Applied Fundamentals for Nitrogen and Phosphorus Removal Optimization

Presenters: JB Neethling, David Stensel, James Barnard and Bryce Figdore

March 17, 2021

12:00 – 2:00 PM EST

THE Water Research FOUNDATION

WRF 4973 Nutrient Optimization

Starting Shortly

Applied Fundamentals for Nitrogen and Phosphorus Removal Optimization

Presenters: JB Neethling, David Stensel, James Barnard and Bryce Figdore

March 17, 2021

12:00 – 2:00 PM EST

Search: WRF 4973 webinar

Housekeeping

- Submit questions through the question box at any time. We will do a Q&A at the end of the webcast.
- Slides and a recording of the webcast will be available at www.waterrf.org.
- Survey at the end of the webcast.

"Live" Interaction Using Menti Meter

You will need a second device for our interactive portion:

1. **Smart phone or other device** <== EASIEST WAY

Or

2. **Second browser** (if you have multiple screens)

Go to:	menti.com
Enter Code:	9616 0848

"Live" Interaction Using Menti Meter

Go to:	menti.com
Enter Code:	9616 0848

Follow cues on your device screen

Remember to SUBMIT your answer

Some questions allow multiple entries


Overview of WRF 4973 -
Guidelines for Optimizing Nutrient Removal Plant Performance

JB Neethling

WRF 4973 Webinar Series

Search: WRF 4973 webinar

Applied Fundamentals for Nitrogen and Phosphorus Removal Optimization	3/17/21
Emerging Technologies for Nutrient Optimization	3/31/21
Beyond Liquid Treatment: Reduce Nutrient Discharge Loads by Other Means	4/14/21
Sidestream Management to Optimize WRRF Nutrient Removal	4/28/21
Instrumentation and Control for Nutrient Optimization – Part 1: Sensors	5/12/21
Instrumentation and Control for Nutrient Optimization – Part 2: Controls	5/19/21
Strategies to reduce O&M Cost in Nutrient Removal WRRFS	5/26/21
Nutrient Reduction from Secondary (BOD removal WRRFs)	6/23/21
Optimizing Nutrient Removal WRRFs	7/7/21
Nutrient Reduction Approaches for Small Systems	7/21/21
Optimize Nutrient Removal WRRF Operations	8/4/21
Tools to Evaluate Nutrient Optimization in WRRFs	8/18/21
Nutrient Discharge Permitting and WRRF Optimization	9/1/21

Search: WRF 4973 webinar

Project Overview

The goal of WRF project 4973 is to provide guidance for optimizing WRRF operation while reducing nutrient discharge into the environment.

Nutrient Optimization	Comment/Goal
Gain "some" nutrient reduction from BOD process	Achieve incremental nutrient load limits
Increase nutrient removal efficiency at a NutRem process	Meet lower limits, increase reliability, increase capacity
Reduce operating cost for nutrient removal	Lower energy, chemical, materials, operator cost
Nutrient reduction by other means	Sidestream treatment, reuse, source control, etc.

Applied Fundamentals to Optimize a WRF for Nutrient Reduction

- What are the fundamentals of a nutrient removal process?
- What impacts the performance (efficiency or cost) of the process?
- How can I achieve better performance?
- How can I reduce the cost of treatment?
- Without Spending an Arm and a Leg

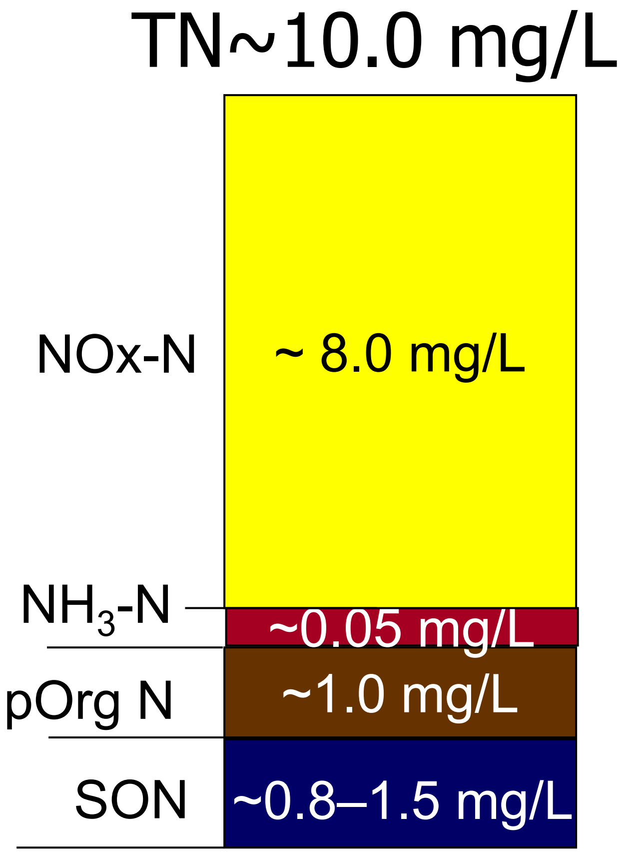
5 Key Things to know

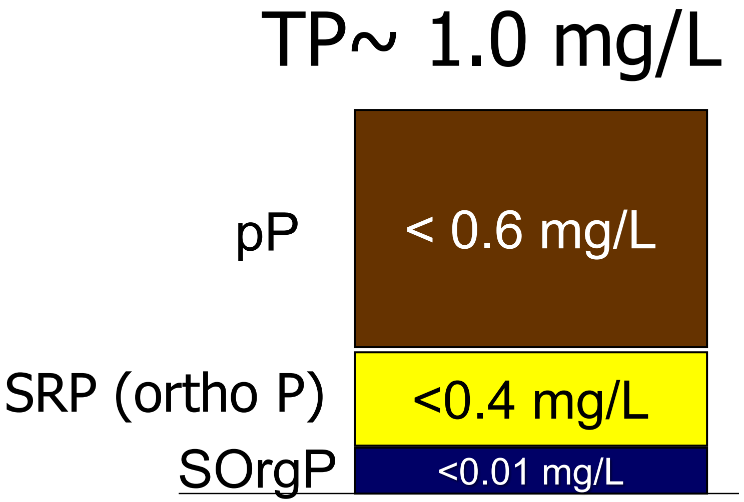
1. Not all nutrient species are equal
2. Performance varies due to internal and external factors
3. Reliable treatment requires an appropriate safety factor
4. Process reactors are not perfect
5. Sidestream (reject water) recycles can impact performance

Understand the dominant nutrient species – Not filtered

SON = Soluble organic N
pOrg N = particulate organic N

pP = particulate P
SRP = Soluble reactive P
SOrgP = Soluble organic P



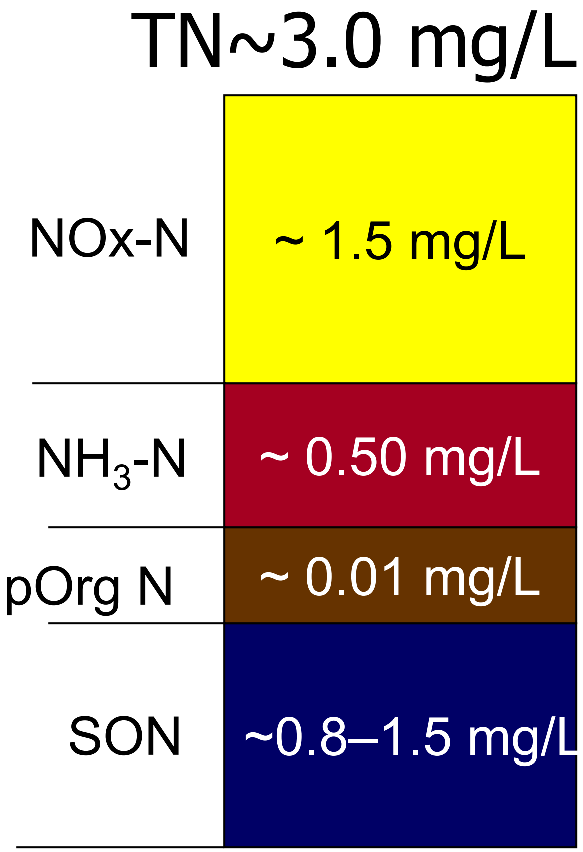


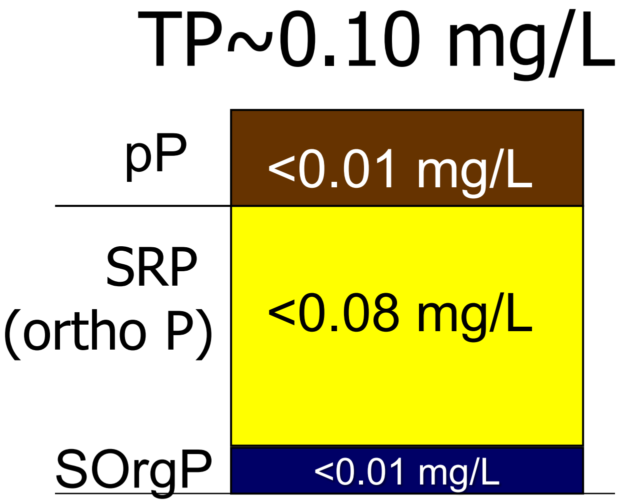
Soluble based on 0.45 um filtration

Understand the dominant nutrient species - Filtered

SON = Soluble organic N
pOrg N = particulate organic N

pP = particulate P
SRP = Soluble reactive P
SOrgP = Soluble organic P



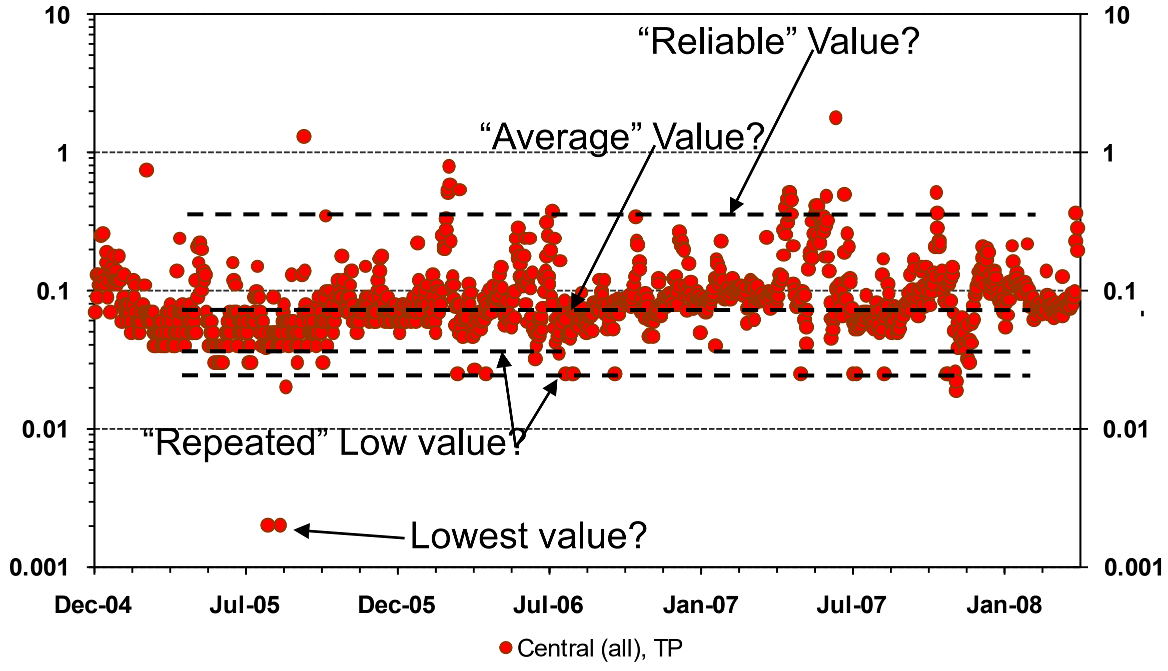


Soluble based on 0.45 um filtration

Performance Varies – Reliable performance requires a factor of safety

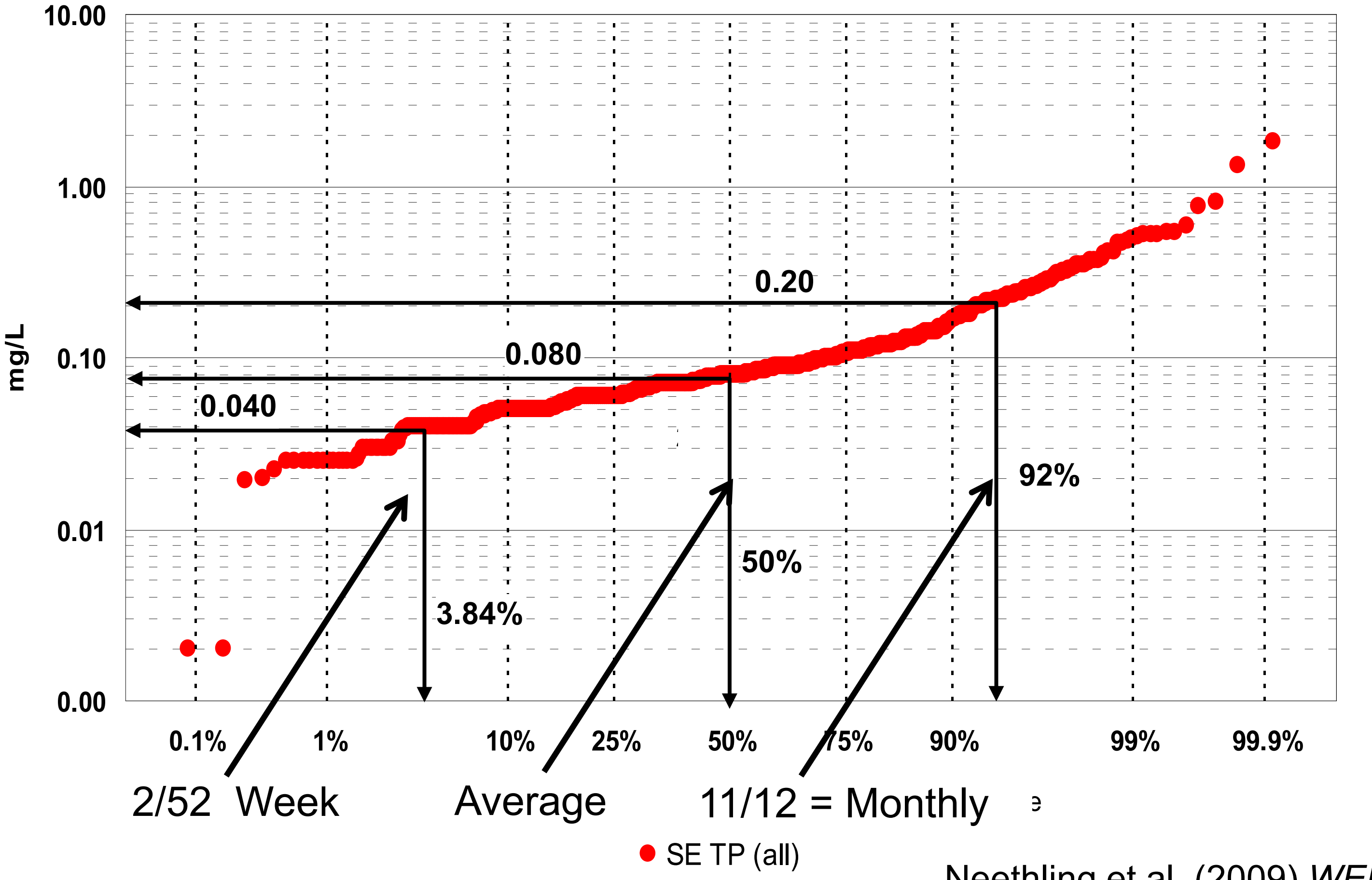
What permit limit can this plant meet?

- Numerical – concentration
- Averaging – daily, weekly, monthly, annual



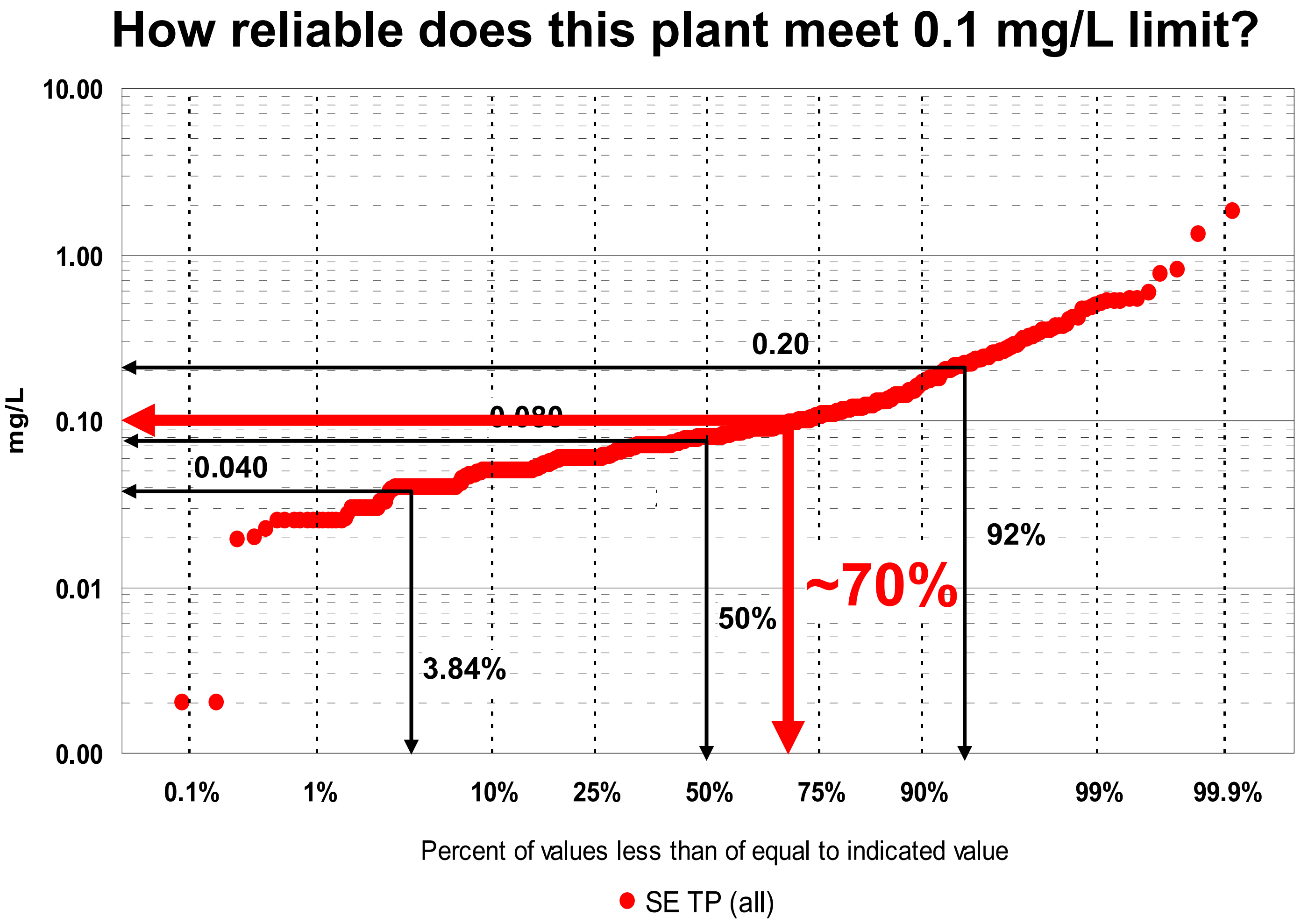
Technology Performance Statistics can quantify variable performance

50% of the time, performance is BELOW average….!



Neethling et al. (2009) *WEF Nutrient 2009,* Alexandria, VA.

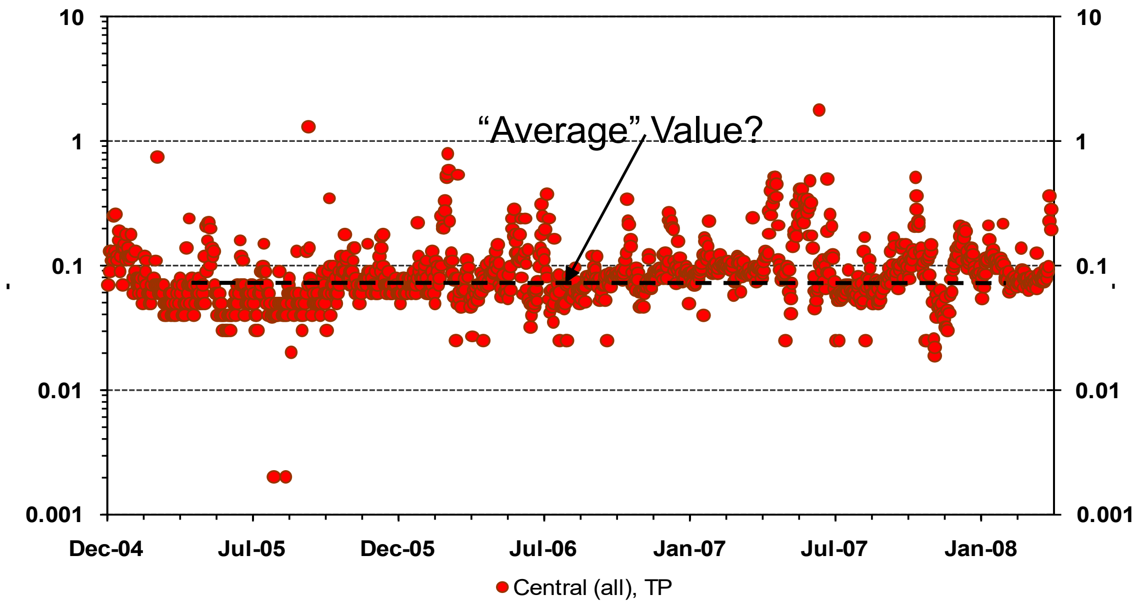
Technology Performance Statistics

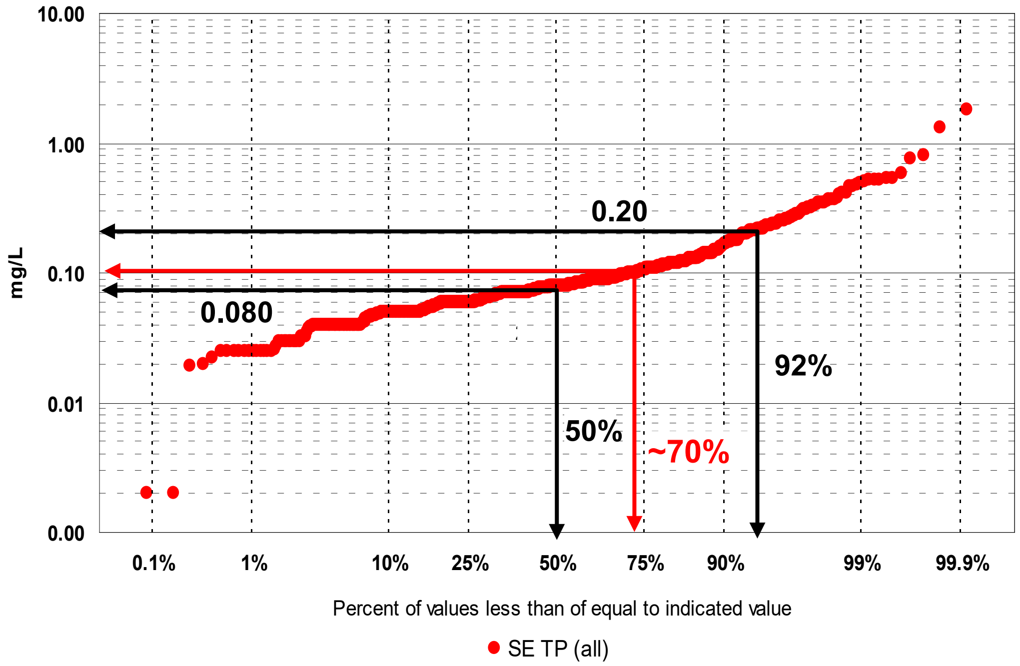


Neethling et al. (2009) *WEF Nutrient 2009,* Alexandria, VA.

Technology Performance Statistics

Role of averaging periods to meet 0.1 mg/L

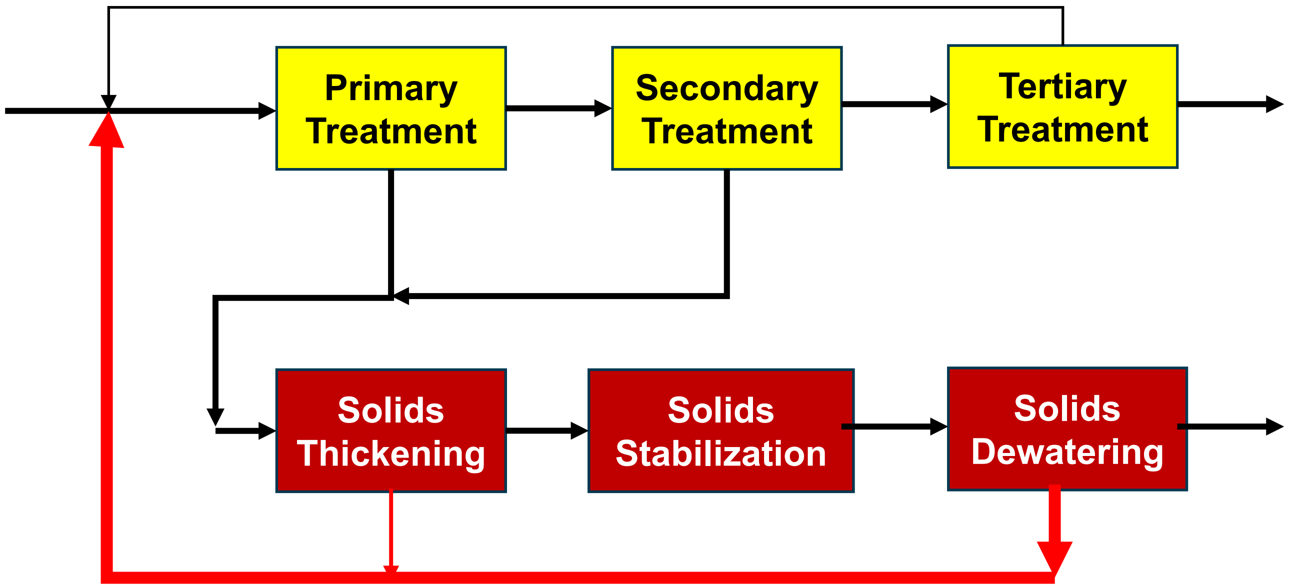


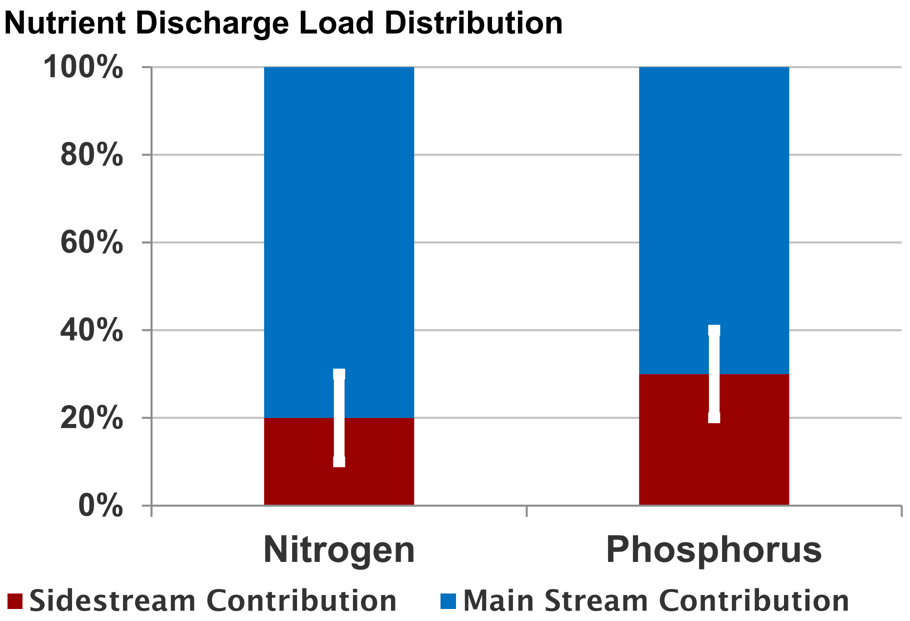


Performance shows achieving 0.1 mg/L (limit) 70% of the time

- Annual average – 50% - they achieve 0.08 mg/L (20% under permit)
- Monthly basis – ~92% - they achieve 0.20 mg/L (100% over permit)

Sidestream (WRF 4973 Webinar, 28 April 2021)

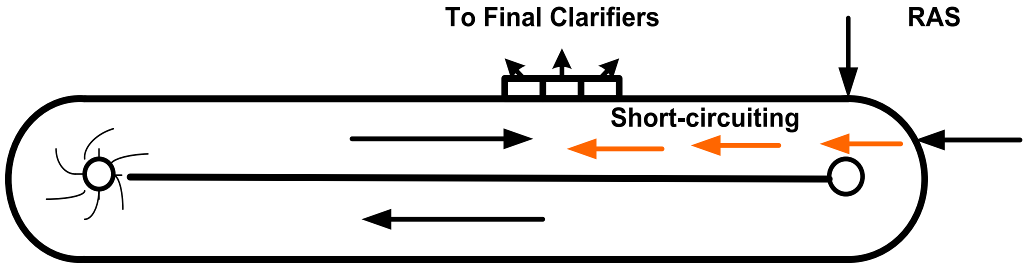




<u>Recycle streams (reject water)</u>

- Increase the nutrient (N & P) load to the treatment process
- Reduce the BOD/N and BOD/P ratio entering the BNR
- Can be intermittent creating performance variability
- Treating this stream can reduce the effluent nutrient load

Hydraulics, Equipment, and Arrangement Matters!



