Metropolitan Water Reclamation District of Greater Chicago

Welcome to the June Edition
of the 2025 M&R Seminar Series

NOTES FOR SEMINAR ATTENDEES

- Remote attendees' microphones are muted at entry to minimize background noise.
  For attendees in the auditorium, please silence your phones.
- A question and answer (Q/A) session will follow the presentation.
- For remote attendees, please use "**Chat**" only to type questions for the presenter. For other issues, please email Pam to SlabyP@mwrd.org.
  For attendees in the auditorium, please raise your hand and wait for the microphone to ask a verbal question during the Q/A session.
- The presentation slides will be posted on the MWRD website after the seminar.
- This seminar has been approved by the Engineering Society of Illinois (ESI) for one PDH and pending approval by the IEPA for one TCH. Certificates will be issued only to participants who attend the entire presentation. For PDH certificate seekers, **please complete a brief course evaluation and submit it**.

Jeffrey Sparks, Ph.D., P.E., CDT
Director of Digital Water
Hampton Road Sanitation District
Newport News, Virginia

Dr. Sparks is a licensed Professional Engineer with 17 years of experience in design, operations, process control, and utility management. He holds a bachelor's degree in Civil Engineering from Virginia Military Institute, a master's degree in Environmental Engineering from Virginia Tech, and a Ph.D. in Water Engineering from Université Laval, Quebec, Canada. As the Director of Digital Water at Hampton Road Sanitation District, Jeff leads efforts to digitalize operations, including deploying Digital Twins, integrating AI, and optimizing processes.

THE X OF INDUSTRIAL CONTROL, DATA-DRIVEN MODELLING, AND DIGITAL TWINS AT WRRFS: ACHIEVING NEXT-GEN BNR WITH BALANCED COMPLEXITY

06/27/2025

Jeff Sparks, PE, PhD, HRSD Director of Digital Water
PhD Defense
Advisors:
Peter A. Vanrolleghem, PhD, Université Laval, co-advisor
Charles B. Bott, PE, PhD, HRSD CTO, co-advisor

Introduction

1. Research Overview
2. Broader Applicability
3. Problem Statement
4. Hypothesis

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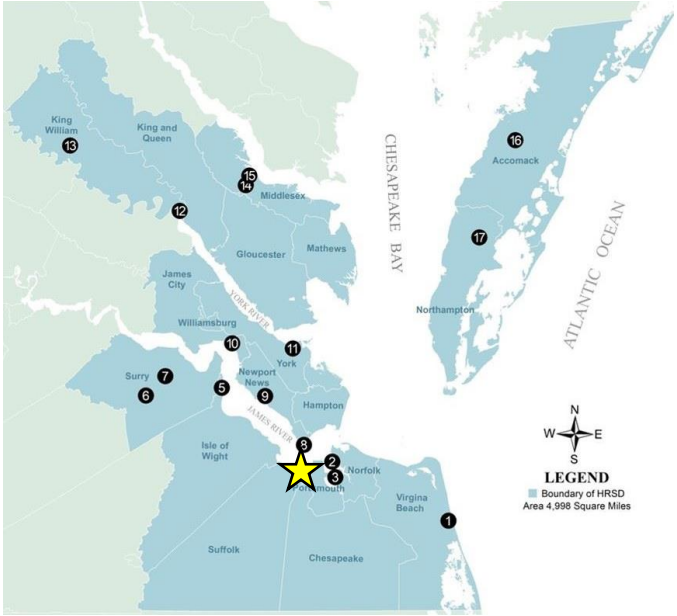
Hampton Roads Sanitation District (HRSD)

- Who are we?
  - Regional utility located in Eastern Virginia (Eastern US).
  - Established in 1940.
  - Serves 20 counties and cities covering nearly 5,000 square miles and including ~ 1.9 million people.
  - 8 major treatment plants and 6 smaller plants.
  - Total combined treatment capacity of 225 MGD.



Research Overview

- Blending the topics of control, modelling, and Digital Twins in a way that is digestible to practitioners (balanced complexity).
- Ammonia-Based Aeration Control (ABAC).
  - What is ABAC?
    - Aerate the least amount possible.
  - Why ABAC? Hasn't this been done before?
    - Novelty – this is ABAC based on Digital Twins (DT) principles with the cutting-edge data-driven tools presented in this work.
    - Novelty – this is ABAC based on Digital Twins (DT) principles built for nitrification enhancement (the first of its kind).
  - Where was this research performed?
    - Bridging the gap between research and practice – research performed at full-scale Water Resource Recovery Facility (WRRF).
    - Bridging the gap between research and practice – research performed at full-scale Water Resource Recovery Facility (WRRF).
    - The Harbor Boulevard Sanitation District (HBSD) Water Reclamation Plant (WRP) in Eastern Region, CA – 114,000 m^3/d, suspended growth, single-sludge, 5-stage Bardenpho facility

Broader Applicability

- This research applies to:
  - Control applications where the Process Variable (PV) is difficult to control due to significant influent load dynamics and there is a relatively plug flow Residence Time Distribution (RTD).
  - Utilities maintaining or interested in a WRRF DT and what value it might offer.
  - Utilities performing or interested in:
    - ABAC,
    - potable reuse, and/or
    - mainstream partial denitrification anammox (PdNA)

