# Achieving Nutrient Removal in High-Purity Oxygen Systems

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CDM Smith

NEWEA – 2020 Annual Conference & Exhibit

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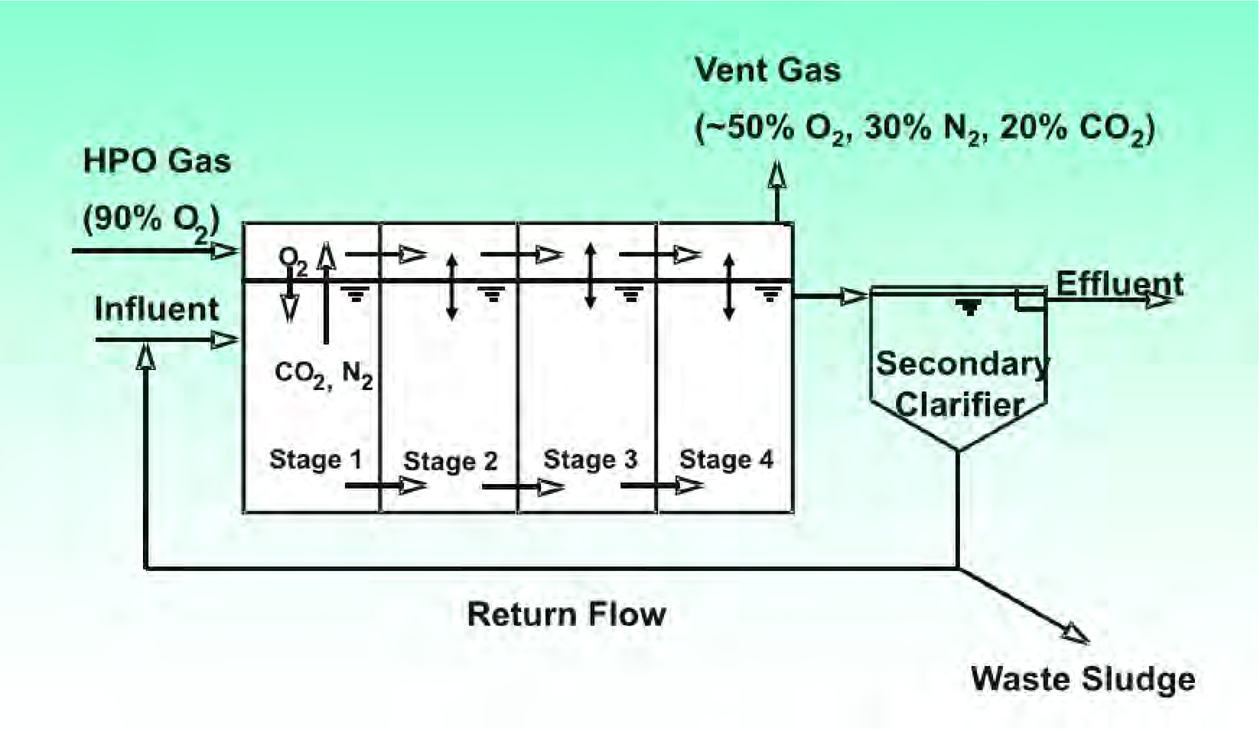
# Agenda

- High Purity Oxygen (HPO) systems
- Typical process design parameters
- Adaptability to nutrient removal
  - Phosphorus
  - Nitrogen
- Evaluation (modeling) tools
- Conclusions

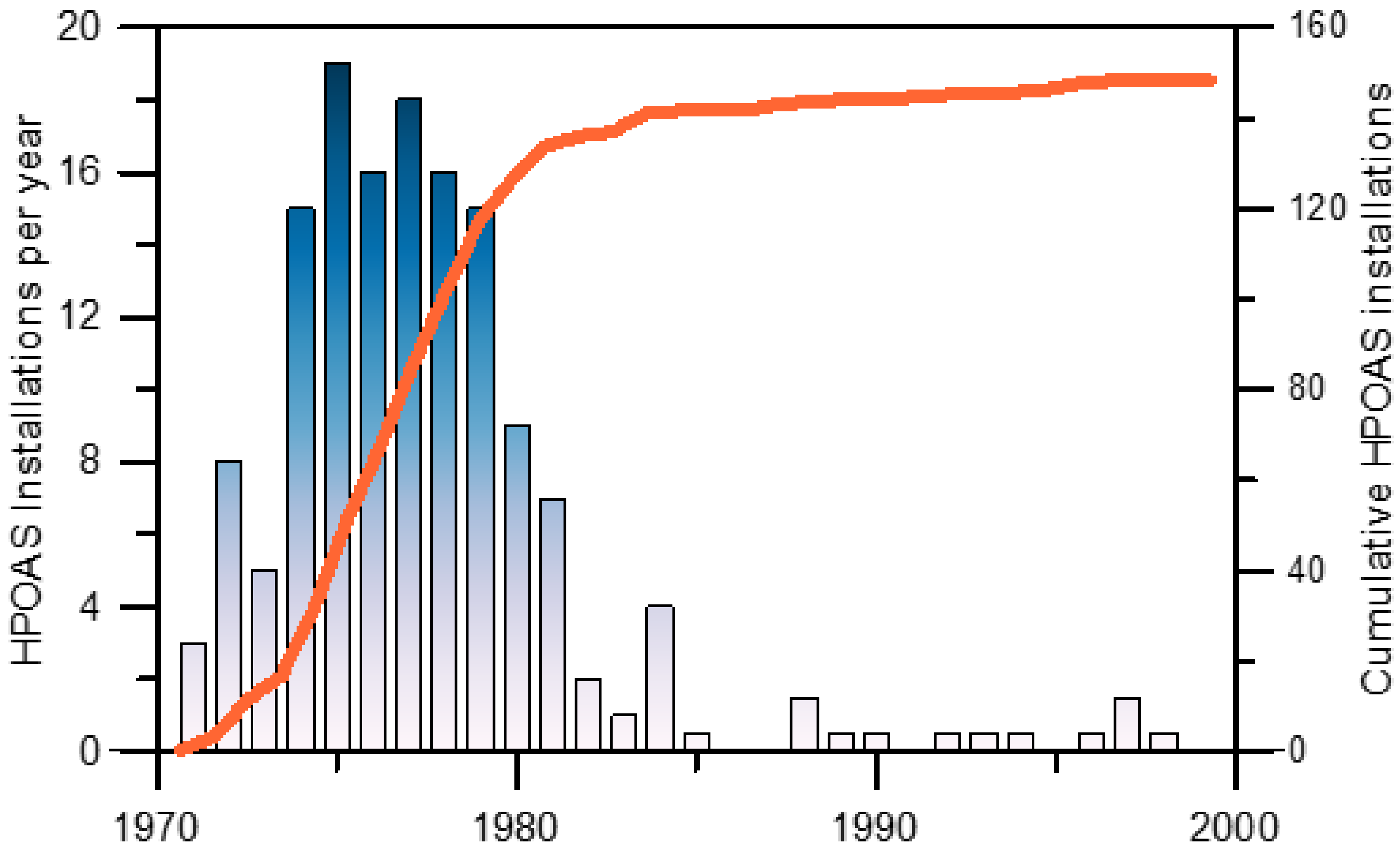
# High Purity Oxygen (HPO) Systems

- Variant of activated sludge
- “UNOX” system by Union Carbide
- Developed and commonly implemented in late 1970s and 1980s Components
  - Pure oxygen supply (>90%)
  - Covered bioreactors
  - Multiple stages
  - Mechanical aerators
- Conventional clarification/RAS/WAS
- Advantages
  - Energy efficiency
  - High rate process kinetics
  - Covered bioreactors – odor control