Barnard et al. 2004 Hydraulics in BNR Plants WEFTEC 2004

Surface flow from Aerobic to Anoxic Zone

Screw pump for RAS return

- Process models assume ideal reactor conditions
- Unintended short circuiting can deteriorate performance
- Equipment function can impact process performance
- Sometimes… non-ideal conditions gives better performance…!

"Live" Interaction Using Menti Meter

Go to:	menti.com
Enter Code:	9616 0848

Follow cues on your device screen

Remember to SUBMIT your answer

Some questions allow multiple entries

Applied Fundamentals for Nitrogen Removal

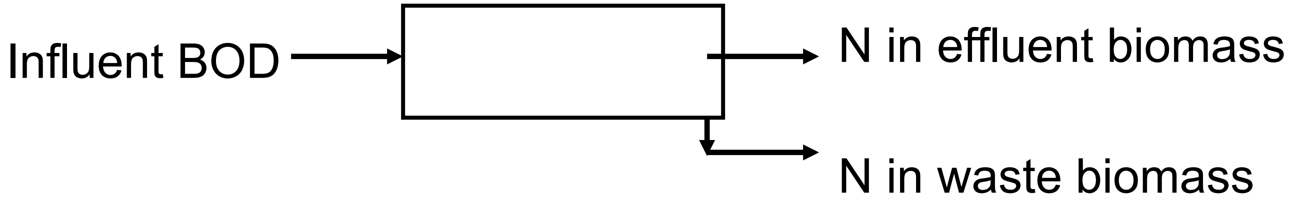
H David Stensel, PhD, PE, BCEE

Outline

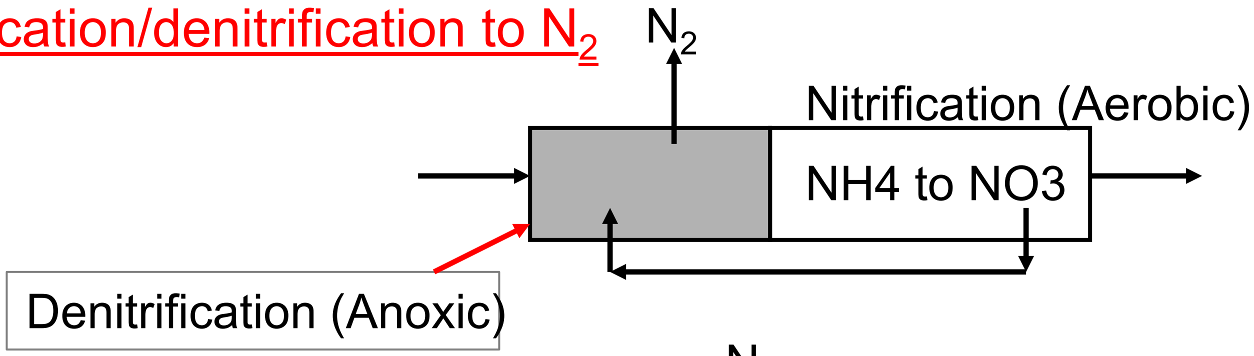
- Biological nutrient removal activated sludge processes
- Nitrogen Removal
  - Pathways for biological nitrogen removal
  - Fundamentals based methods to optimize nitrification
  - Fundamentals based methods to optimize biological nitrogen removal

Three Methods of Nitrogen Removal in Biological Treatment Processes

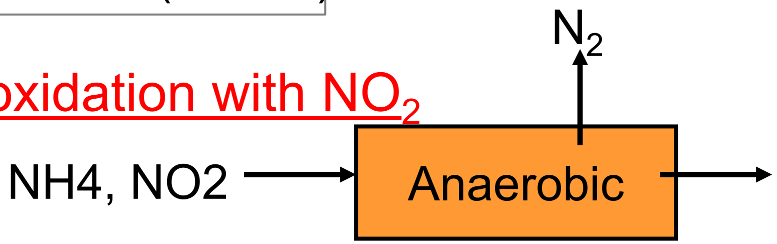
Biomass growth and sludge wasting



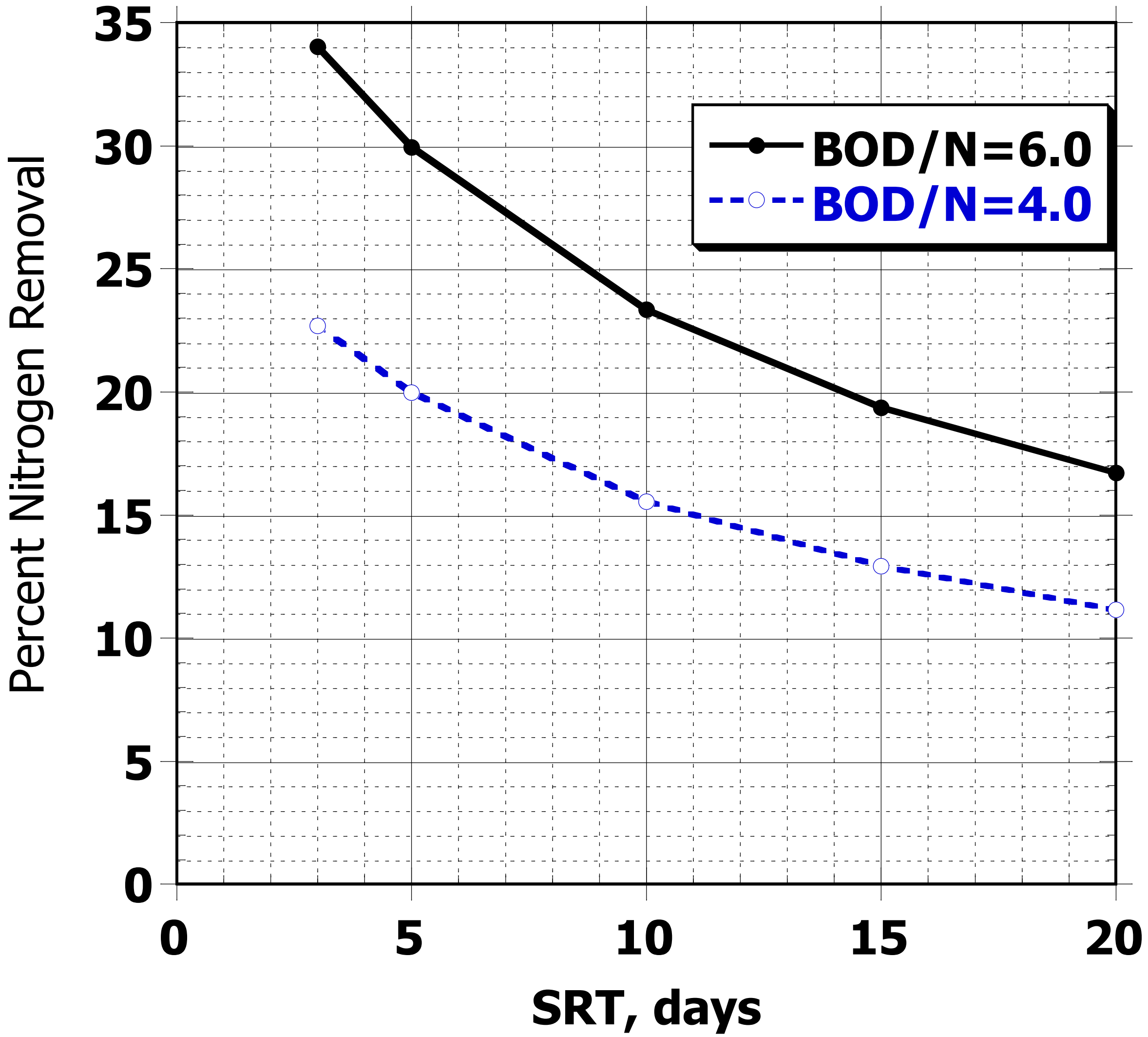
Biological nitrification/denitrification to N_2



Anaerobic ammonia oxidation with NO_2 Anammox



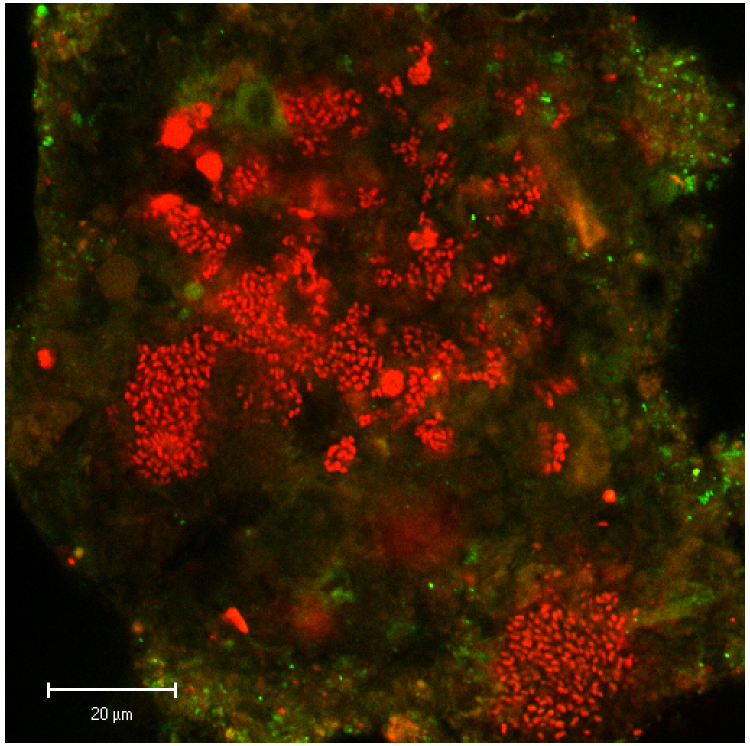
Only ~ 15-25% N removal by biomass growth

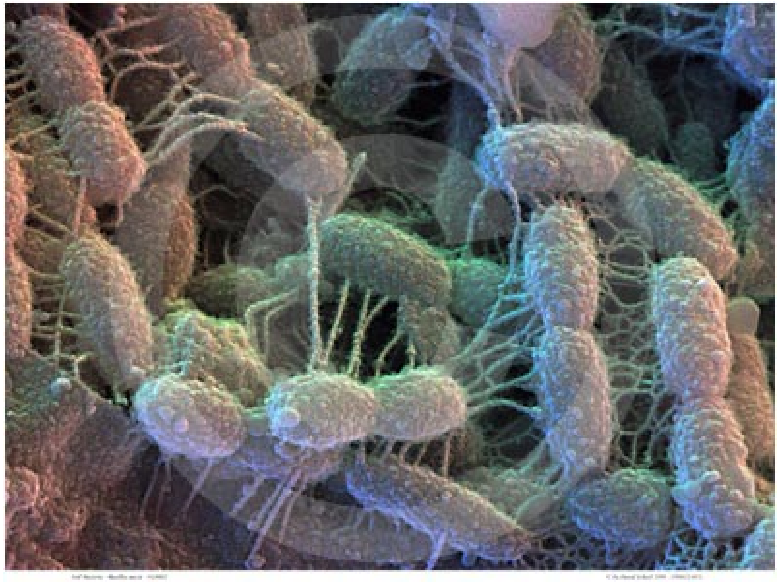


But about half can be released and returned with anaerobic digestion

Need High Amount of Nitrogen Removal specialized “bugs” put to work!!

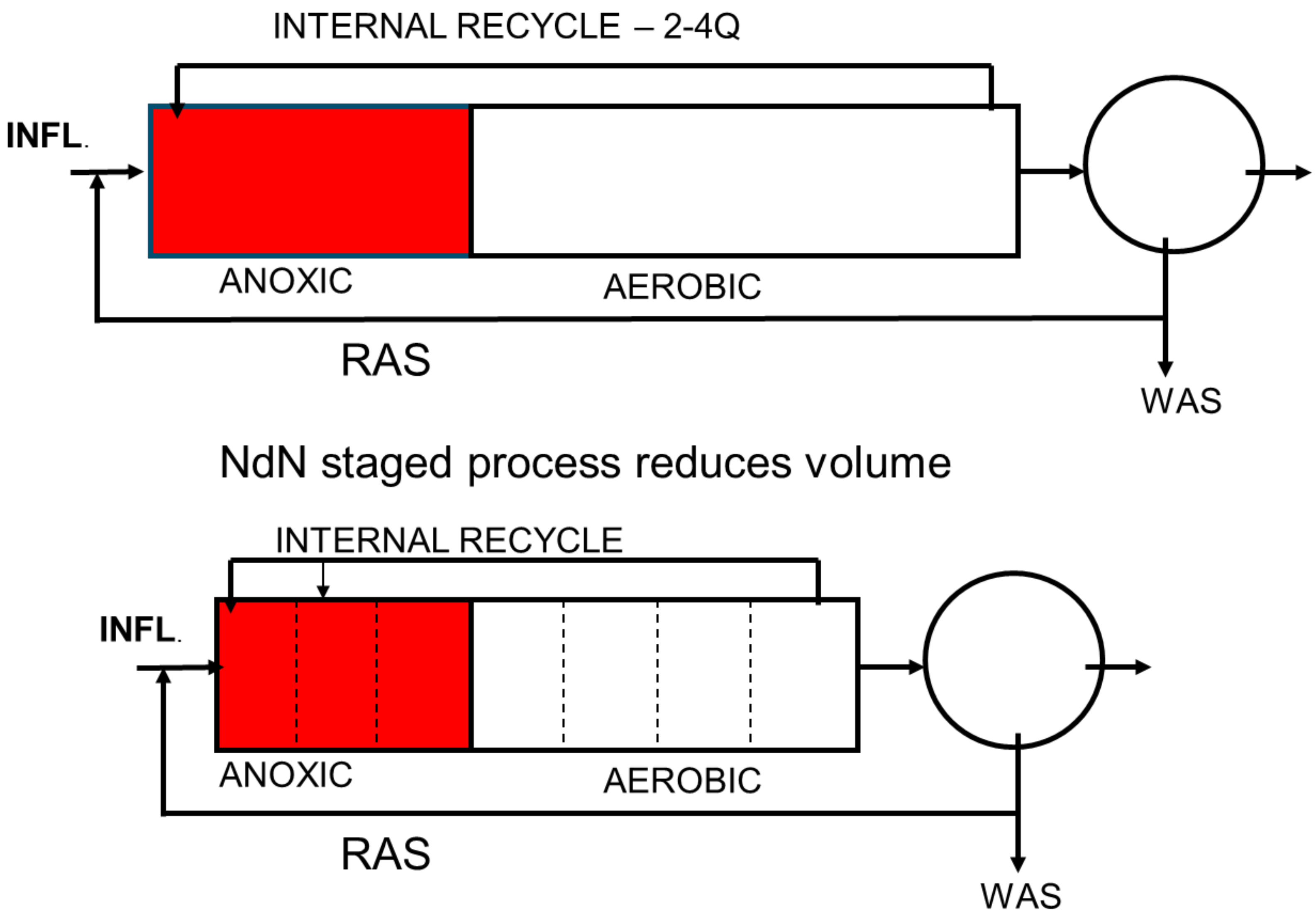
Aerobic -Nitrifiers
Anoxic -Denitrifiers
Anaerobic -Anammox



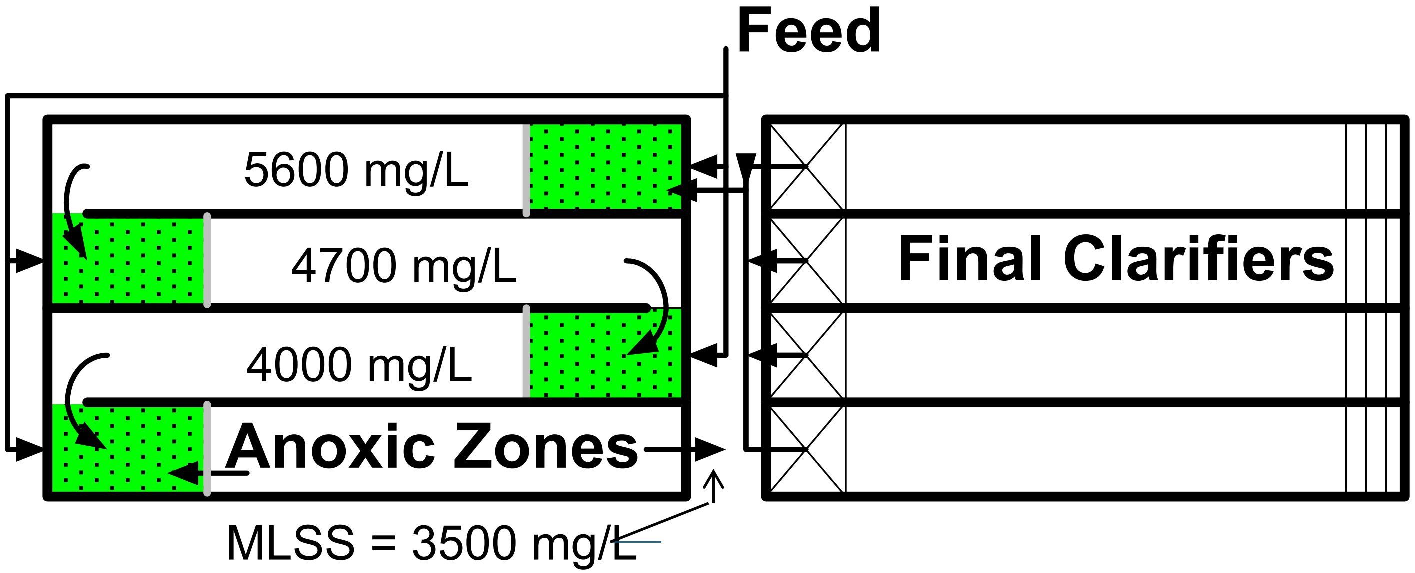


Commonly Used Flow Schemes for Nitrogen Removal by Nitrification/Denitrification

Common single stage anoxic-aerobic (MLE Process) for NdN



Step Feed BNR

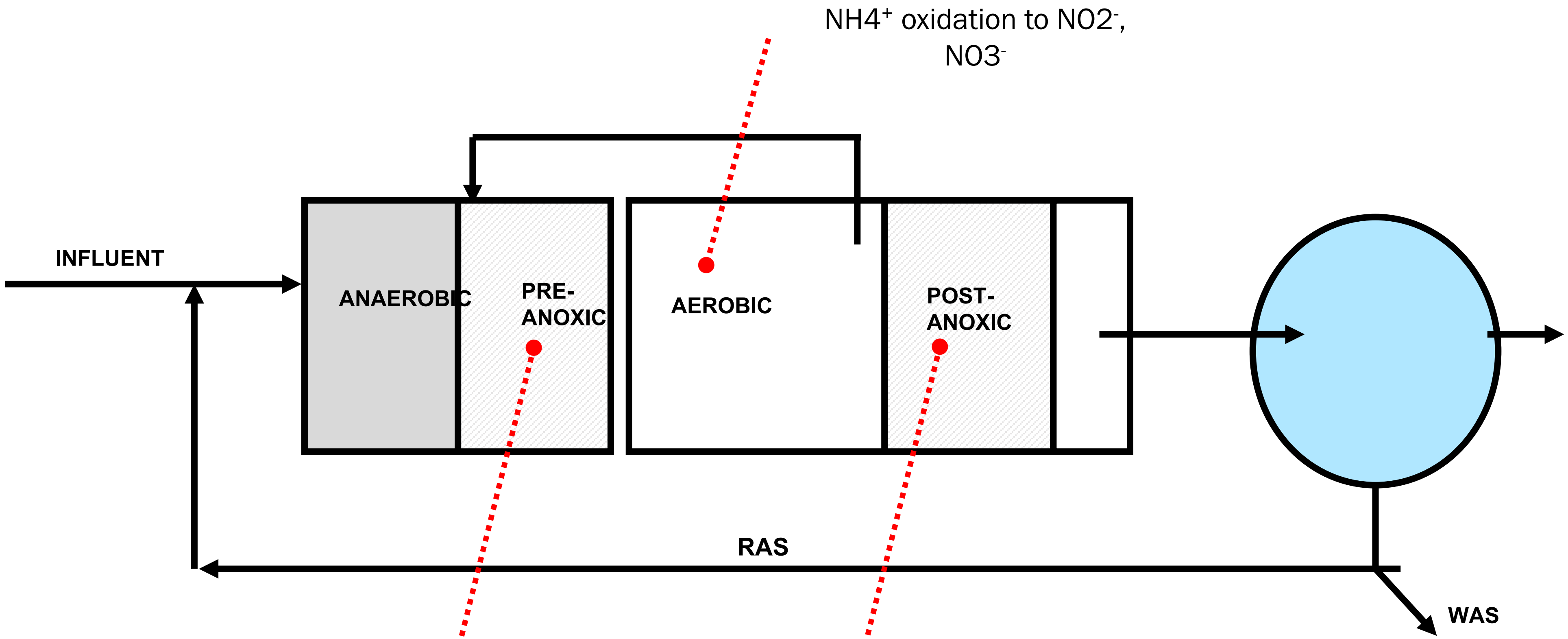


MLSS Gradient –Capacity Increase.

- No MLR pumping, but complex flow dist.
- Control of flow splitting
- May be compatible retrofit method

Conversion for N Removal New York City

Modified Bardenpho Process for N and Phosphorus Removal
Anaerobic Zone and Pre/Post Anoxic Zones



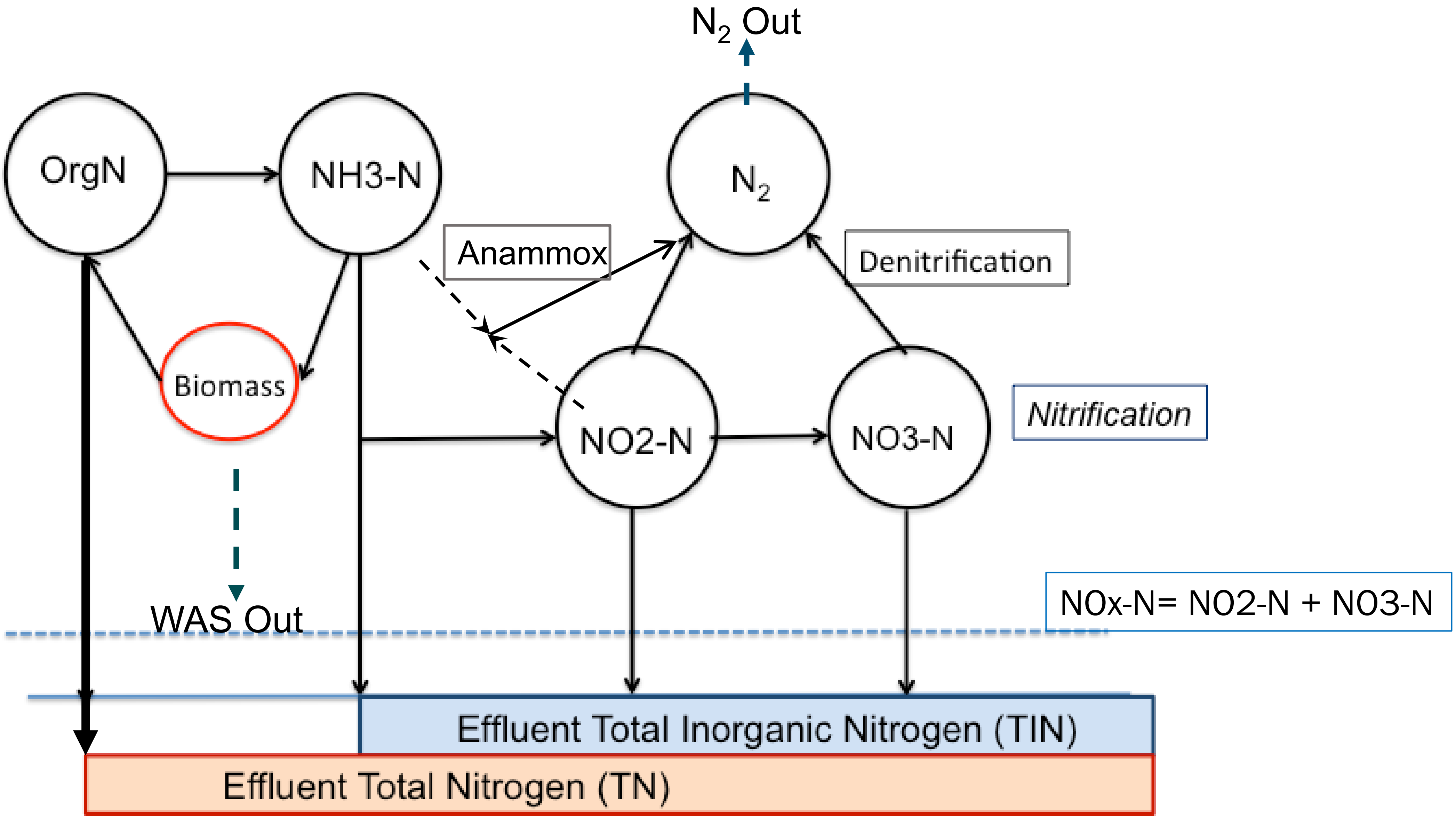
Wastewater BOD
0.05 to 0.30 gNO3-N/gMLVSS-d
f(BOD loading, rbCOD, Temp.)

