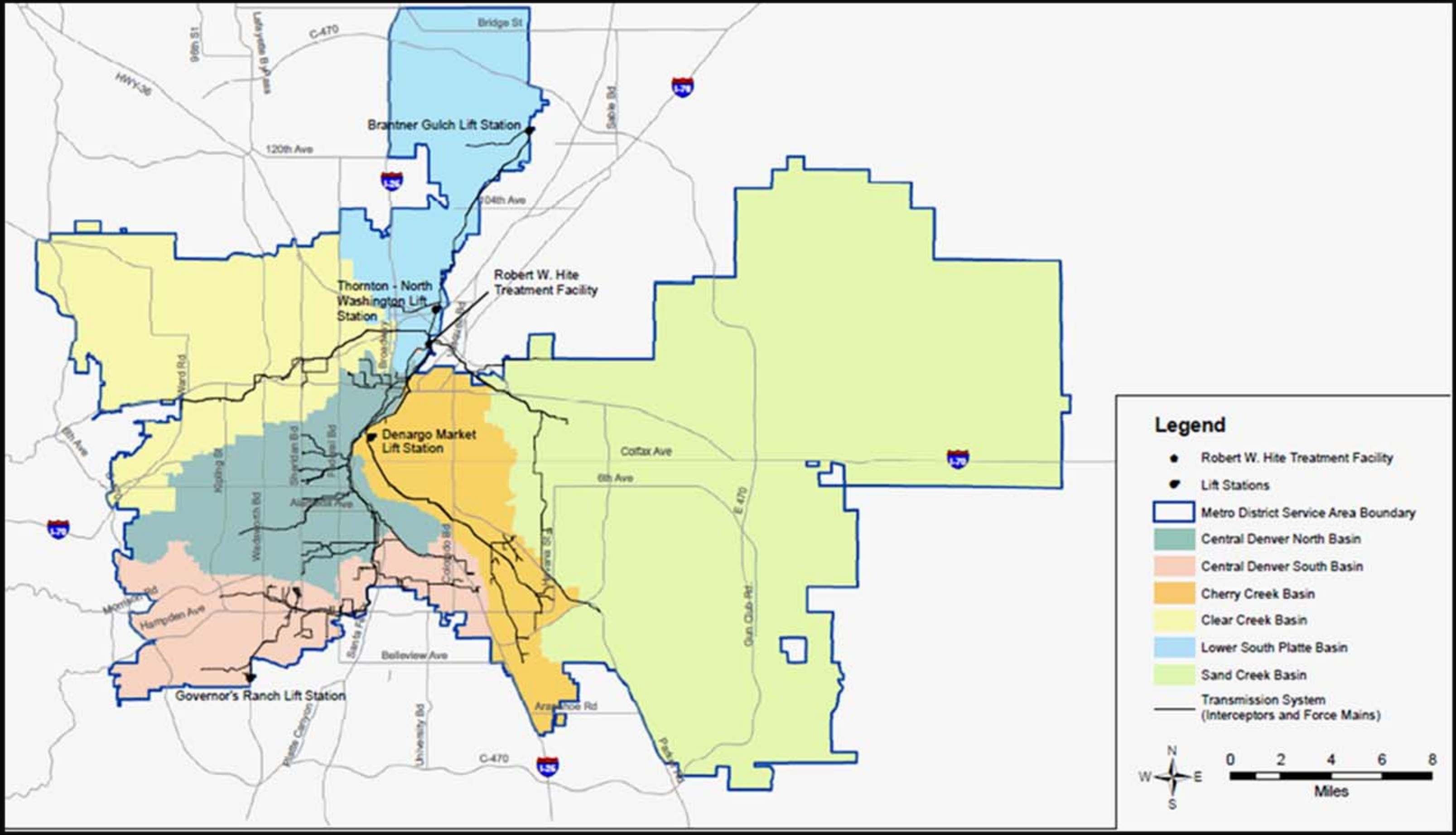
EVALUATION OF SIDESTREAM BIO-P AND DEAMMONIFICATION
A COMPACT BIOLOGICAL PHOSPHORUS AND NITROGEN REMOVAL TREATMENT APPROACH

Outline

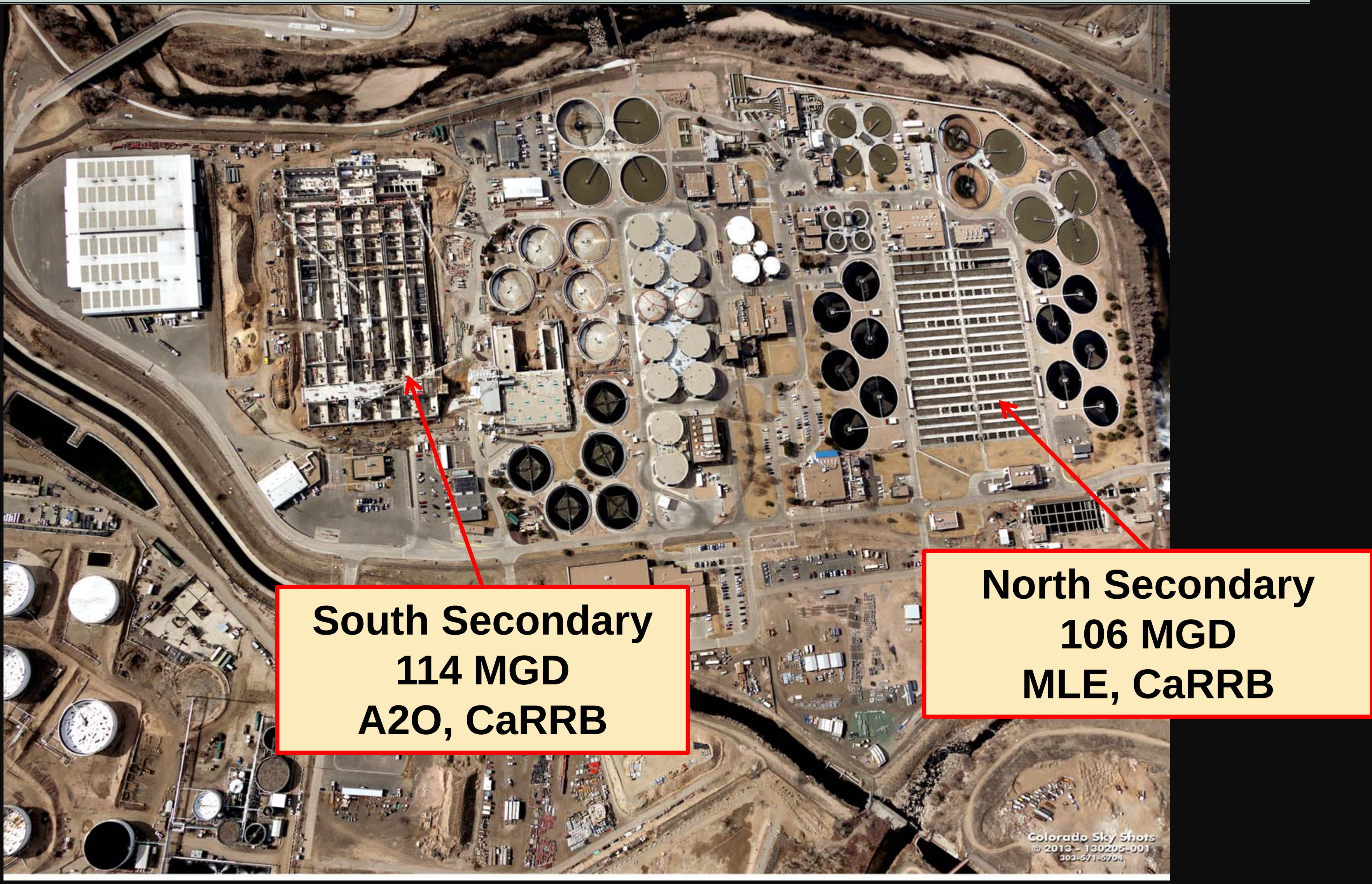
- Background
- Sidestream Bio-P Demonstration Project
- Sidestream Deammonification Pilot Study
- Concluding Remarks

Denver Metro Wastewater Reclamation District

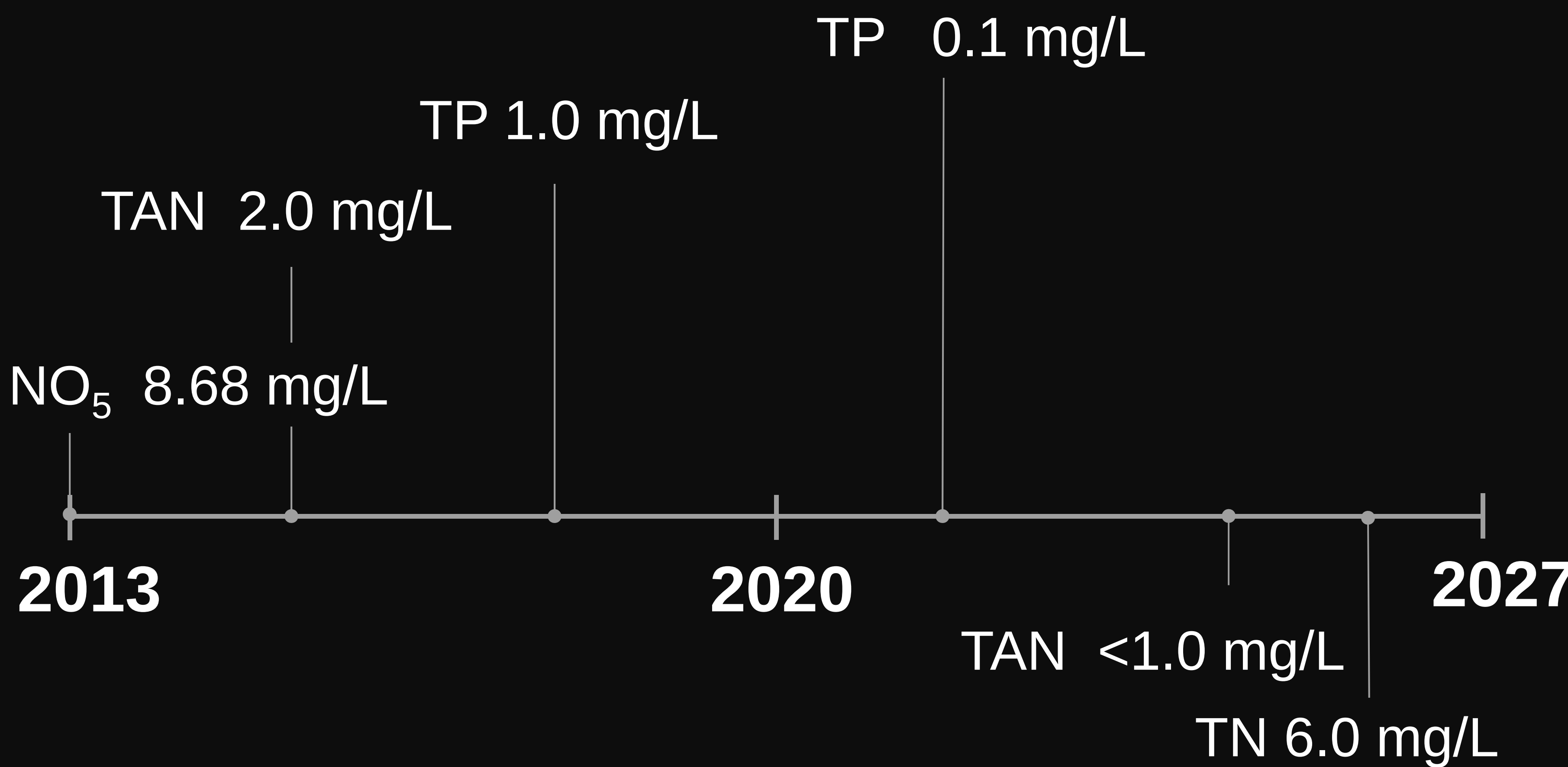
Service Area = 1.7M Population Equivalent
220 MGD Robert W. Hite Treatment Facility



