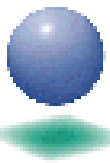


General Operational Considerations in Nutrient and Wet Weather Flow Management for Wastewater Treatment Facilities *Part I*

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CH2MHILL

Ohio WEA Plant Operations
Workshop
September 28, 2011

Presentation Outline

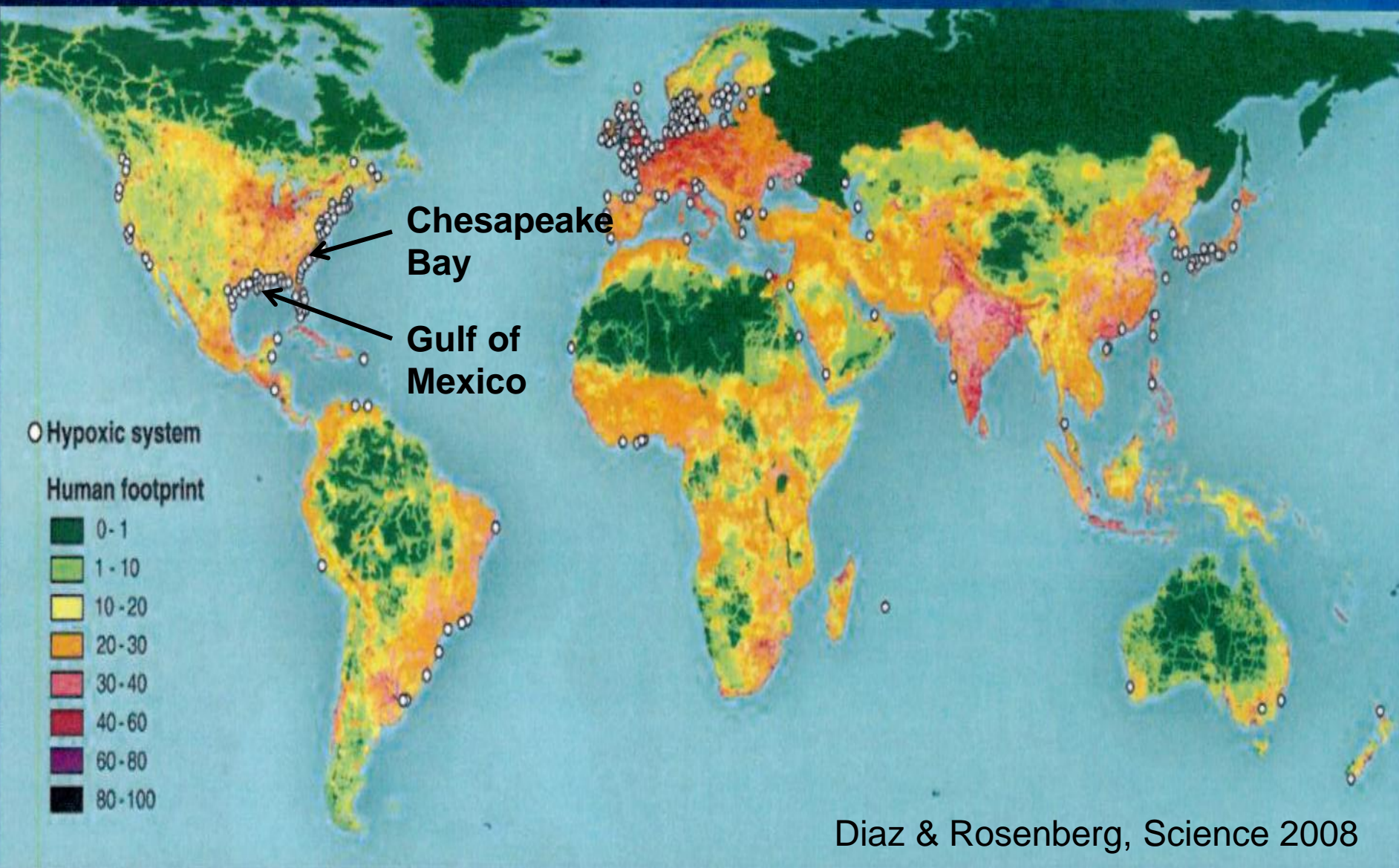
- Why Remove Nutrients?
 - Overview of Wastewater Treatment
 - Nutrient Removal Fundamentals
 - Phosphorus Removal
 - Nitrogen Removal
 - Sustainability Considerations
 - Design & Operational Considerations
 - Managing Wet Weather Flows in Nutrient Removal Facilities
- Part I
- Part II
- Part III



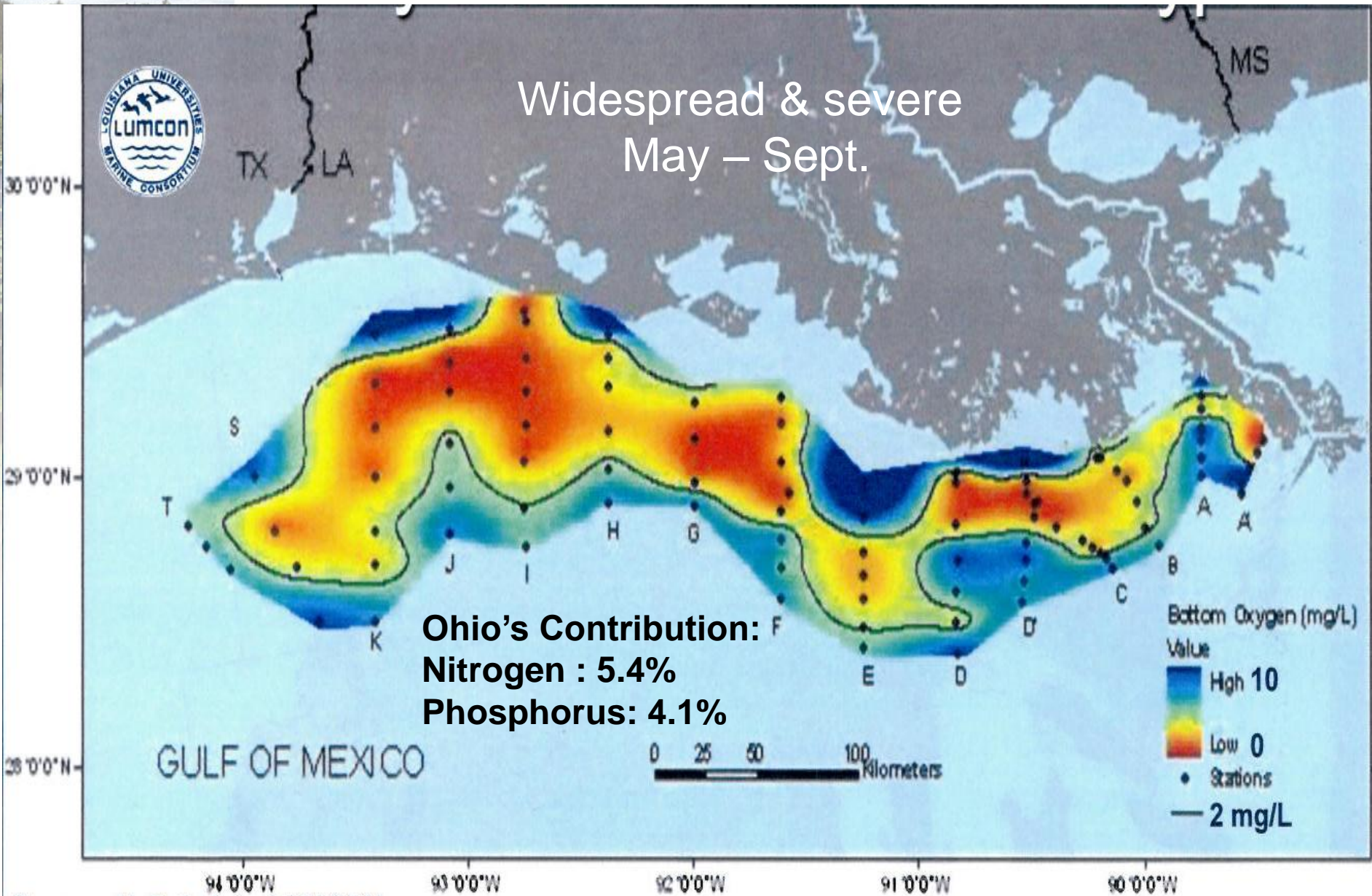
Presentation Outline

- **Why Remove Nutrients?**
- Overview of Wastewater Treatment
- Nutrient Removal
- Sustainability Perspective
- Design & Operational Considerations
- Take Home Messages