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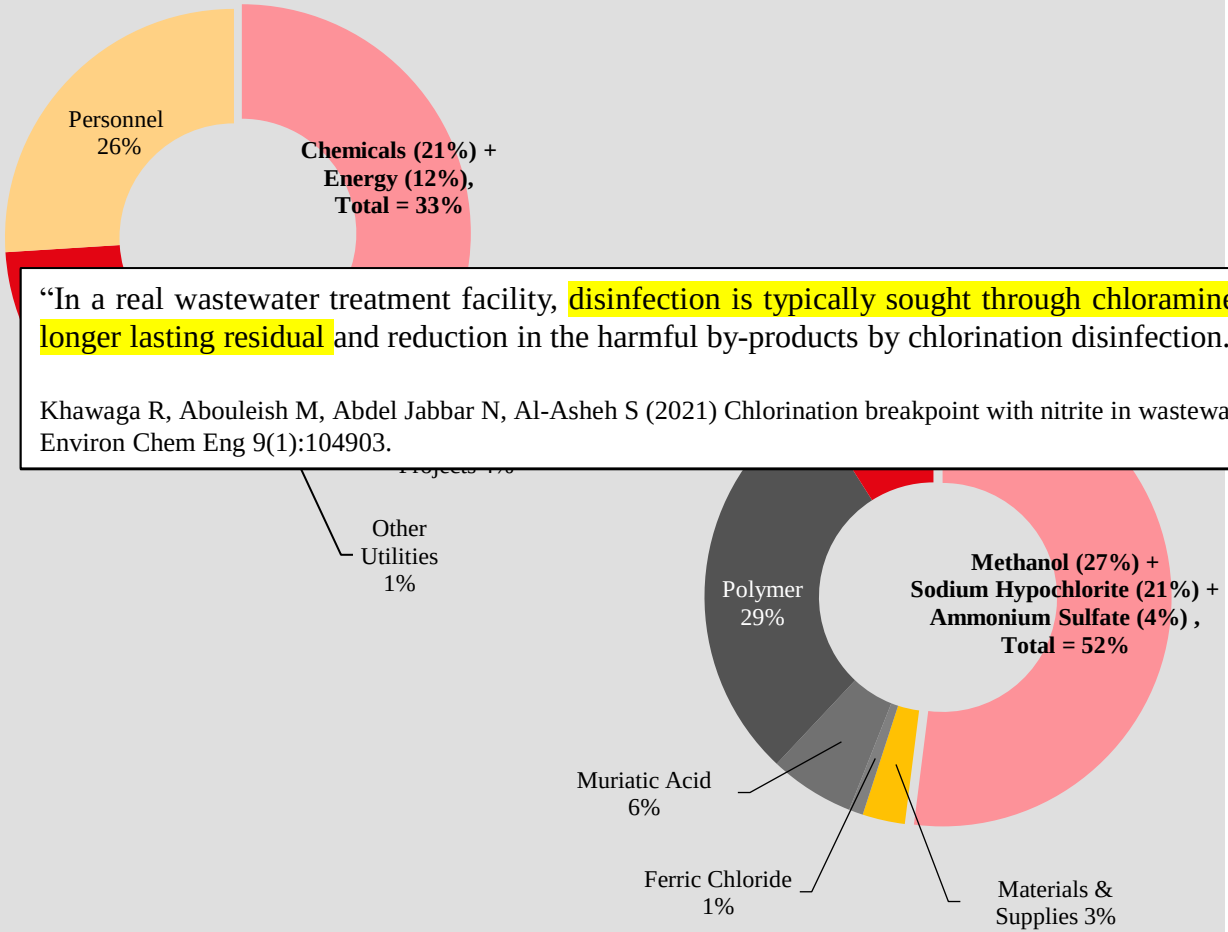
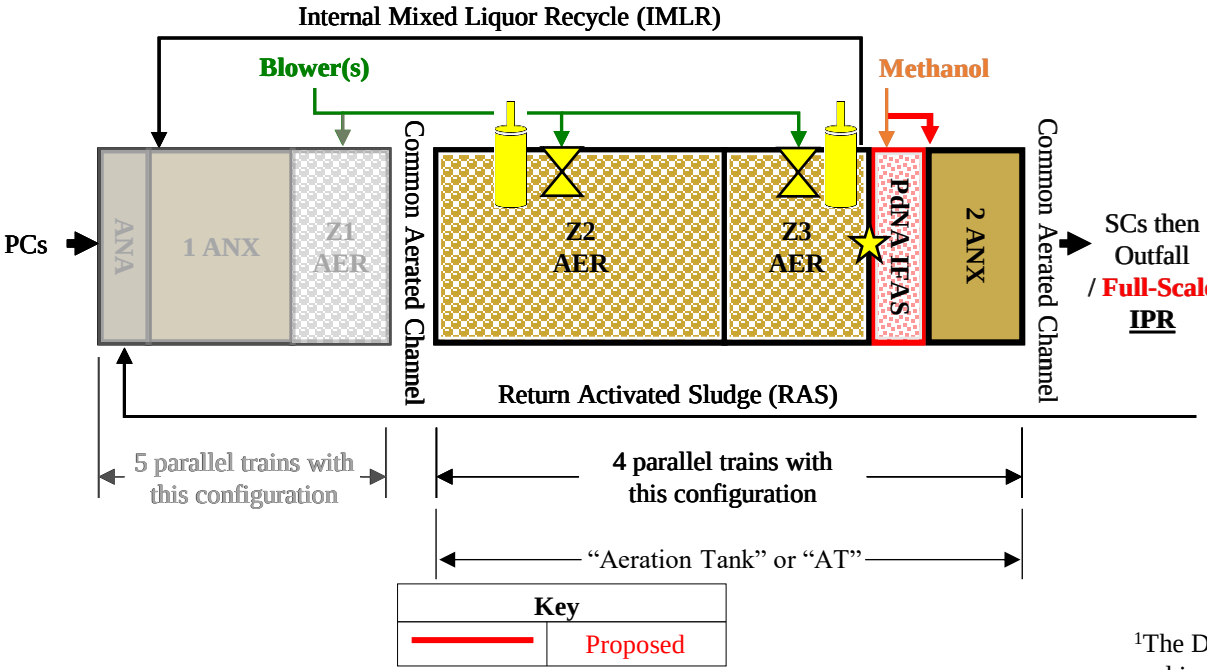
Total Operating Budget

