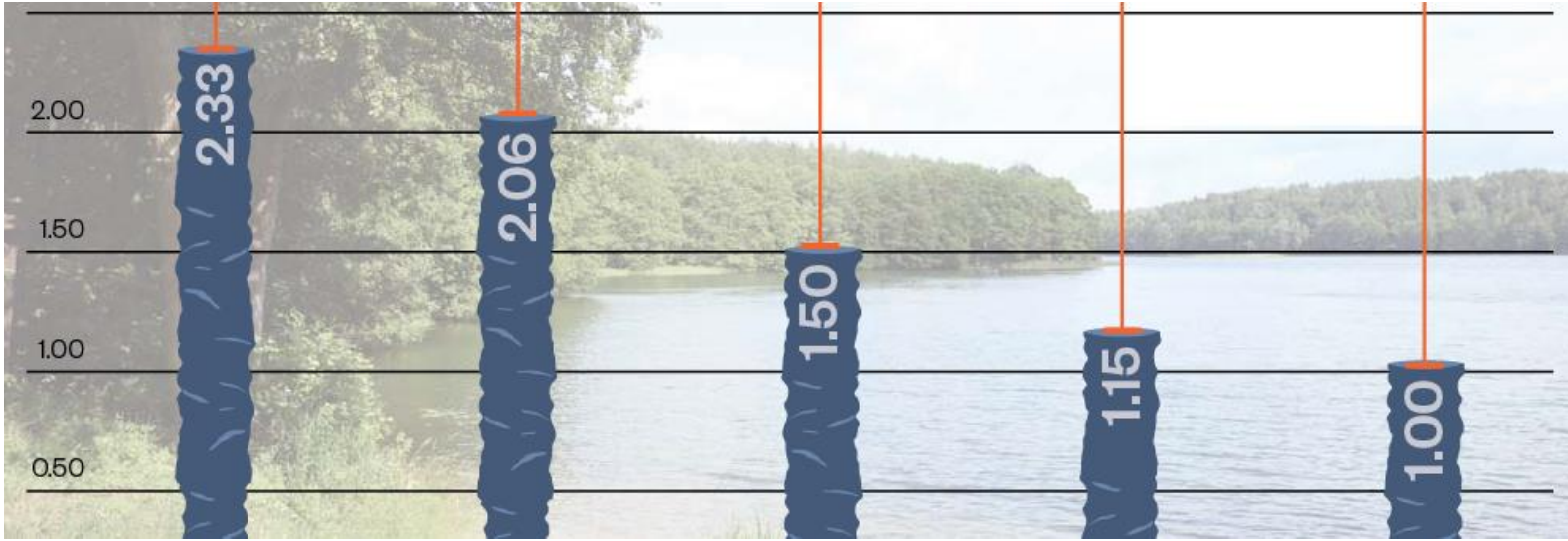
Hazen



Since OTCO 1964

OTCO’s 55th Annual Wastewater Workshop

Advanced Process Control Systems

March 7, 2019
Mark Strahota, PE
Hazen and Sawyer

What are Advanced Process Control Systems?

“Conventional” process controls use dissolved oxygen (DO) setpoints to control aeration and other operational inputs.

“Advanced” process controls use other parameters for control, including:

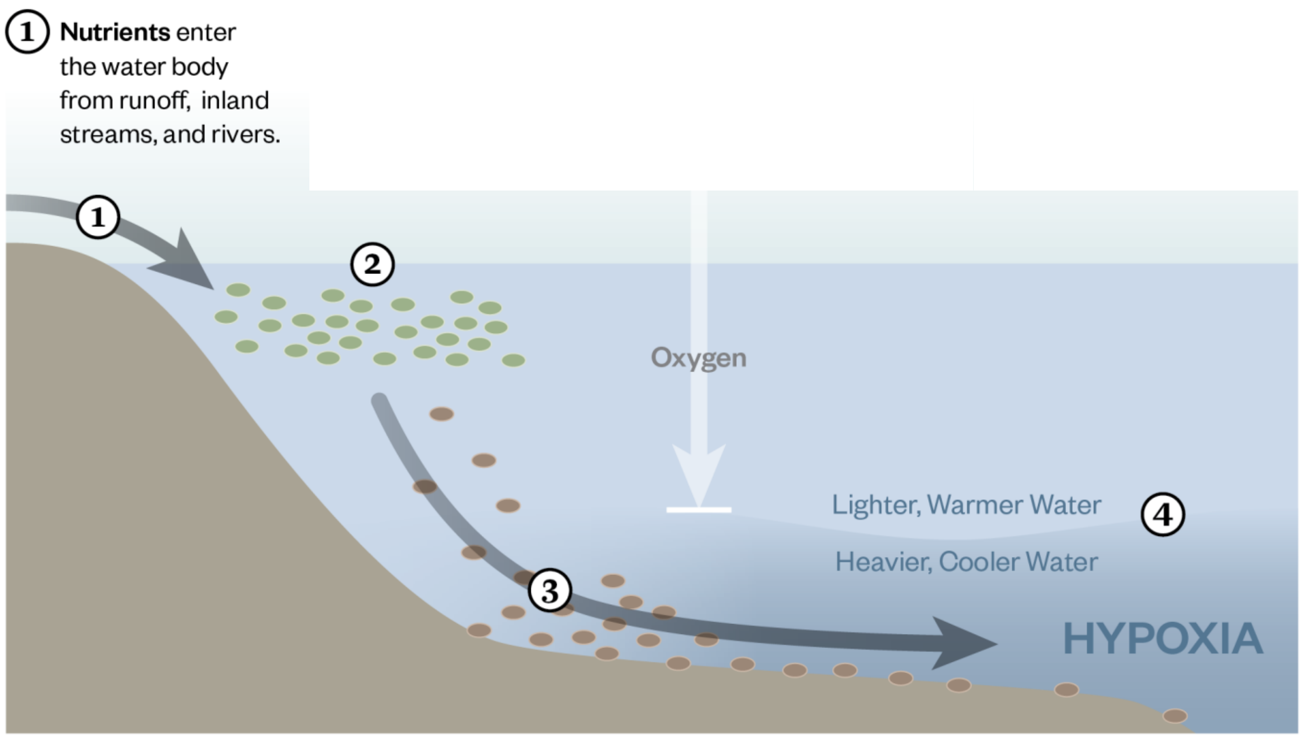
- Ammonia (NH_4)
- Nitrate / Nitrite (NO_3 / NO_2)
- Oxidation-Reduction Potential (ORP)

Typically used in biological nutrient removal (BNR) applications

Hypoxic/Eutrophic conditions have led regulatory agencies to require nutrient removal

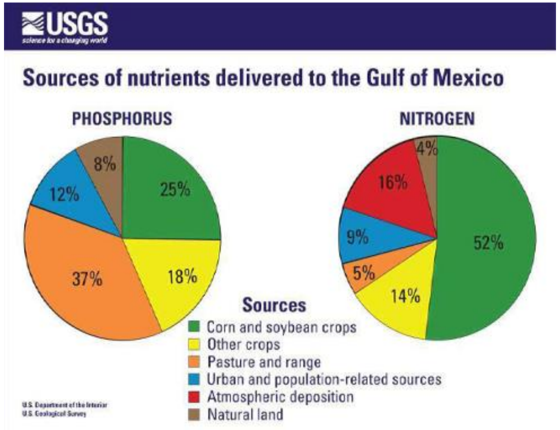
Eutrophication and Hypoxia

Algal Blooms Impact on Nature



Hypoxia has also been a Major Issue in the Gulf of Mexico

- 5,500 sq. mile "Dead Zone"
- ↑ significantly last 50 years
- Primary cause – nutrients from Mississippi River Basin
- Ongoing remediation since 2008



Lake Erie Harmful Algal Blooms (HAB)

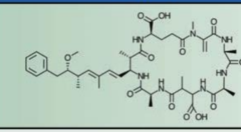
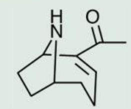
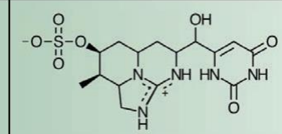
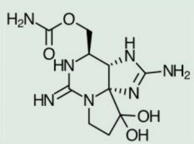
Cyanobacteria and Cyanotoxins caused by nutrients – mostly runoff

Smaller summer harmful algal bloom forecast for western Lake Erie

New satellite data to bring more accurate and detailed predictions

July 12, 2018 —

Source: noaa.gov

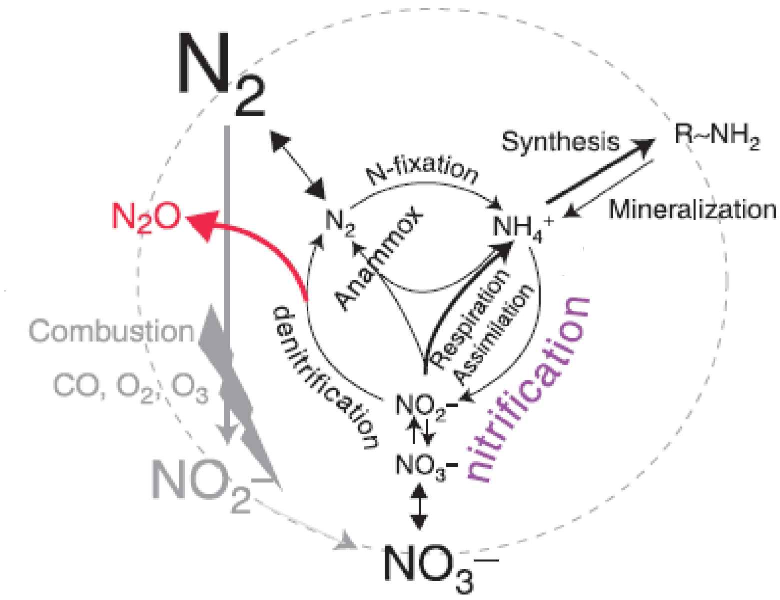
Toxin	Structure	Organ	Genera
Microcystin		Liver (possible carcinogen)	*Microcystis* *Anabaena* *Planktothrix* *Anabaenopsis*
Anatoxin - a		Neurotoxin (nerve synapse)	*Anabaena* *Planktothrix* *Aphanizomenon* *Cylindrospermopsis*
Cylindrospermopsin		Liver (possible kidney, genotoxic and carcinogen)	*Cylindrospermopsis* *Aphanizomenon*
Saxitoxin		Neurotoxin (sodium channel blocker)	*Anabaena* *Aphanizomenon* *Cylindrospermopsis* *Lyngbya* *Planktothrix*

