Nutrient Removal at Wastewater Treatment Facilities

Nitrogen and Phosphorus

Gary M. Grey
HydroQual, Inc.
ggrey@hydroqual.com
201 529 5151 X 7167

Agenda

- Nitrification and Denitrification
  - Fundamentals
  - Processes
- Phosphorus Removal
  - Enhanced Biological Phosphorus Removal
  - Chemical Treatment

Nitrogen and Phosphorus Concentrations in Domestic Sewage

- Total Kjeldahl Nitrogen (25 to 50 mg/L)
  - Ammonium Nitrogen (15 to 35 mg/L)
  - Organic Nitrogen (10 to 20 mg/L)
    (Most organic nitrogen hydrolyzes to ammonia)
- Phosphorus (4 to 8 mg/L)
- Sludge handling streams can contain 100 to 1000+ mg/L TKN and 10 to 100+ mg/L P

Nitrogen Transformation in Biological Treatment

Nitrification by Autotrophic Bacteria

$$\text{ORGANIC NITROGEN} \longrightarrow NH_3\text{-N}$$

$$2\ NH_4^+ + 3\ O_2 \xrightarrow{\text{Nitrosomonas}} 2\ NO_2^- + 4\ H_2O + 4\ H^+ + \text{NEW CELLS}$$

$$2\ NO_2^- + O_2 \xrightarrow{\text{Nitrobacter}} 2\ NO_3^- + \text{NEW CELLS}$$

FOR 1 g NH_3-N OXIDIZED

- 4.33 g OF O_2 ARE CONSUMED
- 7.15 g OF ALKALINITY (as $CaCO_3$) ARE DESTROYED
- 0.15 g OF NEW CELLS ARE FORMED
- 0.08 g OF INORGANIC CARBON ARE CONSUMED

Nitrogen Transformation in Biological Treatment

Denitrification by Heterotrophic Bacteria

NO_3 + BOD → N_2 + CO_2 + H_2O + OH^- + CELLS

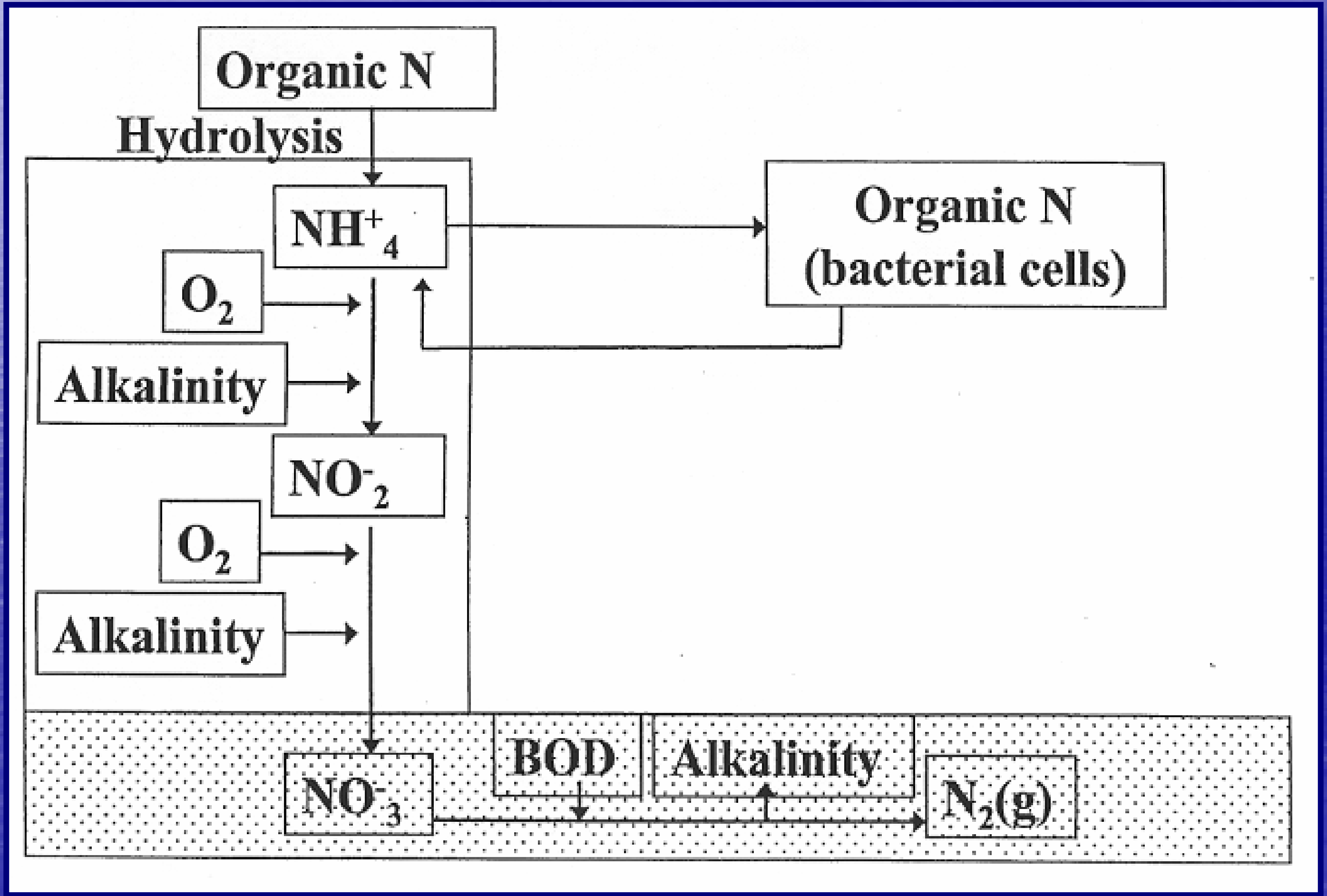
Occurs under anoxic conditions.

