BUILDING A WORLD OF DIFFERENCE

Process Optimization – A New Approach with Old Infrastructure

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BLACK & VEATCH

Facility Challenges

- Increasing Effluent Quality
  - NH4 < 2.0 mg N/L
  - TP < 0.5 mg P/L
  - Total Nitrogen < 10 mg N/L
  - BOD < 5.0 mg/L
- BNR Facilities -> Increased O&M
  - Energy Demand
  - Chemicals
  - Space
  - Instrumentation
- Aeration Energy at BNR Facilities
  - 30-60% of total energy consumption

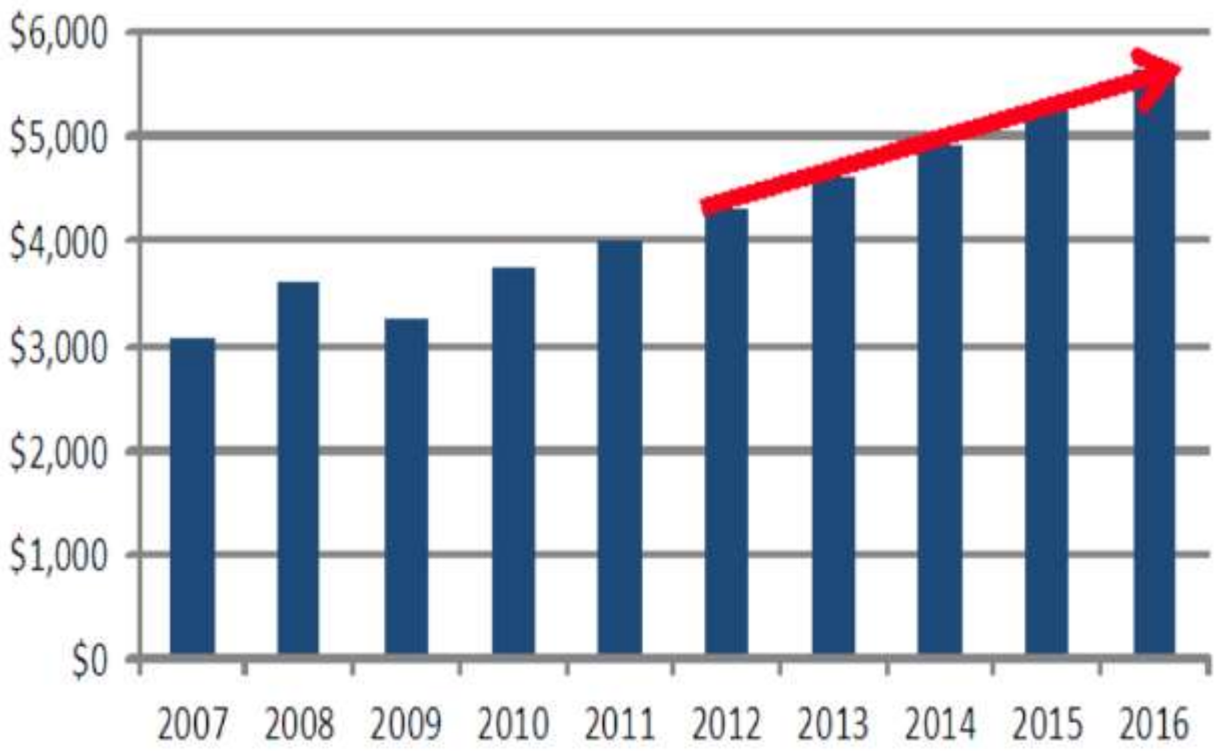


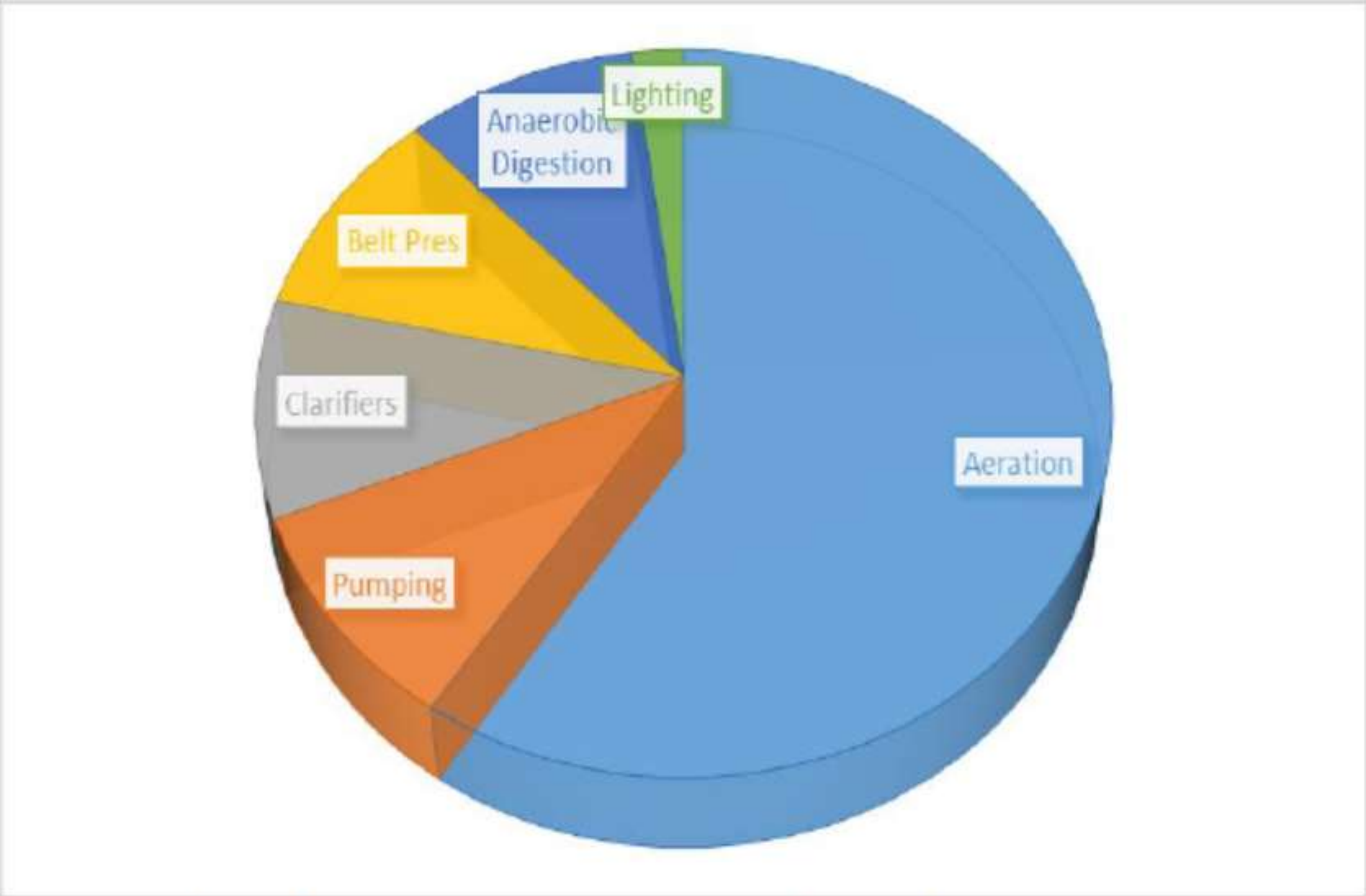
Figure 1-1. U.S. Water and Wastewater Utility Energy Costs (USD Millions).

WERF – Guide to Net-Zero Energy Solutions for Water Resource Recovery Facilities

Can you have optimum treatment performance AND lower O&M requirement?

WERF – Guide to Net-Zero Energy Solutions for WRRFs

- Best Practices – 40% lower energy consumption compared to "typical" performance
- Improved primary treatment, thickening, and dewatering most significant positive impact
  - More concentrated energy available for recovery
  - Less secondary capacity required for BOD, TSS, TKN
- Significant energy savings with reduced fouling of diffusers
- Digestion with CHP most advantageous for recovery
  - Co-digestion significant gains in recovery
- Odor control – significant energy requirements
- Low DO w/ SND achieved 80% energy neutrality at MBR facilities



Graph 1 : Energy Consumption Distrubition in WWTP, (EDI, 2011)

Fine Tuning Aeration to Provide Energy Savings….anything else?

- Simultaneous nitrification/denitrification (SND)
  - Recover alkalinity
  - Beneficial carbon removal
- Over-aerating can cause poor settling – DO >> 3 mg/L
  - Floc breakup and pin floc
- Internal recycle flows
  - Low DO to anoxic zones

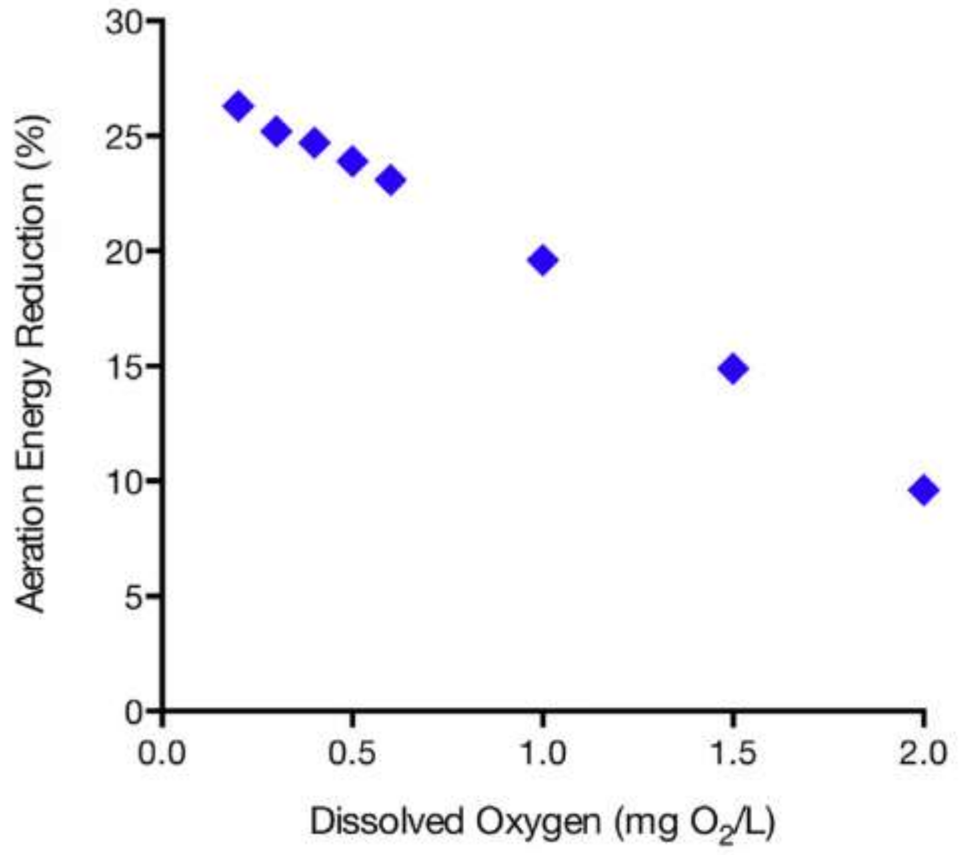


Fig. 11. Estimated energy use reductions at the Nine Springs WWTP for 8 different DO scenarios.

Water Research; Keene et al., 2017

Can we operate with DO concentrations of 0.3-1.5 mg/L?

History of Activated Sludge and Aeration

1800s-1900s
- 1913 Activated Sludge coined
- 1916 San Marcos

20s-50s
- Recognized as Biological
- AS Widespread
- Tapered and Step Aeration

60s-70s
- Reno, Nevada 1st DO Control
- 1st Instrument and Control Conf.