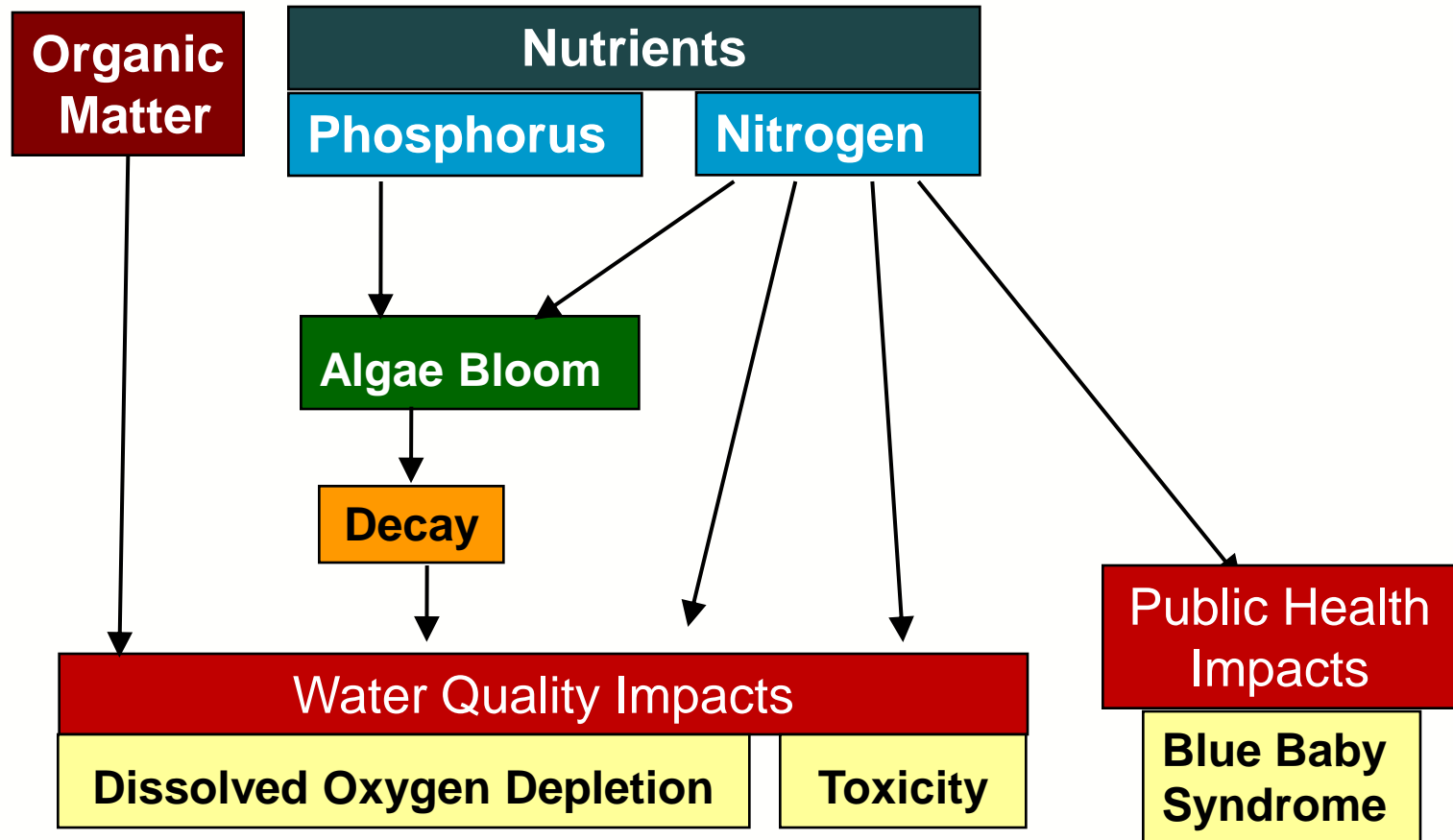
Human Footprint vs. Hypoxia



Bottom-Water Hypoxia (21-27 July, 2007)



The Problem with Nutrients



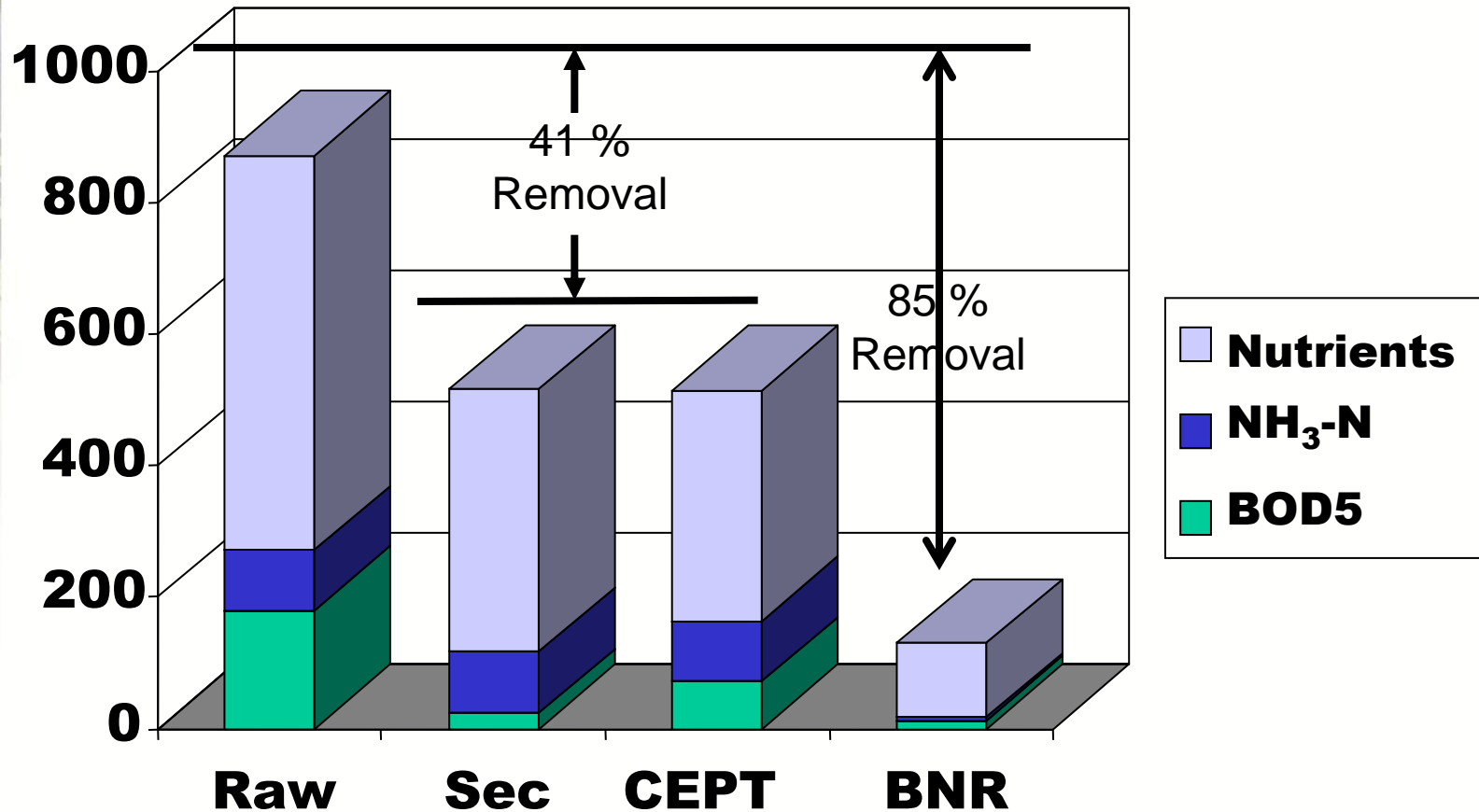


Oxygen Consumption Potential (OCP) Measures O₂ Demand

$$\begin{aligned} \text{OCP} = & \\ & 1.2 \times \text{cBOD}_5 + \\ & 4.6 \times \text{NH}_3\text{-N} + \\ & \text{Greater of } (100 \times \text{TP}; 14 \times \text{TN}) \end{aligned}$$

*Measures environmental impact
of discharging untreated
wastewater*

OCP Comparison Shows Why Nutrient Removal an Issue





The Current Ohio Scene

- Total 4100 NPDES permits
- 188 WWTPs have TP limits
 - Mostly 1.0 mg/L
 - Some 0.5 mg/L
- 353 WWTPs required to monitor TP
 - Many will see a TP limit in the future
- TN limit – Not anticipated in the near future



Presentation Outline

- Why Remove Nutrients?
- **Overview of Wastewater Treatment**
- Nutrient Removal
- Sustainability Perspective
- Design & Operational Considerations
- Take Home Messages



The Three Most Important Considerations in Biological Treatment

Bugs, Bugs, Bugs.....

| Organism | Energy Source | Carbon Source | Oxygen Source | Process |
|--------------|------------------------------|------------------------------|------------------|------------------------------------|
| Heterotrophs | Organic (BOD) | Organic | Dissolved Oxygen | • BOD removal • Biol. P Removal |
| | | | NO ₃ | • Denitrification |
| Autotrophs | Inorganic (NH ₄) | Inorganic (CO ₂) | Dissolved Oxygen | • Nitrification |

Municipal wastewater contains what the bugs need!



If We Provide they Will Come...

“Everything is Everywhere, Environment Selects.”

We select the bugs we need by providing the right environment for them to grow.

However, this could also favor the growth of nuisance organisms

Let's Make a Cake!

“Wastewater treatment is like making a cake!”

- Right ingredients; right amounts
 - Air, food, bugs, environment etc.
 - ***Stoichiometry***
- Right baking time & temp.
 - Solids Retention Time (SRT), HRT is incidental!
 - ***Kinetics***

