Biological Phosphorus Removal

2017 ORWEF Short School

Clackamas Community College

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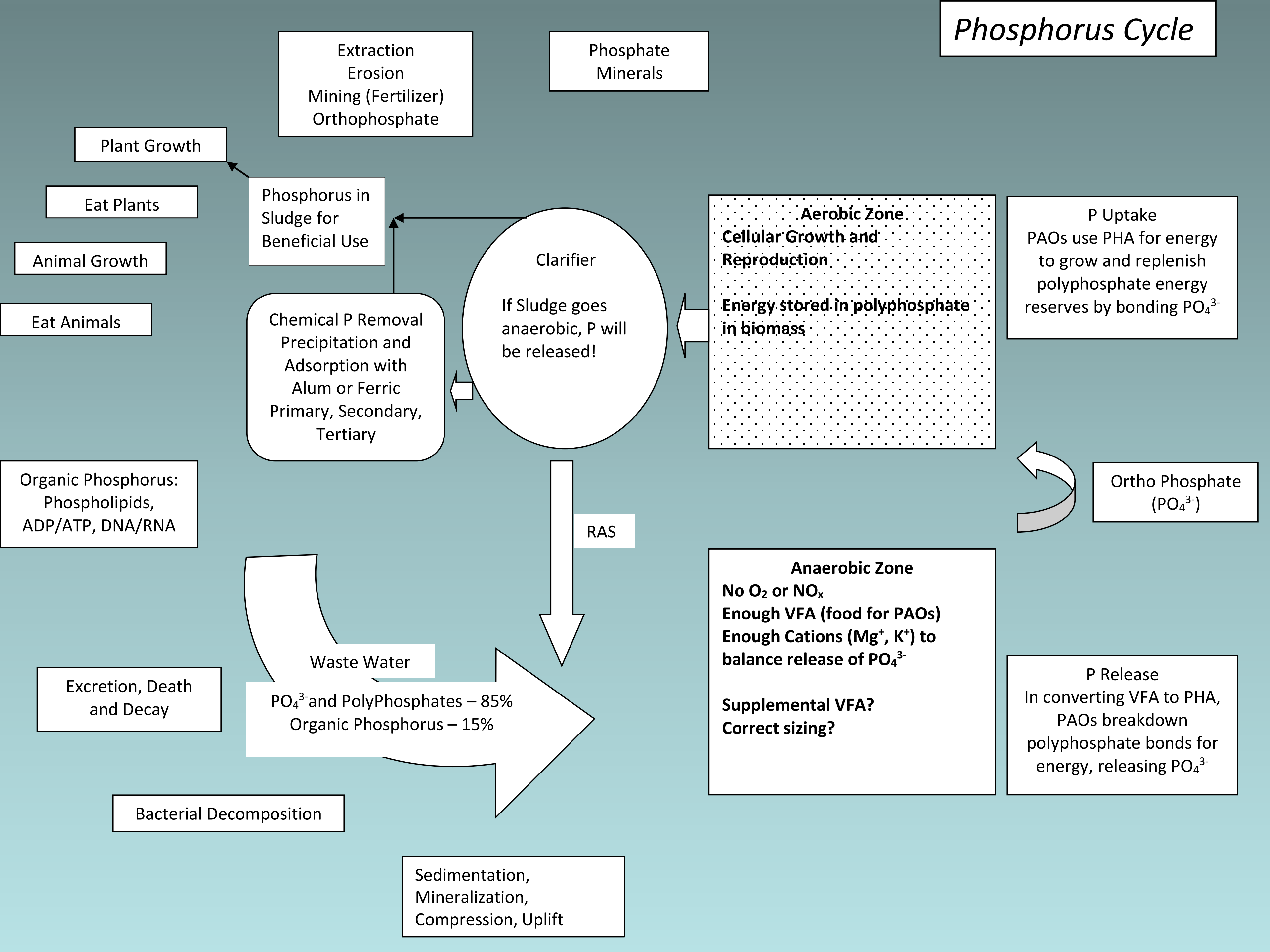
Rock Creek AWTF

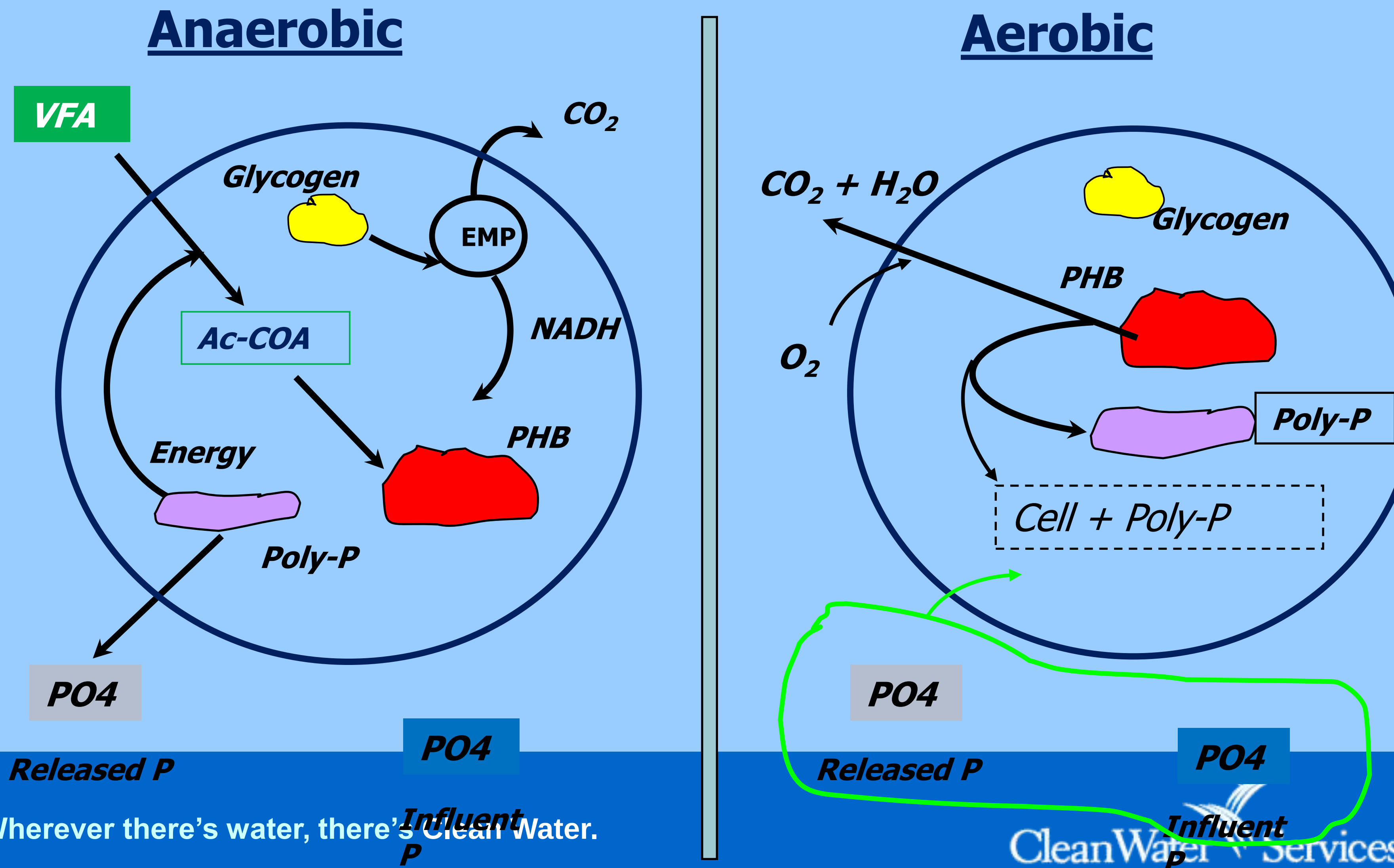
Outline

- Phosphorus Cycle
- Players: PAOs, GAOs, OHOs, DNHOs, DPAOs
- Process Arrangements
- Optimizing and Troubleshooting