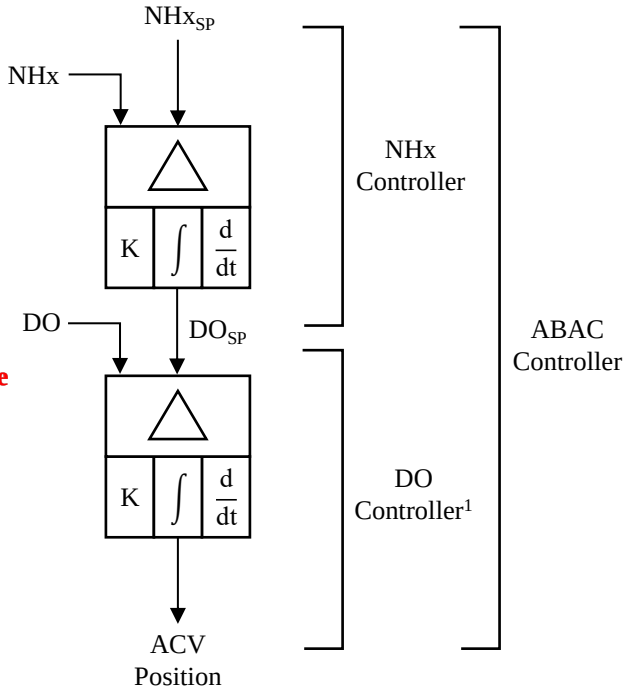


"In a real wastewater treatment facility, disinfection is typically sought through chloramine over free chlorine in order to maintain a longer lasting residual and reduction in the harmful by-products by chlorination disinfection."

Khawaga R, Abouleish M, Abdel Jabbar N, Al-Asheh S (2021) Chlorination breakpoint with nitrite in wastewater treatment: A full factorial design experiments. J Environ Chem Eng 9(1):104903.

HRSD NTP
Baseline Conditions





[1]The DO controller is a cascade controller and includes an air flow controller

Problem Statement

- The p
  ABAC

"The main optimizati
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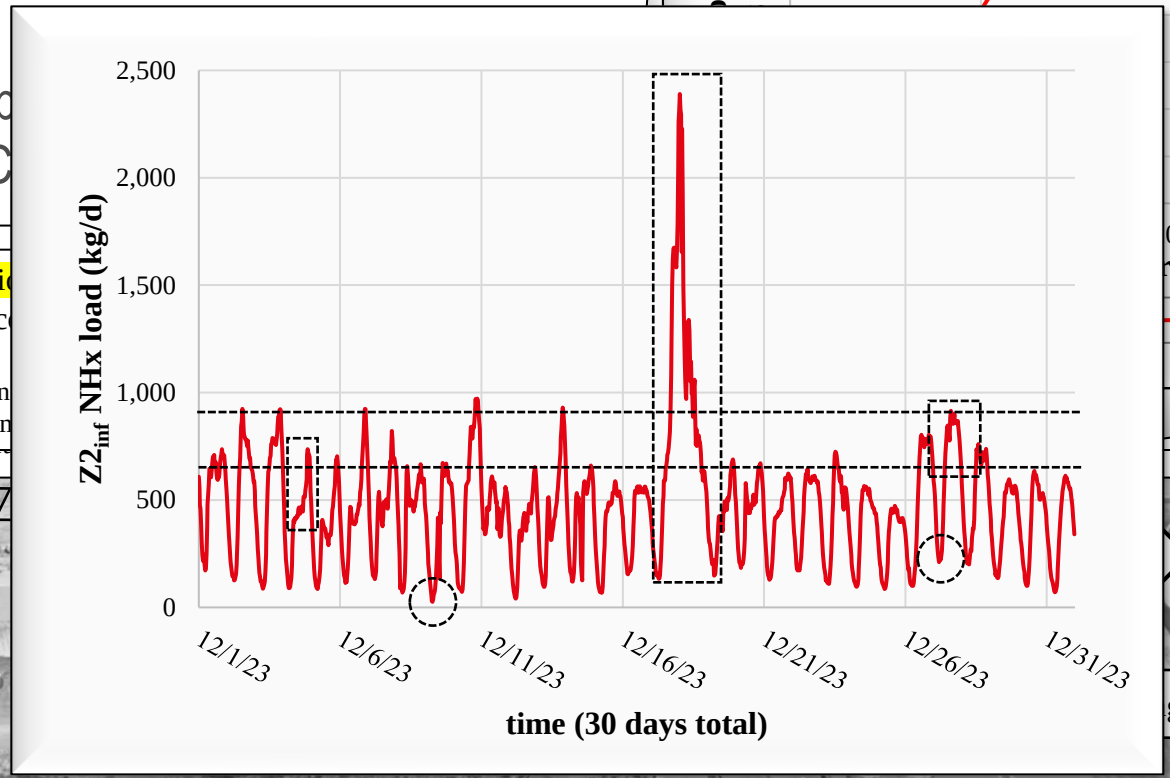
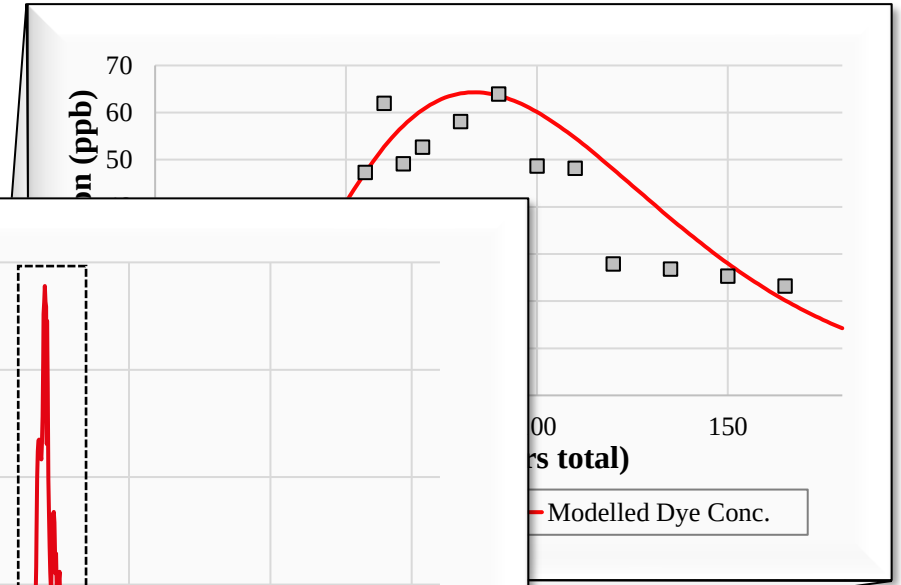
Flow