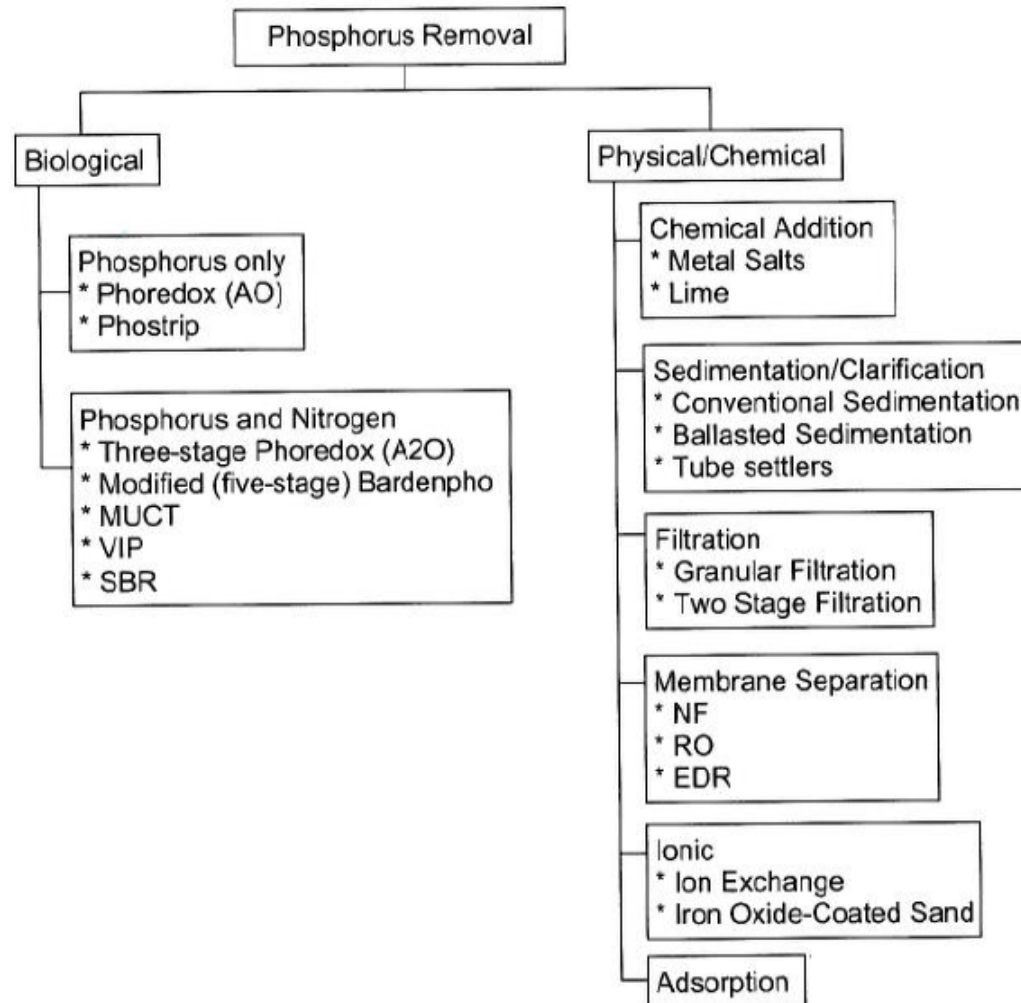
Both are
equally
important



Presentation Outline

- Why Remove Nutrients?
- Overview of Wastewater Treatment
- **Nutrient Removal**
 - **Phosphorus Removal**
 - Nitrogen Removal
- Sustainability Perspective
- Design & Operational Considerations
- Take Home Messages

Phosphorus Removal Alternatives



Phosphorous Removal

Phosphorus removal occurs in all WWTPs due to metabolic requirements

- Secondary sludge contains about 2% P by weight
- Not sufficient for environmental protection

Two methods available for additional P removal:

- Chemical Phosphorous Removal
- Biological Phosphorous Removal

Basic concept:

Reactive P
(mostly ortho-P)



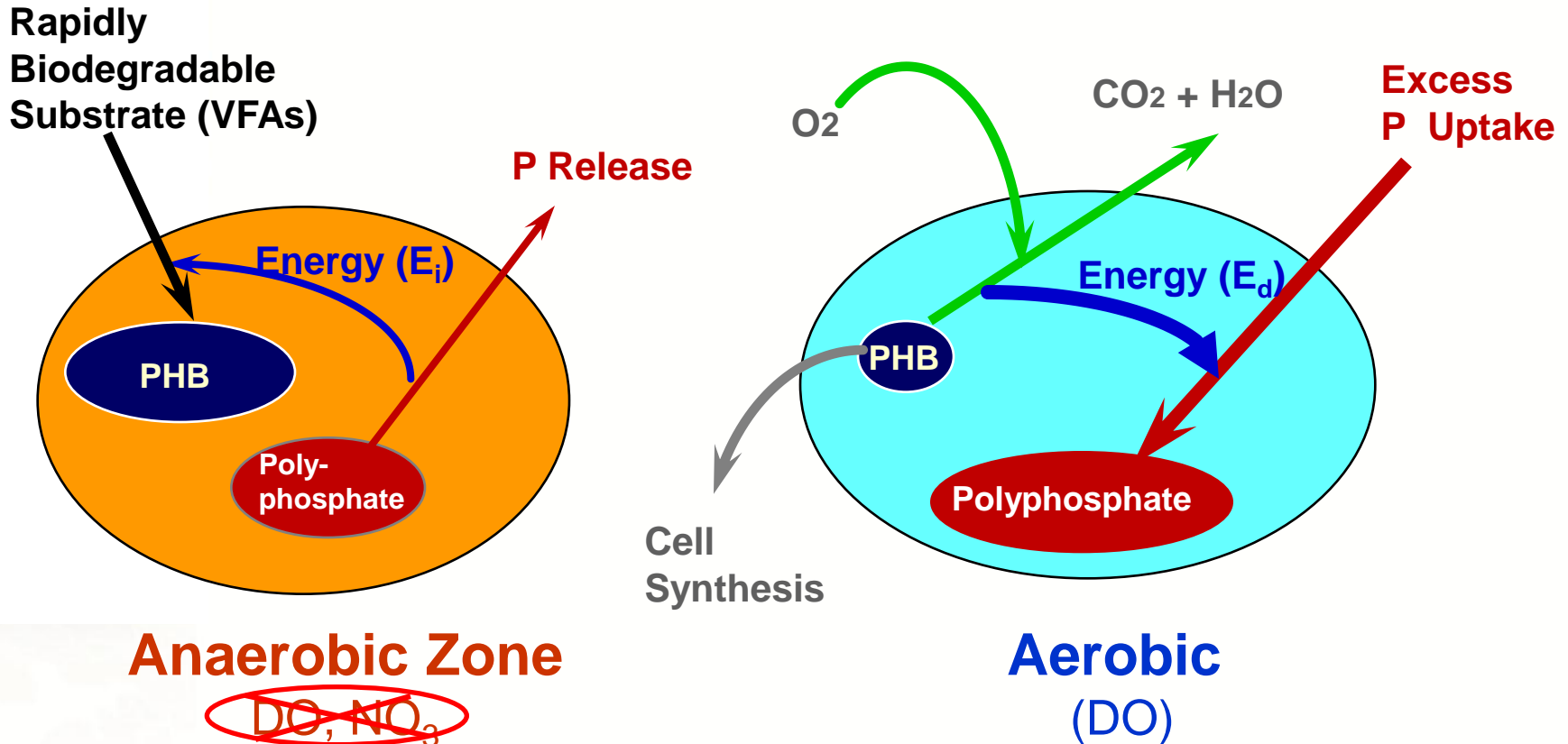
Particulate P ↓

Phosphorus removal occurs when sludge is wasted

Biological Phosphorus Removal

- Removal exceeding metabolic requirements
 - Enhanced Biological P removal (EBPR)
 - Luxury P removal
 - Excess P removal
 - Bio-P
- Mediated by specialized heterotrophs, Phosphorous Accumulating Organisms (PAOs)

Enhanced Biological P Removal (EBPR) Mechanism



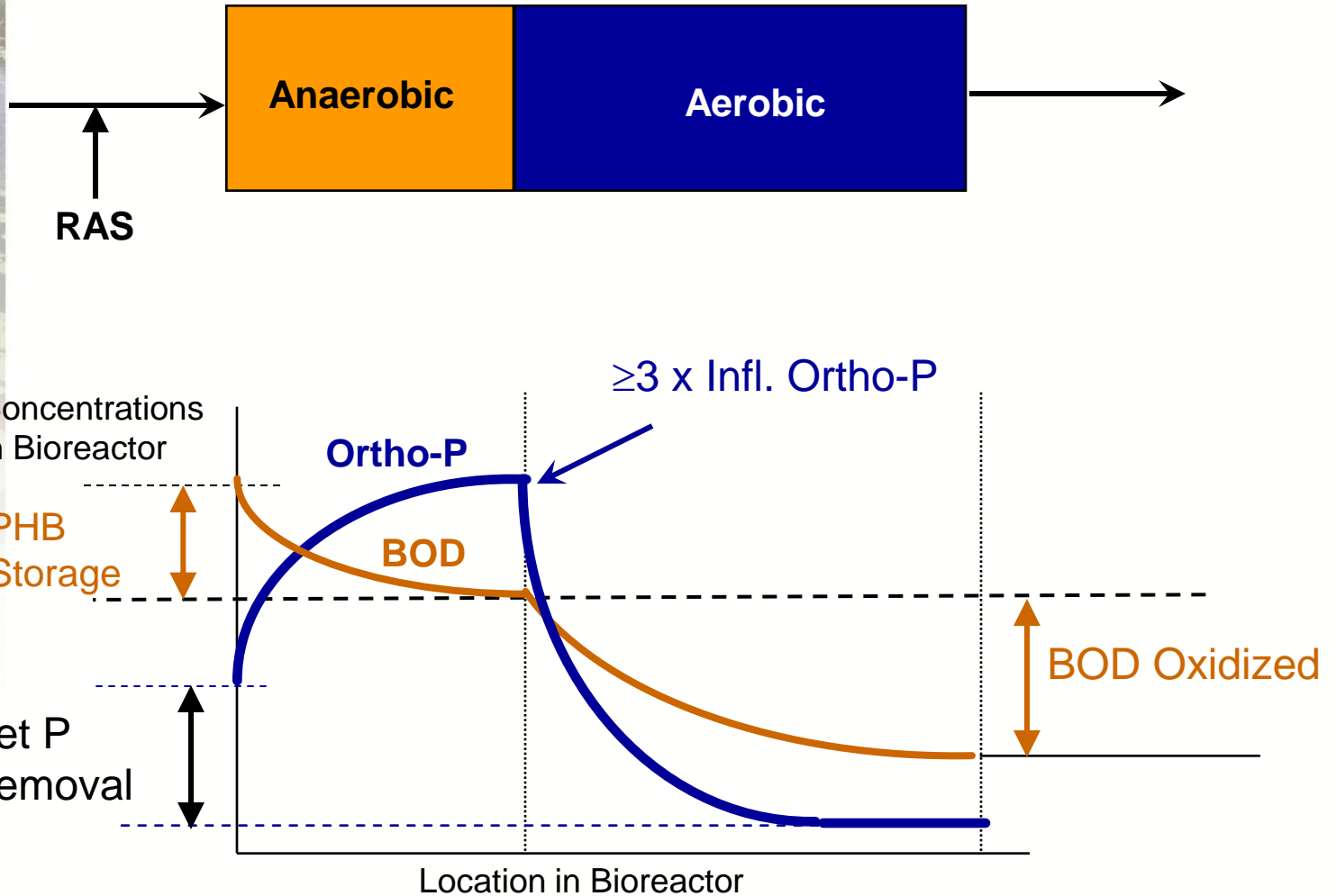
Why does *EBPR* work ?

