characteristics
  - Hold on to the bugs (e.g. step-feed, proper clarifier design, SVI control, etc.)
  - Excess wet weather flow management/treatment
- Redundancy

Take Home Messages

- Effluent TP is highly variable, even from best performing plants.
- Many approaches to reach low effluent P
- Generally requires multi-stage treatment entailing some form of clarification, filtration, & chemical addition
- Highly effective solids capture is critical
- Removing soluble non-reactive P (sNRP) is most challenging (Typical value ≈ 0.01 mg/L)
- RO is effective in removing sNRP but is costly

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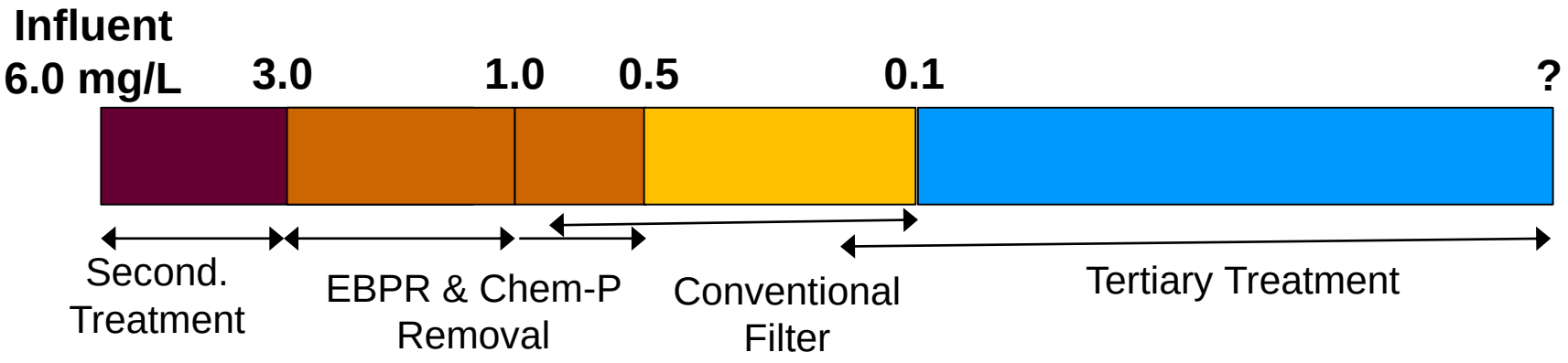
Take Home Messages

- Every plant is different. Site-specific testing can be very valuable. CAUTION: Pilot data may not scale up.
- Final technology selection should be based on an unbiased evaluation of available options.
- Wastewater treatment plant is like a spider web!
- Do not take chances when pushing the envelop – provide ‘safety net’
- How low can we go……..it depends!

In Closing….



Lowest attainable TP will depend on sol. non-reactive P.

Disclaimer

- Not all data presented herein were generated by CH2M HILL. Original sources are not acknowledged.
- This presentation does not endorse any system.

Questions?

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