Stenstrom, 2006

# HPO Installations




Parker, 2011

# Typical HPO Process Design Criteria

| Criterion | Typical Value(s) |
| --- | --- |
| Process goals | Secondary treatment (min. 85% removal of BOD, TSS) |
| MLSS concentration | 1000 – 3000 mg/L<br>(original design ranges 4000 – 8000 mg/L) (*EPA* 1973) |
| HRT | 1 – 3 hours |
| DO concentration | 4 – 10 mg/L |
| SRT | 1 – 3 days common |
| F:M Ratio | 0.5 – 0.8 lbs/lb |



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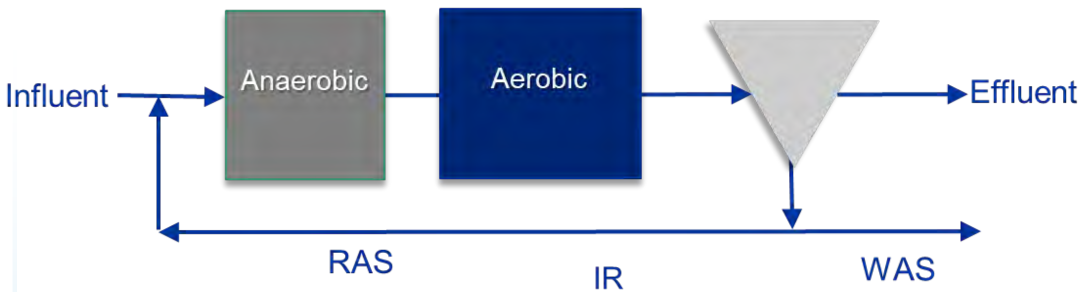
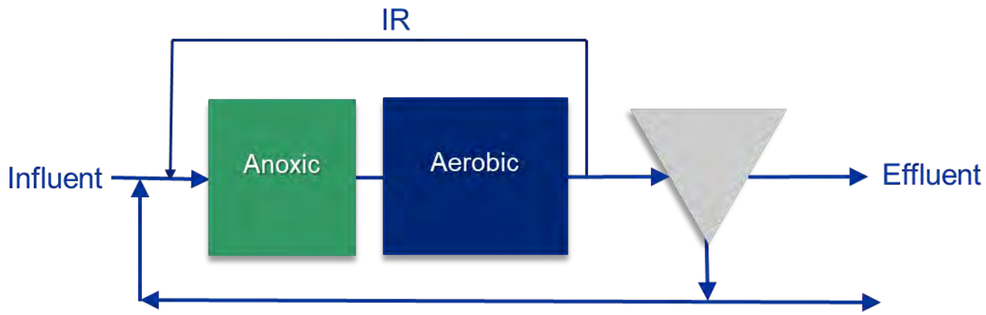
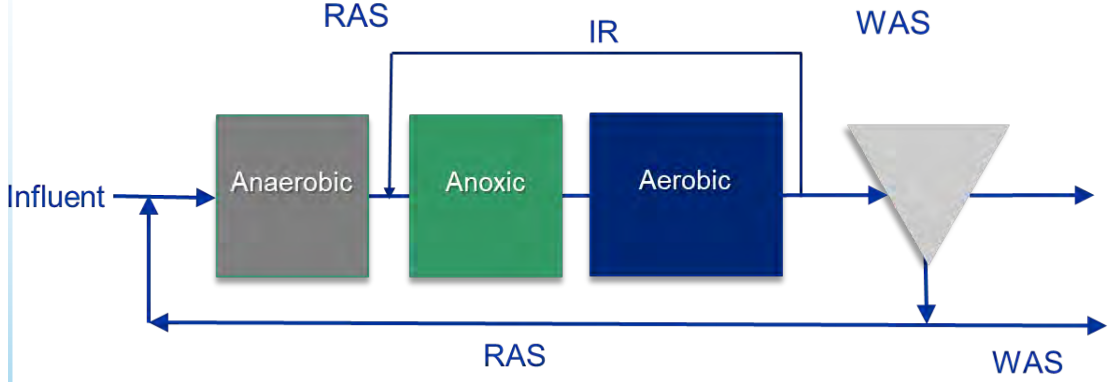
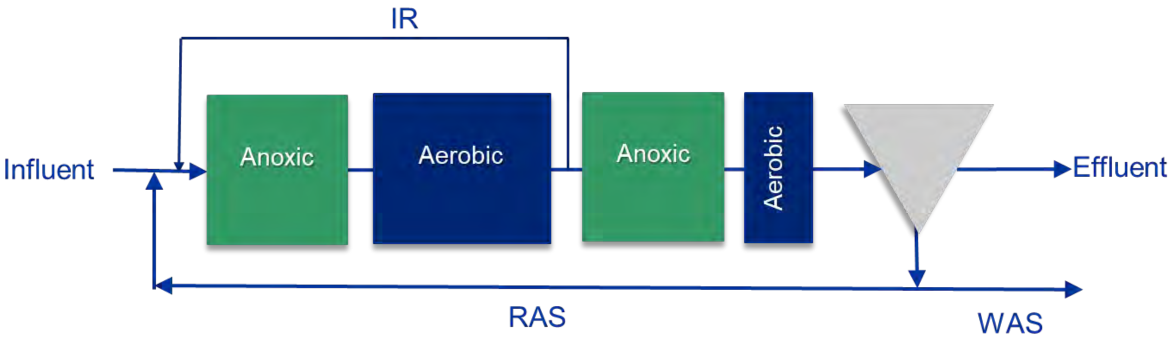
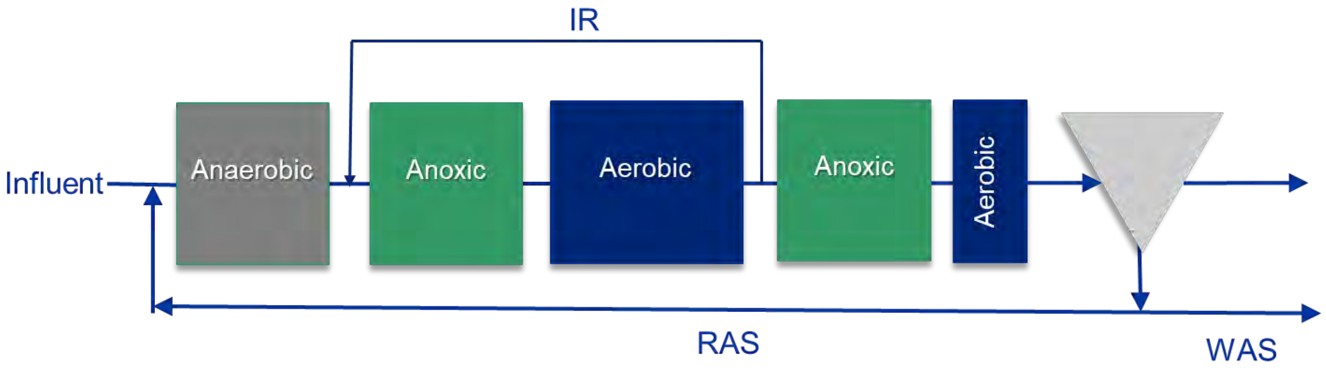
# Adaptability to Nutrient Removal



