Crossing the Finish Line: Integration of Data-Driven Process Control for Maximization of Energy and Resource Efficiency in Advanced Water Resource Recovery Facilities

IEDO

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Abstract

Improvements in process monitoring and control at water resource recovery facilities (WRRFs) could result in reductions in electricity consumption, chemical inputs, and greenhouse gas (GHG) emissions, as well as improved energy and other resource recovery. Many current WRRF data collection, monitoring, and control approaches use 20th century process monitoring and control systems, which require large design safety factors to ensure reliability in the absence of more advanced, precise controls. Implementation of more modern data-driven control tools could lead to more efficient operations that provide intrinsic reliability with better overall process performance at full-scale.

The objectives of this project are to: 1) develop and demonstrate data-driven process controls at full-scale facilities for five promising Applications (i.e., WRRF process technologies) that provide a whole-plant approach and offer substantial energy and resource recovery benefits, 2) create a Toolbox of new process control approaches and an implementation guide for accelerated adoption at WRRFs.

The five promising Applications are: 1) carbon (C) diversion for energy recovery; 2) low energy, low C biological nitrogen removal (BNR); 3) disinfection: peracetic acid (PAA); 4) P-recovery: MagPrex; and 5) biosolids optimization. The project integrates advancements in next gen sensors, data quality methods, & machine learning (ML) tools to bridge the gap between theoretical and full-scale process performance to better achieve treatment, resource recovery, and GHG emissions reduction goals.

Alignment with Office Mission

The implementation of data-driven process controls for these five technologies supports EERE's and IEDO's mission to accelerate the innovation and adoption of cost-effective technologies that eliminate industrial GHG emissions. GHG emissions reductions are achieved through reduction in electricity including aeration energy for degradation of organics and BNR (scope 2), reduction in chemicals including methanol for BNR, PAA for disinfection, magnesium chloride for phosphorus (P) recovery, and polymer for dewatering (scope 3), and reductions in direct emissions of CO_2, N_2O, and CH_4 from the wastewater treatment process (scope 1).

Challenges and Impact

The main challenge is demonstrating such novel controls for the 1st time in full-scale facilities. Potential impacts are below in terms of improvement from baseline.

Energy, Emissions, & Environment: Aeration Energy Reduction: Apps 1, 2, 4, 5: 22%, 44%, 10%, 10% Embedded Chemical Energy Reduction: App 1, 2, 3, 4, 5: 18%, 70%, 25%, 30%, 15%	**Cost & Competitiveness:** OPEX Costs ($/MG) Savings: Apps 1, 2, 3, 4, 5: 20, 77, 25, 26, 9 Potential Plant Capacity Savings: App 1: 24%, App 2: 38%
Technical & Scientific: P Recovery Increase: App 1: 500%, App 4: 200%	**Other Impacts:** Improved Process Reliability: Apps 1, 3, 4, 5: 67%, 43%, 20%, 10%

Project Outline

Innovation: Data Driven Process Controls to Maximize Energy & Resource Efficiency
Project Lead: The Water Research Foundation
Project Partners: Hampton Roads Sanitation District (HRSD), DC Water, Metro Water Recovery, University of Michigan, Northwestern University, US Military Academy - West Point, Oak Ridge National Laboratory, Black & Veatch, & 9 utilities
Timeline: Start: 10/01/2021; End: 3/31/2025; Progress approx. 50% complete.
Budget: The project just completed Budget Period 1 (BP1) and is entering BP2.

	FY21 Costs	FY22 Costs	FY23 Costs	Total Planned Funding
DOE Funded	$52,922	$225,795	$460,000	$1,136,167
Project Cost Share	$0	$445,850	$407,500	$1,137,872

End Project Goal:
Application 1: 10% capacity & 30% effluent total suspended solids improvement.
Application 2: 20% energy and/or 20% methanol savings at one or more facilities.
Application 3: 43% improvement in process reliability, 25% embedded energy savings, and/or $25/MG OPEX cost savings.
Application 4: 20% improvement in process reliability, 10% aeration energy savings, 30% embedded energy savings, 200% increase in nutrient recovery, and/or $26/MG OPEX cost savings.
Application 5: 7.5% decrease in polymer demand.

Background

This project will advance the objectives through the following seven Tasks: **Task 1:** Experimental Design and Data Collection, **Task 2:** Data and Process Analysis, **Task 3:** Modeling and Machine Learning, **Task 4:** Pilot-scale Implementation, **Task 5:** TEA and LCA, **Task 6:** Data-driven Process Controls Toolbox, and **Task 7:** Outreach and Technology Transfer. The specific data-driven objectives for each of the five Applications are provided in Table 1. Figure 1 includes a plant process flow diagram that shows the locations of the 5 Applications.