Required mixing and nitrate recycle.

For 1 gram of NO_3-N Denitrified:

- ~ 3.0 g BOD are consumed
- ~ 0.45 g new cells are produced
- 3.57 g of alkalinity are formed (~50% recovery of alkalinity consumed in nitrification)

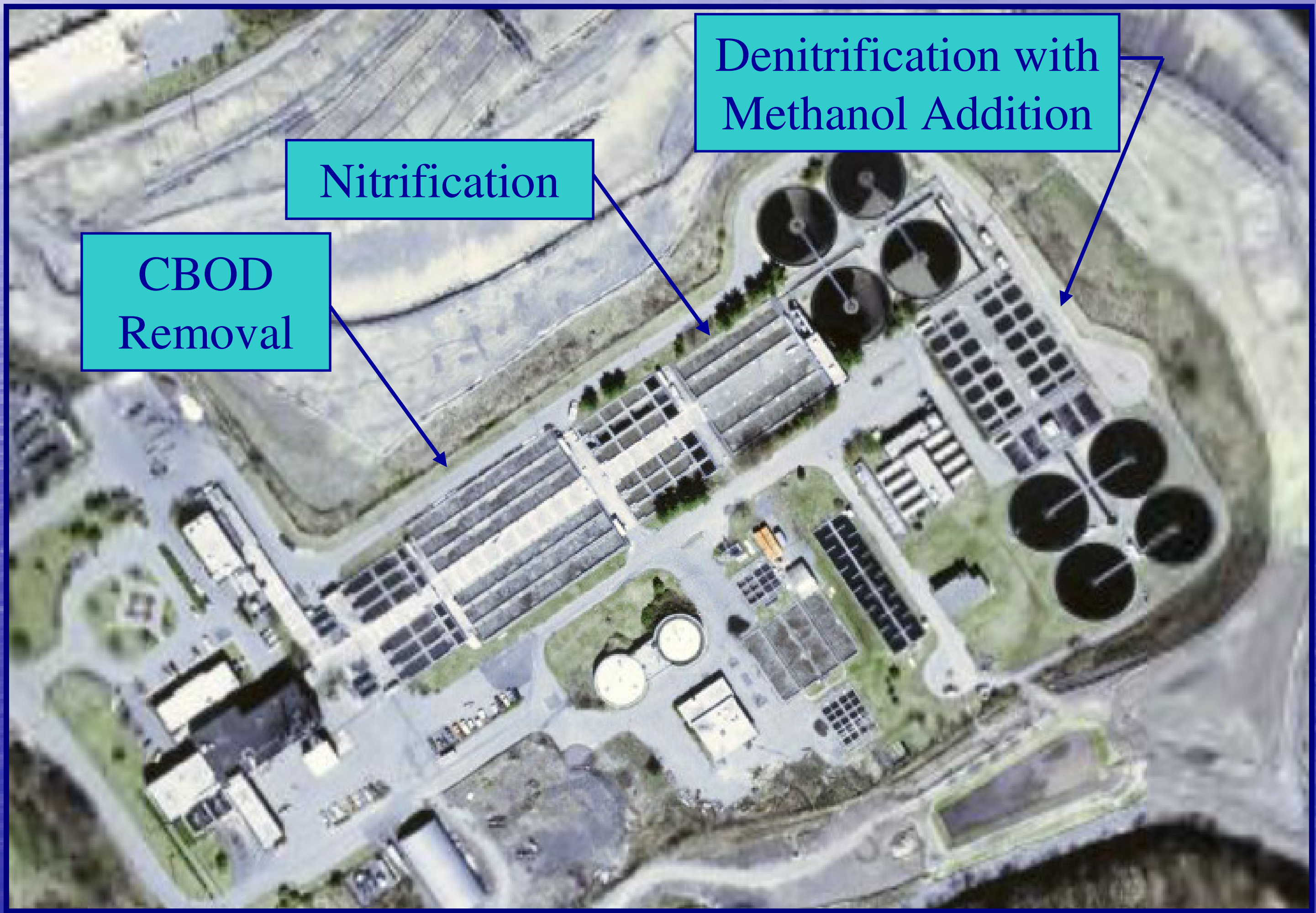
Nitrogen Transformations



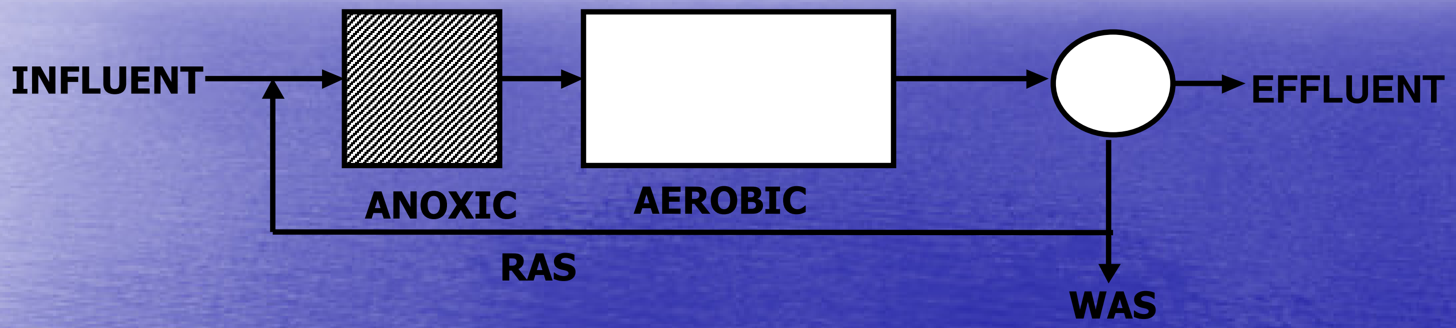