Energy Investment = E_i

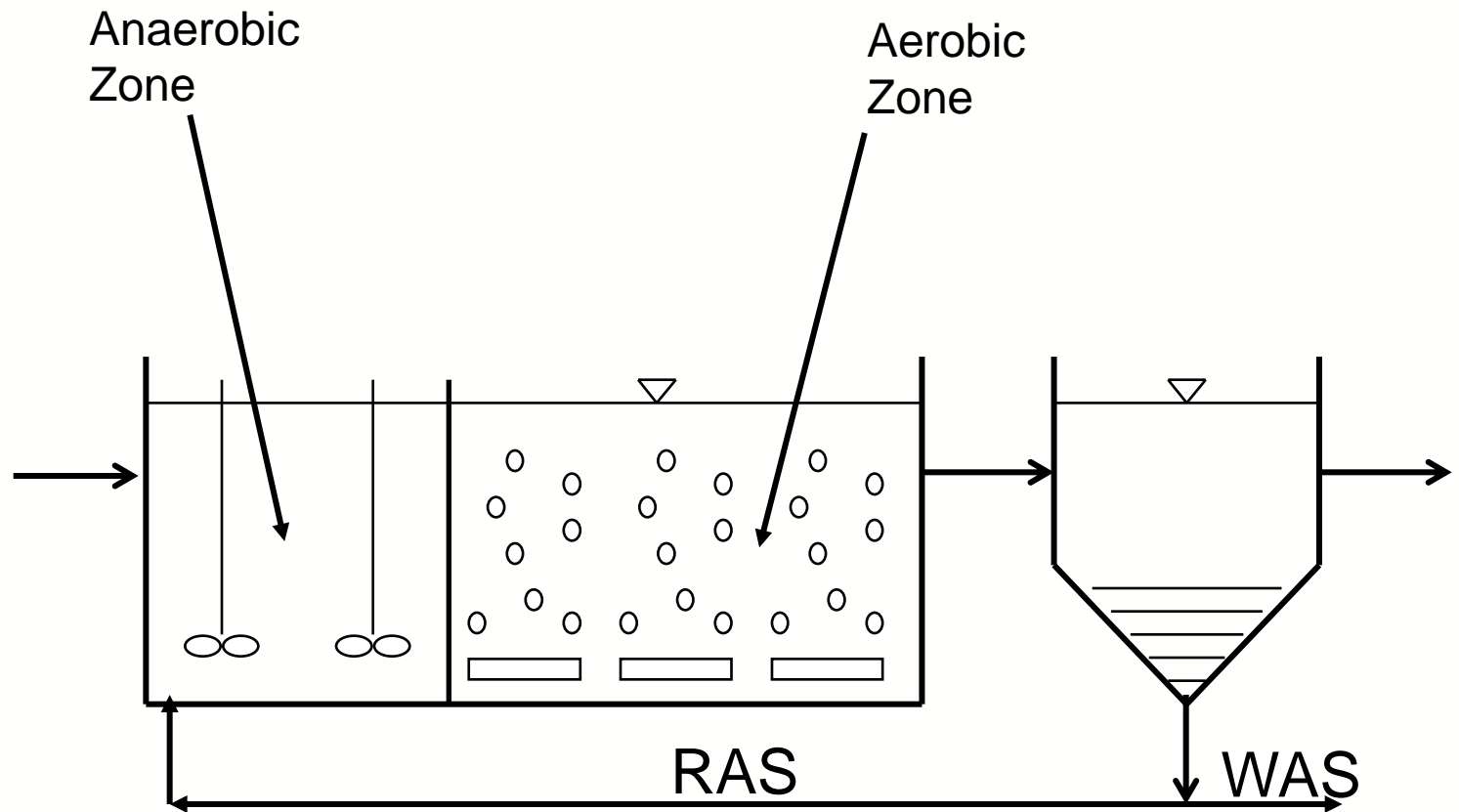
Energy Dividend (E_d) = $24 - 36 \times E_i$

PHB: Poly- β -hydroxybutyrate

Anaerobic/Oxic (A/O) Process Configuration



A/O™ is Basic Bio-P Process



Five Prerequisites for Reliable EBPR

1. Its not the process...
2. Integrity of the anaerobic zone
3. Maximize solids capture
4. Minimize recycle loads
5. A fat PAO is a happy bug

1. It is not the Process...

EBPR needs consistent & adequate supply of VFAs (Food)

- Causes of inadequate VFAs:
 - Excessive BOD removal in the primary clarifier
 - Wet weather flows & snow melts
 - High recycle P loads

Readily Biodegradable Organic Matter is Crucial for EBPR

- VFA requirement
 - Acetic and Propionic Acid: **7 to 10 mg VFA/mg P removed**
- Measure of adequate VFAs
 - cBOD:TP 25:1
 - COD:TP 45:1
 - VFA:TP 10:1
 - rbCOD:TP 15:1
 - Influent to biological system
 - Must consider recycle loads
- Sources
 - Influent (most common)
 - Fermentation in anaerobic zone
 - Primary sludge fermentation
 - Purchased acetic acid

2. Integrity of the Anaerobic Zone

- Anaerobic zone is crucial for PAO selection
- Need to ensure <0.2 mg/L DO

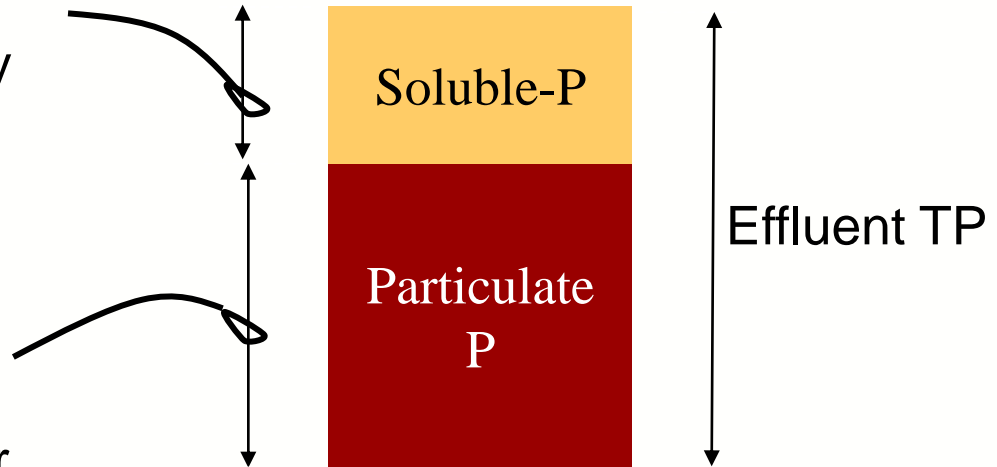
| Source | Dissolved Oxygen | Nitrate |
|-------------------------|------------------|---------|
| Influent (pre-aeration) | √ | |
| RAS | √ | √ |
| Back mixing | √ | √ |
| Vigorous mixing | √ | |