Phosphorus Cycle
Extraction
Erosion
Mining (Fertilizer)
Orthophosphate
Phosphate
Minerals
Plant Growth
Eat Plants
Animal Growth
Eat Animals
Phosphorus in
Sludge for
Beneficial Use
Clarifier
If Sludge goes anaerobic, P will be released!
Chemical P Removal
Precipitation and
Adsorption with
Alum or Ferric
Primary, Secondary,
Tertiary
Aerobic Zone
Cellular Growth and Reproduction
Energy stored in polyphosphate in biomass
P Uptake
PAOs use PHA for energy to grow and replenish polyphosphate energy reserves by bonding PO_4^{3-}
Organic Phosphorus:
Phospholipids,
ADP/ATP, DNA/RNA
RAS
Ortho Phosphate
(PO_4^{3-})
Anaerobic Zone
No O_2 or NO_x
Enough VFA (food for PAOs)
Enough Cations (Mg^+, K^+) to balance release of PO_4^{3-}
Supplemental VFA?
Correct sizing?
Waste Water
PO_4^{3-} and PolyPhosphates – 85%
Organic Phosphorus – 15%
Excretion, Death
and Decay
P Release
In converting VFA to PHA, PAOs breakdown polyphosphate bonds for energy, releasing PO_4^{3-}
Bacterial Decomposition
Sedimentation,
Mineralization,
Compression, Uplift

Two Steps of the BPR Process Governed by Different Considerations

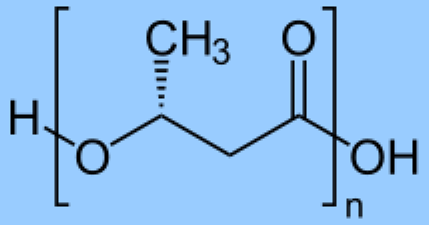


Fundamental fundamentals

- Bugs are creatures that live on Earth, just like you and me.
- Need Oxygen (or other e^- acceptor)
- Need Water
- Need to Eat
  - Eat carbon, but also need nitrogen, phosphorus, and vitamins and minerals
- Need Energy source
- Like to reproduce
- Like to eat, drink and do different things
- Grow at different rates and have varying lifespans

Carbon

- CBOD
  - Various CHONP compounds ($C_6 H_{12} O_6$)
- VFA Volatile Fatty Acid
  - Acetic, Propionic, Butyric
  - CH_3COOH
- PHB Polyhydroxybutyrate



Operator

Species	Carbon Source	Energy Source	Electron Acceptor
WWTP Operator	CBOD (Organic Carbon)	CBOD (Organic Carbon)	O_2

- Tends to prefer carbon in a fermented liquid form

Ordinary Heterotroph (OHO)

Species	Carbon Source	Energy Source	Electron Acceptor
OHO	CBOD (Organic Carbon)	CBOD (Organic Carbon)	O_2

Remember back to High School biology…Ms Lynch…got to sit next to Kathy…Oh yeah…

Cellular respiration relies on the ADP – ATP cycle where energy is stored and released through phosphate bonds

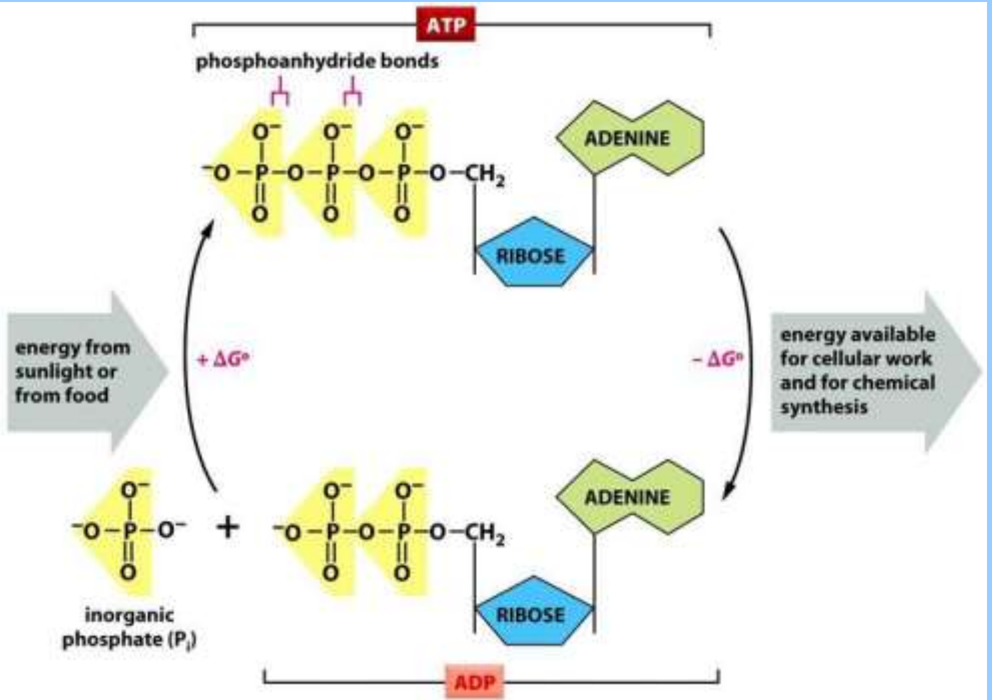


Figure 3-31 Essential Cell Biology 3/e (© Garland Science 2010)

Denitrifying Heterotroph (DNHO)

Species	Carbon Source	Energy Source	Electron Acceptor
DNHO	CBOD (including VFA)	CBOD (including VFA)	NO_3