Source: American Water Works Association

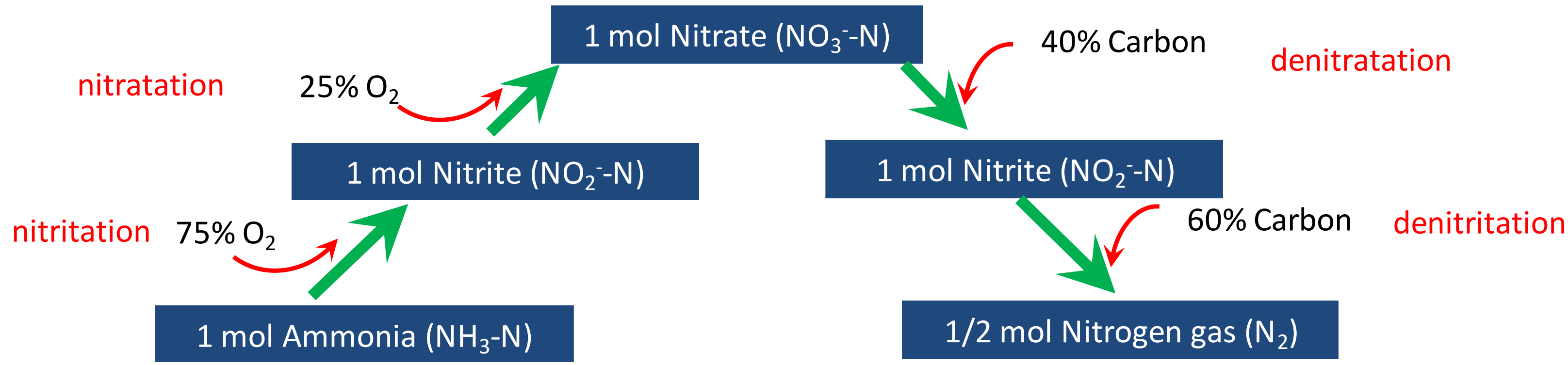
Biological Nutrient Removal Technologies – Where We’ve Been

Conventional Nitrogen Removal

Goal has been to produce N_2 gas in most cost effective manner



Conventional Approach for Performing Nitrogen Removal at WRRFs

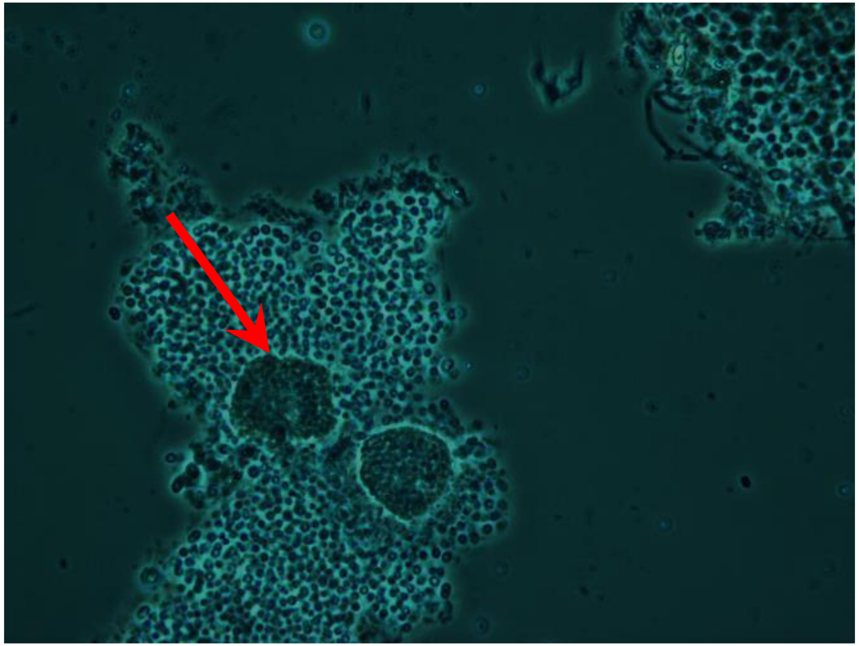


Ammonia converted to nitrogen gas using nitrification and denitrification

Process requires

- 4.6 lb O_2/lb NH3 removed
- 7.1 lb Alk/lb NH3 removed
- 4 to 6 lb COD /lb NO_3 removed

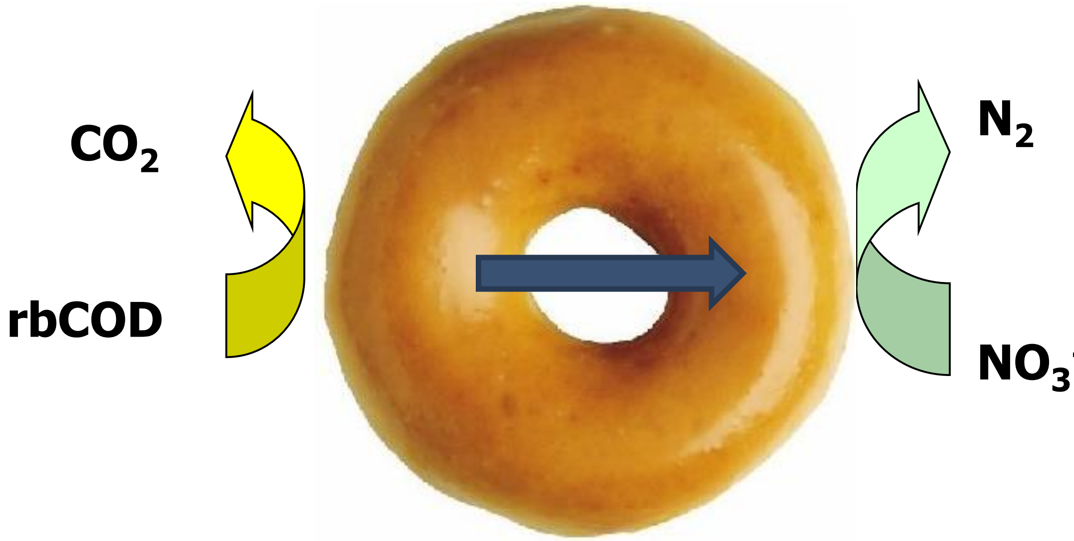
Microscopic Analysis – Nitrifying Bacteria



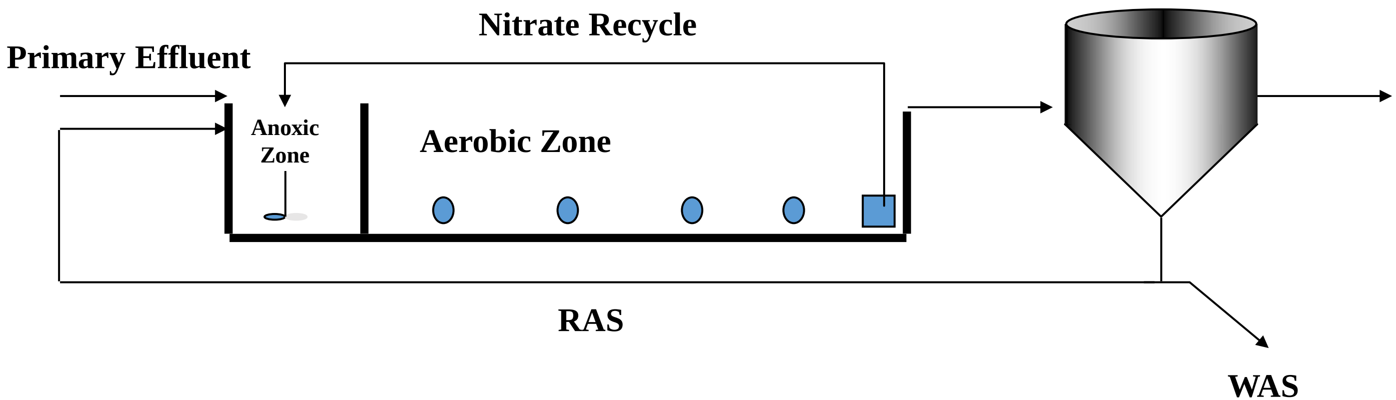
Nitrification

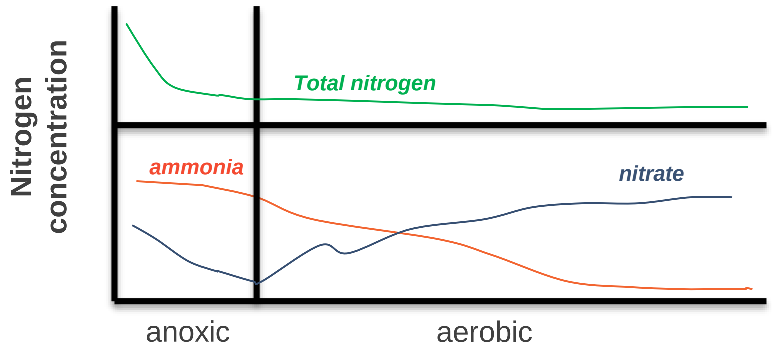
Denitrification

- Conducted by heterotrophic facultative aerobes under **anoxic** conditions
- Need a carbon source!



Conventional Approach for Performing Nitrogen Removal at WRRFs





Combine aerobic and anoxic conditions to achieve nitrification and denitrification

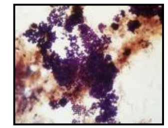
Conventional Phosphorus Removal

Goal has been to minimize effluent P in the liquid stream and maximize the P leaving in the sludge/solids form