Factors Affecting Biological Nitrification and Denitrification Kinetics

Parameter	Nitrification	Denitrification
Sludge Age	X	
Effluent Ammonia Concentration	X	
Dissolved Oxygen (DO)	X	X
pH	X	X
Temperature	X	X
Inhibition	X	
Substrate Biodegradability		X

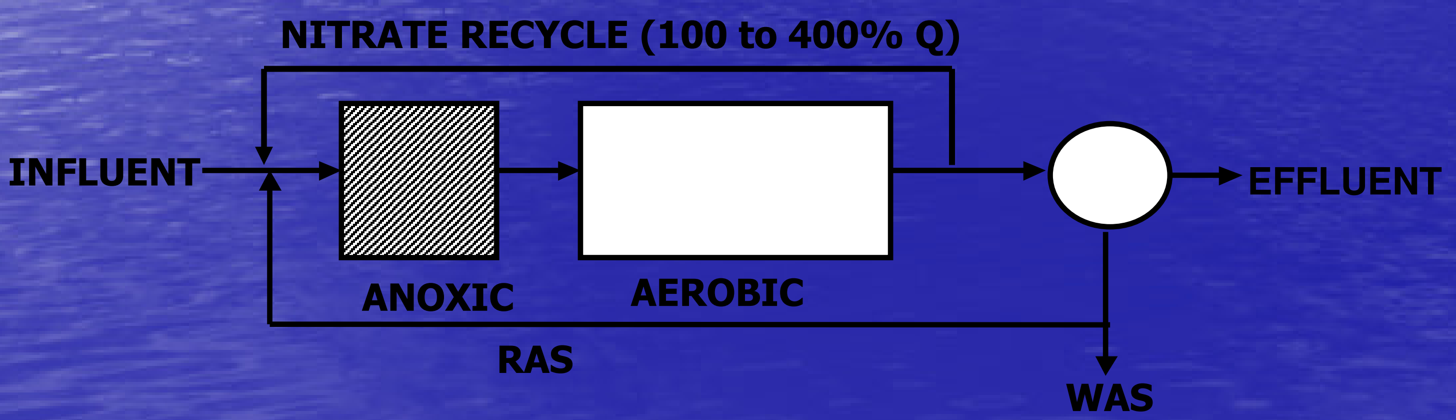
Original Nitrification/Denitrification Facilities Used Two or Three Sludge Processes