Robert W. Hite Treatment Facility



Regulatory Drivers

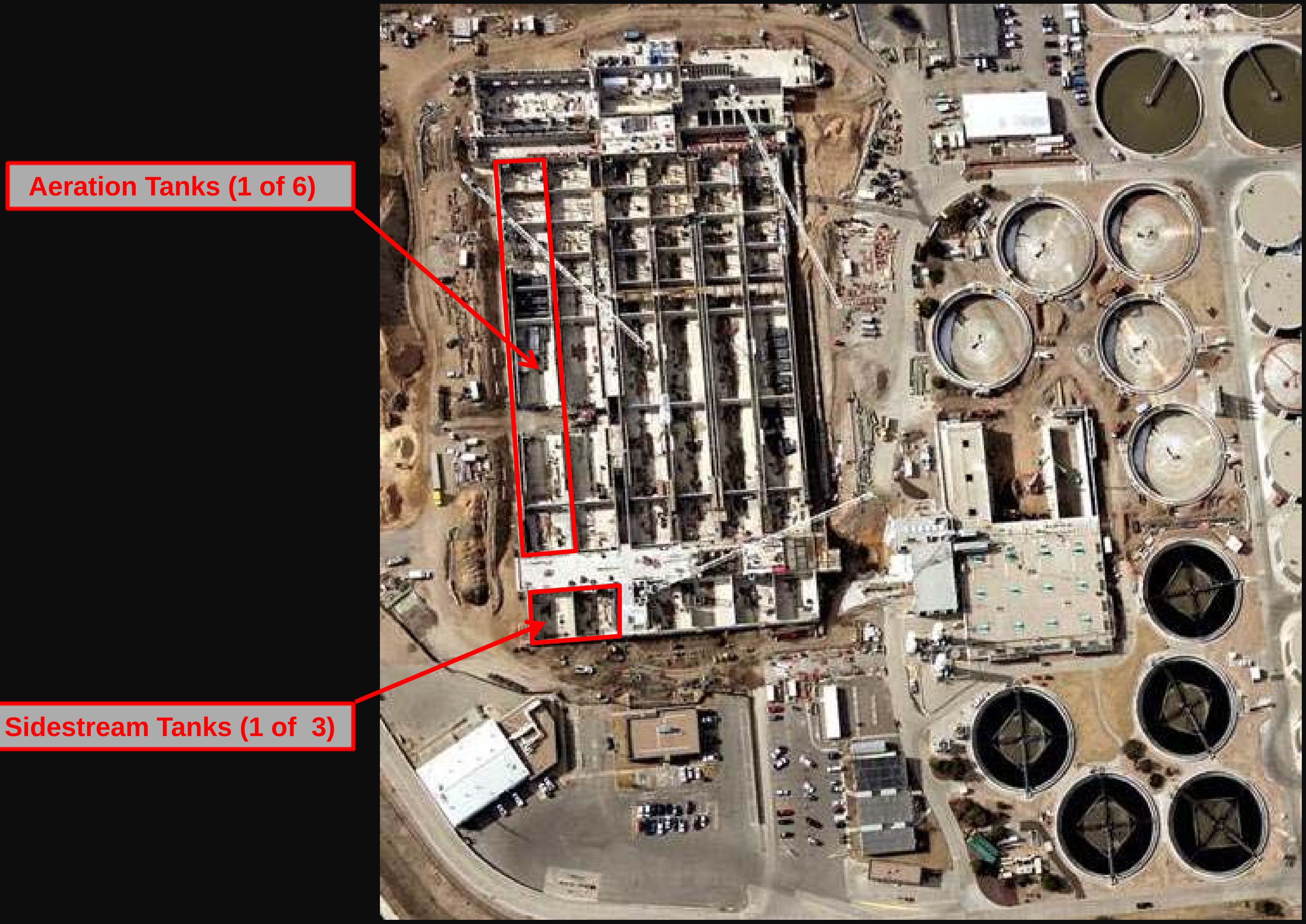


There Are Other Drivers

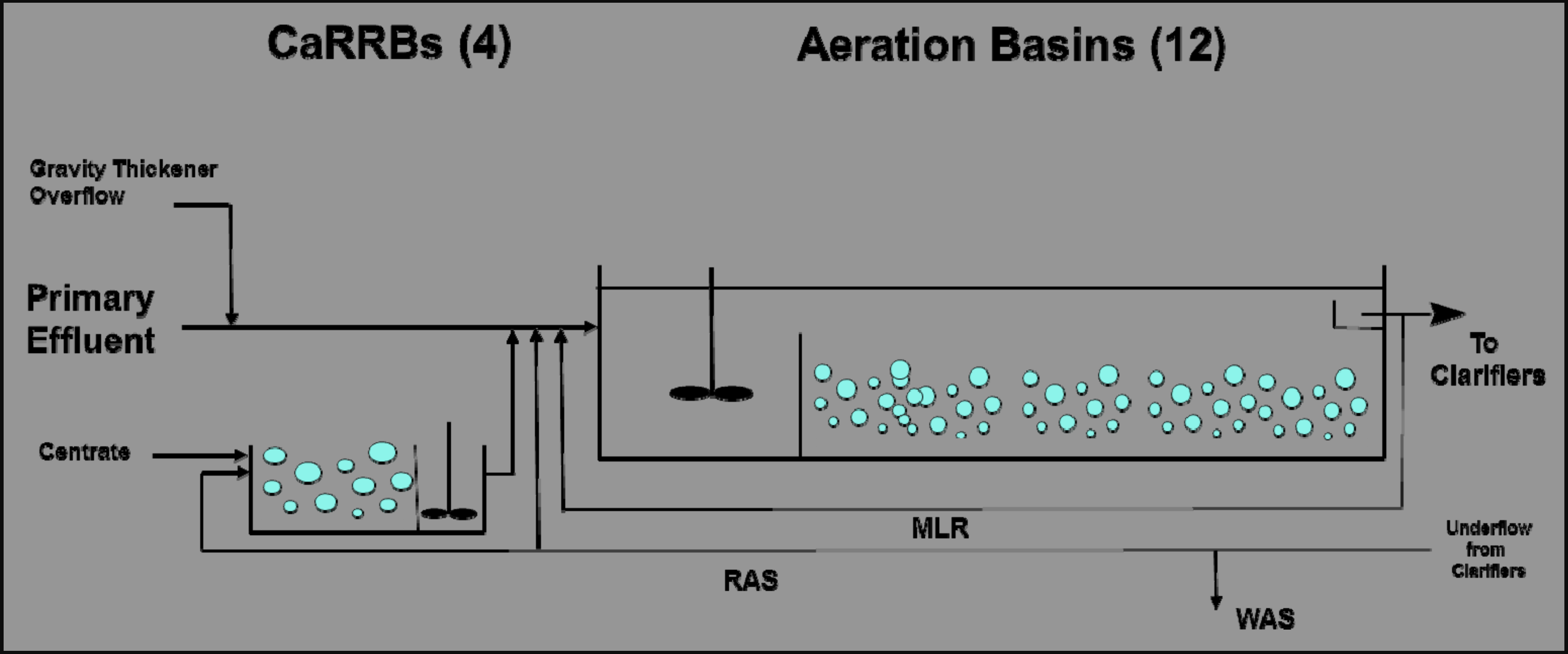
- Capital Cost (CAPEX)
  - Chances of Success
    - 100% Certainty
    - Managing Risks
- Operating Cost (OPEX)
  - Operating Culture
  - Performance Culture?
- Site Constraints
- Money Value of Time

