Enabling Next-Generation Process Automation: Where are the Next Innovations in Sensing and Data Analytics?

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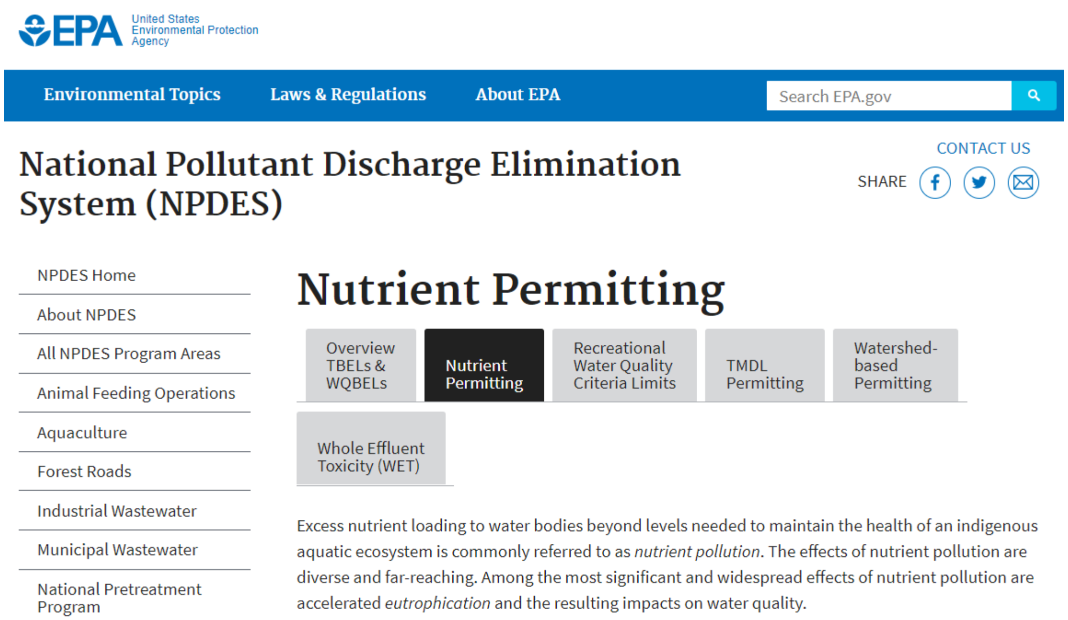
Motivations for the field of WWTP

Responding to tightening discharge limits


EPA United States Environmental Protection Agency

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National Pollutant Discharge Elimination System (NPDES)

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- Forest Roads
- Industrial Wastewater
- Municipal Wastewater
- National Pretreatment Program

Nutrient Permitting

Overview TBELs & WQBELs | Nutrient Permitting | Recreational Water Quality Criteria Limits | TMDL Permitting | Watershed-based Permitting | Whole Effluent Toxicity (WET)

Excess nutrient loading to water bodies beyond levels needed to maintain the health of an indigenous aquatic ecosystem is commonly referred to as *nutrient pollution*. The effects of nutrient pollution are diverse and far-reaching. Among the most significant and widespread effects of nutrient pollution are accelerated *eutrophication* and the resulting impacts on water quality.

Source from EPA (2017)
https://www.epa.gov/npdes/nutrient-permitting

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Motivations for the field of WWTP