Problem Statement

Barriers to Good Control Authority

- In the context of this work, **Control Authority (CA)** is defined by whether a controller is **operating on a bound**. If the NHx is elevated, we want to increase the Dissolved Oxygen Setpoint (DO_{SP}) and vice-versa. This is not possible if we are on a bound.
- Current barriers to good control authority:
  - non-ideal controller tuning
  - NHx controller produced DO_{SP} bounds set too tight
  - poor waste rate and aerobic SRT control
  - controller delays

Hypothesis

The implementation of modern data-driven control tools, including DTs and Data-Driven Models (DDMs), into a facility's ABAC control philosophy offer a significant improvement over existing technology. By overcoming the limitations of traditional systems, these tools **have the potential to achieve a level of performance necessary for mainstream partial denitrification anammox (PdNA).** Furthermore, they **allow for full-scale potable reuse** while simultaneously optimizing operational costs associated with energy and chemical usage. Ultimately, these advancements lead to enhanced overall process performance and higher effluent quality at full-scale.

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Methods

1. Digital Twin
2. 3-Pronged Approach to Nitrification Enhancement

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Digital Twin

Nitrifier Population & Kinetics Estimations

X_{NITO} based on known NHx removal across the facility and $\mu_{max\text{-}NITO}$ estimated through Nelder-Mead optimization

Mechanistic Model Error Determinations

$NHx_{mod} - NHx_{obs}$

1

2.a

Waste Rate Scenario Analyses

Identify the ideal waste rate to maximize CA based on # of PCs in-service, possible NHx/TKN_{inf} Fractions, and $Temp_{wast}$

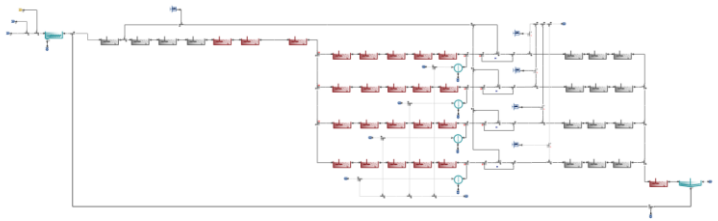
NHx_{mod} at 5 different waste rate changes

3.a.ii

3.a.i

X_{NITO}

$\mu_{max\text{-}NITO}$



CA Estimations

$\mu_{max\text{-}NITO}$

Control System

3-Pronged Approach to Nitrification Enhancement

NITO population & kinetics

- X_{NITO} and $\mu_{max\text{-}NITO}$ estimations using the DT and a Nelder-Mead optimizer, based on observed operational data.

Waste rate suggestions for max CA

- Waste rate change suggestions for the operator to maximize CA, based on scenario analyses that account for possible *NHx/TKN$_{inf}$ Fractions*. Other inputs include known historical *TKN$_{inf}$ Loads* and *Temp$_{fcast}$* , as well as $\mu_{max\text{-}NITO}$ and X_{NITO} from (1).

Feedforward-Feedback ABAC

- Hybrid model-based control of *Z3$_{eff}$ NHx*, based on X_{NITO} and μ_{NITO} from (1), and data-driven forecasted mechanistic model errors.