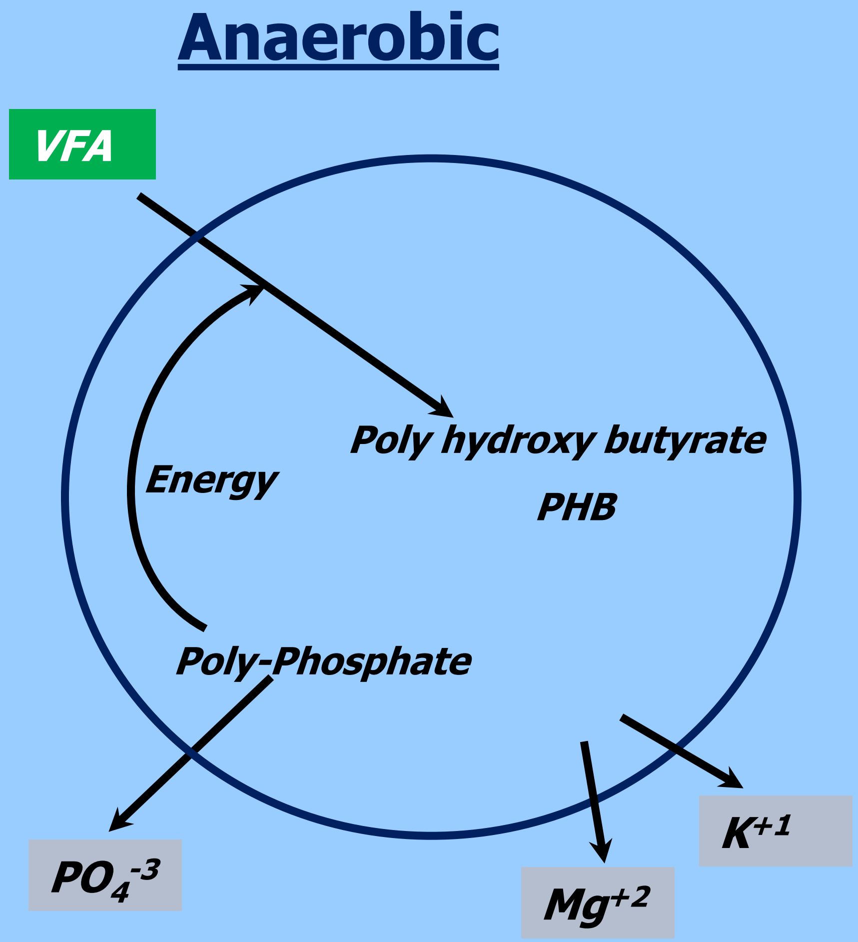
- ADP – ATP cycle
- Competes for VFA

Phosphorus Accumulating Organism (PAO)

Species	Carbon Source	Energy Source	Electron Acceptor
PAO	VFA	VFA	O_2

- ADP – ATP cycle expanded to polyphosphate chains
- Competes for VFA
- Specialized to store carbon under anaerobic conditions
- That stored carbon becomes the energy and carbon source under aerobic conditions

BPR Process Relies on Anaerobic/Aerobic Cycling: The Release



PAO gets energy from breaking phosphate bonds

That energy is used to consume VFA and convert to polyhydroxybutyrate (PHB) – kind of like a "fat" reserve

The discarded phosphate exits the cell

Cell maintains neutral charge by discarding +3 charges

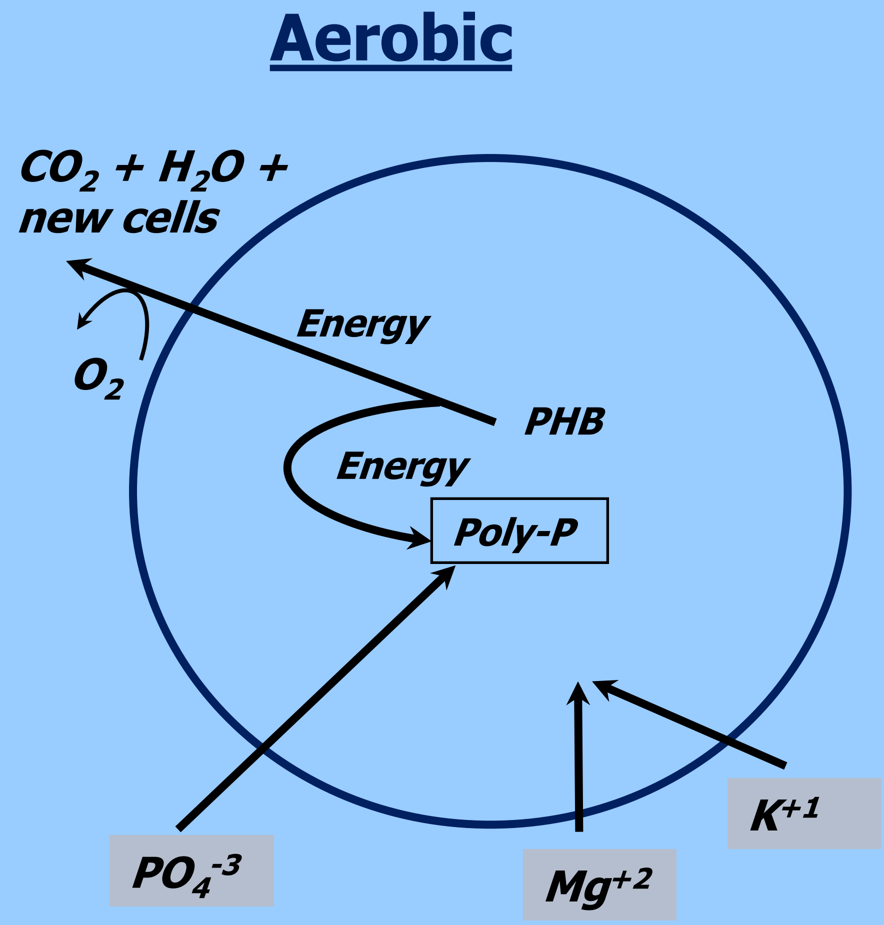
BPR Process Relies on Anaerobic/Aerobic Cycling: The Uptake

PAO now behaves like an OHO

Use stored carbon (PHB) as energy source and carbon source to grow, reproduce

Is conditioned to recharge the poly-P battery

Released PO_4^{3-} and influent PO_4^{3-} is stored

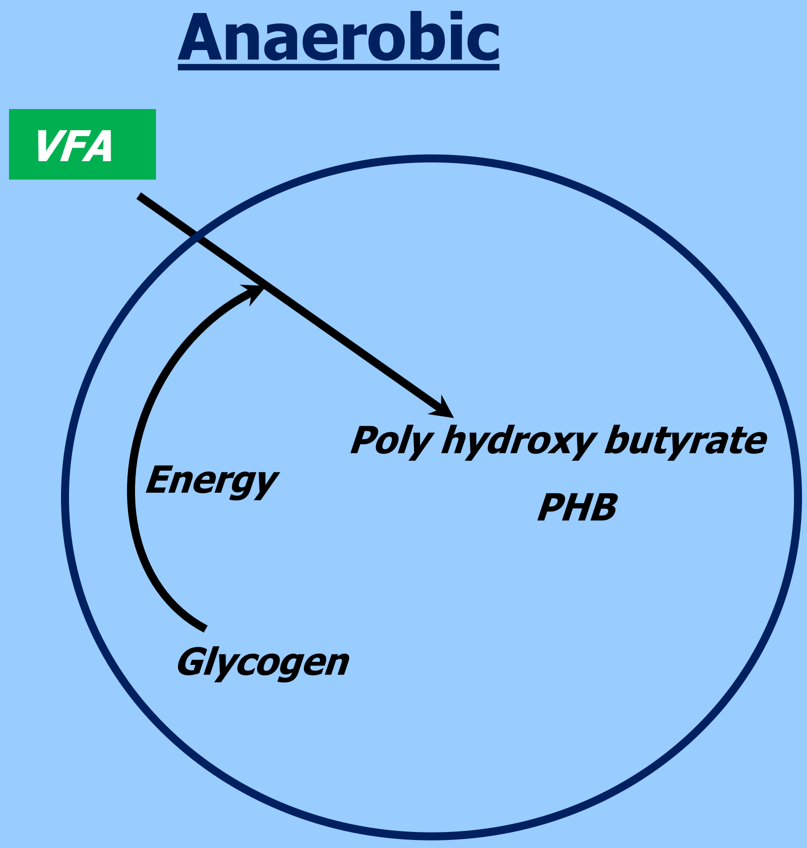


Glycogen Accumulating Organism (GAO)

Species	Carbon Source	Energy Source	Electron Acceptor
GAO	VFA	VFA	O_2

- ADP – ATP cycle
- Competes for VFA
- Specialized to store carbon under anaerobic conditions
- That stored carbon becomes the energy and carbon source under aerobic conditions

Glycogen Accumulating Organism (GAO)



- In contrast to PAOs, GAOs utilize energy from glycogen breakdown to take in VFAs.
- GAOs do not take in P in the aerobic zone.