Wastewater Phosphorus Speciation & Removal Methods

Total Phosphorus

- **Ortho-Phosphate**



Biological P Removal

Chemical P Removal

- **Poly-phosphate**

Chemical P Removal
Biological P Removal

- **Particulate Phosphorus**

Solids Separation

- **Non-bioavailable Soluble**

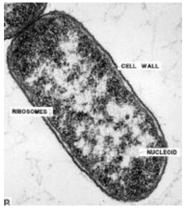
Chemical Coagulation
Adsorption

- **Inert Soluble**

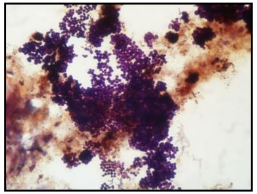
Reverse Osmosis

Conventional Approach for Performing Phosphorus Removal at WRRFs

1. Removal by biomass uptake → Between 2 to 10 % soluble P removal



2. Biological - (EBPR) → Up to 90 % soluble P removal

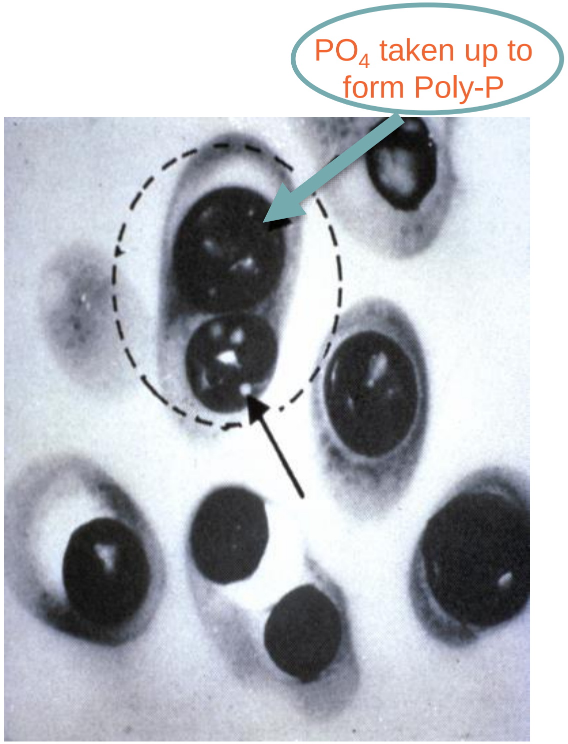


3. Chemical Removal → > 99% removal of soluble and total P

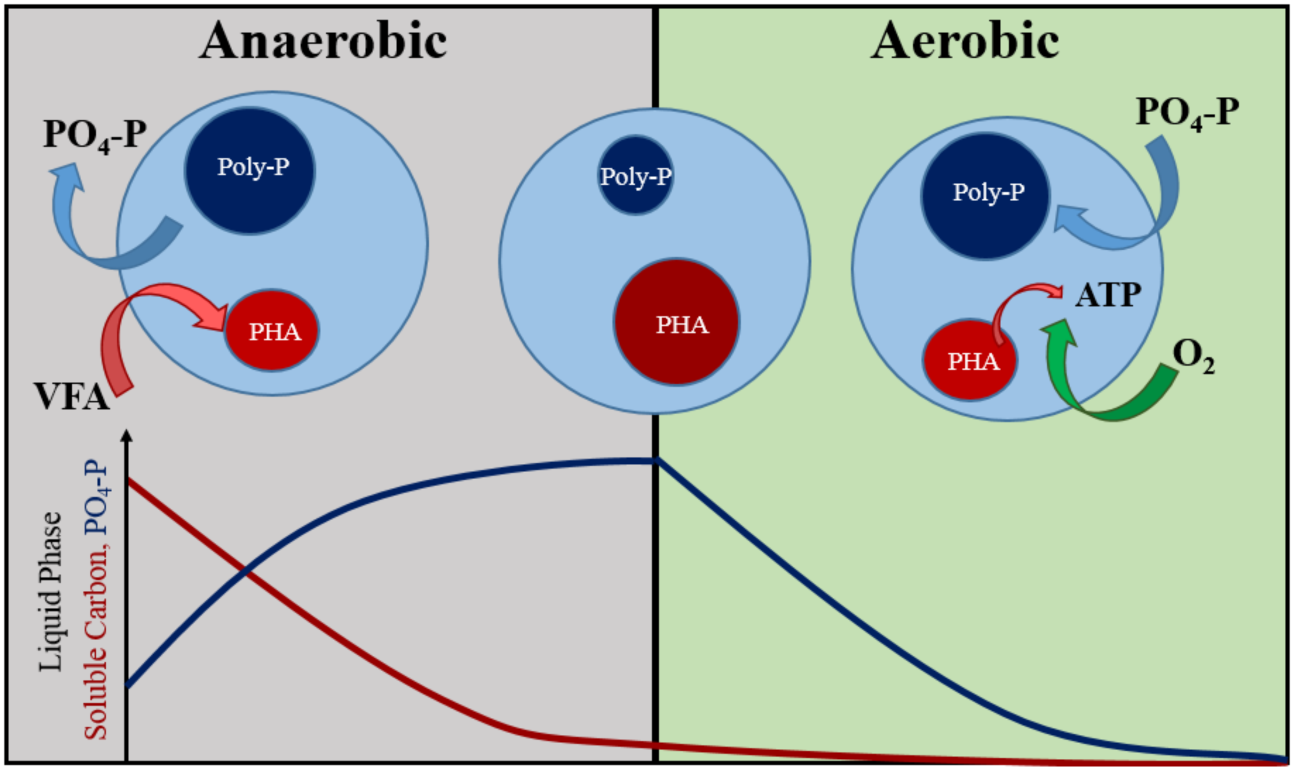
   (Ca^{2+}, Al^{3+}, or Fe^{3+})

Enhanced Biological Phosphorus Removal

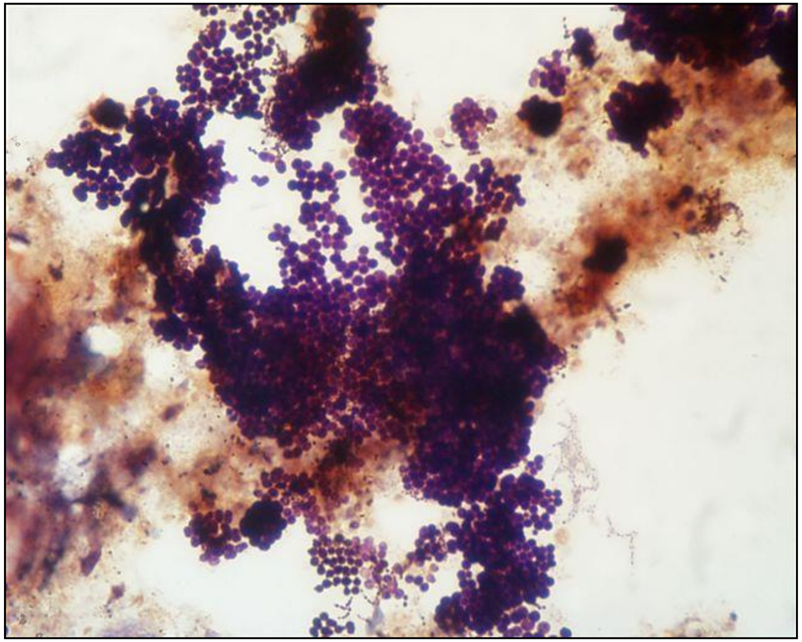
- Specific bacteria (known as **Phosphate Accumulating Organisms (PAOs)** can sequester high levels of phosphorus by storing it inside their cell as poly-phosphate (poly-P).
- An EBPR process is designed to select for these bacteria and waste them while poly-P content is high



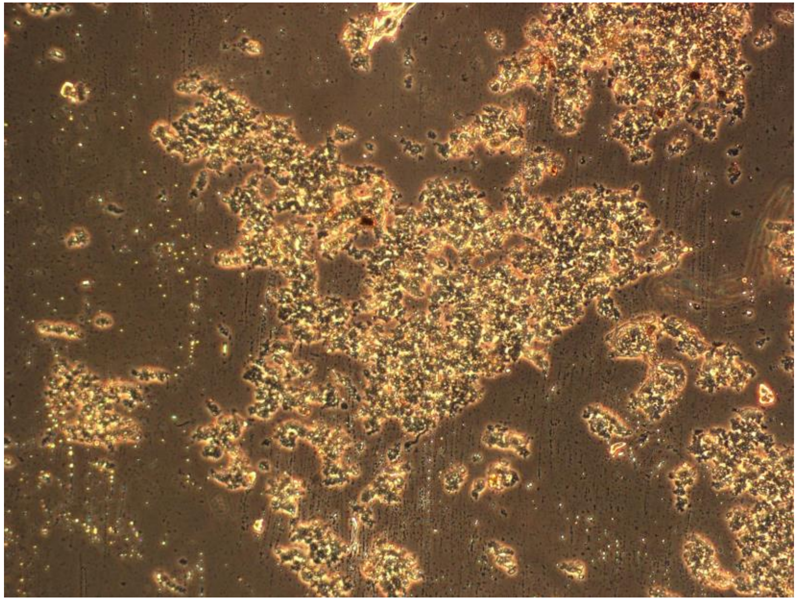
Required Conditions for Enhanced Biological Phosphorus Removal (EBPR)



Enhanced Solids Removal Drives the Ability to Achieve Low TP Limits (< 0.5 mg/L)

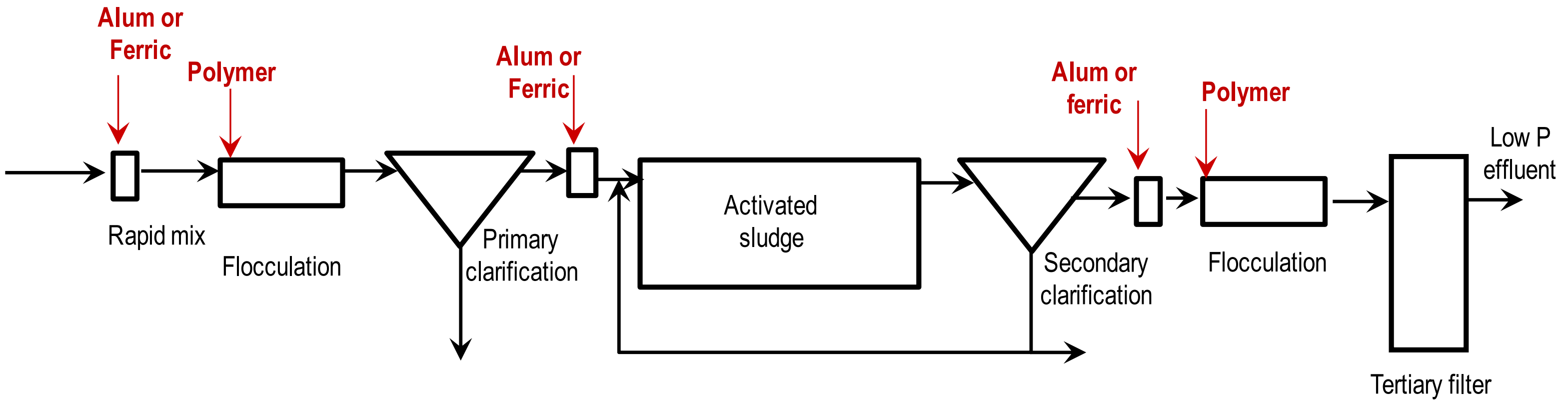


EBPR biomass is approximately 6% phosphorus (can be as high as 8%-12%)



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

Combination of Biological and Chemical Processes for Phosphorus Removal



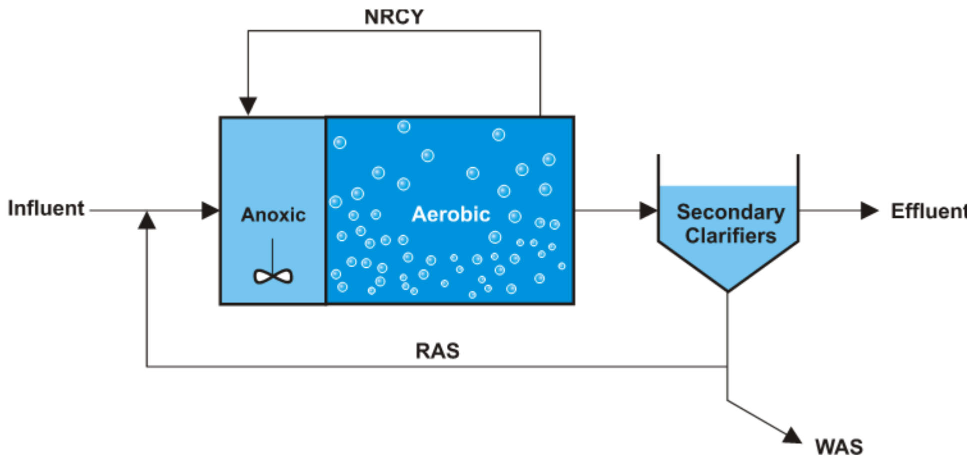
- Multipoint chemical addition can be used in concert with Bio-P to achieve low effluent P levels with reduced sludge production and chemical costs

Conventional Biological Nutrient Removal Configurations

MLE
AO
A2O
Bardenpho
Step-Feed

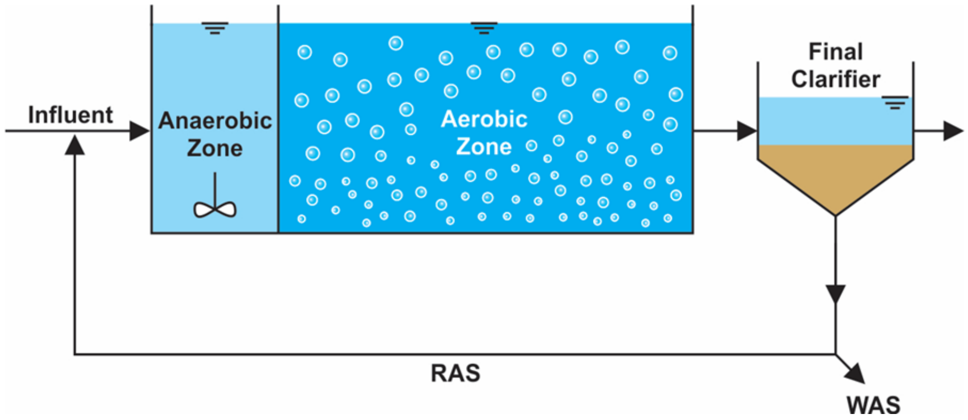
Modified Ludzack Ettinger (MLE) Process

- Provides biological nitrogen removal
  - Nitrate return via internal pumping (NRCY, IMLR, MLR)
  - Limited biological phosphorus removal