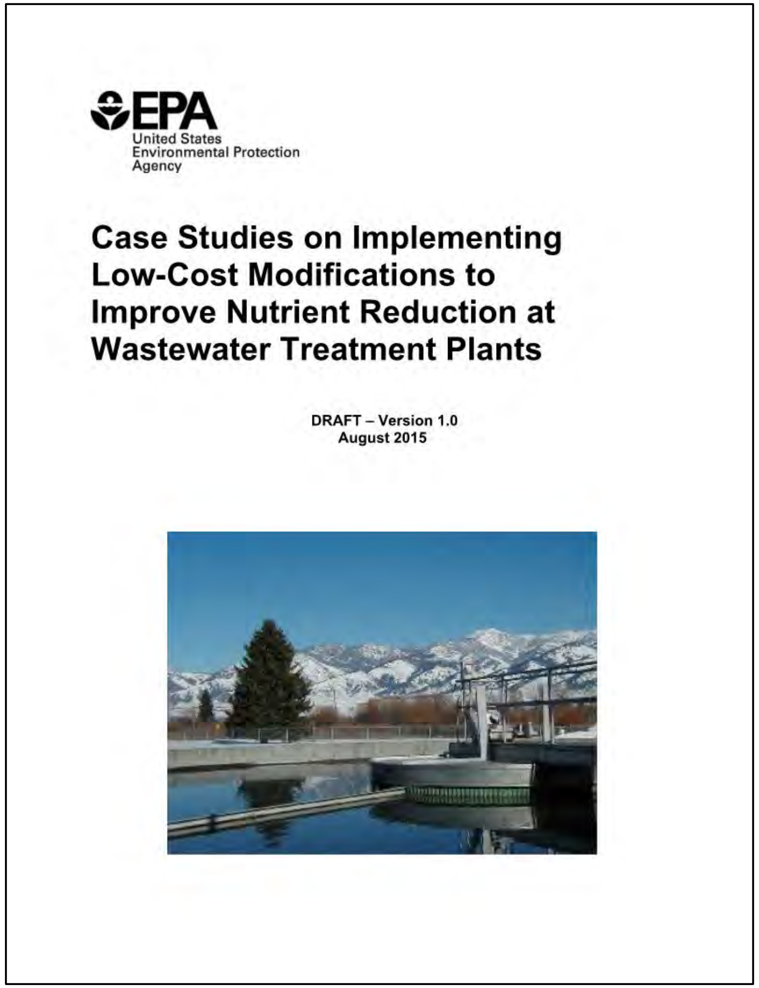



# Nutrient Removal – Can the Process be "Tweaked"?

- Typical tweaking concepts
  - Turn the air off
  - Cyclic aeration
  - Low DO operation – Simultaneous Nitrification/Denitrification
  - Unaerated (anaerobic or anoxic) zone
  - Swing zone
- Tweaking is great, but:
  - HPO not among these EPA case studies
  - Frequently insufficient process volume for nitrification
  - Nitrification inhibition
  - Often inadequate control of DO


EPA
United States Environmental Protection Agency

Case Studies on Implementing Low-Cost Modifications to Improve Nutrient Reduction at Wastewater Treatment Plants

DRAFT – Version 1.0
August 2015



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# Enhanced Biological Phosphorus Removal (EBPR)

- EBPR:
  - Wastewater characterization
  - Anaerobic zone/detention time
- Compatibility w/HPO System Design Criteria
  - Short SRT may be acceptable
  - Oxygen depletion accounted for
- In retrofit, modifications required
  - Covers
  - Aerators/mixers changeout
  - Controls

# EBPR Case Study – Lancaster, PA

- 26 MGD capacity
- Existing A/O configuration (orig. design)
- Sufficient process volume/capacity to nitrify ~ 10 day aerobic SRT
- Two plants:
  - South plant – converted to HPO with A/O in 1980s
  - North plant – new HPO plant with A/O in 1980s
  - Both plants can nitrify
  - $CO_2$ vent stage
- Annual mass limits equate to concentrations of:
  - TP:  1 mg/L
  - TN:  8 mg/L (to be revisited later)



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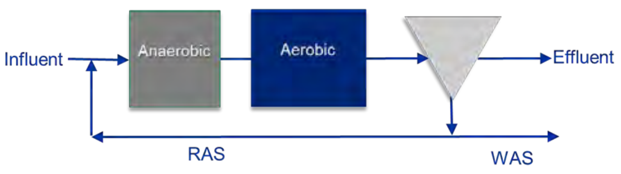
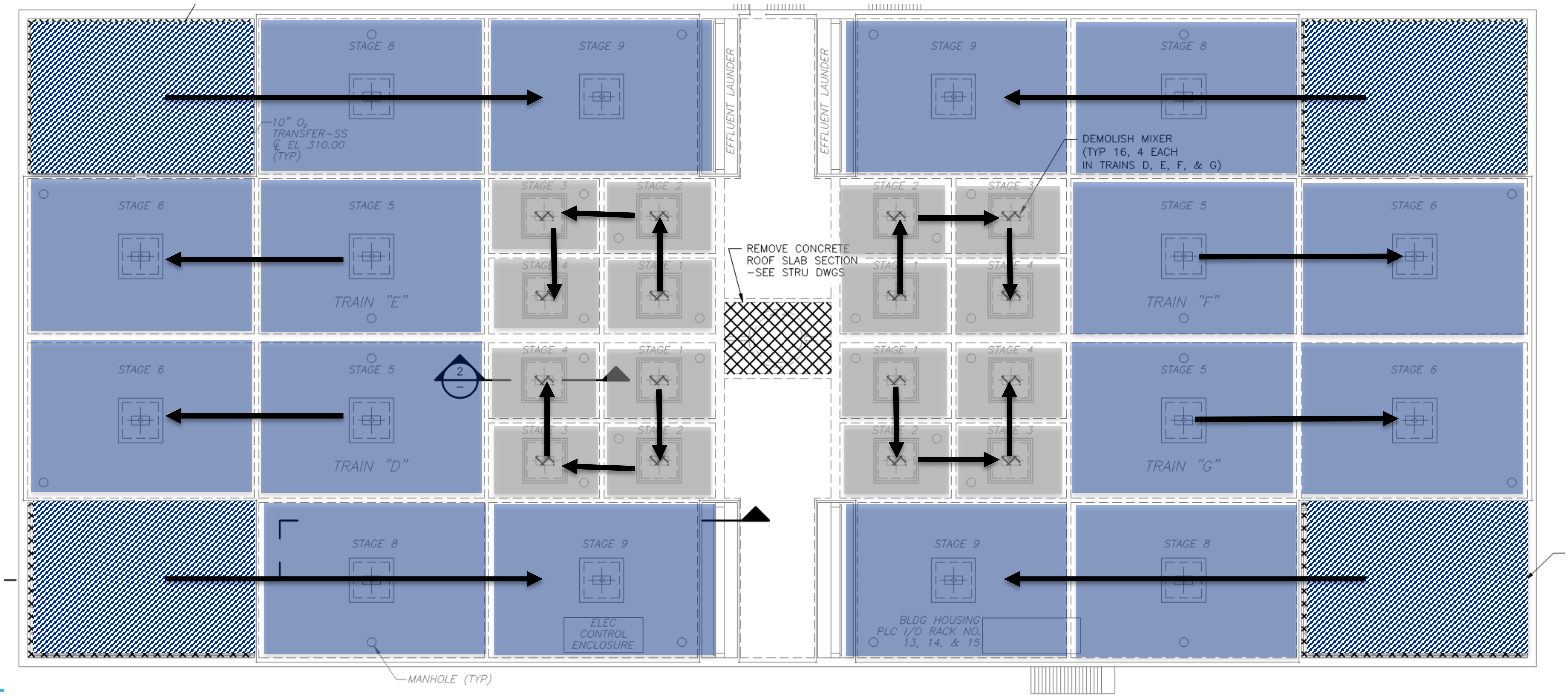
# EBPR Case Study – Lancaster, PA (North Plant)