Keys to BPR

Anaerobic

- Sufficient VFA. PAOs can't store other forms of carbon.
- Maintain advantage for PAOs by managing competition for VFAs from O_2 and NO_3
- Minimize phosphorus release in secondary clarifiers

Aerobic

- Good oxygen supply in the initial aerobic zones to ensure high initial aerobic P uptake.

Keys to BPR: VFA

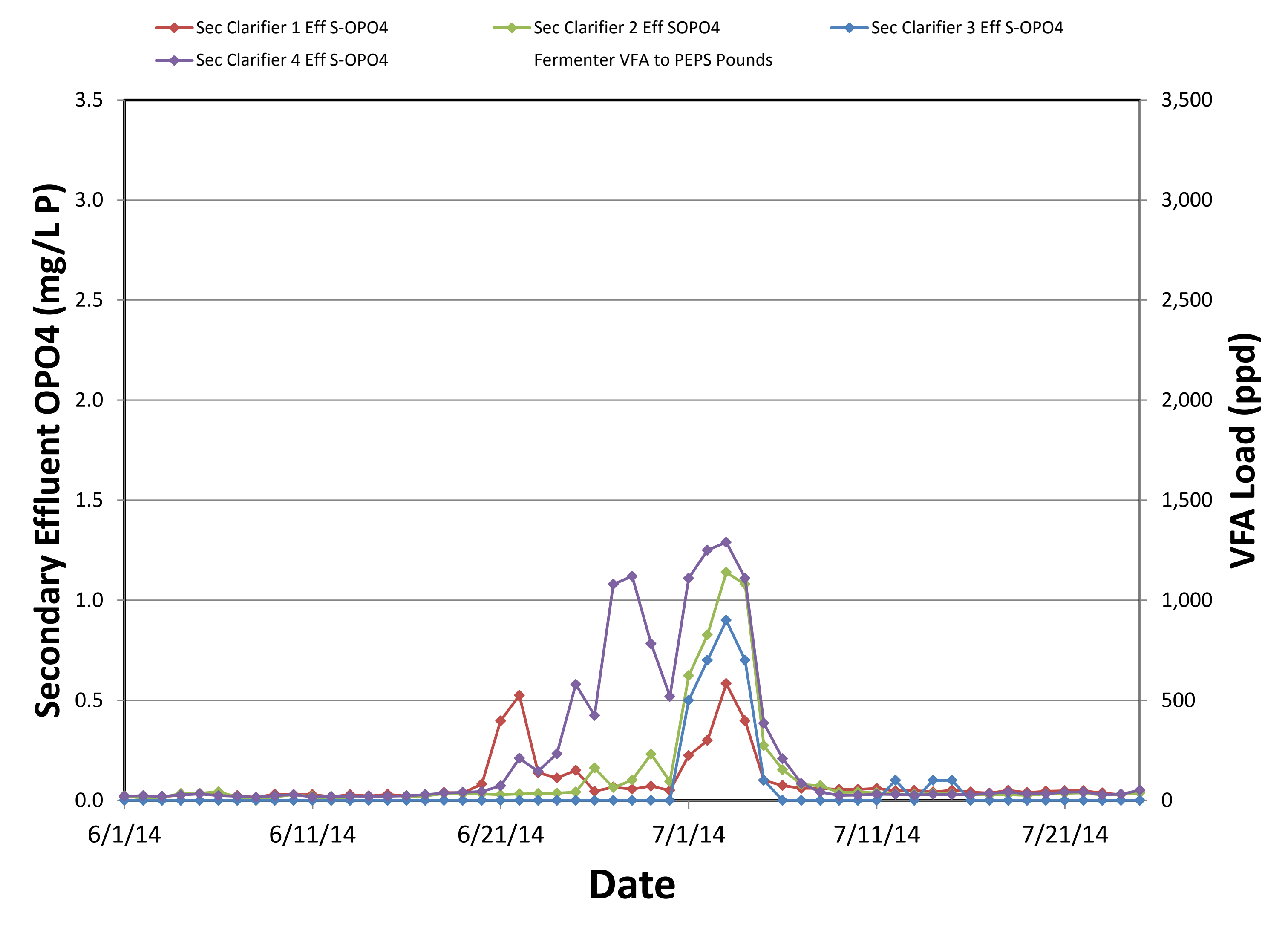
Three sources of VFA:

(1) Influent wastewater

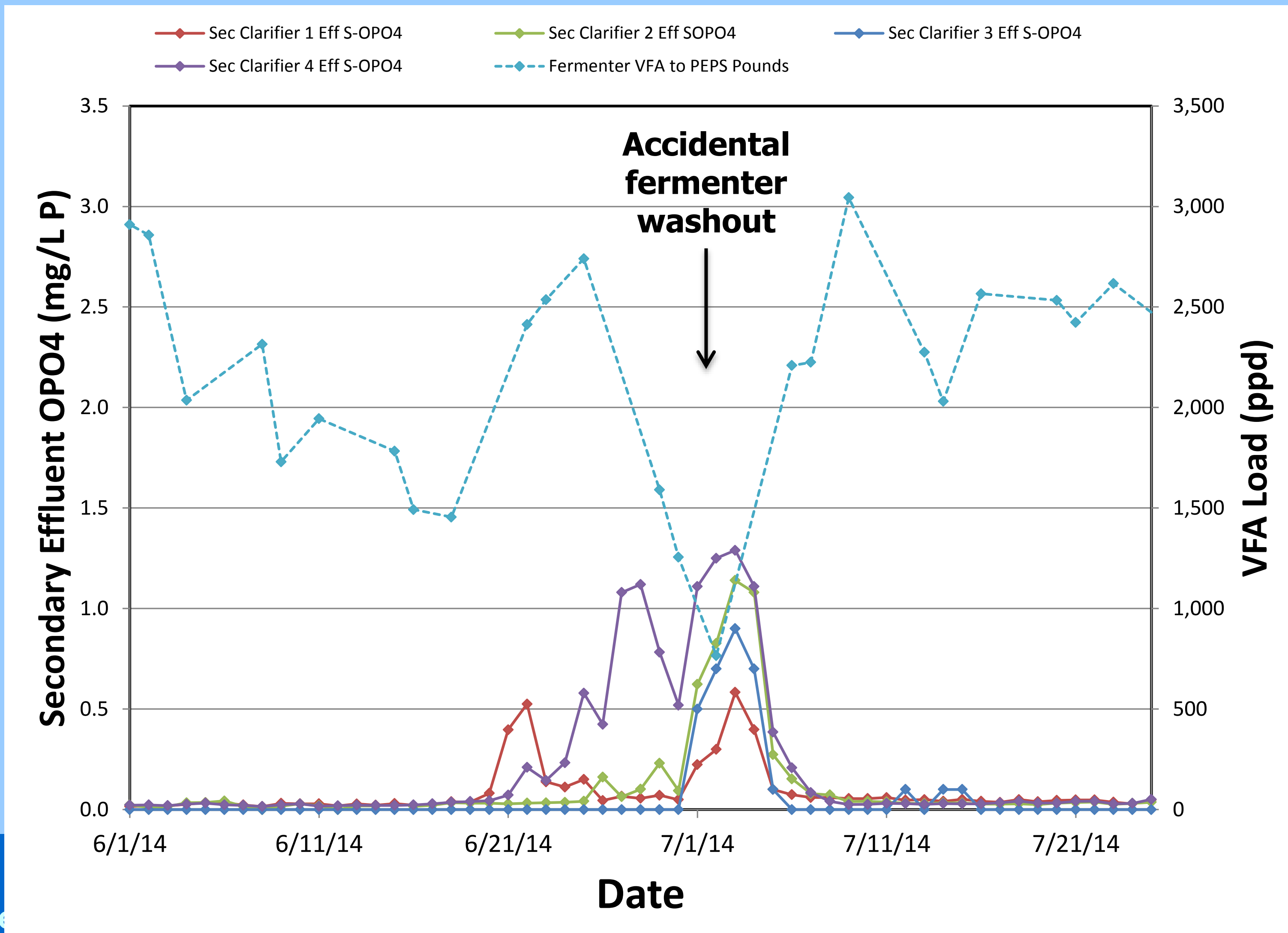
(2) Fermenter

(3) Fermentation in anaerobic zone

Example Bio-P Upset Due to VFA Limitation



Example Bio-P Upset Due to VFA Limitation



Keys to BPR

Anaerobic

- Sufficient VFA. PAOs can't store other forms of carbon.
- Maintain advantage for PAOs by managing competition for VFAs from O_2 and NO_3
- Minimize phosphorus release in secondary clarifiers

Aerobic

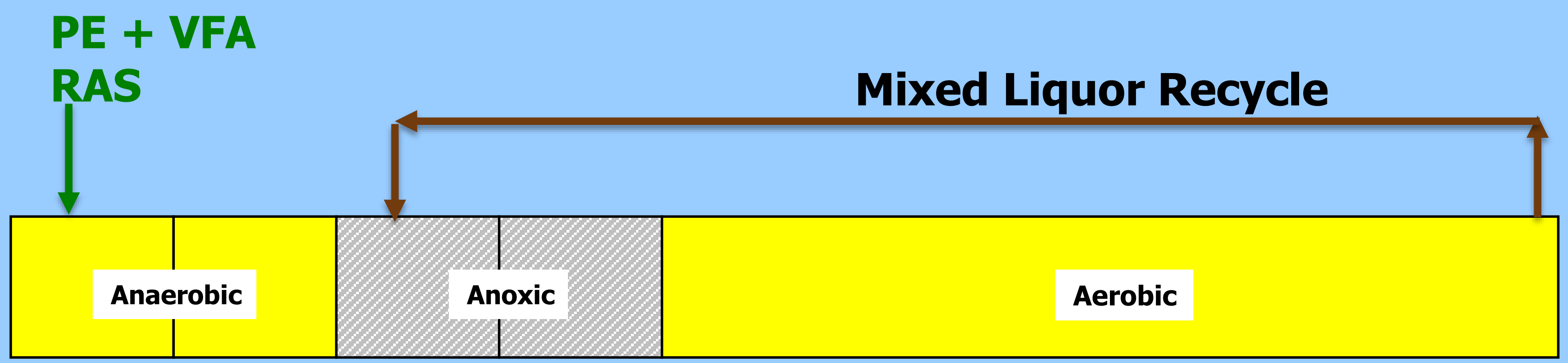
- Good oxygen supply in the initial aerobic zones to ensure high initial aerobic P uptake.
- Avoid low DO conditions that could cause secondary release

Keys to BPR: Managing Conditions

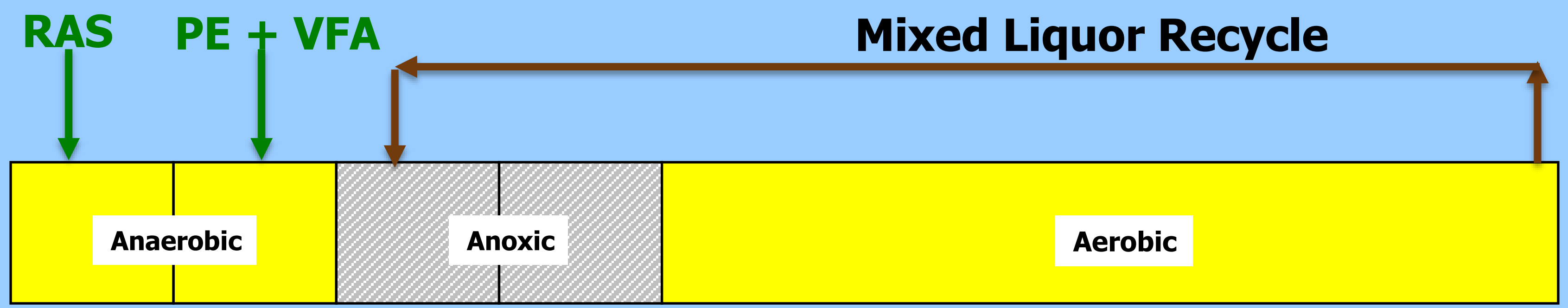
- In presence of nitrate or oxygen, VFA in the anaerobic zone will be used for metabolisms other than bio-P.
- 1 mg/L DO uses up ~ 3 mg/L VFA as COD.
- 1 mg/L nitrate uses up ~ 7 mg/L VFA as COD.
- Nitrate and oxygen can enter the anaerobic zone through the RAS and/or primary effluent.
- Different process configurations that can be used to minimize interference.

Keys to BPR: Managing Conditions

A2O Configuration

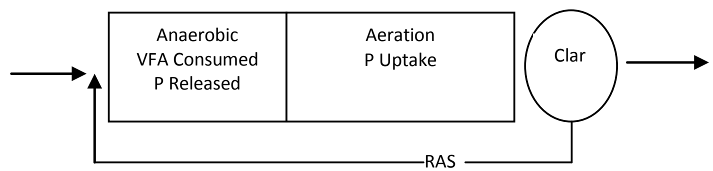


Johannesburg Configuration - *Question: how does this configuration help?*
allows RAS to use O_2 and/or NO_3 endogenously before VFA fed to anaerobic zone