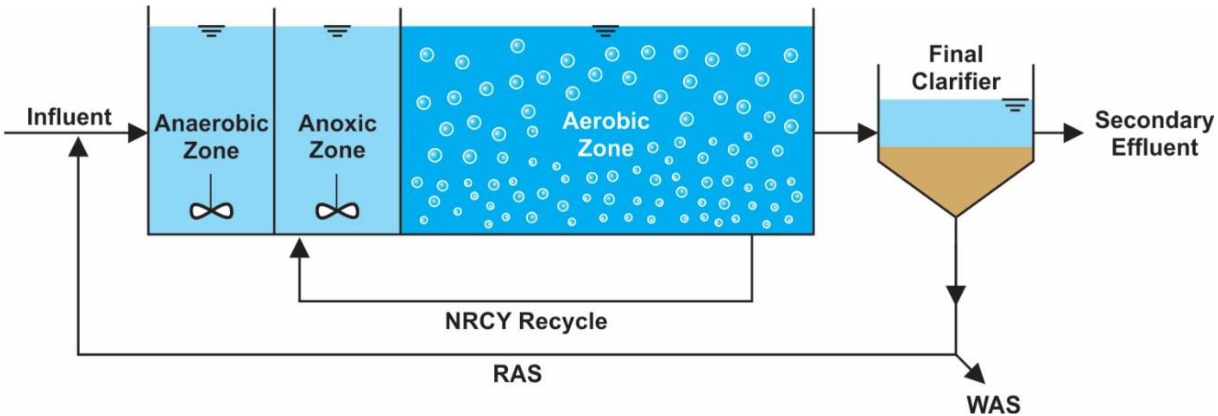
Anaerobic/Oxic (AO) Process

- Provides biological phosphorus removal
  - Nitrate only removed from RAS
  - Impacted by high nitrate return in nitrifying systems



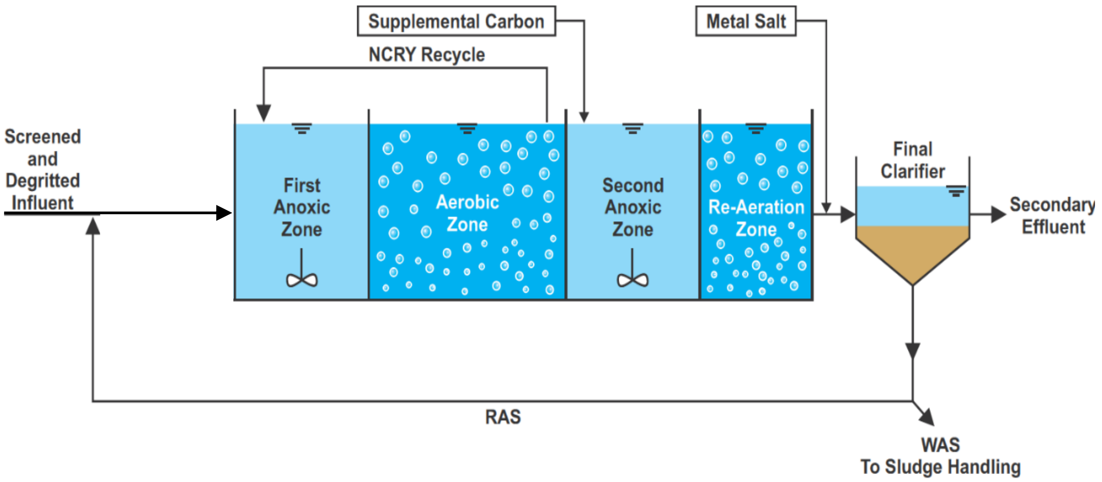
Anaerobic/Anoxic/Oxic (A^2O) Process

- Anaerobic zone + MLE Process
  - Provides nitrogen and phosphorus removal



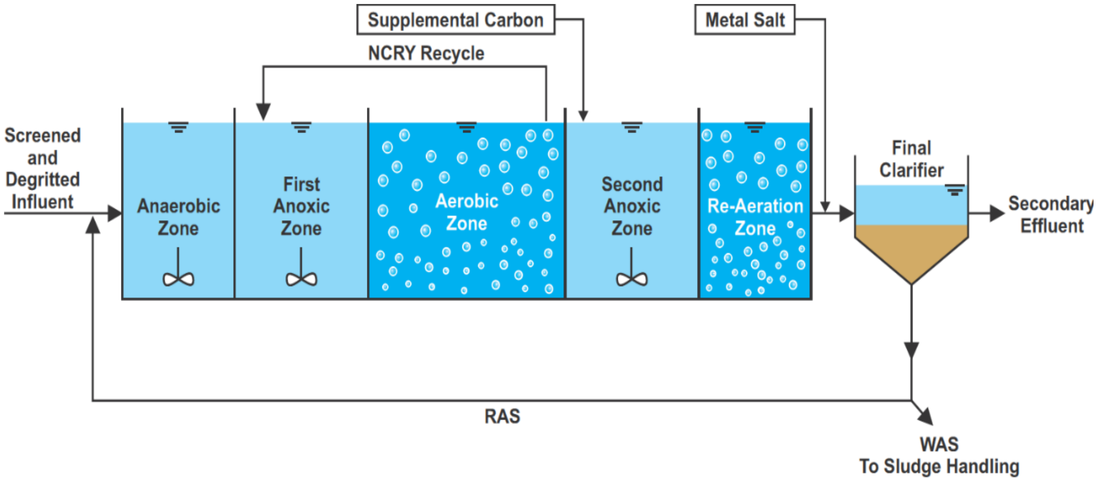
4-Stage BNR (Bardenpho) Process

- Add post-anoxic and reaeration zone to MLE process
- Supplemental carbon feed to post-anoxic



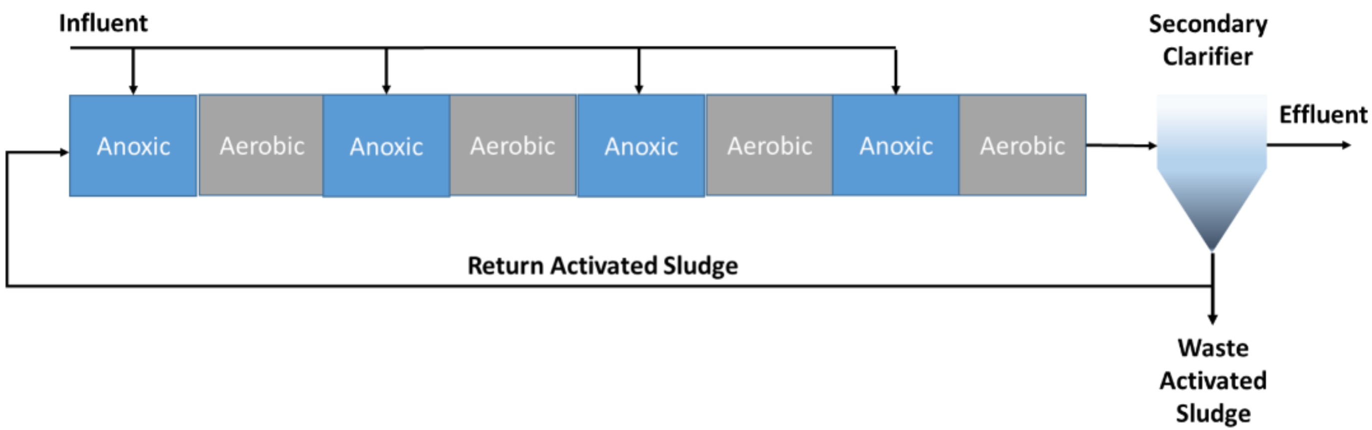
5-Stage BNR (Bardenpho) Process

- Add post-anoxic and reaeration zone to A2O process
- Supplemental carbon feed to post-anoxic