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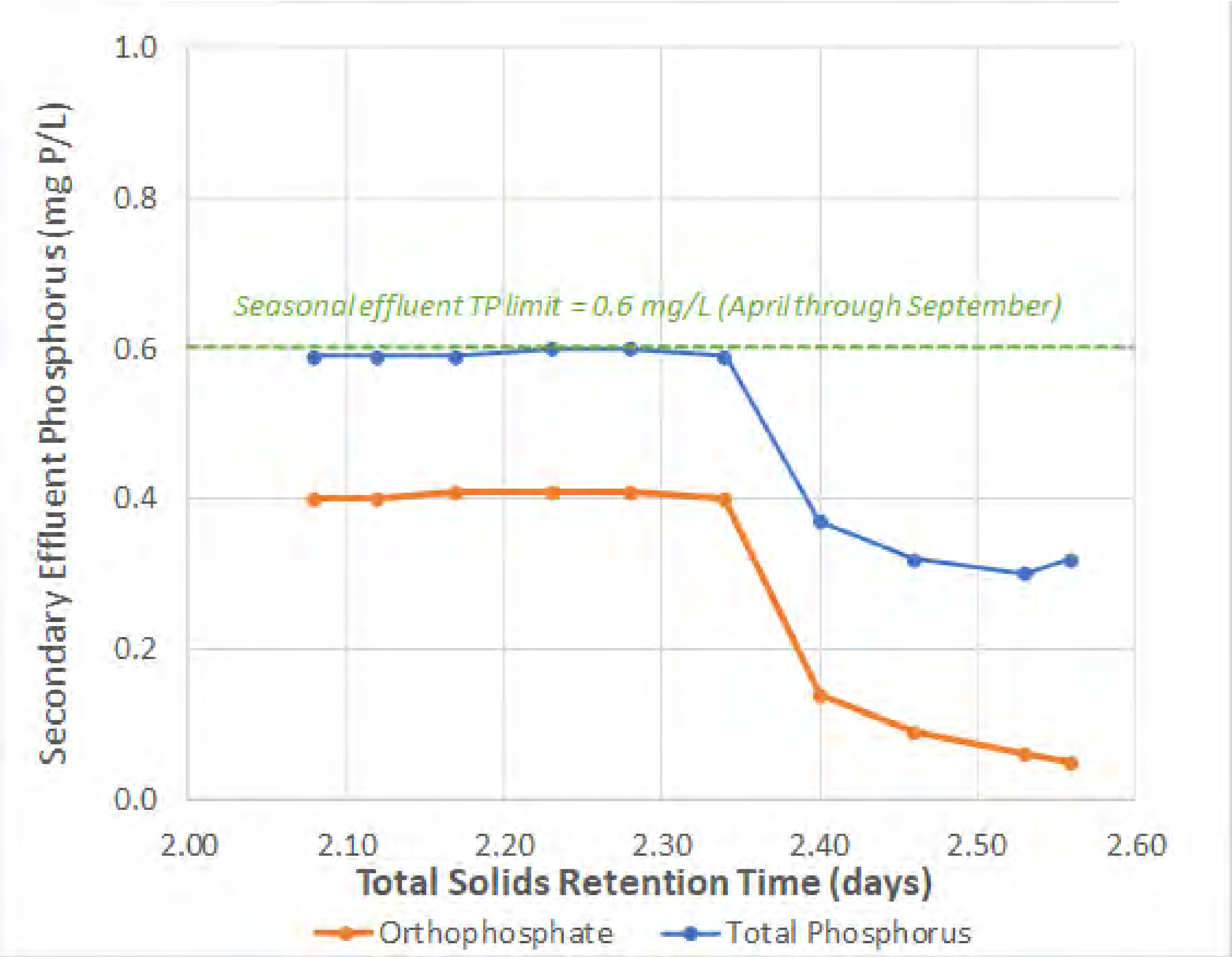
# A Caution on Short SRT and EBPR

- PAO growth rate is not as fast as OHO growth rate
  - Biowin defaults:
    - OHO: 3.2/day
    - PAO:  0.95/day
- So, it's possible to washout PAOs



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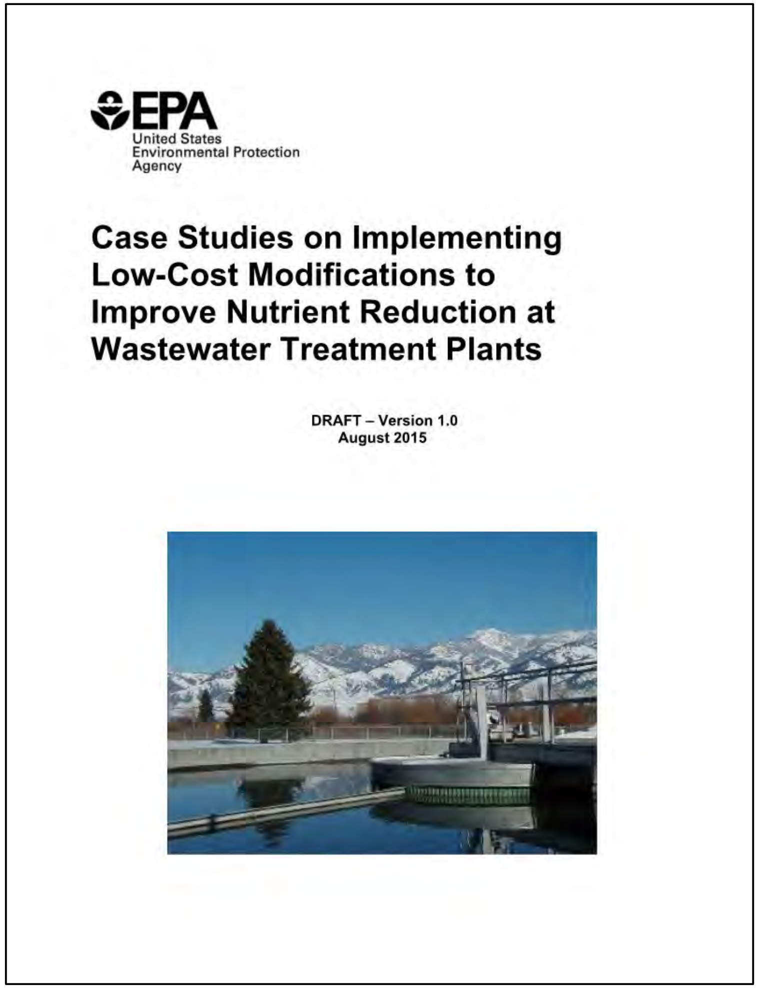
# Nitrogen Removal