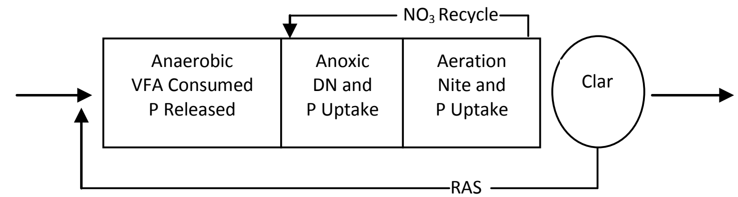


Phosphorus Removal Processes

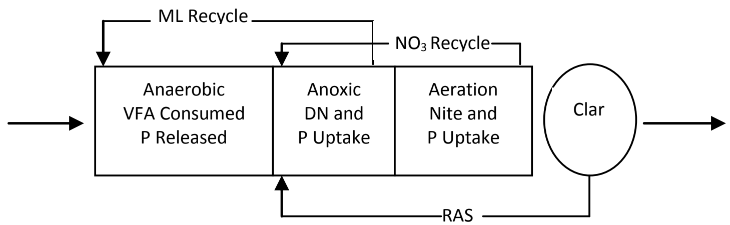
A/O: Anaerobic/Aerobic



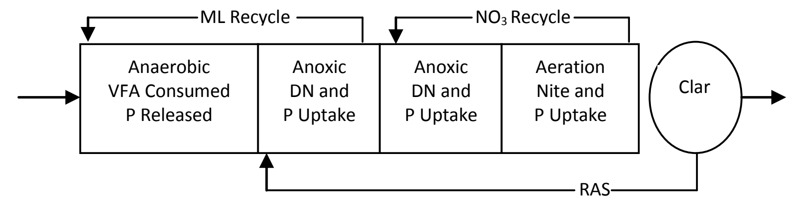
A2/O: Anaerobic/Anoxic/Aerobic



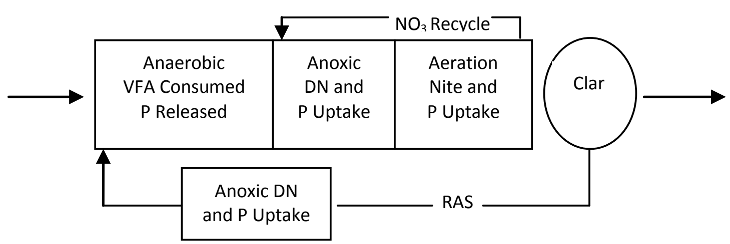
UCT: Universtiy of Cape Town



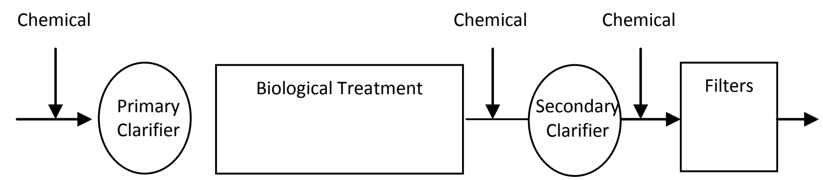
Modified UCT



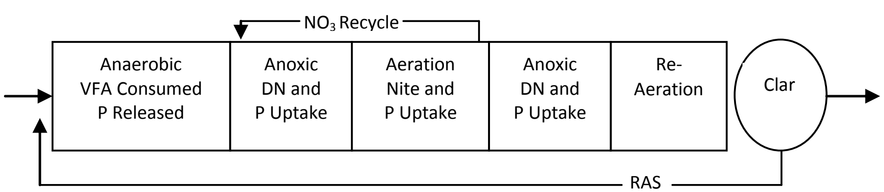
JHB: Johannesburg



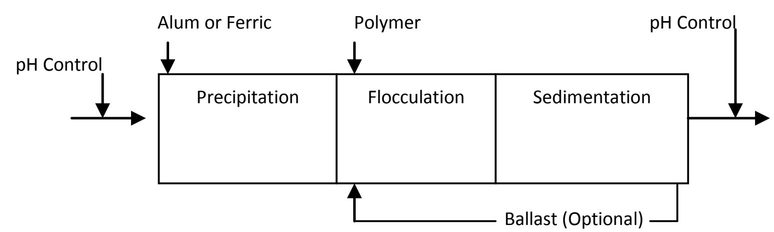
Chemical Precipitation; Primary, Secondary, Filtration



Bardenpho (5 Stage)

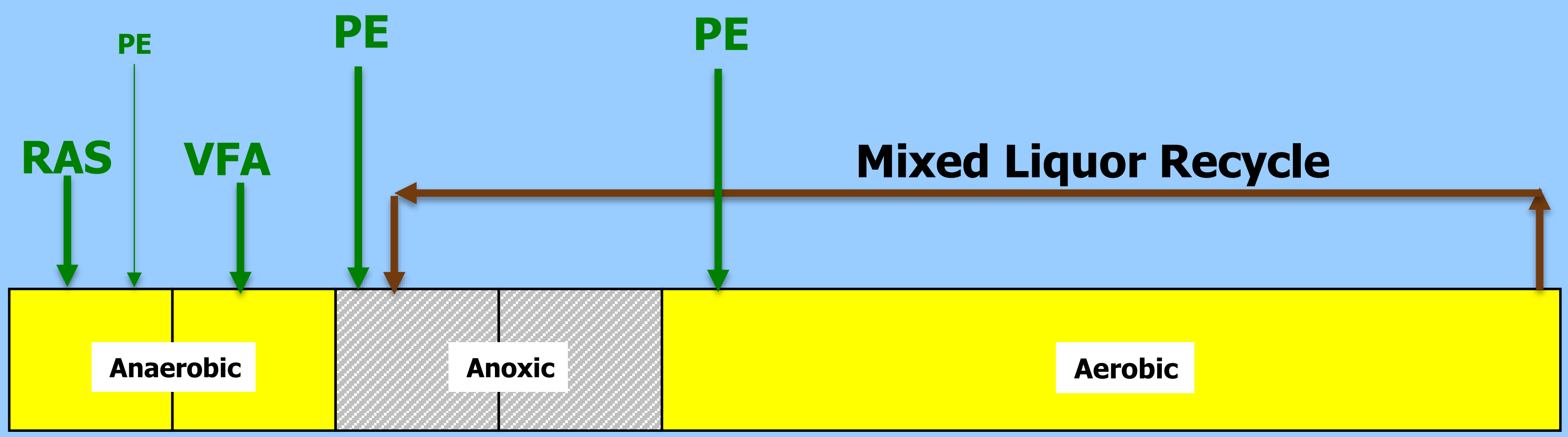


Chemical Precipitation, Tertiary



Keys to BPR: Managing competition

AB4&5 Configuration



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Anaerobic

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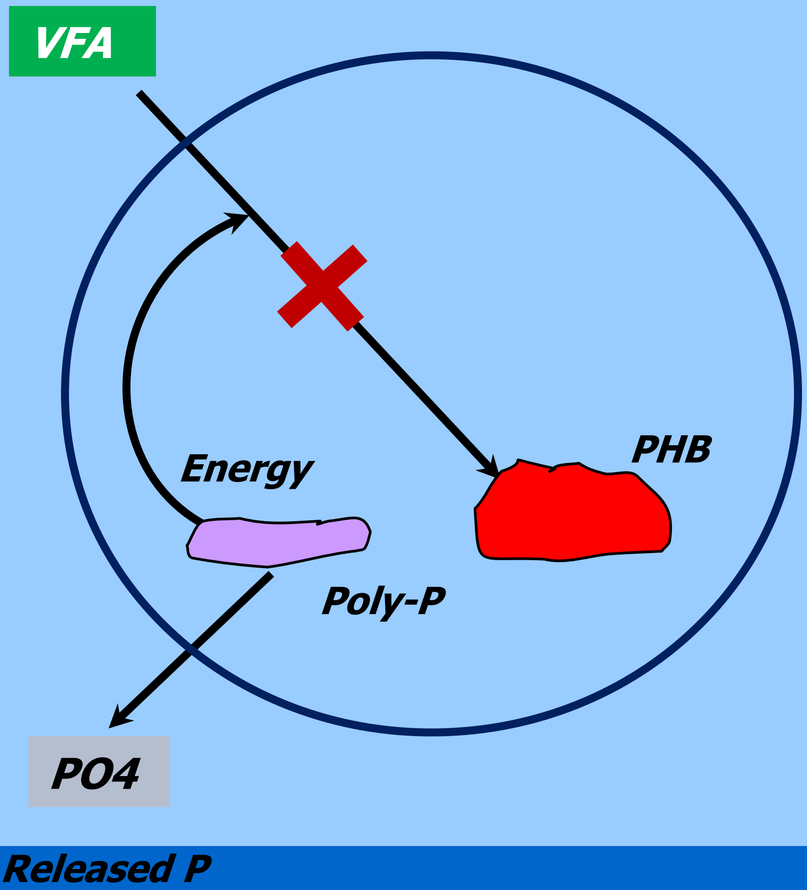
- Maintain advantage for PAOs by managing competition for VFAs from O_2 and NO_3
- Minimize phosphorus release in secondary clarifiers

Aerobic

- Good oxygen supply in the initial aerobic zones to ensure high initial aerobic P uptake.