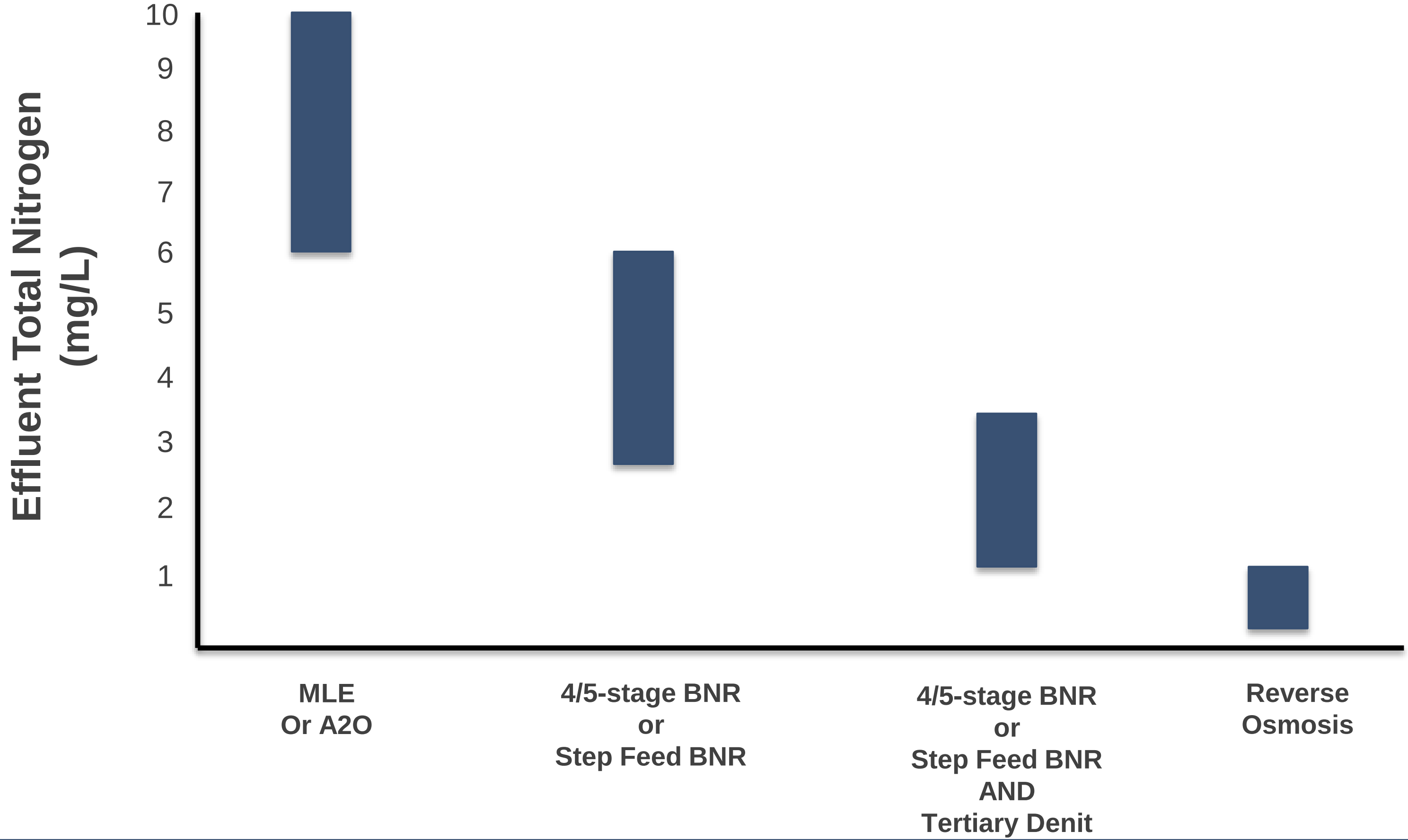


Step Feed BNR Process

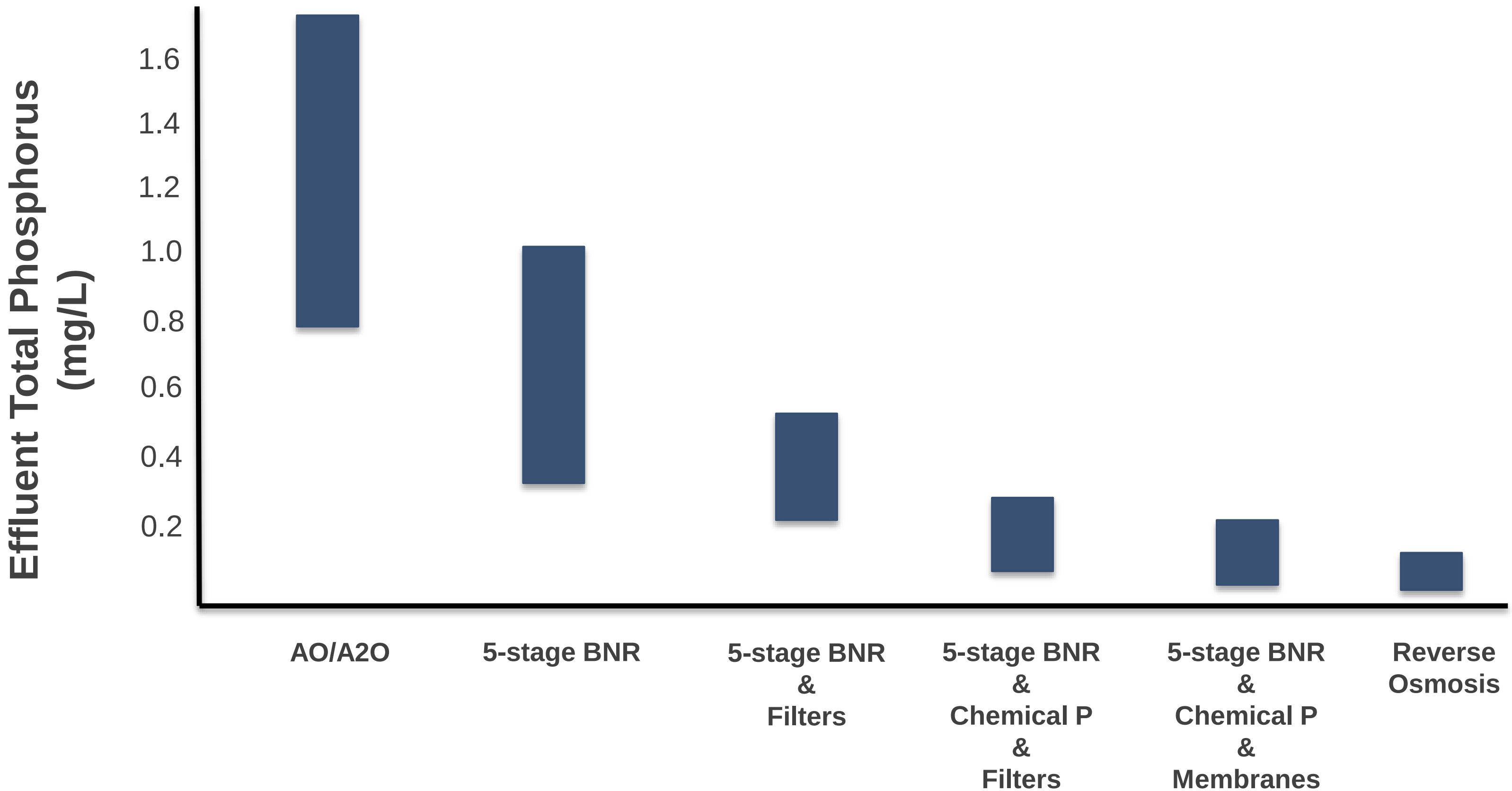
- Alternate anoxic and aerobic zones
  - RAS returned to front of basin
  - Influent fed to multiple anoxic zones in the basin
  - Typically limited biological phosphorus removal



Effluent Limits Impact Treatment Approach and Cost



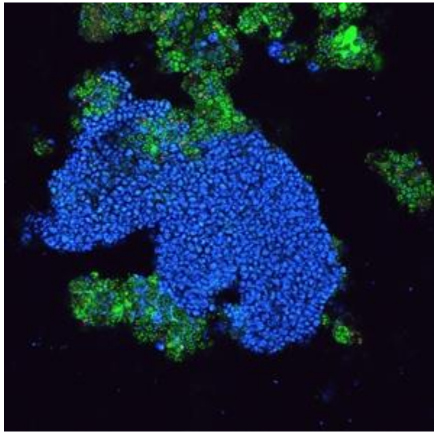
Effluent Limits Impact Treatment Approach and Cost



Biological Nutrient Removal Technologies – Where we're heading

Enhanced Biological Phosphorus Removal Intensification

- PAOs may be a very diverse population that can thrive in various environmental niches
  - Example - *Tetrasphaera*
    - Can assimilate different substrates (VFAs, glucose, amino acid) anaerobically
    - Can ferment complex organics, glucose and amino acids
    - Anaerobic phosphorus uptake through energy generated from carbon fermentation
    - Can denitrify
    - Potential low dissolved oxygen niche



Design Considerations for Intensifying EBPR

- Sidestream MLSS/RAS fermentation
  - Select for *Tetrasphaera?*
  - Similar performance observed by shutting off mixers
- Split primary effluent between anaerobic and anoxic zones
  - Bypass all wet weather flows directly to anoxic zone
- Low DO
  - Synergy with next generation nitrogen removal processes & net-zero energy
- Physical separation to retain PAOs
  - Hydrocyclones (i.e. inDENSE™) and screens
- **Low ORP operation**
  - **< 300 mV - select for *Tetrasphaera?***

Biological Process

What is Oxidation Reduction Potential (ORP)?

- The ORP of a solution depends on the oxidation and reduction agents present within the solution
- ORP trends closely to DO in aerobic conditions
- ORP is used as indirect measurement or impact of DO in low concentrations
  - At low concentrations, DO can not be measured directly by a DO probe
  - The operating range of a ORP probe is greater than a DO probe in low DO conditions, which leads to greater accuracy

Biological Process

Oxidation Reduction Potential (ORP)

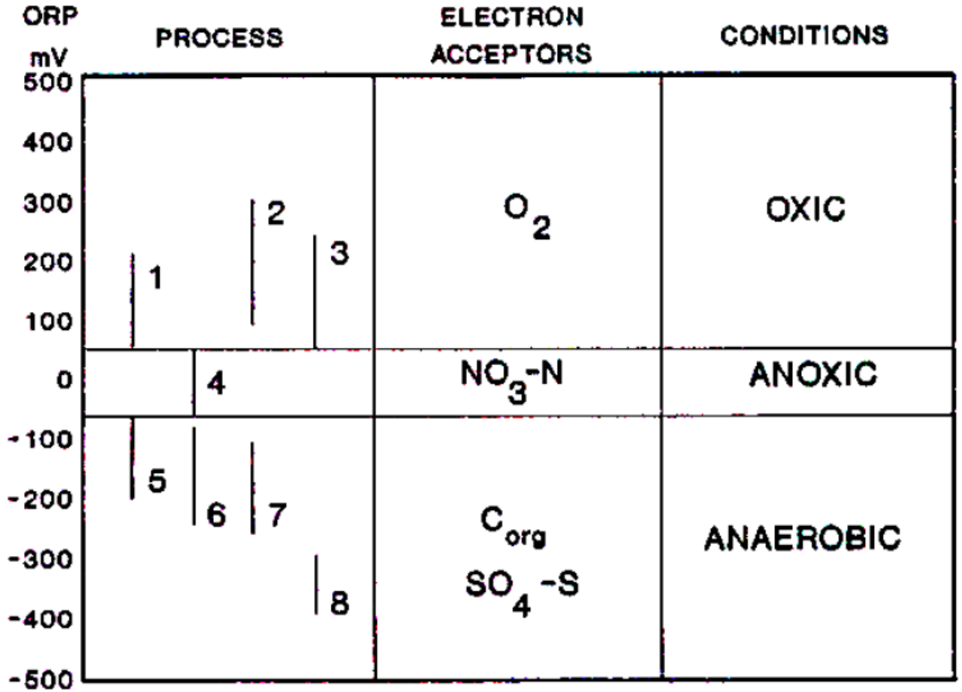
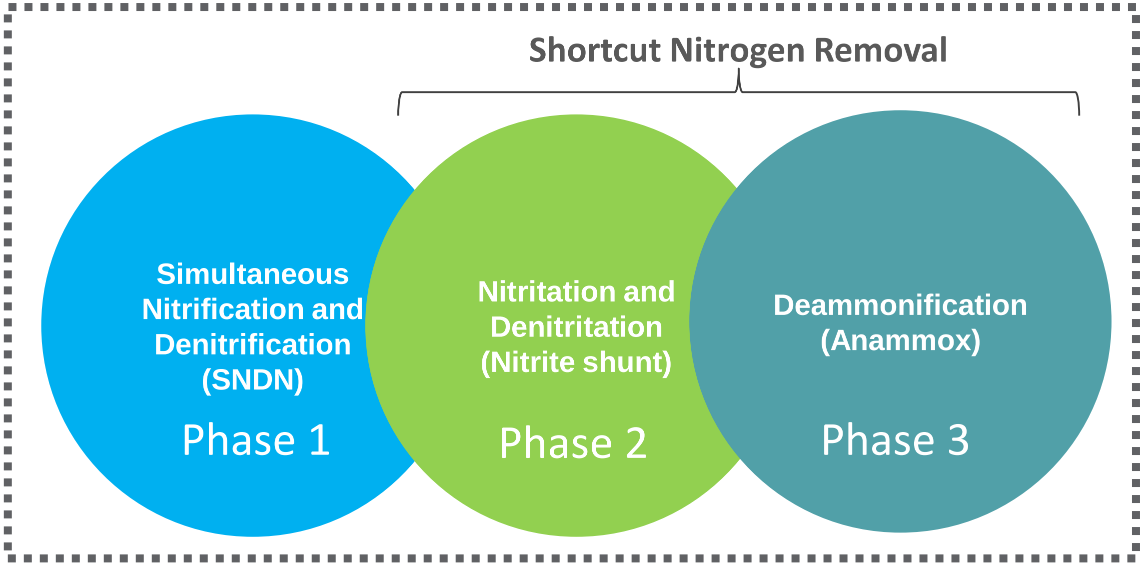


Figure 1.1 Classification of cultivation conditions according to the oxidation-reduction potential. 1—Oxidation of organic carbon; 2—accumulation of polyphosphates; 3—nitrification; 4—denitrification; 5—depolymerization of phosphates; 6—desulfatation; 7—acido- and acetogenesis; 8—methanogenesis.