Reducing energy costs

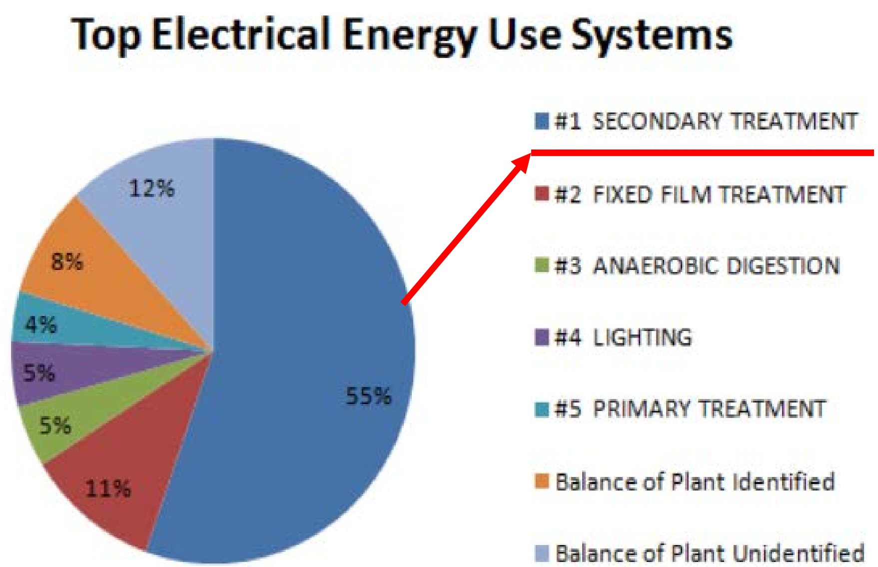

Figure from EPA (2012)

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Motivations for the field of WWTP

Enabling transformation into *wastewater resource recovery facilities* (WRRF)

Image from Durham phosphate recovery facility

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Goals of our work

- **Understand what is possible**
- **Identify the roadblocks**
- **Look for promising solutions**

Methods

- Literature review: Research and implementation stages
- Workshops (as discussed earlier in this session)

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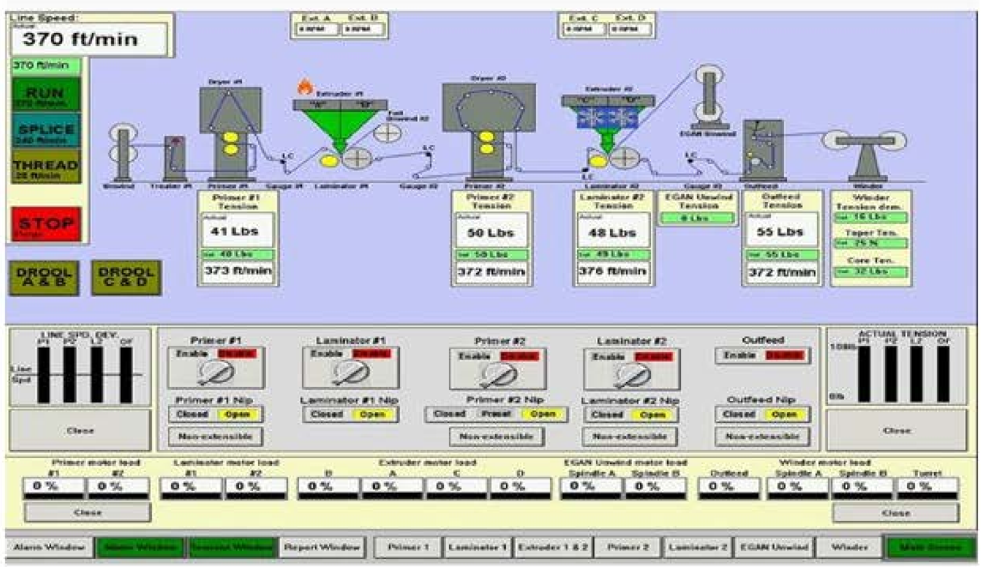
Tools to improve process performance

