Advanced control systems for nitrogen removal in full-scale water facilities - International Water Association

WEDNESDAY 26TH JULY 2023

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WEBINAR INFORMATION

the international water association

- This webinar will be **recorded and made available "on-demand"** on the IWA Connect Plus platform, with presentation slides, and other information.

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- The opinions, hypothesis, conclusions or recommendations contained in the presentations and other materials are the **sole responsibility of the speaker(s)** and do not necessarily reflect IWA opinion.

WEBINAR INFORMATION

- **‘Chat’ box**: please use this for general requests and for interactive activities.
- **‘Q&A’ box**: please use this to send questions to the panelists.

  (We will answer these during the discussions and in post-webinar materials.)

Please Note: *Attendees’ microphones are muted. We cannot respond to ‘Raise Hand’.*

AGENDA

	Speaker(s)
Welcome Note – ICA SG	Janelcy Alferes
General Opening and Introduction	Pau Juan-Garcia and Ali Gagnon
Advancing ABAC using predictive modelling	Jeff Sparks
Full scale implementation of pH/ORP-based control	Victoria Ruano
Process Control for Mainstream Anammox	Stephanie Klaus
Interactive panel discussion	All speakers, moderators and participants
Conclusion and closing	Pau Juan-Garcia and Ali Gagnon

MODERATORS & SPEAKERS

Jeff Sparks
Process Engineer
HRSD

Vicky Ruano
Associate Professor
Universitat de València

Stephanie Klaus
Process Engineer
HRSD

Dr. Janelcy Alferes
IWA SG
ICA (Chair)

Pau Juan-Garcia
Senior Consultant
Atkins
(Moderator)

Alexandria Gagnon
Process Engineer
HRSD
(Moderator)

ICA WELCOME NOTE IWA Instrumentation, Control and Automation (ICA) Specialist Group

DR. JANELCY ALFERES (CHAIR) & DR. YANCHEN LIU (VICE-CHAIR)

vito WaterKlimaatHub

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INTRODUCTION TO THE ICA SG

Objectives

- International discussion forum to collect, exchange methodologies & experience in all aspects of ICA for water systems
- Collect, summarize and publish practical experience to support and promote the use if ICA in practice
- Highlight socio-economic & sustainability aspects of ICA: management problems, operator aspects or incentive systems

→ Knowledge

→ Dissemination

→ Application






INTRODUCTION TO THE ICA SG

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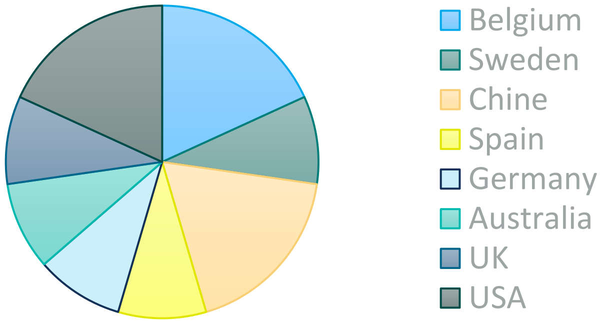
Main activities

- Updating IWA Connect & social media with relevant information
- Group newsletters (available on the SG's IWA Connect page)
- Organizing and supporting conferences & workshops
- Supporting Task Groups, Working Groups & Clusters
- Organizing webinars
- Encouraging publications of ICA related papers at conferences and in scientific journals.
- Leveraging partnerships & relationships with industry organization with overlapping missions (e.g. the Smart Water Network Forum)

INTRODUCTION TO THE ICA SG

Main activities

ICA management comittee members



Newsletter

Content

- Welcome to the ICA SG
- New projects, activities and issues
- Upcoming events
- PhD thesis
- News from IWA Publishing & IWAHQ
- Write to us

IWA – connect plus

Specialist Group |

Instrumentation Control and Automation

Feeds Events Documents Members Meeting Mail/Newsletter

Janelcy Alferes Castano

Posted in Instrumentation Control and Automation | 7 hours ago

ICA Webinar on Advanced Control Systems for Nitrogen Removal

Don't miss the opportunity to join our ICA webinar on Advanced Control Systems for Nitrogen Removal in full-scale applications, next July 26th. Have a look at the detailed information and register in the link !https://iwa-network.org/learn/nitrogen-removal/

See More

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The ICA-SG provides the monitoring and control tools needed to meet current and future technology innovations for the water and wastewater industries. The methodologies are used to monitor and control unit processes, plant behaviour or lar...

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April 2023 | NEWSLETTER2023

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ICA SG: UPCOMING EVENTS

14th IWA Conference on Instrumentation, Control and Automation

- Oslo, Norway, 2025

Webinars

- Advanced biological nutrient removal control: developing novel strategies towards process optimization (2023)
- Series on N_2O measurement, control and mitigation (2023 – 2024)

Call for new MC members

Stay tuned and follow the group!

IWA CONNECT PLUS https://www.iwaconnectplus.org/dashboard

in Instrumentation Control and Automation

INTRODUCTION TO THE WEBINAR

PAU JUAN-GARCIA (SENIOR CONSULTANT ATKINS) & ALEXANDRIA GAGNON (PROCESS HRSD ENGINEER)

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Activated Sludge Process

- Widely used biological treatment method in wastewater treatment plants to remove organic pollutants and nutrients from wastewater
- The process involves the growth of microorganisms (activated sludge) in aeration tanks where they consume and break down organic matter present in the wastewater
- As the microorganisms metabolize the organic pollutants, they form flocs that settle out as sludge in a secondary clarifier

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Nitrification

- Nitrification is the biological conversion of ammonia (NH3) to nitrate (NO3-) through a two-step aerobic process
- Nitrifying bacteria oxidize ammonia to nitrite (NO2-) and then further to nitrate in the presence of oxygen
- To promote nitrification, aeration is essential to maintain sufficient dissolved oxygen levels in the aeration tank

Denitrification

- Denitrification is the biological conversion of nitrate (NO3-) to nitrogen gas (N2) under anoxic (low oxygen) conditions
- Denitrifying bacteria utilize the oxygen from nitrate molecules instead of dissolved oxygen, thereby converting nitrate to nitrogen gas which escapes into the atmosphere
- Aeration control is critical in denitrification to maintain a controlled low oxygen environment in specific parts of the treatment process, such as in anoxic zones or denitrification tanks

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Aeration control

- Managing the dissolved oxygen levels within the aeration tank to create favorable conditions for both nitrification and denitrification processes
- This can be achieved by employing advanced process control strategies, such as dissolved oxygen probes and online monitoring systems
- Limiting aeration will also reduce energy consumption and improve bio-P performance and reduce the extent of effluent ammonia peaks

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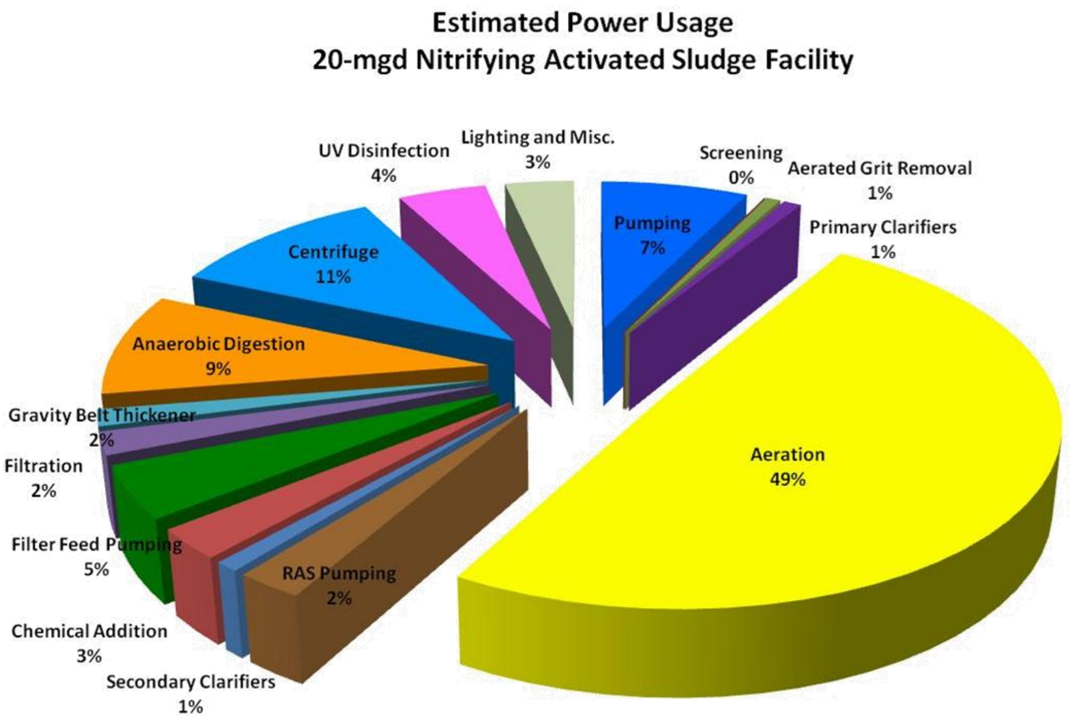
Challenges

- High variability of incoming load and temperature
- Fixed reactor volumes
- WWTP design based on peak load
- Additional infrastructure, implementation, maintenance

Opportunities

- Make use of all available capacity
- Increases efficiency/robustness



Source: "Energy Conservation in Wastewater Treatment Facilities" – Manual of Practice – No. 32, Water Environment Federation – Copyright 2009

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Process requirements

- Sufficient provision of dissolved oxygen
- Ammonia as substrate (+ essential nutrients)
- Sufficiently long aerobic sludge retention time
- Sufficient mass of nitrifiers

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This webinar

- Will explore the potential of different approaches for optimising nitrogen removal in activated sludge systems at full-scale.
- The benefits and limitations of using pH and ORP sensors, ion-selective ammonia sensors, or nitrate sensors within different control structures and reactor configurations will be discussed.
- Each presentation will focus on:
  - Potentials of integrating a digital twin and machine learning with industrial controllers for Ammonia-Based Aeration Control (ABAC).
  - Successful experiences of full-scale implementation of pH/ORP-based control for optimizing biological nitrogen.
  - Potentials of implementing a complementary ammonia vs. NOx (AvN) + partial denitration with anammox (PdNA) control scheme