May also add external carbon
for low influent BOD:N ratio

Endogenous Decay
0.01 to 0.03 g NO3-N/gMLVSS-d

Or add external carbon
0.05 – 0.15 g NO3-N/gMLVSS-d

Fate of Influent Nitrogen



Aerobic nitrification is a two-step process with autotrophic bacteria

Nitroso-bacteria (AOB)

$$2NH_4^+ + 3O_2 \rightarrow 2NO_2^- + 4H^+ + 2H_2O$$

Nitro-bacteria (NOB)

$$2NO_2^- + O_2 \rightarrow 2NO_3^-$$

$$NH_4^+ + 2O_2 \rightarrow NO_3^- + 2H^+ + H_2O$$

2 moles of oxygen per mole of N= 4.57 gO2/gNH4-N

Nitrification Kinetics and Operating SRT

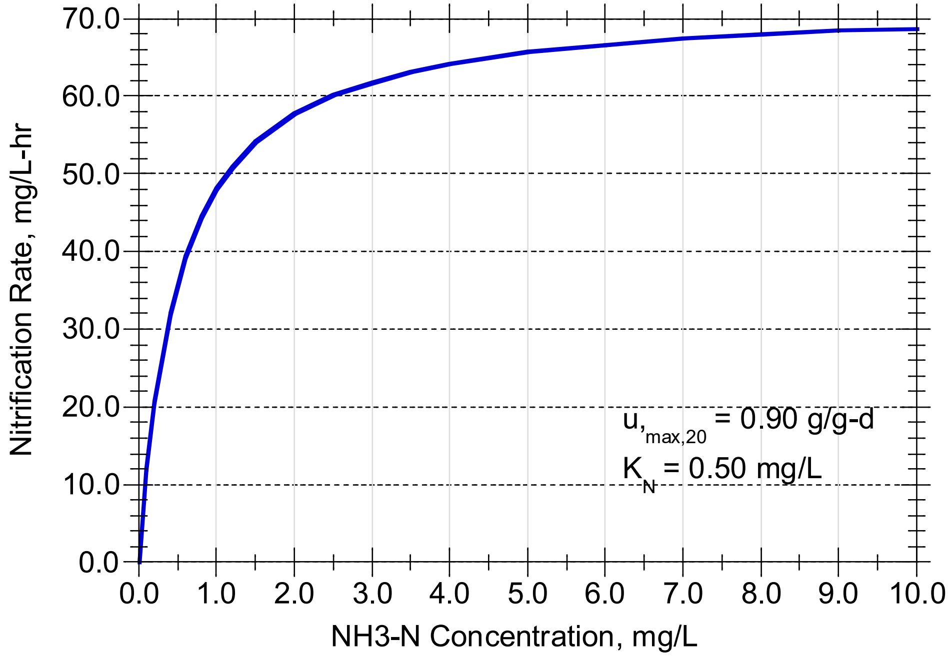
$$\frac{1}{SRT} = \mu = \mu_{max}\left[\frac{N}{N+K_N}\right]\left[\frac{DO}{DO+K_o}\right] - b$$

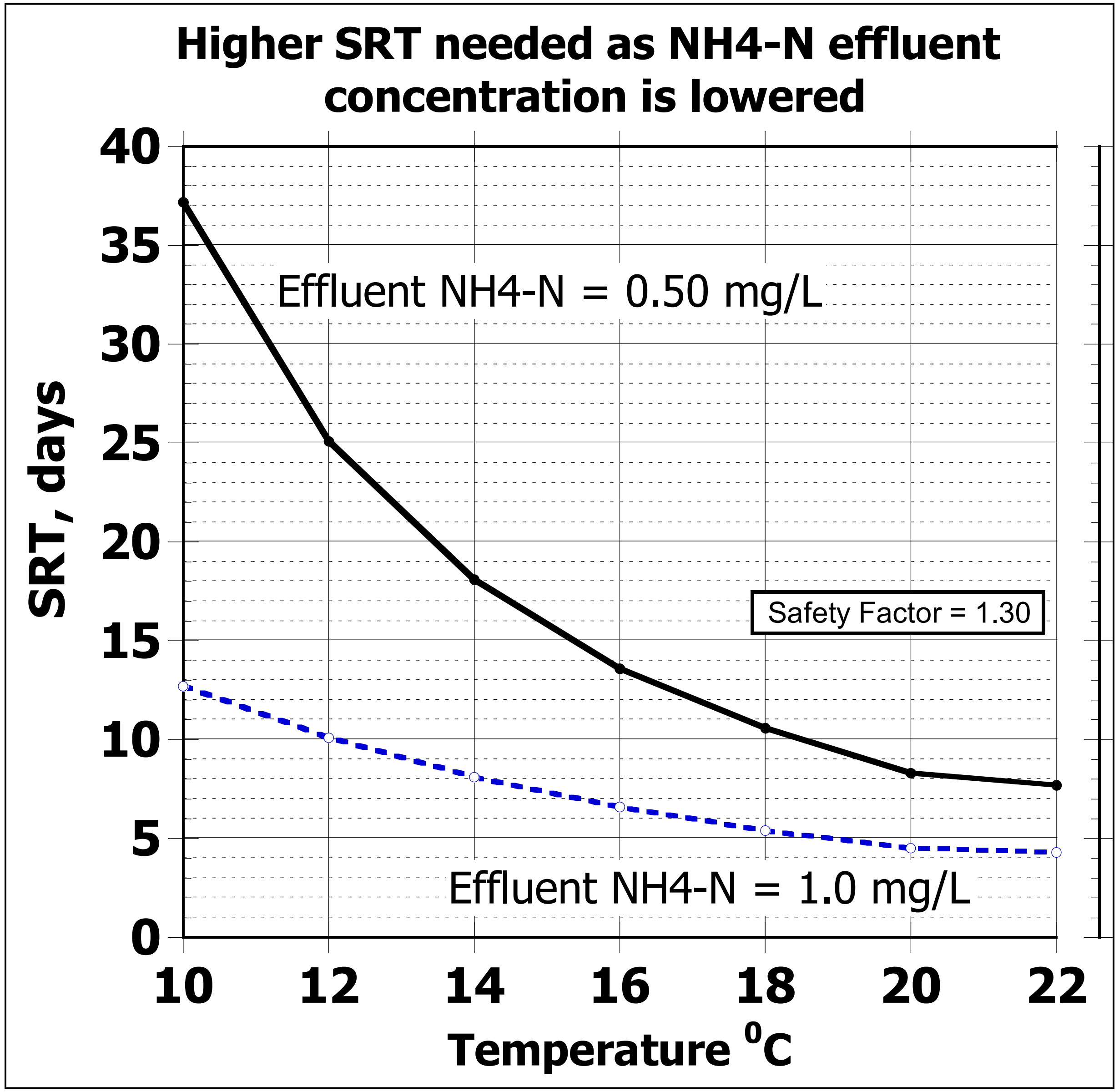
K_N and K_o, NH_3-N and DO half-velocity coefficients

μ_{max} increases with temperature

SRT inversely proportional to μ_{max}

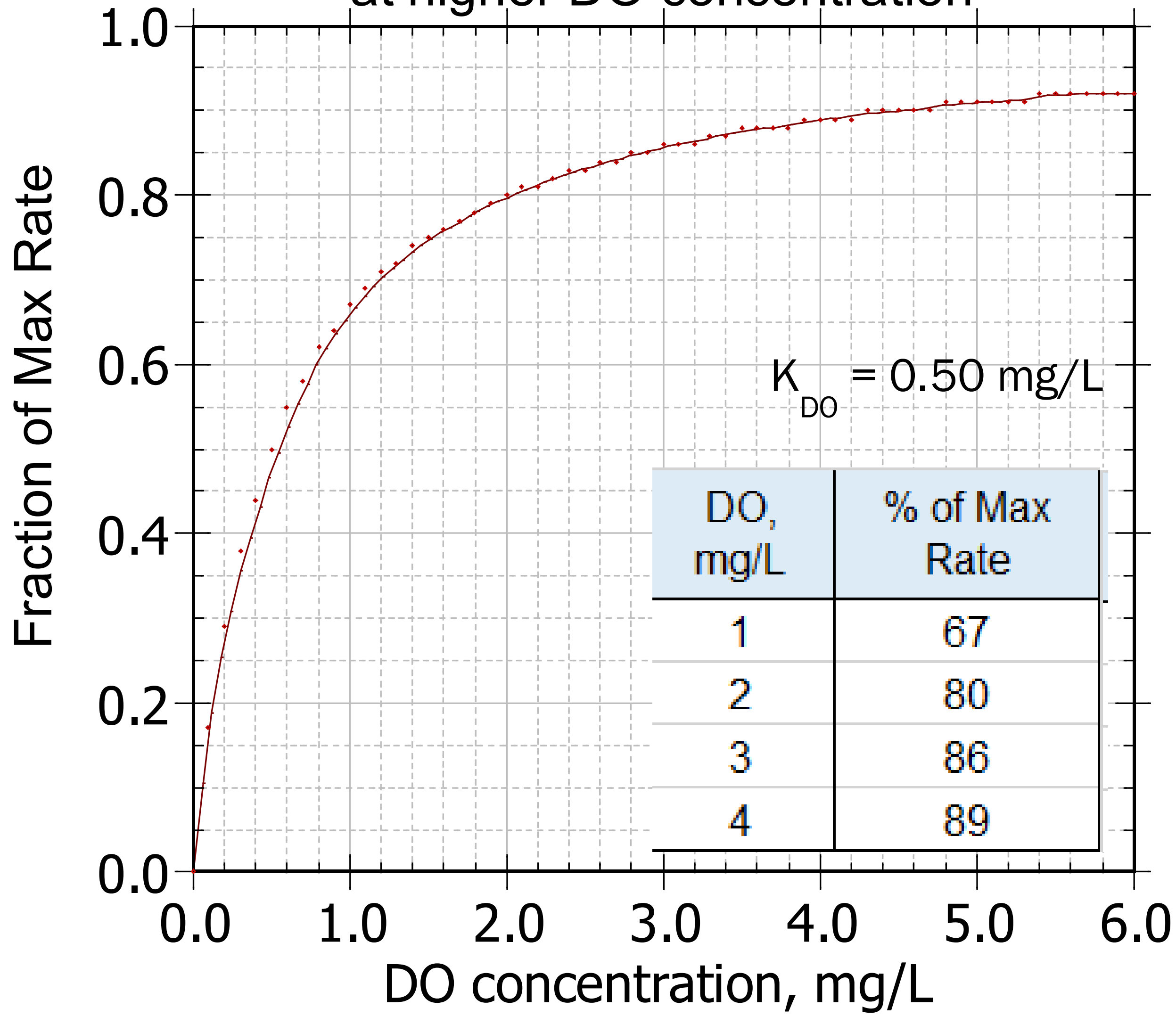
Greater SRT requires more volume





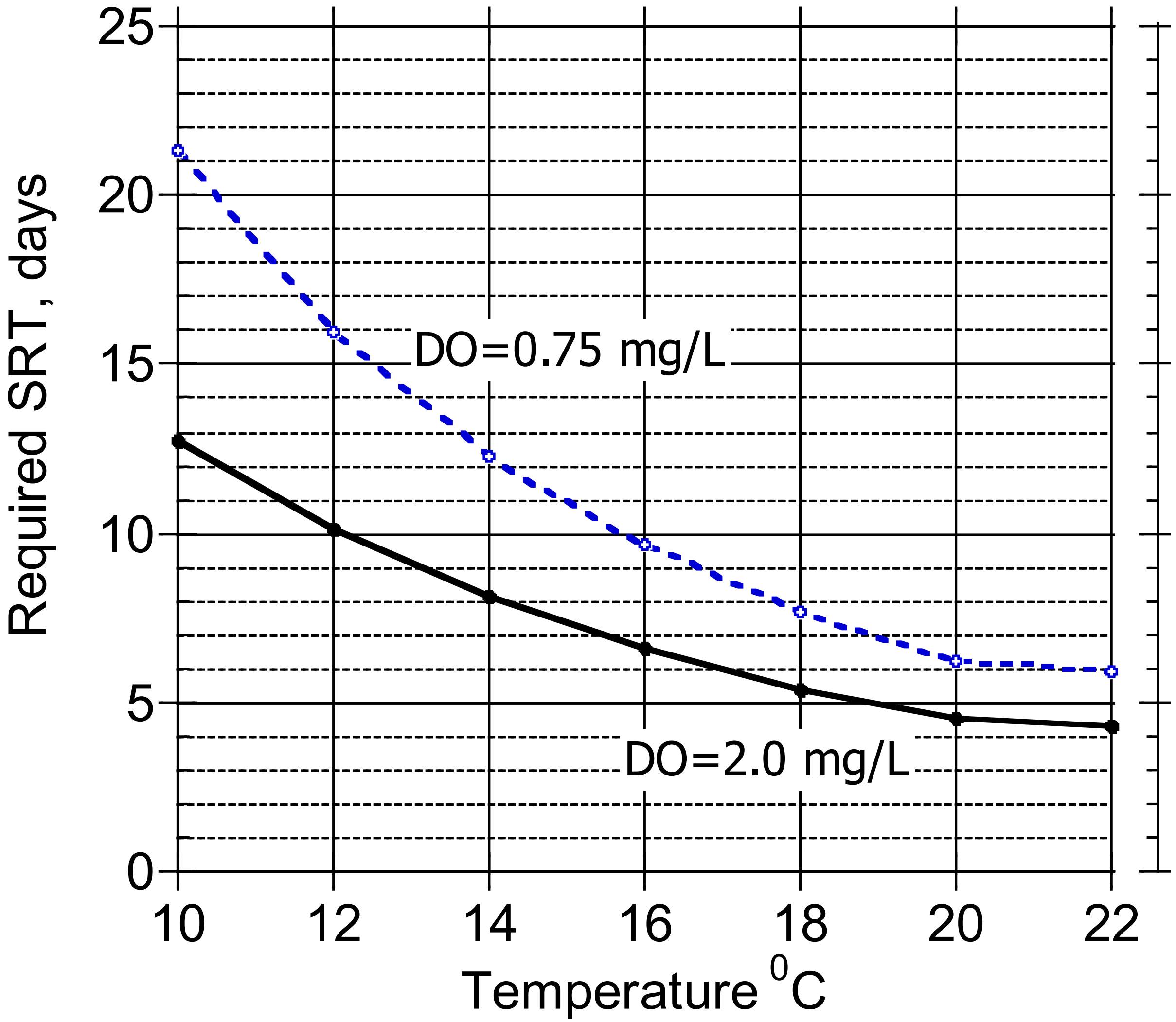
Higher SRT needed as NH4-N effluent concentration is lowered
SRT, days
Temperature 0C
Effluent NH4-N = 0.50 mg/L
Effluent NH4-N = 1.0 mg/L
Safety Factor = 1.30
0
5
10
15
20
25
30
35
40
10
12
14
16
18
20
22

Faster nitrification rate and lower SRT at higher DO concentration

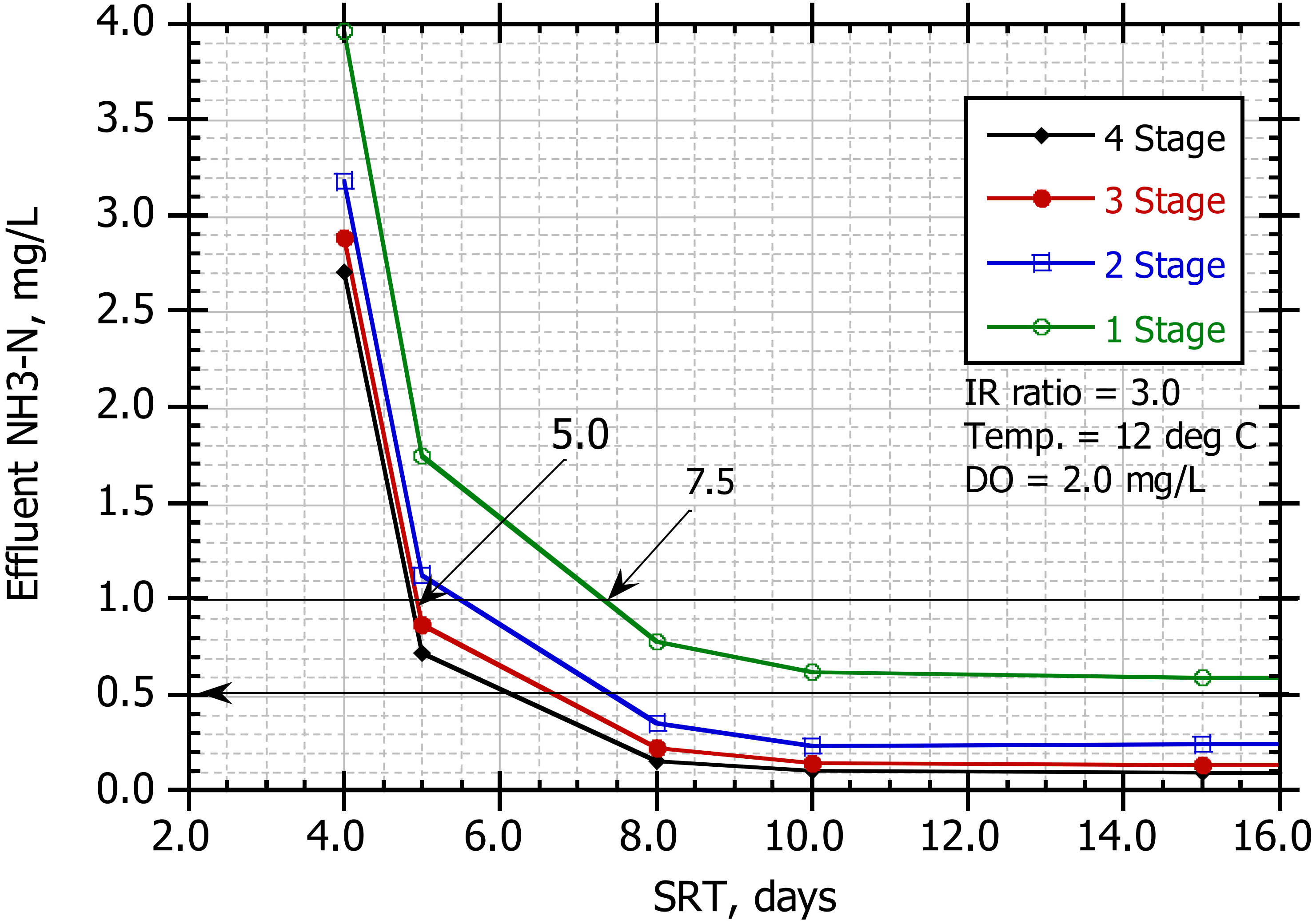


DO, mg/L	% of Max Rate
1	67
2	80
3	86
4	89

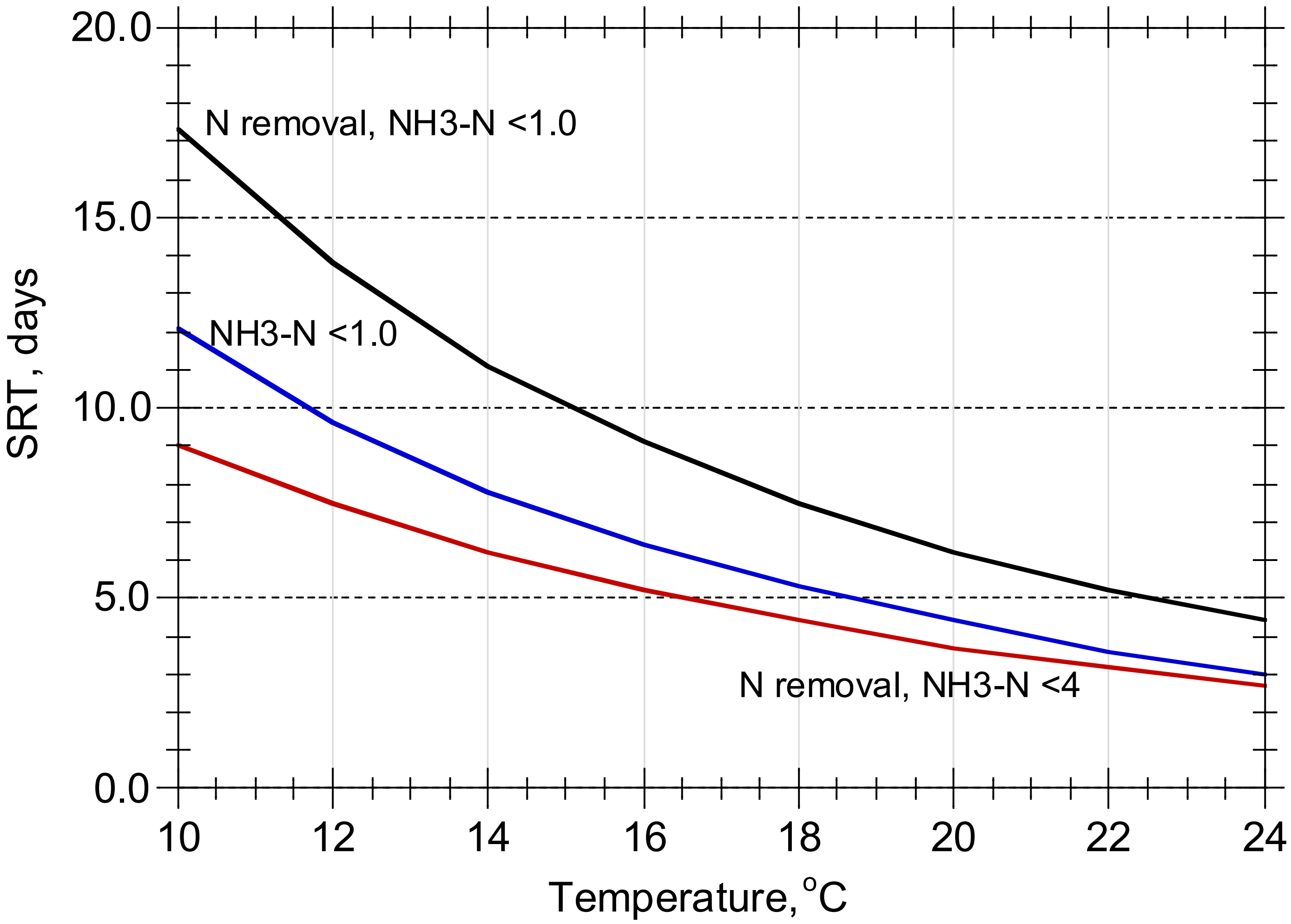
Lower DO requires longer SRT (Effluent NH4-N = 1.0 mg/L)



Aerobic reactors in series decreases SRT and/or lowers NH3-N concentration



Effluent Goals for Nitrogen Removal and Nitrification Impacts Bioreactor SRT



- Higher SRT – greater volume
- Higher influent BOD – greater volume
- Higher MLSS – less volume

Oxygen and alkalinity balances are important for aeration supply and pH

pH > 6.8 is more favorable

Reaction	g O_2 per g of N oxidized	g Alkalinity Used as CaCO3 per g N	g Alkalinity Produced as CaCO3 per g N
NH_4 to NO_2	3.43	7.14	
NO_2 to NO_3	1.14	0	
NO_2 to N_2	-1.71		3.57
NO_3 to N_2	-2.86		3.57

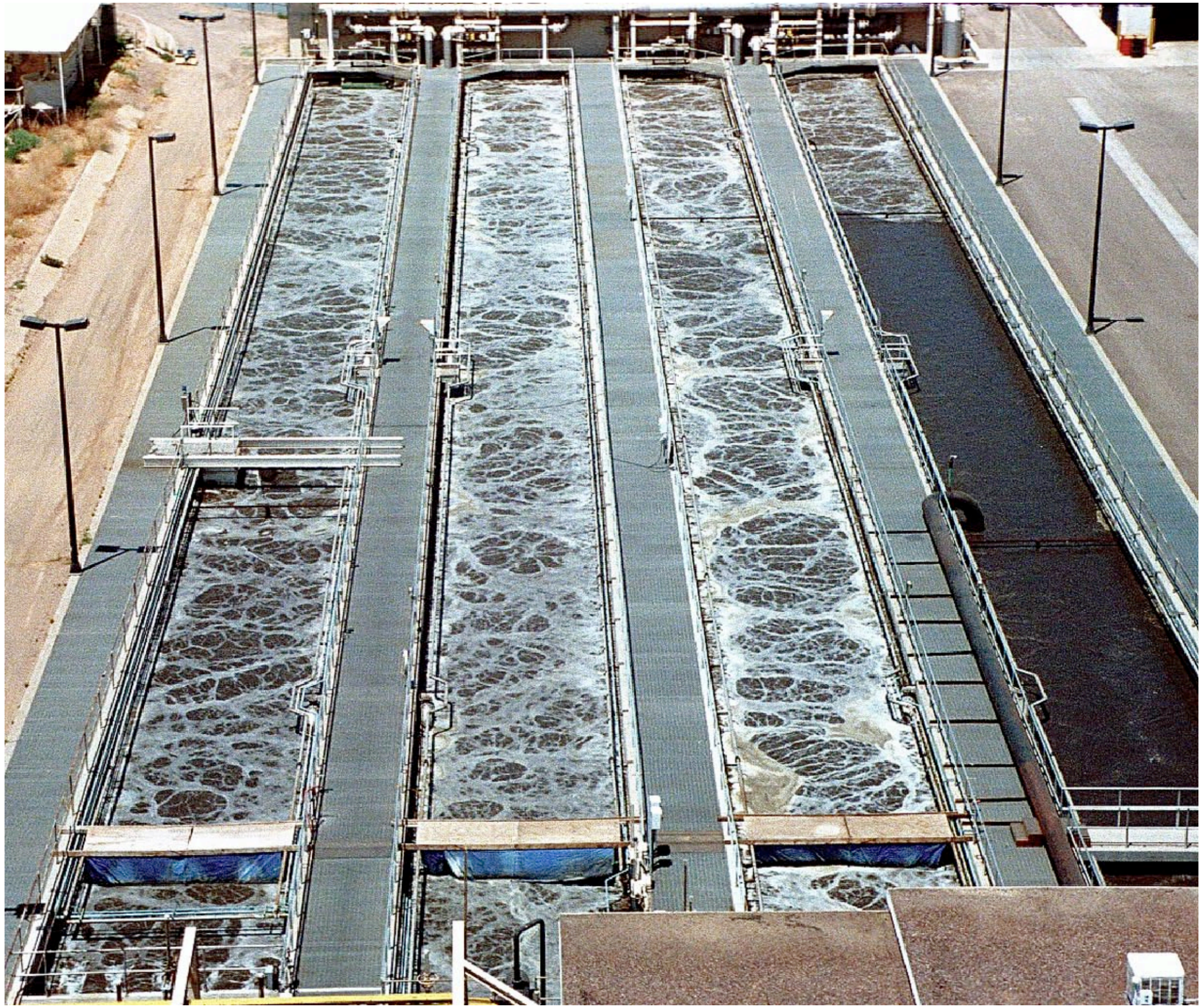
Applying Nitrification Fundamentals for optimization to decrease volume or have lower effluent NH_3-N

Optimization	Comment
Warmer temperature	Site climate
Add alkalinity to increase pH	More important at low temperatures
Increase DO concentration	Faster nitrification rate
Use multiple aerobic tanks in series	Faster nitrification in upstream stages
Increase MLSS concentration	Improve SVI (granulation/densification)

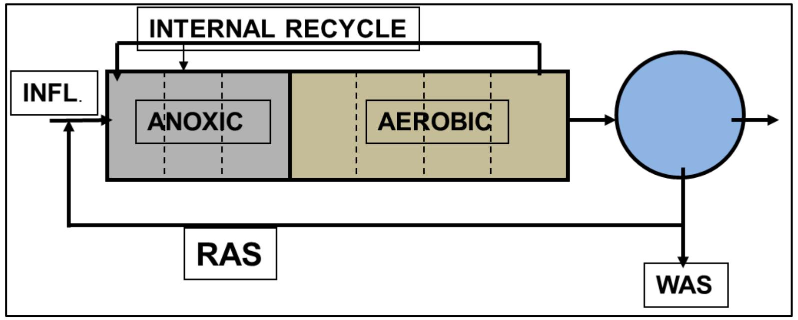
Overcoming Site Specific Limitations to Optimization

Site Condition	Possible Action
High diurnal variation in influent TKN load	Influent equalization
Recycle N load over a few hours each day	Return flow equalization
Influent inhibitory substances to nitrification	Local source control

If Nitrification – then best to have denitrification



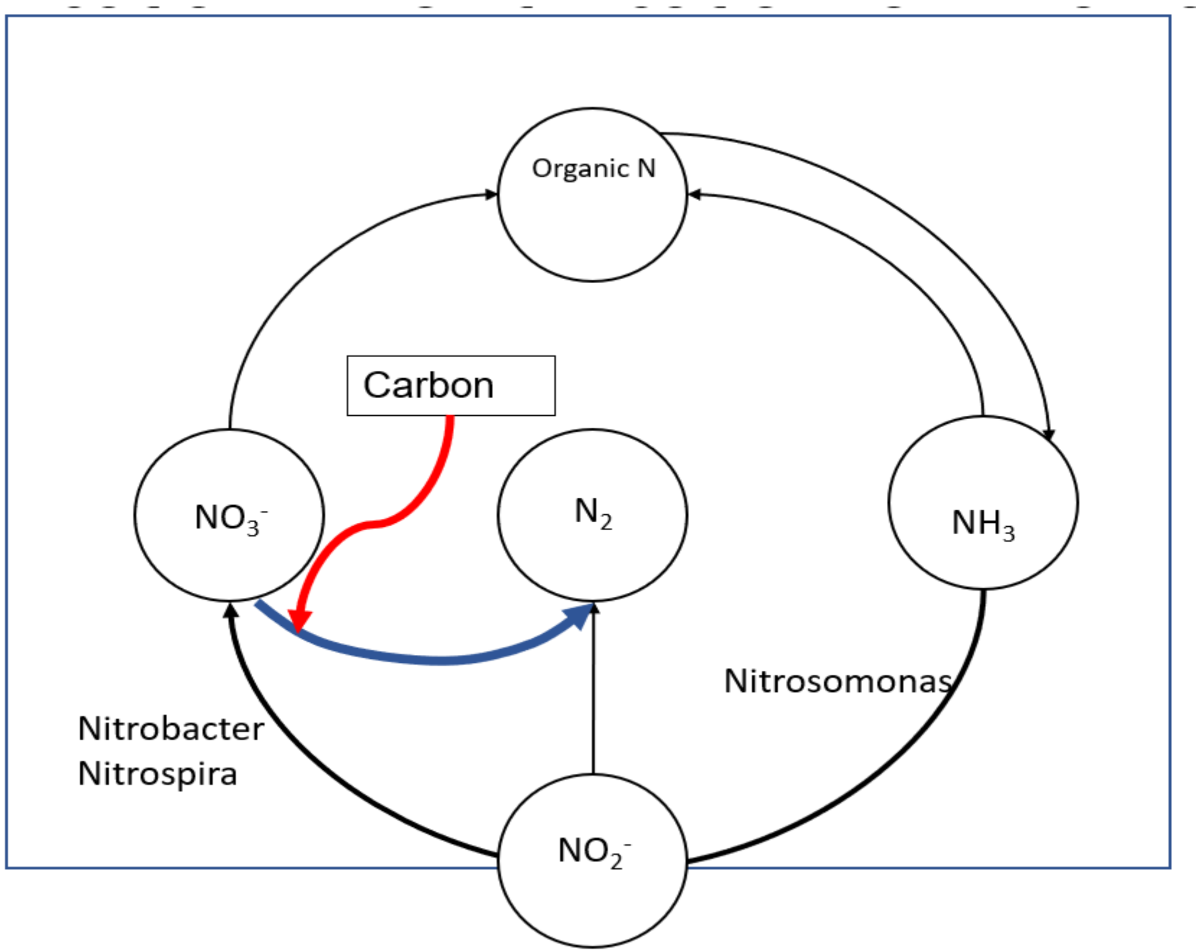
Phoenix 23rd Ave
Converted to anoxic/aerobic