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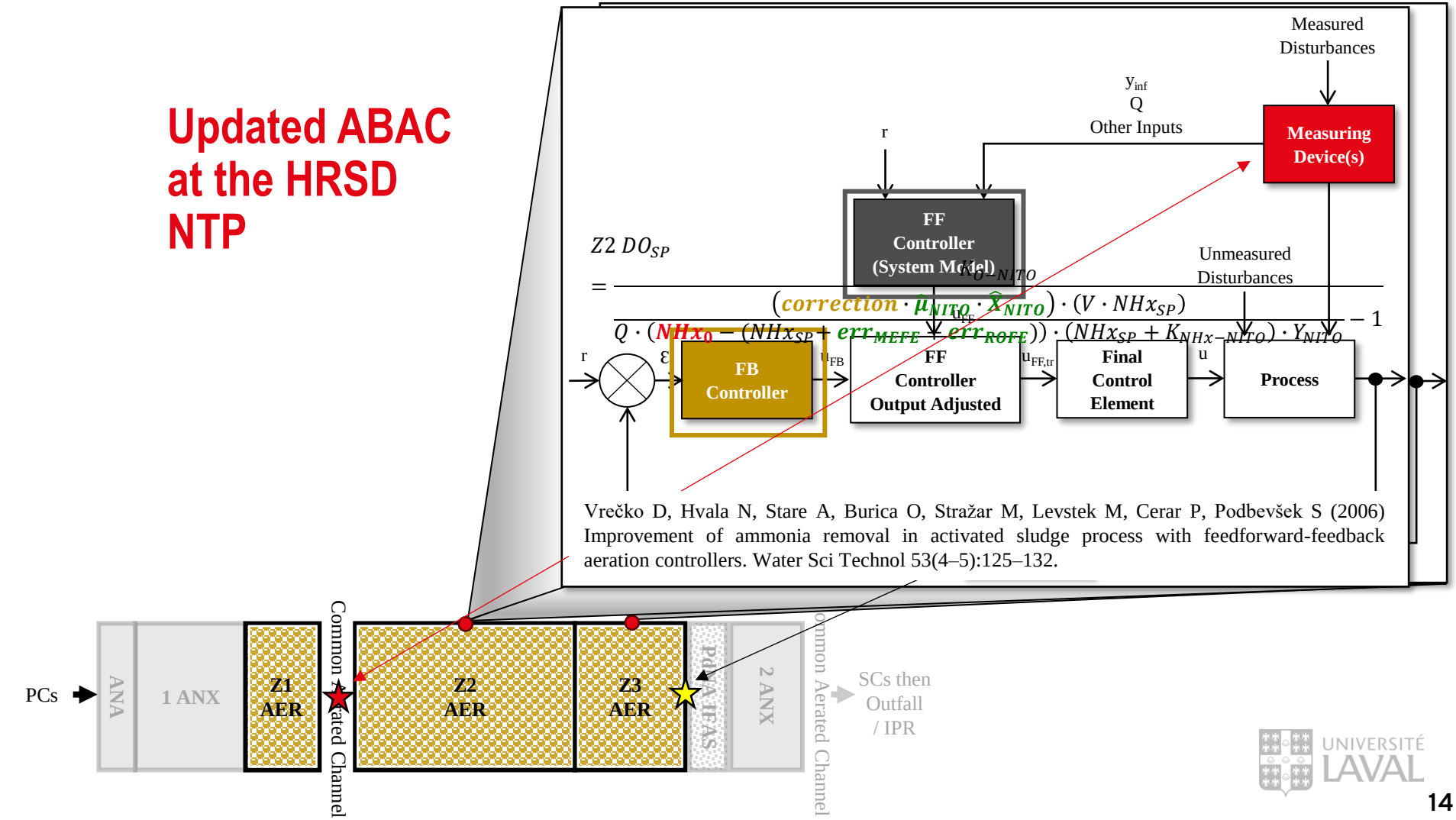
Updated ABAC at the HRSD NTP



Results & Conclusions

1. X_{NITO} & $\mu_{max\text{-}NITO}$ soft sensor
2. Waste Rate Scenario Analyses
3. Feedforward-Feedback ABAC

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3-Pronged Approach to Nitrification Enhancement

NITO population & kinetics

- X_{NITO} and $\mu_{max\text{-}NITO}$ estimation using the DT and a Nelder-Mead optimizer, based on observed operational data.

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Results & Conclusions

Prong 1 – X_{NITO} & $\mu_{max\text{-}NITO}$ soft sensors

1) If the objective is NHx prediction accuracy, then only $\mu_{max\text{-}NITO}$ needs real-time