Advancing Ammonia Based Aeration Control (ABAC) using Predictive Modelling

JEFF SPARKS, PETER A. VANROLLEGHEM, & CHARLES BOTT

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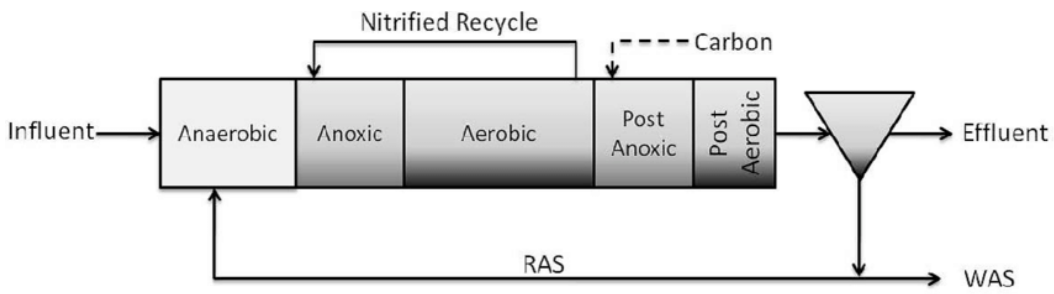
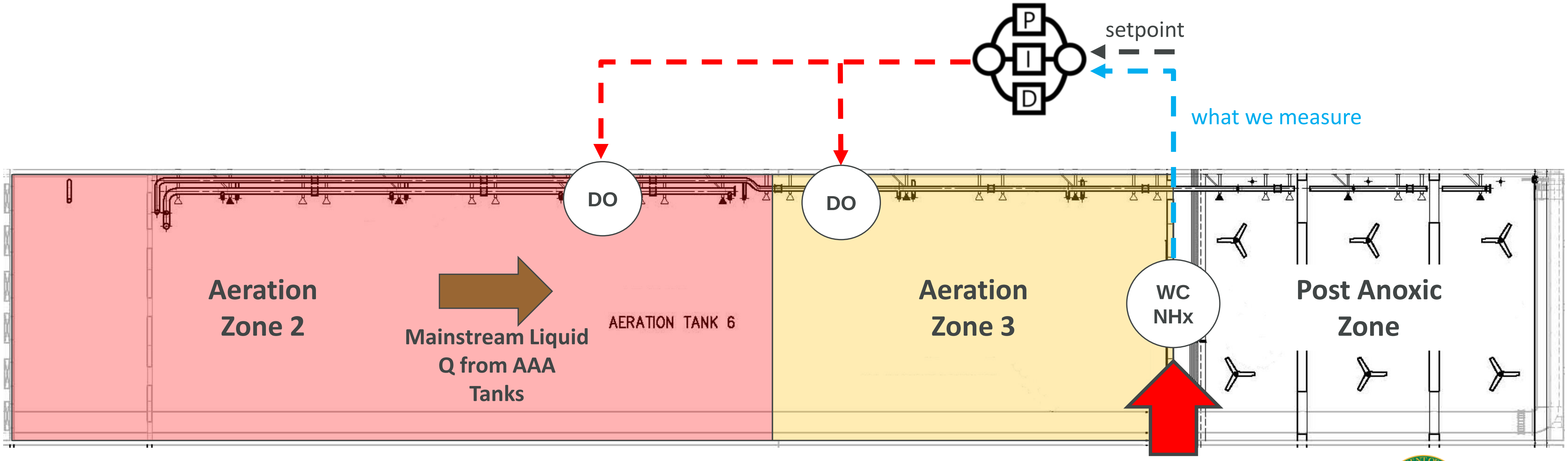
OBJECTIVE

- To use a hybrid model feedforward approach to control the aerobic volume and DO setpoint, keep positive NHx at the end of the aeration tank, and stay below the max Total Inorganic Nitrogen (TIN) concentration of 5 mg/L in the secondary effluent.