- good SVI
- good N removal
- alkalinity return
- energy savings
- improved aeration alpha

Nitrification – Denitrification for N removal

- 4.6 g O2/g NH4-N oxidized
- 6.0 g COD/g NO3-N reduced
- 50% Alk recovery from Nitrogen



Key Fundamentals of Denitrification

- Heterotrophic bacteria including PAOs and GAOs use $NO3^-$ and/or $NO2^-$ as electron acceptors for carbon oxidation

- Need sufficient available carbon
  - Wastewater BOD/TKN ≥ 4.0

- How much anoxic volume is needed?
  - Amount of NOx-N to remove,
  - MLSS concentration and specific denitrification rate
    - Type of carbon source and associated kinetics
  - Temperature

External Carbon Addition Often Needed To Meet Lower TN Concentrations

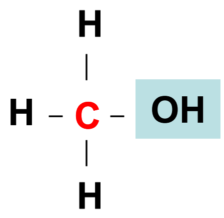
- BOD/N < 4.0 and for low effluent TN
- Methanol, Ethanol
- Acetic Acid
- Glycerol
- Industrial By-product (clean source)
  - Pharmaceutical
  - Soft drink bottlers
  - Breweries
  - Yeast factories
  - Fruit juice canneries

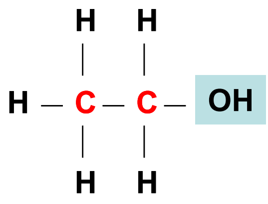
Methanol degraders use less carbon - **but are slower and need acclimation time**

- Bacteria are not common in wastewater
  - May take 1-2 weeks to develop population
- Requires a sufficient anoxic zone SRT to maintain organisms in system
  - Typically 2.5 to 3.0 days

Days added	MeOH	Ethanol
1	1.2	4.0
50	2.0	4.1

Ratio of denite rate in mixed liquor after exogenous carbon addition



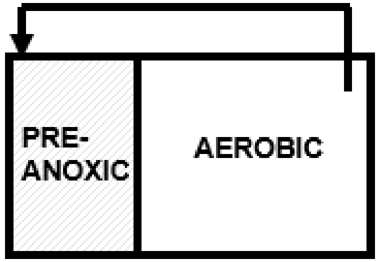


Glycerol much faster kinetics than methanol

Limited glycerol dose 2.5- 3.0 gCOD/g N can result in NO3 to only NO2

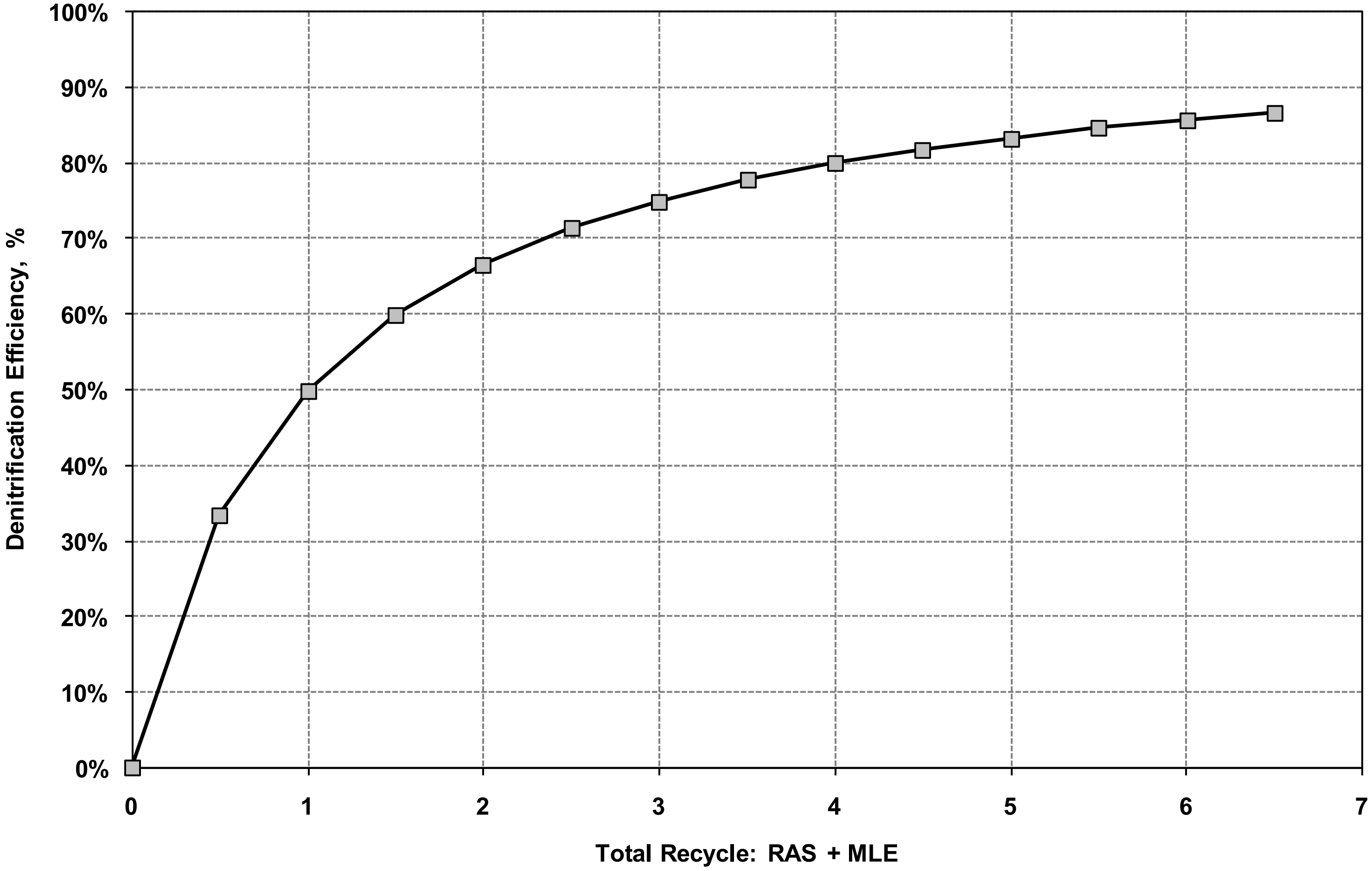
Anoxic-Aerobic

Denitrification Efficiency Can Theoretically Increase with Internal Recycle Rate - but about 3:1 to 4:1 is common – ~80% removal



Beware of recycle DO!

Higher recycle ratios can decrease denite rates by diluting carbon concentration!



How can the efficiency of denitrification be optimized?

(less energy, less volume, lower effluent NOx-N)

Method	Comment
Add supplemental carbon	Carbon dose per g NOx-N removed function of substrate
Methanol	Less needed per g NOx-N removed but slower kinetics Continuous to maintain methanol degrading population
Acetate, ethanol, glycerol	Faster kinetics, higher dose needed, can use on/off, some have less safety hazards
Use primary sludge fermentation	Produces VFA which has good kinetics Extra treatment process, odor control

How can the efficiency of denitrification be optimized?

- less energy, less volume, lower effluent NOx-N

Method	Comment
Recycle more NOx-N to preanoxic	If sufficient carbon and time available
Increase MLSS by increasing overall SRT	Increases removal if sufficient carbon
	Increases endogenous decay denitrification in post anoxic
Decrease N load from dewatering recycle	Sidestream Treatment or Management
Sidestream treatment	Anammox removes nitrogen without carbon need Ammonia recovery Nitritation-denitritation process (SHARON) uses less carbon

Methods to Reduce Carbon Cost and Energy for Biological Nitrogen Removal

- Operate system to accomplish shortcut nitrogen removal
  via simultaneous nitrification/denitrification (SND)

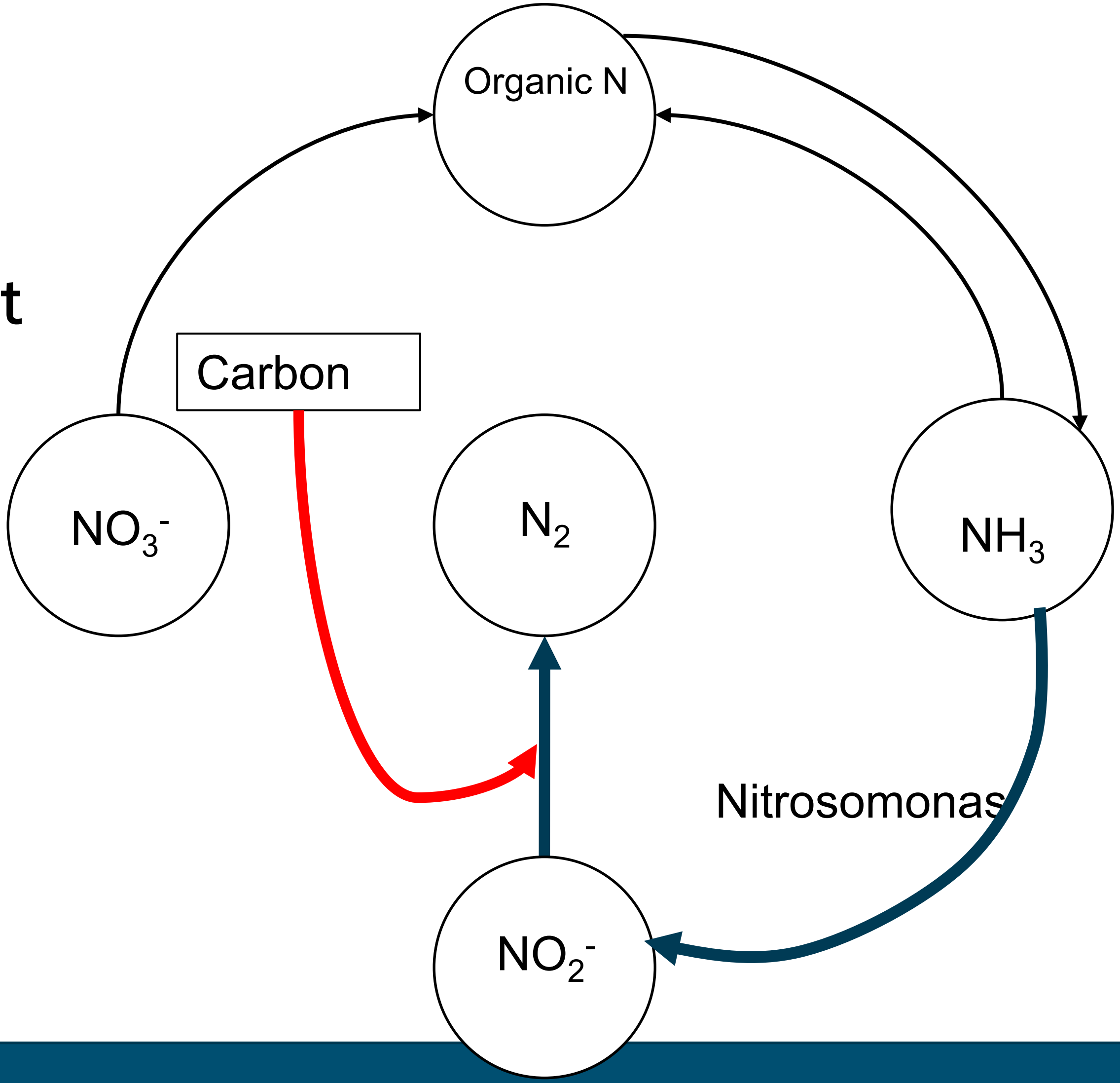
- Use Anammox Process in sidestream treatment
  - Oxidizes $NH4^{+}$ with $NO2^{-}$
  - Saves energy for $NH4^{+}$ and $NO2^{-}$ oxidation
  - Saves carbon cost
  - Less alkalinity consumed

- Use primary sludge fermentation for supplemental carbon

What is Short Cut N removal?

Inhibit NO2 Oxidation

25% less energy
40% less carbon
50% Alk recovery from Nit



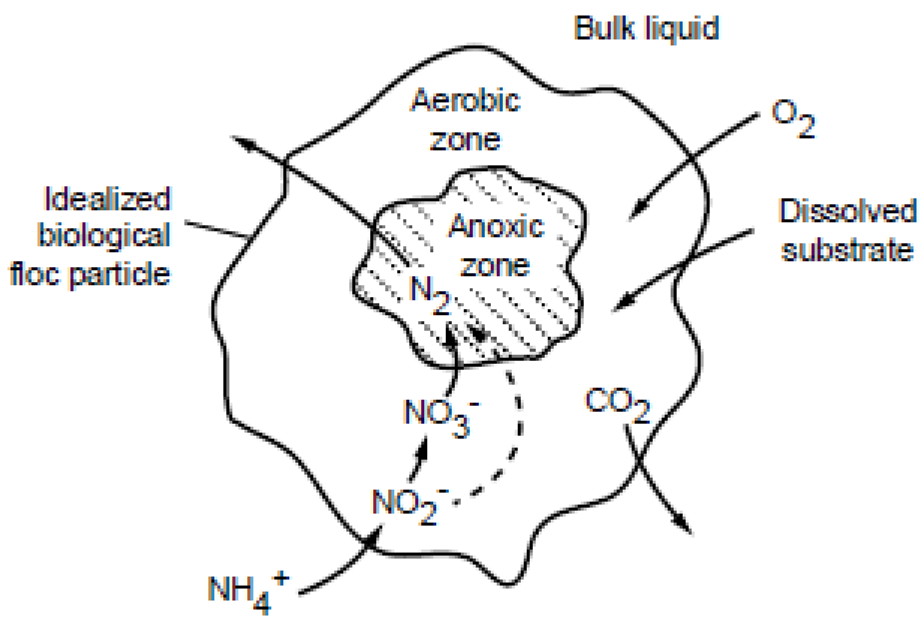
So nitrifying to only NO_2-N is GOOD!

How can that be done?

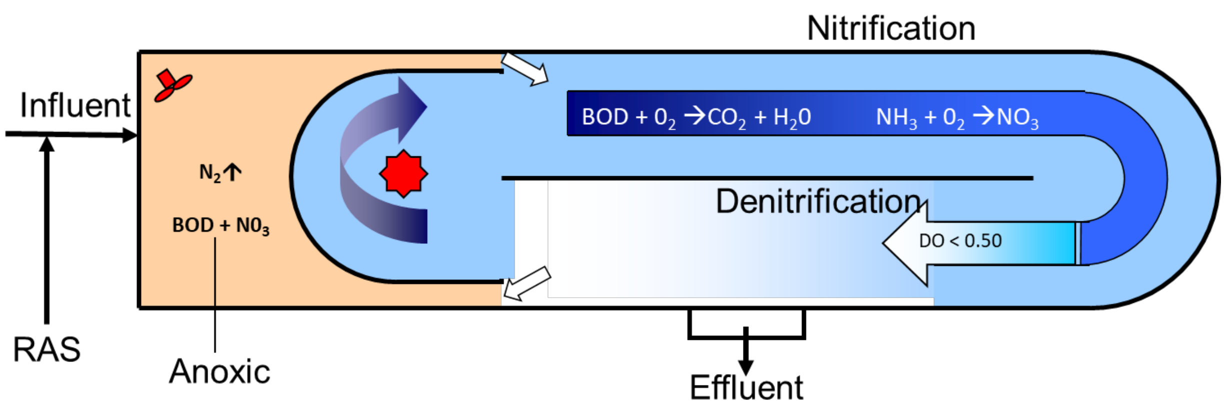
- Very low DO in activated sludge nitrification to inhibit
- Periods of on/off aeration (DO)
- Periods of high free NH_3 exposure

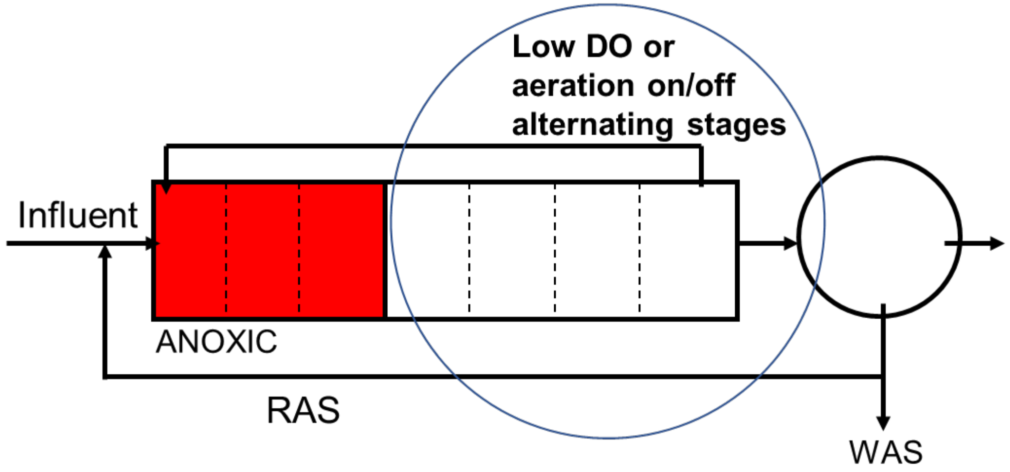
- BUT - Other NOB species may grow in response to low DO and high fee NH_3
  - (acclimation observed)

Low DO control to obtain simultaneous/nitrification denitrification (SND) **- possibly with short cut N**



Orbal/Ditch Flow





SND Pluses and Minuses

PLUS

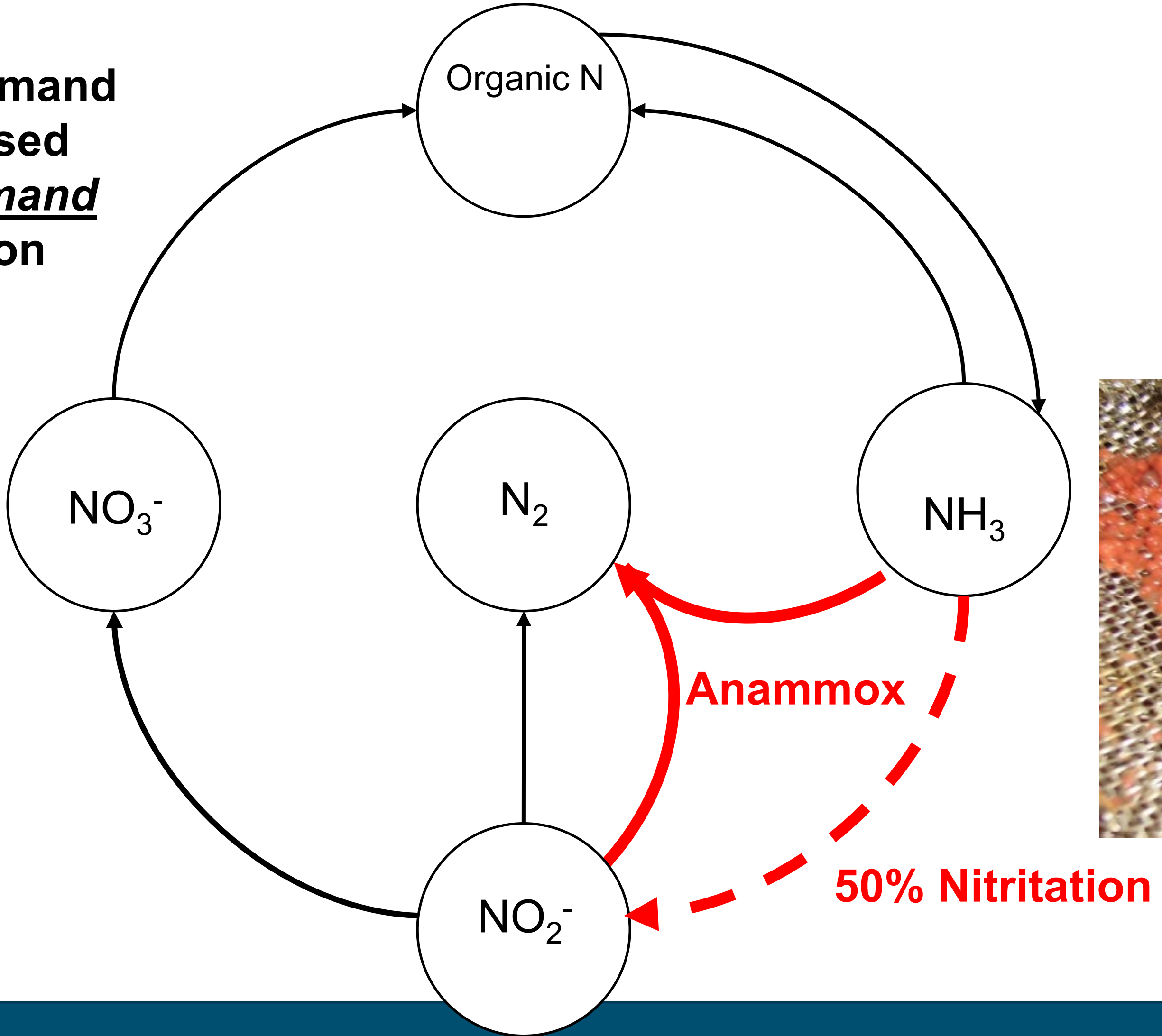
- Warmer Temperature
- Low SRT
- High feed BOD/TKN ratio
- DO is controlled at lower concentration or aeration is on/off
- Orbal configuration

MINUS

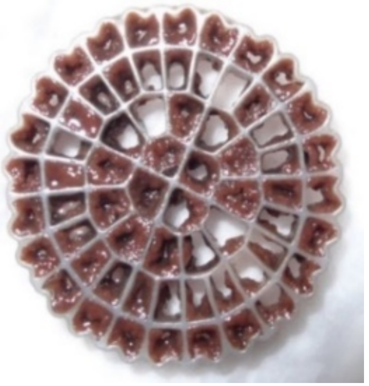
- Reaction rates are slower for nitrification and denitrification
- Low DO may select for Nitrospira NOB
  - Some species able to oxidize NH_3-N (to NO_3-N)
  - Comammox

Sidestream Deammonification/Anammox for BNR Reduces carbon needs and saves energy

- **62.5% Less Oxygen Demand**
- **63%   Less Alkalinity Used**
- ***100% Less Carbon Demand***
- **Low Biomass Production**

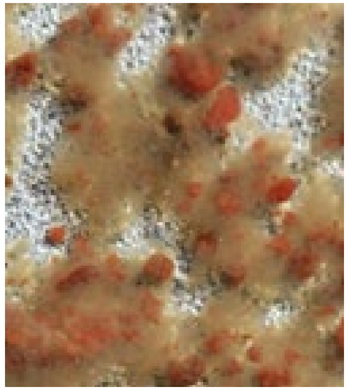


Deammonification processes demonstrated worldwide offer compact and efficient sidestream N removal in various types of processes



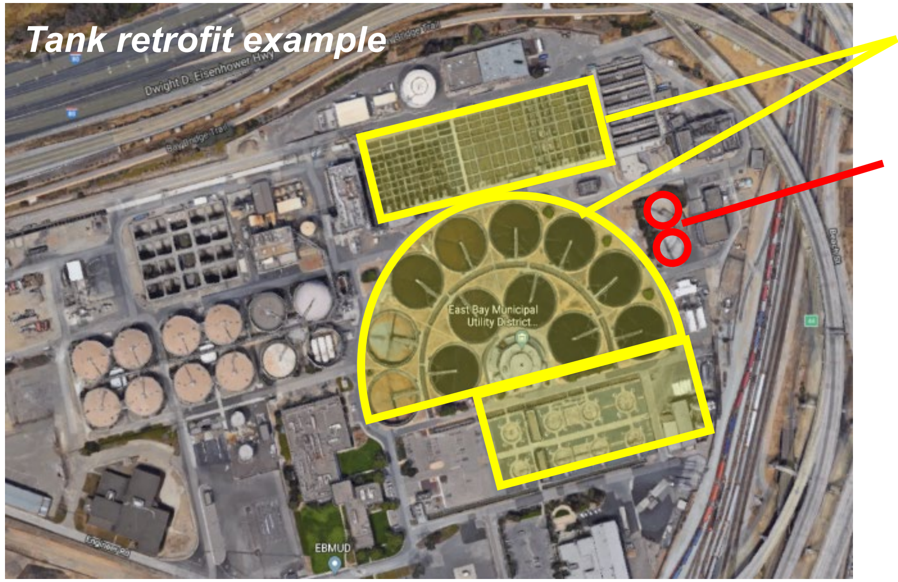
Attached-growth:
Veolia AnitaMox

Granular growth:
Ovivo Anammopaq



Hybrid floc/granular:
WWW Demon

Design loading rates typically >1 kg N/m3-d



Primary clarifiers and Secondary HPO-AS

Convert to sidestream deammonification

~35% reduction in effluent TN load

(High sidestream load from regional solids and organics treatment)

Key fundamentals to be considered for optimization of Nitrogen Removal performance

- Effluent goals
- SRT selection and control
- Environmental conditions – Temperature
- Wastewater characteristics – TN, alkalinity, pH
- Possible process configurations
- DO selection and alkalinity addition
- Supplemental carbon
- Sidestream treatment processes and recycle streams
- Variations in plant loadings

Thank You!

"Live" Interaction Using Menti Meter

Go to:	menti.com
Enter Code:	9616 0848

Follow cues on your device screen

Remember to SUBMIT your answer

Some questions allow multiple entries

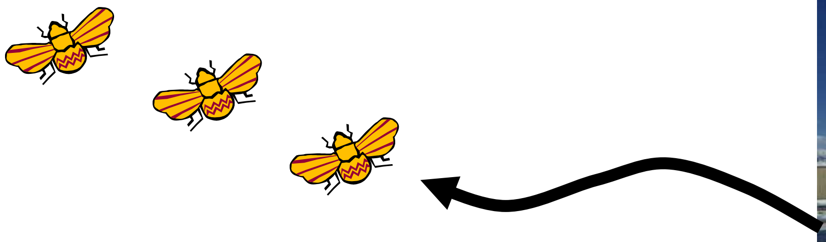

Stretch Break!