Current Biological Nitrification / Denitrification Processes



Ludzack-Ettinger Process

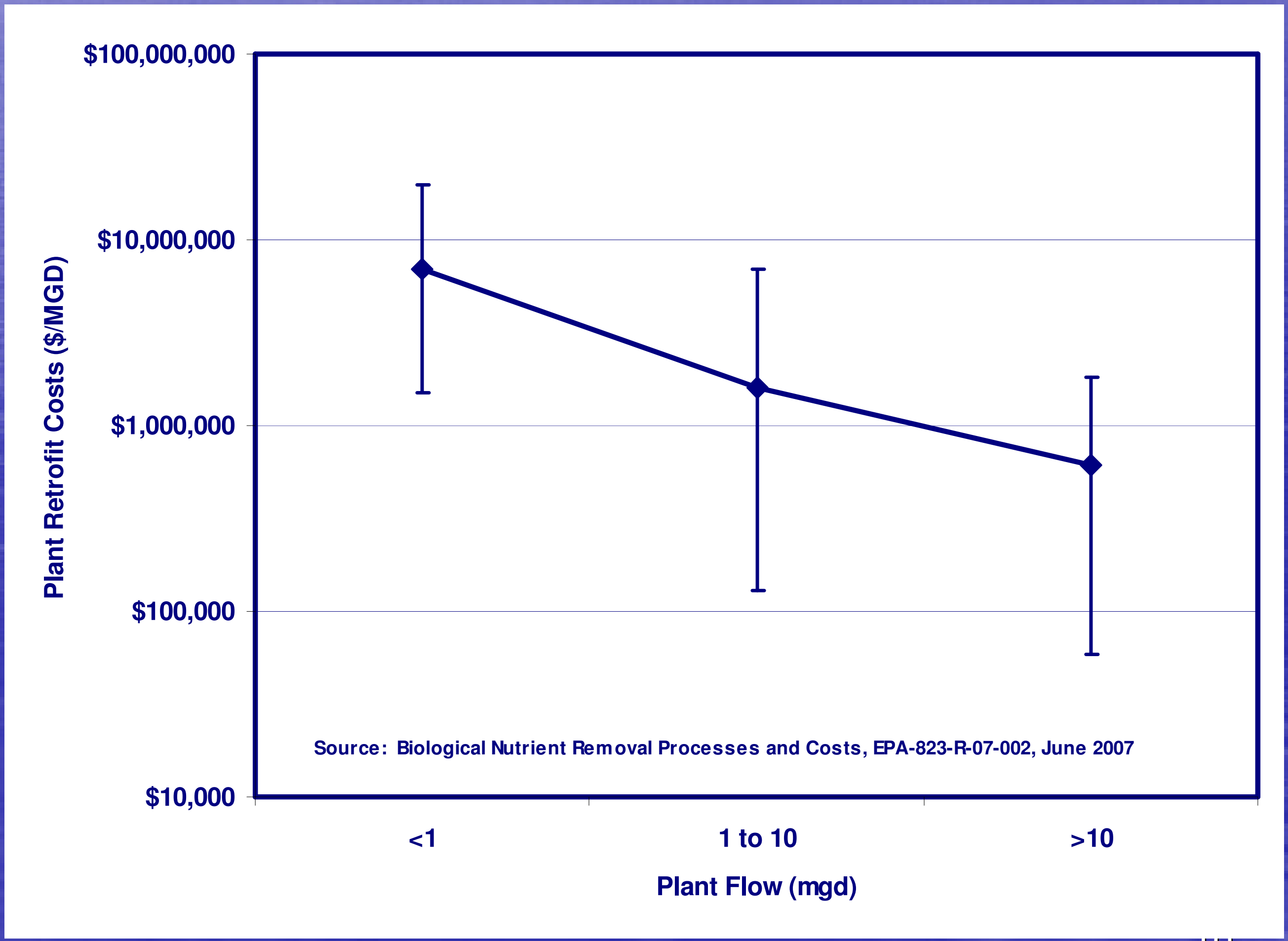


Modified Ludzack-Ettinger (MLE) Process

BNR Retrofit Costs

<u>Cost Factors</u>

- Mixers
- Nitrate Recycle Piping and Pumps
- Tank Baffles
- Supplemental Carbon



Nitrification/ Denitrification Summary

- Effluent Quality
  - NH_3-N <<1 mg/L
  - NO_3-N <1 to 5 mg/L depending on process, nitrate recycle and carbon availability.
  - Organic nitrogen 1 to 2 mg/L (higher with industrial sources)
- Nitrification is more sensitive to toxic and inhibitory substances than CBOD removal.
- Denitrification provides alkalinity recovery and can reduce energy costs.
- Consider sludge handling return streams.
- Good process control needed for year-round performance.

Phosphorus Removal

- Enhanced Biological Phosphorus Removal (EBPR)
- Chemical Precipitation

What is Enhanced Biological Phosphorus Removal (EBPR)?

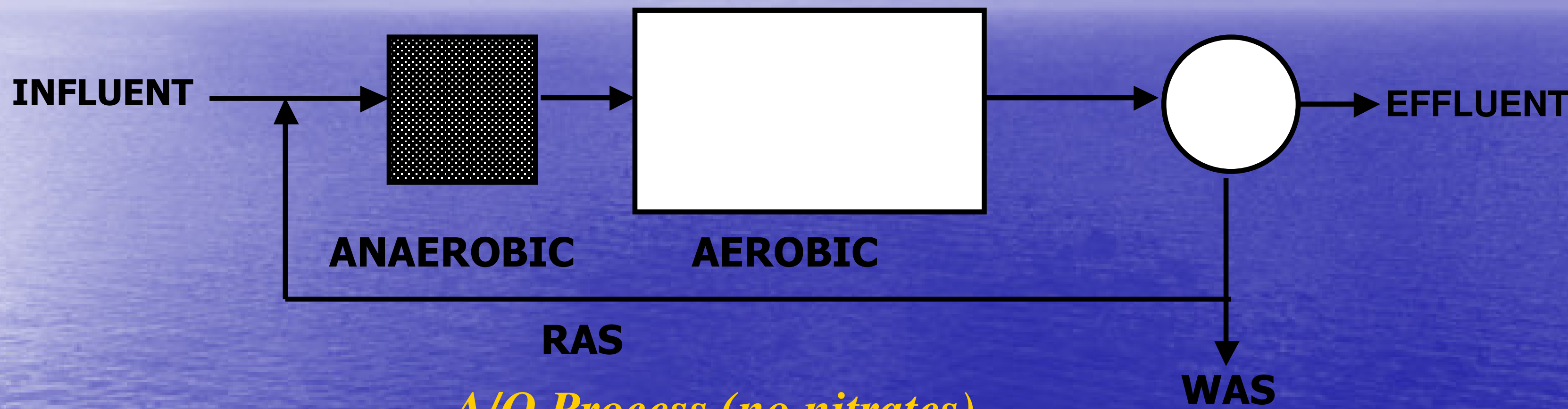
Biological Process that promotes the growth of phosphorous accumulating organisms (PAOs) that are able to take up and store high concentrations of phosphorus