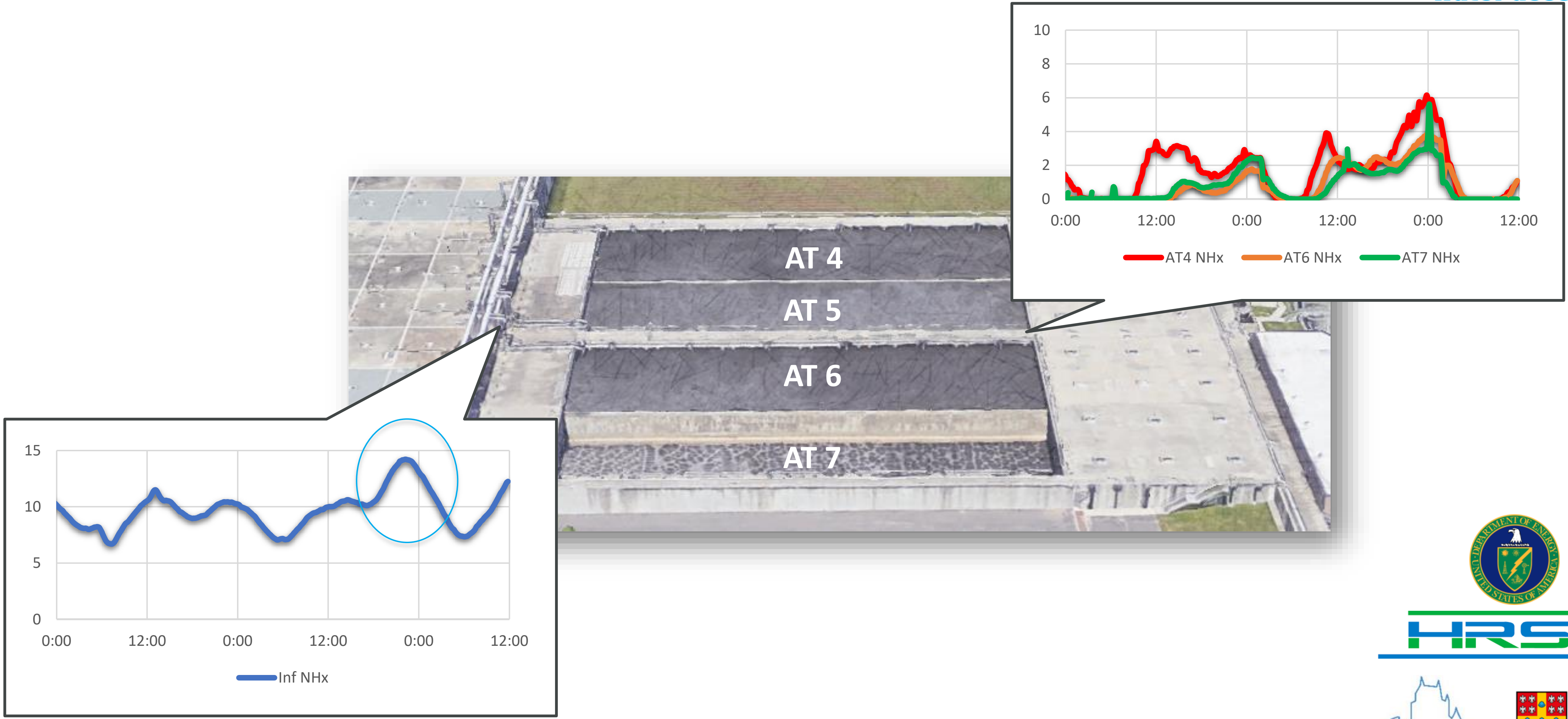


EXISTING ABAC CONTROLLER

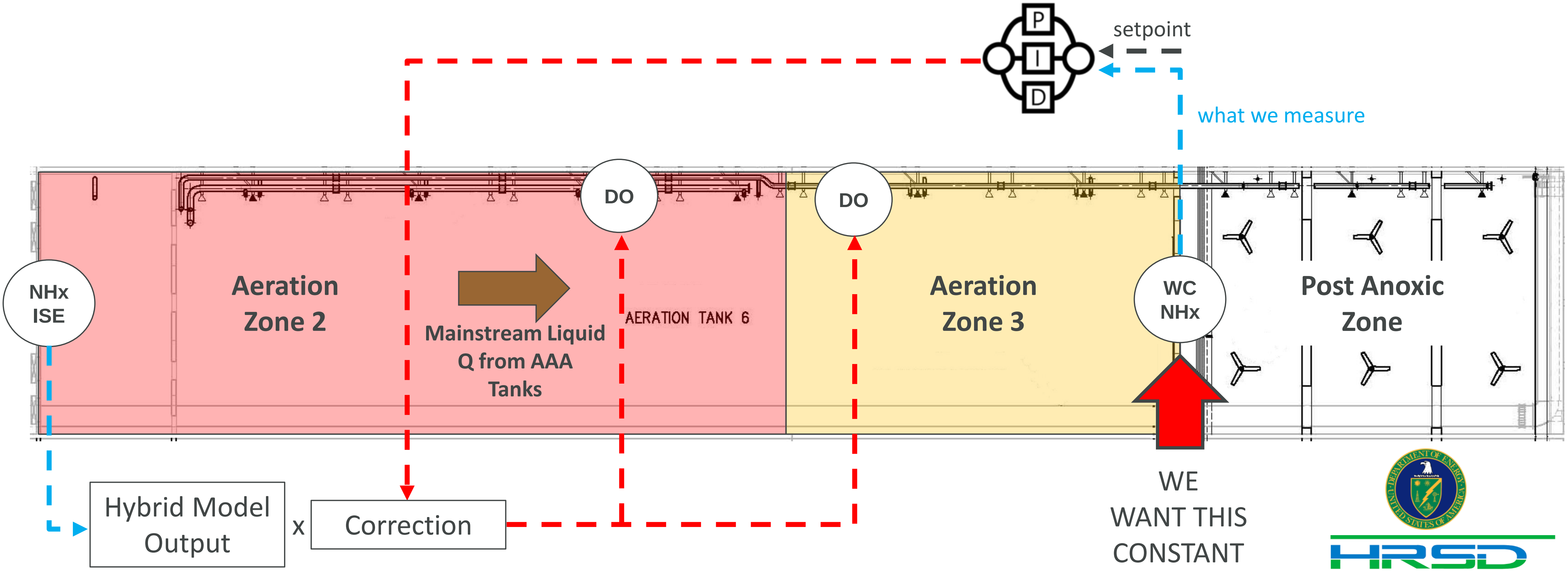


WE
WANT THIS
CONSTANT

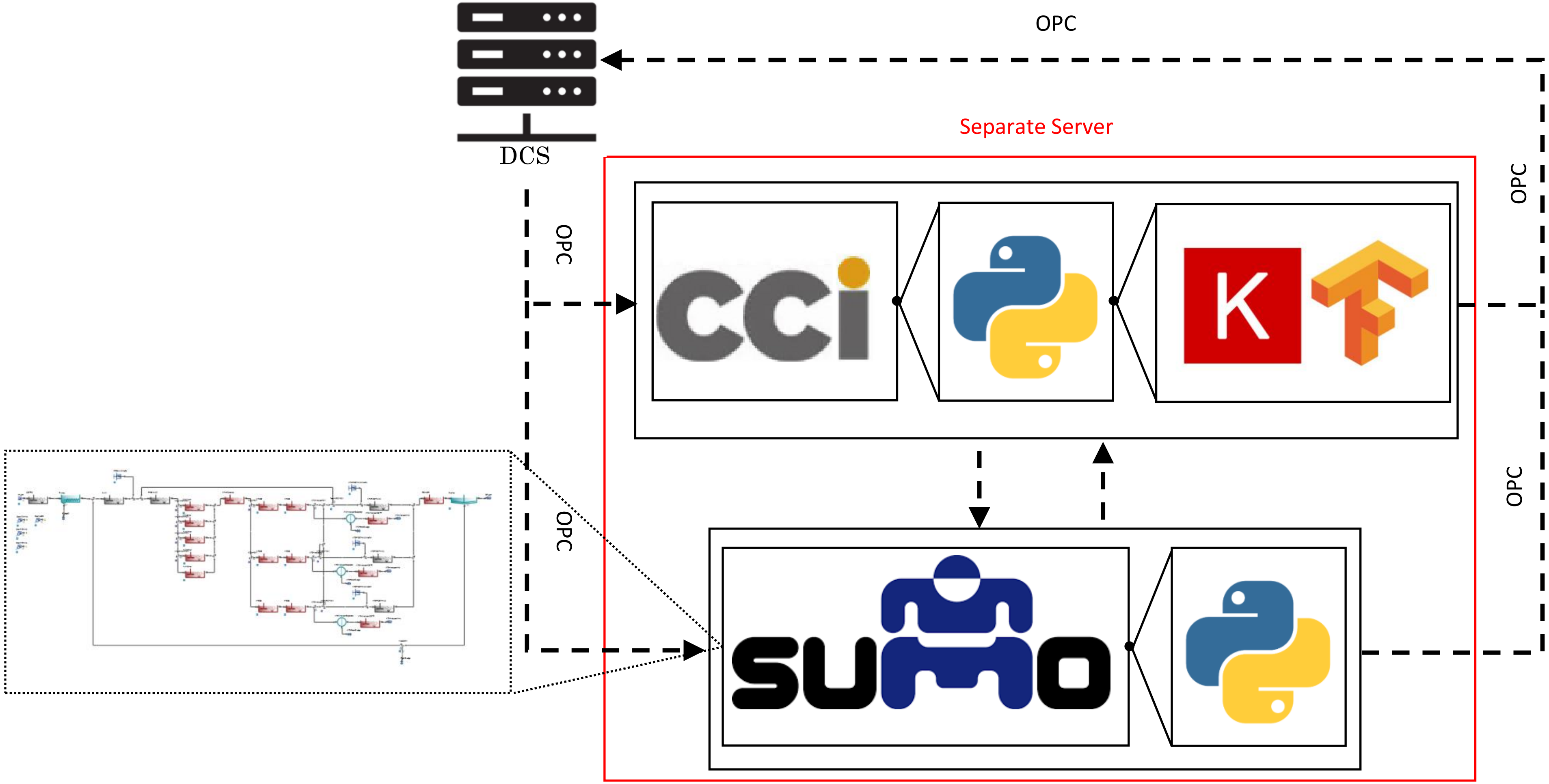
EXISTING ABAC CONTROLLER



UPGRADED ABAC CONTROLLER



HARDWARE/SOFTWARE



HYBRID MODEL OUTPUT

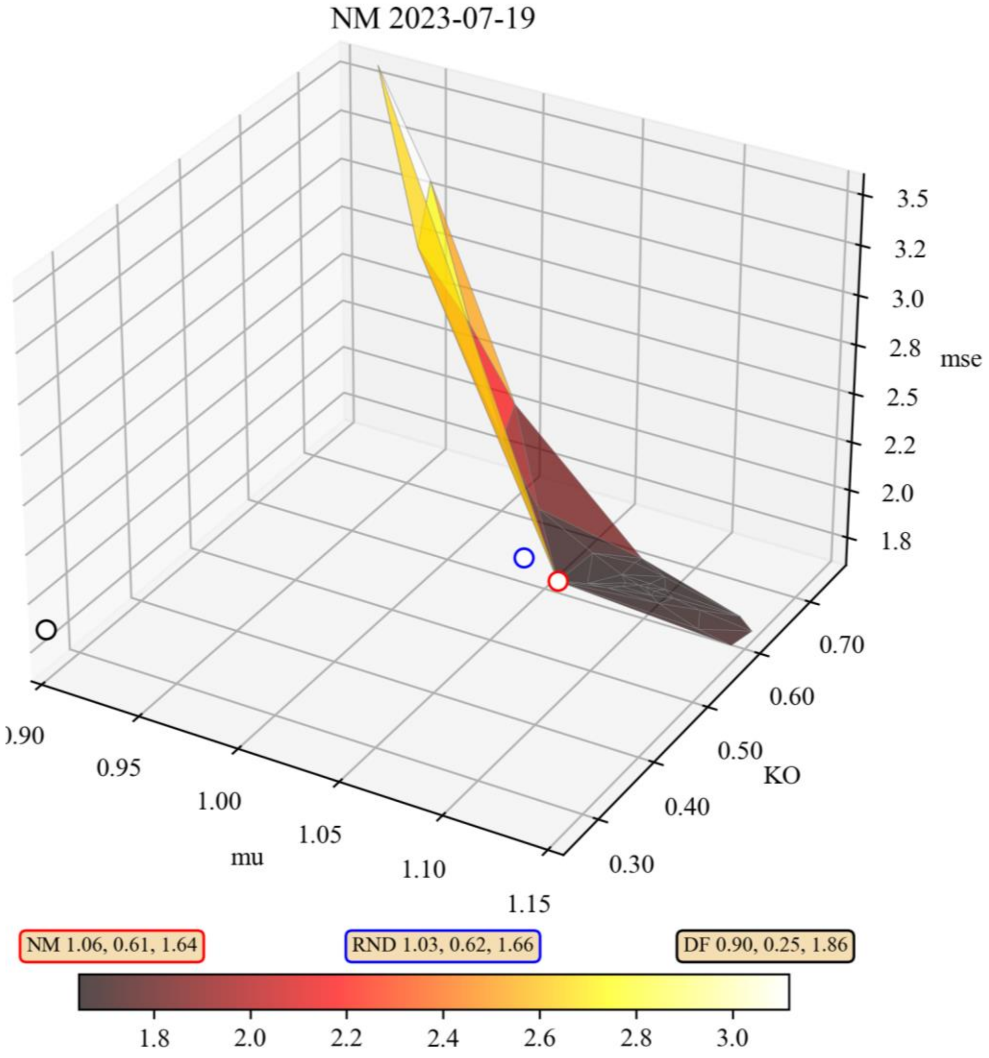
- In the DCS:

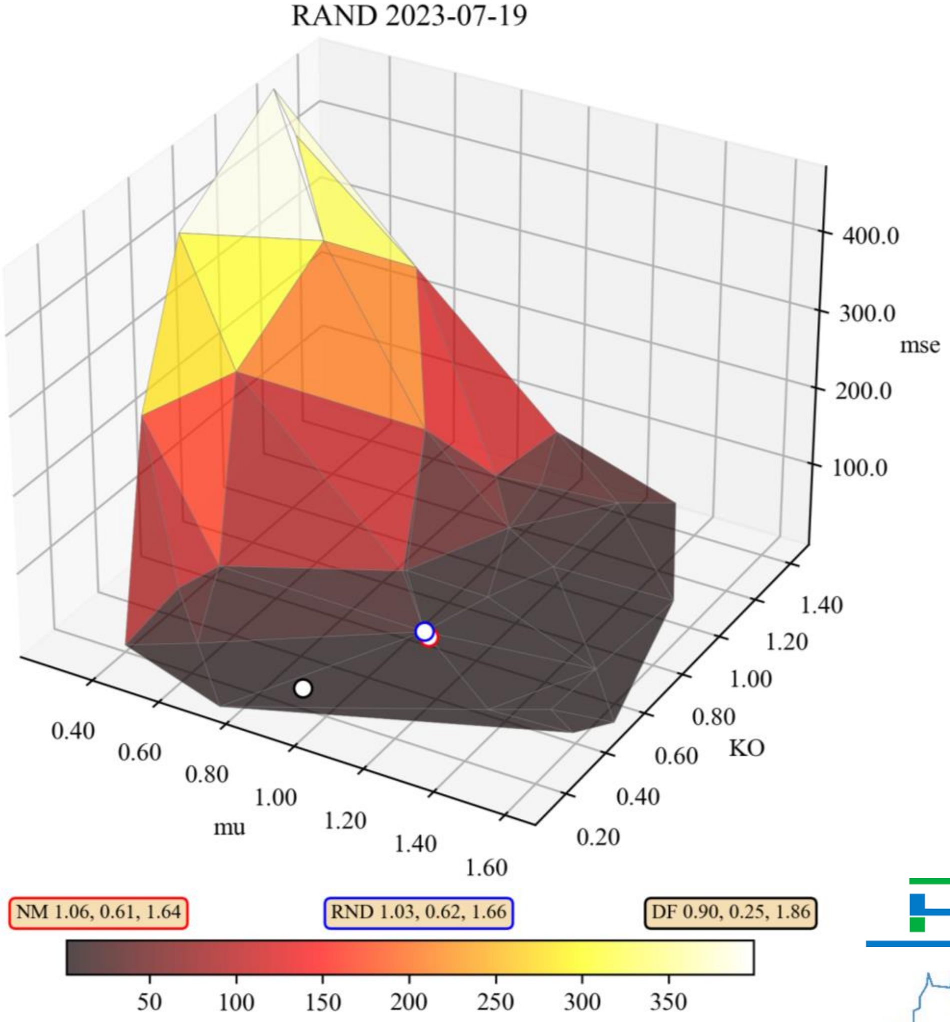
$$DO_{SP} = \frac{K_{O,A}}{\frac{\left(X_{B,A} \cdot V \cdot S_{NH_{SP}} \cdot \mu_A\right)}{Q\left(S_{NH_0} - \left(S_{NH_{SP}} - mech\_err\right)\right)\left(S_{NH_{SP}} + K_{NH}\right)Y_A} - 1}$$

  - **Blue** = measured/known
  - **Green** = setpoint
  - **Yellow** = determined via optimization
  - **Red** = data-driven model output
    - DDMs: linear regression, triple exponential smoothing, XG Boost, LSTM neural network
  - Others = from mechanistic model (Sumo)