- **Data analytics for real-time data processing**
- **Online control schemes**



SCADA architecture example

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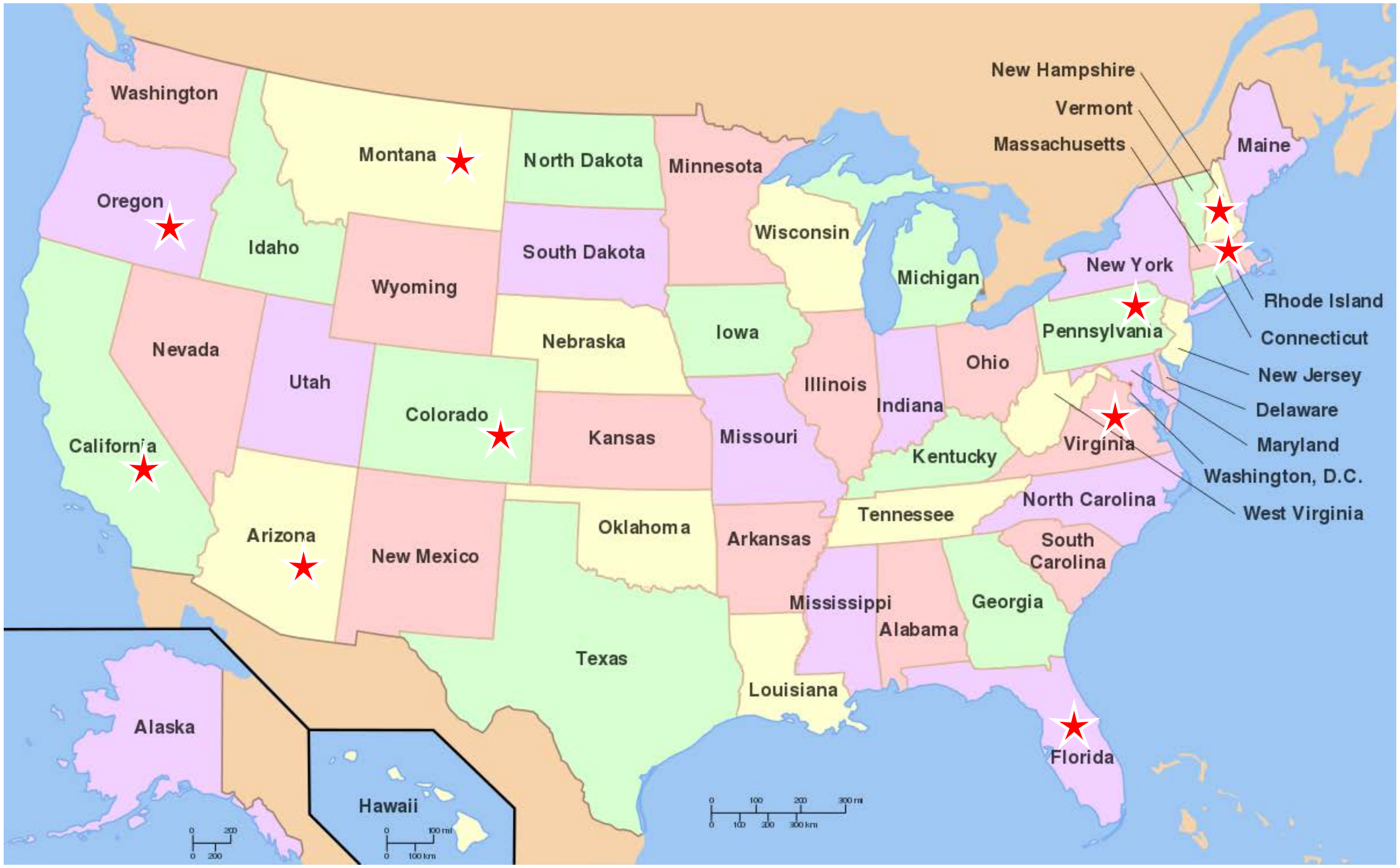
Innovation is already well underway



★ States that have published reports that have upgraded with innovated sensing technology

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Case study 1: City of Layton WWTP, FL

Upgrade type and year: SBR for nitrification/denitrification (full-scale), 2009

Sensing strategy: DO, ORP, and TSS sensors

Sensor location: installed in each SBR

Updated control: from a level batch process to a timed batch

TN Permit: 10 mg/L

	Influent Total Nitrogen	Effluent Total Nitrogen		
	Average Concentration	Average Concentration	Standard Deviation	Units
Pre-upgrade	89.3	7.88	4.26	mg/L
Post-upgrade	64.1	3.33	1.87	mg/L

58% decrease

EPA (2015)
https://www.epa.gov/sites/production/files/2015-08/documents/508

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Case study 2: Wildcat Hill WWTP, AZ

Upgrade type and year: Process control for activated sludge in MLE (full- scale), 2013

Sensing strategy: combined ammonia/nitrate probe (ISE type), ORP

Sensor location: installed at the end of the anoxic zone

Updated control: DO control

TN permit: 10 mg/L

Parameter	Pre-upgrade	Post-upgrade
Final Effluent NO3	12.5	7.0
Final Effluent TN	14.0	8.5

40% decrease

EPA (2015)
https://www.epa.gov/sites/production/files/2015-08/documents/508

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Looking forward: data analytics for real-time data processing

- **Ingest and respond to data streams from multiple sensors simultaneously**
- **Ability to learn from collected historical datasets**
- **Modeling of highly non-linear processes without requirement of modeling process physics or biology**

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Case study 1: Lab analysis with real plant data