3. Maximize Solids Capture

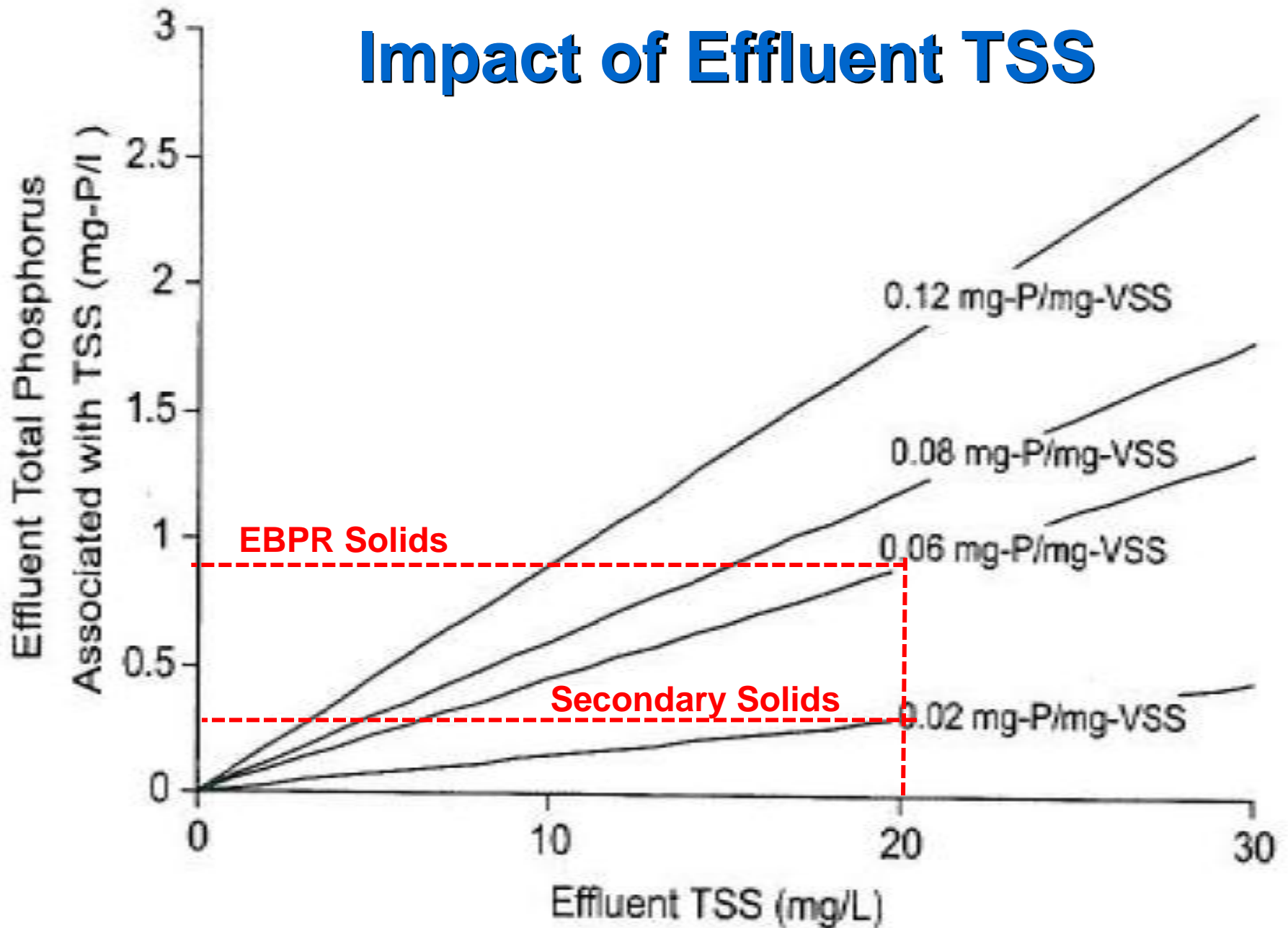


Determined by
EBPR or Chem-P
removal efficiency

Determined by
solids capture
efficiency (clarifier
& filter)



Impact of Effluent TSS



4. Minimize Recycle Loads

- EBPR sludge can release P during anaerobic digestion
- The resulting P-rich recycle from dewatering operation can overload the main process
- Potential TP non-compliance

5. A Fat PAO is a Happy Bug!

Minimize competition from Glycogen Accumulating Organisms (GAOs)

| | Anaerobic | Aerobic |
|------|--|---|
| PAOs | <ul style="list-style-type: none">• VFA uptake & PHB storage• P Release | <ul style="list-style-type: none">• Excess P Uptake• PHB metabolized |
| GAOs | <ul style="list-style-type: none">• VFA uptake & PHV storage• Glycogen used | <ul style="list-style-type: none">• Glycogen storage• PHV metabolized |

Adequate VFAs does not necessarily ensure reliable EBPR

Conditions Thought to Favor GAO Dominance

- Warmer temperatures
- Long SRT
- Anoxic and anaerobic HRTs too long
- Variable supply of VFAs
- Continued use of acetic acid
- pH significantly less than 7

Current Understanding of the Chem - P Removal Mechanism

Fe & Al salts are most commonly used. Involve similar reactions.

1. Hydrous metal oxide (HMO) floc forms (predominant)



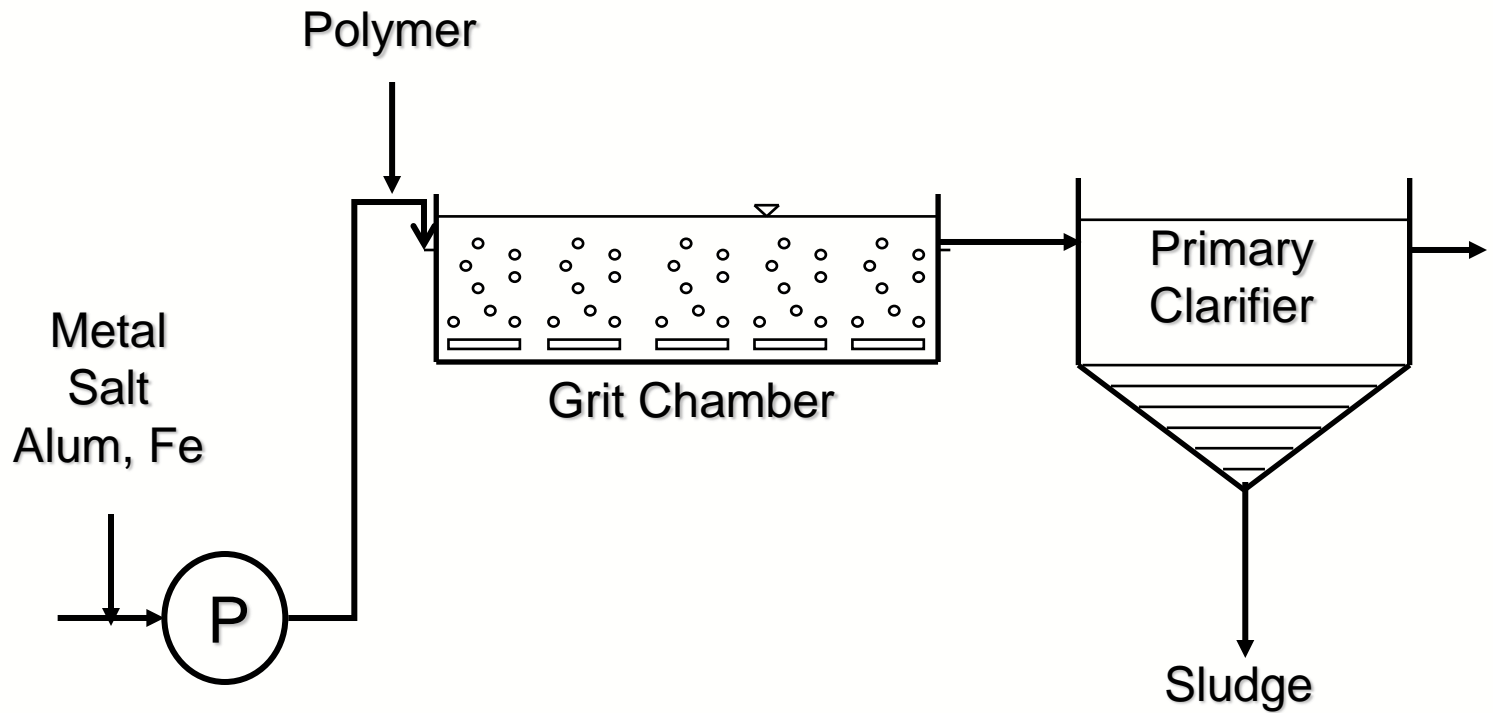
2. Soluble P (PO_4) adsorbs to HMO reactive sites



Continued chemical addition results in

- Larger floc size; fewer adsorption sites
- Less P removal per mg chemical added

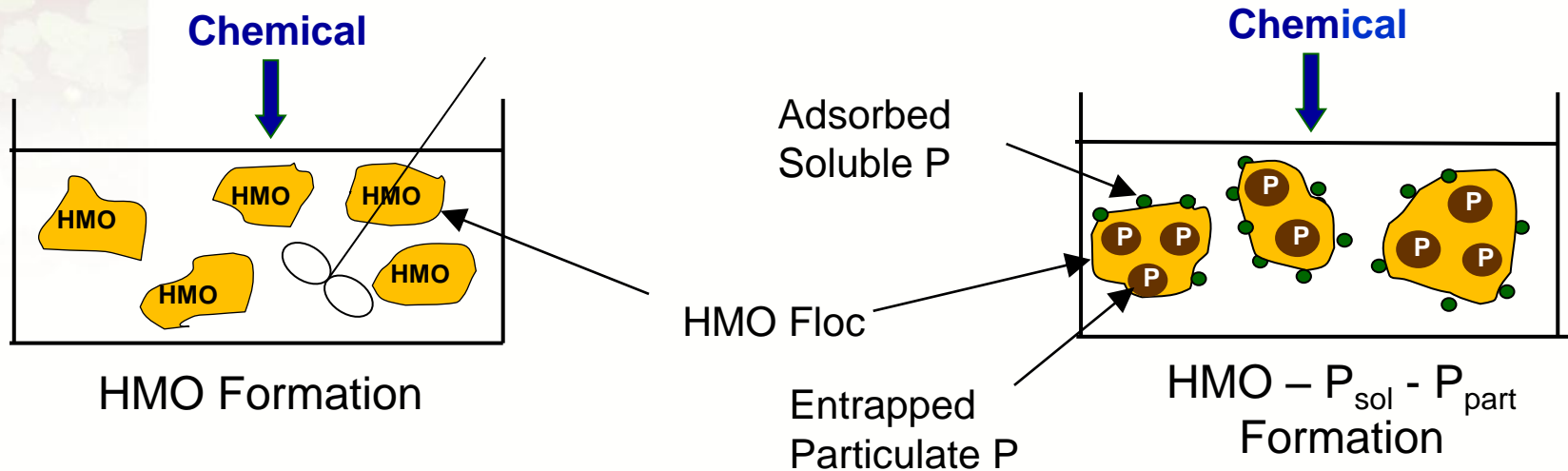
Chemical P Reduction can be *Easily* Incorporated into Primary Treatment Systems...Operations will be Much Simpler (but not Necessarily Cheaper) than BNR!