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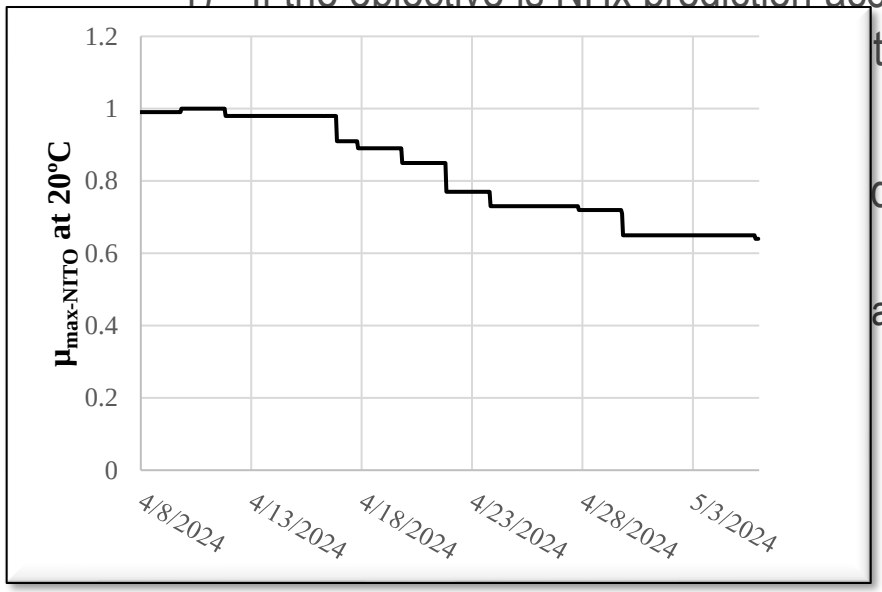

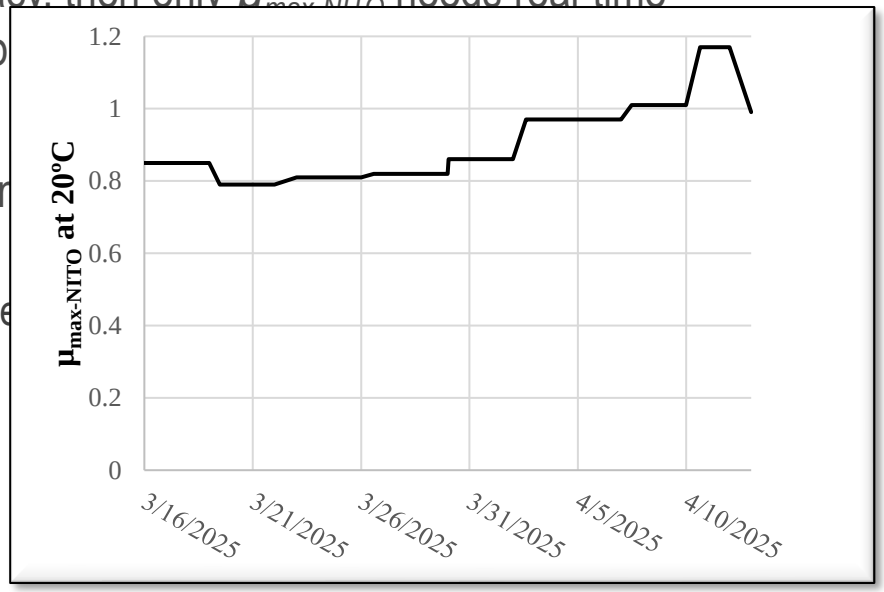

3-Pronged Approach to Next-Gen Nitrification

NITO population & kinetics

- X_{NITO} and $\mu_{max\text{-}NITO}$ estimation using the DT and a Nelder-Mead optimizer, based on observed operational data.

Waste rate suggestions for max CA

- Waste rate change suggestions for the operator to maximize CA, based on scenario analyses that account for possible *NHx/TKN$_{inf}$ Fractions*. Other inputs include known historical *TKN$_{inf}$ Loads* and *Temp$_{fcast}$* , as well as $\mu_{max\text{-}NITO}$ and X_{NITO} from (1).

Feedforward-Feedback ABAC

- Hybrid model-based control of *Z3$_{eff}$ NHx*, based on X_{NITO} and μ_{NITO} from (1), and data-driven forecasted mechanistic model errors.

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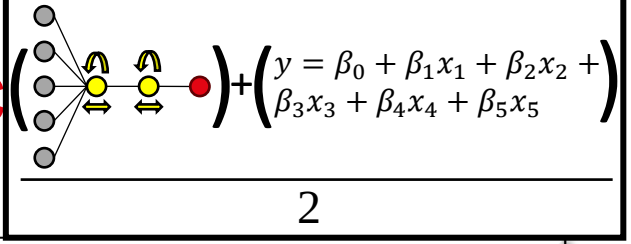
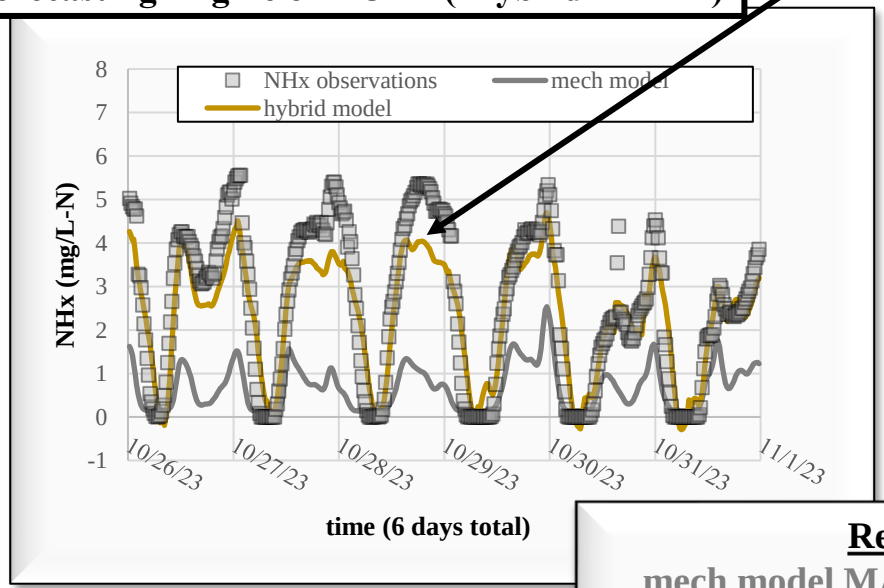
Results & Conclusions