Goal of the study: To improve emissions prediction such as odor nuisance

Instrument: Odalog Logger L2 instrument for H_2S gas

Instrument location: Headworks influent chamber

Model applied: Principle component analysis (PCA) + artificial neural networks (ANN)

Output	RMSE	R^2
EF-flow [0–500 mg/m^3]	15.26 mg/m^3	0.95

Zounemat-Kermani et al., 2019

Case study 2: Moving towards operational use

Goal of the study: To handle noise and extract useful information

Instrument: UV/Vis spectrometer for COD, TSS, oil & grease, turbidimeter

Instrument location: Effluent of a restaurant on campus

Model applied: Weighted partial least square (nonlinear regression)

Output	RMSE	R^2
COD [0-2500 mg/L]	141 mg/L	0.952
TSS [0-550 mg/L]	30.2 mg/L	0.965
O&G [0-550 mg/L]	34 mg/L	0.945

Qin et al., 2012

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Online control algorithms and applications

Algorithms

- **PID** (proportional-integral-derivative) control is commonly applied in the wastewater industry already
- **Fuzzy logic** control is drawing interest in academia

Applications

- DO control
- ABAC (ammonia-based aeration control)

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Case study 1: Ejby Mølle WWTP, Denmark

Motivation: To reduce N_2O emissions and improve energy efficiency

Control method: From intermittent aeration to continuous aeration with DO-based control

Process type and scale: Partial nitrification-denitrification, full scale

Application year: 2014

Results:

- 56% increase in N_2O emissions removal efficiency
- 18% energy savings

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Case study 2: Hampton Roads Sanitation District WWTP, VA

Motivation: To improve energy efficiency

Control method: From DO-based control to ammonia-Based Aeration Control (ABAC)

Process type and scale: 5-stage Bardenpho process, full scale

Application year: 2013

Results:

- 53% decreased supplemental carbon for denitrification
- 10% energy savings compared to DO setpoint control

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Case studies in research: Fuzzy logic control

Advantages:

- Can implement human experience/intuition/uncertainty into the controller
- May achieve better results than PID control

Disadvantages:

- Hard to turn the parameters

Study with fuzzy logic	Scale	Result
Fiter et al., 2010	Bioreactor that models ASM1	13% decreased energy usage compare to ON/OFF control
Bouzas et al., 2019	20.6 L EBPR lab reactor	29.6% P recovery - compared to 13.7% with PID

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Challenges in bringing research to practice

- **Every plant is unique, no one-size-fits-all algorithm/model**
- **Lab experiments control variables to assess repeatability, may not represent results under operational conditions**
- **As model complexity increase, it is difficult to assess the expected response to all possible conditions**

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Gaps and challenges

Slow transfer of innovation from academic labs to practice

- Cost of sensors, complexity of data algorithms

How to ensure sensor data will be useful in plant operations?

- True impact of upgrading strategies rarely clear from research publications

Knowledge gaps between existing environmental engineering training and these numerical skillsets

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Suggestions for Enabling Solutions

Enable operators to evaluate cost/benefit in reference to the status quo

- Reporting results with new sensors and data methods under realistic conditions

Training of environmental engineers and plant operators

- Skills such as statistics, data processing, data visualization, etc.
- Leverage state or federal grants for workforce development

Partnerships between operators and researchers

- **Enable development of novel analytical approaches**
  - Data sharing
  - Developing new data integration/visualization tools
- **Exploring process dynamics, leveraging existing facilities**
  - Build more realistic test facilities (e.g., Tucson WEST, HRSD)
  - Generate results that are more useful/interpretable for plants
  - Improve utility and trust of new algorithms
- **Build workforce of tomorrow**
  - Give students a window into true challenges/context

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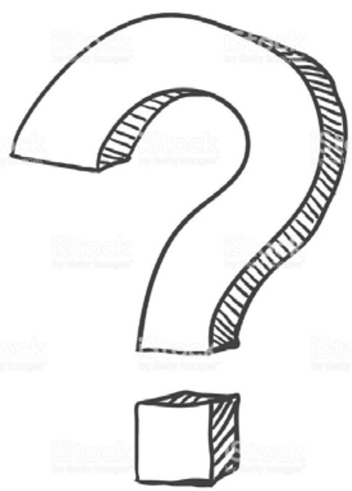
Questions?

1. Current innovations in real-time sensing applied in WWTPs
2. Data analytics and online control for treatment processes
3. Gaps and solutions – COLLABORATION!



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