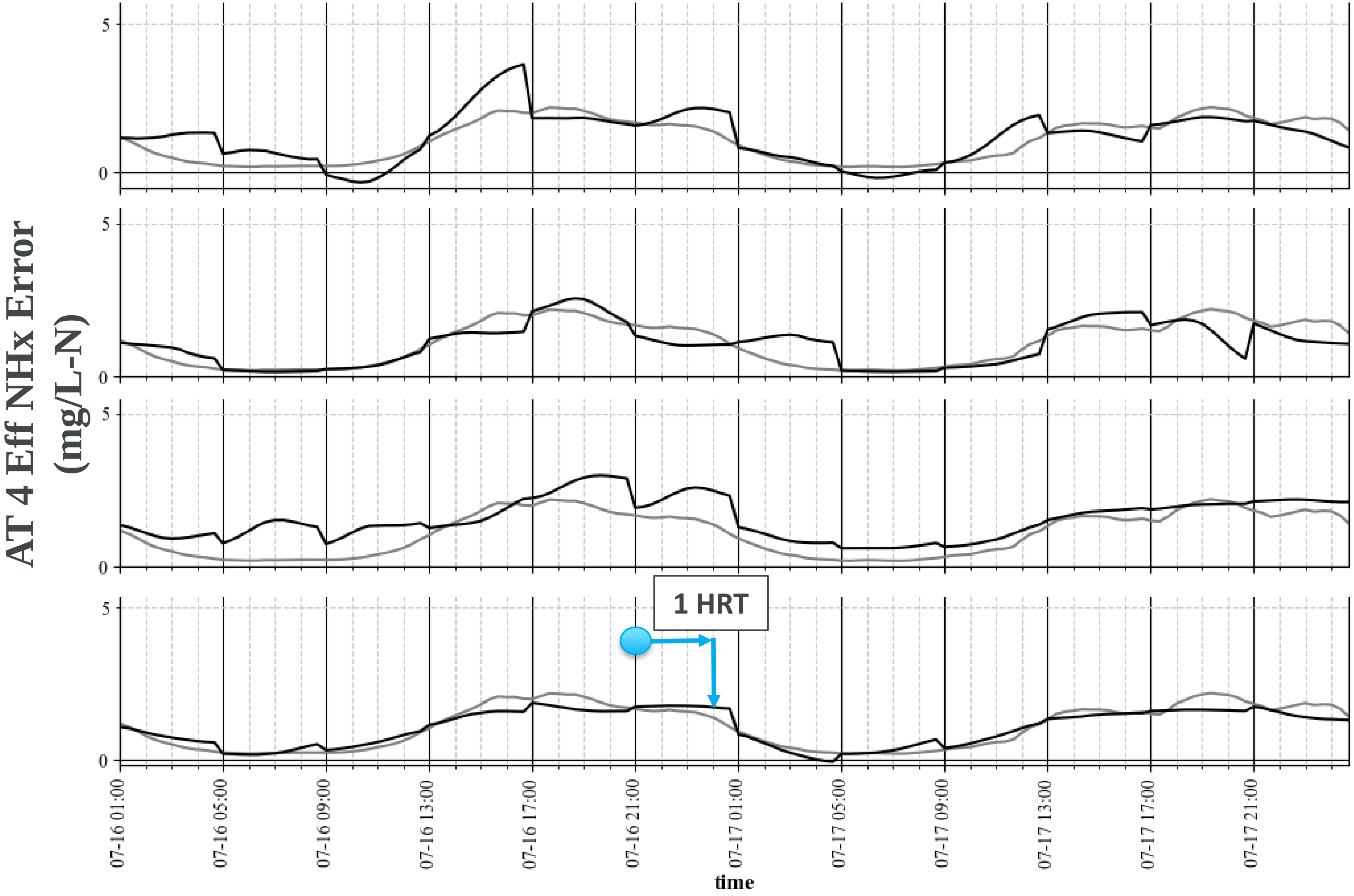
D. Vrečko, N. Hvala, and B. Carlsson, "Feedforward–feedback control of an activated sludge process: a simulation study," Water Science and Technology, vol. 47, no. 12, pp 19-26, 2003.

KINETIC PARAMETER OPTIMIZATION (K_O, MU_A)





PERFORMANCE FOR DIFFERENT DATA-DRIVEN MODELS



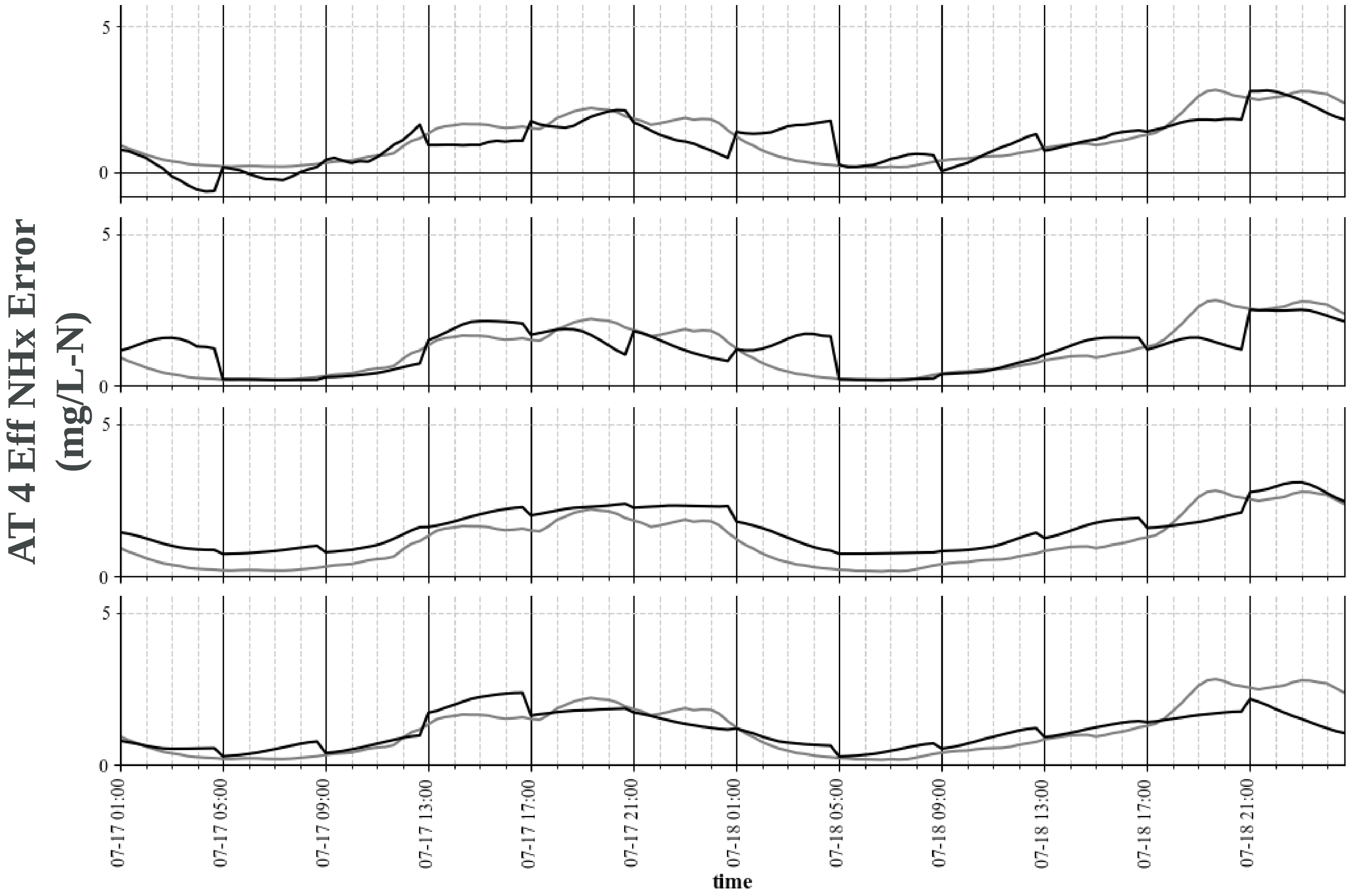
LR
mse = 0.23 mg/L

TES
mse = 0.25 mg/L

XG Boost
mse = 0.43 mg/L

LSTM
mse = 0.11 mg/L

PERFORMANCE FOR DIFFERENT DATA-DRIVEN MODELS



LR
mse = 0.24 mg/L

TES
mse = 0.28 mg/L

XG Boost
mse = 0.34 mg/L

LSTM
mse = 0.21 mg/L

CONCLUSIONS

- Aeration tanks having a plug flow orientation (long and narrow) with relatively long detention times may have a Residence Time Distribution (RTD) that does not favor feedback-only ABAC.
- Nitrifier kinetics can be reasonably estimated, and similar results achieved using a random search space and Nelder-Mead optimization algorithm.
- Mechanistic model errors can be reasonably forecasted using univariate time series algorithms. The choice of algorithm may change depending on the desired level of complexity, forecasting accuracy, and composition of the test set data.

ACKNOWLEDGEMENT & DISCLAIMER

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- *Acknowledgment:* This material is based upon work supported by the U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy (EERE) under the Advanced Technology Office, Award Number DE-EE0009508.

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Full-scale implementation of pH/ORP-based control

VICKY RUANO, ASSISTANT PROFESSOR

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Process Control for Mainstream Anammox