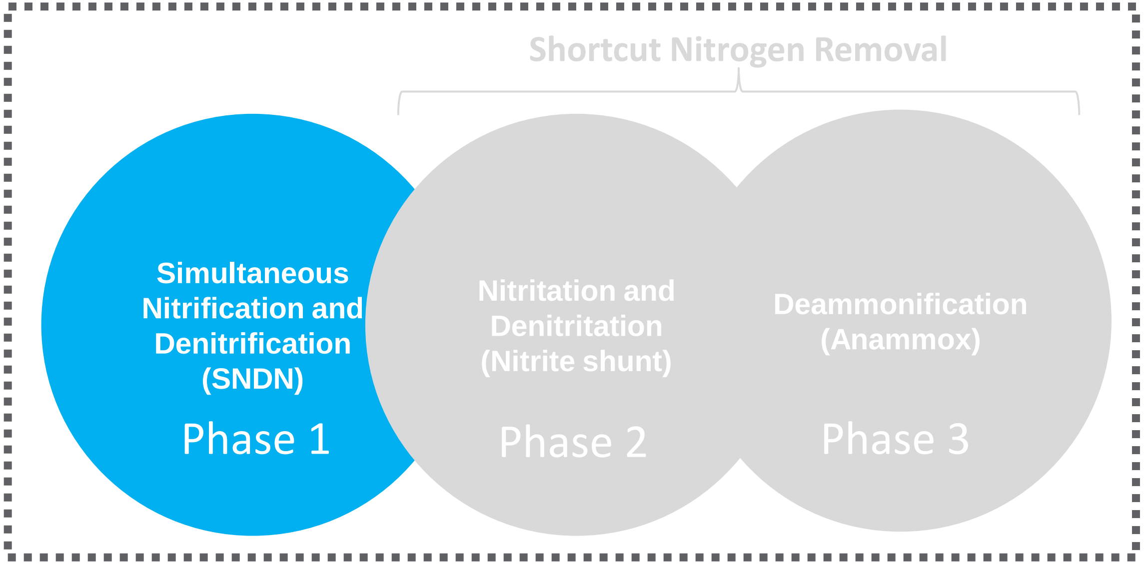
Eckenfelder, 1992

Next Generation Nitrogen Removal

Next Generation Nutrient Removal (NGN)



Next Generation Nutrient Removal (NGN)



Simultaneous Nitrification and Denitrification (SND)

What?

- Optimization of nitrification/denitrification to minimize aeration and carbon requirement using dynamic DO control

Why?

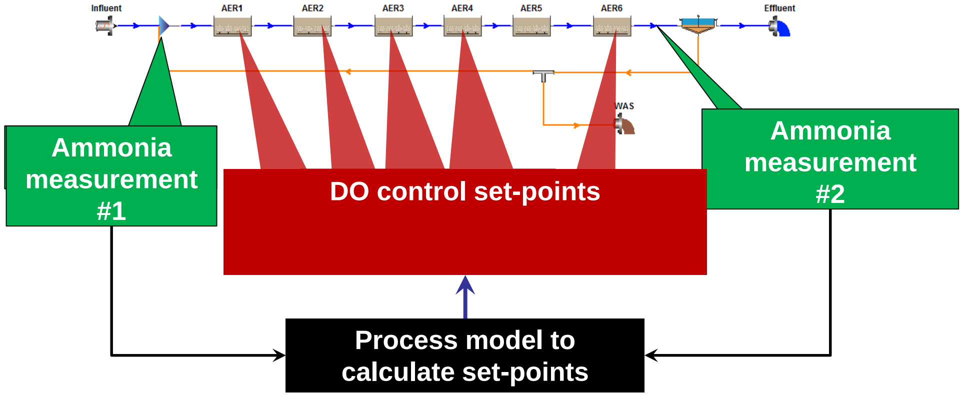
- Reduced carbon, alkalinity, volume, aeration requirements

Where?

- Oxidation Ditch Plants (historically)
- Many others

20% reduction in aeration

25% reduction in carbon



Trends in NGN Aeration Control – Ammonia-Based Aeration Control (ABAC)

What?

- Limit aeration to that required to reduce ammonia sufficiently to meet permit limits

Why?

- Reduce aeration, carbon demand

How?

- Ammonia based dissolved oxygen (DO) setpoint adjustment
- Adjust aeration input based on effluent ammonia (feedback control)
- Adjust aeration input based on influent ammonia (feed-forward control)

Trends in NGN Aeration Control – Ammonia versus NO_x-N (AvN™)

What?

- Limit aeration to that required to reduce ammonia and NOx sufficiently to meet permit limits

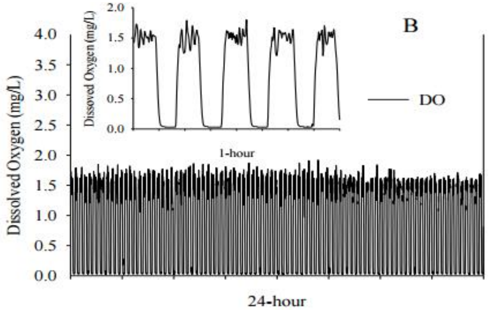
Why?

- Further reduce aeration, carbon demand

How?

- Control aeration to target a specific NH_3-N/NO_x-N ratio to maximize TN removal
- Patented process from HRSD and DC-Water that is licensed by World Water Works
- Ammonia and nitrate/nitrite analyzers required
- Typical 1:1 NH3/NOx ratio target

World water works
Clean Water and Energy from Wastewater



Trends in NGN Aeration Control – Equalization of Nutrient Loads

What?

- Create "smooth road" for influent or sidestream nutrients

Why?

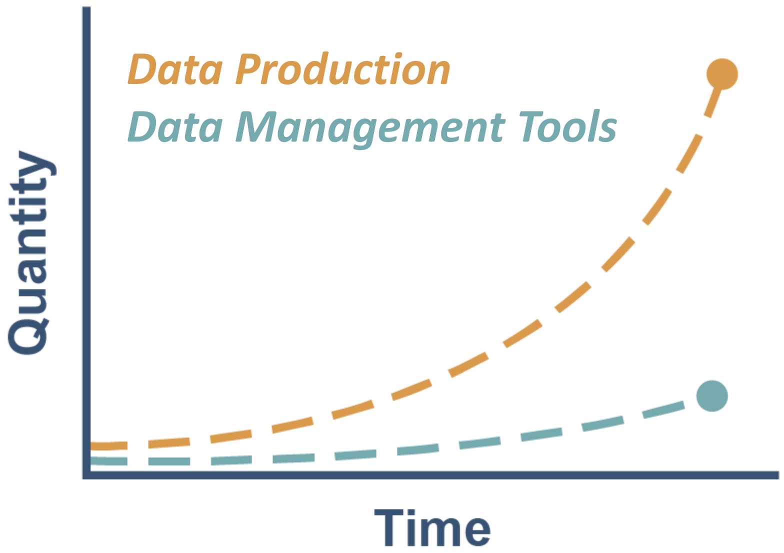
- More consistent operation typically equals better efficiency
- Keep microorganisms fed during low load conditions

How?

- Bleed back solids treatment sidestreams based on nutrient load rather than just flow rate
- Equalize influent to reduce diurnal nutrient loads

State of the Industry

- Access to advance analytics
- Advancements in Instrumentation
- Ability to generate huge amounts of data
- Connectivity



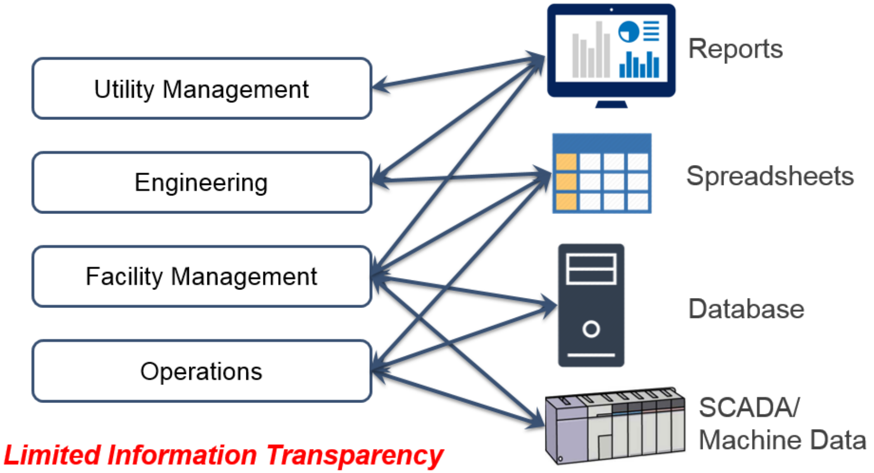
"Data Production is Outpacing Adoption of Data Management Tools"

Industry Challenges – Information Transparency

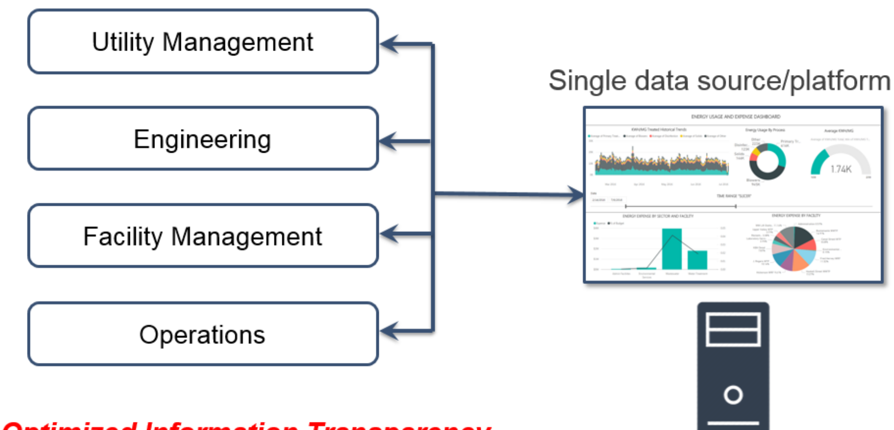
Reduce labor to acquire data

Increase data accessibility

Reduce potential for errors



Limited Information Transparency



Optimized Information Transparency

Conclusions

Advanced process controls can help reduce operational costs and complexity at BNR plants