North Secondary with CaRRB

South Secondary with CaRRB

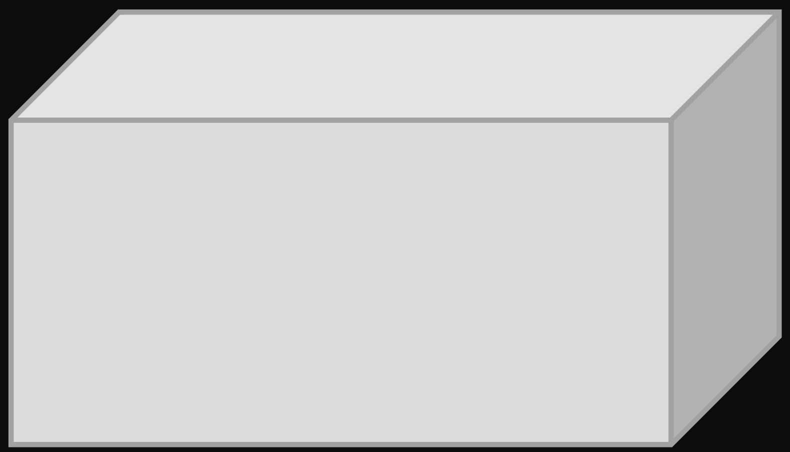


CaRRB Schematic

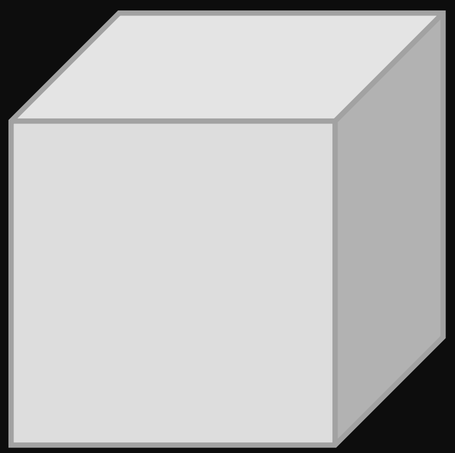


NSEC 4.25 day Aerobic SRT @ 16 C
SSEC 6.00 day Aerobic SRT @ 16 C

Sidestream RAS Reactors



1-day's worth of SRT
MLSS = 3,000 mg/L
Tank Volume = 1 Unit

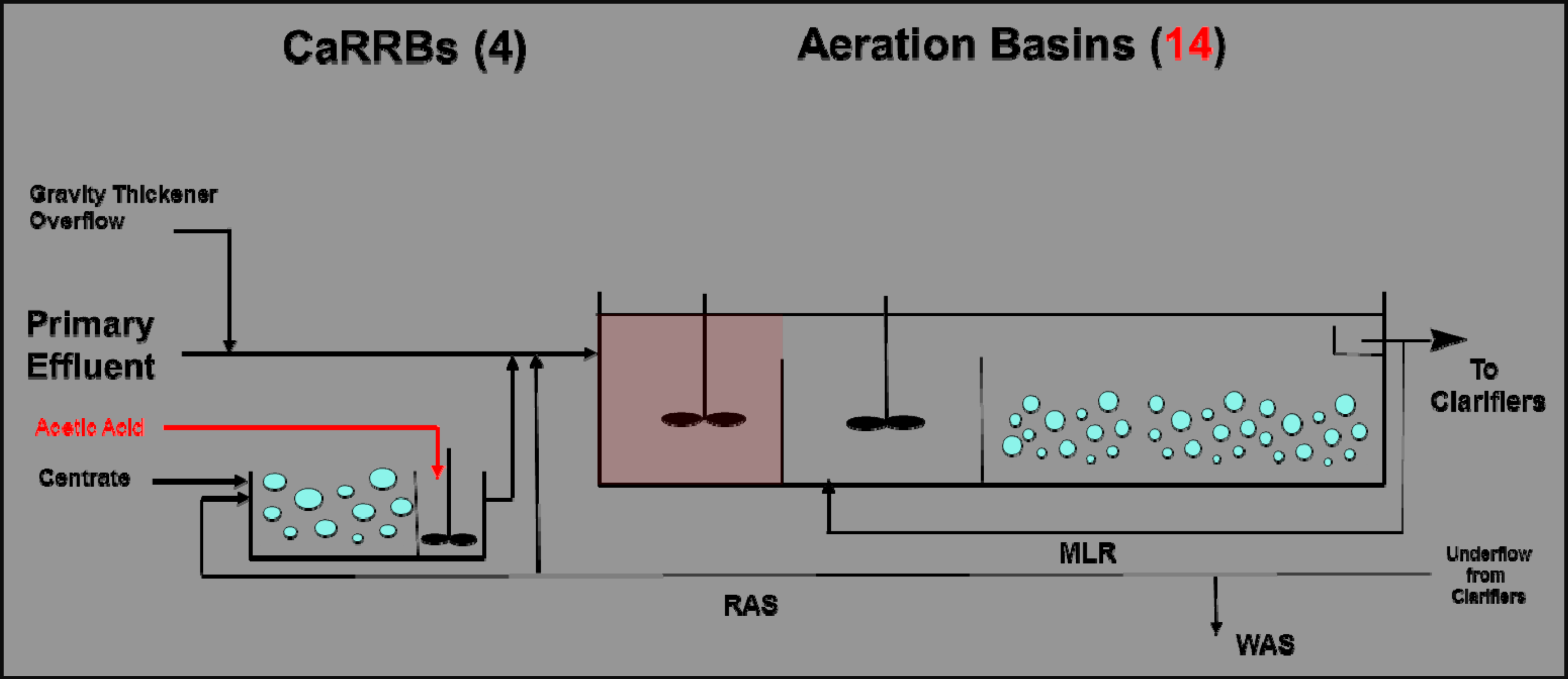


1-day's worth of SRT
MLSS = 6,000 mg/L
Tank Volume = 0.5 Unit

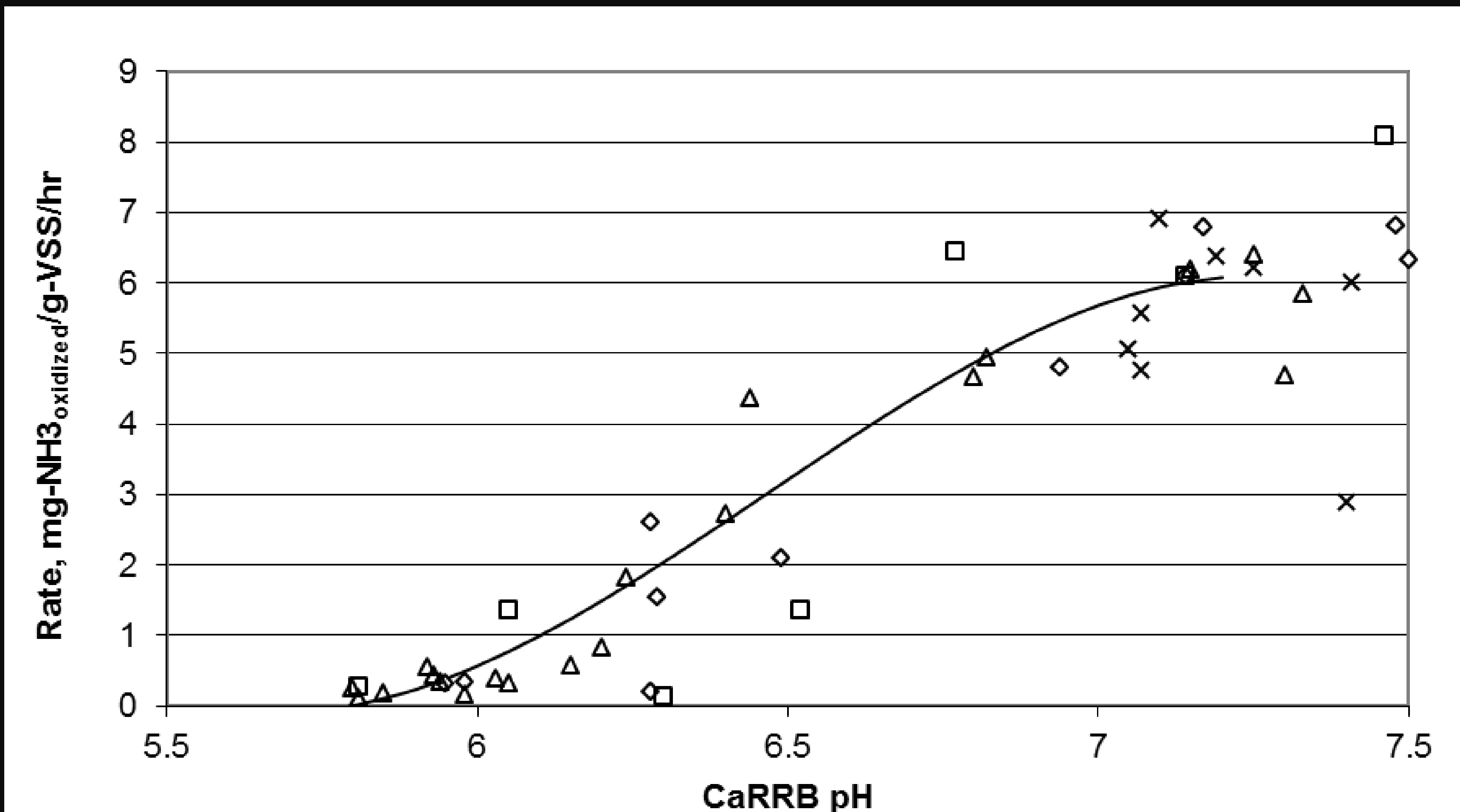
Outline

- Background
- Sidestream EBPR Demonstration Project

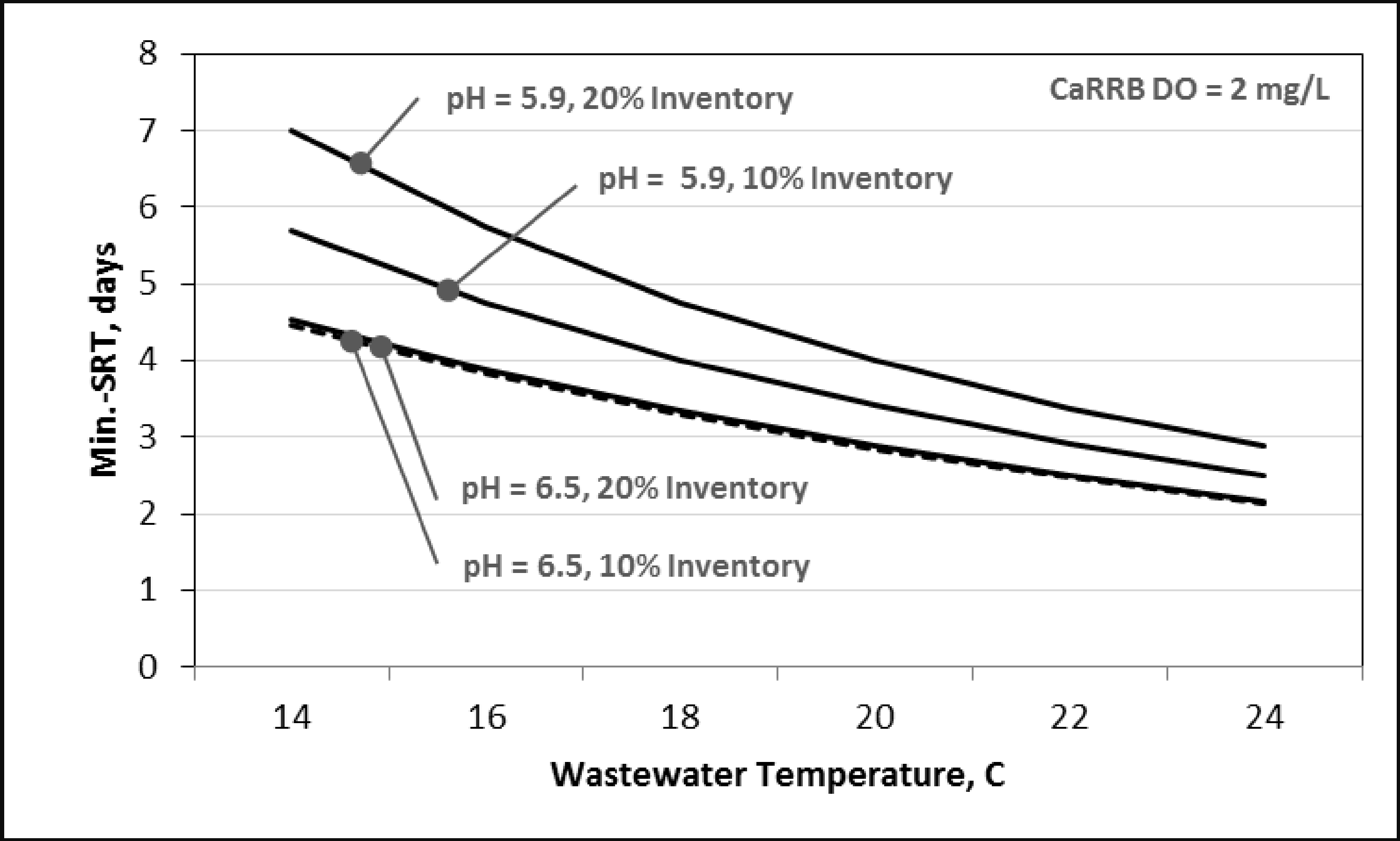
Original EBPR Approach



Influence of pH in CaRRB



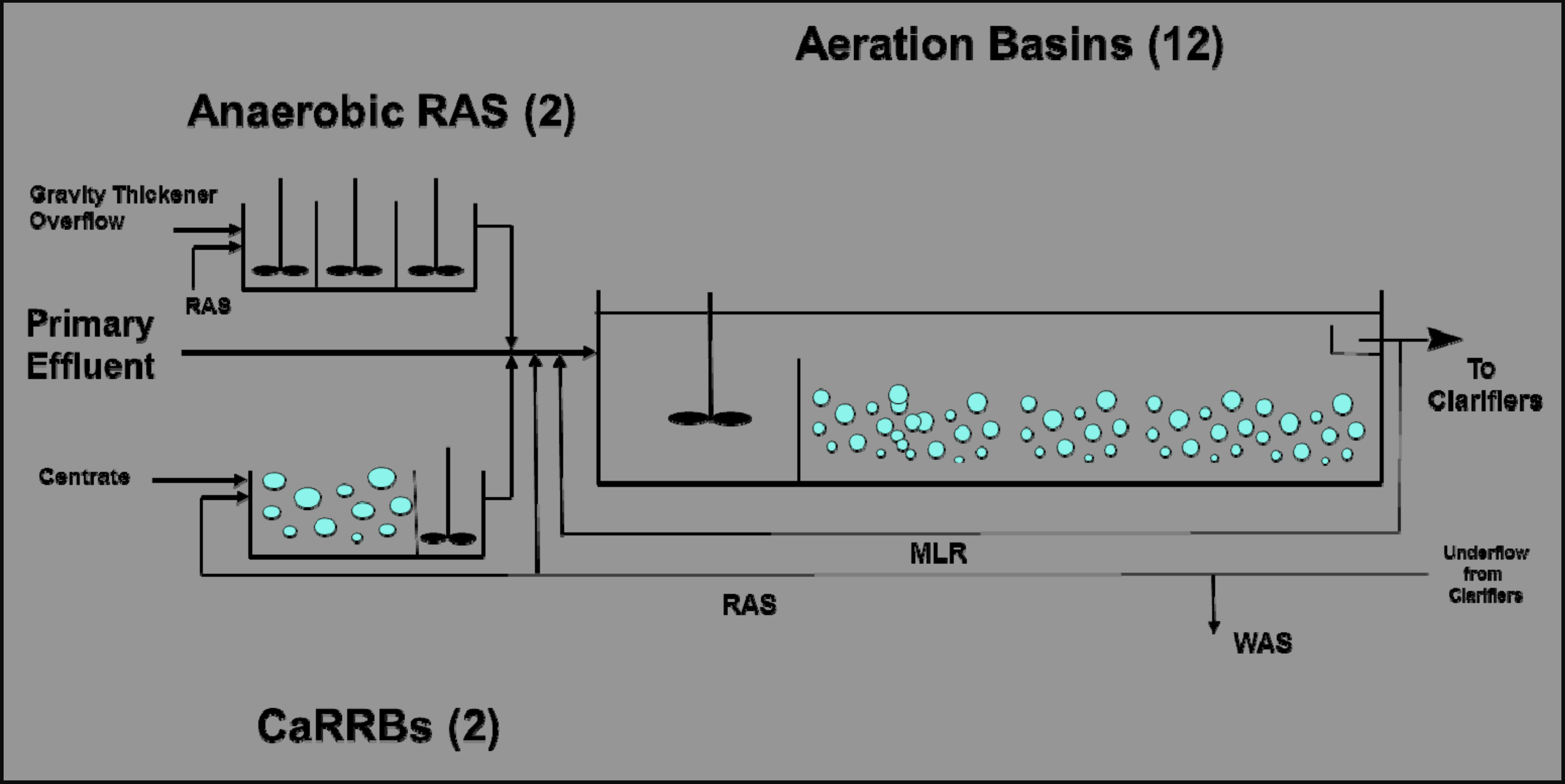
Operating Experience Supports "Re-purposing" Two Reactors



McQuarrie J., Holland P., Rauch-Williams T., Barnes C., (2012), Practical Application of an SRT Calculator Tool that Accounts for pH, DO, and Temperature, Proceedings of WEFTEC 2012, Water Environment Federation Alexandria, VA

GVT + Anaerobic RAS Reactor

An Alternative EBPR Schematic



$175k of Physical Modifications

Two Anaerobic RAS Reactors

Temporary Gravity Thickener Overflow Feed

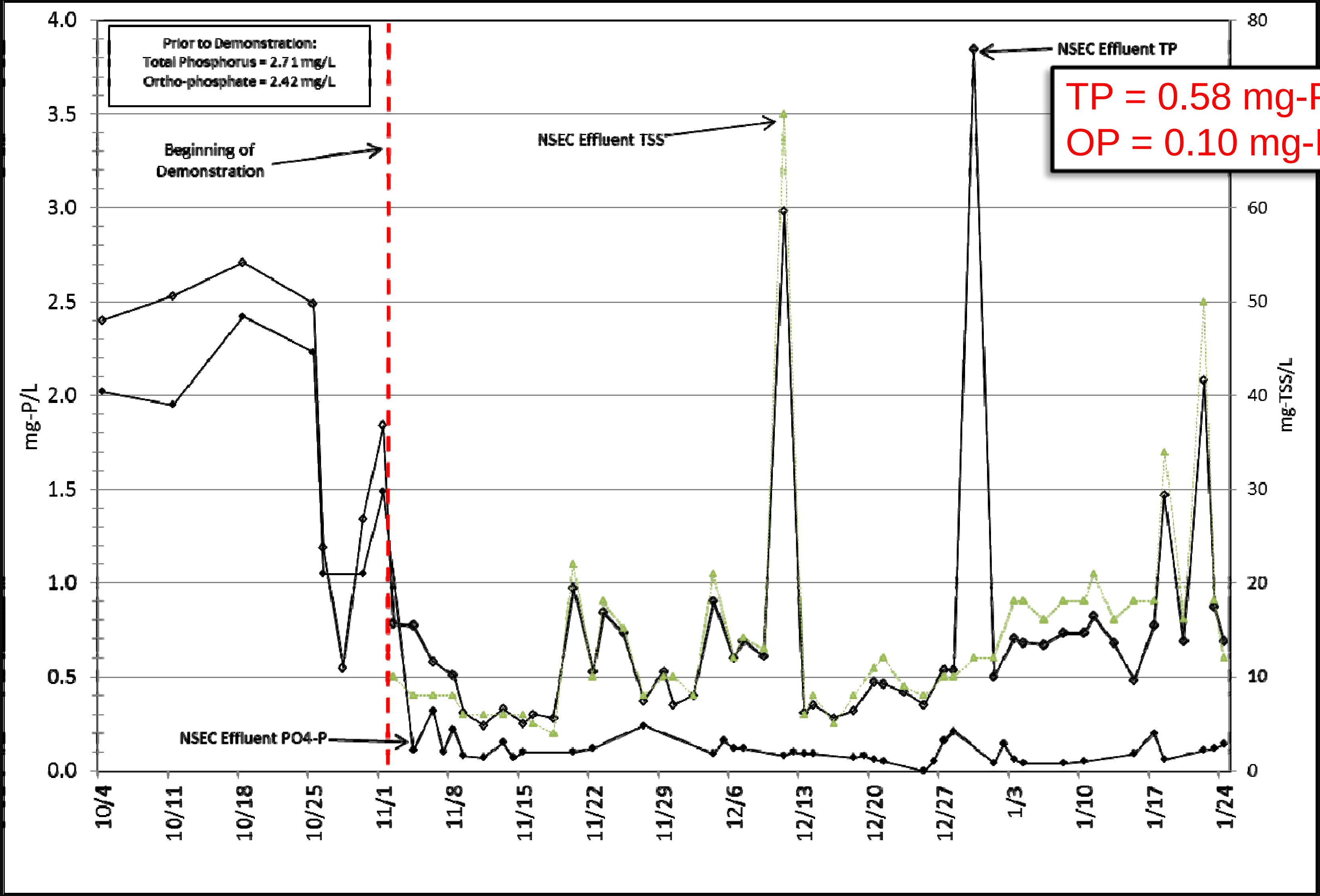
Study Curiosities

- Less than 1/3 of RAS through Anaerobic Reactor
- 0.3 to 0.5-day anaerobic SRT
- 1.3-hr anaerobic HRT
- 80% to 100% of the centrate returned to NSEC
  - Option to precipitate some PO_4 in centrate
- 100% of the gravity thickener effluent to NSEC
  - Low C:P ratio compared with literature
  - No formal provisions to promote fermentation
- Very low energy mixing (2.5 W/m^3)