- Nitrogen limits sometimes provide flexibility
  - Year-round vs. seasonal
  - Monthly average vs. rolling average
  - Concentration vs. load vs. both
- Limitations on the effectiveness of process tweaks
  - Cold wastewater temperatures
  - SRT limitations – nitrification
  - Low pH impacts



EPA
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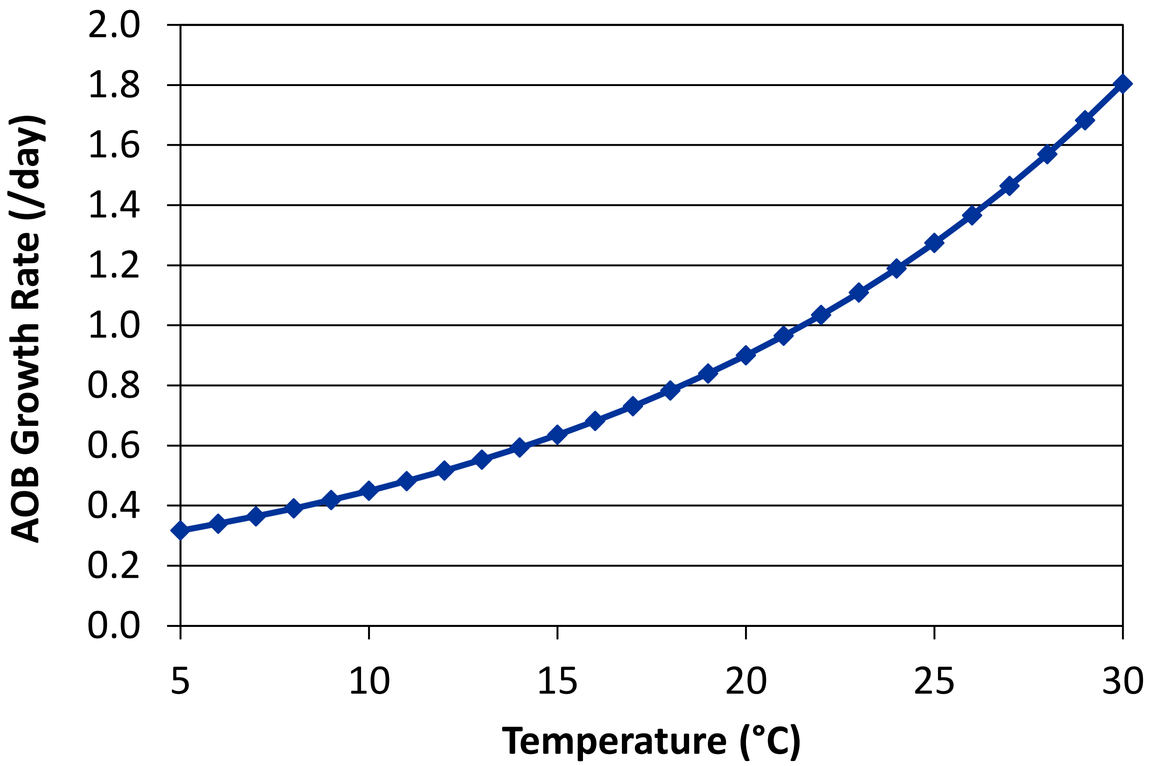
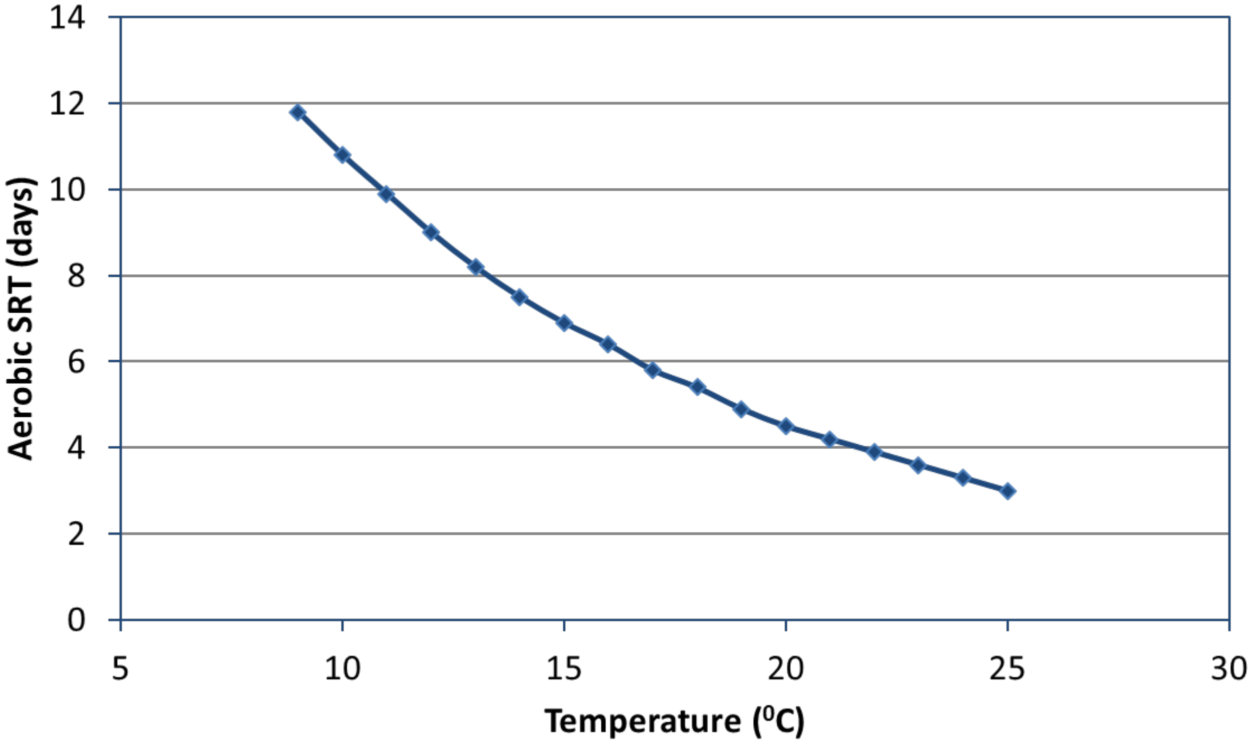
# Nitrification – Aerobic Solids Retention Time




- Above is at neutral pH
- Can MLSS concentration be increased sufficiently?
- Solids loading limitations to clarifiers
- Foaming common at high MLSS concentrations

# Nitrification Rate – Impacts of Low pH

- Nitrification severely inhibited by low pH
- Nitrification rate at pH of 6.0 is less than ½ of rate at pH of 7.0