80s
- Process automation – limited computer use

90s
- Wastewater simulators
- Ion-Selective Membrane Probes

2000s
- Optical DO Probes
- Widespread processor application (PLC)

Aeration control provides increased process performance and management of energy

Historical Aeration Approach

- Complete Stirred Tank Reactors (CSTR)
  - Maintain consistent tank concentrations
  - Microbial populations not exposed to substrate gradients
- High SVIs (>300) commonly observed
- "…fully aerobic reactor DO > 2.0 mg/L"

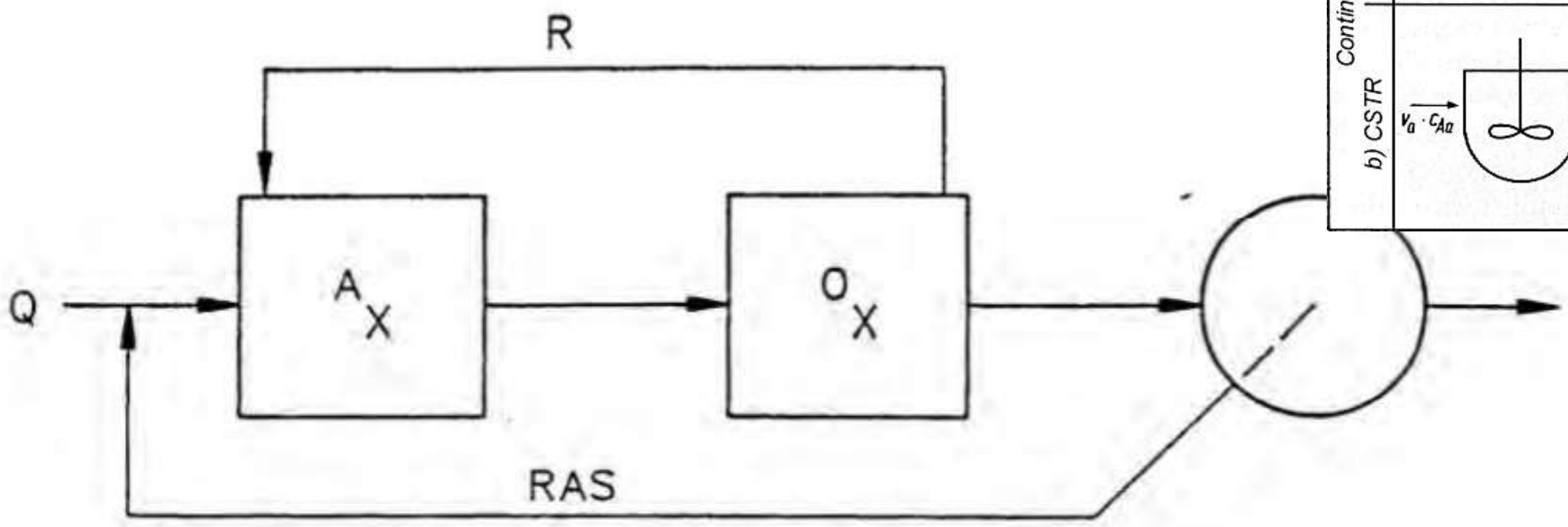
TABLE III. Combinations of COD removal rate and aeration basin dissolved oxygen concentration where bulking and nonbulking sludges occur (completely mixed systems).

COD Removal Rate, *q* (g COD removed/kg VSS/d)	Aeration Basin Bulk DO (mg/l)											
	0.1–0.5	0.5–1.0	1.0–1.5	1.5–2.0	2.0–2.5	2.5–3.0	3.0–3.5	3.5–4.0	4.0–4.5	4.5–5.0	5.0–5.5	5.5–6.0
0.20–0.30	No bulking											
0.35–0.45	Bulking	No bulking										
0.45–0.55		Bulking	No bulking									
0.50–0.60			Bulking	No bulking								
0.60–0.70				Bulking	No bulking							
0.75–0.85					Bulking	No bulking						
0.80–0.90						Bulking	No bulking					
0.95–1.05							Bulking	No bulking				
1.05–1.15								Bulking	No bulking			
1.40–1.50									Bulking	No bulking		
1.50–1.60										Bulking	No bulking	
1.60–1.70											Bulking	No bulking

Palm et al., 1980

Reactor Design Improvements

- Plug Flow Reactors
- Introduction of Bioselectors (1970s)



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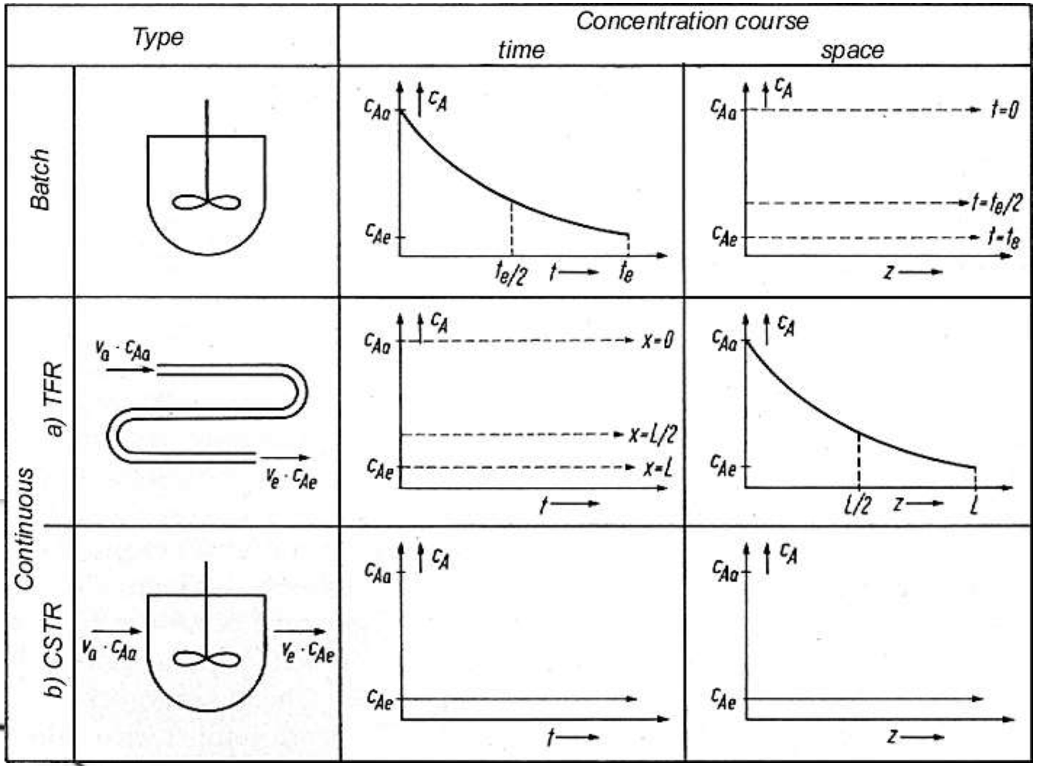
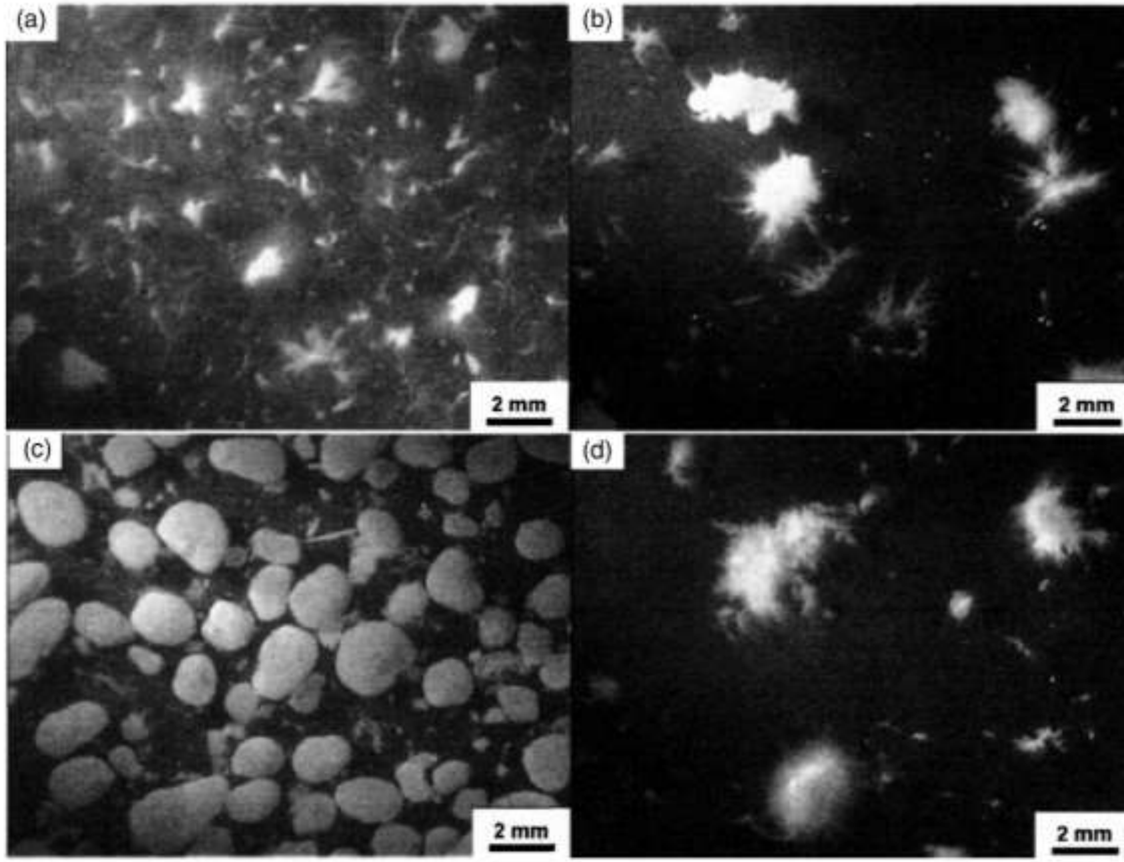


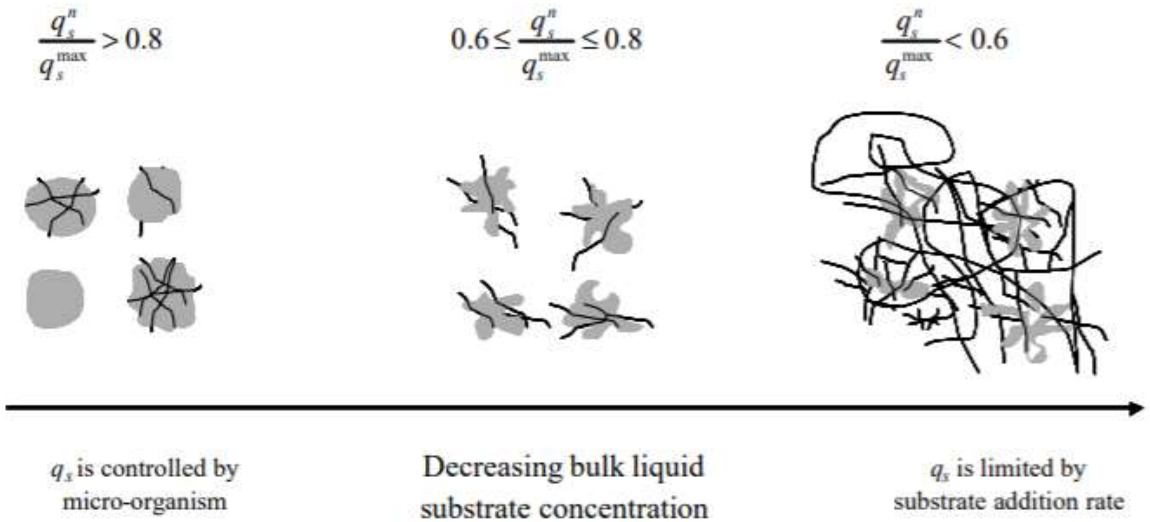
Poor settling sludge led to reactor improvements – nutrient removal was not initial driver

What effect does reactor configuration have on activated sludge settling?