9-Month Full-Scale Study

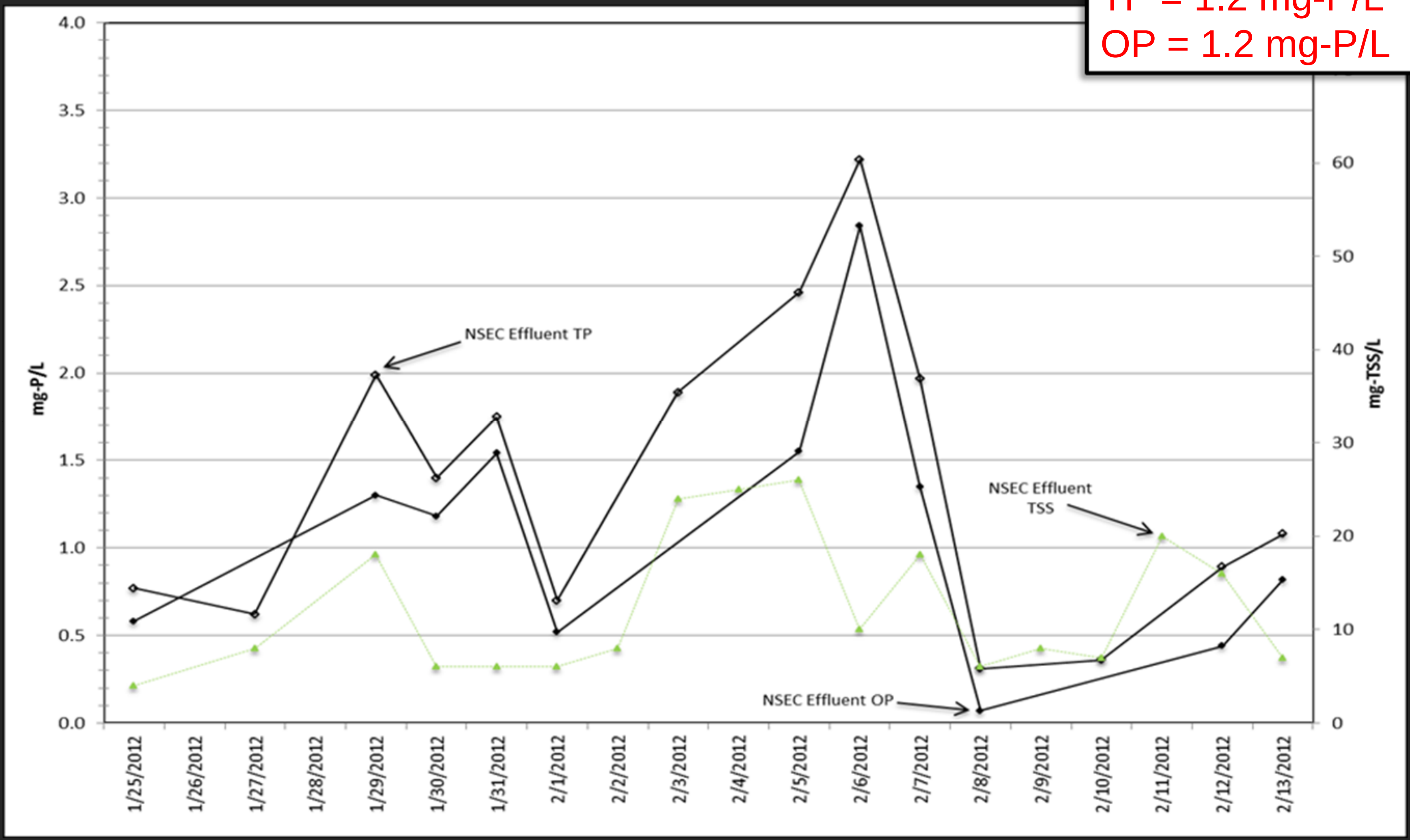
- *Phase I* Proof of Concept
- *Phase II* Influence of Gravity Thickener Operation
- *Phase III* Influence of PAX for *M. parvicella* Control
- *Phase IV* RAS Fermentation
- *Phase V* Increase in Centrate N and P Load
- *Phase VI* Bind some PO_4 in Centrate Return (Proof of Concept)
- Phase VII Acetic Acid in place of Gravity Thickener