- Normally bacteria in activated sludge contain 1-1.5 % P
- In the EBPR process, bacteria that store phosphorus are selectively retained in the biological process and they contain 20-30% P
- Need an anaerobic/aerobic process to select for these PAOs (phosphorus accumulating organisms)
- PAOs require readily biodegradable COD (rbCOD) as volatile fatty acids (VFAs)
- Denitrification bacteria out compete PAOs for rbCOD. Need anoxic zones for denitrification if nitrates are present.
- Supplemental carbon or fermentation may be needed of wastewater is carbon deficient.
- Phosphorus is removed by wasting PAOs.

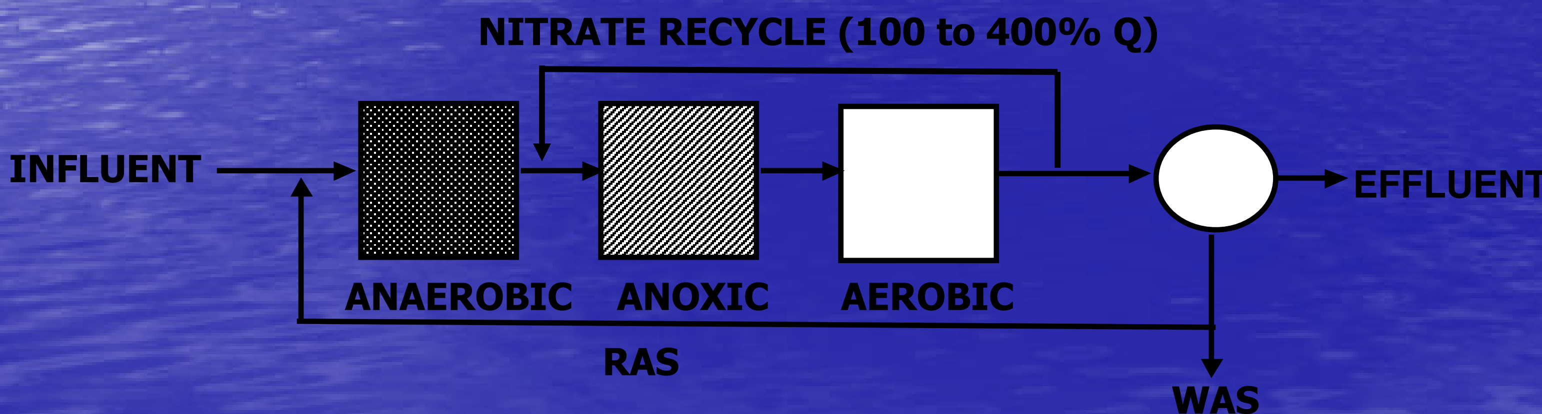
Plant EBPR Retrofit Requirements

- Volume for anaerobic contact zone
  - About 1 hour detention time
- A significant EBPR factor for achieving 1 mg/L is the BOD/P ratio.
  - >40 may be able to achieve effluent P < 1 mg/L
  - 25 to 35 will need chemical treatment for polishing
  - <25 may require chemical treatment only.
- Most domestic wastewaters yield 1-2 mg/L effluent phosphorus by EBPR unless supplemental carbon is provided.
- Low effluent phosphorus limits (<0.5 mg/L) will require effluent filtration.
- Minimize return loads containing phosphorus
  - Anaerobic or aerobic sludge digestion (> 50 mg/L P)