App.	Table 1: Specific Data-driven Objectives for Each Application
1	Balance minimum energy input with settleability in high-rate Contact Stabilization (CS) system.
2	Ammonium versus NOx (AvN) aeration control & partial denitrification-anammox (PdNA) supplemental carbon feed to optimize aeration energy, supplemental carbon control, and carbon capture.
3	Model Peracetic Acid (PAA) disinfection performance to adjust dose based on water quality and operational conditions.
4	Adjust reagent dosing and identify optimum upstream operational conditions for maximum phosphorus (P) recovery at lowest energy cost.
5	Minimize polymer costs and maximize cake solids through holistic biosolids facility optimization and acoustic sensor integration.

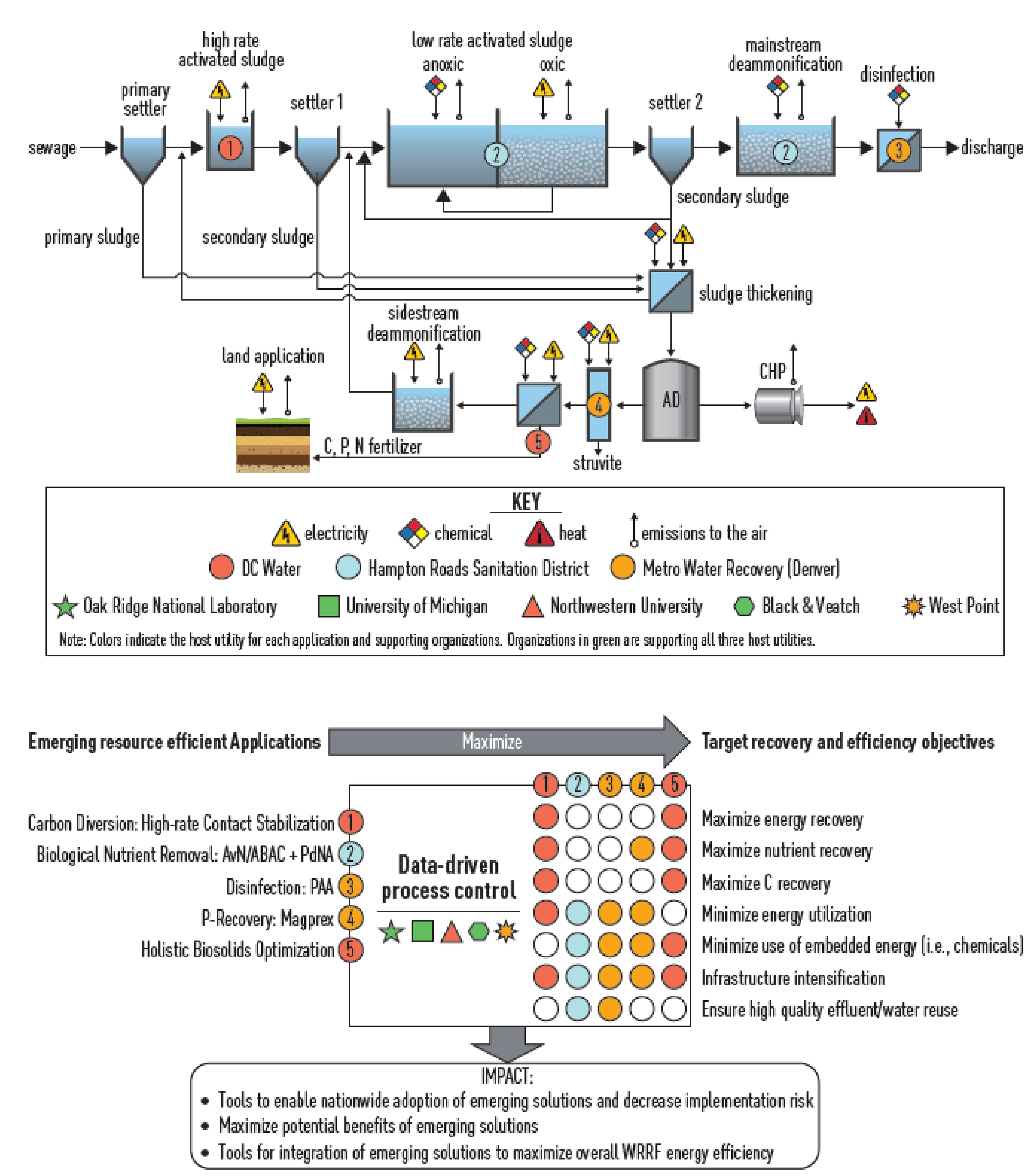

Figure 1: Emerging resource efficient Applications selected for this project and the target recovery and efficiency objectives they address. The plant process flow diagram shows the locations of the five Applications which will demonstrate a whole plant approach for data-driven process controls. Utility and academic partner roles are identified and color coded. ABAC: ammonium-based aeration control.