Applied Fundamentals for Chemical Phosphorus Removal

JB Neethling

Fundamental Principle of P Removal

There is no airborne (gaseous) form of phosphorus



The exception

Fundamental Principle of P Removal

Consequence:

100% of the P entering the treatment plant will exit the treatment plant…. as:

- Effluent P
- P in Biosolids
- P recovered

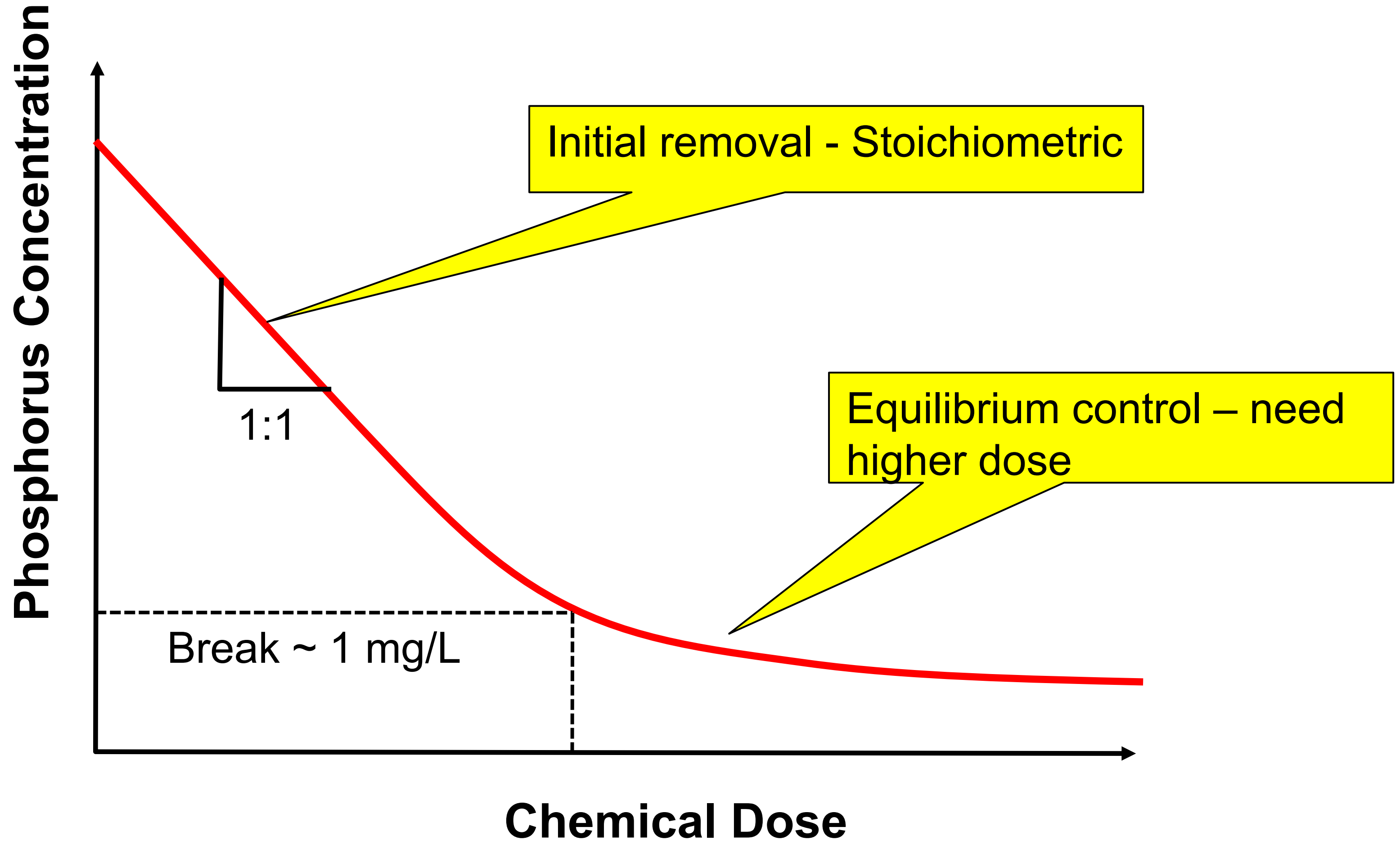
To be removed, convert P to particulate:

- Biosolids
- Chemical precipitant

Commonly Used Chemicals for P removal

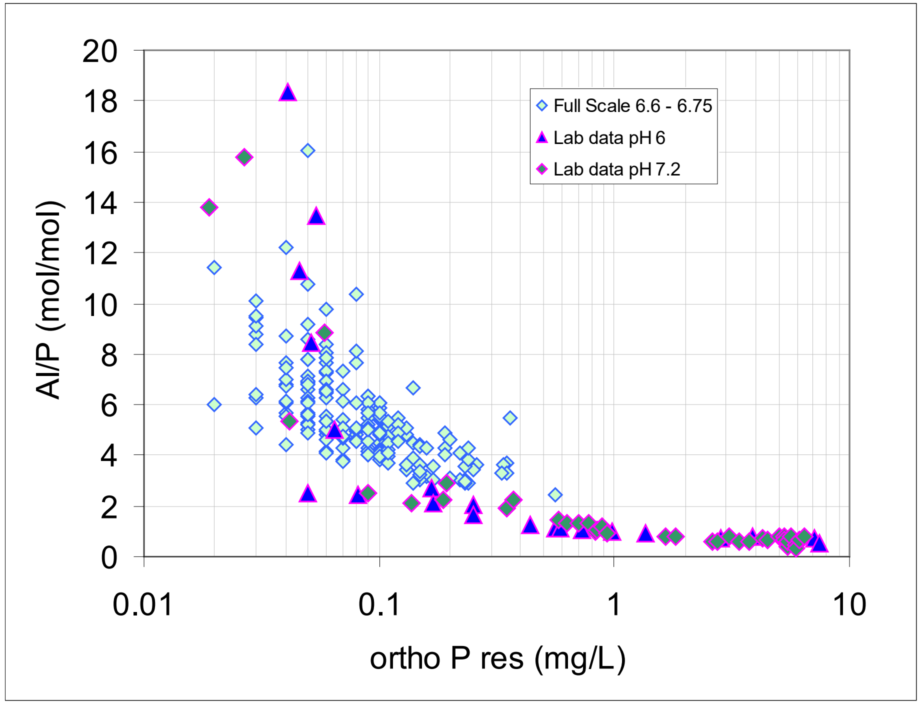
Chemical	***Formula***	***Removal mechanism***	***Effect on pH***
Aluminum Sulfate (Alum)	$Al_2(SO4)_3.14.3(H_2O)$ M.W. = 599.4	Metal hydroxides	removes alkalinity
Ferric Chloride	$FeCl_3$ M.W. = 162.3	Metal hydroxides	removes alkalinity
Poly Aluminum Chloride	$Al_nCl_{(3n-m)}(OH)_m$ $Al_{12}Cl_{12}(OH)_{24}$	Metal hydroxides	none
Ferrous sulfate (pickle liquor)	Fe_2SO_4	Metal hydroxides	Removes alkalinity
Lime	$CaO, Ca(OH)_2$	Insoluble precipitate	Raises pH to above 10

Phosphorus Removal – Dose/Response

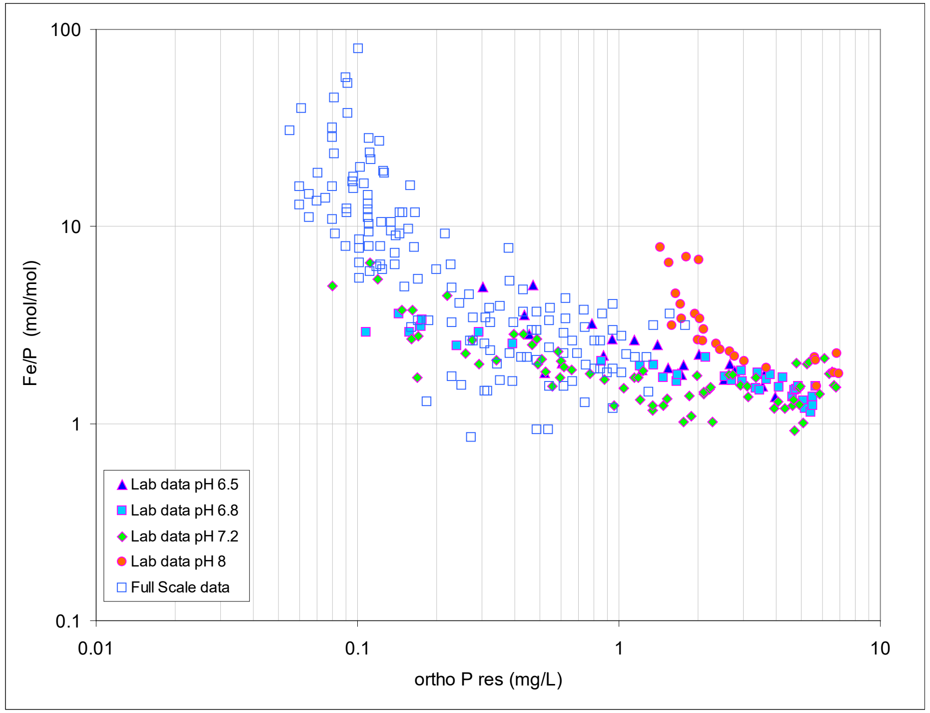


Molar Dose Ratio From Tests

Alum – Al



Ferric – Fe



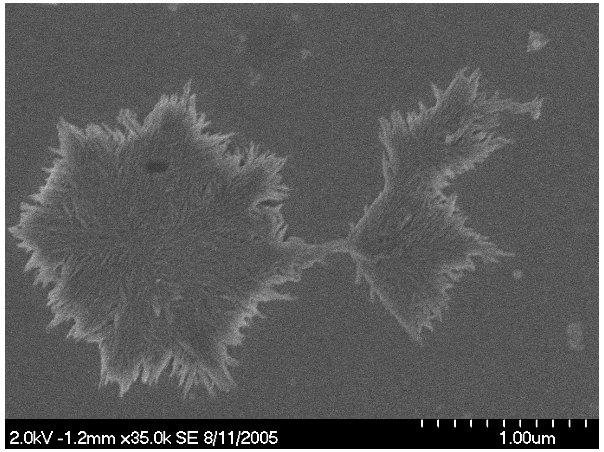
Slav Hermanowicz, Chemical Fundamentals of Phosphorus Precipitation, WERF Boundary Condition Workshop, Washington DC, 2006

Metal Hydroxide plays central role an chemical P removal

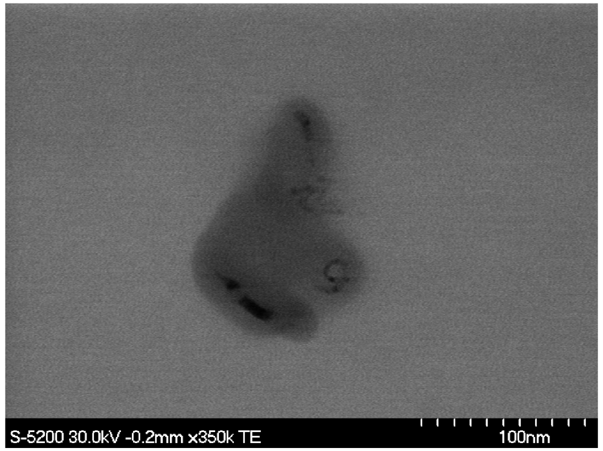
- Metal hydroxide formed
- Co precipitation of P into hydrous ferric oxides structure
  - $Fe(OH)_3$, $Fe(OH)_4^-$
- Surface complexation between P and metal hydroxide compounds
- Phosphorus and Iron share oxygen molecule:
  - $FeOOH + HOPO_3 = FeOOPO_3 + H2O$

- Hydroxide formation stoichiometry can be simply represented:
  - $FeCl_3 + 3H_2O = Fe(OH)_3 + 3\ HCl$
  - $2\ FeCl_3 + 3Ca(HCO_3)_2 = 2\ Fe(OH)_3 + 3\ CaCl_2 + 6CO_2$
  - $Al_2(SO_4)_3.14H_2O + 3\ H_2O \rightarrow 2Al(OH)_{3(s)} + 3H_2SO_4$
  - Same alkalinity affect as above
  - Or 0.5 g alkalinity per g of Alum and 0.92 g alkalinity per g of ferric chloride

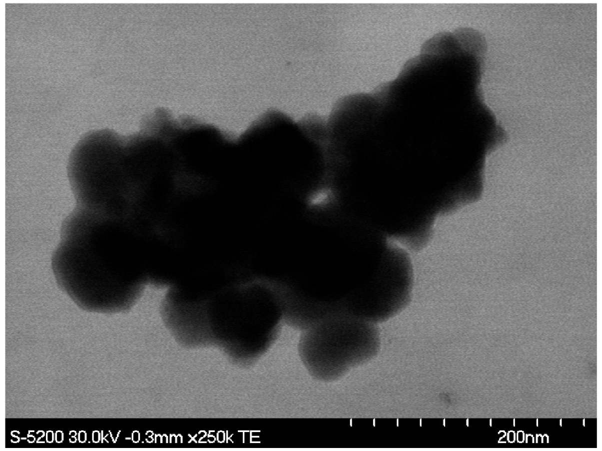
Photomicrographs of Phosphate Precipitants



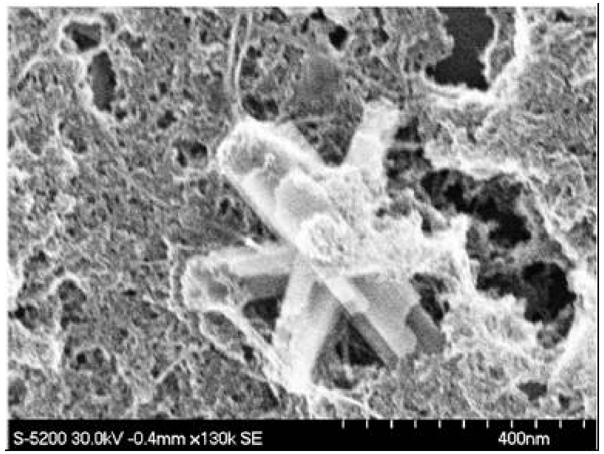
pH 7 = Fresh?



Fresh HFO



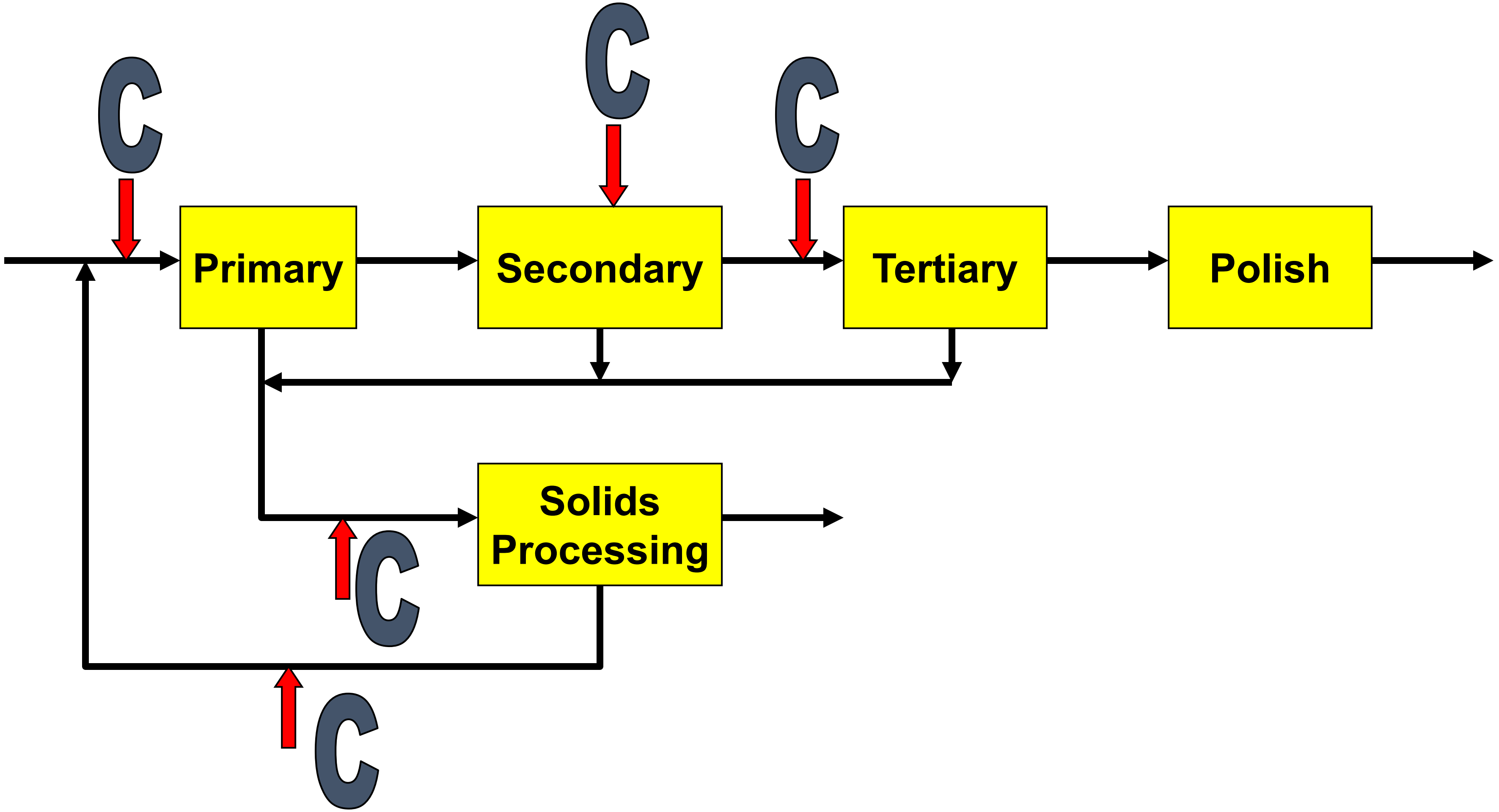
Young



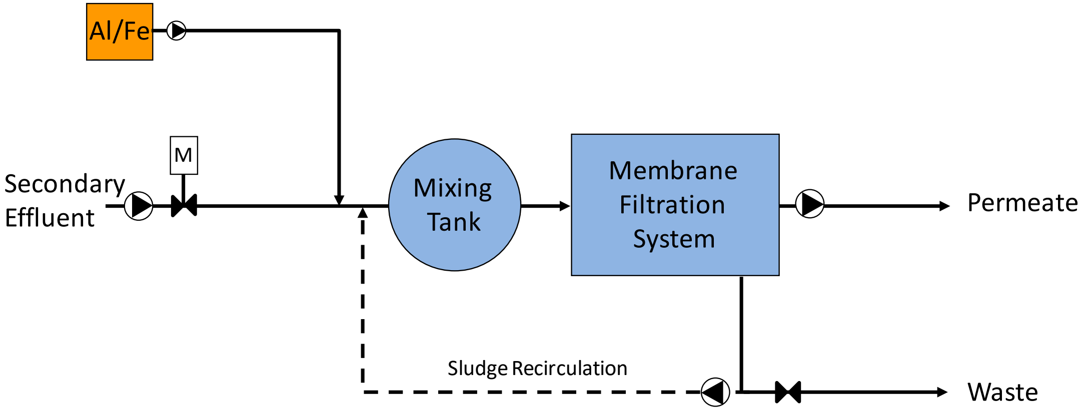
Aged

Scott Smith, Wilfrid Laurier University

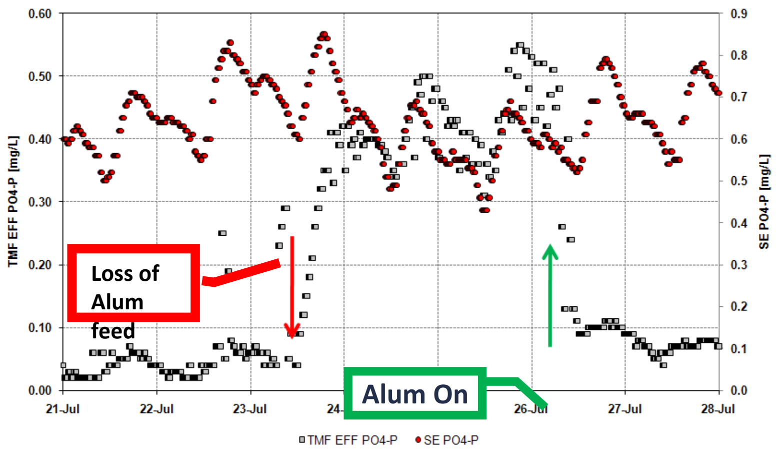
Typical Chemical Treatment Opportunities



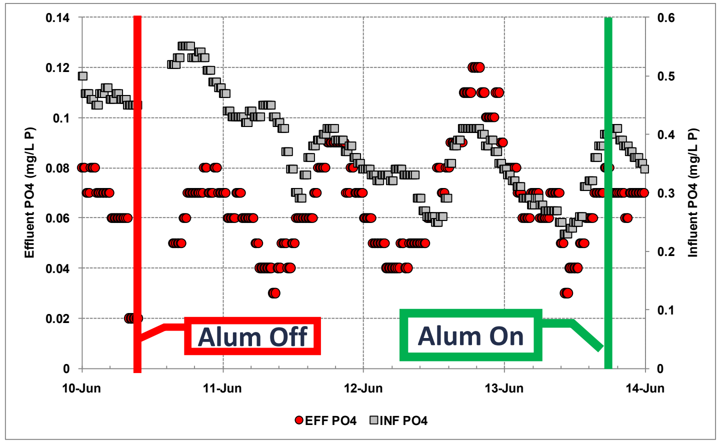
Chemical Hydroxides continue to Remove P



Coeur d'Alene Pilot Study



No Solids Inventory



With Solids Inventory

Chemical P Removal Key Fundamentals

- 100% of the P entering WRRF leaves with solids or liquid effluent
- Chemical dose is linear to ~ 1 mg P/L
- Good mixing is important
- Chemical sludge continue to removal P
- Dose/Response time is quick
- Adding metal salts will:
  - Increase solids production
  - Reduce alkalinity

"Live" Interaction Using Menti Meter

Go to:	menti.com
Enter Code:	9616 0848

Follow cues on your device screen

Remember to SUBMIT your answer

Some questions allow multiple entries

Applied Fundamentals for Biological Phosphorus Removal

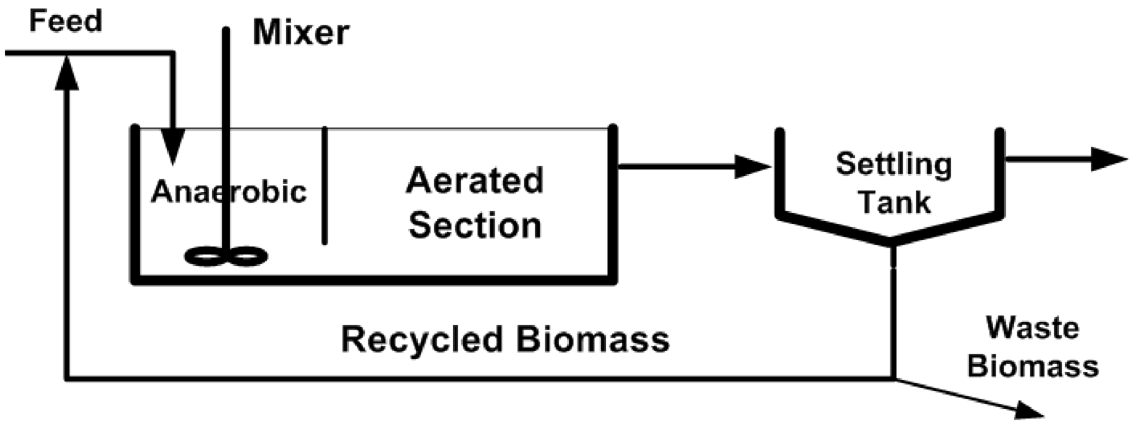
James Barnard

Biological Phosphorus Removal

- Mechanism for Accummulibactor species
- First observed side-stream fermentation
- Development into what is now considered “conventional” flowsheets
- Rediscovery of need for side-stream fermentation
- Ease of adapting to conventional systems or even apply to plants not designed for EBPR
- Why not stay with chemical phosphorus removal?
- At Durham OR switching to EBPR with chemical polishing reduced Alum consumption from 170 mg/L to 25 mg/L to achieve around 0.08 TP in final effluent and allowed recovery of struvite

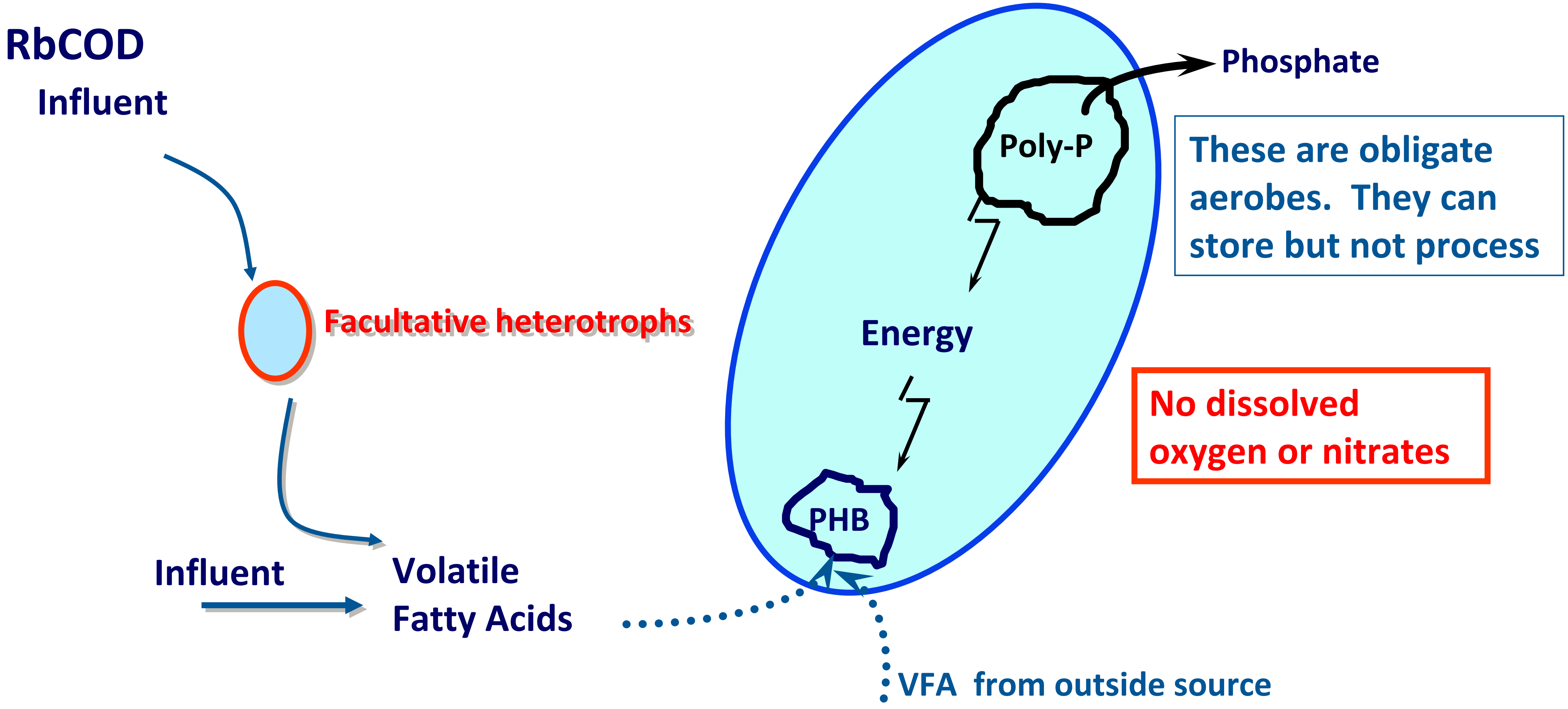
Biological Phosphorus Removal

- A two-step process of phosphorus release and uptake under alternating anaerobic and aerobic conditions.
- Phosphorus is released in the anaerobic zone to 25 to 40 mg/L, taken up in the aeration basin to as low as 0.05 mg/L soluble P.

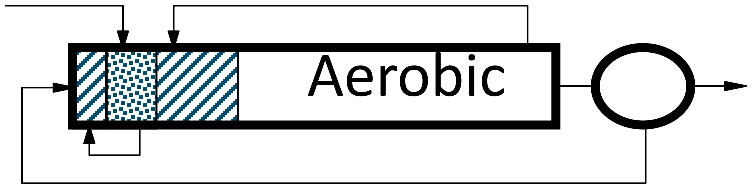


WHY?