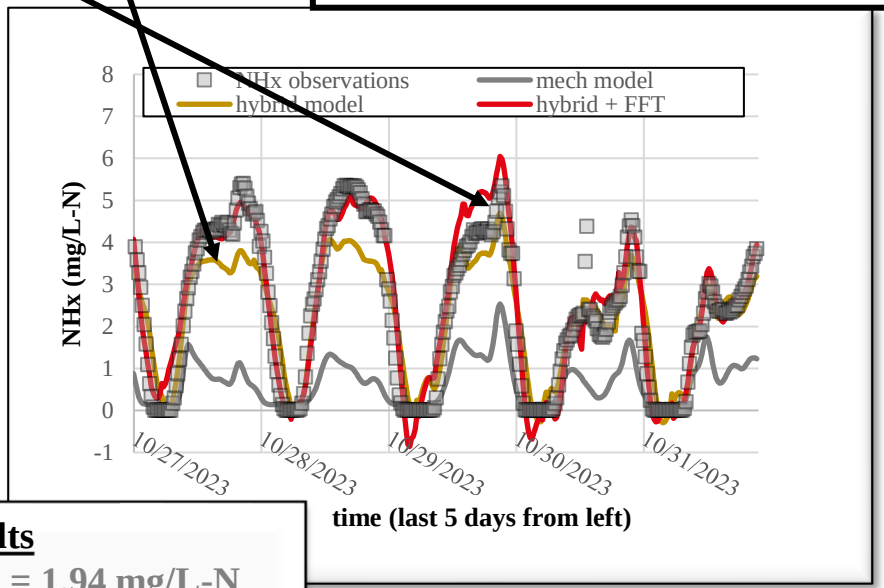
Prong 3 – Hybrid feedforward-feedback ABAC

Mechanistic Error Forecasting Engine or MEFE ("hybrid model")



Addition of the Residual Oscillation Forecasting Engine or ROFE ("hybrid + FFT")





Results

mech model MAE = 1.94 mg/L-N

MEFE MAE = 0.57 mg/L-N

ROFE MAE = 0.37 mg/L-N

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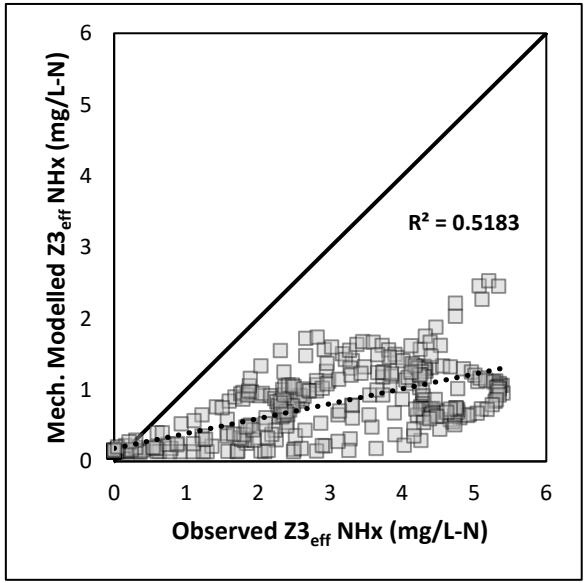
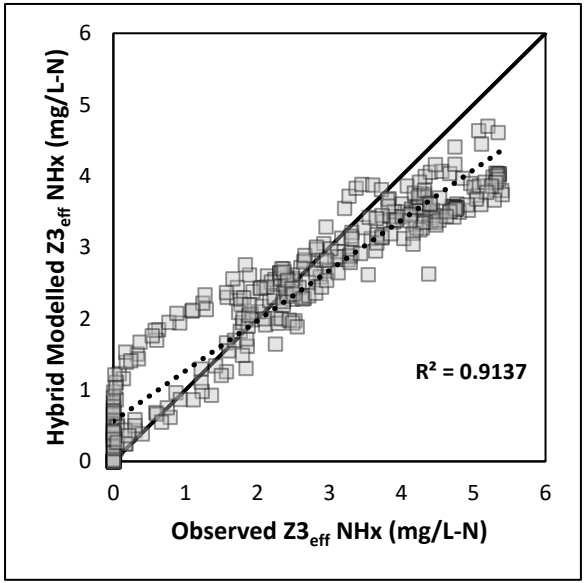
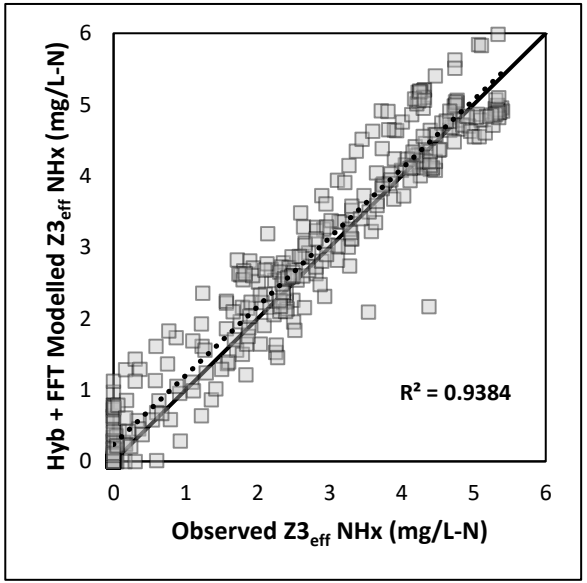
Results & Conclusions