Biological Phosphorus Removal Processes

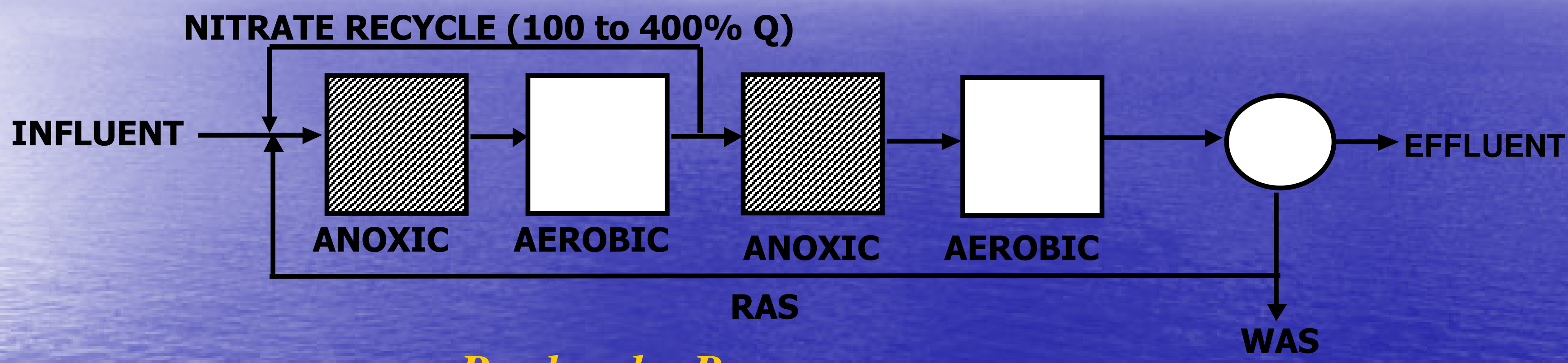


A/O Process (no nitrates)

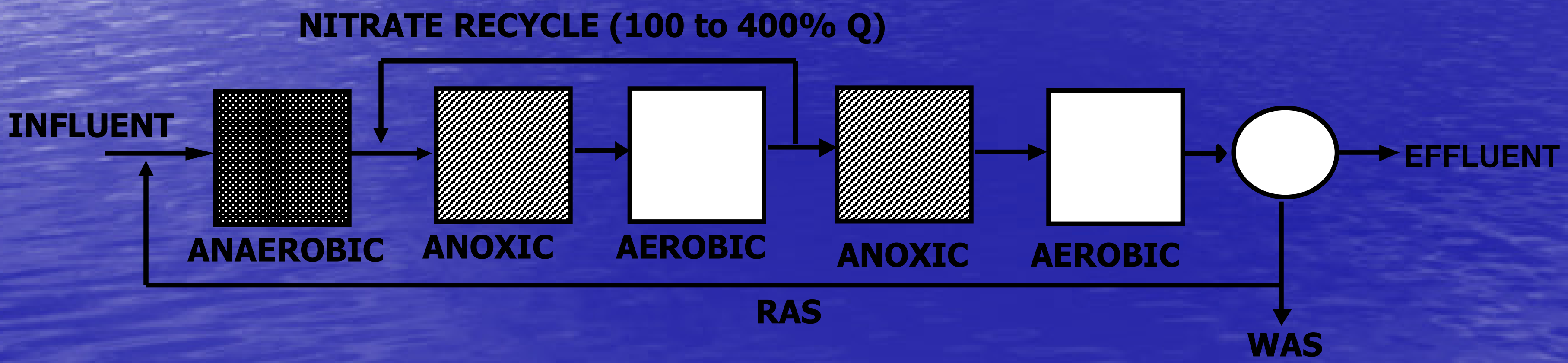


A^2O Process

Biological Phosphorus Removal Processes



Bardenpho Process



Modified Bardenpho Process (phosphorus removal and fermentation)

Chemical Treatment

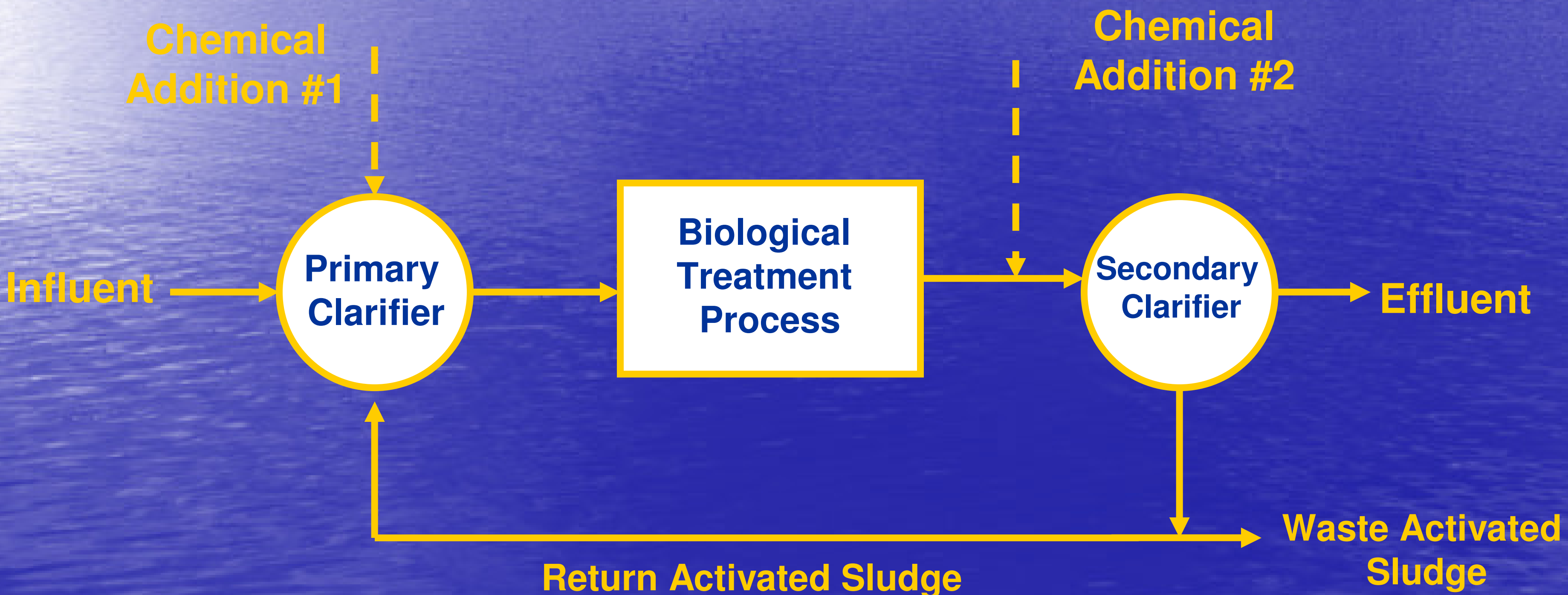
- Phosphorus Removal Mechanism
  - Metal salt precipitate at stoichiometric dose but …..
  - For very low P concentration metal-hydroxide formed