Phase I – Proof of Concept



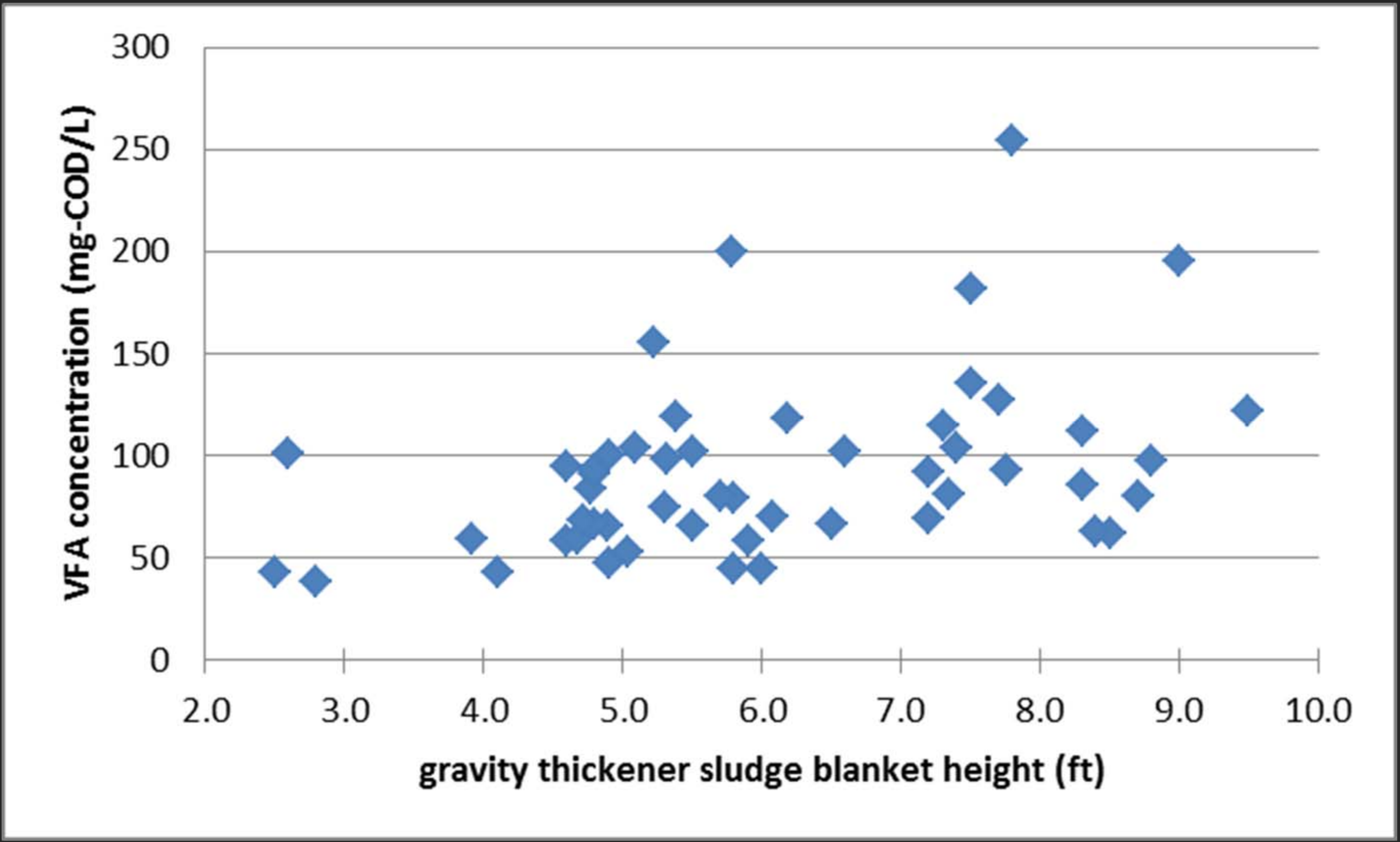
TP = 0.58 mg-P/L
OP = 0.10 mg-P/L

Phase II – Varied SRT in GVT



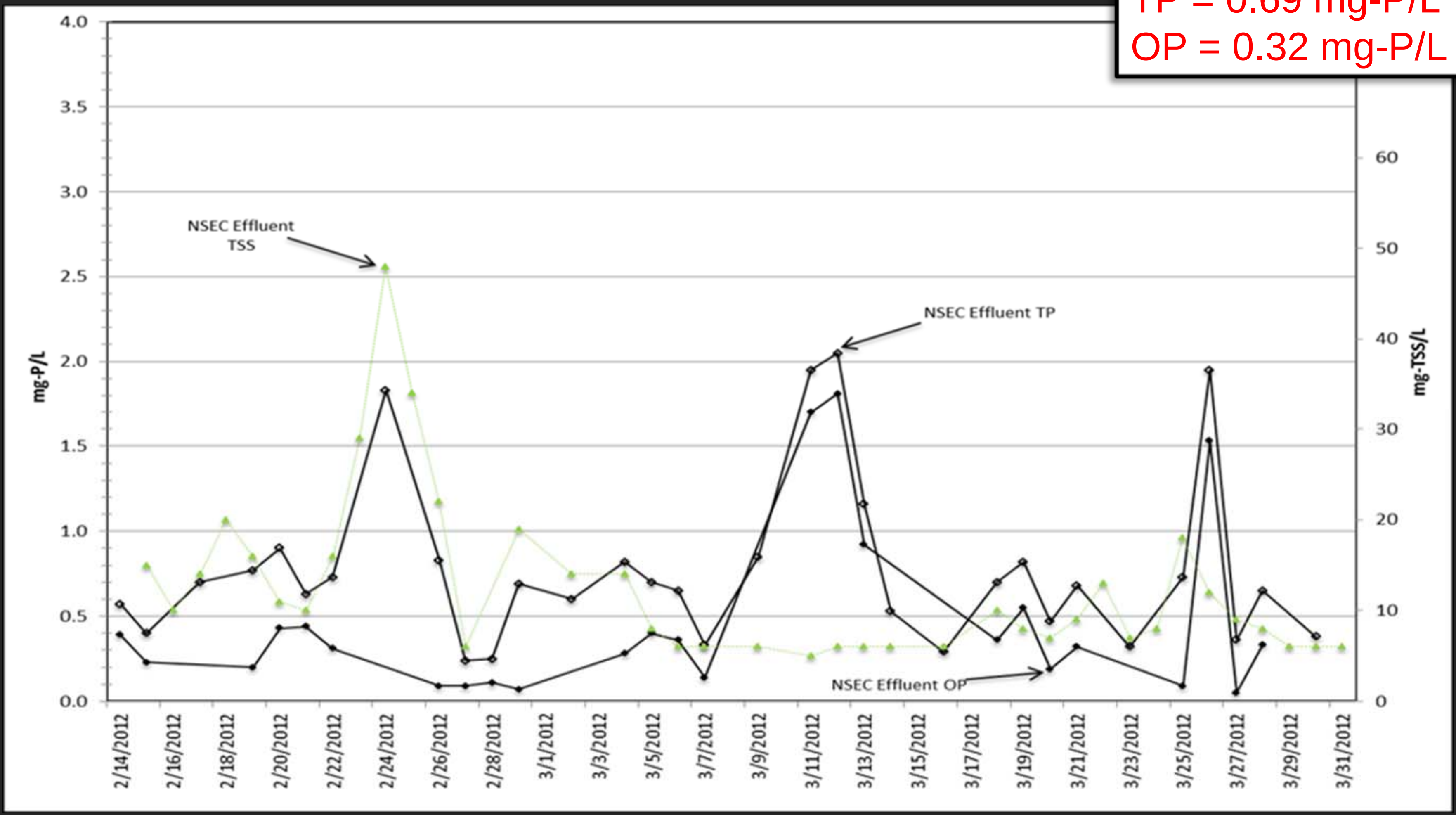
TP = 1.2 mg-P/L
OP = 1.2 mg-P/L

GVT SRT and VFA



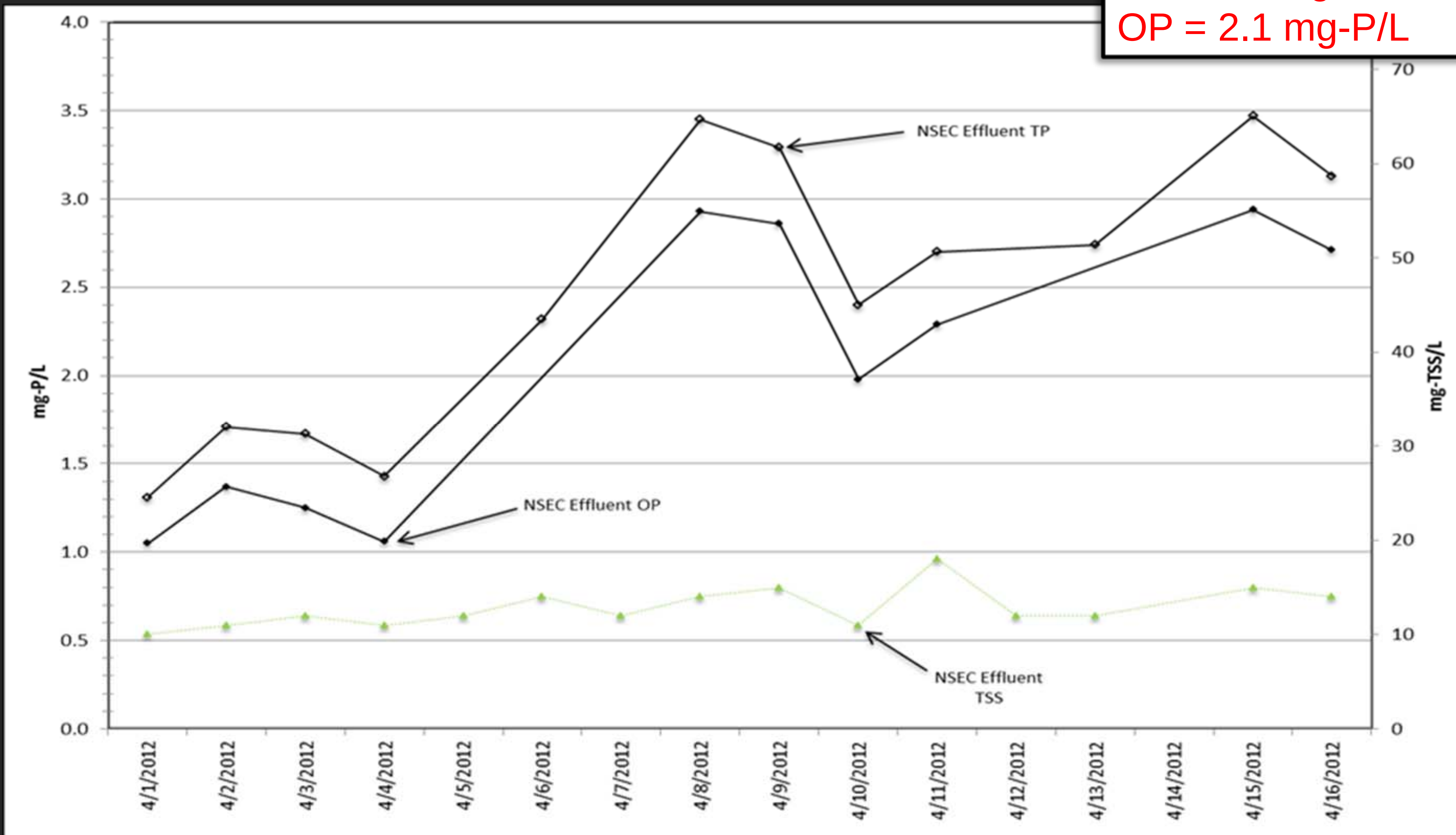
Phase III – Influence of PAX

TP = 0.69 mg-P/L
OP = 0.32 mg-P/L



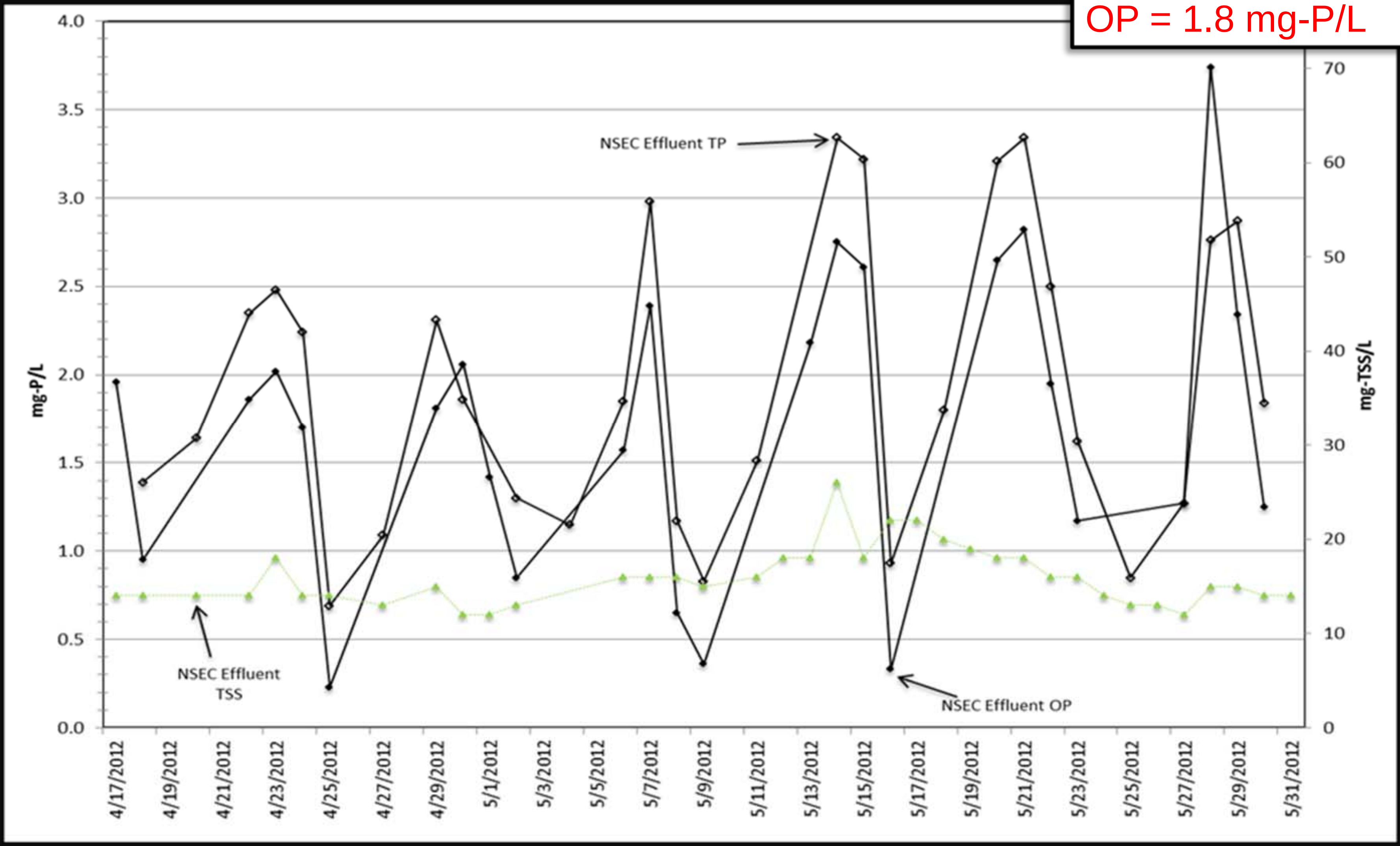
Phase IV – RAS Fermentation

TP = 2.1 mg-P/L
OP = 2.1 mg-P/L



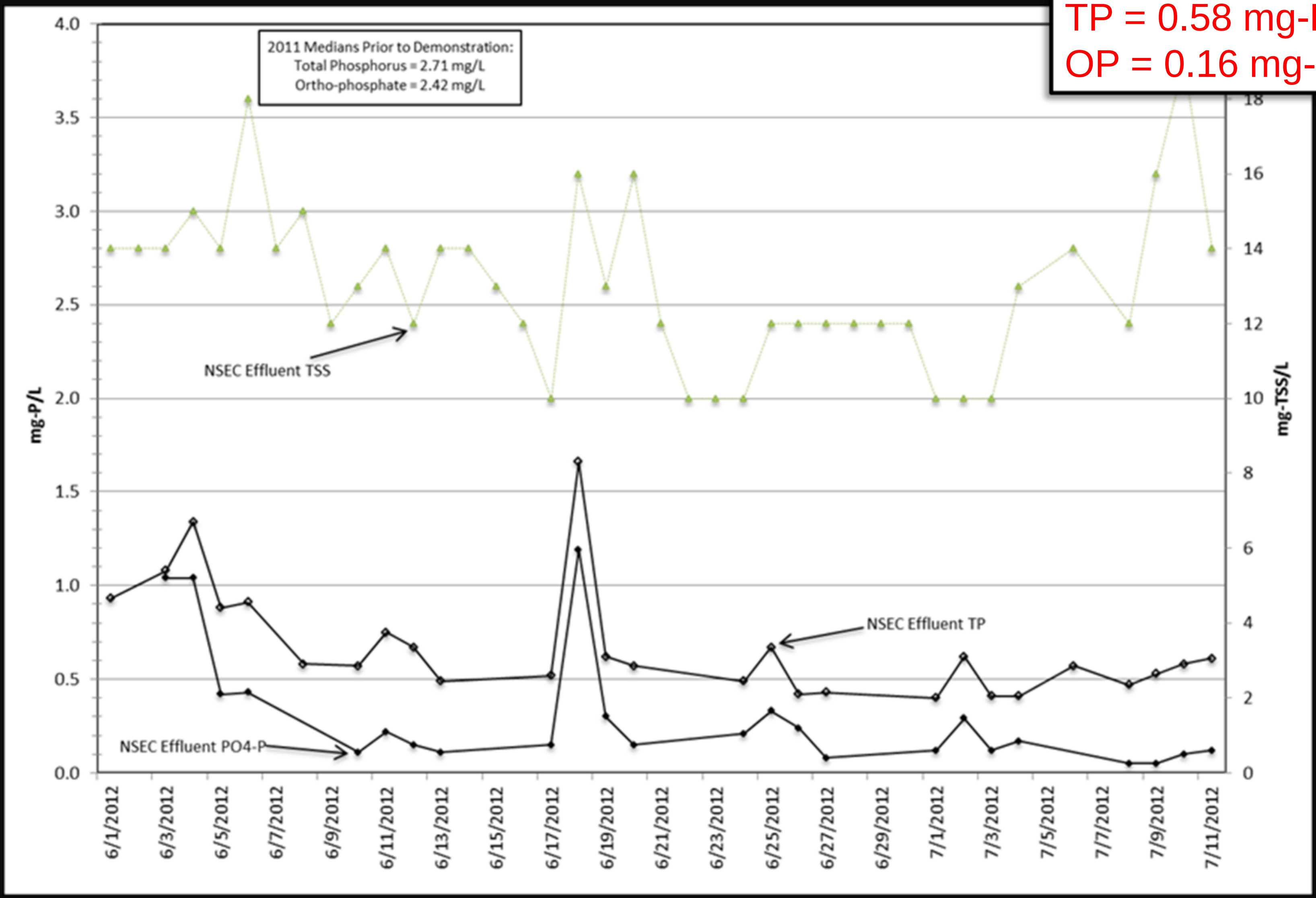
Phase V – Increase Centrate N & P Load

TP = 1.8 mg-P/L
OP = 1.8 mg-P/L

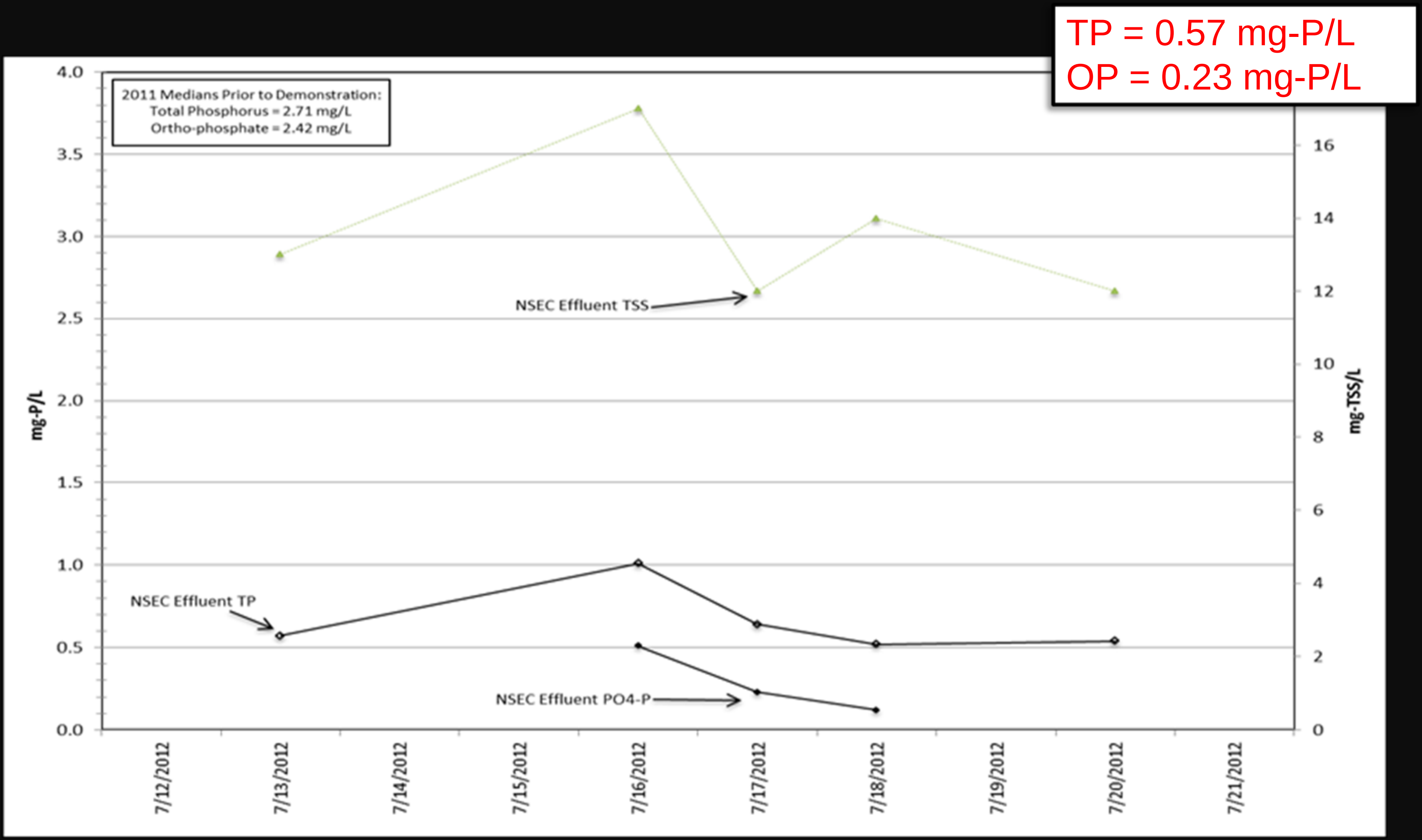


Phase VI – Bind Some PO4 in Centrate Return (Prove the Concept)

TP = 0.58 mg-P/L
OP = 0.16 mg-P/L



Phase VII – Acetic Acid



BOD:ΔP Ratio

Type of BPR Process	BOD/ΔP (mg BOD/mg P)	COD/ΔP (mg COD/mg P)
High efficiency (e.g., A/O without nitrification, VIP, UCT)	15 – 20	26 – 34
Moderate efficiency (e.g., A/O and A^2/O with nitrification)	20 – 25	34 – 43
Low Efficiency (e.g., Bardenpho)	> 25	>43
District EBPR Trial	2.5 – 7.5 (median = 4)	4 – 13 (median = 7)