Results

- Experimental/quality assurance project plan (QAPP) completed.
- Extensive wastewater and process data needed for ML and model development collected at the three host utilities: HRSD, DC Water, and Metro Water Recovery.
- Data cleaning, analysis, treatment, exploration, and visualization conducted for each of the 5 Application datasets.
- Initial models developed for each of the 5 Applications, including ML models (purely data driven) and hybrid mechanistic-ML models.
- An initial Toolbox framework was developed to provide guidance on the ML & model process: Define Problem, Get Data, Prepare Data, Train Model, & Deploy.
- Initial LCA/TEA models developed for all 5 Applications & findings summarized.

Conclusions

The team made significant progress on data collection, analysis, and initial ML model development in the first half of the project, as well as the development of a Data-Driven Controls Toolbox. Initial LCA models confirm the new process controls will provide significant beneficial environmental impacts including GHG emissions reduction (e.g. Fig 2).

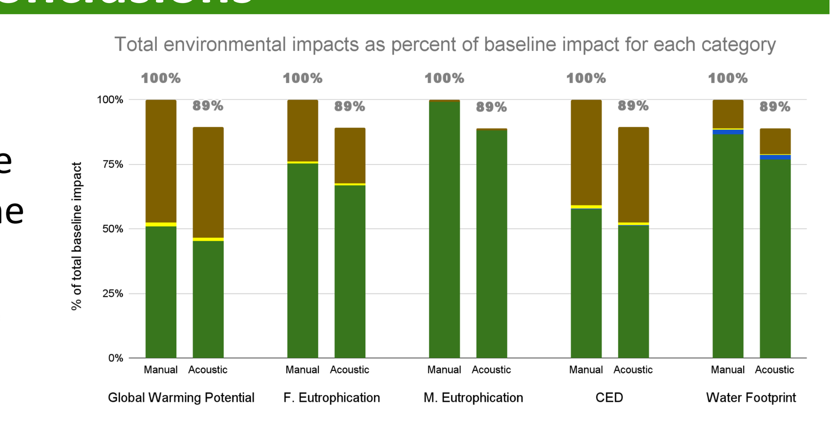

Fig 2: Application 5 (biosolids optimization) - Environmental impacts for the baseline scenario with manual polymer dosing and the hypothetical goal scenario with acoustic-sensor dosing. CED: Cumulative Energy Demand.

Key Achievements

To date, Applications 1, 2, 3, and 5 have achieved the go/no-go decision criteria for developing model structures that can simulate real-time prediction with reasonable accuracy and demonstrating readiness for pilot-scale implementation (e.g., Fig. 3). Application 4 is anticipated to achieve the go/no-go decision soon.

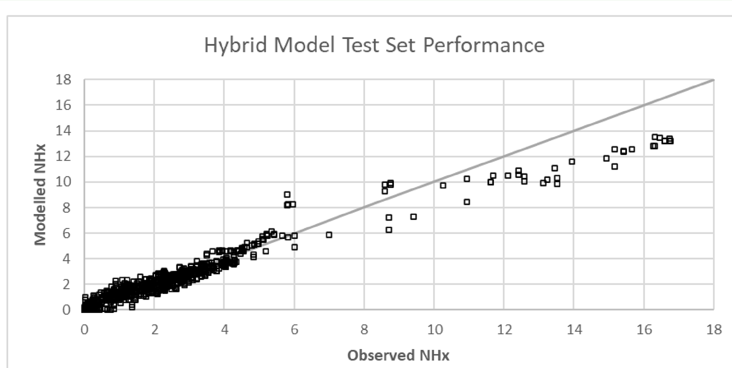

Fig. 3: Application 2 (low-energy, low-carbon BNR) - hybrid model performance on unseen test data.

The team has given 10+ conference presentations and 2 papers. More are pending.

Future Work

Future work will focus on refining the data-driven process control models for all 5 Applications and pilot-scale implementation at the utilities. The team will develop A final LCA/TEA, Toolbox, & implementation guide, & conduct technology transfer.

Technology Transfer

- WRF has established a Utility Advisory Committee or UAC (see Acknowledgements) of 9 progressive utilities that are interested in adopting the technology if successful and are engaged in the research & learning process.
- WRF will host a webcast for its 1,000+ utility members and others to share the final Toolbox & implementation guide to accelerate adoption at other utilities.
- WRF will host a 1-2 day in-person workshop at project end that will include utilities, consultants, regulators, academics, manufacturers, and others.
- WRF will post the final Toolbox on its website, and disseminate it via its magazine, newsletter (35,000+), social media (60,000+), and targeted outreach.

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