STEPHANIE KLAUS, HRSD

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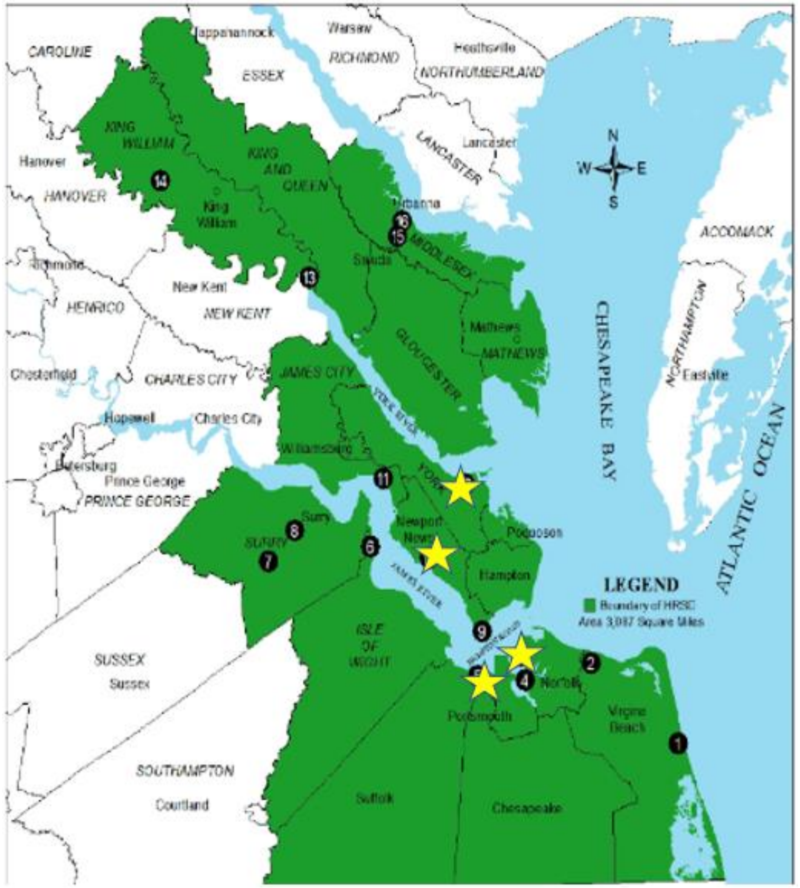
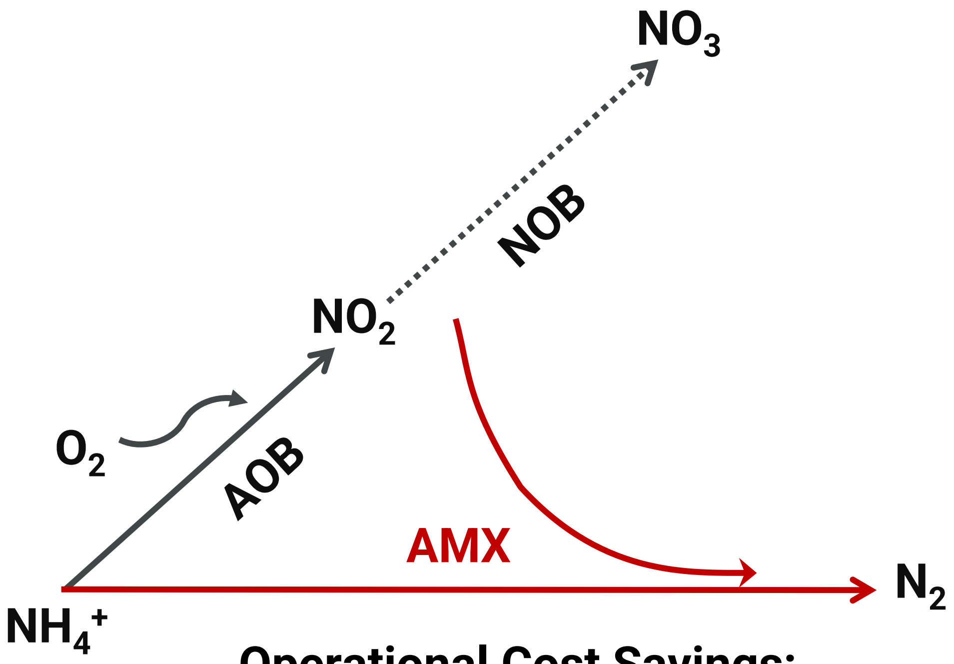
PdNA/PNA at HRSD

- PdNA pilot work:
  - A/B BNR pilot polishing MBBR (2012-2018)
  - York River filter pilot (2020-2021)
  - James River MBBR & IFAS (2020-present)
- PdNA full-scale status
  - York River filter 2018
  - James River IFAS 2022
  - Nansemond IFAS full plant design/construction 2024 startup
  - James River MBBR in construction 2025 startup
  - Army Base IFAS feasibility study



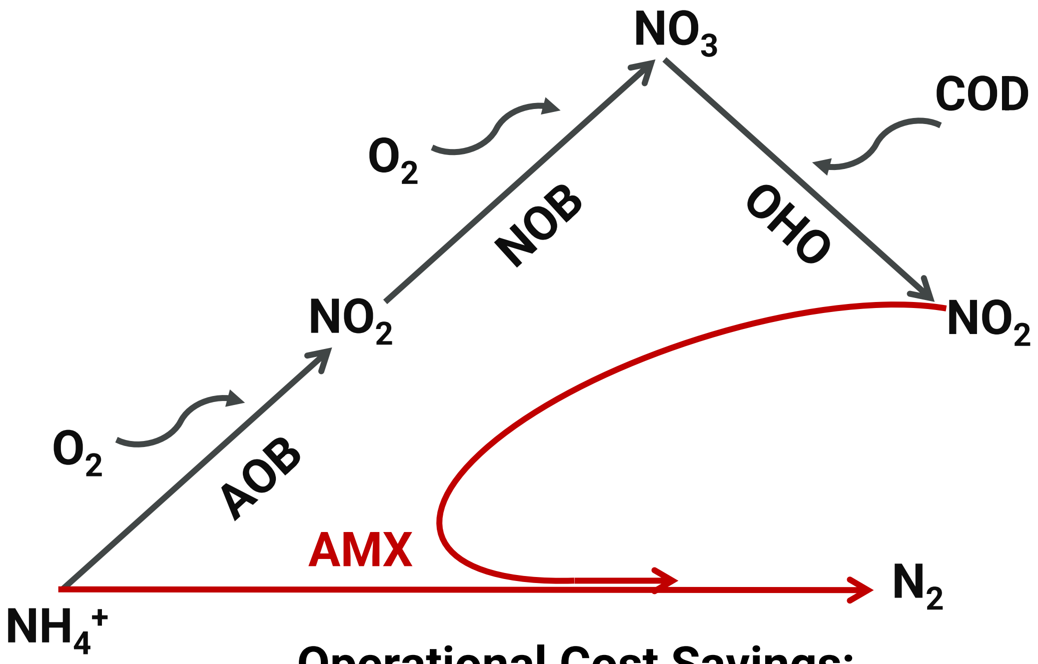
Taking a DETOUR to achieve mainstream shortcut N removal – Partial Denitrification-Anammox (PdNA)

PNA = NOB Out-Selection Route



Operational Cost Savings:
- 60% in aeration
- 100% in carbon

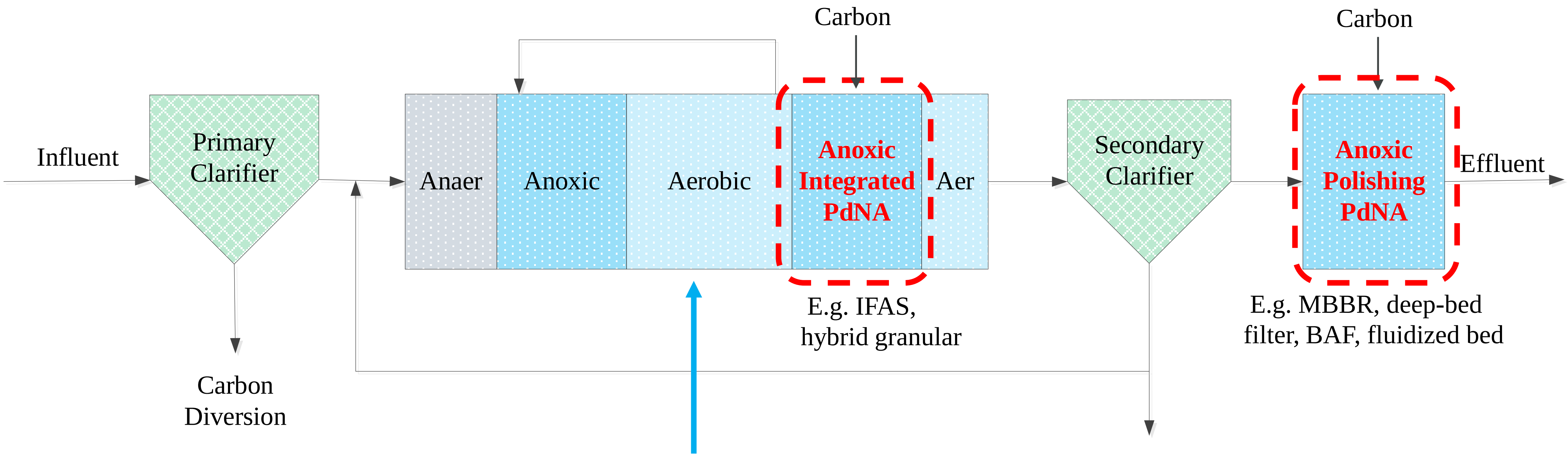
PdNA Route



Operational Cost Savings:
- 50% in aeration
- 80% in carbon

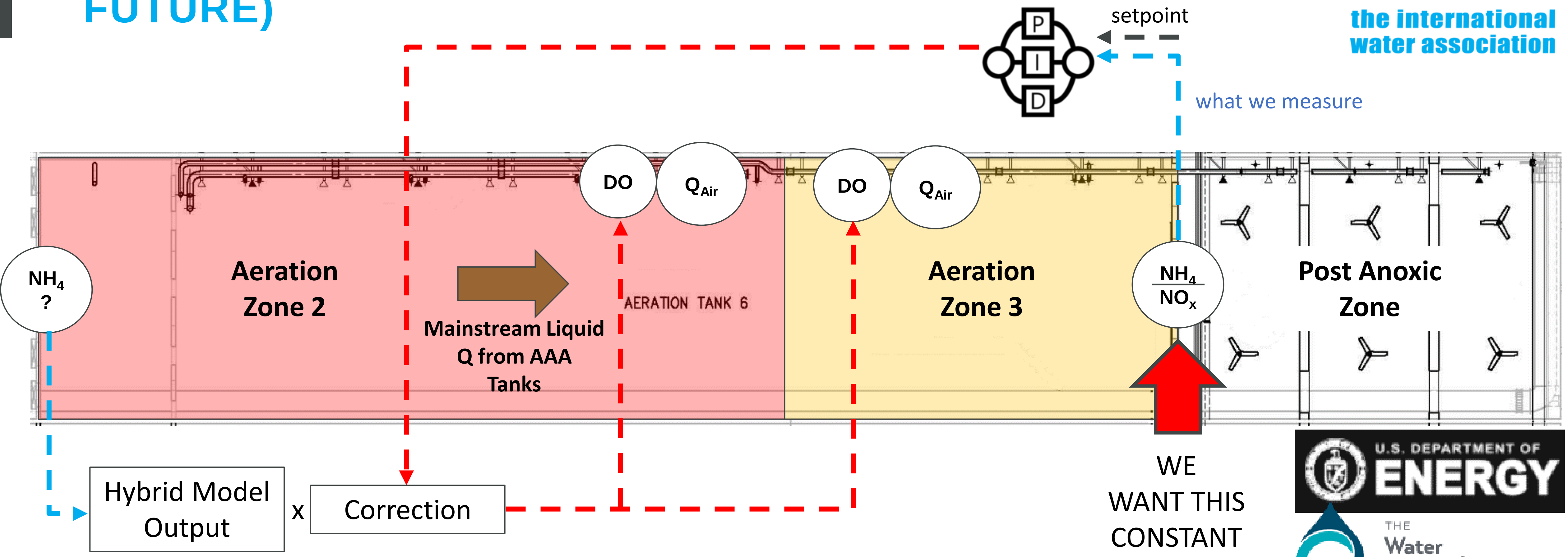
PDNA IMPLEMENTATION

Carbon Dosing Control



Ammonia vs NOx (AvN) aeration control

UPGRADED ABAC (TO BE EXTENDED TO AVN – FUTURE)