- Most significant impacts to bulking sludge
  - High F/M gradients in a plug flow reactor
  - Anaerobic/Anoxic Zones (Bioselectors)



*Tay et al (2004) Journal of Environmental Engineering **130**(10)*

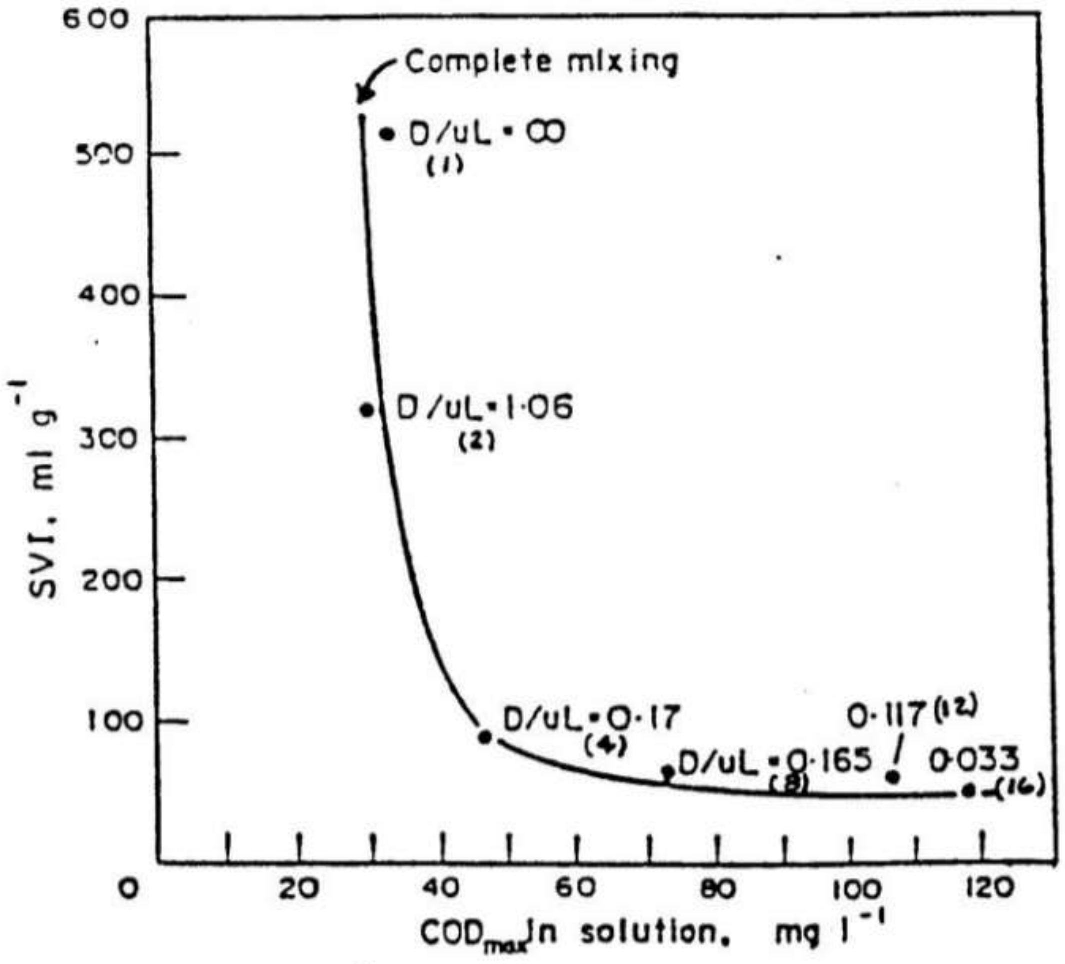


Martins et al., 2003

Obtain Feast and Famine Periods within Activated Sludge Process

What effect did this have on actual settling SVIs?

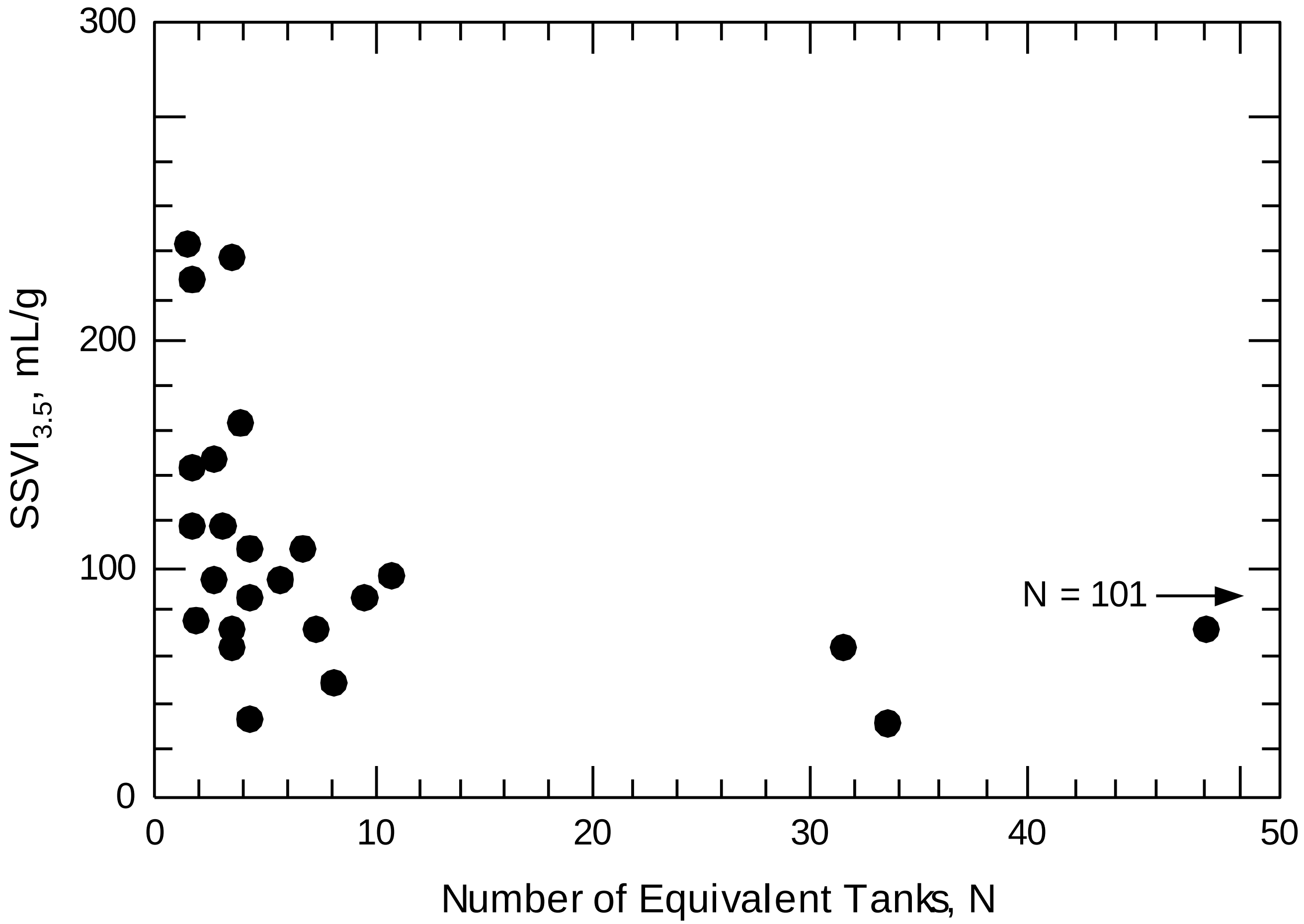
High Food / Microorgansim (F/M)



Relationship of SVI and sCOD in First Compartment of Reactors (1, 2, 4, 8, 12 and 16 Compartments)