- $Al_2(SO_4)_3 \cdot 18H_2O + 2H_3(PO_4) \Rightarrow 2Al(PO_4)\downarrow + 3H_2SO_4 + 18H_2O$

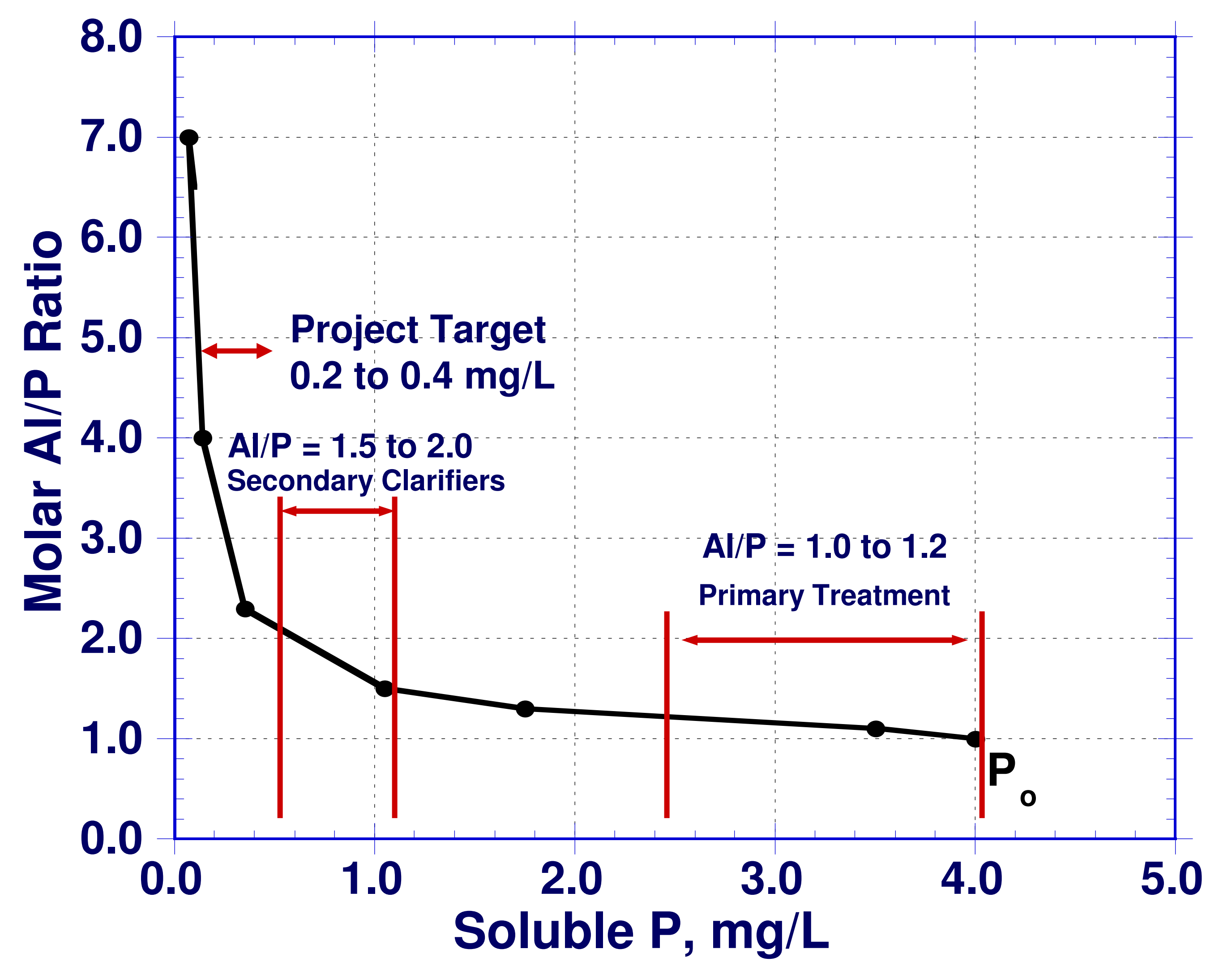
- $FeCl_3 + H_3(PO_4) \Rightarrow Fe(PO_4)\downarrow + 3HCl_3$