Prong 3 – Hybrid feedforward-feedback ABAC







Results

AT 6 Controller MAE = 0.81 mg/L-N

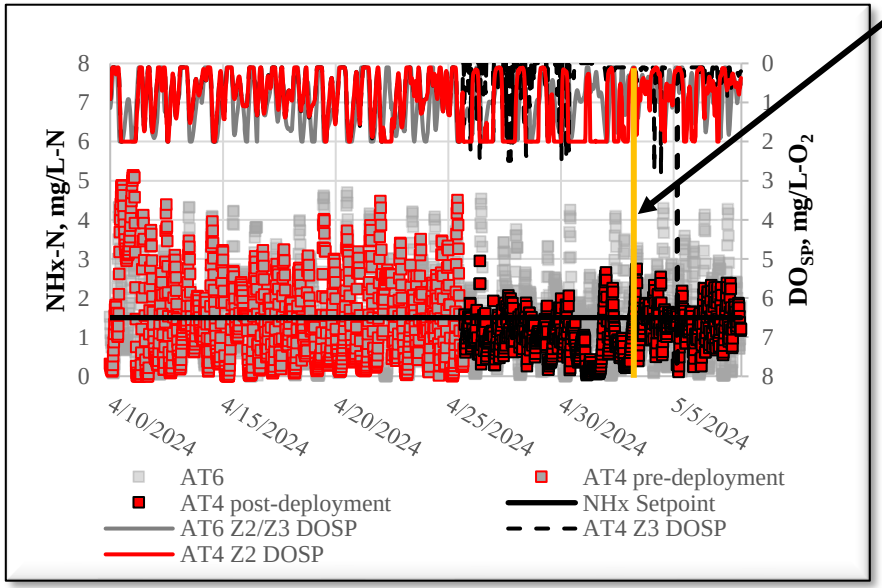
AT 4 MAE before tuning = 0.55 mg/L-N

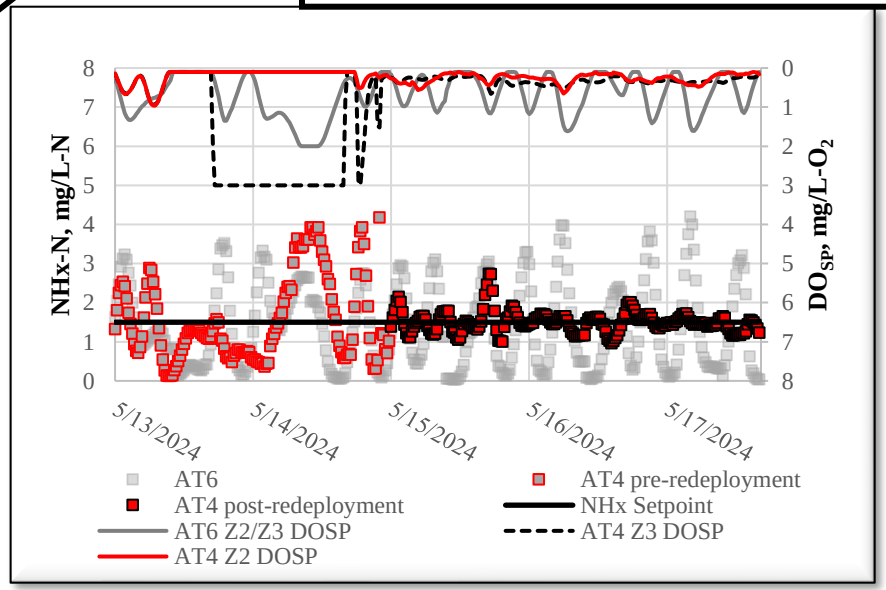
AT 4 MAE after tuning = 0.20 mg/L-N

Results & Conclusions

Prong 3 – Hybrid feedforward-feedback ABAC

feedback component added to feedforward equation.





Advanced Control in AT4 vs Baseline Control in AT6

Results & Conclusions

Prong 3 – Hybrid feedforward-feedback ABAC

1) The DT's mechanistic performance in **each AT** is hampered by physical disparities between the tanks and unknown influent / environmental conditions.

2) The DT's performance in **each AT** can be improved significantly through data-driven correction of the mechanistic model using time-series DDMs, based on "recent" error behaviour, in a parallel hybrid architecture.

Overall Conclusions

1) The data do not support maintaining a constant model parameter set for the mechanistic model inside the DT.
2) A DT for operator training, providing nitrifier performance metrics, and informing future expansion designs can also be leveraged for calculating the DO_{SP} in a feedforward-feedback ABAC scheme. The decision to do so depends on drivers.
3) Data-driven tools can be leveraged to provide robust ABAC for IPR, also paving the way for mainstream PdNA.

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Merci!
Questions?

Jeffrey Sparks/Université Laval

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For PDH Certificate seekers,

the course evaluation form and instructions are available in “Chat”.