Additional instrumentation and control requires increased maintenance

Multiple ways to take advantage

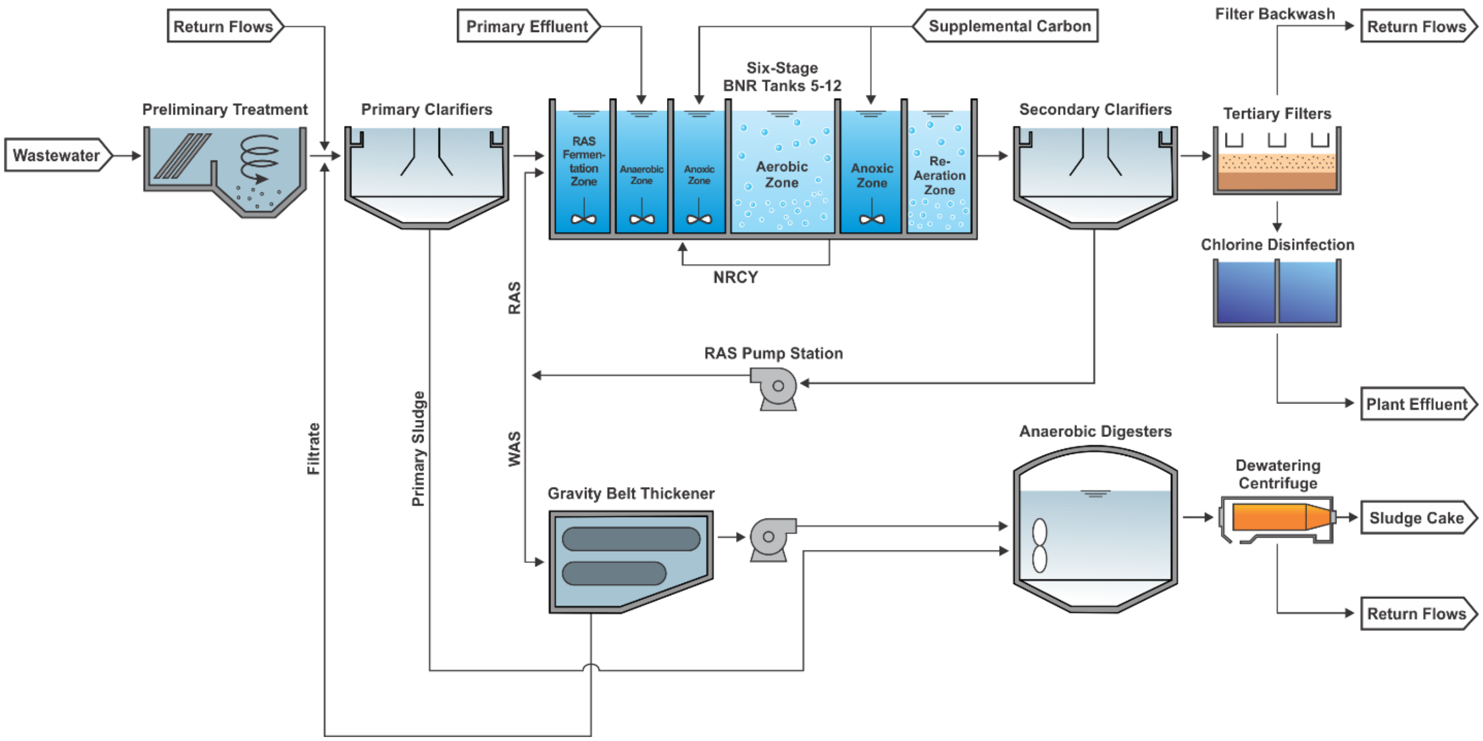
- Determine which parameters are key to effluent limits
- How best to implement with existing infrastructure

Challenges in effective use of “big data”

Bullpen

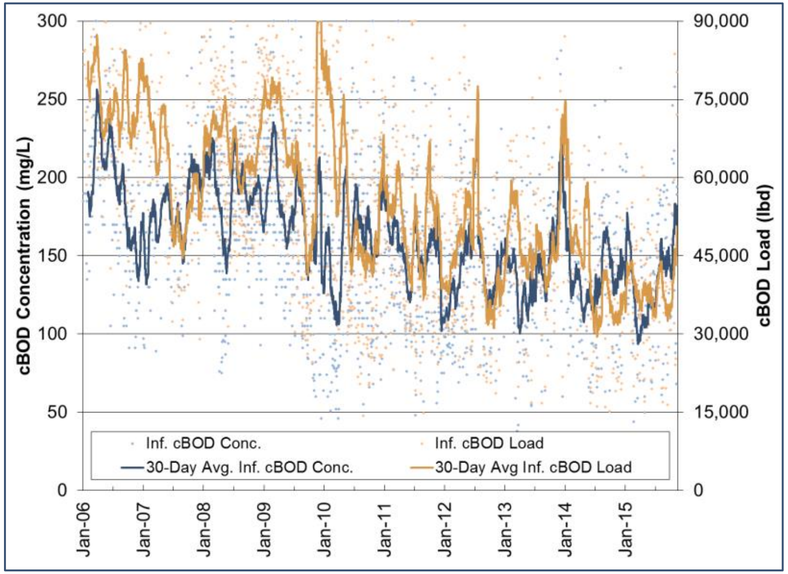
Henrico County ABAC Case Study

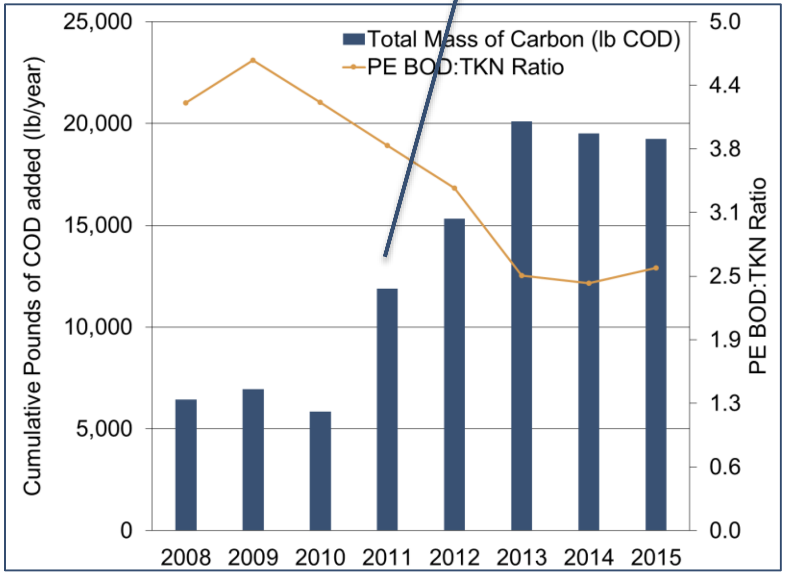
Henrico County Process Flow Diagram



Henrico has had Decreasing PE C:N Ratio and Increasing use of Glycerin

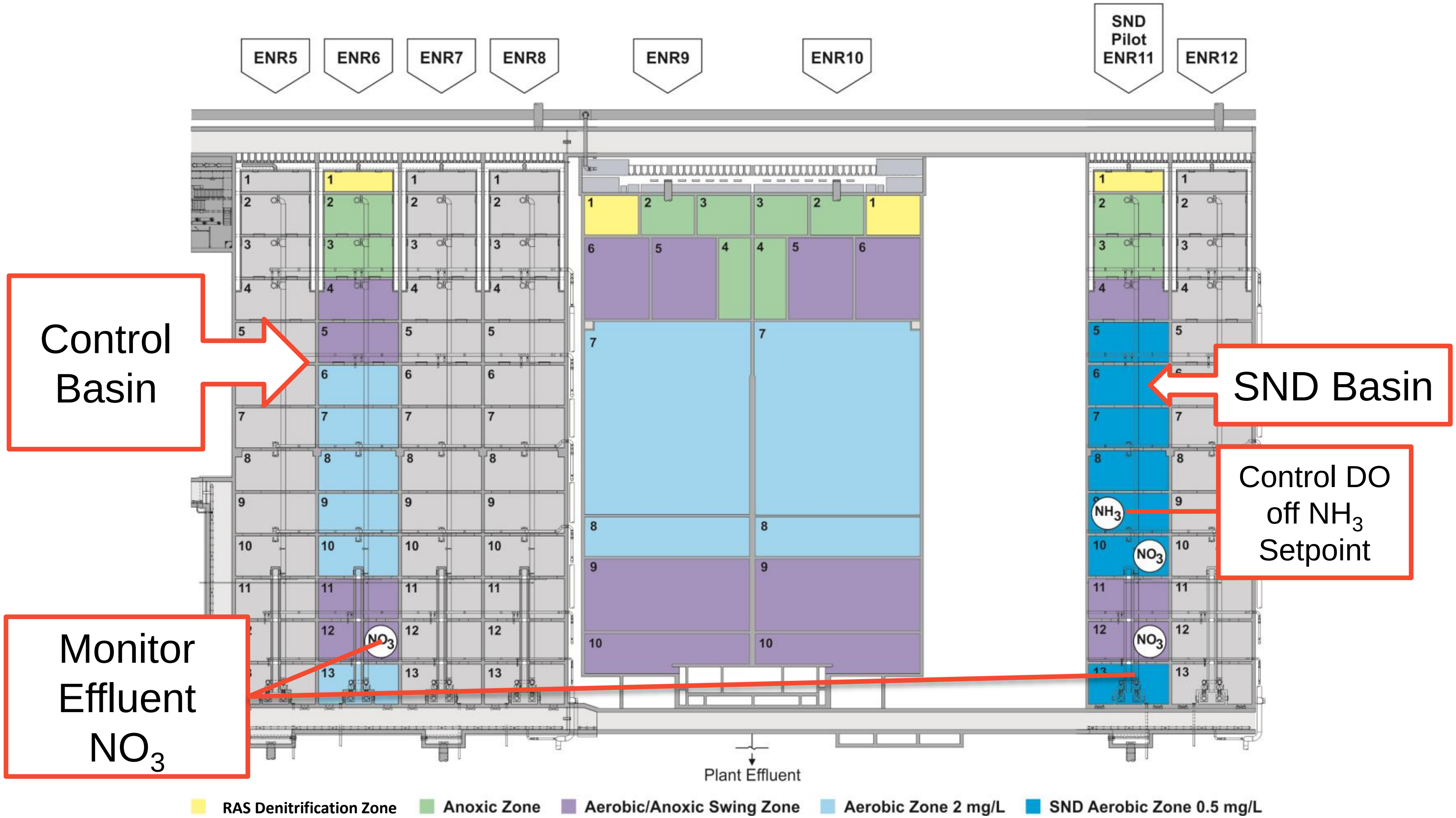
2011 - Effluent TN decreased from 8.0 to 5.0 mg/L



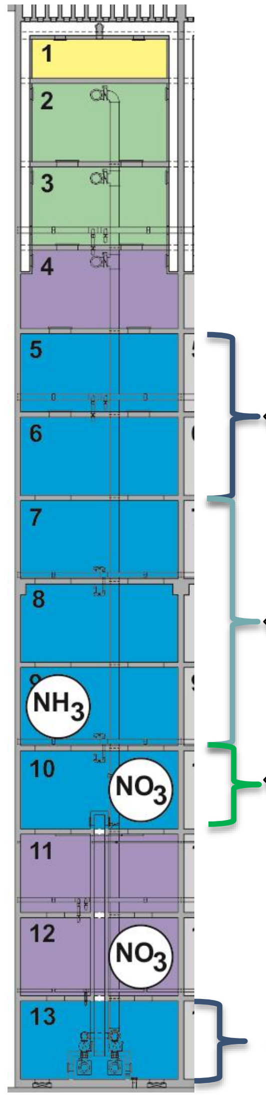


- Facility reduces number of PCs online to increase PE BOD:TKN ratio
- PE BOD:TKN ratio has leveled at ~2.5