- Chemical treatment will deplete alkalinity, decrease pH and increase TDS

Two Point Chemical Addition Example

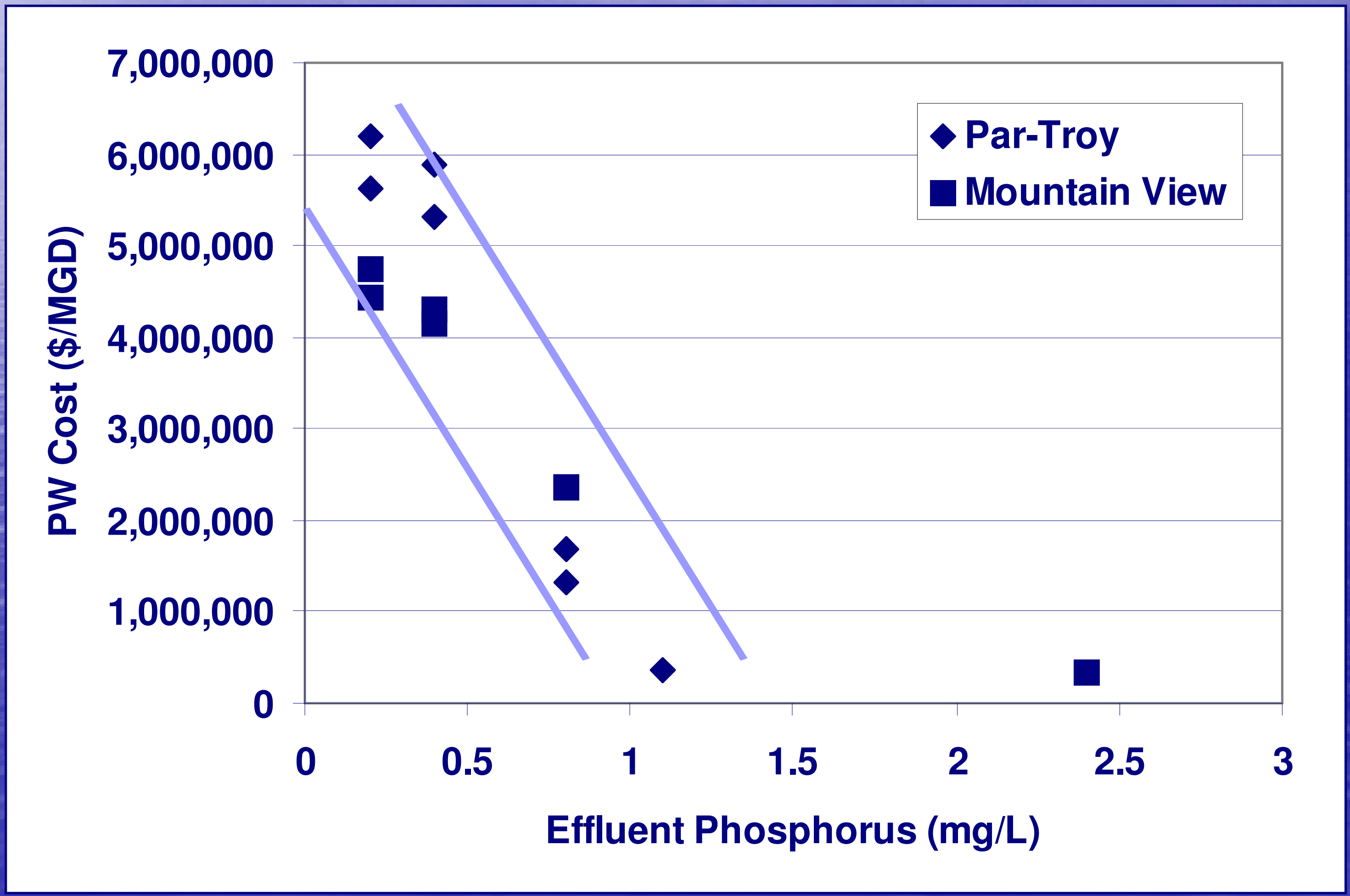


Al/P Or Fe/P Dose Is Function Of Effluent P Concentration



Chemical Addition to Secondary Clarifiers

Escalation of Costs for Achieving <1 mg/L Phosphorus



Phosphorus Removal Conclusions and Observations

- EBPR has higher capital costs and lower O&M costs, chemical treatment has lower capital costs and higher O&M costs.
- Costs increase dramatically for effluent limits <1 mg/L
- Wastewater characteristics must be determined to establish process requirements and effectiveness of EBPR.
- Standby chemical treatment should always be provided.
- For chemical treatment alone, two-point addition is the most cost effective.
- Sludge processing return streams must be characterized to assess their contribution of influent P load.
- Source control should be considered when P concentrations are above 6 to 8 mg/L or at low BOD/P ratios.

Questions?

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