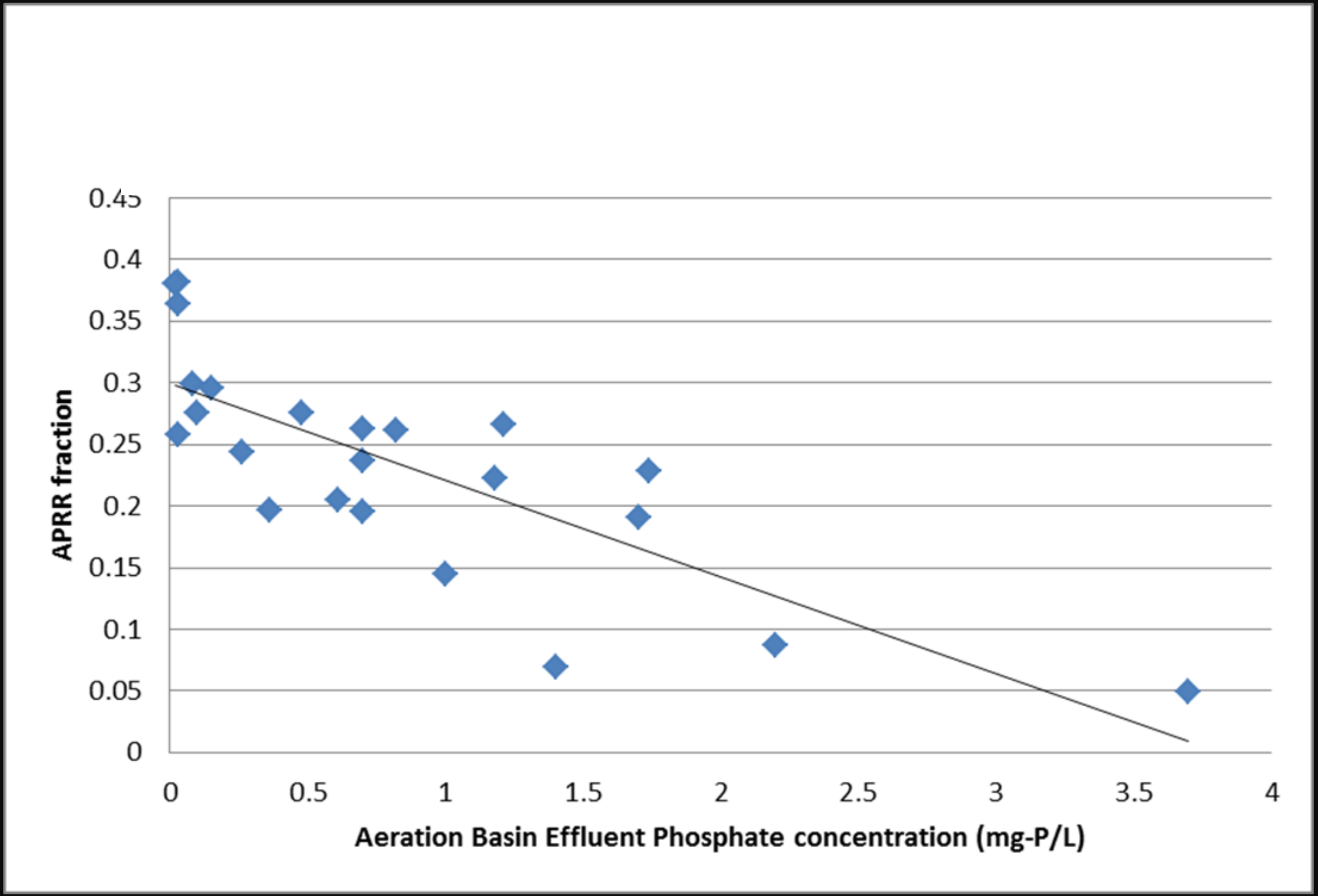
BOD:ΔP Ratio

- Separate carbon feed points for BPR and BNR
- Just 30% of RAS Rate to Anaerobic Reactor
- High-rate Short SRT System
- Minimum mixing energy allowing large-particle flocculation.
- Long HRT design (hydrolysis – fermentation)

Summary of Phases

Phase	SRT-Anaerobic	RAS through Reactor	OP Uptake kg-P/day	Effluent TP Mg-P/L
I	0.49	18%	1,700	0.58
II	0.48	18%	1,300	1.2
III	0.43	18%	-	0.69
IV	0.39	19%	940	2.1
V	0.36/0.44	21%/32%	950/1,100	1.8
VI	0.46	30%	1,400	0.58
VII	0.50	30%	1,400	0.57

Anaerobic P Release Rate

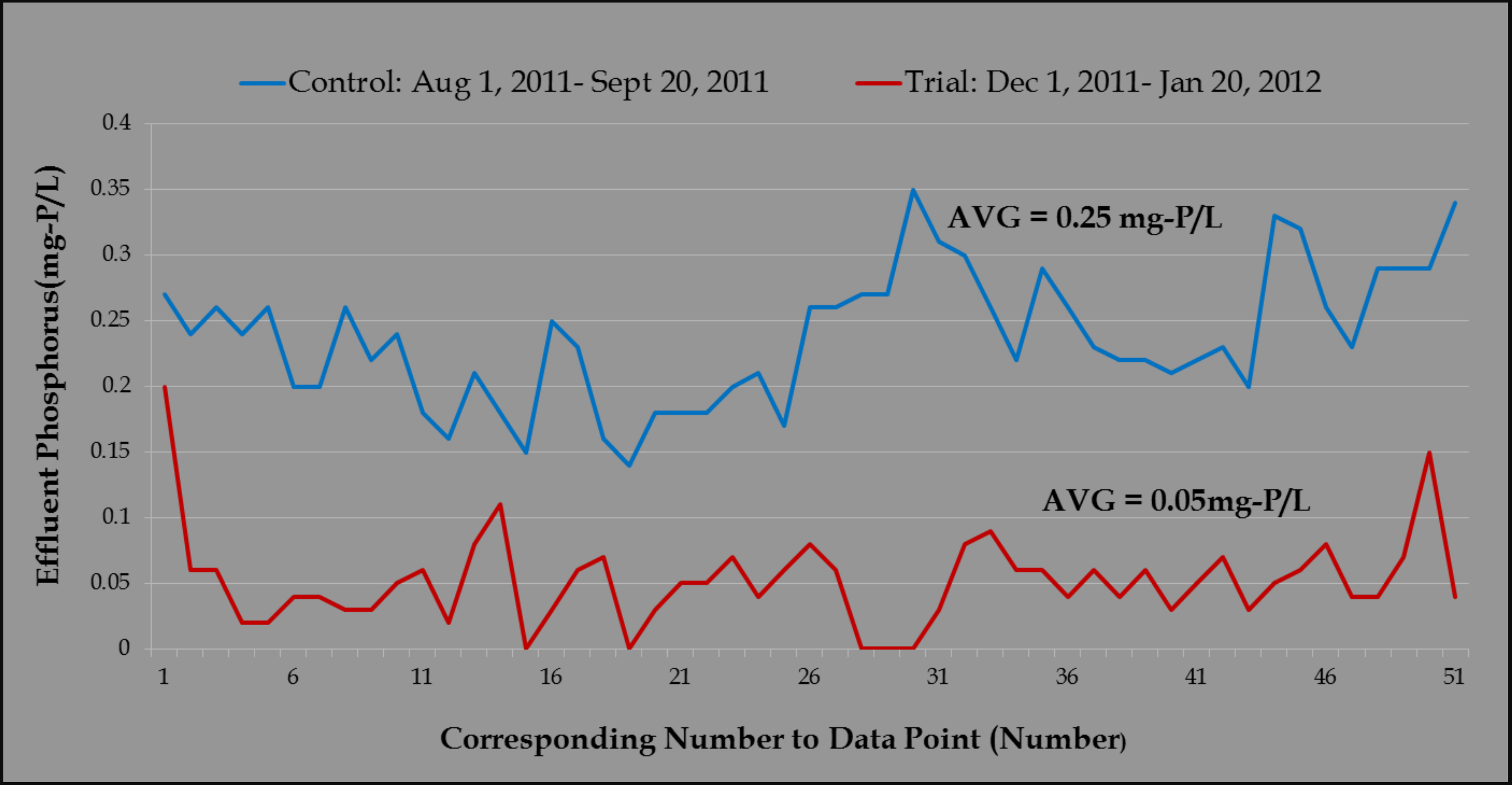


Comeau, Y., Oldham W.K., and Hall K.J., 1987. Dynamics of carbon reserves in biological dephosphatation of wastewater. In *Proceedings of an International Association on Water Pollution Research and Control on Biological Phosphate Removal from Wastewaters*, ed. R. Ramadori, 39-55. Oxford: Pergamon Press.

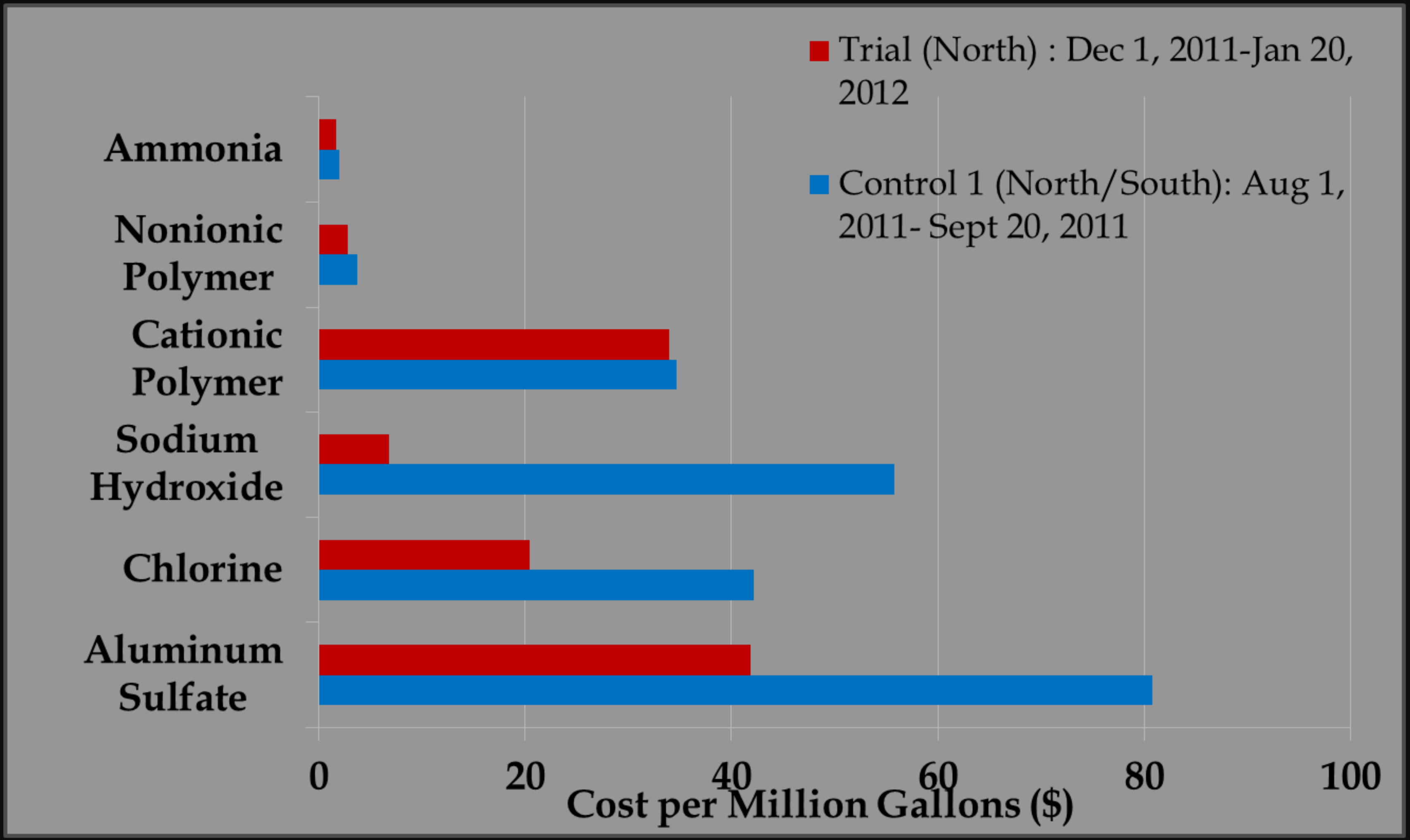
Areas of Optimization

- Anaerobic SRT is sensitive to SVI and RAS Rate
- Optimum Percentage of RAS to send through the Anaerobic Reactor to Condition PAOs
- Matching Phosphorus load with VFA load
  - Ensure a P-limited EBPR process
- Consider Acetic Acid to "backstop" process
  - Low Anaerobic SRT
  - High P load

Denver Reuse Facility Experience



Denver Reuse Facility Experience



Windom, L., (2012), Bio Phosphorus Trial, Performed by Metro Wastewater Reclamation District, Alters Chemical Phosphorus Removal Process of Denver Water Recycling Plant, Internal Communication

Bio-P Concluding Remarks

- Findings
  - Achieved the desired level of performance
  - Can Save significant CAPEX and OPEX
  - Study led to operational refinements
- Money Value of Time
  - Managed Risk
  - Lower Cost and High Certainty
  - Sludge Dewaterability
- Reuse Facility Experience
  - The next money Value of Time?