SND Pilot Summer 2015 Configuration



DO Setpoints on SND Tank



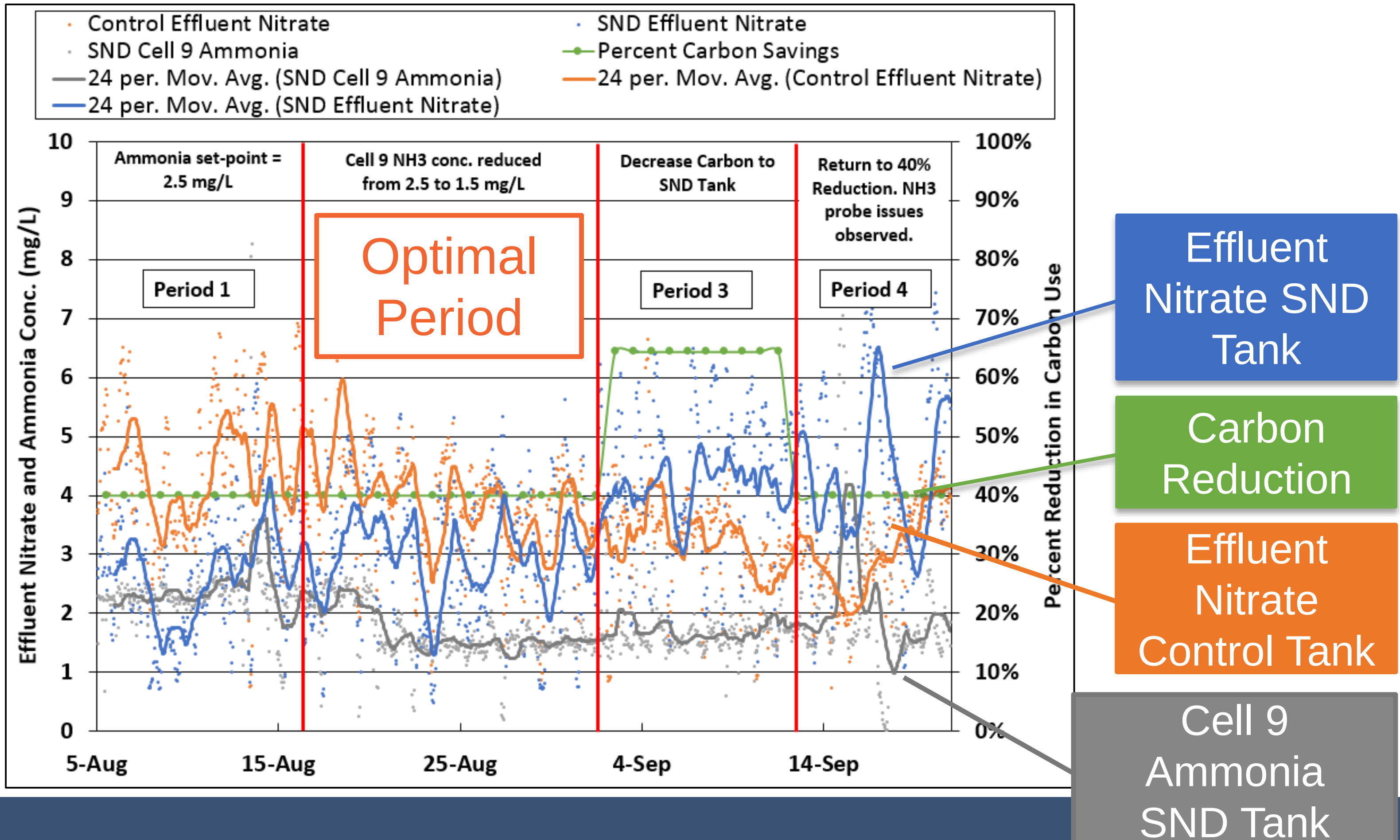
Zone 1: Cells 5-6
Low DO – 0.5 mg/L
High DO – 1.0 mg/L

Zone 2: Cells 7-9
Low DO – 0.75 mg/L
High DO – 3.0 mg/L

Zone 3: Cell 10
Low DO – 1.9 mg/L
High DO – 2.1 mg/L

Zone 4: Cell 13
Set-point of
2.0 mg/L

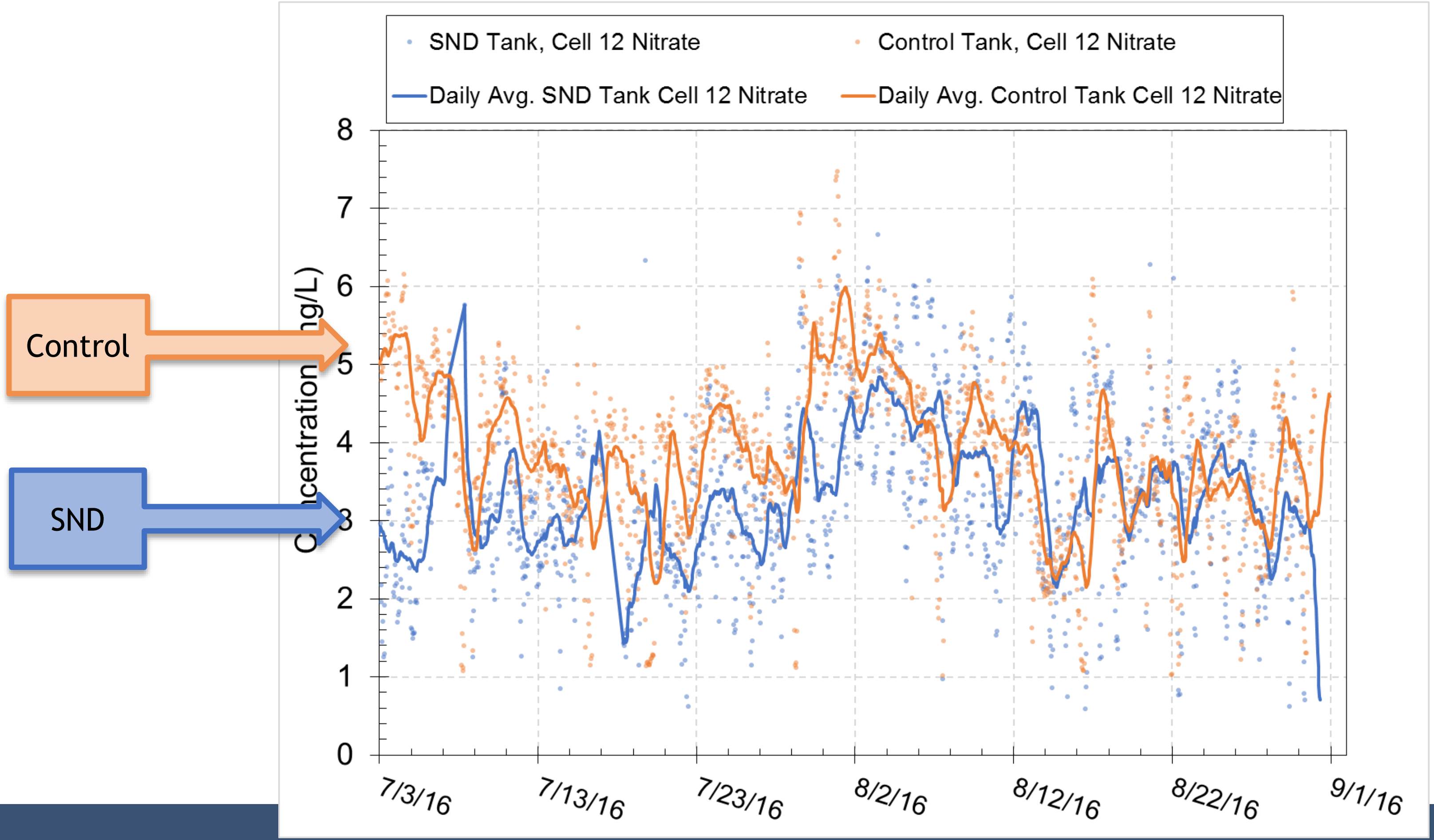
SND Pilot Resulted in 40% Reduction in Supplemental Carbon Dose



2015 Summer SND operation savings if Operated in Full Scale Mode

- Savings between $260,000 and $500,000 per year in supplemental carbon
  - Based on 6 months of summer operation, all basins run in SND mode

2016 SND Tank Pilot Also Showed 50% Reduction in Supplemental Carbon

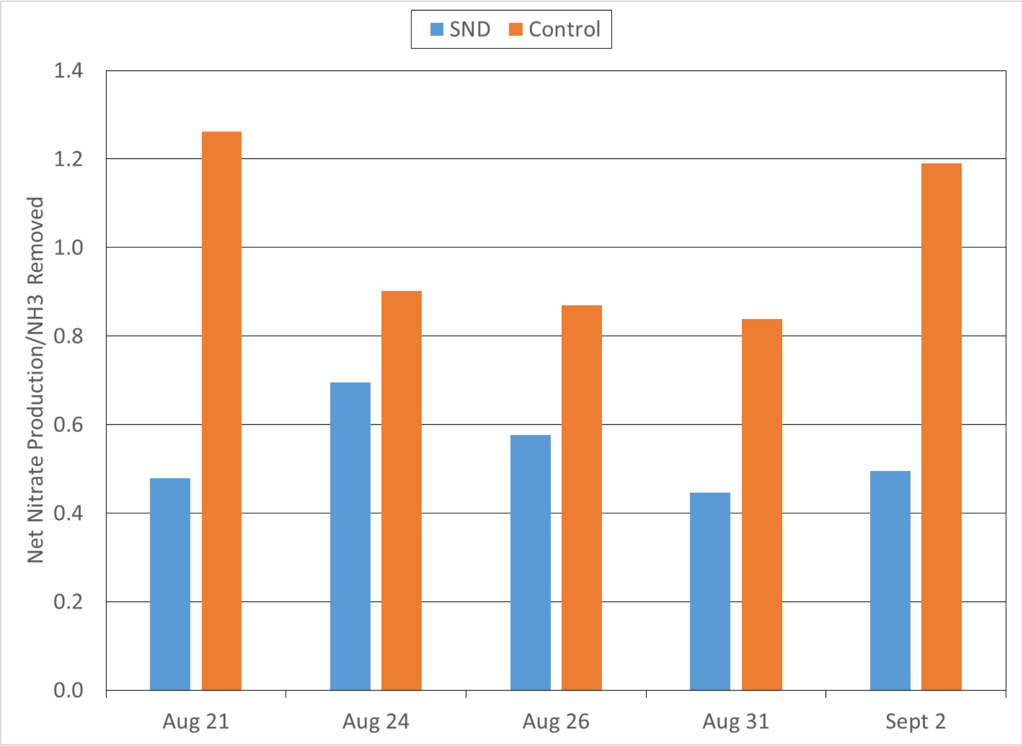


Henrico SND ABAC Summary

- Carbon reduction of up to 40-50% possible while running in SND mode
- Full nitrification achieved in SND tank by end of AE Zone
- DO and Aerobic HRT important factors and affect degree of SND occurring

Net Nitrate Production per Pound of Ammonia Removed for the Control and SND tank

- Multiple profiles performed by facility
- Looked at nitrate and ammonia at the beginning and end of the "Aerobic Zone" during the optimal period
- **Less nitrate is produced in the SND tank per pound of ammonia removed than the control tank**
  - **Suggesting nitrate is being denitrified in the aerobic zone**



Nitrification

REQUIREMENTS

- Microbiology
  - Nitrifiers
- Dissolved oxygen
- pH/Alkalinity

KEY PROCESS VARIABLES

- Solids control – SRT and F/M
- DO
- pH
- Temperature
- Inhibitory compounds

Nitrification Issues

- Increased ammonia levels in effluent
- Without effective nitrification – denitrification will not occur resulting in poor TN removal
- Nitrification is most sensitive BNR process
- Multiple culprits for decreased nitrification
    - Solids Inventory(SRT)
    - D.O.
    - pH (alk)
    - Temp.
    - Inhibition

Operational Targets for Nitrification Solids Inventory

- Solids Inventory/Aerobic SRT
  - Slow growth of nitrifying population requires adequate aerobic SRT