<u>Feedforward – three approaches being evaluated at HRSD</u>:

1. Controller adjusts for changes in influent flow only (already applied to AvN) – Mike Parsons, James River (AvN)
2. Feedforward model predictive controller from regression analysis of calibrated process model simulations (no additional sensors) – Ali Gagnon, VIP (ABAC now, soon to AvN)
3. Hybrid mechanistic and data/ML model with added NH4 sensor – Jeff Sparks, Nansemond (ABAC soon to AvN)

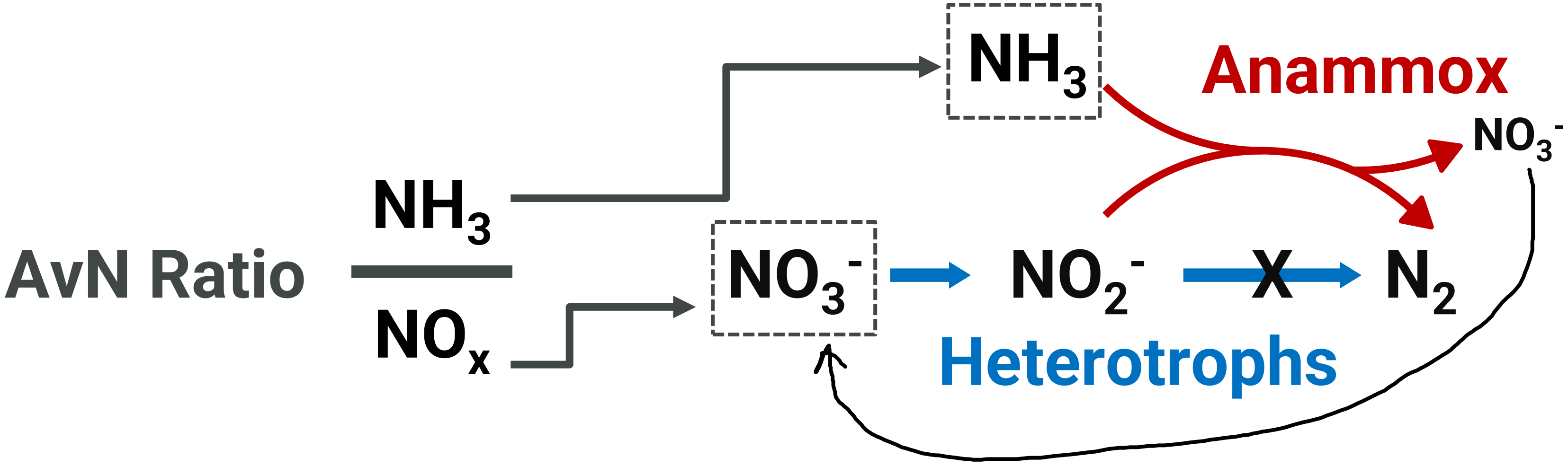
NOB Outselection (PNA) is hard… PdNA is "easy"

Challenge:

The biggest challenge for polishing PdNA is operating AvN aeration control to consistently meet the required effluent targets out of the PdNA zone