Koller et al., 1966

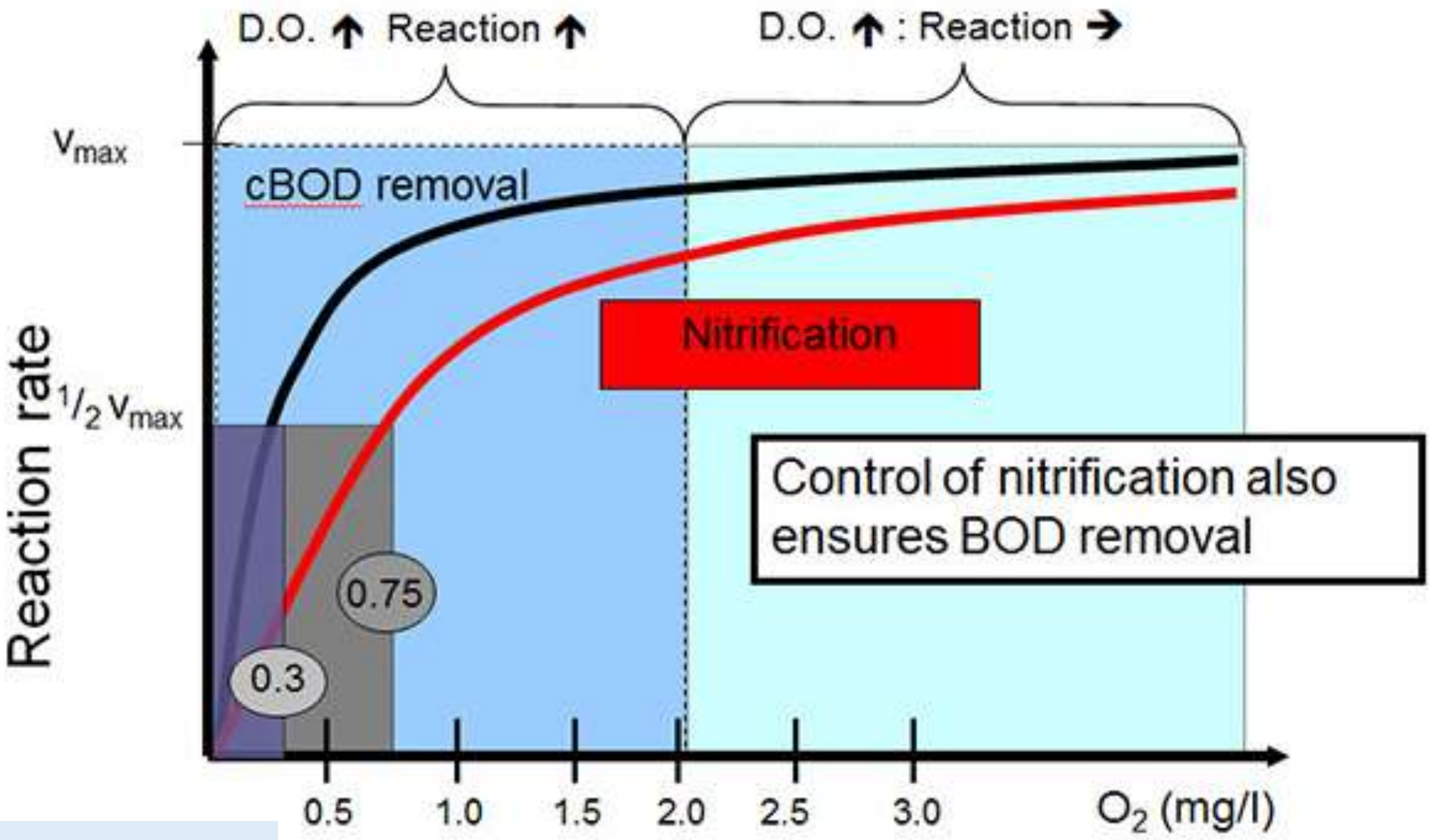
Bioselectors and Plug Flow Reactors

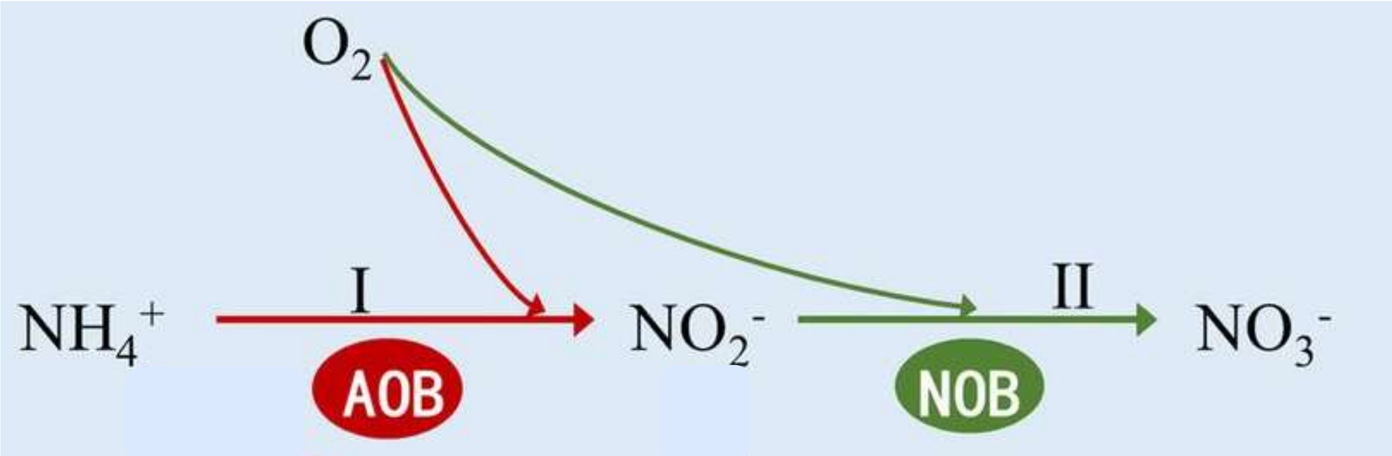


From E. J. Tomlinson and B. Chambers, The effect of longitudinal mixing on the settleability of activated sludge. Technical Report TR 122, Water Research Centre, Stevenage, England, 1978. Reprinted by permission of the Water Research Centre.)

Nitrification kinetics historically drive design and operational decisions

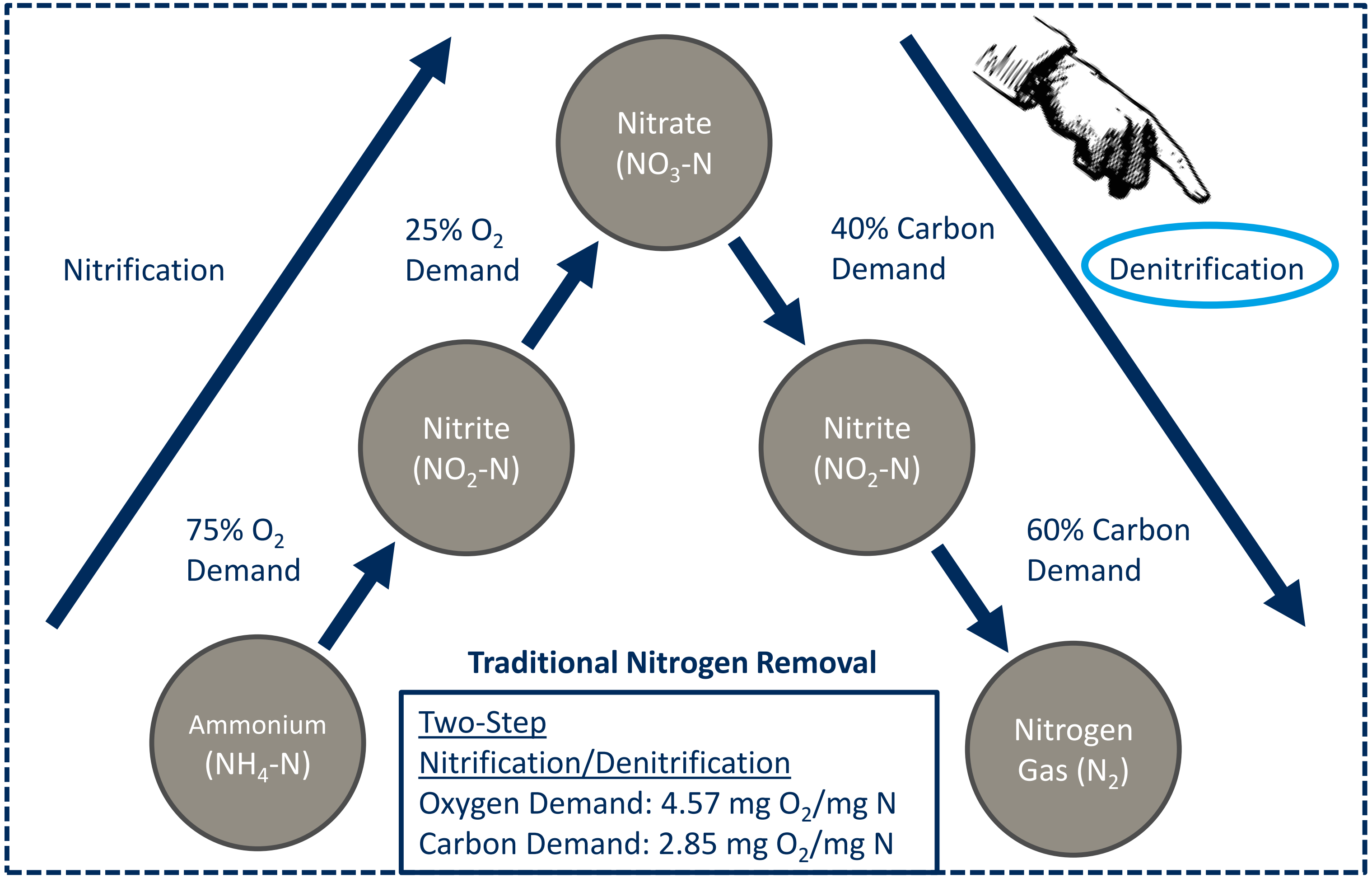
- Reactor design – optimize growth rate
  - Nitrifiers slowest growth rate
- Growth rate of early studies
  - AOB – DO > 2.0 mg/L
  - NOB – DO as high as 4.0 mg/L

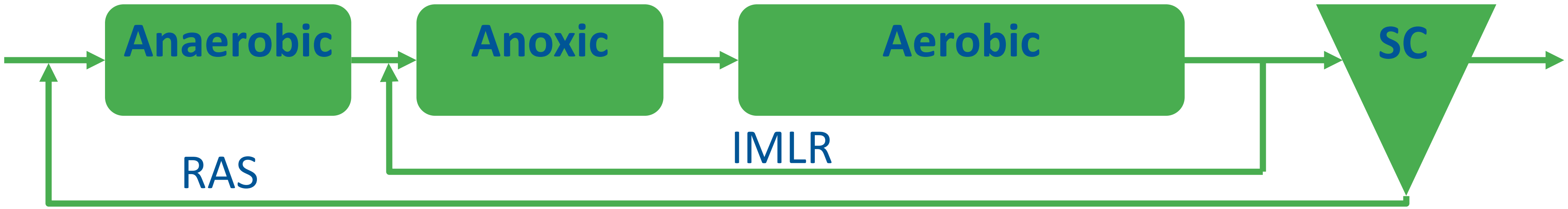




What about denitrification?

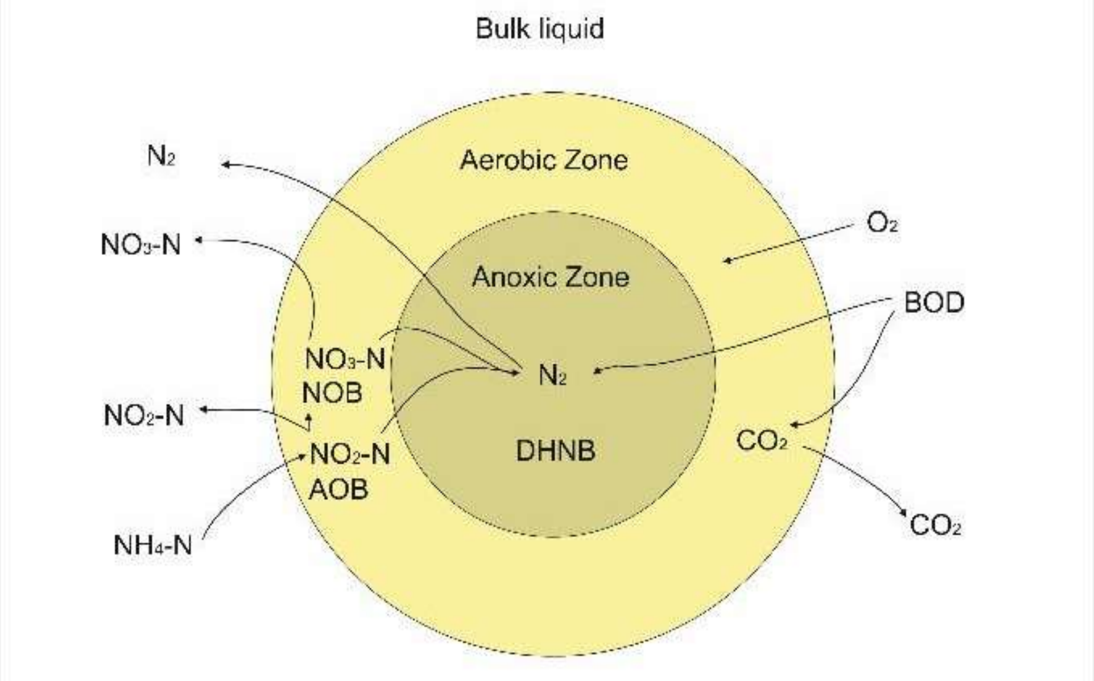
- Traditionally carried out in a step-wise fashion with distinct zones and pumping
- Can we take advantage of denitrification?
  - 2.85 mg O_2/mg N
  - OR 2.85 mg BOD to remove 1 mg of N