Mechanism in Anaerobic Zone



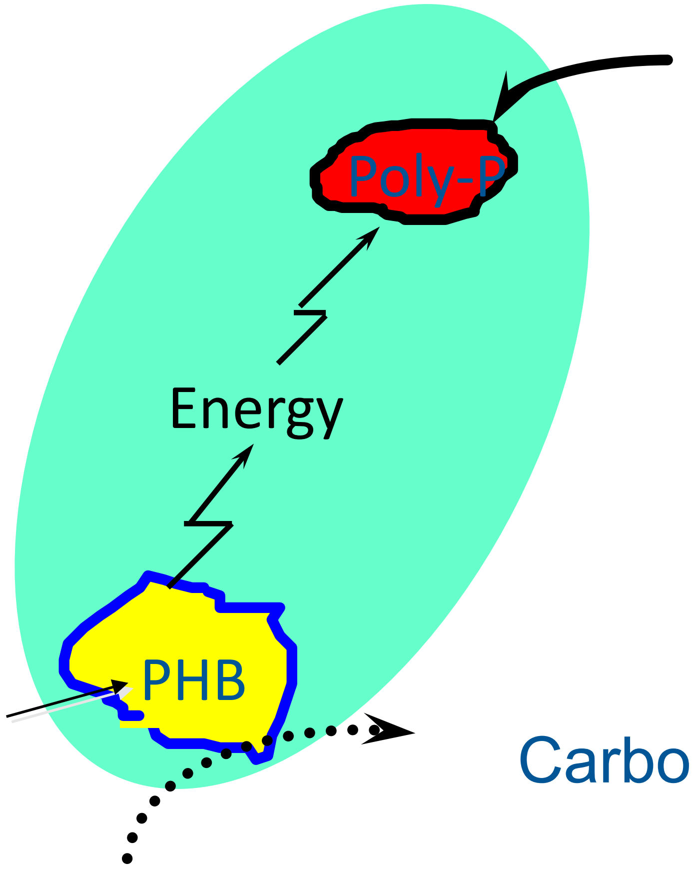
Mechanism in Aerobic Zone



Modified JHB Process

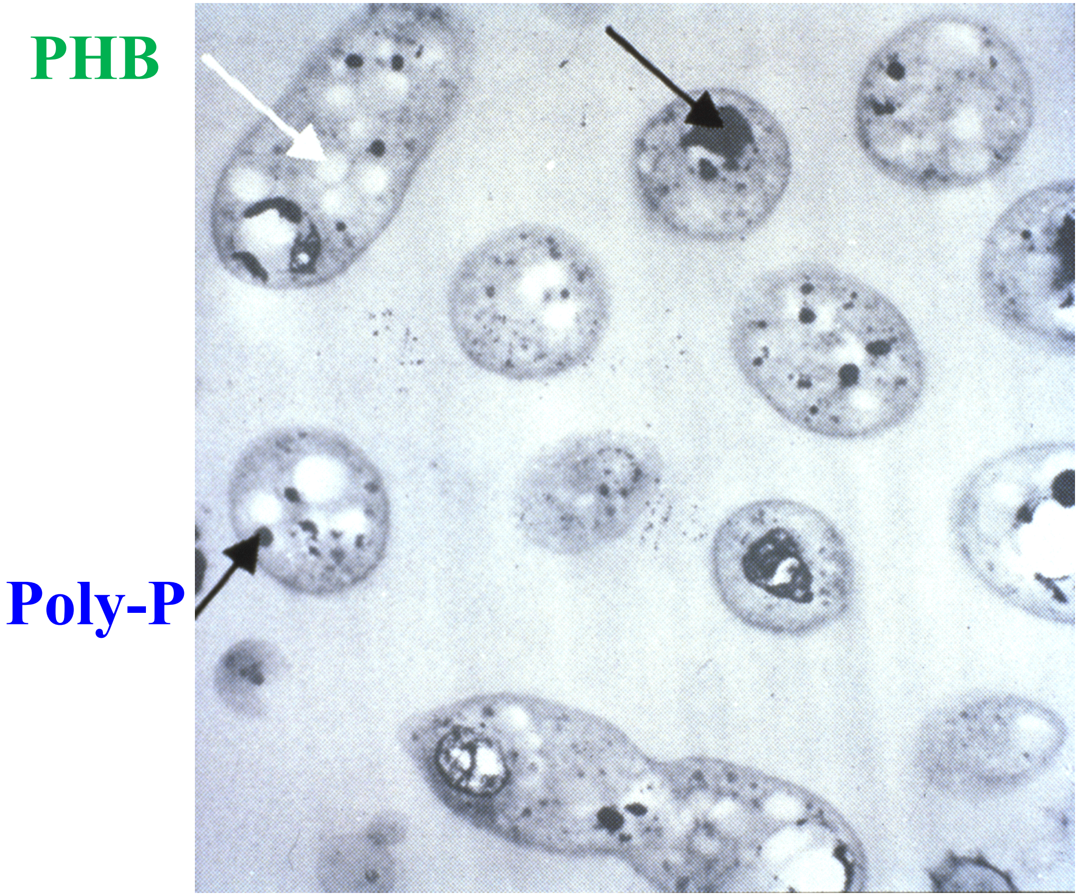
Stored in anaerobic zone.

Consumed in aeration basin providing energy for storage of phosphorus

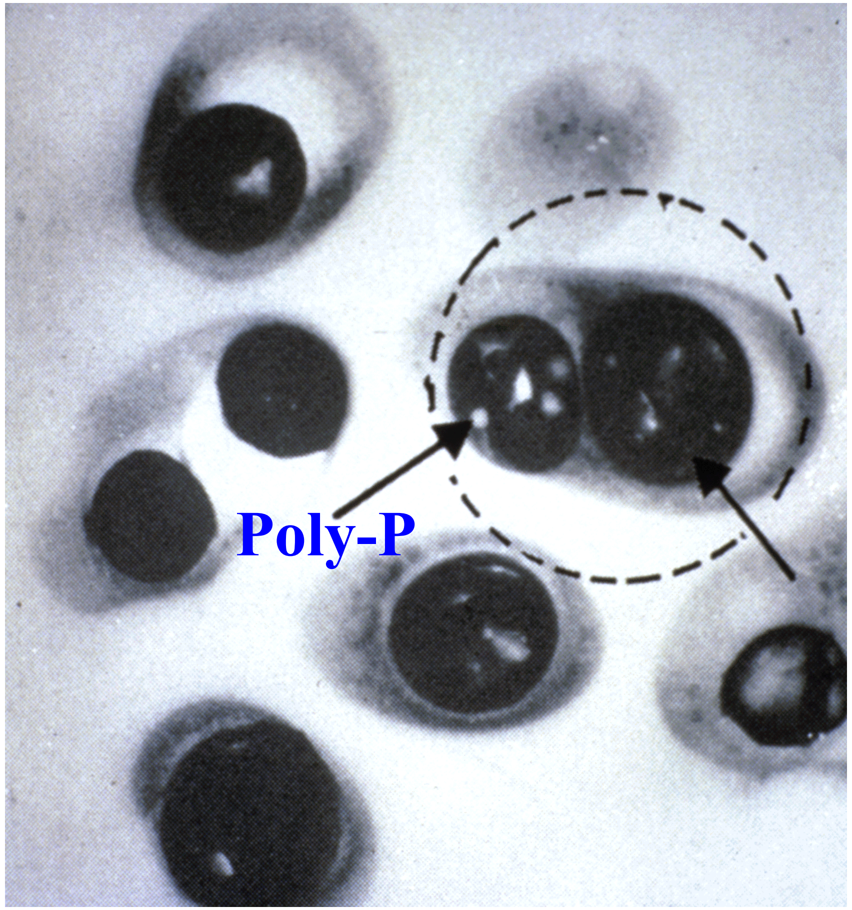


But it could be much more complex

Phosphorus granules in PAO



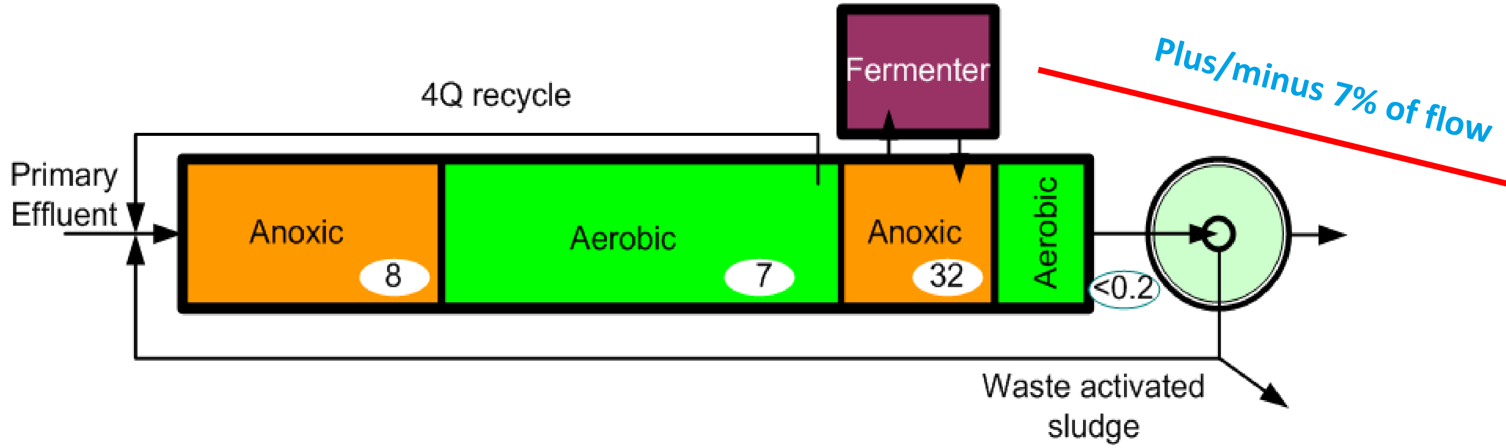
Anaerobic Zone



Aerobic Zone

It Started With Mixed Liquor Fermentation

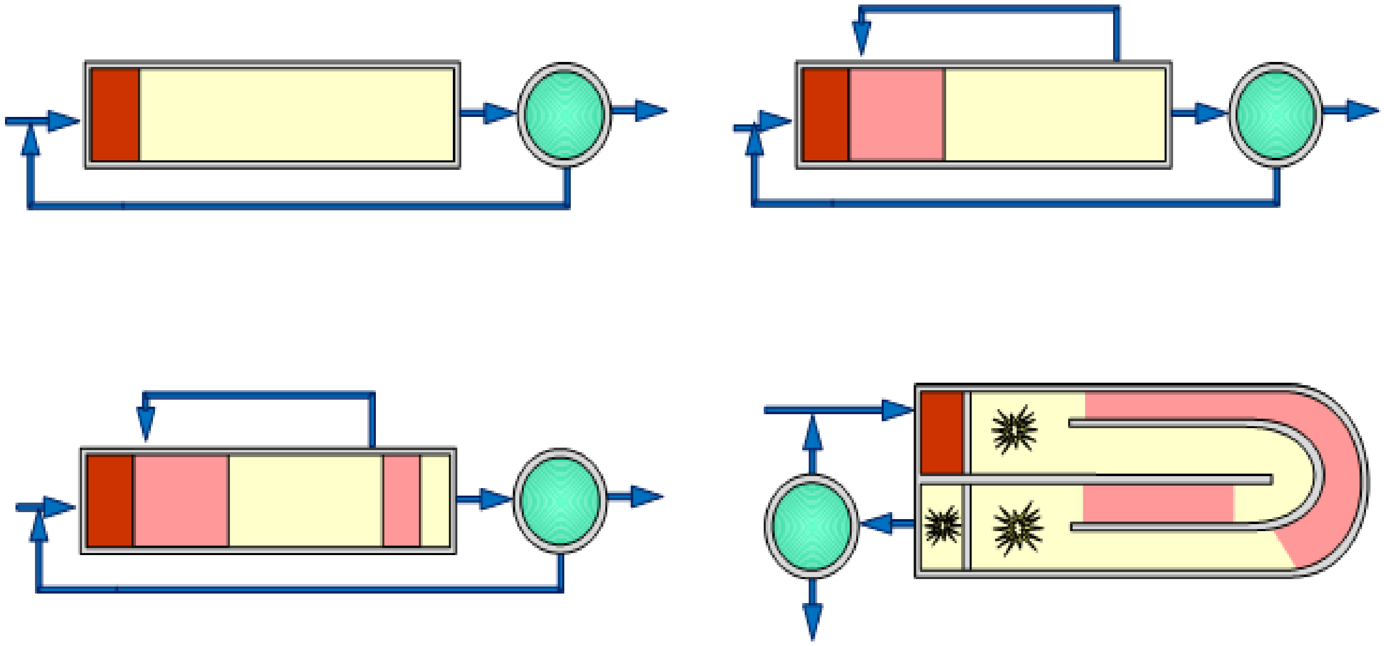
- Fermenter resulted from basin configuration and considered a “dead zone”
- Excellent phosphorus removal resulted
- Note orthophosphates profile through plant with high release in 2nd Anoxic zone
- Performance could not be replicated in laboratory
- Barnard postulated that organisms (PAO) should pass through anaerobic phase with low ORP and P release, which triggered EBPR
- Suggested Phoredox process by adding anaerobic zone up front

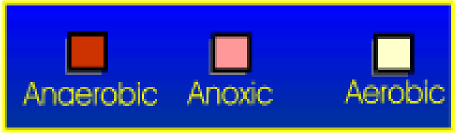


- Primary Effluent to Anoxic zone

Barnard 100 m^3/d pilot 1972

Proposed Phoredox Flow Sheets

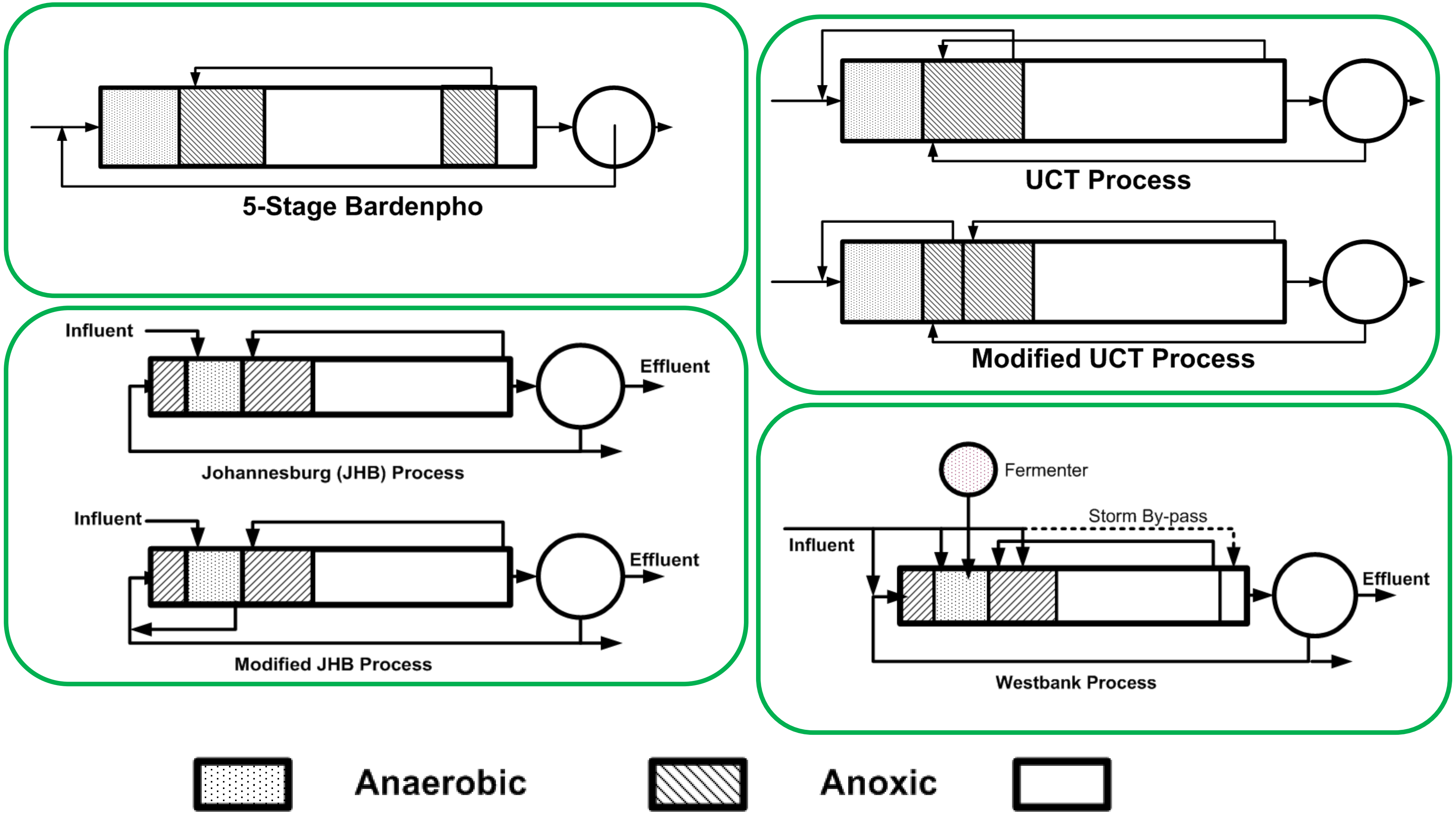




Construction Started October 1974
Flow Diagrams Published July 1975 as Phoredox
Renamed AO, A2O, April 1976

These were followed by others such as UCT, JHB & Westbank

Some Traditional Flow Diagrams



Palmetto FL BNR plant

TN < 3 mg/L

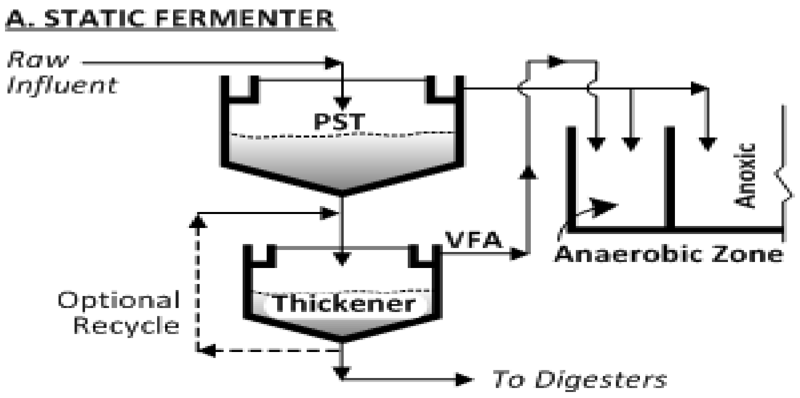
TP < 1 mg/L

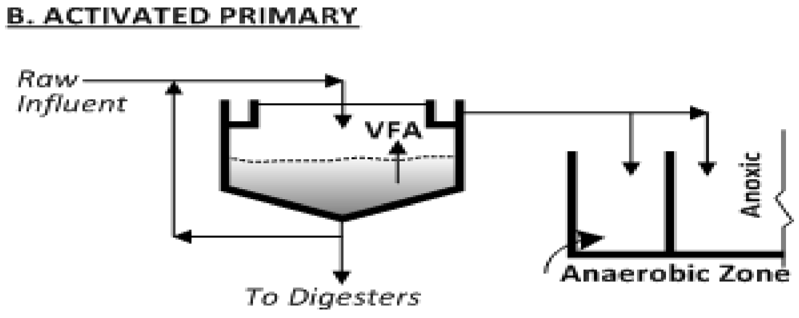
Constructed before Fuhs & Chen theory was published. Fortunately sufficient VFA in the influent.

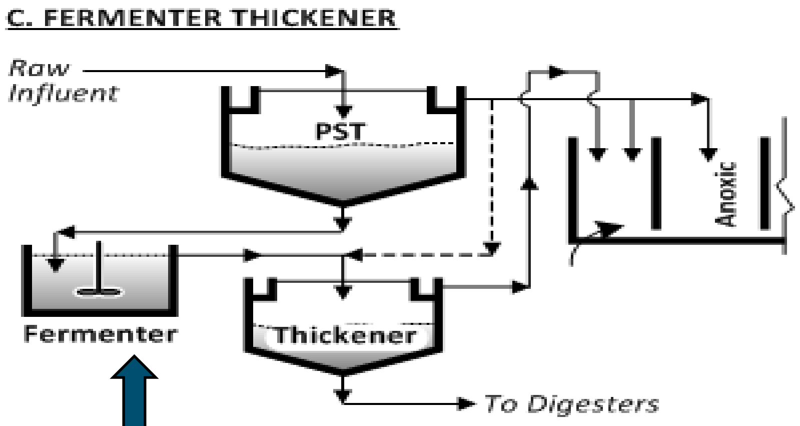
Applying Primary Sludge Fermentation Kelowna B.C.

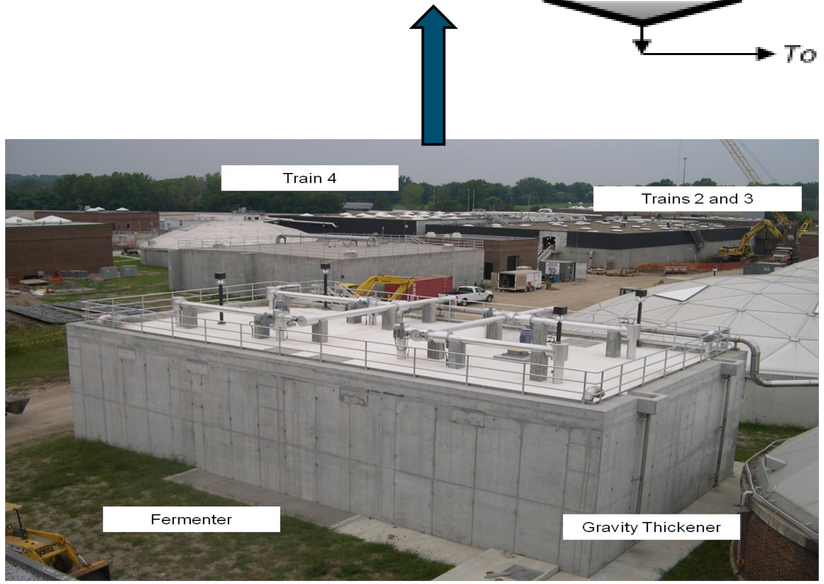
VFA from Fermenters

when not enough VFA in the primary effluent

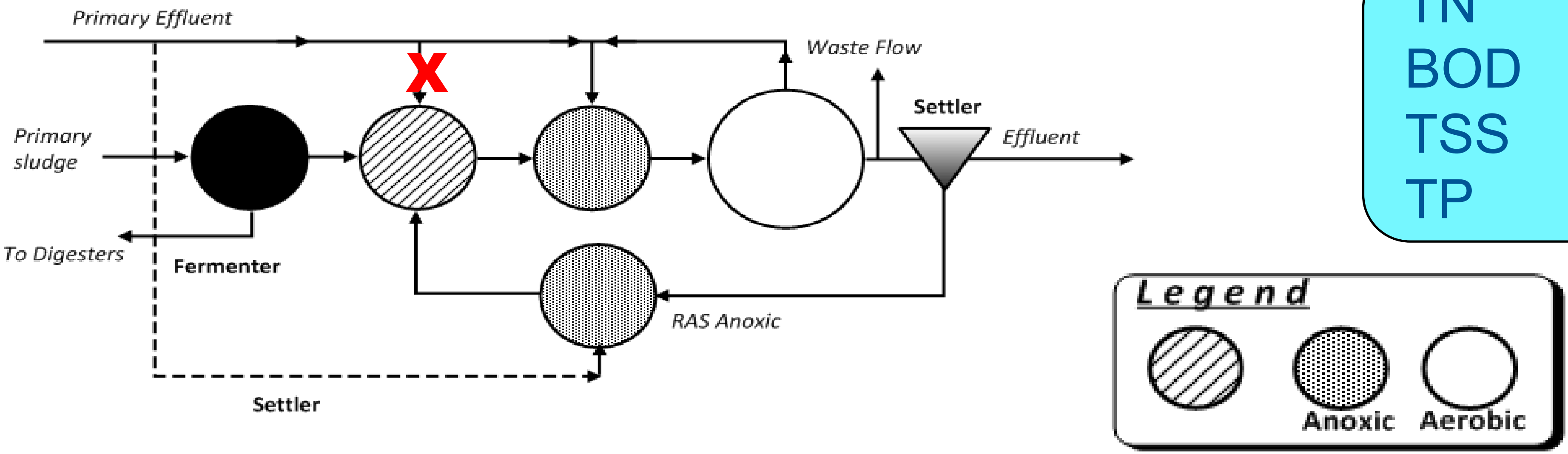






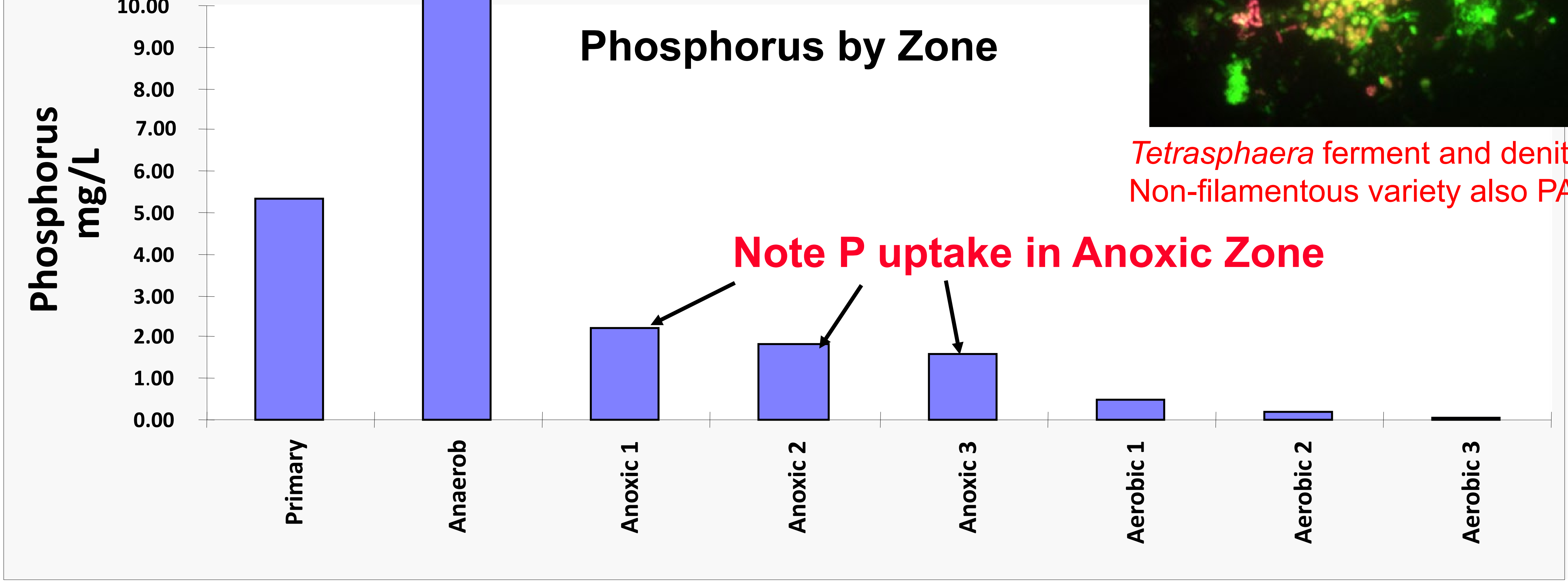


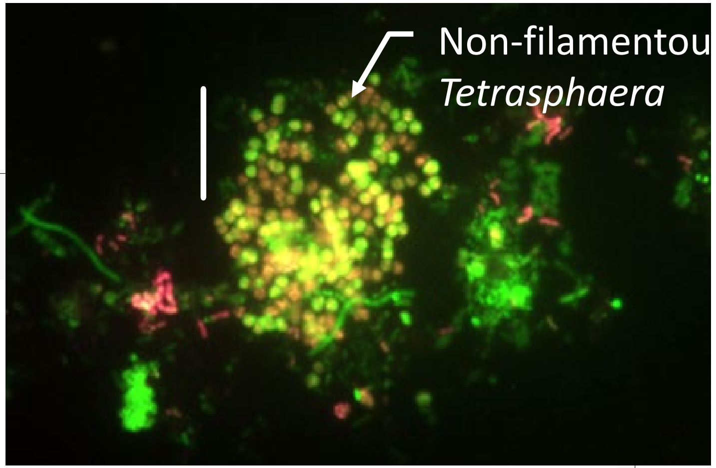
Westside Kelowna BC {Westbank}



TN	< 6 mg/ℓ
BOD	< 5 mg/ℓ
TSS	< 2 mg/ℓ
TP	< 0.15 mg/ℓ

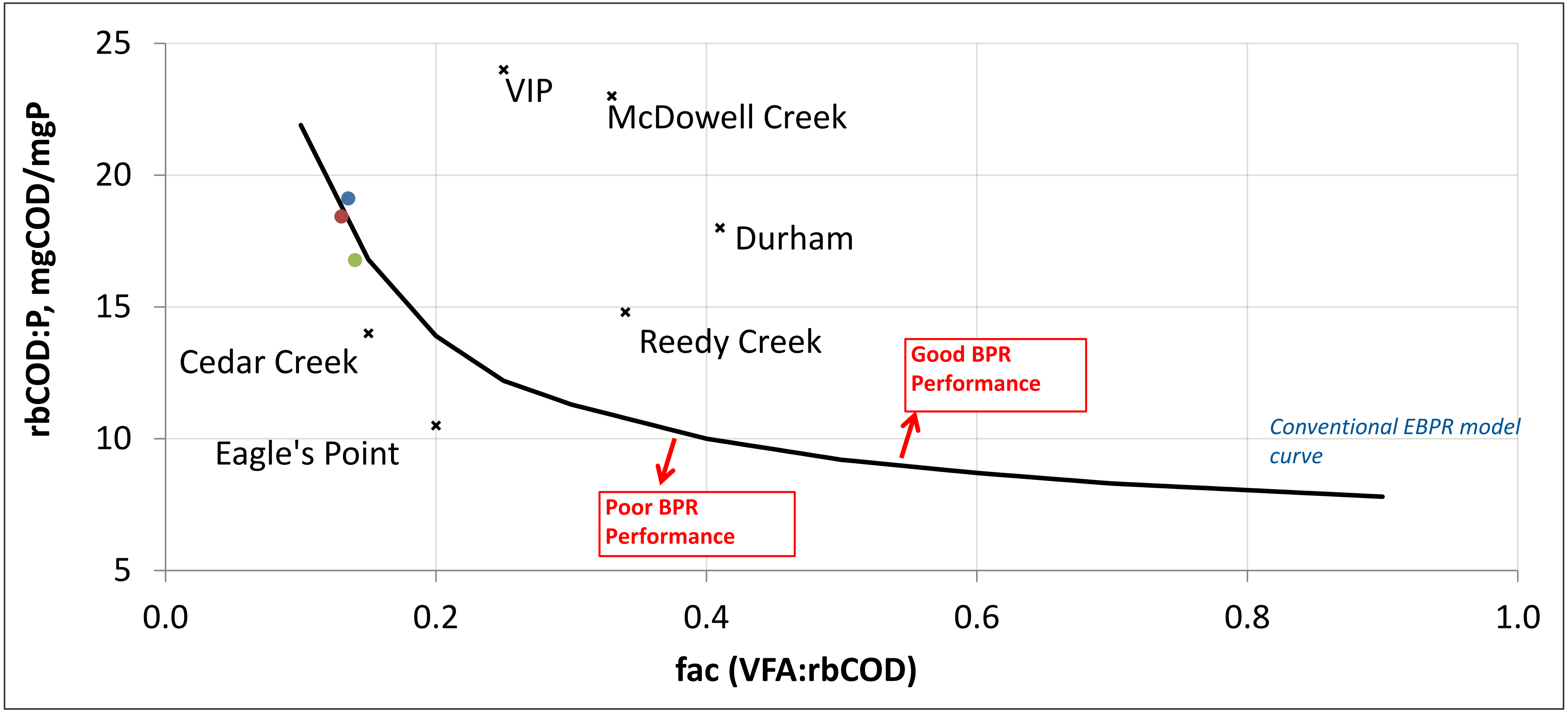
Westside WWTP – Ortho-P Profile through plant





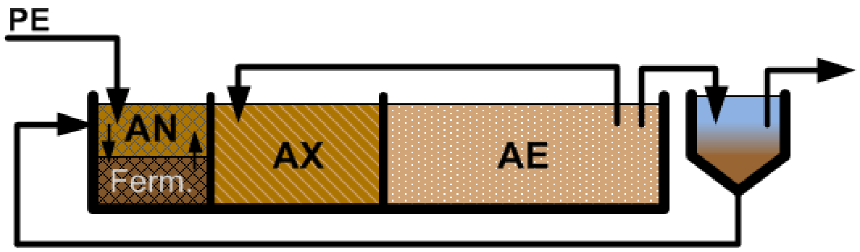
Tetrasphaera ferment and denitrify.
Non-filamentous variety also PAO.