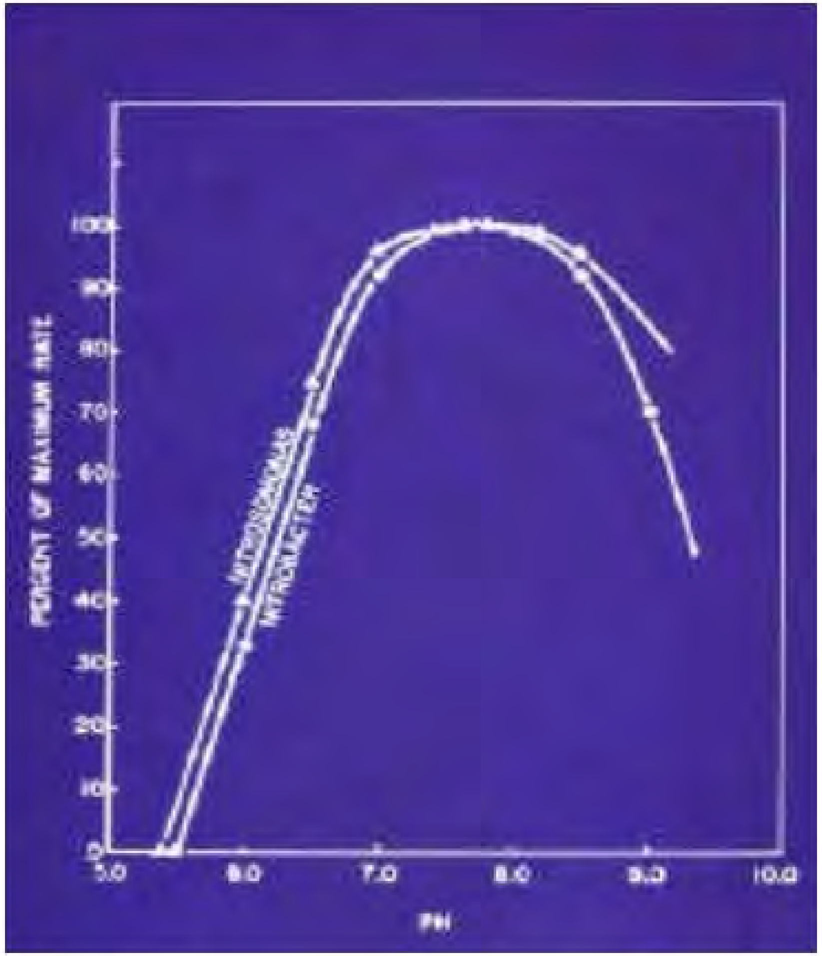
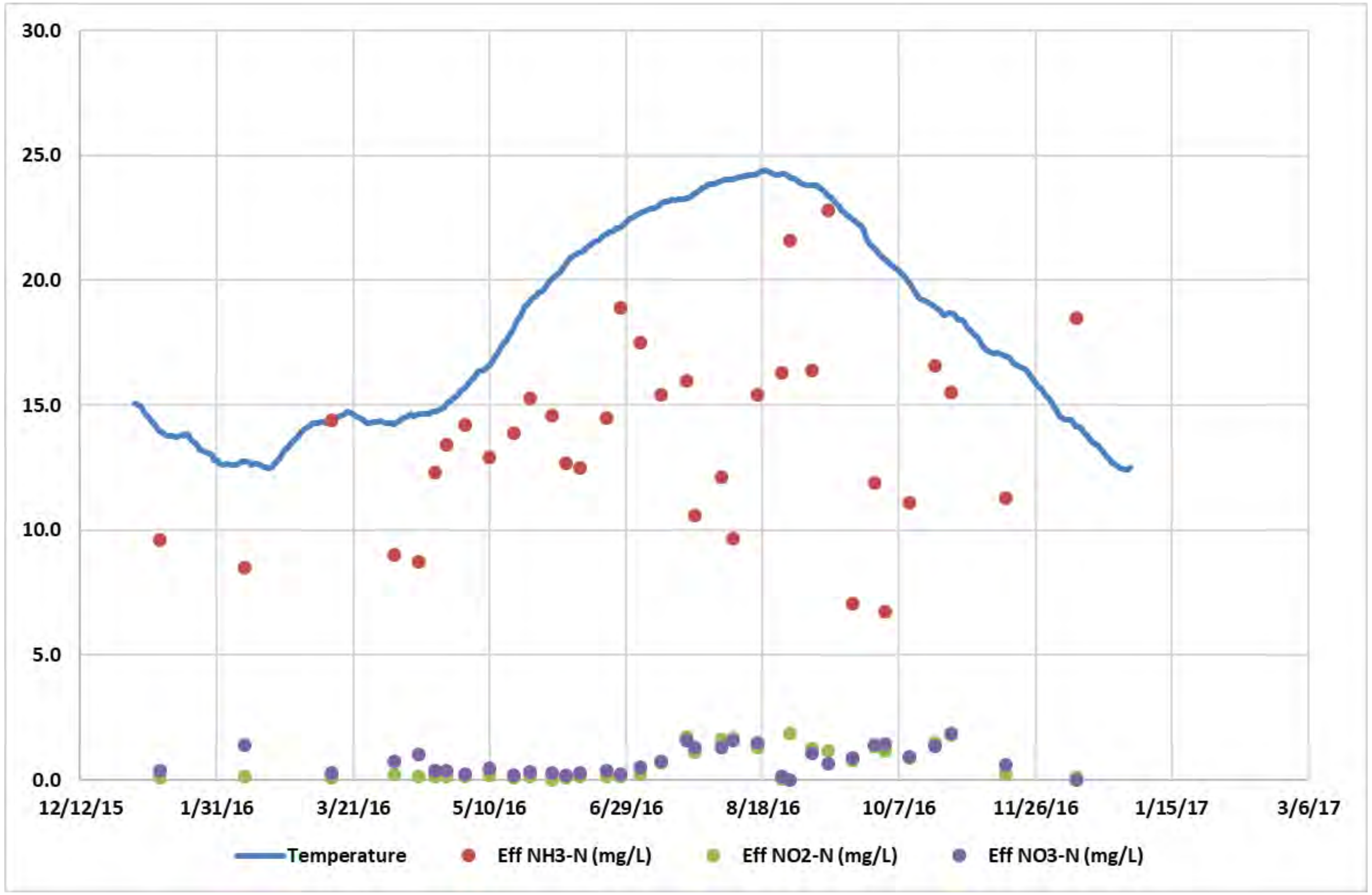



**Figure 29.** Effect of pH on the growth rate of nitrifying organisms

**EPA, 1975**

# Fall River, MA WWTF – Nitrification Data

- SRT ~ 3-4 days
- DO > 6 mg/L



# Achieving Nitrogen Removal

- Utilize (build?) sufficient process tankage (as conventional activated sludge)
- Remove covers at strategic locations to vent $CO_2$
  - Alternatives to covered cells with mechanical aerators
- Add anoxic process volume and internal recycle
  - Consider DO depletion
- Adequate DO control