Keys to BPR: Avoid secondary P release

Anaerobic



- Secondary release occurs when PAOs use poly-p to gain energy but don't store VFA at the same time.
- If PHB is not stored, subsequent P uptake can't occur
- Secondary release occurs when the clarifier blankets go anaerobic due to long sludge detention time

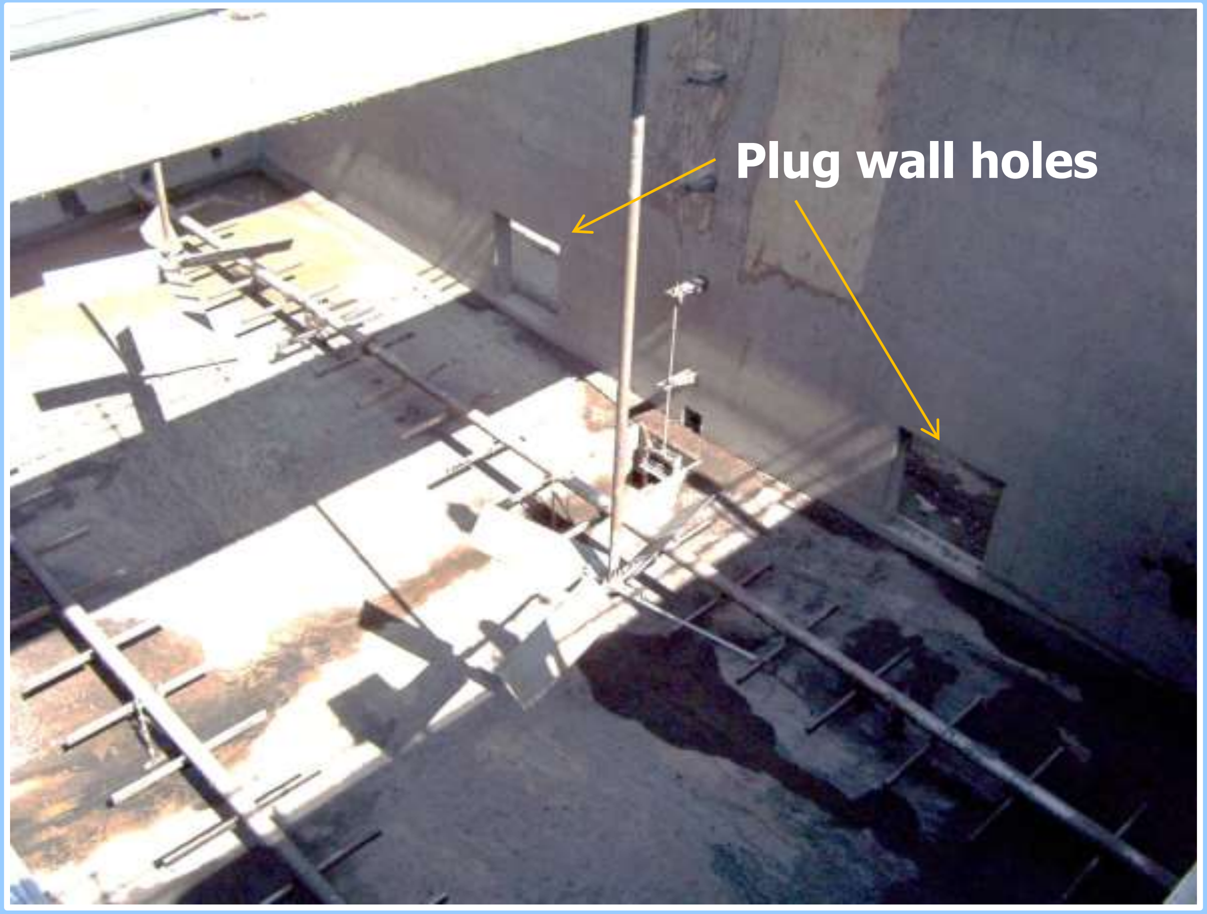
Manage Competition
Conditions Favoring GAOs over PAOs:

- High Temperatures (typically > 20 deg C).
- Low pH (typically < 7).
- High SRTs (typically > 20 days).
- Pure acetate (or acetate source such as glucose) fed to the anaerobic zone.
- Too large unaerated zones.
- Excess VFA available.

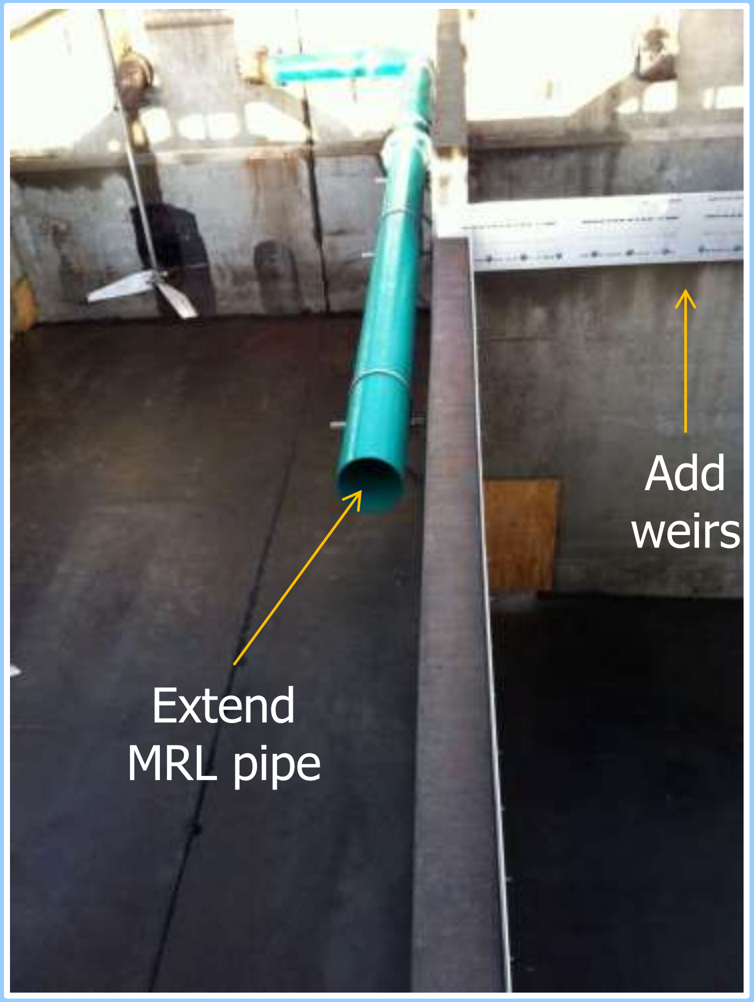
Strategies to Avoid Out-competition of PAOs by GAOs:

- Operate at lowest possible SRT
- Try to operate with the minimum anaerobic retention time.
- Alkalinity addition when the pH drops below 7.
- Natural fermentate (combination of acetic and propionic acid) best source of supplemental carbon for PAOs.
- Divert excess VFA if possible