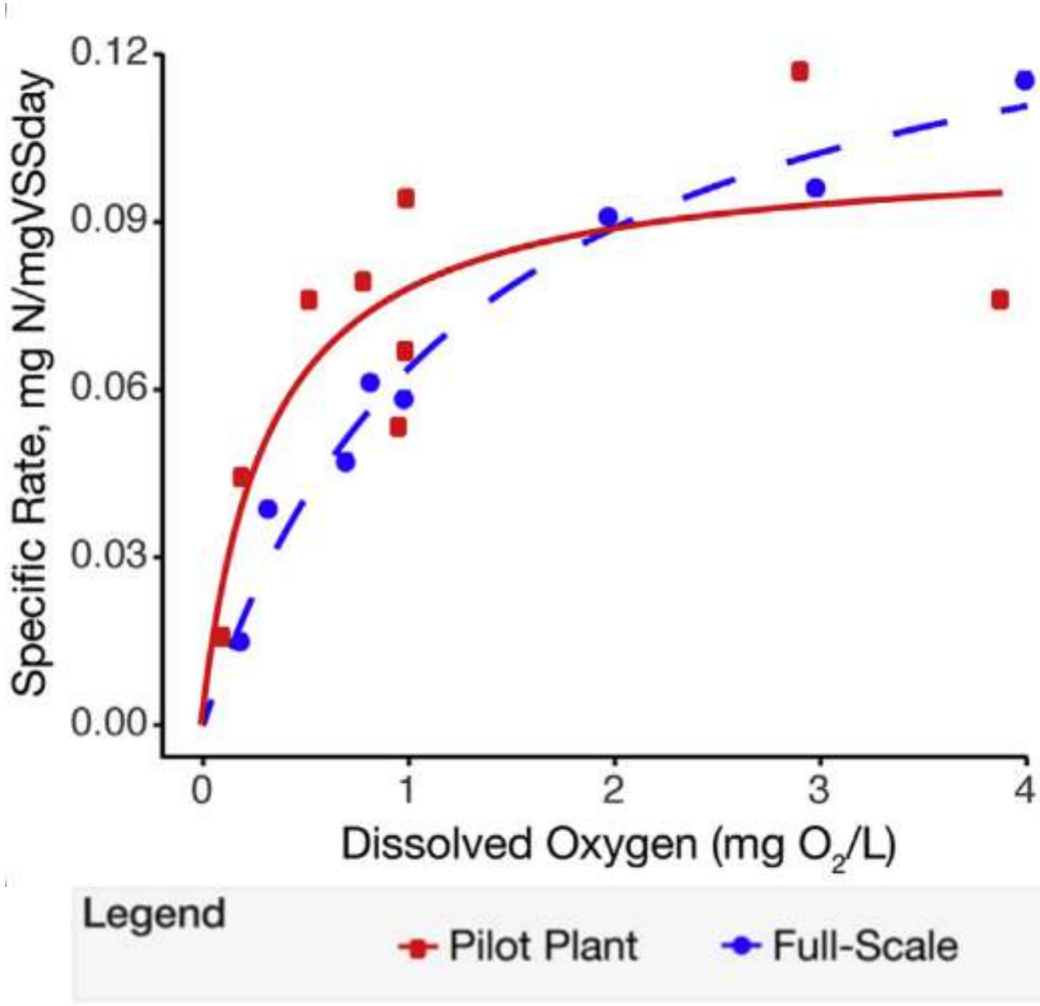




Low DO Nitrification - Promoting Simultaneous Nitrification/Denitrification

- Historical approach – DO > 2.0 mg/L
  - AOB/NOB population kinetics thought to be optimized at higher DO concentrations
- Recent work shows low DO nitrification is possible and kinetics are similar to those at higher DO concentrations

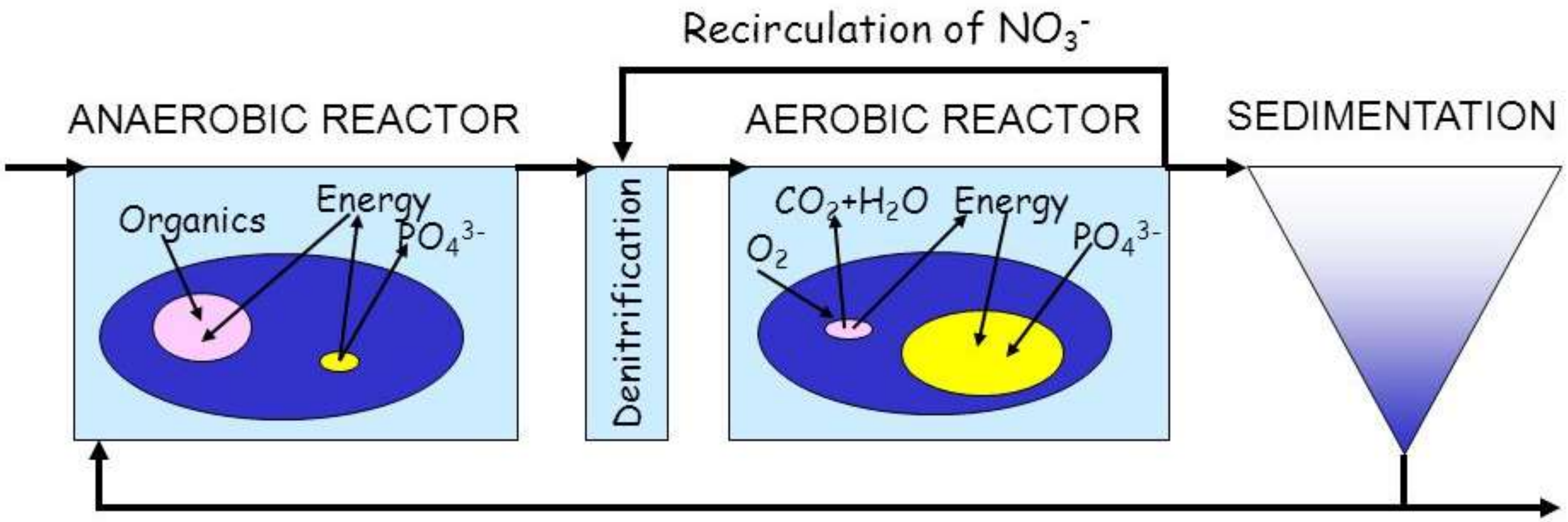




Water Research; Keene et al., 2017

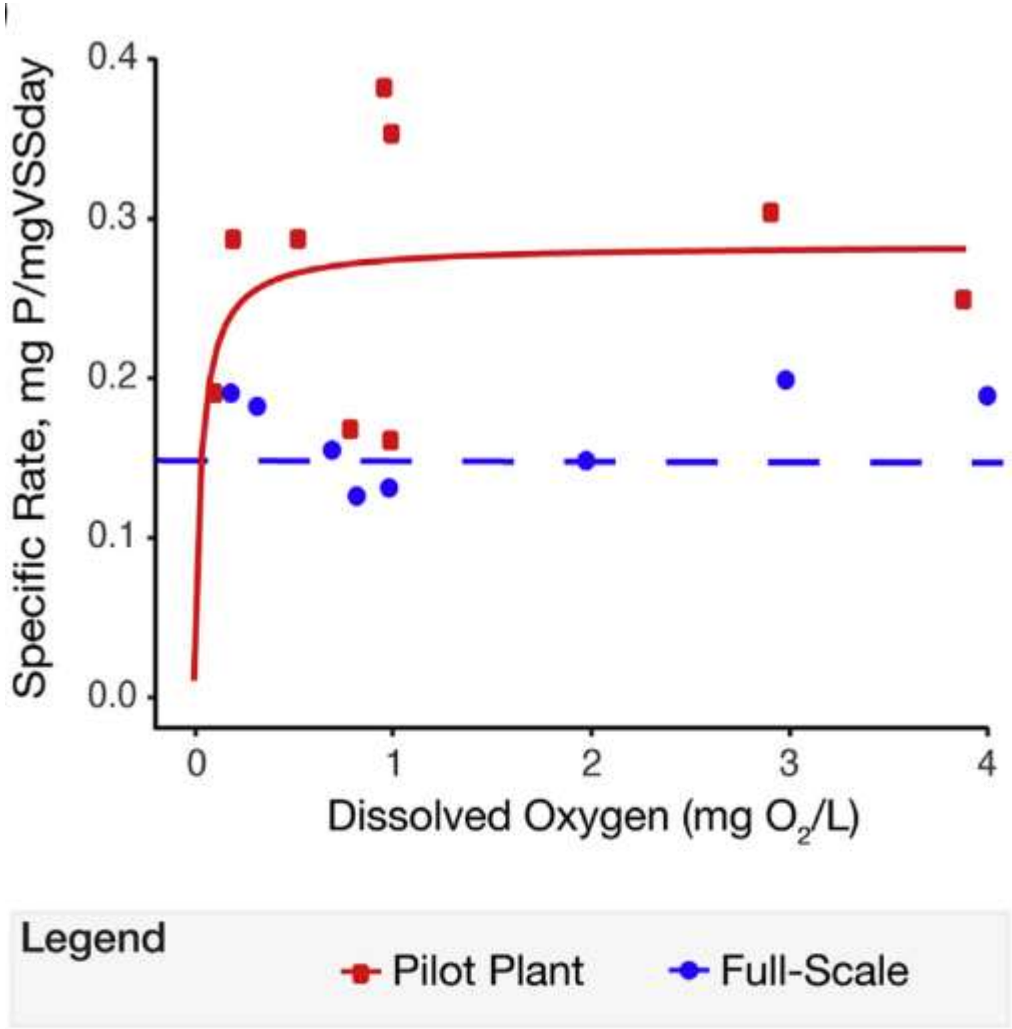
Low DO to promote SND – optimized energy and carbon usage

Traditional Enhanced Biological Phosphorus Removal



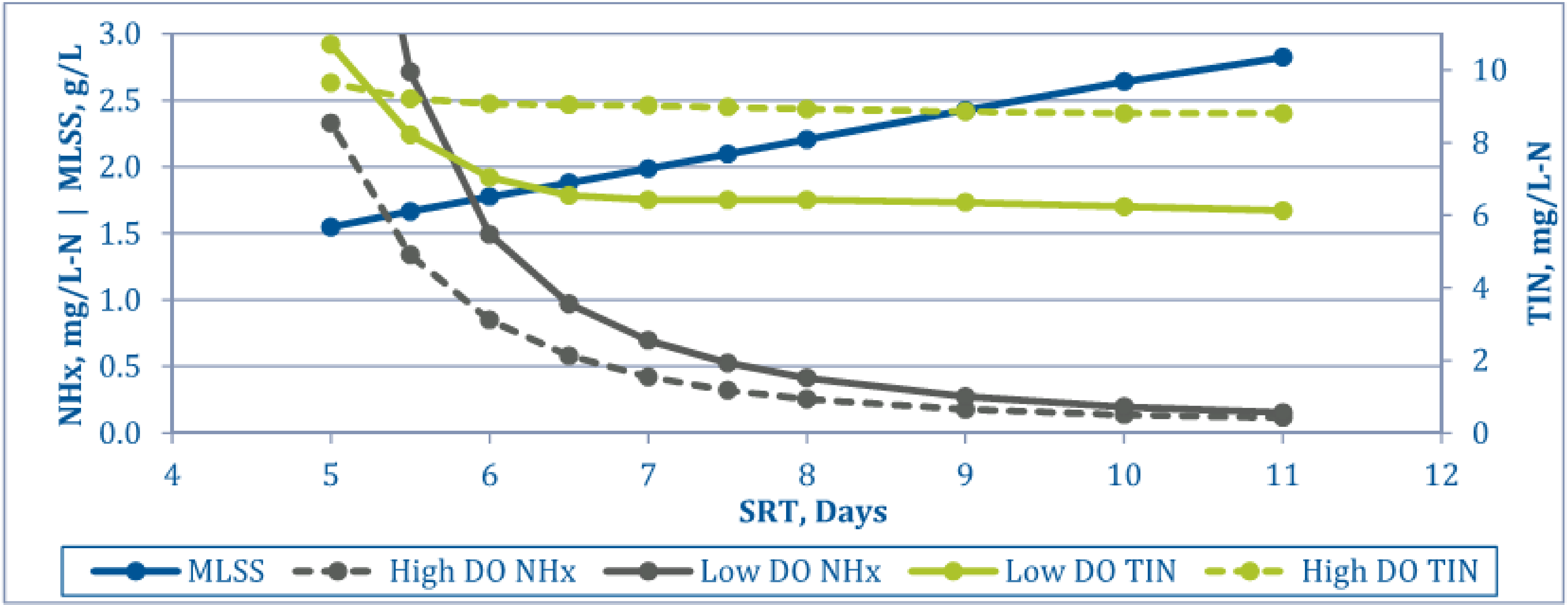
Enhanced Biological Phosphorus Removal

- **Multiple studies and full-scale experiences**
  - Lower DO led to improved Bio-P
  - PAO organisms have high DO affinity
- **DPAOs**
  - Ability to use NO_3/NO_2 as electron acceptor in lieu of O_2