Impact of Influent Characteristics on BPR Performance

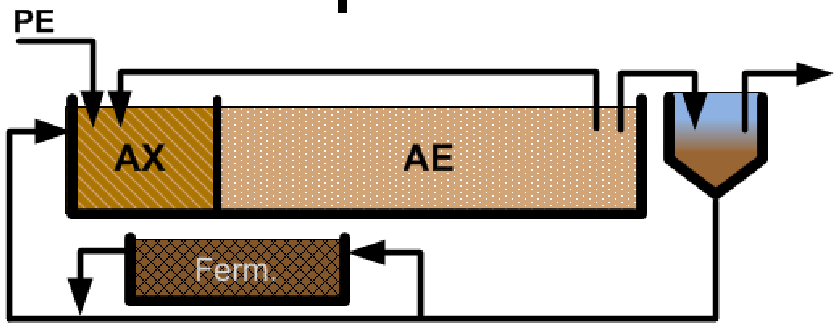


Examples of S2EBPR

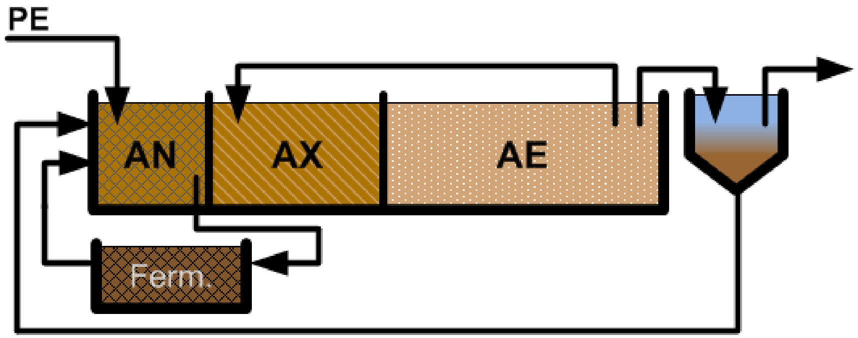
Four Major S2EBPR Process Examples



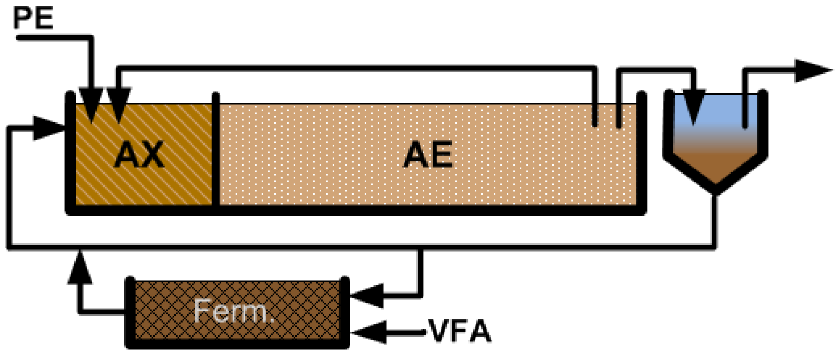
Unmixed In-Line Mixed Liquor Fermentation (UMIF)



Side-Stream RAS Fermentation (SSR)



Side-Stream Mixed Liquor Fermentation (SSM)



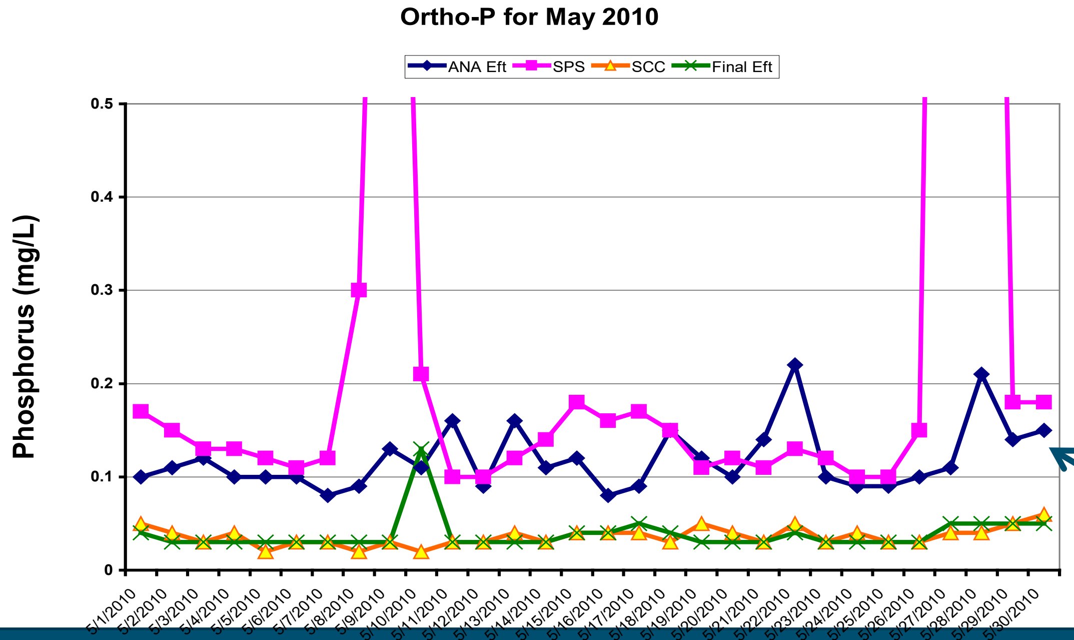
Side-Stream RAS Fermentation w/ Additional Carbon (SSRC)

WERF research team found S2EBPR in 75+ facilities in 10+ configurations

Carousel Plant Henderson NV

16 mgd– Upgraded to BNR

- Adding nitrates for odor control destroyed VFA in the influent
- Switching off a mixer in the anaerobic zone resulted in In-plant Fermentation



Orthophosphates in Final clarifier effluent

Switching off air at MWRDGC

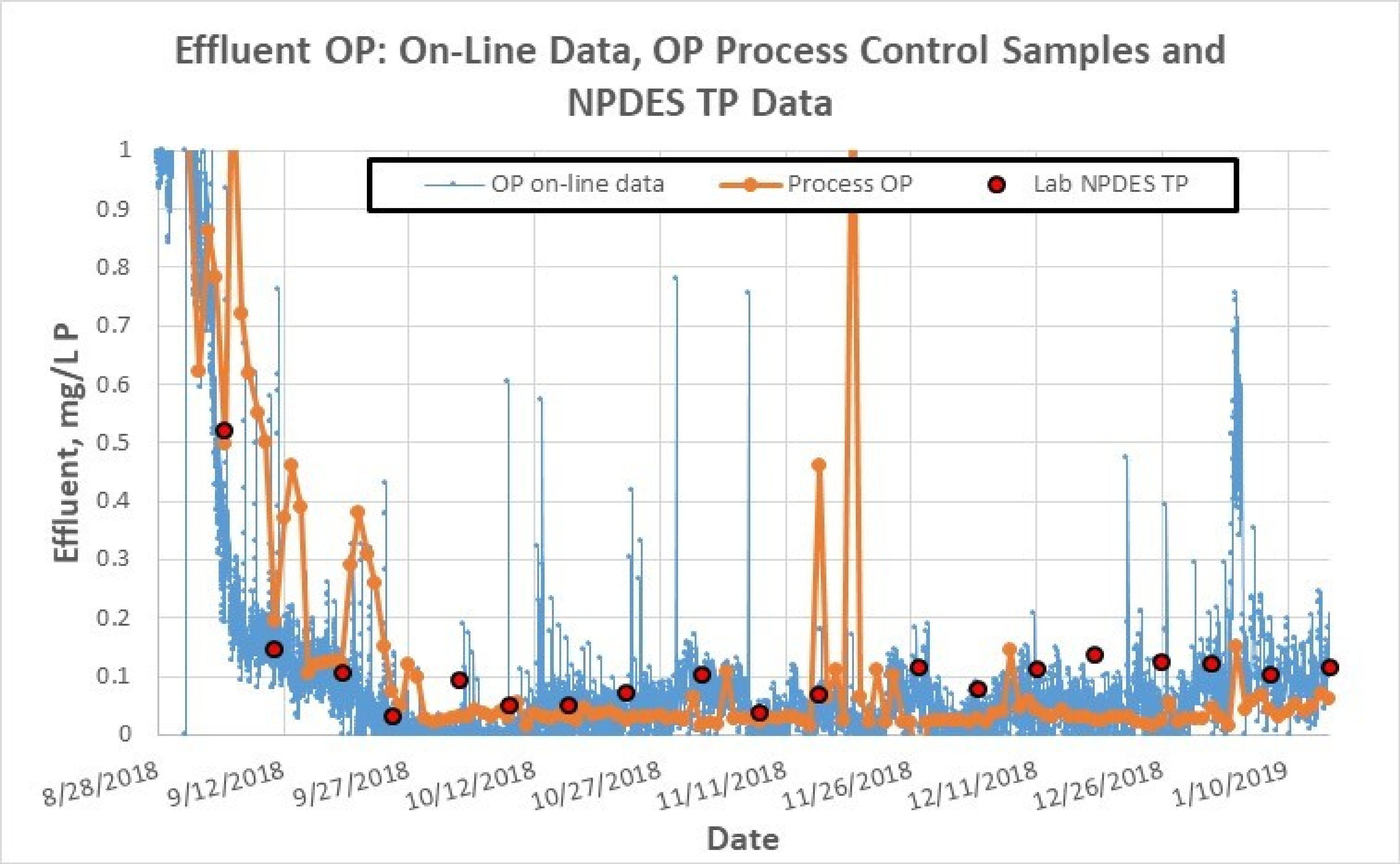
- Flow 800 mgd
- Four pass plug-flow
- Switching off air in half of 1st pass
- Achieving P removal, allowing struvite recovery
- Later discussion

Site of Ostara plant

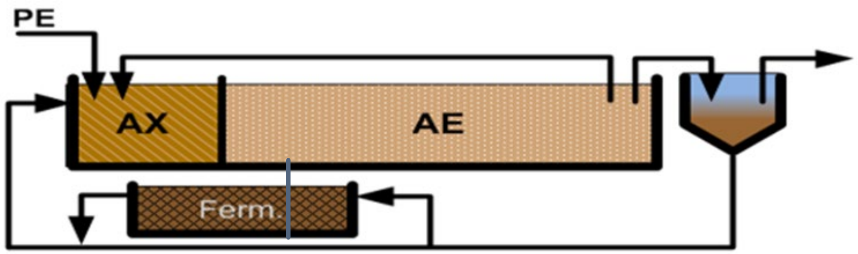
Mixed liquor Fermenter at Wakarusa WWTP (Lawrence, KS)

- Greenfield, Oxidation Ditch Plant
- ADF of 2.5 mgd, peak of 7.5 mgd
- 3-Stage BNR Configuration
- S2EBPR design, MLSS Fermentation
- Plant is heavy with on-line instrumentation: Eff OP, Eff NH3-N, Eff NO3-N, Anoxic inf and eff NO3-N, TSS in oxic zone, anaerobic zone and fermenter

Results of Wakarusa plant using S2EBPR

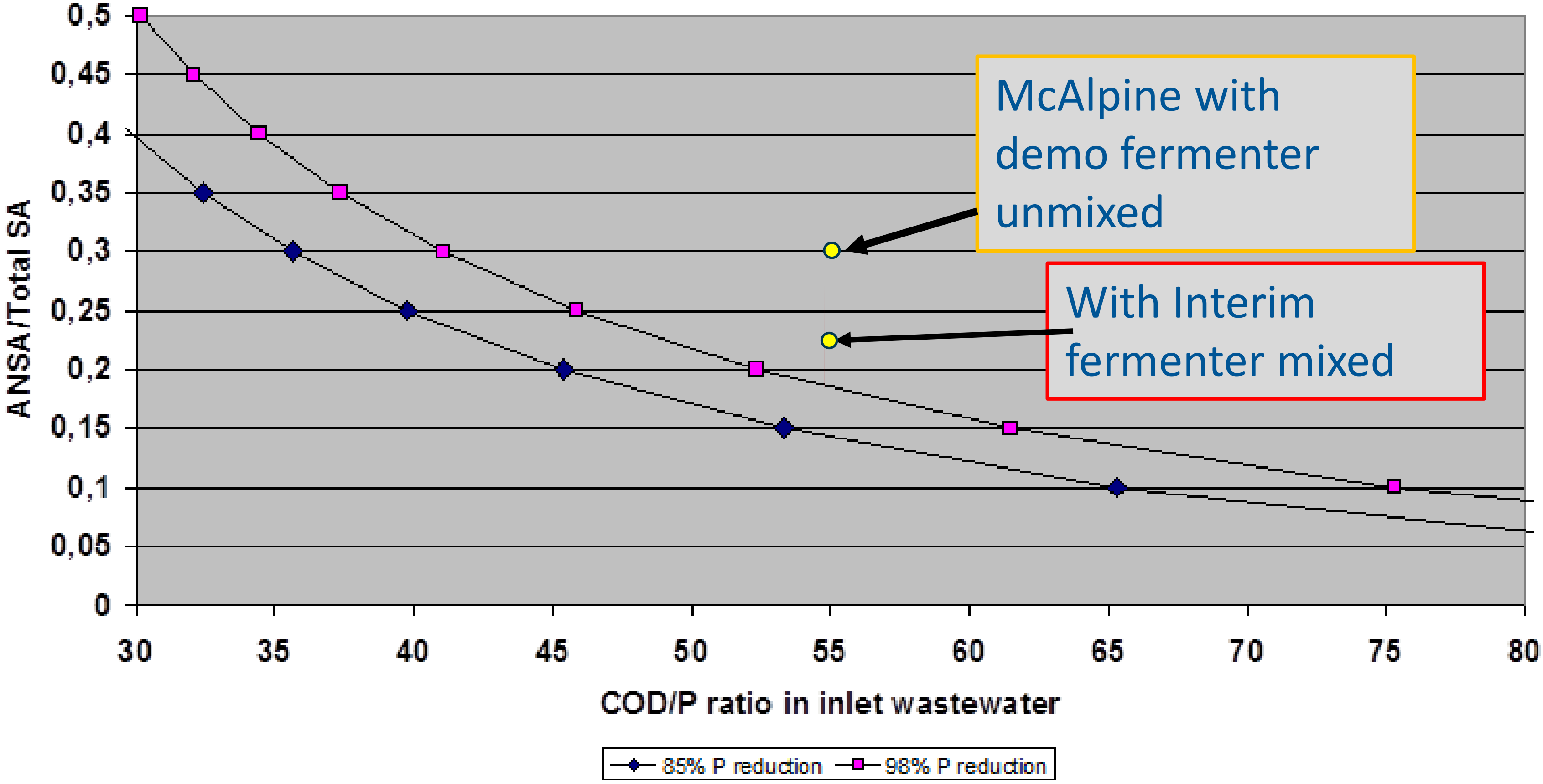


Danish Approach



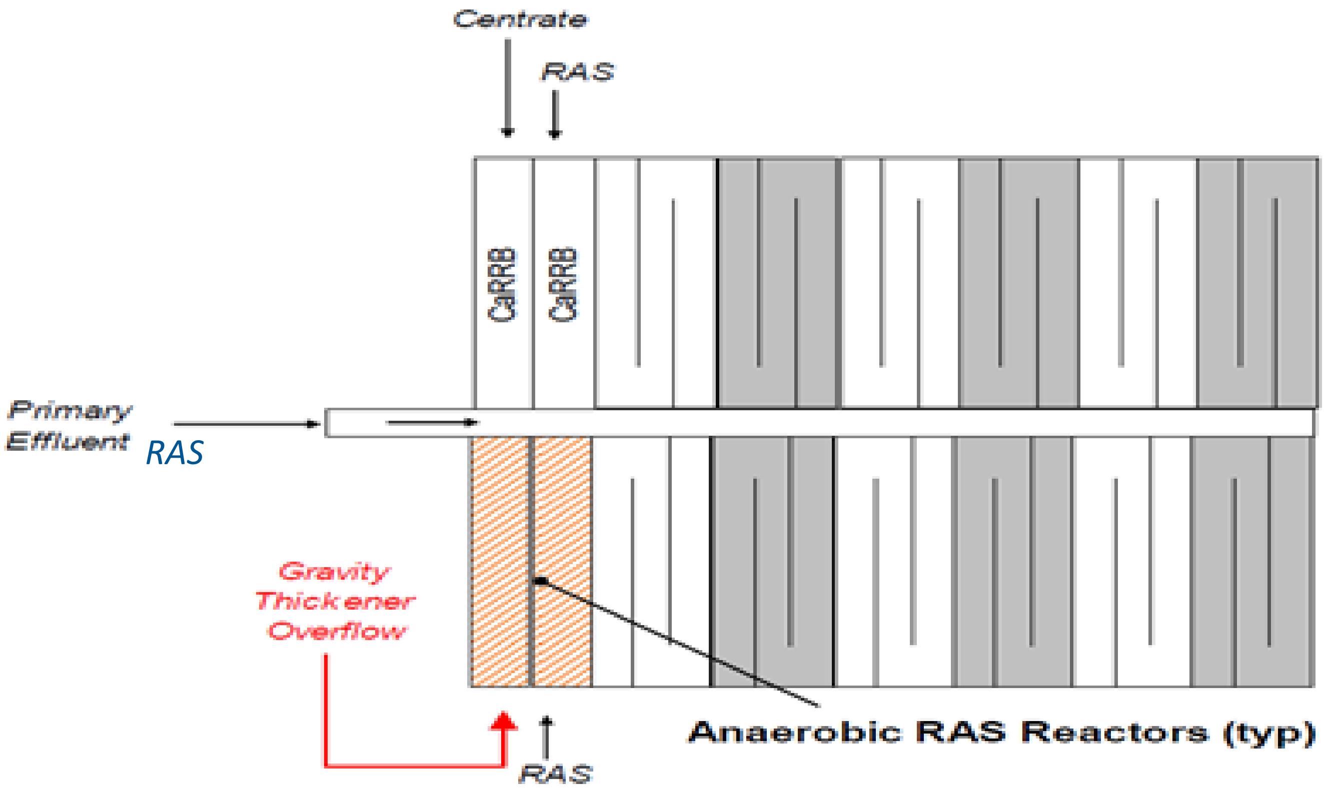
Side-Stream RAS Fermentation (SSR)

Neccesary ANSA for BIO-P plants yielding 85 to 98% P reduction



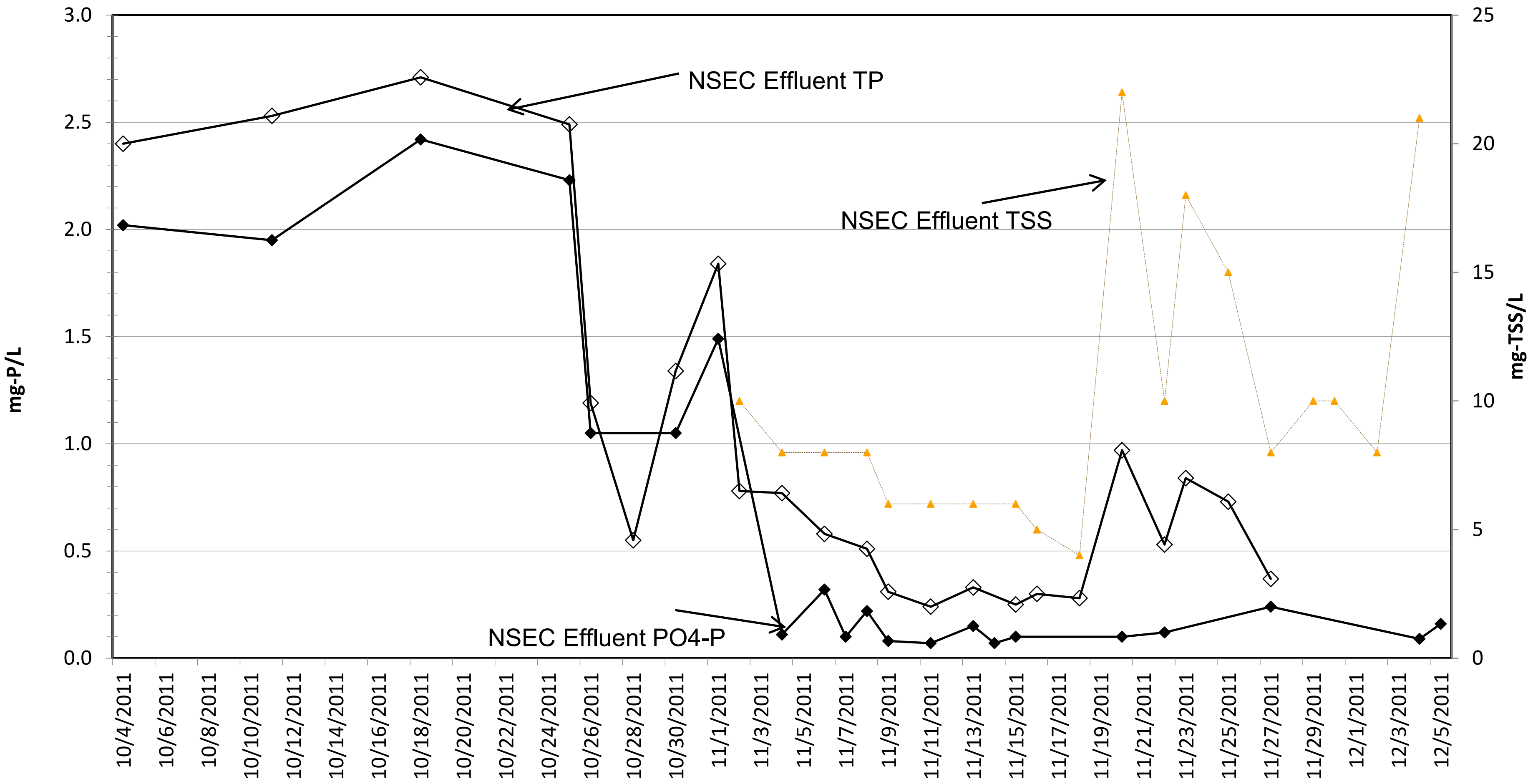
Experiment at Denver Metro*

- 100 mgd plant
- Used two existing CaRRB basins 5% of MLE basin volume
- Installed six top entry slow speed mixers – plug-flow effect
- No surface air entrainment
- Added gravity thickener overflow to 18% of RAS



*Cavanaugh, L., Carson, K., Lynch, C., Phillips, H., Barnard, J. and McQuarrie, J. (2012) A Small Footprint Approach for Enhanced Biological Phosphorus Removal: Results from a 106 mgd Full-Scale Demonstration. *Proceedings of the 85th Annual Water Environment Federation Technical Exhibition and Conference*, New Orleans, LA, October 2012.

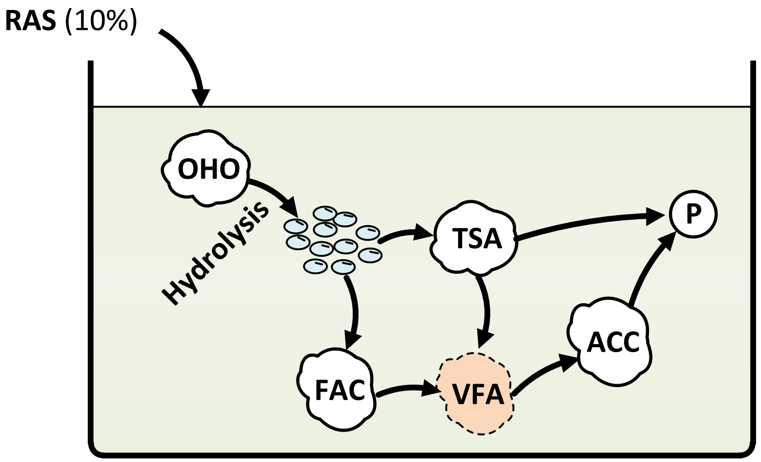
Phosphorus Removal by RAS Fermentation – Denver Metro

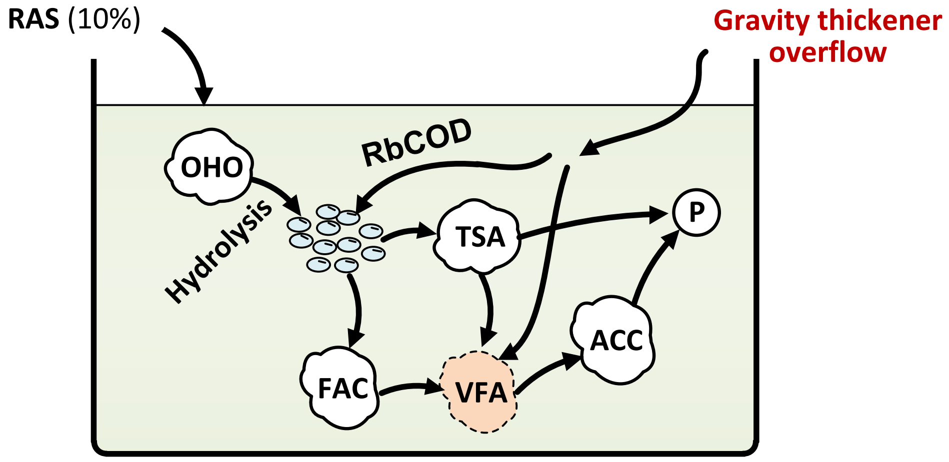


Cavanaugh, L., Carson, K., Lynch, C., Phillips, H., Barnard, J. and McQuarrie, J. (2012) A Small Footprint Approach for Enhanced Biological Phosphorus Removal: Results from a 106 mgd Full-Scale Demonstration. *Proceedings of the 85th Annual Water Environment Federation Technical Exhibition and Conference*, New Orleans, LA, October 2012.