# Nitrogen Removal Case Study – Holyoke WPCF

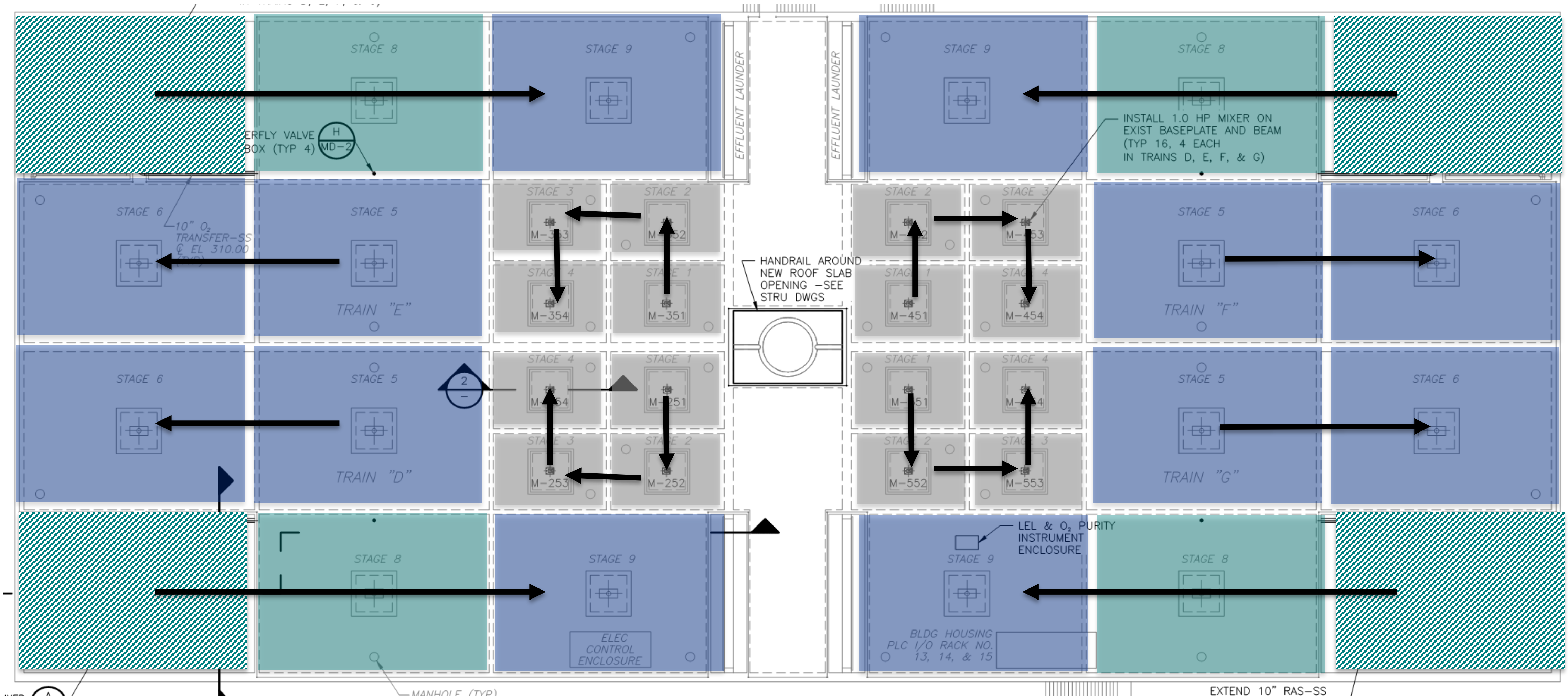
- 17.5 MGD
- Required to optimize TN removal
- "Baseline" effluent TN per EPA: 696 lbs/day
- Replacement for covered cells:
  - Praxair I-SO$^{TM}$
  - Similar equipment: Aqua Aerobics Oxymix$^{TM}$

# Nitrogen Removal – Lancaster, PA Revisited

- Existing A/O configuration – Converted to combined EBPR and nitrogen removal
- Convert 20% of existing aerobic volume to anoxic
- Optimize control system (base on DO, not vent O2 or headspace pressure)

| Criterion | Value |
|---|---|
| WW Temperature (min. month) | 11 deg. C |
| MLSS concentration (max. month) | 3,800 – 4,550 mg/L |
| Aerobic SRT | 10 days |
| DO concentration | 5 – 10 mg/L |
| Tank SWD | 15 ft (south); 20.3 ft (north) |

# Lancaster North Plant Modifications





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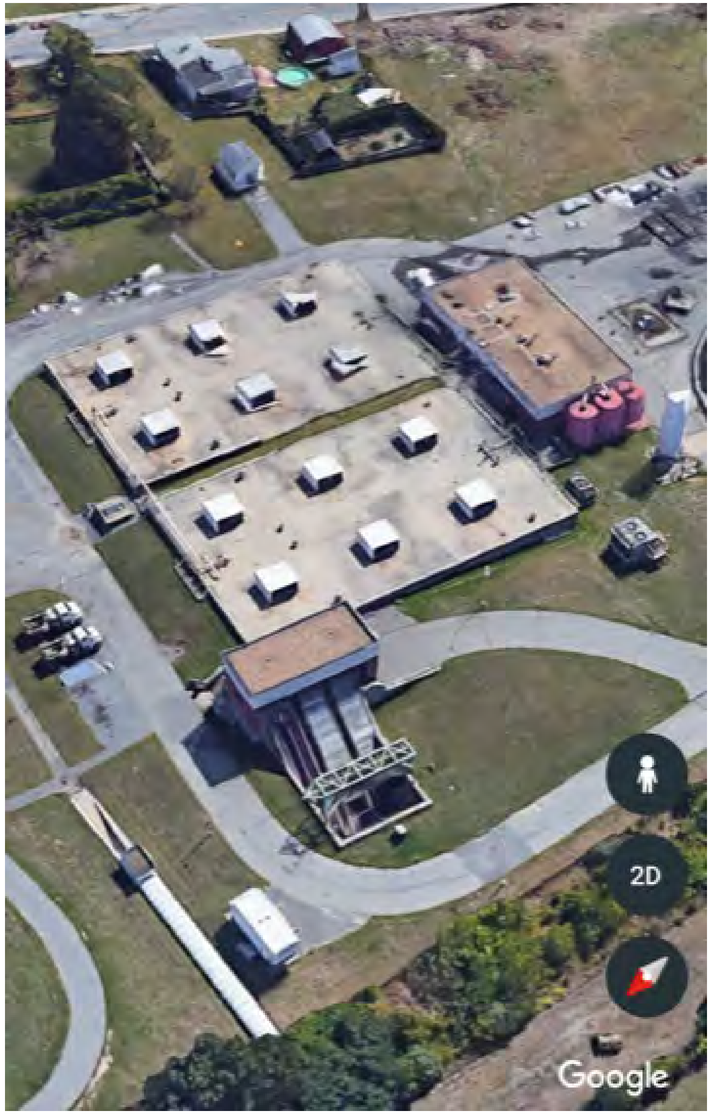
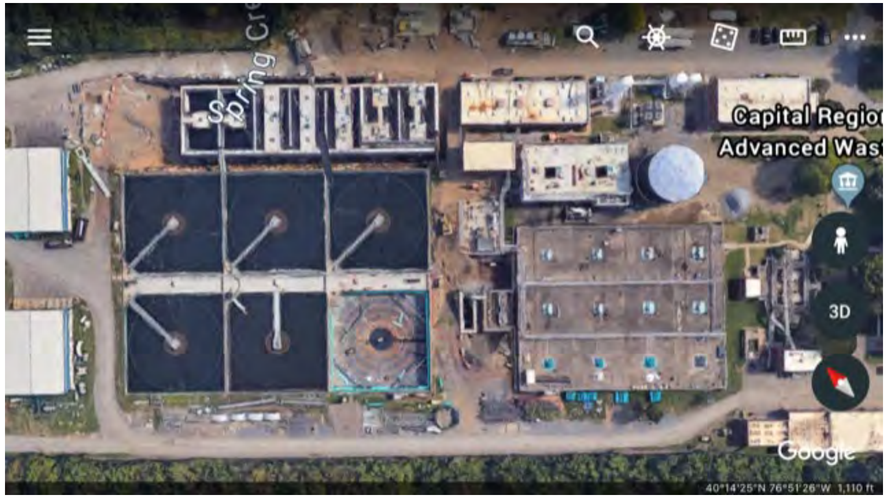
# Nitrogen Removal Case Study – Fall River, MA