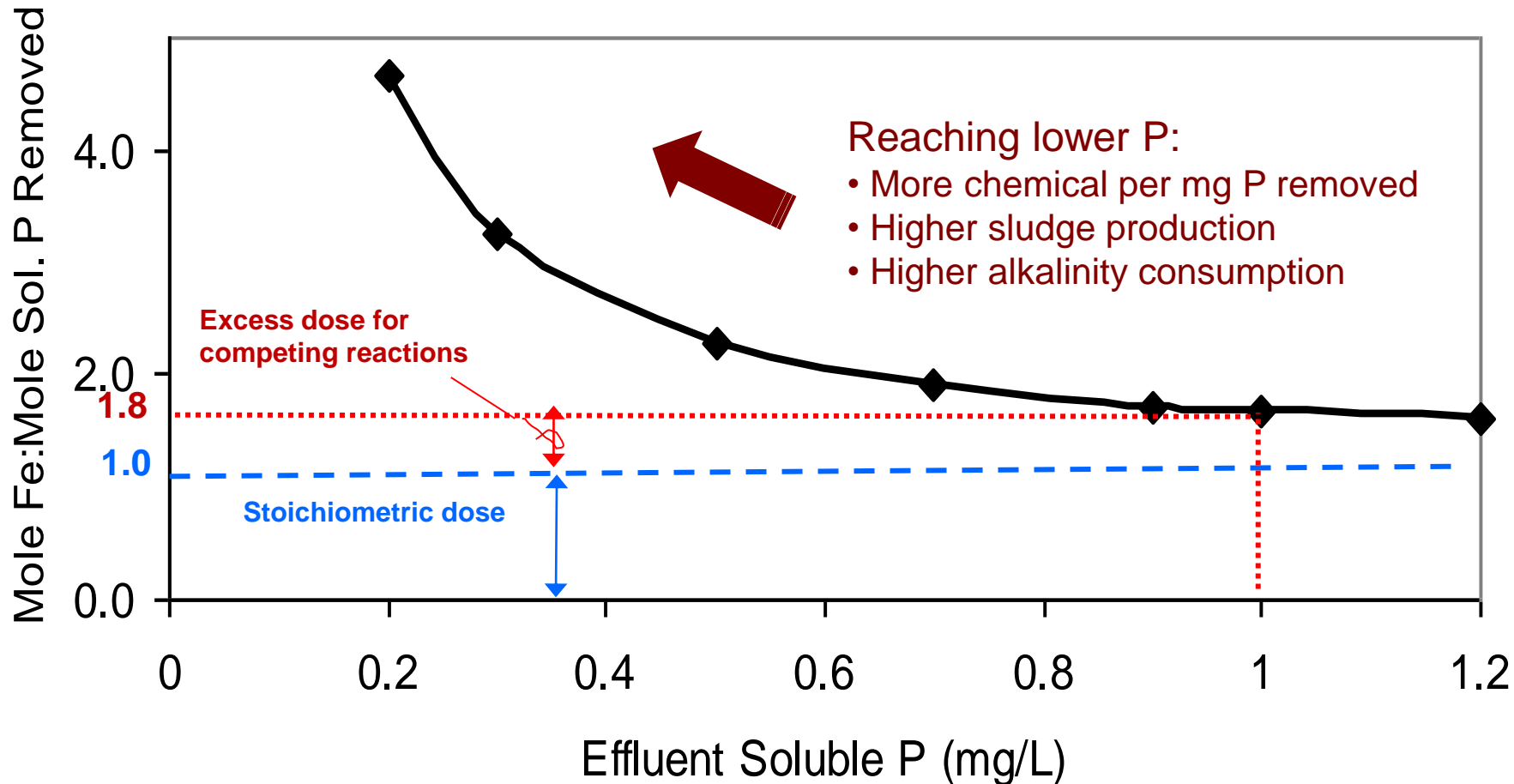
Current Understanding of the Chem - P Removal Mechanism

Minor reactions also occur concurrently

- Co-precipitation: HMO enmeshes colloidal P



What Plant Data is Telling Us...



Best fit curve based on plant data (WEF)

Plant Wide Impacts of Chem-P Removal

- Decreased UV transmittance
- Increased inert fraction in the MLSS
 - Overestimate of VSS
 - Higher MLSS
- Increased sludge production
- Alkalinity consumption
- Continued P removal after chemical feed is terminated

What is the Limit Of Technology (LOT) for TP

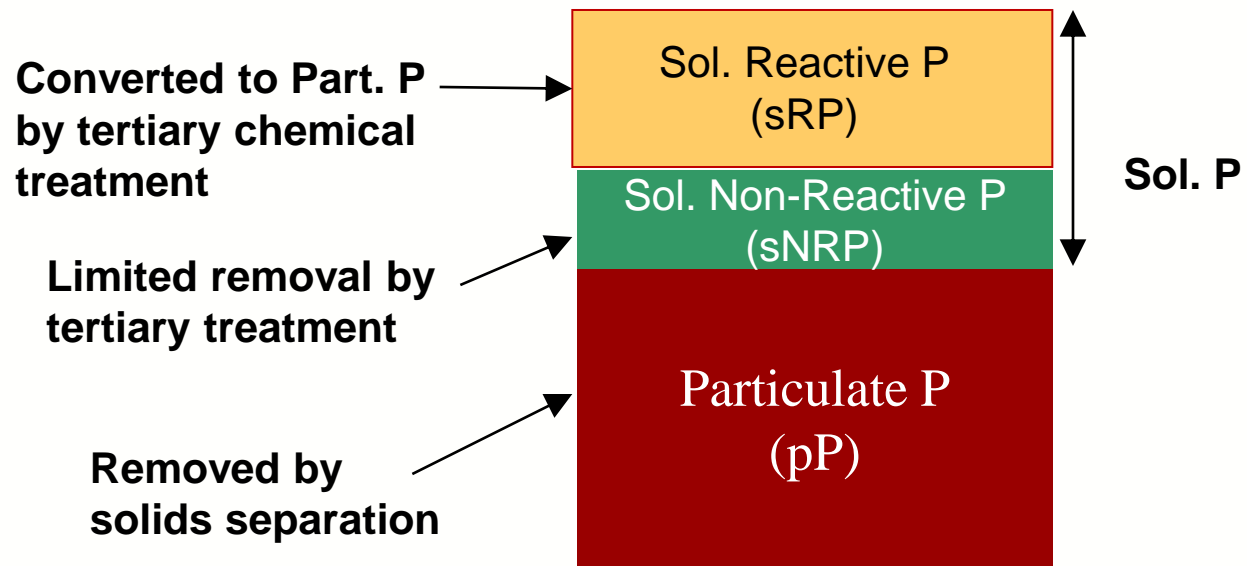
The LOT with EBPR and Chem-P removal:

- W/O Filtration: 0.5 – 1.0 mg/L TP
- W/Filtration: 0.1 – 0.5 mg/L TP

Can we
go lower
than
LOT?

Achieving < 0.1 mg/L TP Requires an Understanding of TP Speciation

- Achieving < 0.1 mg/L TP calls for tertiary treatment
- Removal of sNRP is challenging & determines how low we can go.



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 | ++++ | +++ | ++++ |

sRP

sNRP

pP

- Need efficient removal of 3 components to achieve low effluent TP
- Difficult to achieve low TN & TP levels simultaneously



Phosphorus Recovery



The Importance of Phosphorus

- Essential element of all life forms:
 - Genetic material, ATP , Bones
- A primary nutrient required for plant growth
- Detergents, crop protection, pharmaceuticals, flame retardant, etc.
- **Essential – no substitutes, natural or synthetic**
- **Non-Renewable**

**An average human body
contains 650 g of Phosphorus.**

Phosphorus Reserves & Production Worldwide



Together with nitrogen and potassium, phosphorus is a crucial ingredient in fertilizer. It is extracted from phosphorus-rich rock in the form of phosphate. Morocco, China, South Africa and the U.S. hold 83 percent of the world's easily exploitable phosphate rock and contribute two thirds of the annual phosphorus production (circles, below). At current rates of extraction (bars, below), known U.S. reserves are projected to last 40 years. Globally about 90 years' worth of phosphorus remains. Once the resource starts running out, less economical supplies may have to be tapped, which could result in higher prices and market disruption. U.S. production has been declining despite the incentives of rising prices (graph, right); last year the price spiked up because of supply and increased demand.

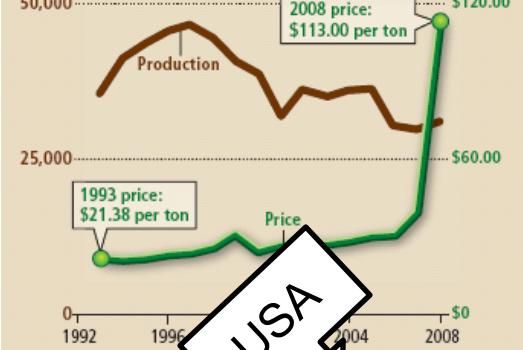
China

MOROCCO

S. Africa

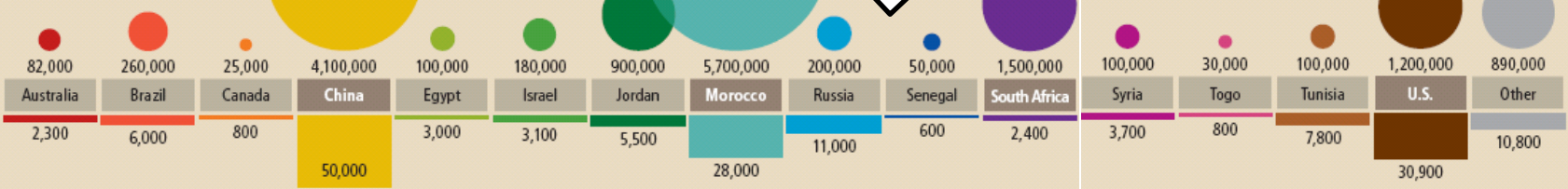
U.S. PRODUCTION IN DECLINE AS PRICE SOARS

Phosphate Rock Production (millions of metric tons)