Advantage of Adding Carbon Source

- **Cavanaugh demonstrated that adding gravity thickener overflow (rbCOD) made it possible to use only 12 h SRT in fermenter**





OHO – other heterotrophic organisms. FAC – facultative bacteria TSA – Tetrasphaera, ACC – Accumulibacter

1.5 d to 2 d SRT for RAS only 12 h when feeding fermentate – Why?

What we know about S2EBPR

- Carbon is still driving the process so COD/P ratio is important.
- We are still studying the effect of temperature and pH on the process
- The nitrate concentration in the RAS is important - requires denitrification step ahead of SS fermenter
- Plants performing at lower temperature and using primary sludge fermentation seem to gain from lack of fermentation the collection system which results in more fermentable primary sludge but them needs longer SRT 2 to 4 days. Kalispell MT is doing well at winter temperature of 12°C
- With 10% of RAS and gravity thickener overflow to side-stream fermenter and a ratio of anaerobic SRT/Total SRT of more than 20% proved adequate

S2EBPR (continued)

- When using mixed liquor fermentation, take 10% of flow out of end of anaerobic zone to fermenter.
- Advantage of mixed liquor fermentation is some adsorbed COD that is fermentable – especially when no primary settling tanks
- Design for 2-day anaerobic SRT with mixers on or off
- Apparent lowering of SVI
- Guideline for anaerobic SRT/total SRT follow the Peterson curve shown previously which relates the anaerobic SRT fraction with the influent COD/P ratio

"Live" Interaction Using Menti Meter

Go to:	menti.com
Enter Code:	9616 0848

Follow cues on your device screen

Remember to SUBMIT your answer

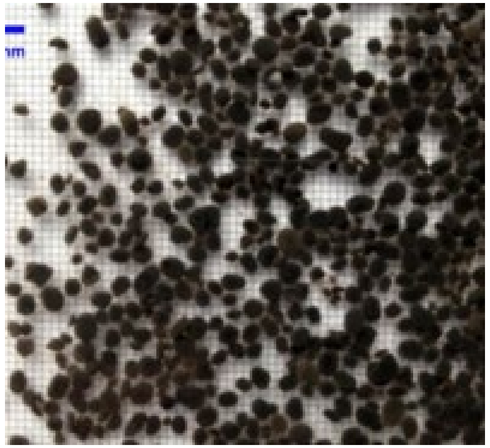
Some questions allow multiple entries

Granulation / Densification

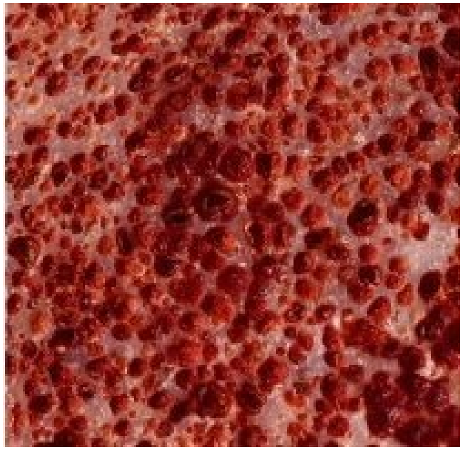
Bryce Figdore

What are granules?

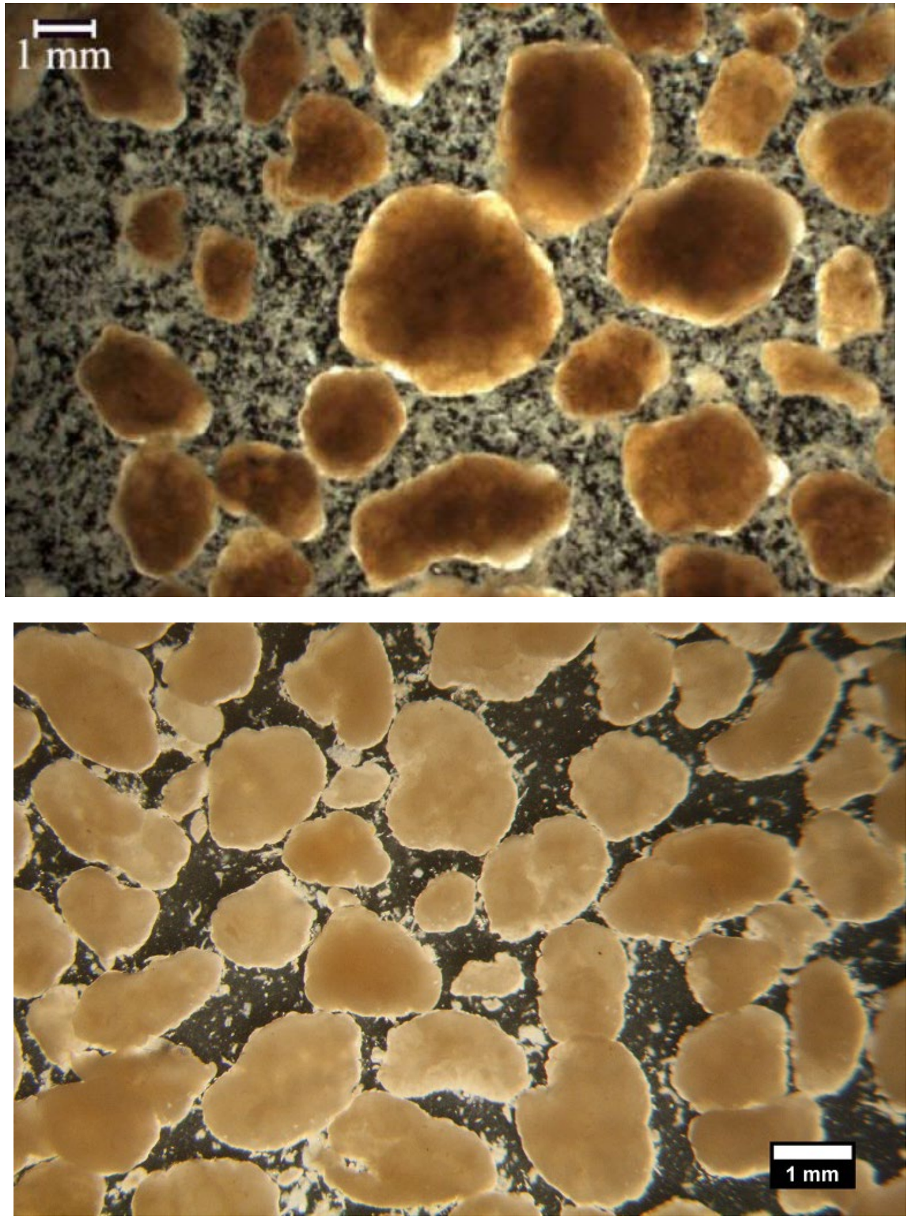
- Microbial biofilms
- Formed without carrier media
- Larger and faster-settling than flocs
  - Particle size >200 um
  - SVI_{30min} 30-50 mL/g
  - Discrete settling, complete in 5 minutes



Anaerobic granules



Anammox granules



Aerobic Granular Sludge (AGS)

What is densified activated sludge (DAS)?

- Activated sludge possessing granule-like attributes but not fully granular
- SVI_{30min} 50 to 100 mL/g
- Smooth, dense floc morphology
- Particles generally smaller but may include fraction >200 um
- May provide similar benefits as AGS with less extensive retrofits in flow-through systems

Optimization potential with granular/densified sludge

- Improved settling characteristics
- Increase design MLSS concentration
- Less tank volume – smaller footprint
- Increase capacity
- Biological nitrogen and phosphorus removal

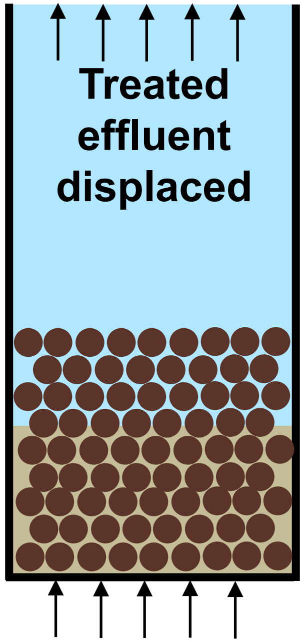
Selective Pressure Categories

1. Biological – must have
2. Physical – bonus for larger particles

Feeding regime and reactor kinetics provide fundamental biological selection for granule growth

1. High F/M anaerobic contacting → selects PAOs/GAOs for rbCOD uptake and drives diffusion to inner layer
2. Batch or plug-flow kinetics → feast-famine induces cell aggregation and EPS production

Nereda® SBRs



Slow upflow plug-flow anaerobic feeding through settled sludge bed

Well-Demonstrated

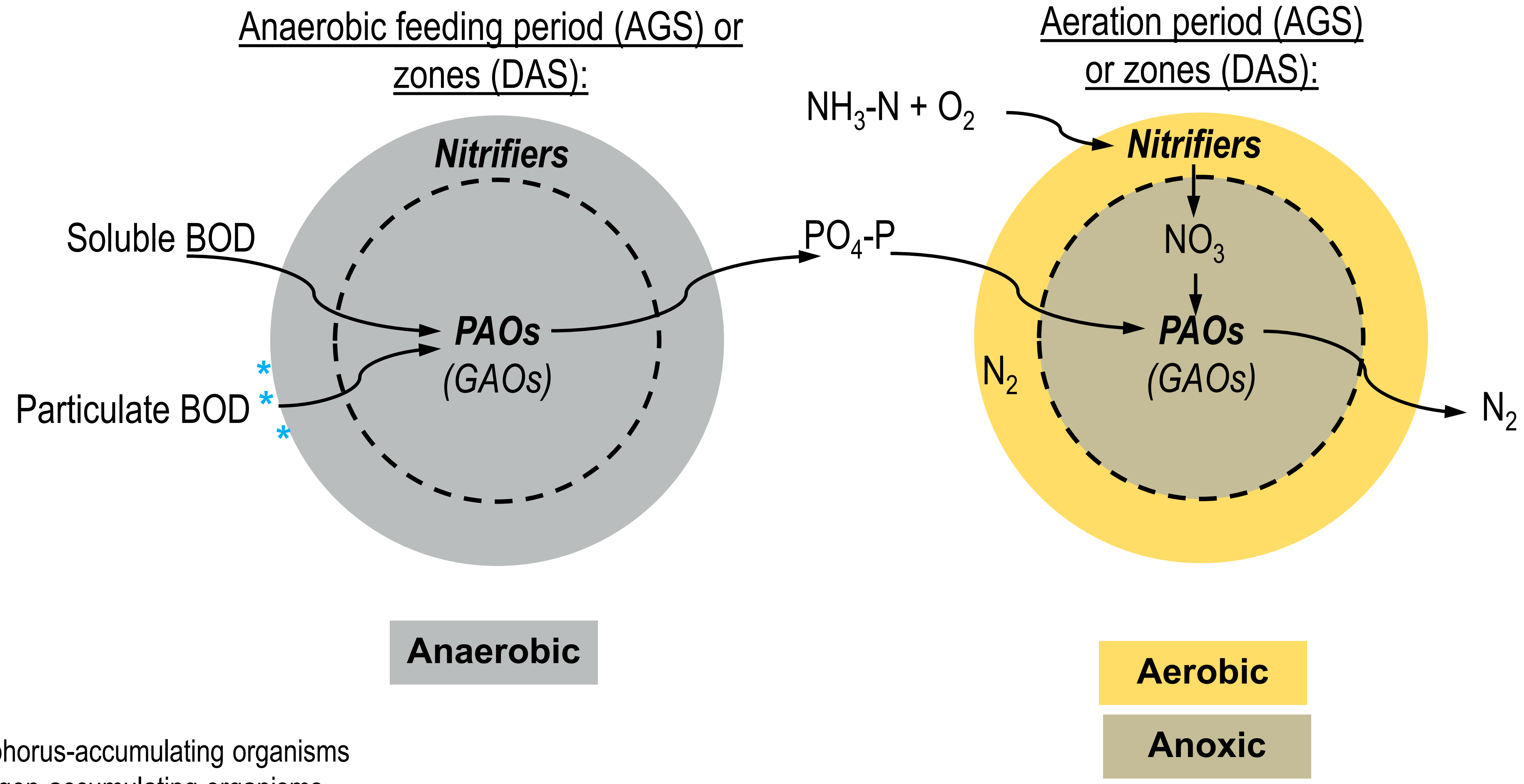
Continuous flow systems:

Ongoing development

Toolbox:
- **Staged anaerobic selectors**
- **Plug-flow reactors**
- **RAS/MLSS fermentation**
- **RAS denitrification**

Selection pressure not as strong as bottom-fed SBRs

Nutrient Removal goes hand-in-hand with biological selection for AGS/DAS



Simultaneous nitrification-denitrification (SND) with EBPR

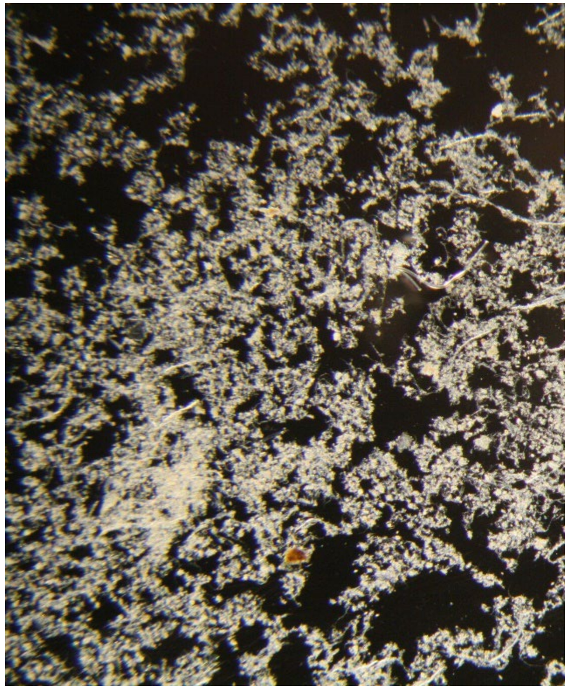
and/or

Storage-driven denitrification (may include anoxic zones)

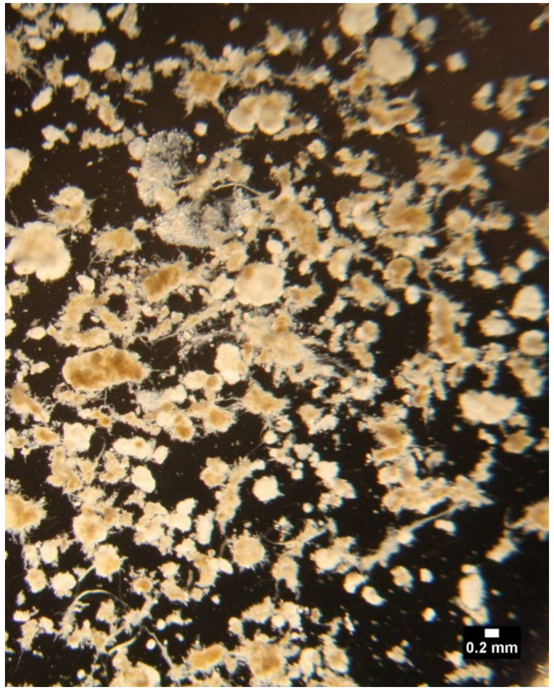
PAOs = phosphorus-accumulating organisms
GAOs = glycogen-accumulating organisms
EBPR = enhanced biological phosphorus removal

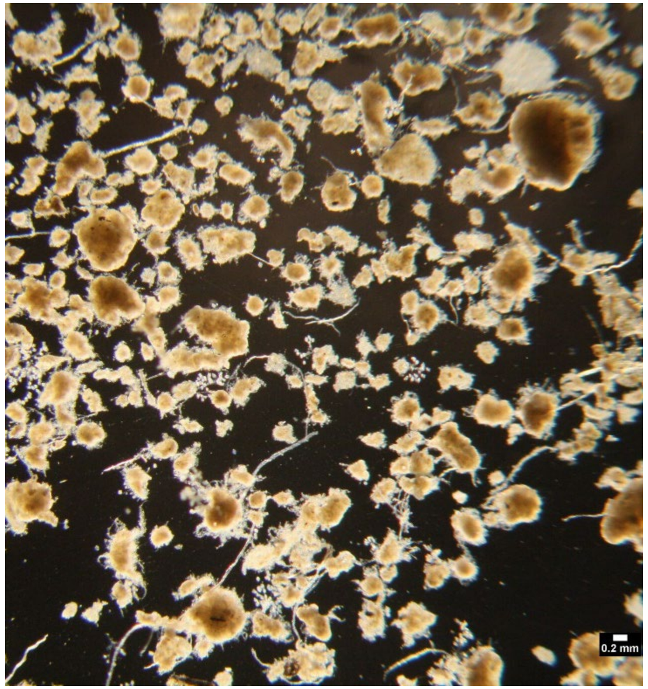
Densified Activated sludge Continuum

Increasing densification *Fully Granular*

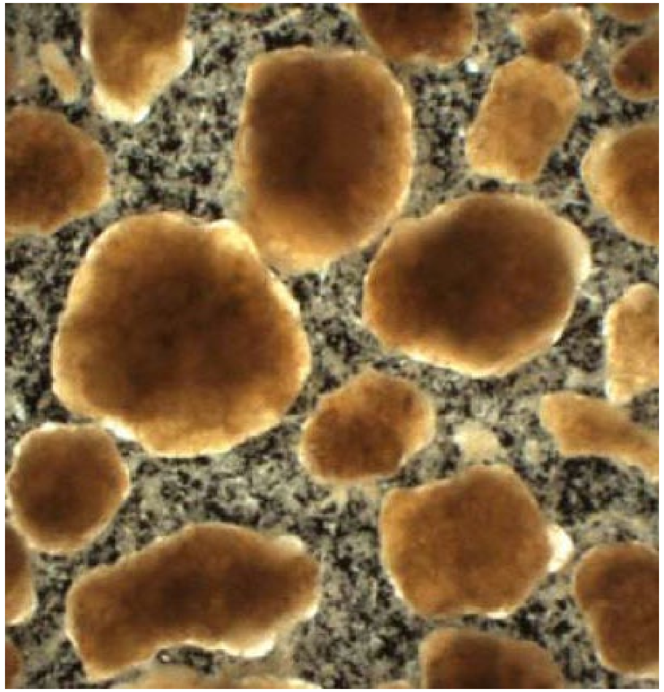


Conventional Sludge:
SVI >100
Few particles >200 um





Densified sludge: SVI ~50 to 90
May contain some granules >200 um
No physical selection
Larger particles enriched with PAOs/GAOs (Wei et al., 2019)



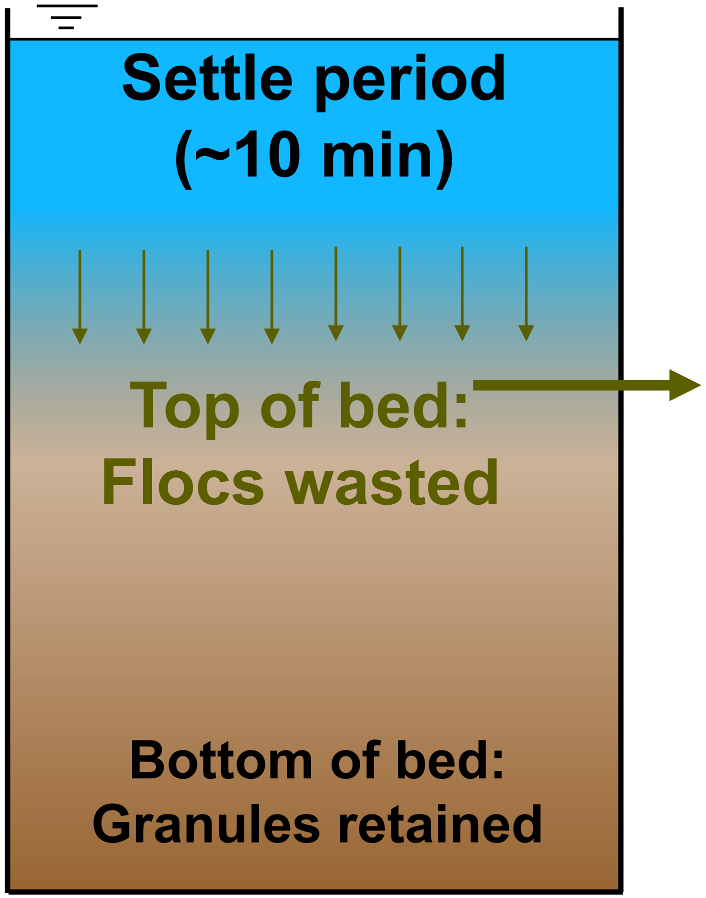
Granular sludge: SVI <50
>80% MLSS mass >200 um

Selective wasting provides fundamental physical selection for larger, faster settling granules over flocs

Nereda® SBRs (and lab SBRs):

- Short settling times in SBRs
- Slower-settling flocs and GAOs selectively wasted
- Largest granules on bottom of bed have **preferential access to food** during upflow feeding

Well-Demonstrated



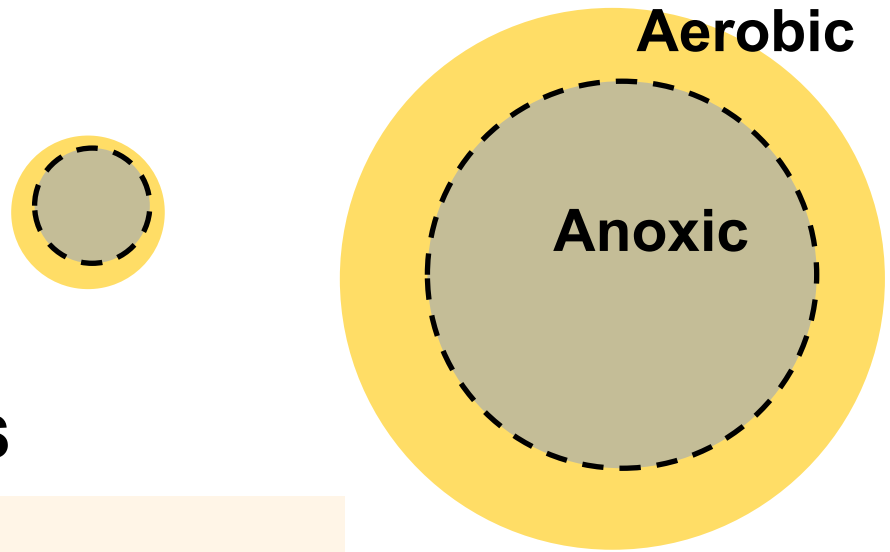
Continuous flow systems:

Ongoing development

Toolbox:

- inDENSE WAS cyclones
- Sieves/Screens
- Gravimetric selectors
- Surface wasting

AGS/DAS Particle Size Affects Operating Conditions for SND and Presents Optimization Potential



	DAS	AGS
Particle size:	Smaller	Larger
Specific surface area:	Higher	Lower
DO concentration for nitrification and SND:	Lower	Higher

Takeaways

- Granular and densified sludge present optimization opportunities.
- Granulation principles can be applied to achieve densified sludge in flow-through reactors.
- Biological selection is the cornerstone and sufficient to achieve densified sludge.

"Live" Interaction Using Menti Meter

Go to:	menti.com
Enter Code:	9616 0848

Follow cues on your device screen

Remember to SUBMIT your answer

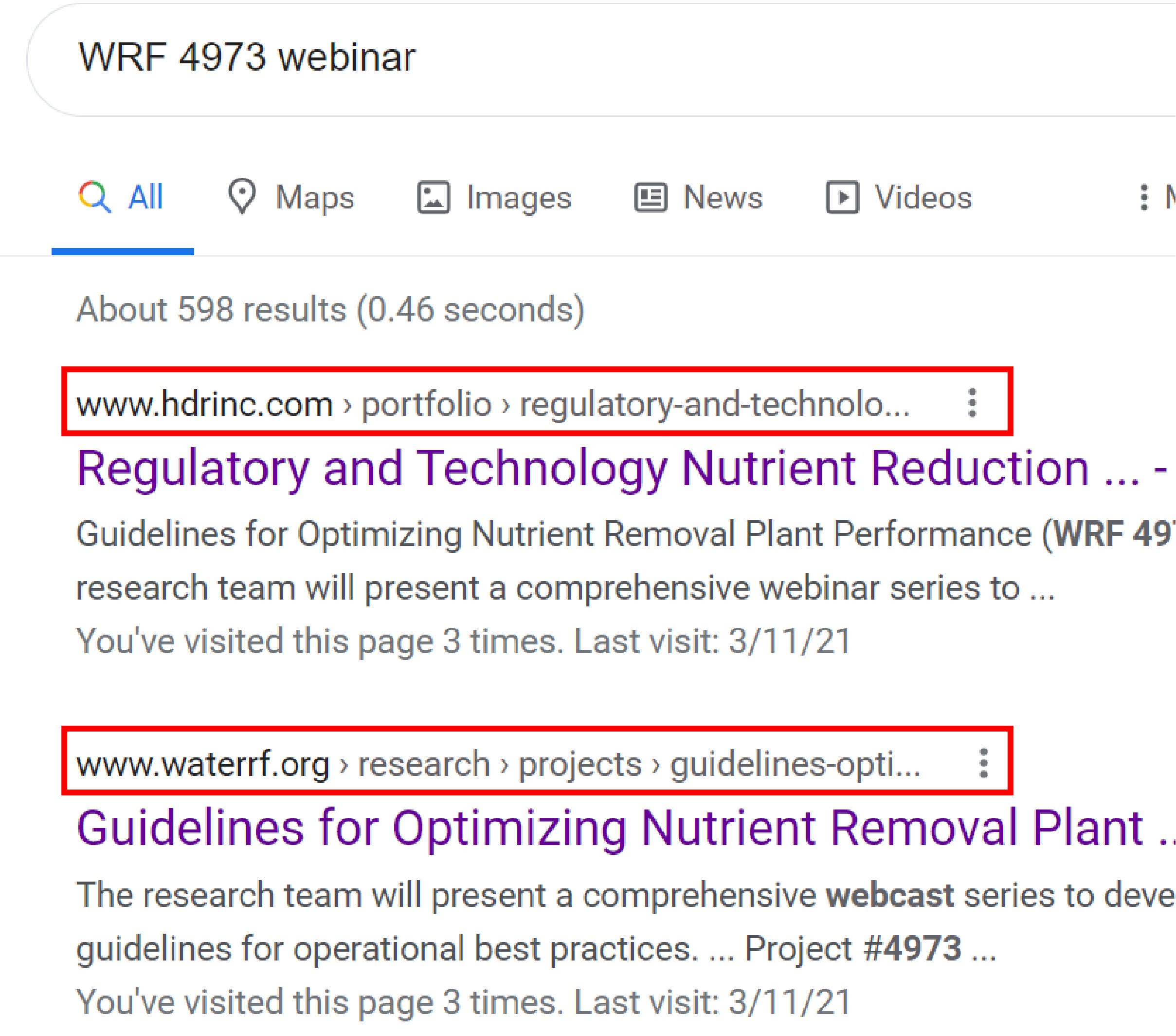
Some questions allow multiple entries


Closing

JB Neethling

WRF 4973 – Upcoming Webinars

- Approximately every 2 weeks, Wednesday noon ET (9 PT)
- Emerging Technologies for Nutrient Optimization – 3/31/21
- Beyond Liquid Treatment: Reduce Nutrient Discharge Loads by Other Means – 4/14/21
- <u>Search:</u> WRF 4973 webinar



Questions

Thank you

Comments or questions, please contact:

Stephanie Fevig: sfevig@waterrf.org

For more information, visit www.waterrf.org