- Facilities plan evaluation
  - TN limit expected
  - Can anything low-cost be done?
- 30.9 MGD
- 4 trains, 3 cells each
- Equipment >30 years old
- Findings:
  - Insufficient tankage for nitrification (2x)
  - Conversion to air-activated sludge system configured for BNR recommended




# Nitrogen Removal Case Study – Harrisburg, PA (Frank, 2017)

- New annual mass TN limit equal to ~6 mg/L at design flow
- 38 MGD
- 3 trains, 4 cells each
- Anaerobic digestion
- Expanded bioreactor tankage, overall >2x
- RAS “regeneration”
- Bioaugmentation
- Startup in 2016; excellent TN removal reported




| | HPO REACTORS WITH STAGE 1 CONVERTED TO ANOXIC ZONE | | | | | NEW AEROBIC REACTOR | | NEW SWING, POST-ANOXIC, & POST-AERATION REACTOR TANKAGE | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Zone (No.) | 1 | 2 | 3 | 4 | | 5 | | 6 | 7 | 8 | 9 | 10 | 11 |
| Volume (MG) | 0.7885 | 0.7885 | 0.7885 | 0.7885 | | 1.00 | | 0.49 | 0.49 | 0.49 | 0.49 | 0.49 | 0.400 |
| Air Status | Ax | Ao | Ao | Ao | | Ao | | Swing | Swing | Swing | Ax | Ax | Ao |

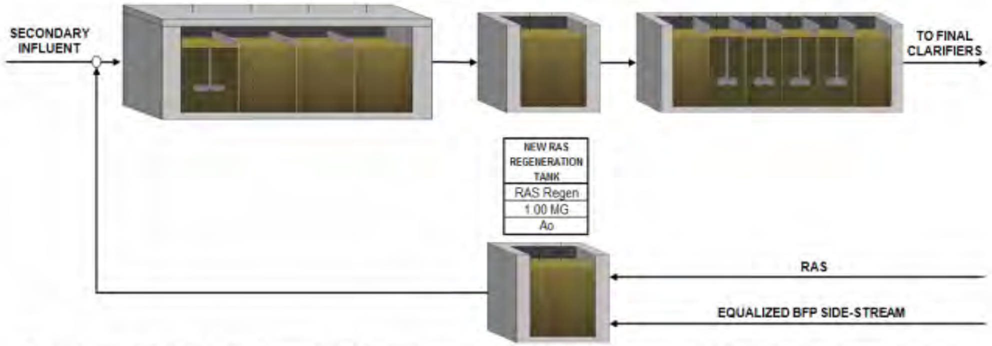
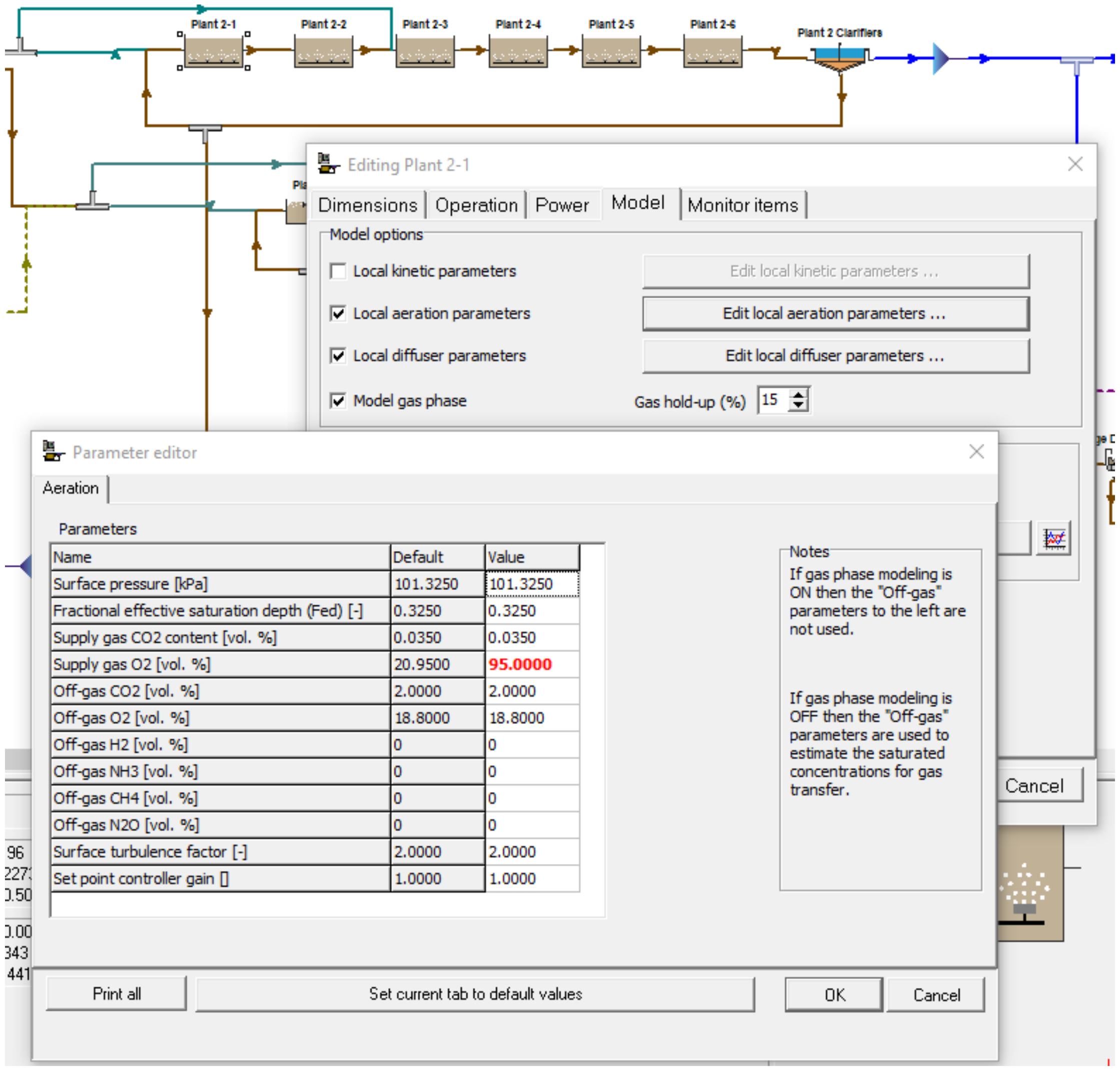



**Figure 18.** Ludzack-Ettinger-Wuhrmann process with RAS regeneration sidestream treatment

**Frank, 2017**

# Evaluation Tools –Modeling

- Biowin™
  - Excellent biological process model
  - Predictions of process oxygen requirements by cell
  - Allows modeling of gas-phase, but is iterative process
  - Off gas from one cell is feed gas to next; requires manual adjustment between model runs
- SUMO™
  - Similar to Biowin™ in that there is no HPO model
- GPS-X™
  - Closed or open HPO reactors can be utilized
  - Reactors in series can be modeled to avoid manual iterations
- HiPURE™
  - Developed by Michael Stenstrom
  - Dynamic model that incorporates biological processes, gas phase, O2 transfer capability



# Conclusions

- HPO systems largely not originally intended to provide nutrient removal
- Low-cost tweaking may not be feasible
- Upgrades possible to achieve nutrient removal
- No “magic” to required process configurations
- Range of evaluation tools available, the right choice depends on project goals

# References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