Plant Modifications

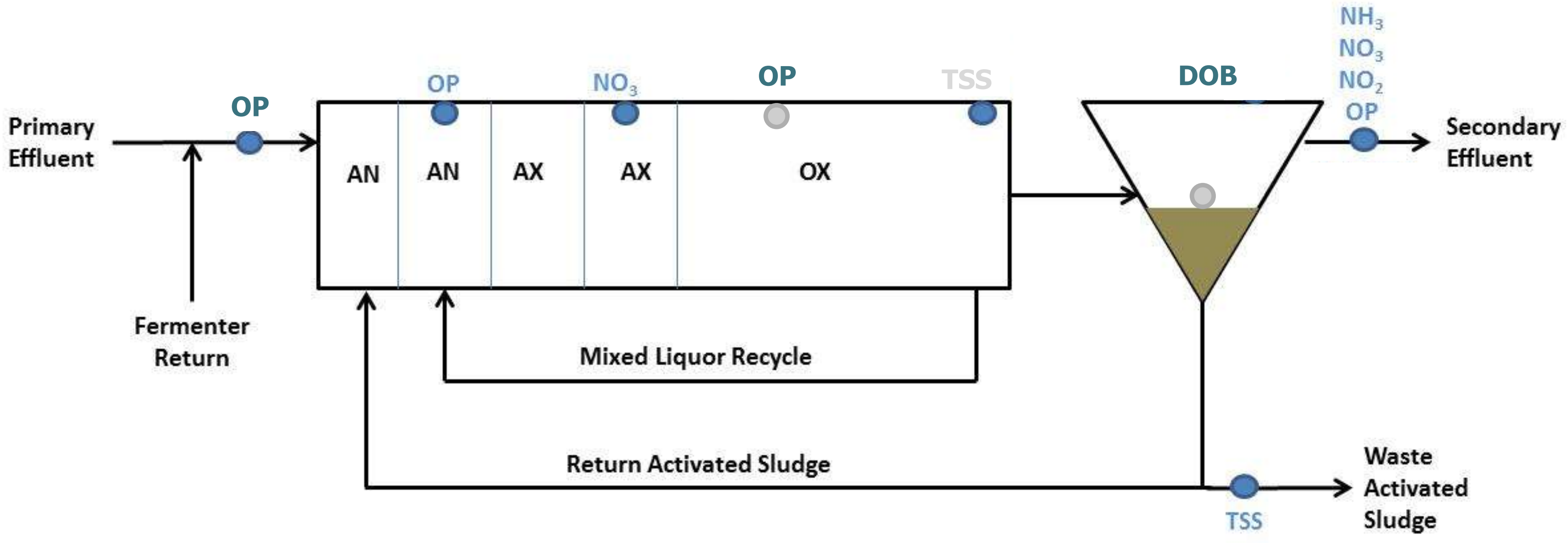


Plant Modifications



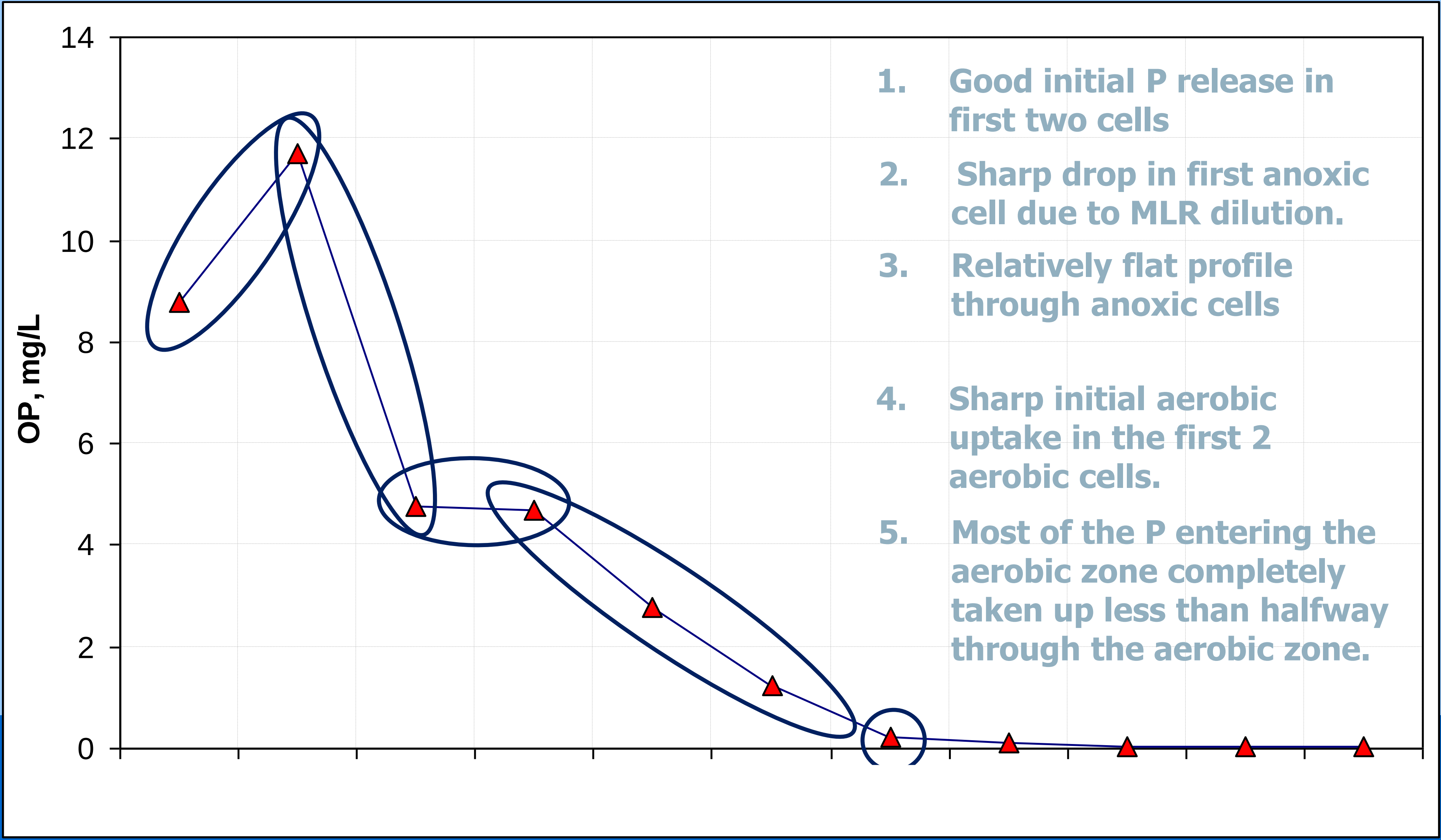
Troubleshooting Bio-P with Online Instrumentation

Question: How can each of these measurements help you troubleshoot or monitor bio-P?



VFA = volatile fatty acid; NH_3 = ammonia; OP = ortho-phosphate; NO_3 = nitrate; NO_2 = nitrite; TSS = total suspended solids; DOB = depth of blanket; AN = anaerobic zone; AX = anoxic zone; OX = aerobic zone

Keys to BPR: High initial DO



Summary

- VFA
  - Are you VFA limited?
  - Are you wasting VFA with O_2 or NO_3?
  - Are you wasting VFA with GAOs?
- PHB
  - VFA must be converted to PHB for uptake to happen
  - P Release without P uptake indicates the wrong release