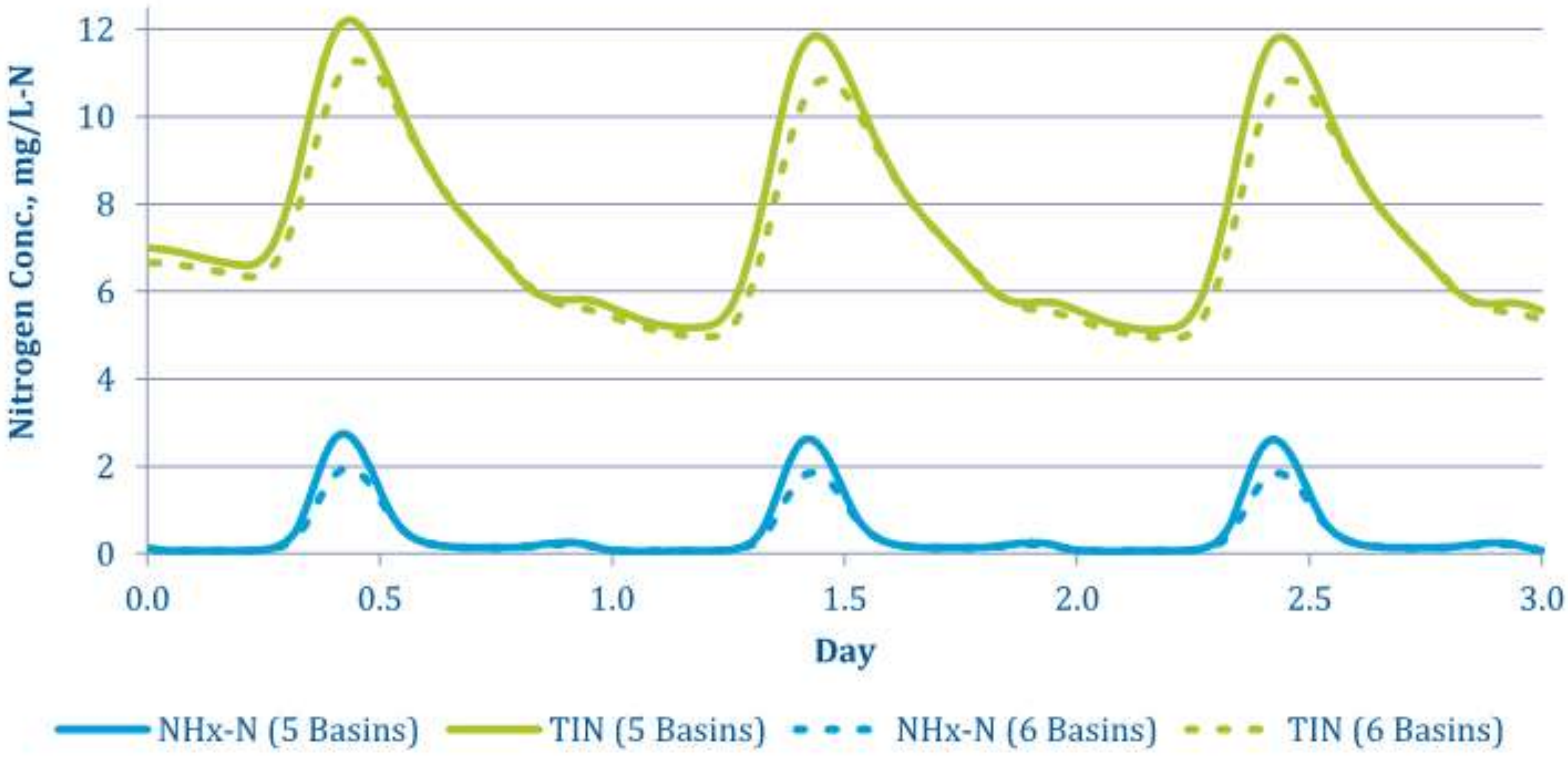


Water Research; Keene et al., 2017

Implementation Considerations – Solids Retention Time (SRT)



Determine Risk – Dynamic Diurnal Simulations



Instrumentation Considerations

- DO Probes
  - Placement
  - Maintenance
- NH4/NO3 Probes
  - Monitor performance
  - Potential to incorporate into control scheme (ABAC or AvN)
- TSS Probe
  - Accurate SRT control
- ORP Probe
  - Monitor anoxic and anaerobic zones