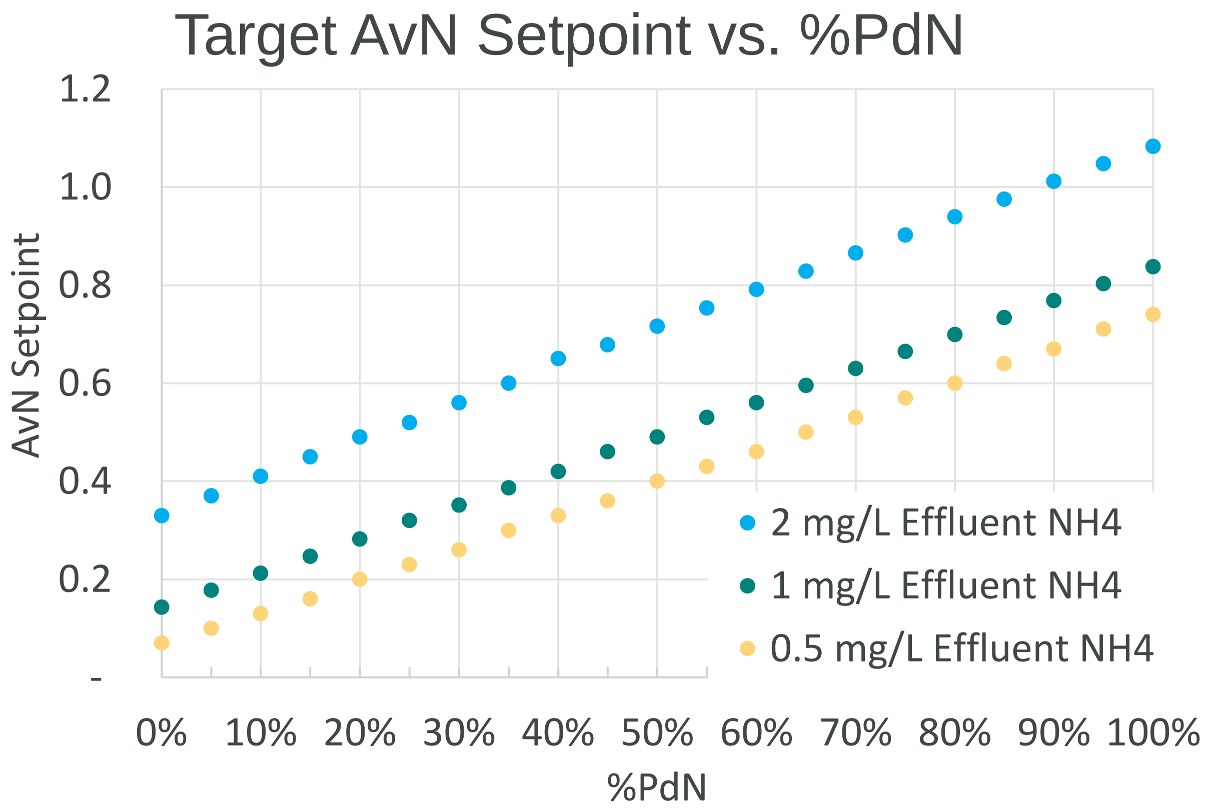
AMX Stoichiometry

- NO2 rem/NH3 rem = 1.32
- NO3 prod/NH3 rem = 0.26
- NO3/NH3 Target = 1.06

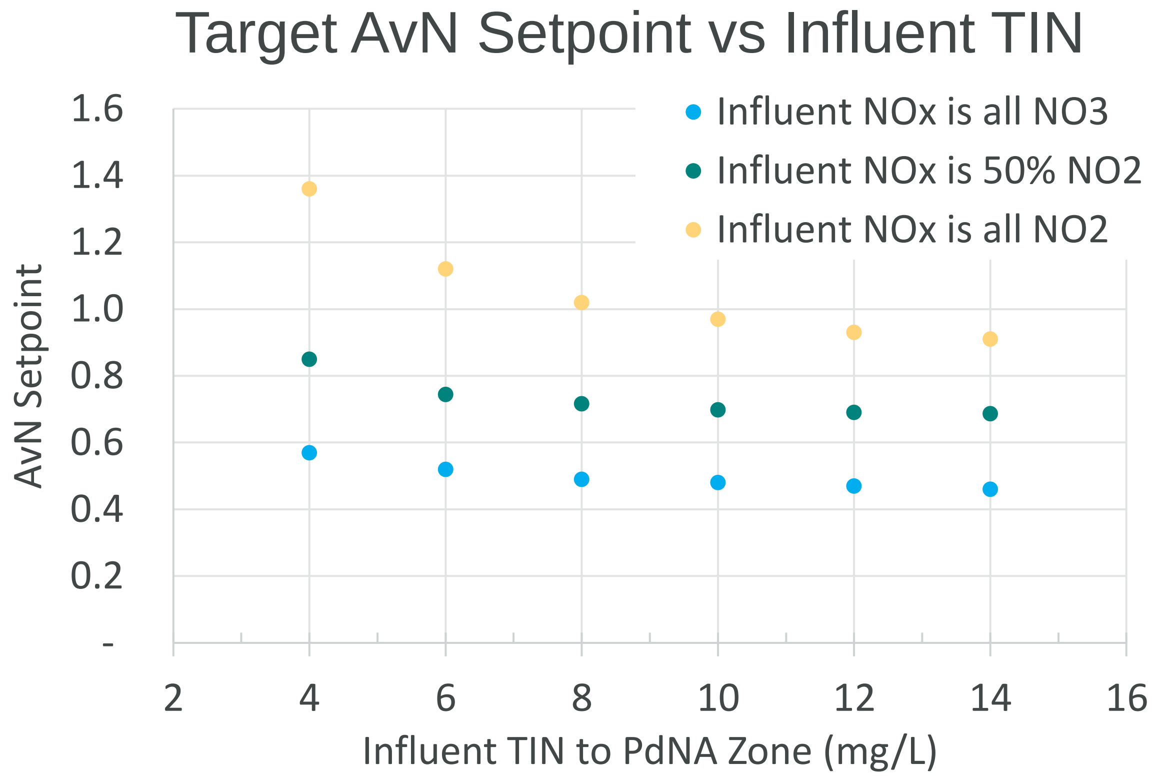


If NO3 >> NH3	wastes carbon, NO2 breakthrough
If NH3 >> NO3	NH3 breakthrough

TARGET AVN SETPOINT DEPENDS ON TIN LOADING, EFFLUENT GOALS, PDN%, AND INFLUENT NOX COMPOSITION



- Influent TIN is 8 mg/L
- Effluent NO3 is 1.5 mg/L
- All influent NOx is NO3



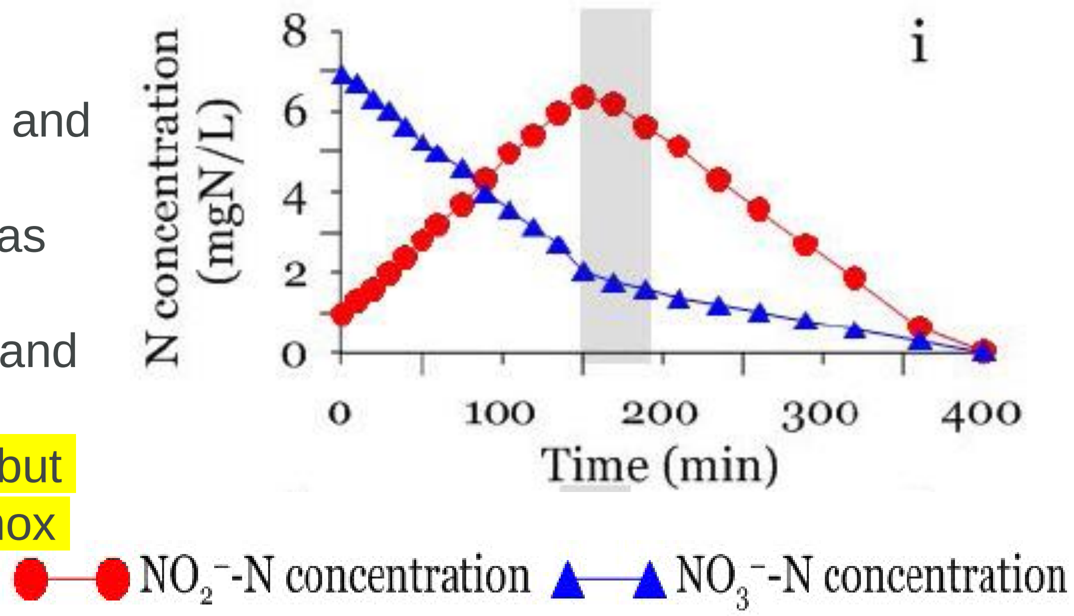
- Effluent NO3 is 1.5 mg/L
- Effluent ammonia target is held at 1.0 mg/L
- Composition of influent NOx varies to allow for PNA

IMPACT OF CARBON SOURCE AND COD/N ON THE CONCURRENT OPERATION OF PARTIAL DENITRIFICATION AND ANAMMOX

Tri Le,[1,2*] Bo Peng,[2,3†] Chunyang Su,[2] Arash Massoudieh,[1*] Alba Torrents,[3*] Ahmed Al-Omari,[2*] Sudhir Murthy,[2*] Bernhard Wett,[4*] Kartik Chandran,[5*] Christine DeBarbadillo,[2*] Charles Bott,[6*] Haydée De Clippeleir[2*]

Practitioner points

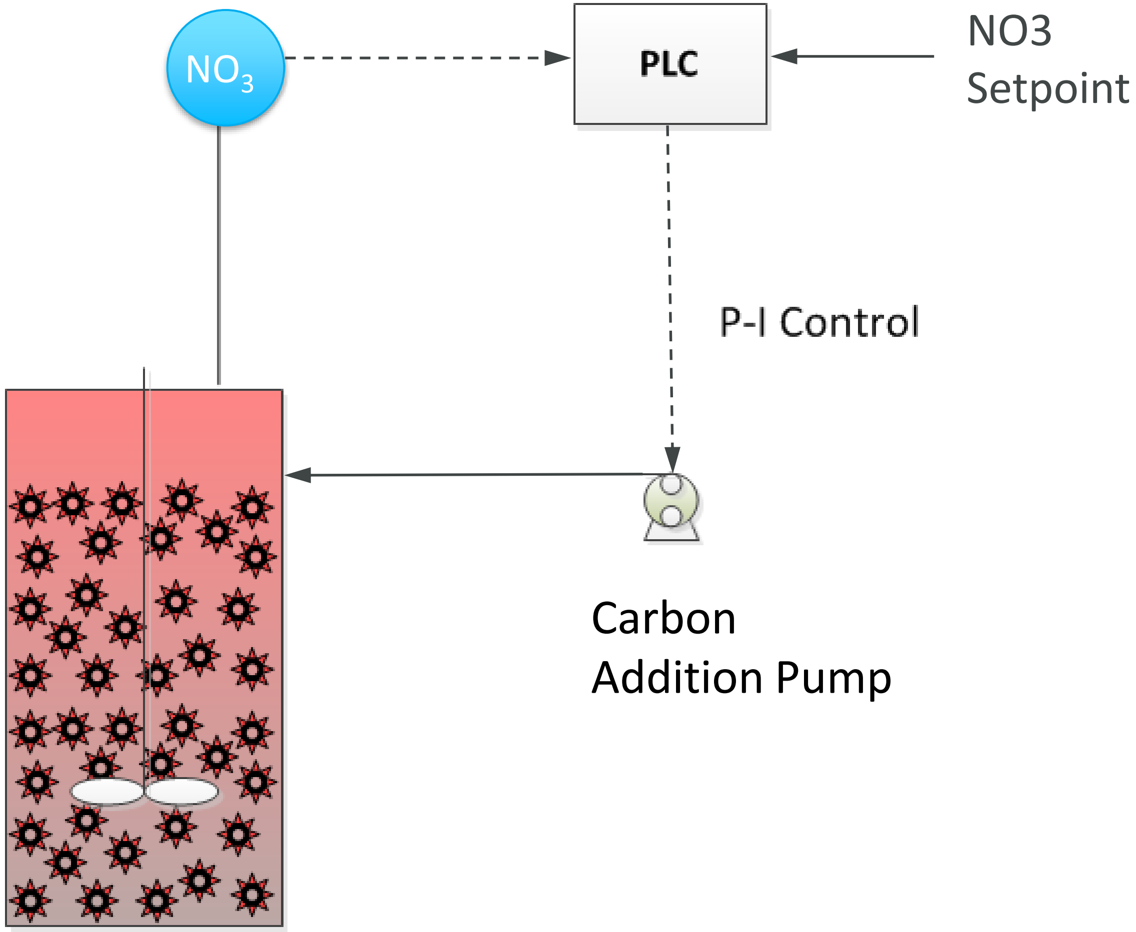
- The authors aimed to investigate the impact of carbon sources and COD/NO3 -N ratio on partial denitrification selection.
- All the carbon sources supported partial denitrification as long as the nitrite sink was available.
- 90% partial denitrification could be achieved with both acetate and glycerol in long-term operations.
- COD/NO3 -N ratio did not directly control partial denitrification but can be used to balance between denitrification rate and anammox rate.



dc water is life

Le, T., Peng, B., Su, C., Massoudieh, A., Torrents, A., Al-Omari, A., … Clippeleir, H. D. (n.d.). Nitrate residual as a key parameter to efficiently control partial denitrification coupling with anammox. *Water Environment Research*, *0*(0). https://doi.org/10.1002/wer.1140

FEEDBACK CARBON DOSING CONTROL



SUPPLEMENTAL CARBON CONTROL
NO3-IN-CALCULATED/NOX-OUT-TRIM (NIC/NOT)

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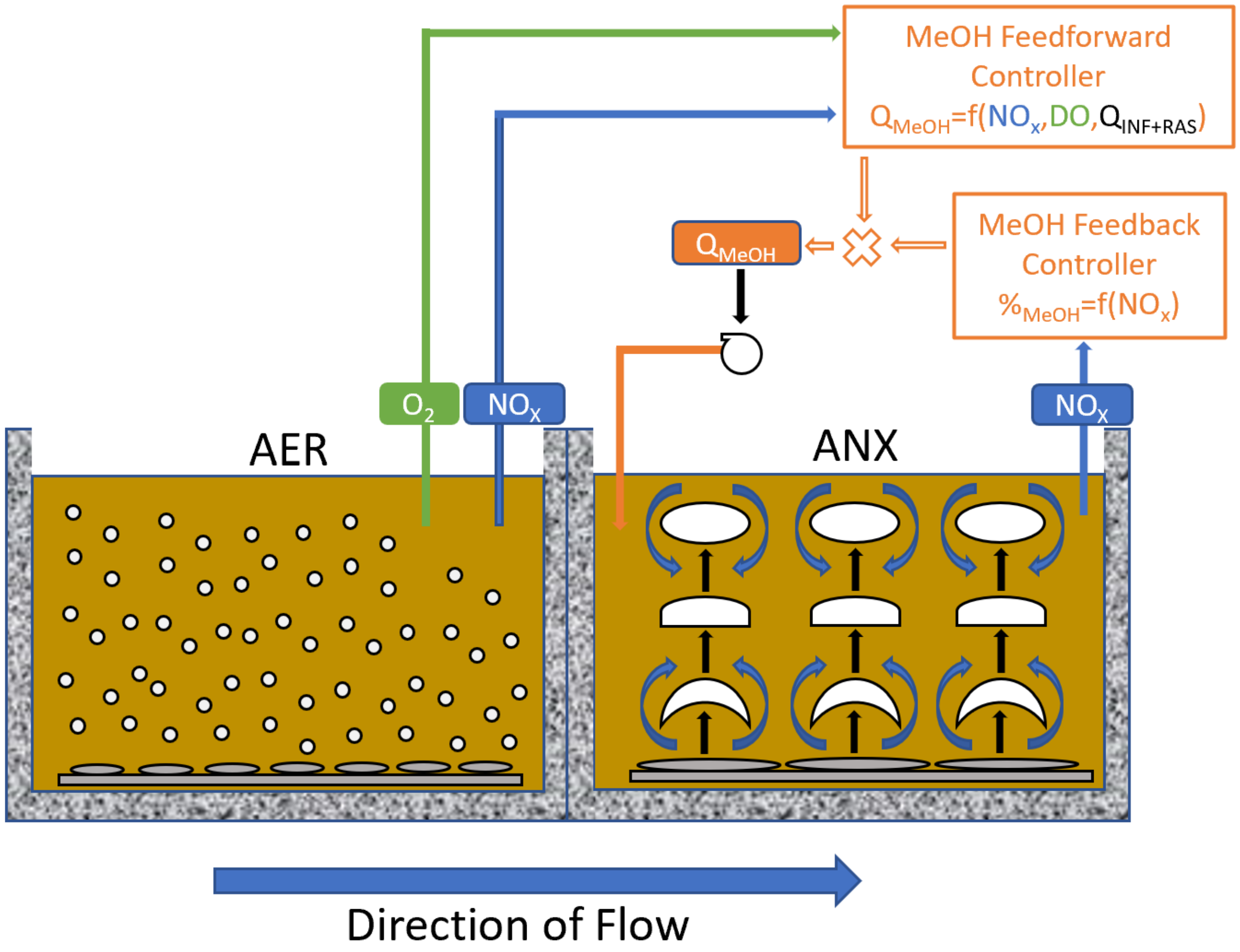
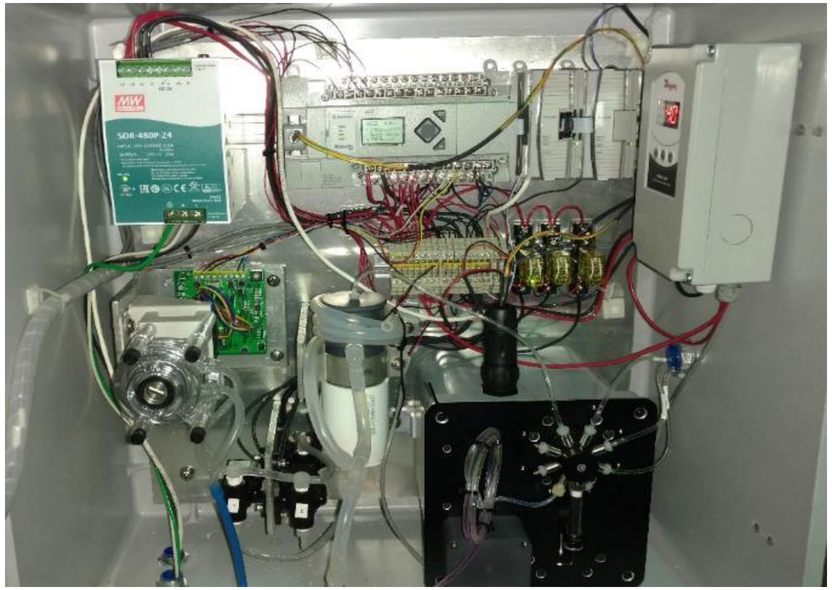
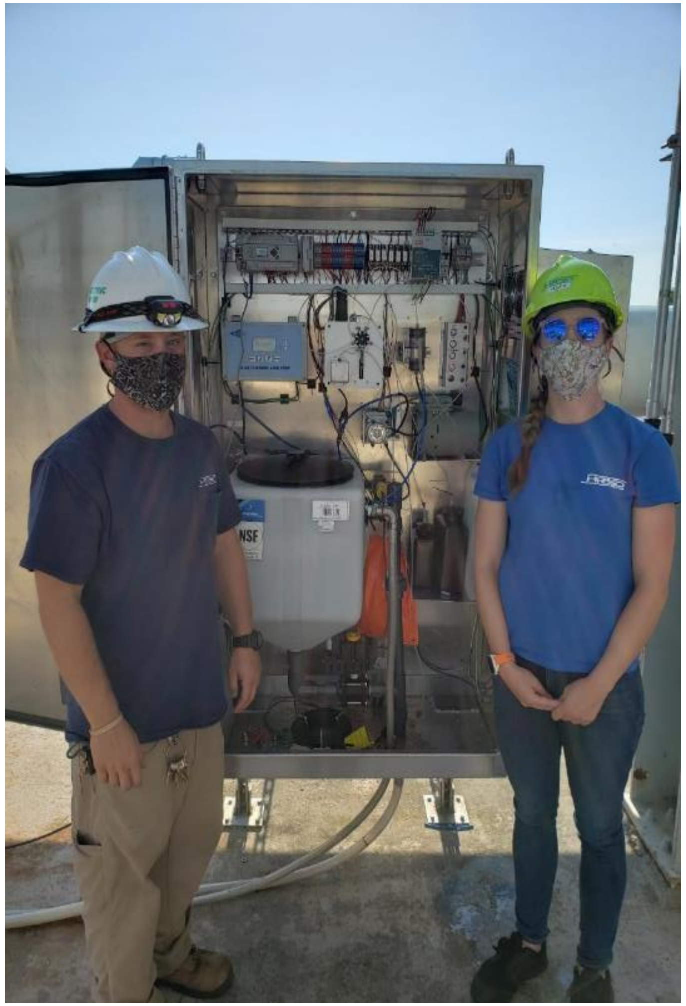