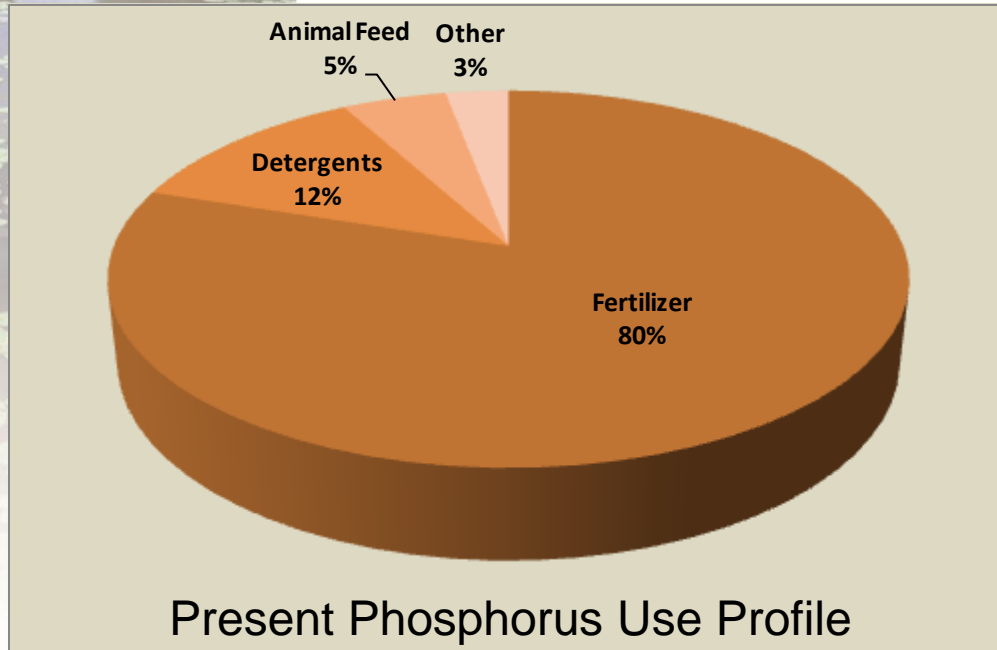
USA

Phosphate Rock Reserves (thousands of metric tons)



2008 Mine Production (thousands of metric tons)

Current Phosphorus Use Profile



Fertilizer use expected to increase due to

- Rapid population growth
- Increased intensive agriculture



The Phosphorus Crisis

- Phosphorus resources are declining both in quality & accessibility

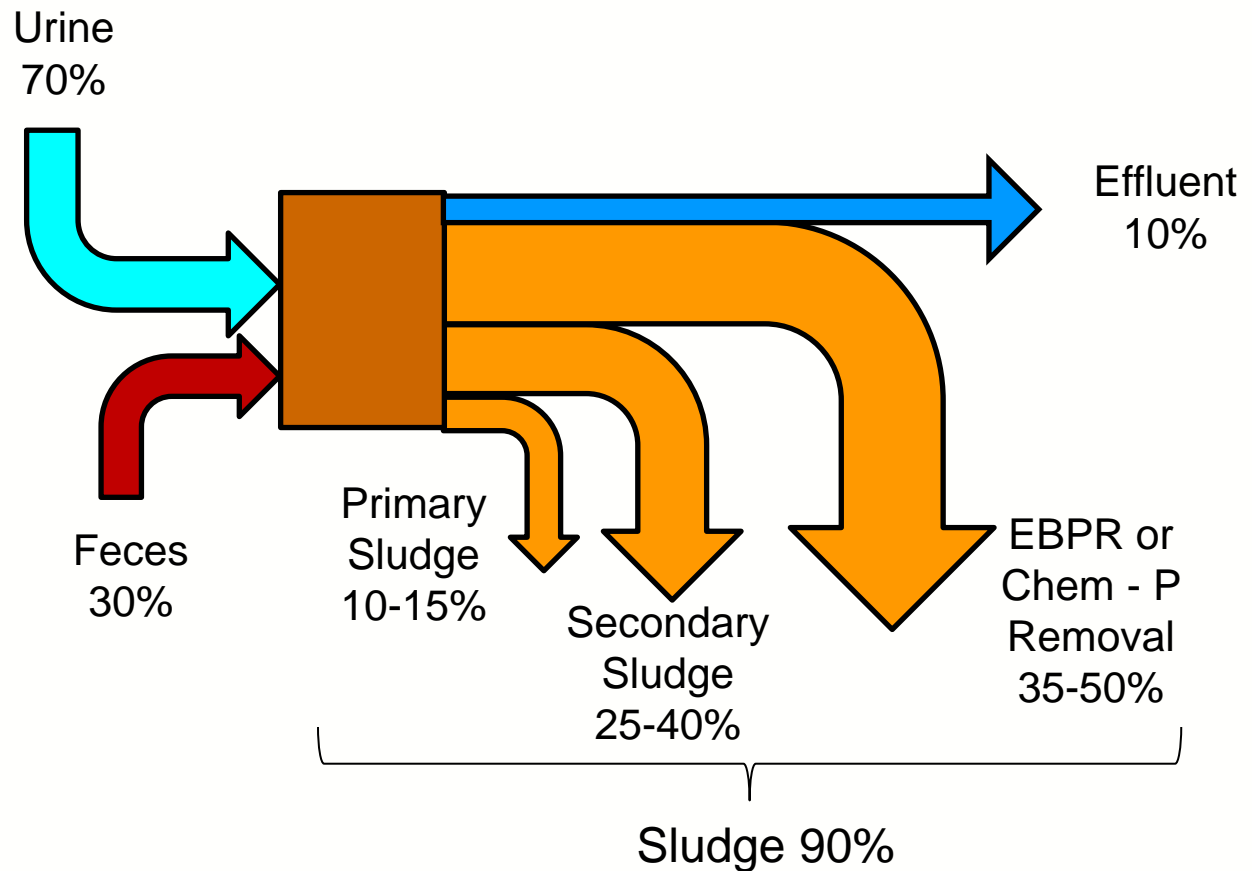
Availability of high quality P:

- 100 years globally
- 40 year in the US

- Poor quality sources have increasing amounts of contaminants (Cd, U, Ni, Cr, Cu, Zn)
 - Higher cost of recovery
 - Global response:
 - Sweden : 60% of P recycled from wastewater by 2015
 - China: 135% export tariff
 - Use of special urine separation toilets (Japan & Europe)
-

Phosphorus Distribution in Domestic Waste

400,000 tons/year of phosphorus in US sewage



Struvite – Friend or Foe?

- Struvite is Magnesium Ammonium Phosphate (MgNH_4PO_4)
 - Kidney stones
- Forms readily when:
 - Molecular ratio of Mg:N:P is 1:1:1
 - pH around 9.0.
- Often an O&M nightmare at EBPR facilities:
 - Anaerobic digestion releases P, Mg, & ammonia
 - Turbulence drives out CO_2 resulting in pH rise & struvite scaling

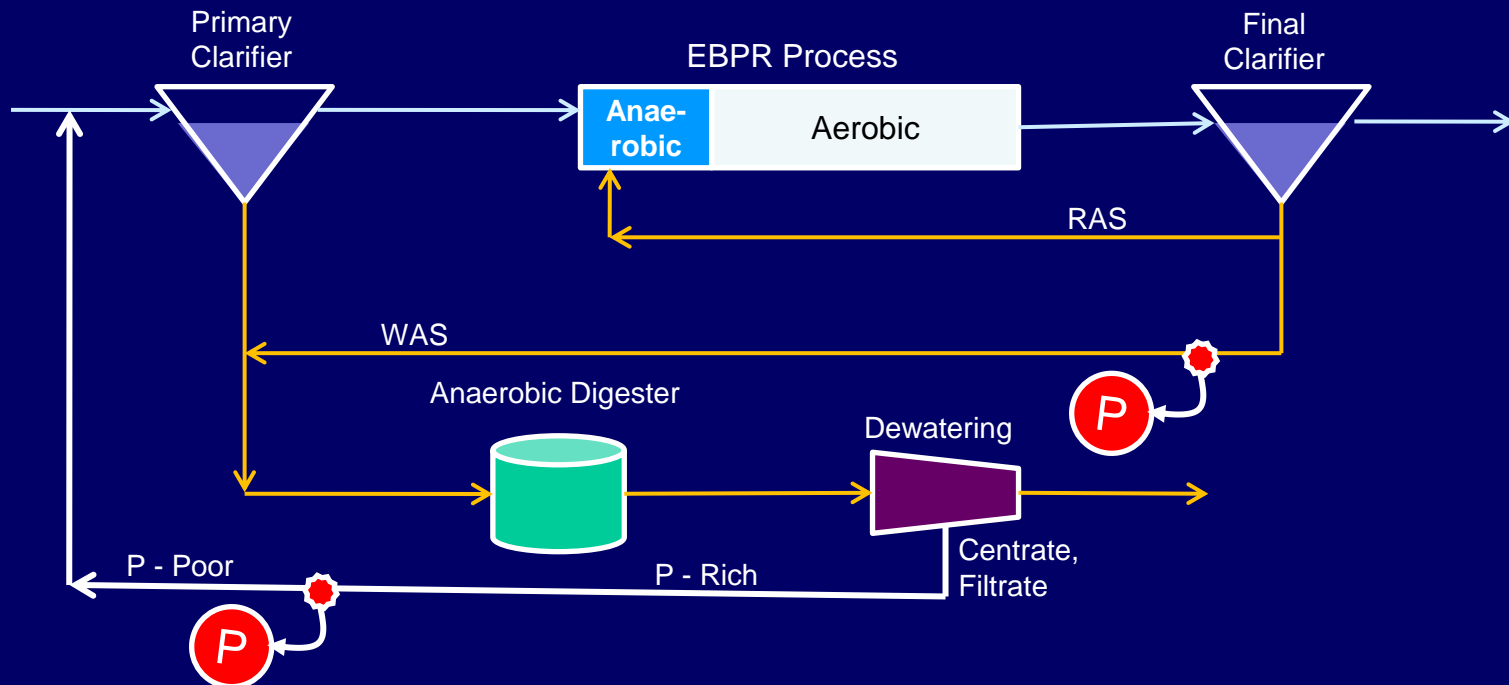


When Fate Hands a Lemon..