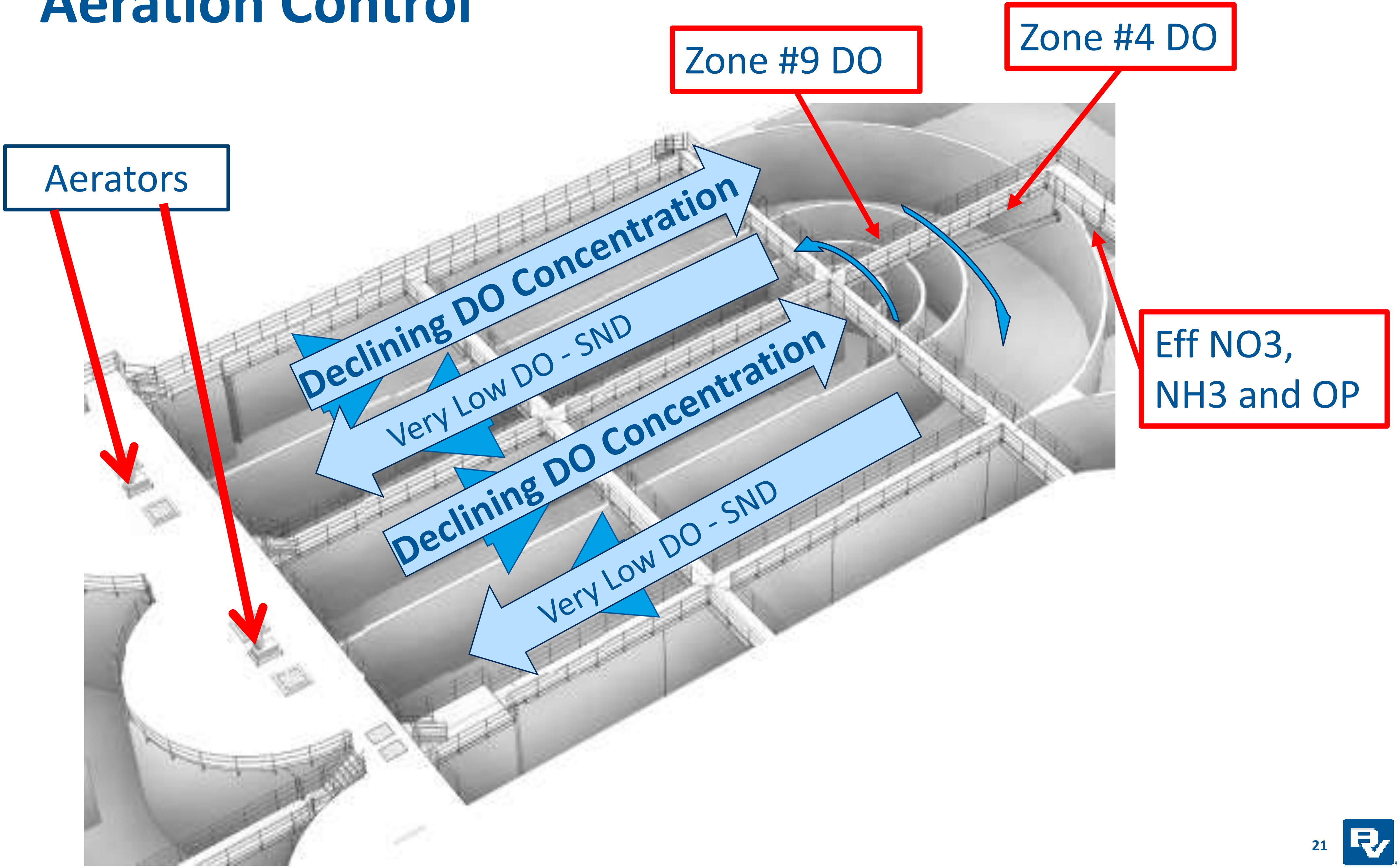
Two Case Studies

- Wakarusa River WWTP (Kansas)
- Denver North Treatment Plant

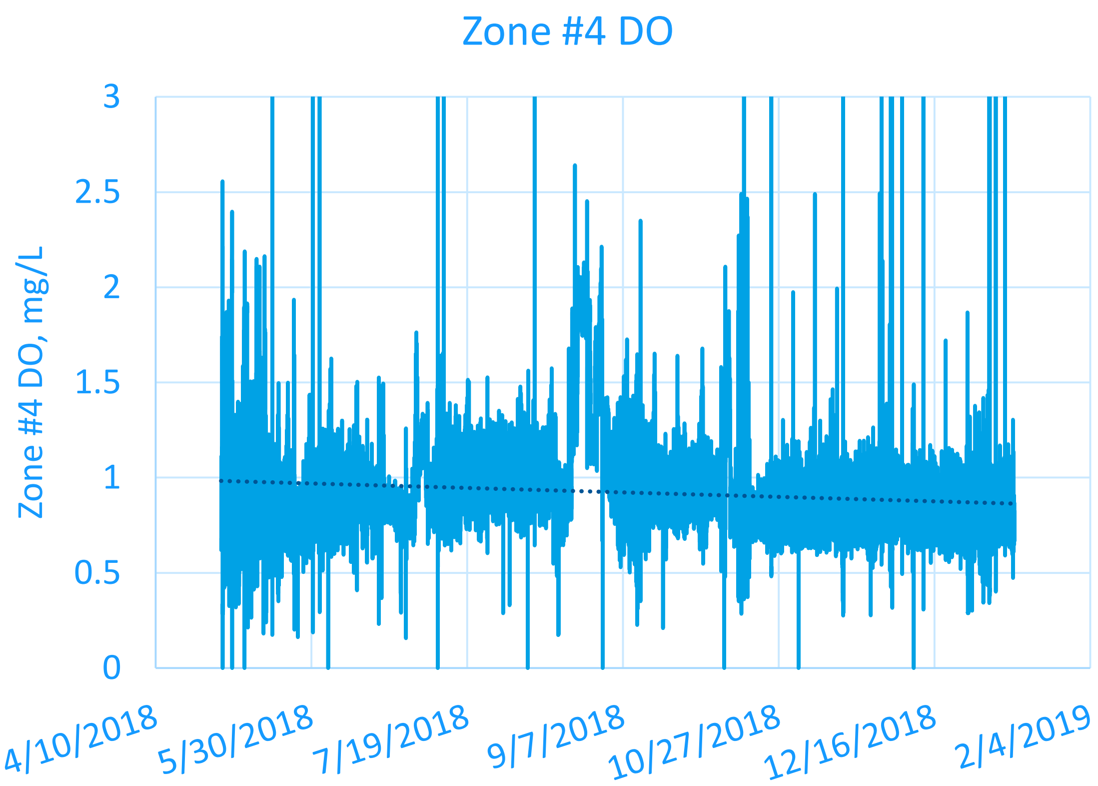
Case Study – Wakarusa River WWTP

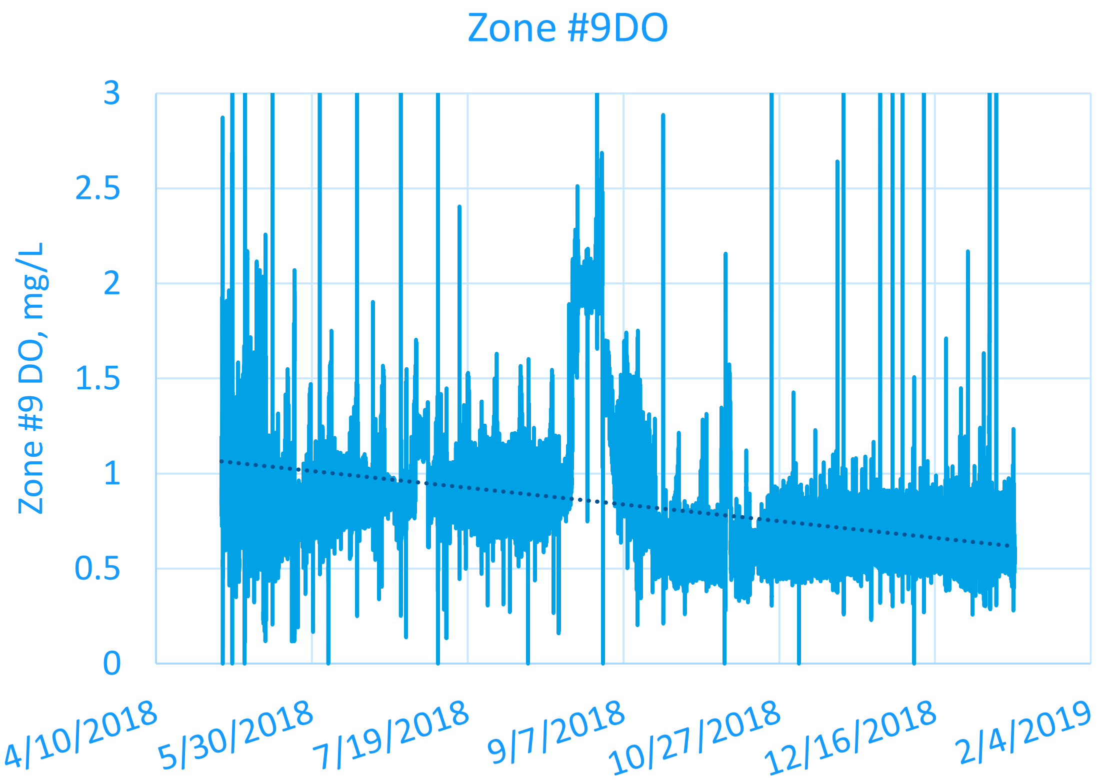
- 2.5 mgd facility
- BNR facility achieving TP and TN removals
- Two Aerated Zones
  - Zone 4 – 0.8 mg/L
  - Zone 9 – 0.6 mg/L