Outline

- Background
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- Sidestream Deammonification Pilot Study

Deammonification Drivers

- **Ammonia**

  Volumetric Efficiency (A2O v. MLE w/Sidestream EBPR)
  Load Attenuation
  More Efficient with Alkalinity

- **Nitrogen**

  Carbon – Conserves Mainstream C:N Ratio

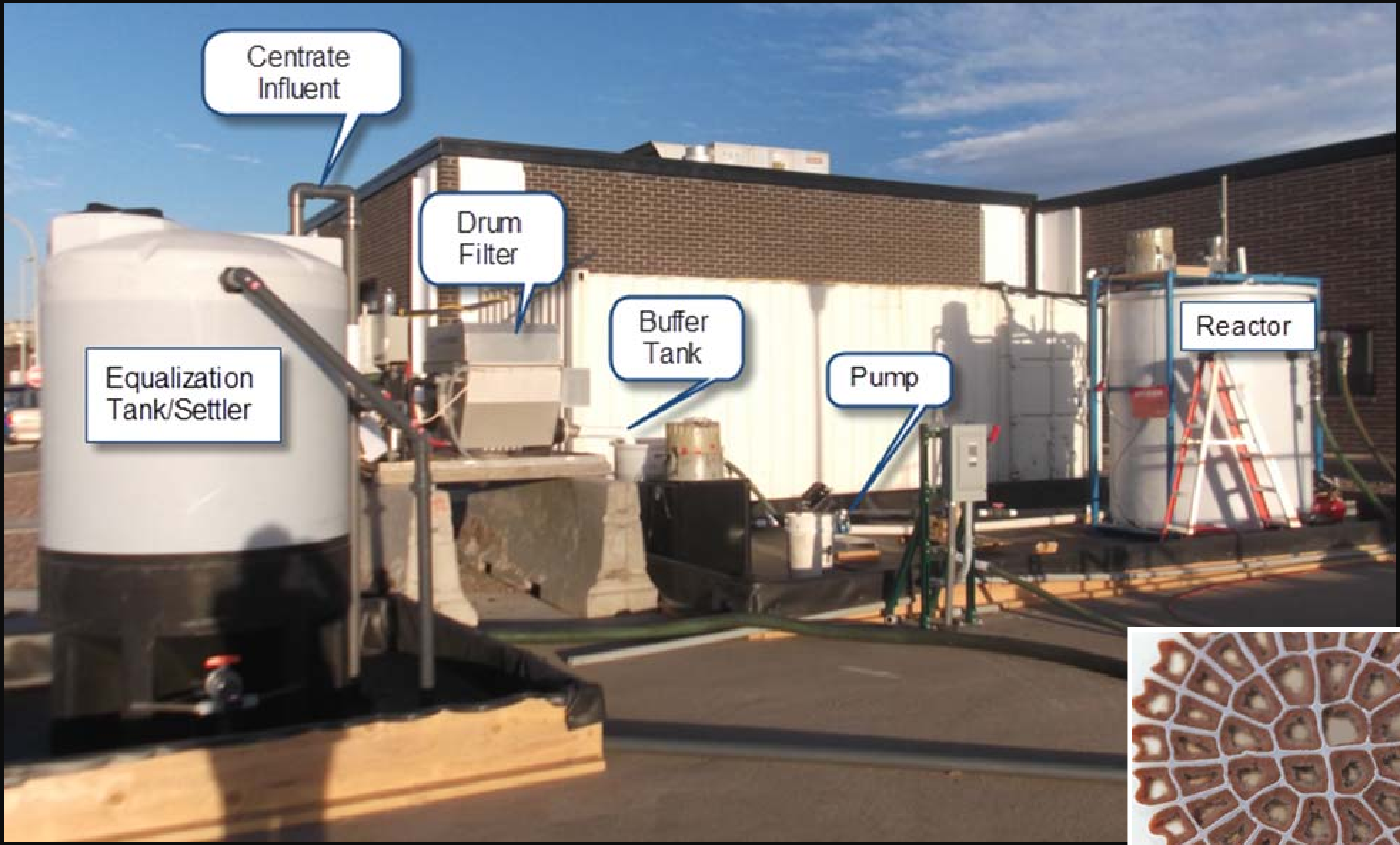
- **Phosphorus**

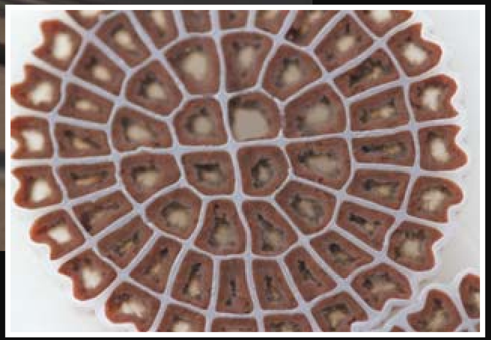
  Nitrate – Improved Nitrate Control in Anaerobic Reactors

Evaluate Three Retrofit Approaches

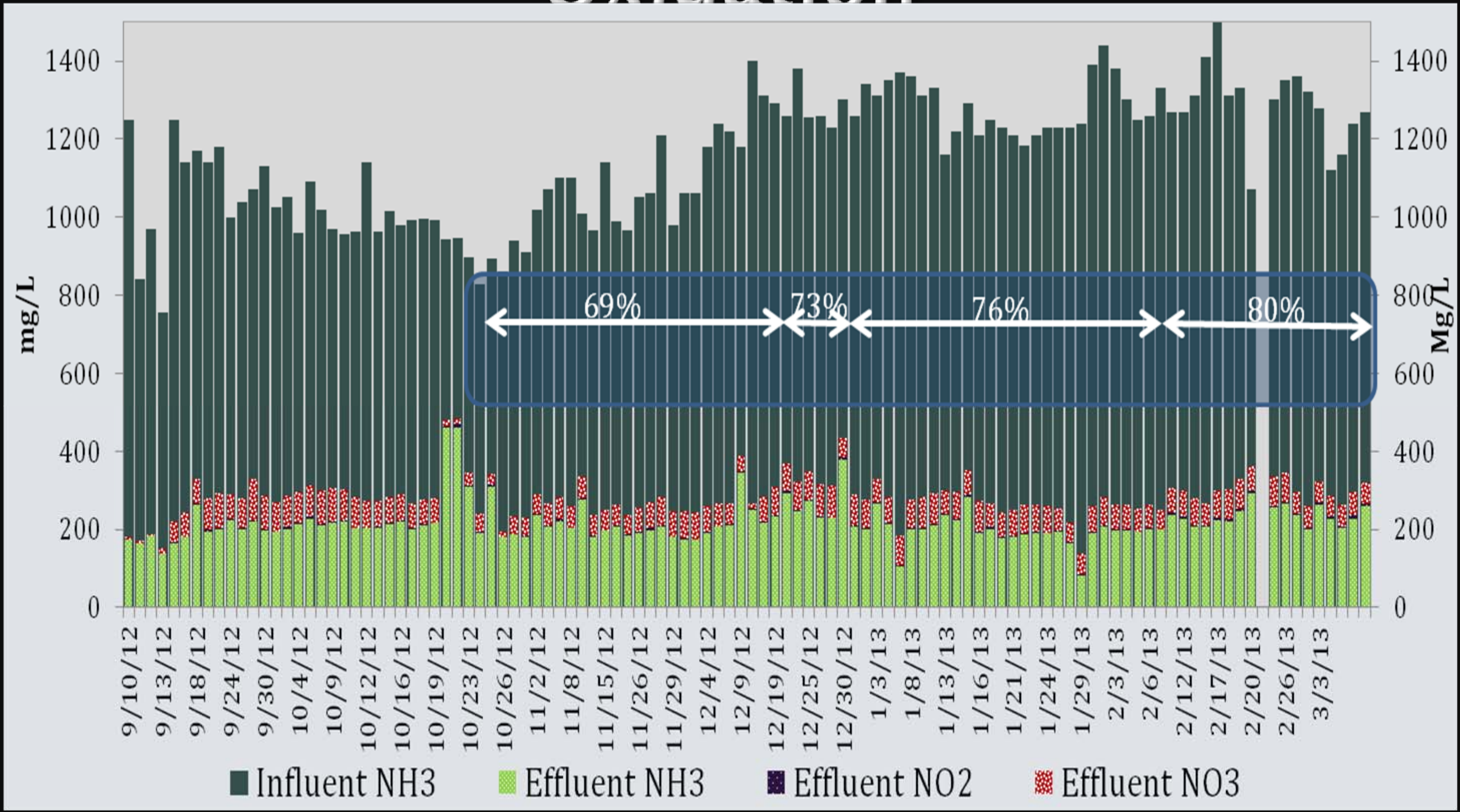
- Sequencing Batch Reactor (Chicago)
  - Demon
  - 2 of the CaRRB Reactors
- Moving Bed Biofim Reactor (Denver)
  - Anita-Mox
  - 2 of the CaRRB Reactors
- Granular Sludge Reactor
  - Paques Anammox
  - 1 CaRRB Reactor