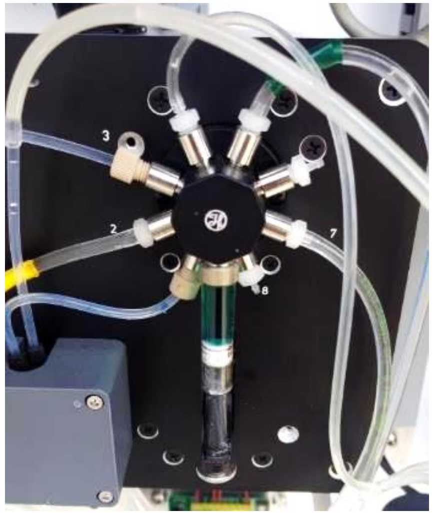
REQUIRES GOOD SENSORS!

- Good NH_4 measurement, even at low concentrations
- Discrimination of NO_3 and NO_2 without interferences (depends how much NO_2 is around)

HRSD’S ONLINE ANALYZER – “JARBALYZER”
NH4, NO3, NO2, OP



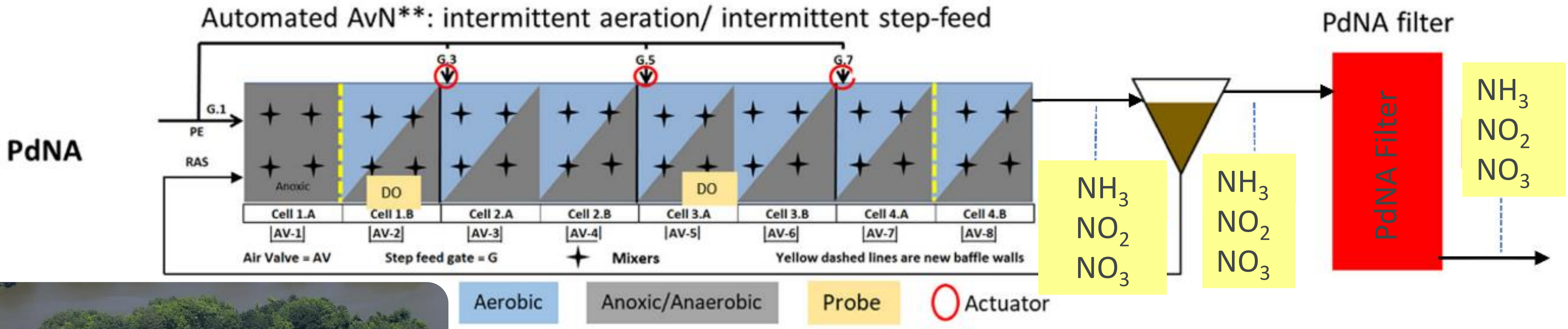




YORK RIVER PROCESS CONTROL

Aeration = AvN

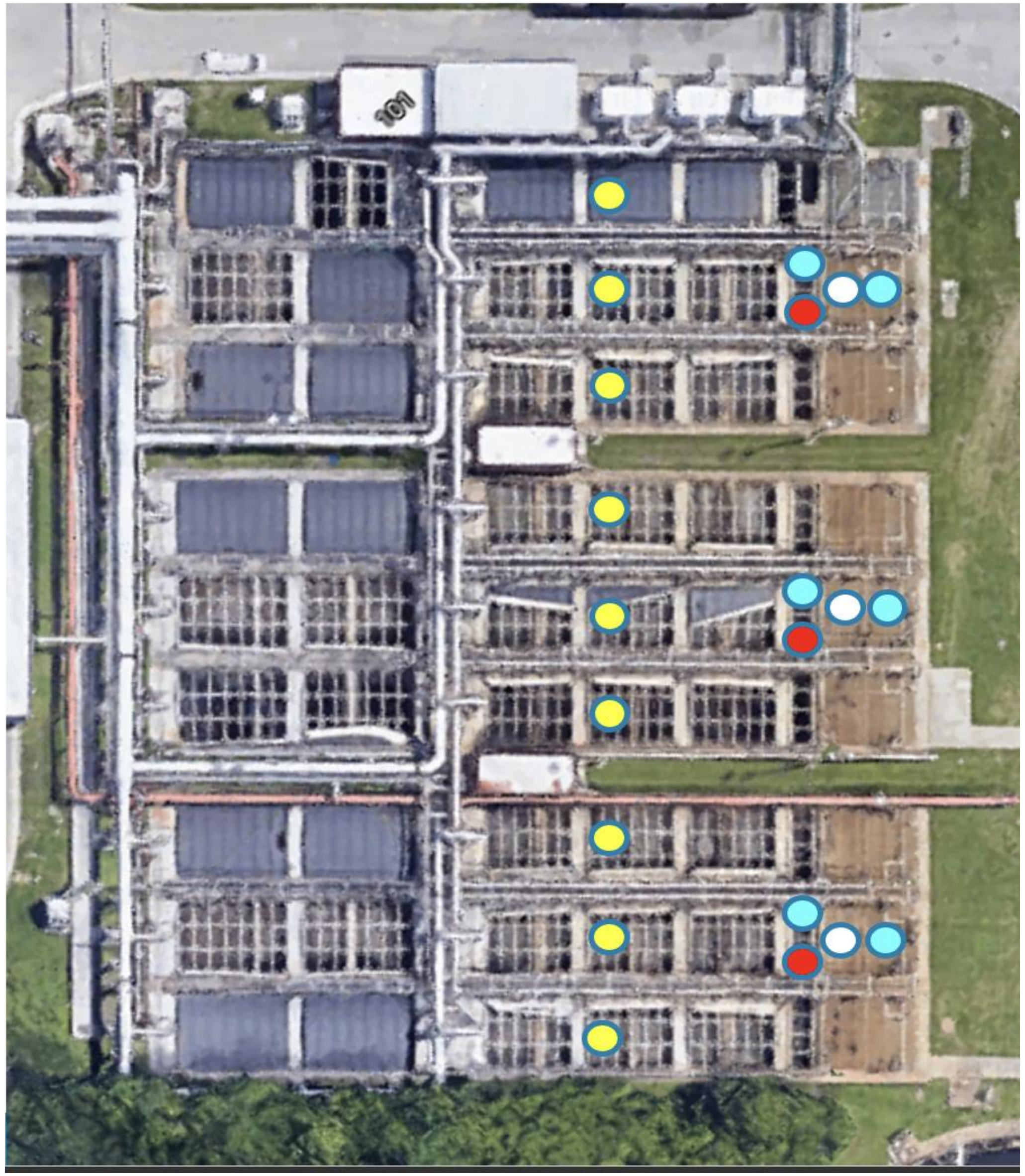
Carbon = Feedforward/feedback



12 DO probes
2 Jarbalyzers (3 Sample locations)

JAMES RIVER PROCESS CONTROL

- DO (Insite)
- NH3 (YSI ISE)
- NOx (Hach Nitratax)
- Jarbalyzer wet chemical



Process Control
1. AvN aeration
2. Feedback carbon dosing

Q&A DISCUSSIONS

MODERATOR: PAU JUAN & ALI GAGNON

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