Aeration Control



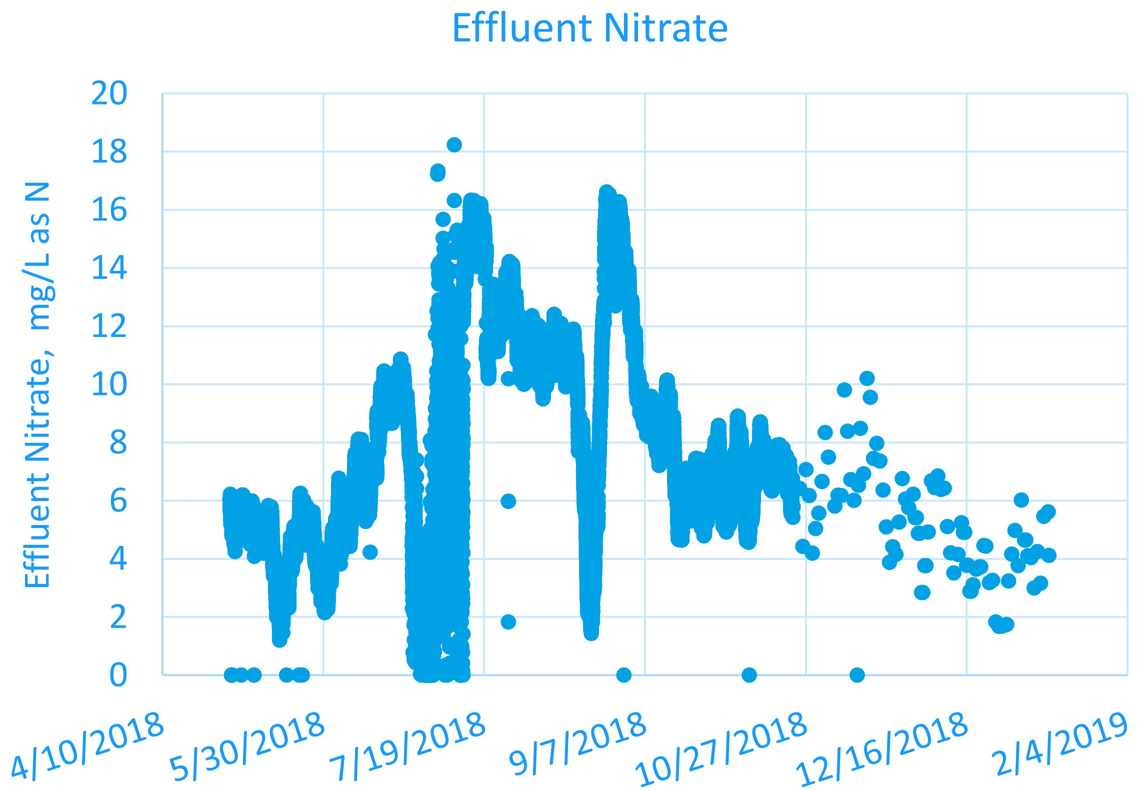
Case Study - Wakarusa

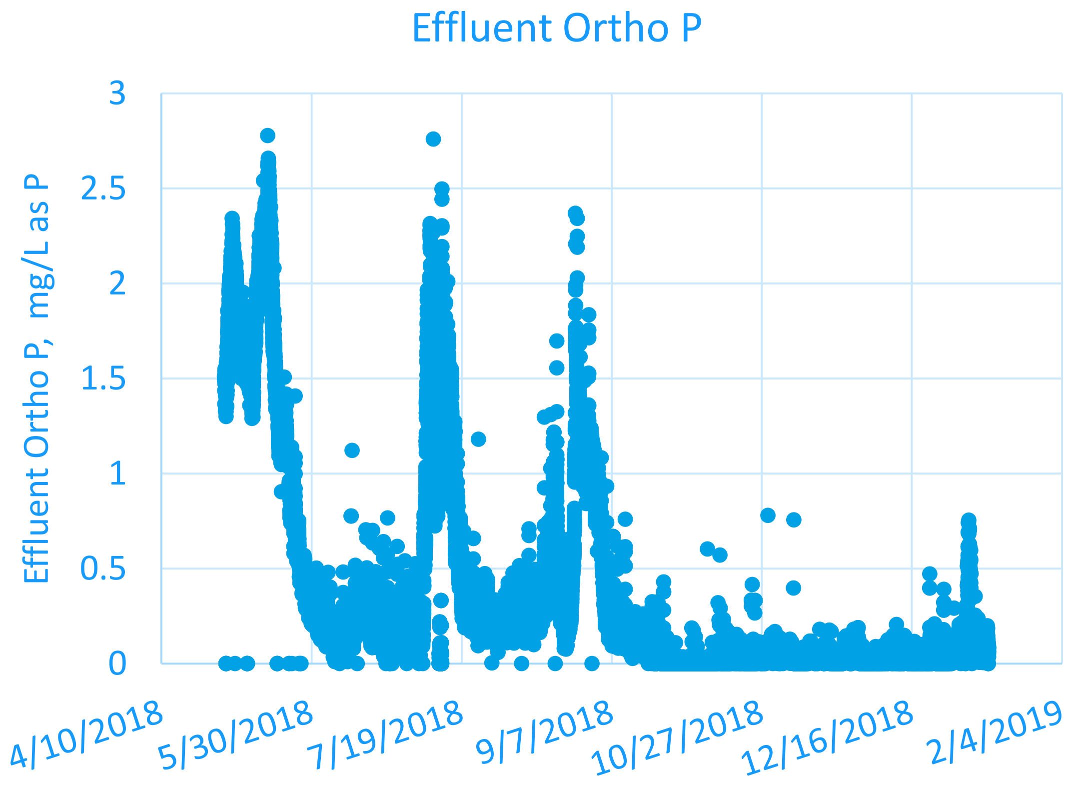




Case Study - Wakarusa

- **Outcome**

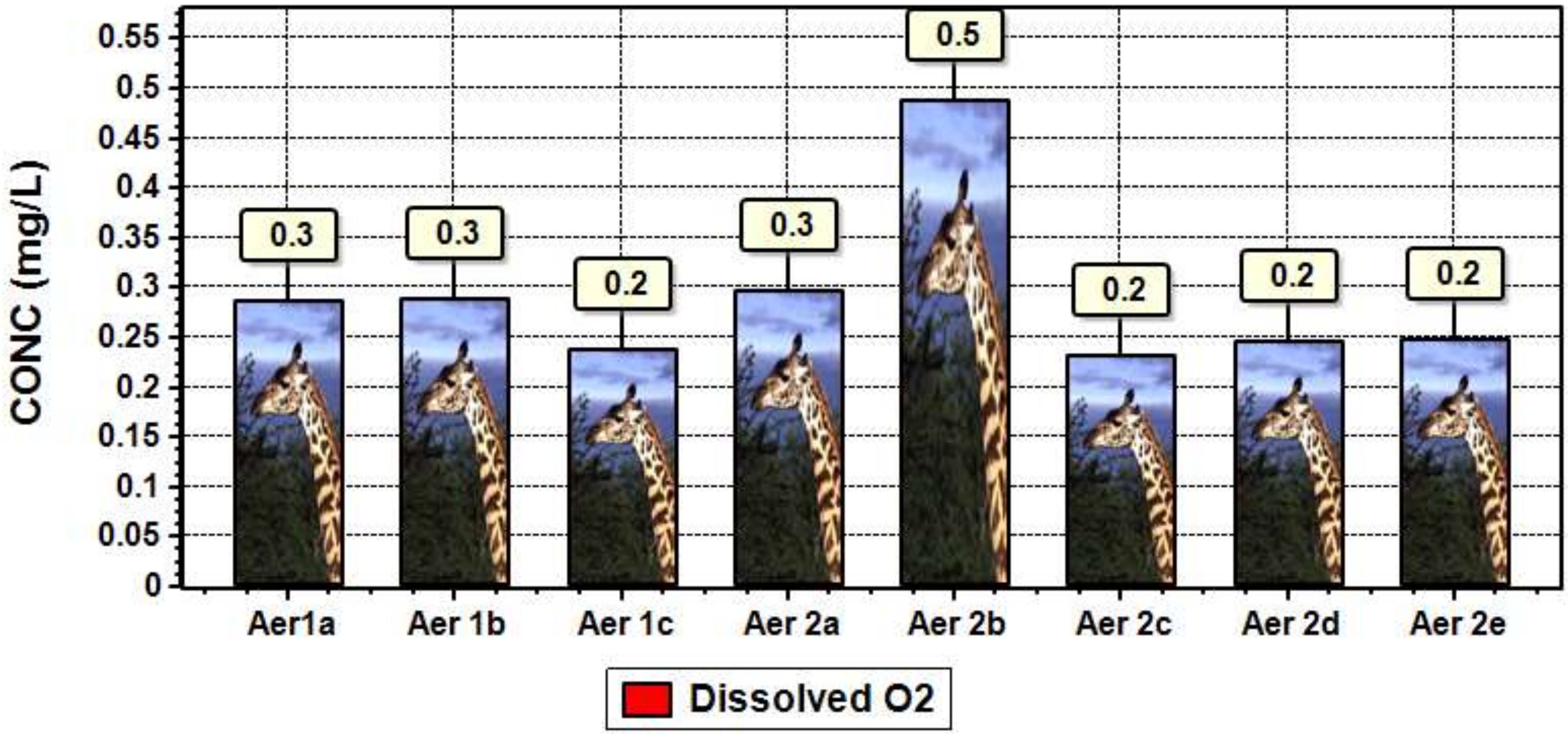




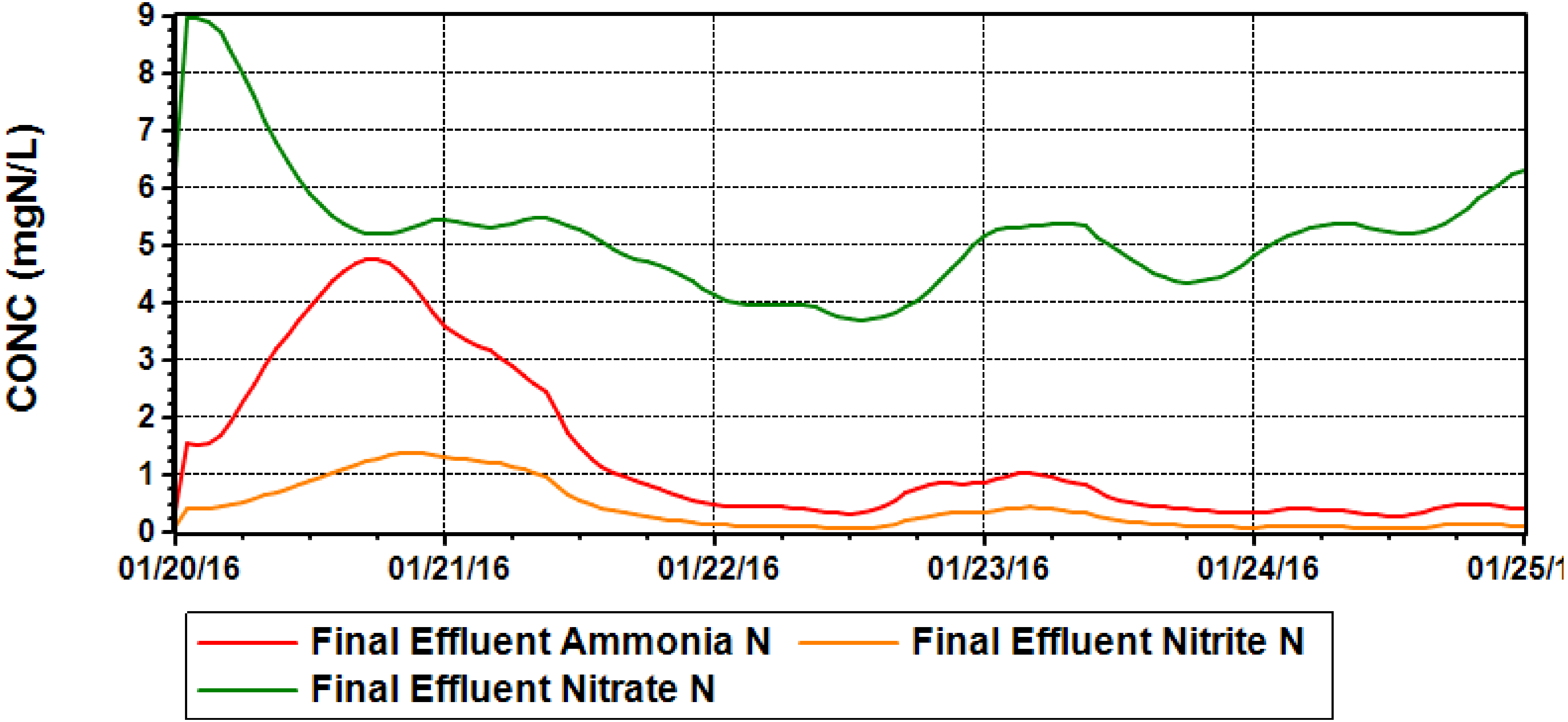
Case Study – Denver North Treatment Plant

- 5 mgd AADF
  - 10 mg/L effluent NO3 (daily max)
  - 1 mg/L TP (95th percentile)
- Startup 2016
- Operating at low DO conditions throughout basins
- Step Feed Facility

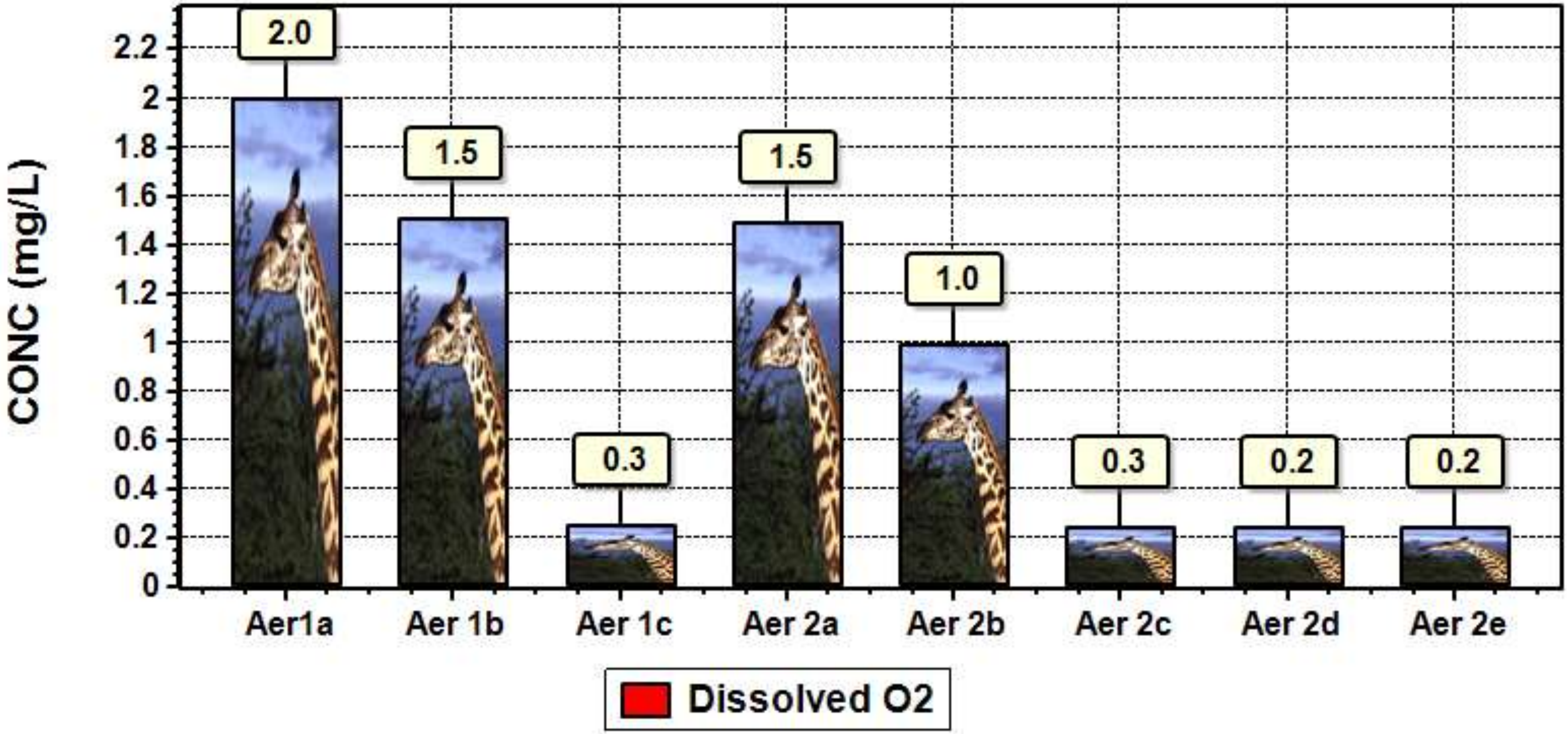
A modeling based approach – startup guidance



Predicted effluent nitrogen species



A modeling based approach – would higher DOs improve performance?



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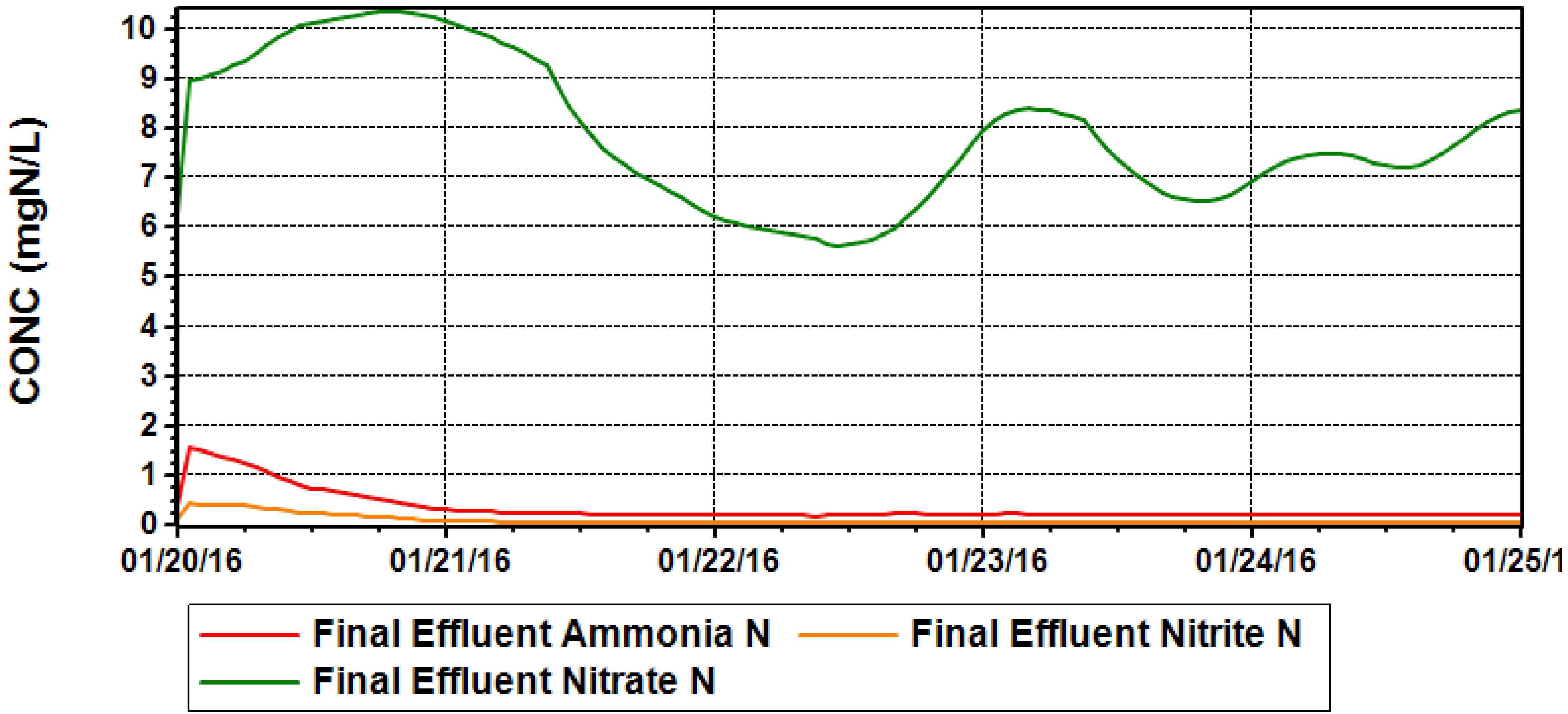

Denver North Treatment Plant – Results and Experience

- Continued low DO operation - > 2 years since startup
- Meeting effluent requirements
  - ABAC controls implemented to control during high loading periods
- Solids settling SVI is poor
  - Common characteristic of step feed facilities – low F/M ratios

Implementation Considerations

- Plan, Do, Check, Act
- Instrumentation
- SRT
- Patience

Questions?

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