Pilot System Overview

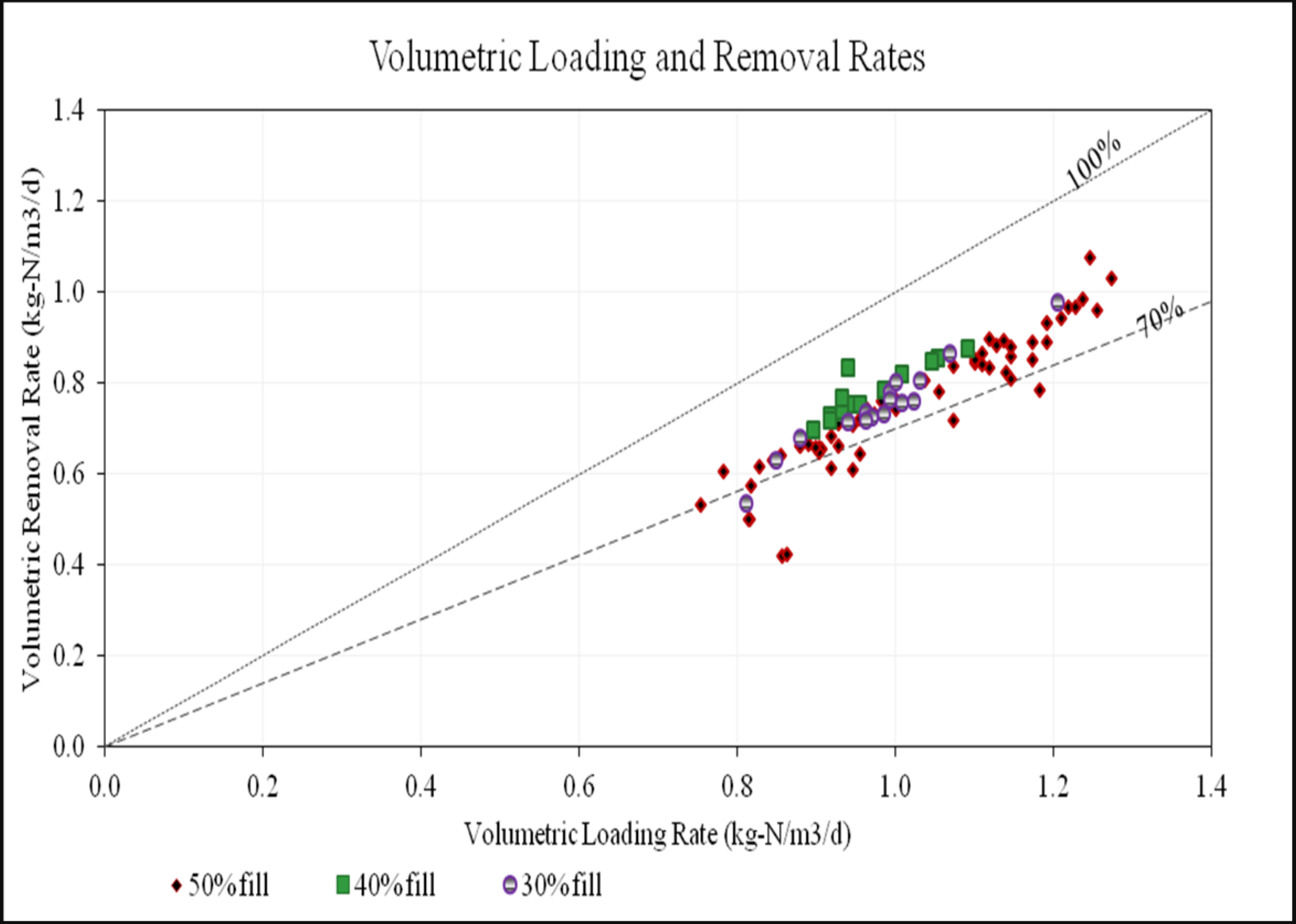




6 months of Reliable Nitrogen Elimination and Ammonia Oxidation

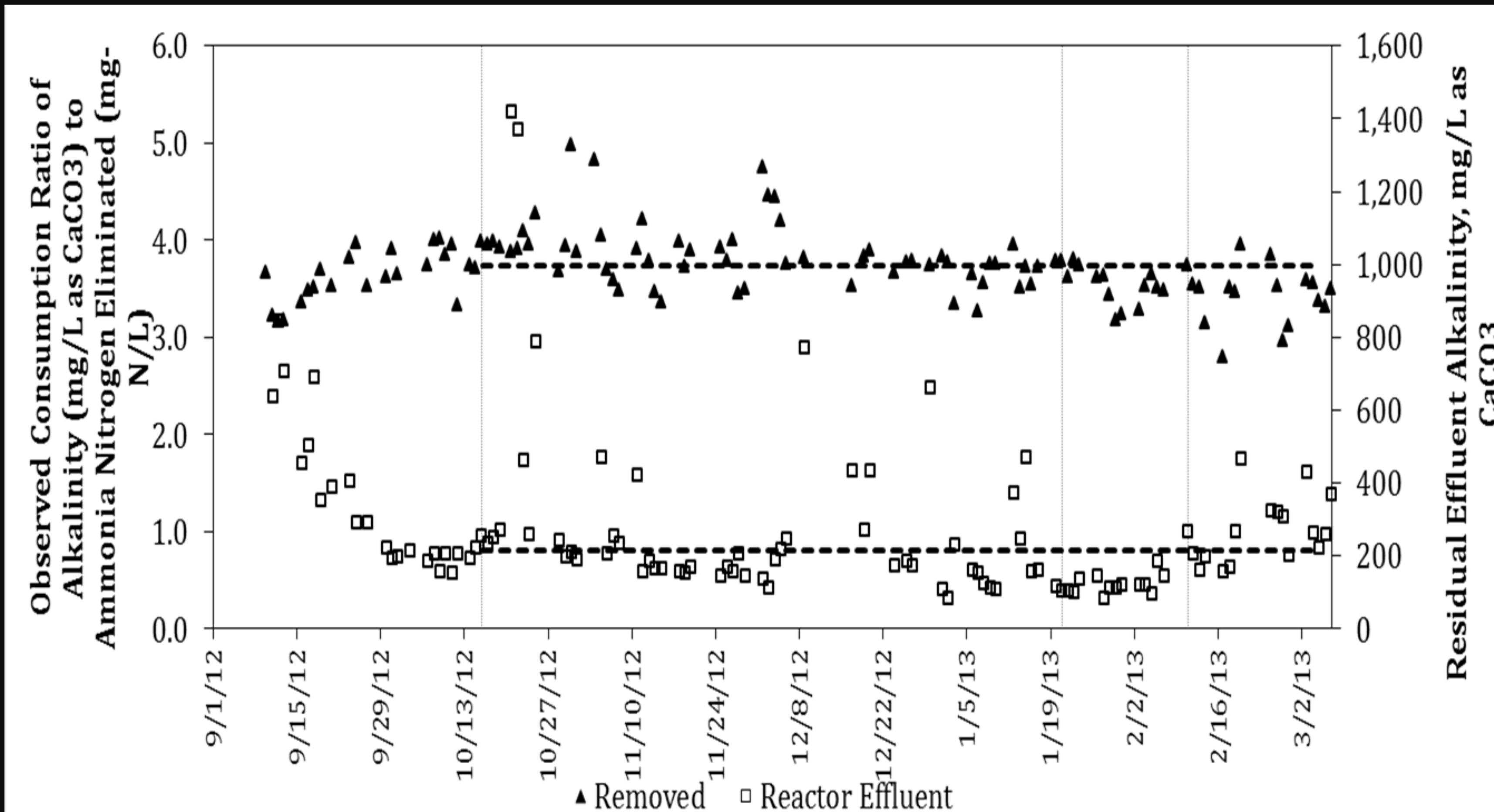


Volumetric Efficiency



Vazquez-Padin's Activity Expressions

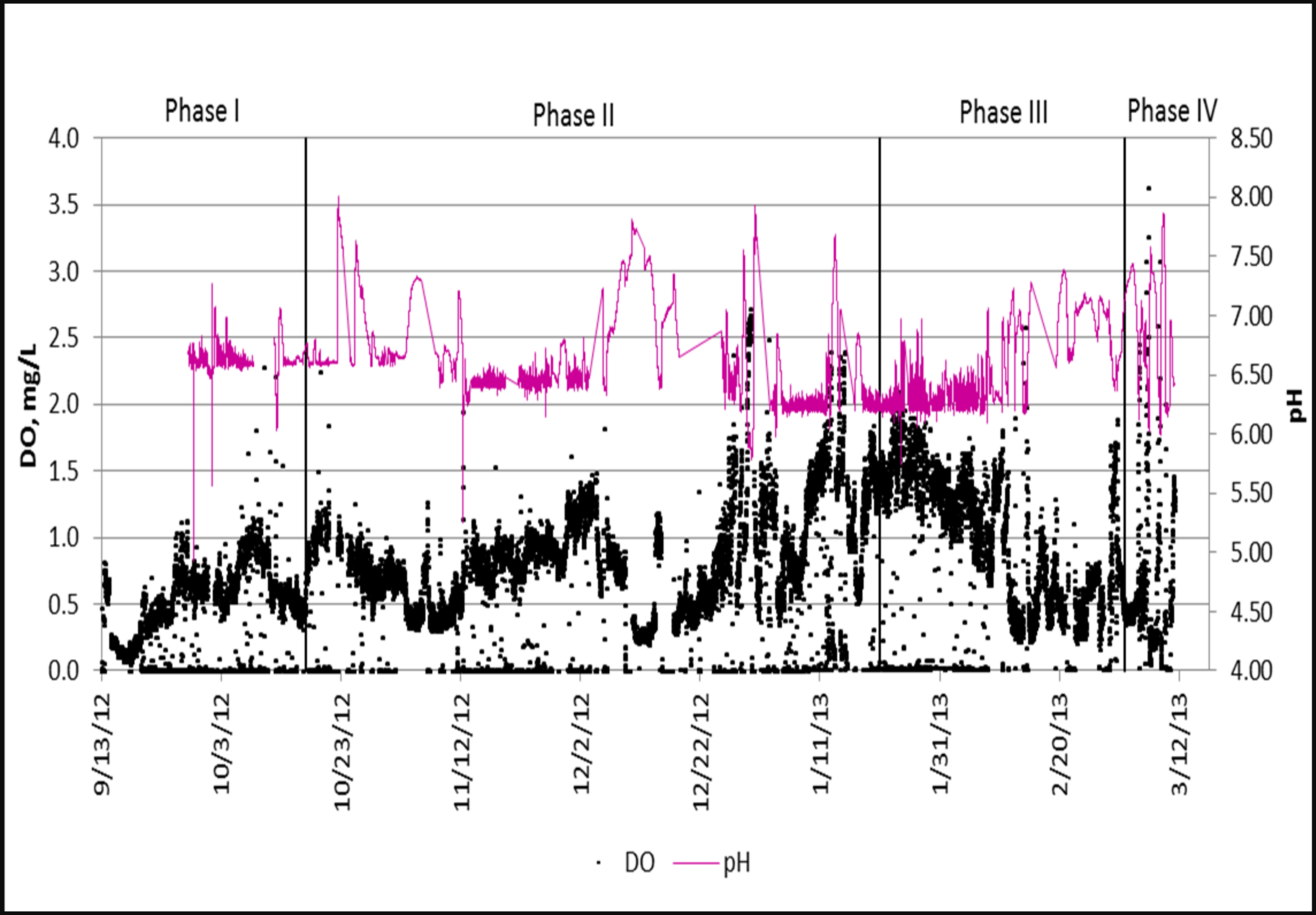
Alkalinity



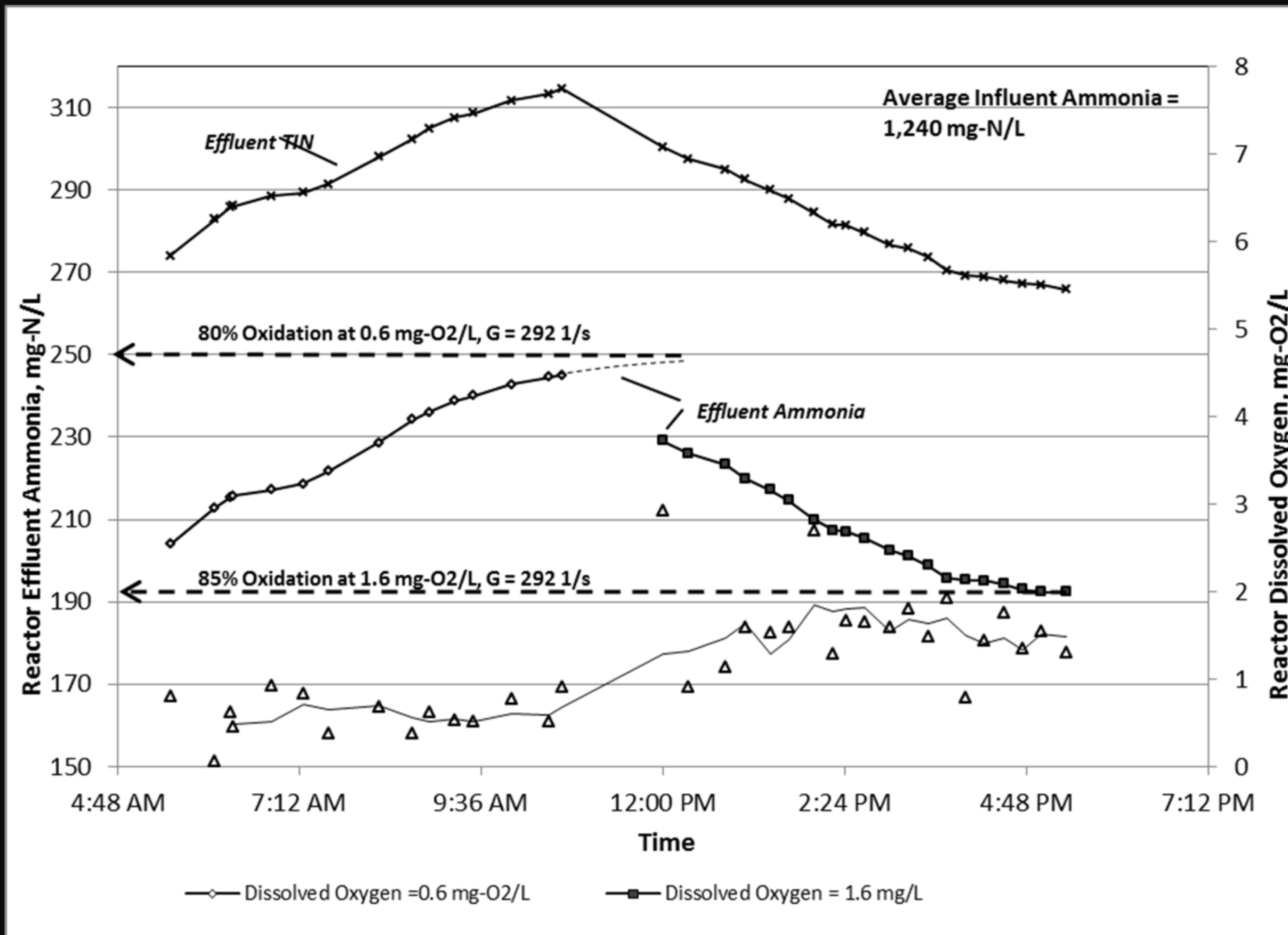
Nitrification/Denitrification – 7.14 mg/L of alkalinity needed

Deammonification – 4 mg/L of alkalinity needed

Dissolved Oxygen and pH



Mixing Energy and Bulk DO Concentration



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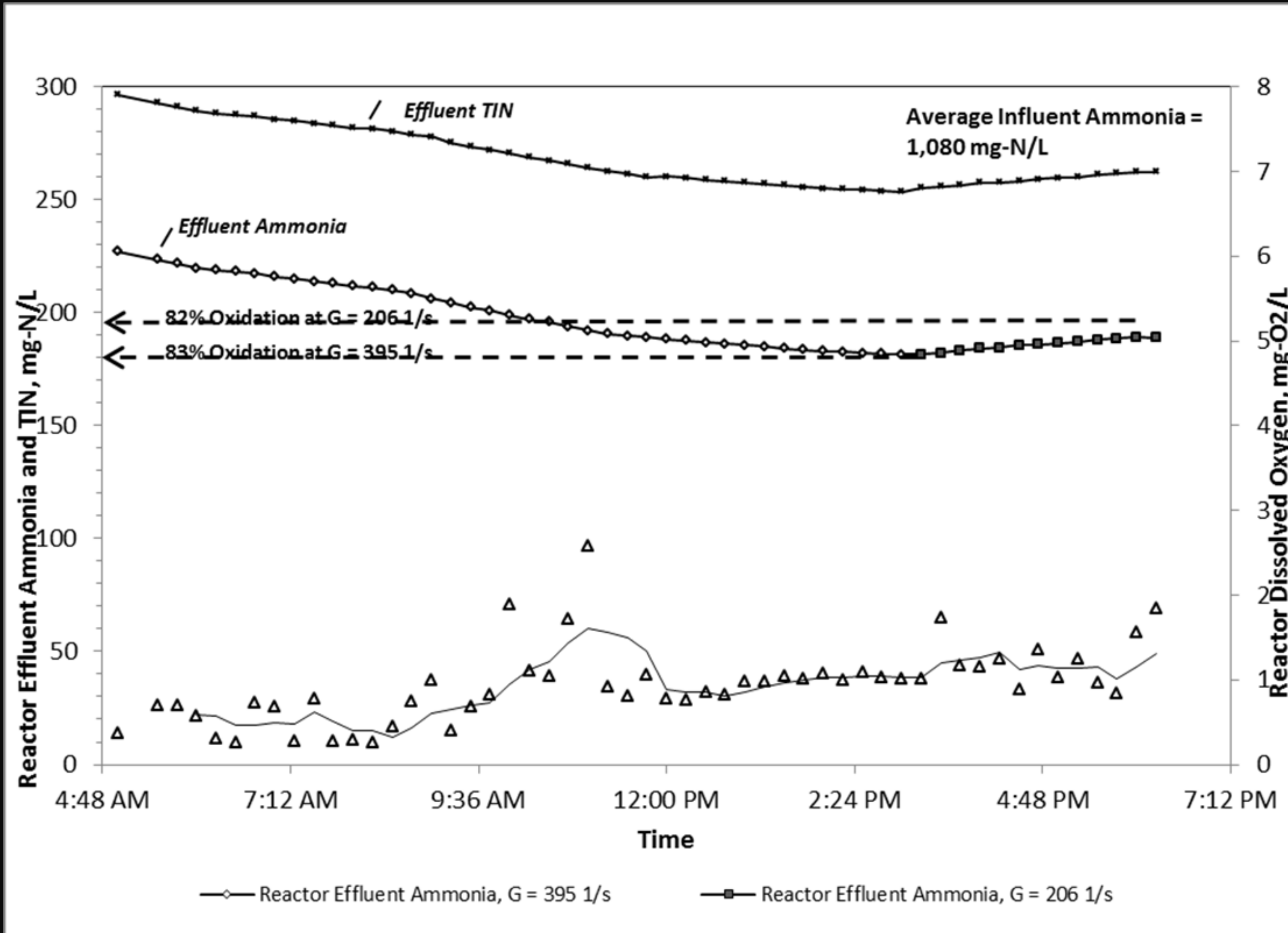

Deammonification vs. CaRRB

	Deammonification	Sidestream Nitrification
System	Fixed film MBBR	CaRRB
NH4 Oxidation	85%	60%
Nitrogen Removal	80%	10%
Volumetric Requirement	1/4	1

Deammonification Pilot Conclusions

- Volumetrically efficient
  - Refined Design Concept (Tank Volume, SALR, DO)
  - Scale-down Effect (G v. DO)
  - Frees up 15 mgd of Capacity
- Simple to Operate
  - Uncertainty on Aeration Control Strategy
  - Robust/Recover quickly
  - Centrate Quality
  - Performance limited by AOB activity
  - Operated over a wide pH range
- Straightforward Retrofit to Full-scale

Global Concluding Remarks

- Compact N & P Removal Concept
  - Sidestream Bio-P
  - Sidestream Deammonification (or perhaps shortcut nitrogen elimination?)
- The Money Value of Time
  - Manage Risks v. Taking Risks
  - Aggressive, Refined, Confident Design
- Seek Opportunities to Collaborate with Other Utilities