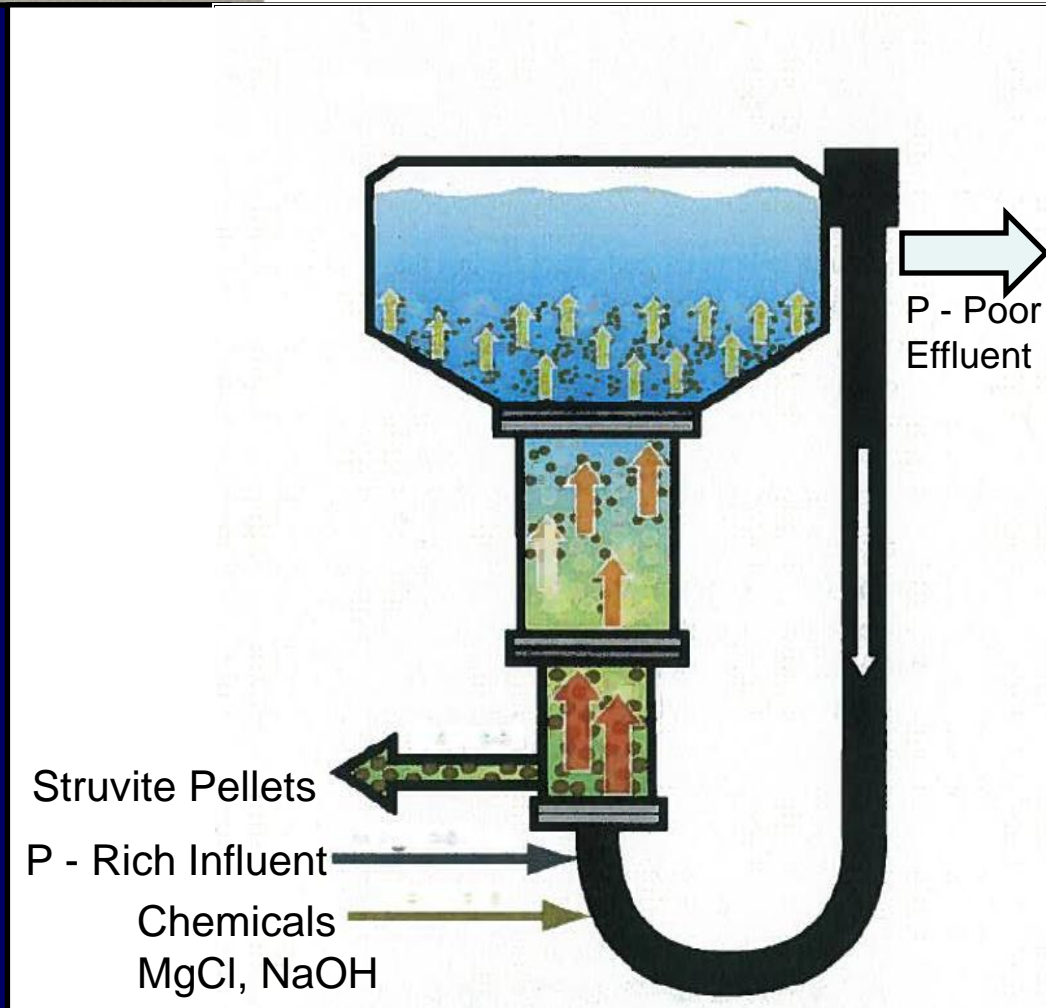
- Controlled Struvite formation & collection
- Source of slow release fertilizer – highly marketable
 - 5% N; 28% P; 0% K

Other benefits:

- Recycle treatment
- No struvite scaling



Ostara P Removal Process

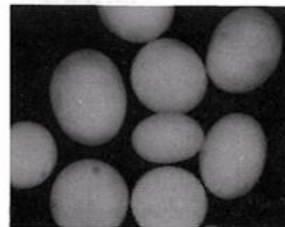
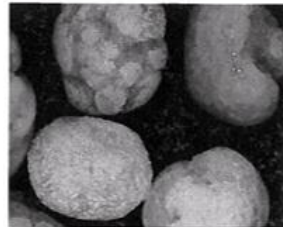


Requirements:

- $\text{PO}_4\text{-P} > 75 \text{ mg/L}$
- $\text{TSS} < 1000 \text{ mg/L}$
- 500 & 2000 kg/d modules
- Plant size $>5 \text{ MGD}$

Ostara Installations

| Facility | Plant Capacity, mgd | Feed Source | Operational |
|------------------------------------|---------------------|---------------|-------------|
| Durham WWTP Portland, OR | 20 | WAS, Filtrate | 2009 |
| Gold Bar WWTP Edmonton, Alberta | 32 | Filtrate | 2007 |
| Nansemond WWTP HRSD, VA | 30 | Centrate | 2010 |
| York WWTP York, PA | 26 | Centrate | 2010 |
| Rock Creek WWTP Portland, OR | 30 | WAS | 2011-2012 |





Durham WWTF
Portland, OR

Emerging P Recovery Technologies

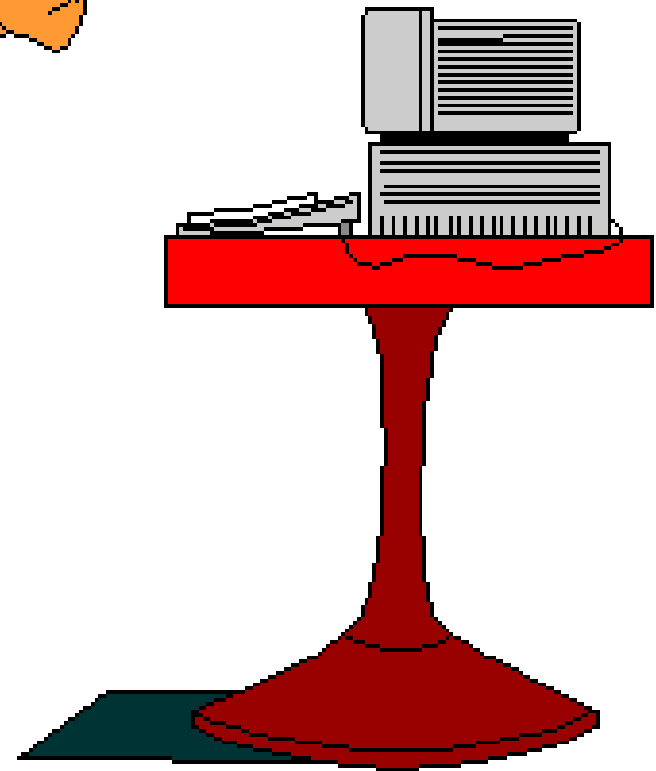
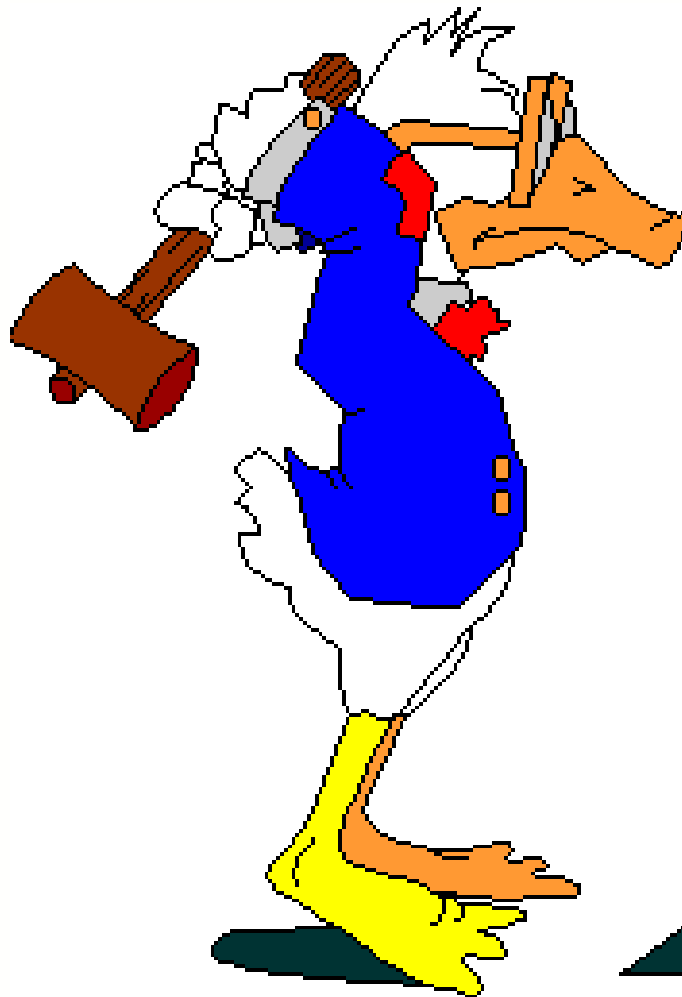



| Technology | Origin | Feed Stream | Product | External Inputs |
|------------|---------|-----------------|---------------------------|------------------------------------|
| KREPO | Sweden | Primary sludge | Ferric Phosphate | Heat, pressure, H_2SO_4 , NaOH |
| Seaborne | Germany | Digested sludge | Struvite | Heat, H_2SO_4 , NaOH, $Mg(OH)_2$ |
| Kemicond | Sweden | Primary sludge | Ferric Phosphate | H_2SO_4 , H_2O_2 , polymer |
| BioCon | Denmark | Incinerator ash | H_3PO_4 | H_2SO_4 , ion-exchange |
| SEPHOS | Germany | Incinerator ash | $AlPO_4$, $Ca_3(PO_4)_2$ | H_2SO_4 , NaOH, Ca^{2+} |

Take Home Messages

- Many OH plants will see TP limits (1.0 - 0.5 mg/L TP).
- Most sensitive performance factors:
 - EBPR: VFAs, anaerobic conditions, solids capture, & recycle loads.
 - Chem-P removal: Mixing, alkalinity, & solids capture
- Beware of plant-wide impacts:
 - EBPR: Influent characteristics, secondary release
 - Chem-P removal: Sludge production, alkalinity, UVT
- Technology limits:
 - EBPR or Chem-P. No filtration; 1.0 mg/L TP
 - EBPR or Chem-P + Filtration: 0.5 – 0.1 mg/L TP
 - Tertiary treatment to remove sNRP: <0.1 mg/L TP

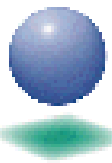
Questions?





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