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Process Control: Theory, Practice, Data Quality and Compliance Optimization

Thursday, March 11, 2021

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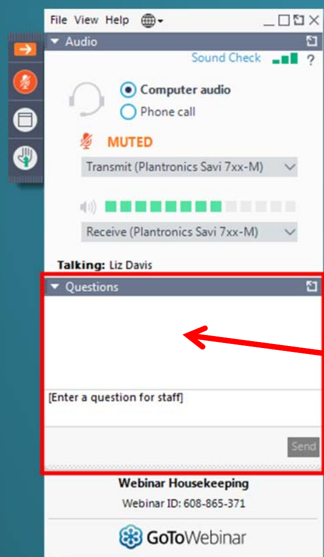
How to Participate Today



- **Audio Modes**
  - Listen using Mic & Speakers
  - Or, select "Use Telephone" and dial the conference (please remember long distance phone charges apply).
- **Submit your questions using the Questions pane.**
- **A recording will be available for replay shortly after this webcast.**

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Today's Moderator

John B. Copp Ph.D.
Primodal Inc.
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Primodal
Earth Essential Technologies

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Control Subtleties – Mar. 11, 2021

An MRRDC Short Course:

Process Control:
Intro, Data and Lessons Learned

- Topics:
  - Introduction to Control Concepts
  - Real Data, Practical Issues
  - Case Studies
    - Ontario
    - DC Water

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Control Subtleties – Mar. 11, 2021

An MRRDC Short Course:

Process Control:
Intro, Data and Lessons Learned

Oliver
Schraa
inCTRL

John
Copp
Primodal

Hank
Andres
OCWA

Ryu
Suzuki
DC Water

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Our First Speaker

Oliver Schraa, M.Eng.
inCTRL Solutions Inc.
Dundas, Ontario, Canada

inCTRL SOLUTIONS

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PROCESS CONTROL – STRATEGIES, ISSUES, AND ADVANCEMENTS

Oliver Schraa

CTO, inCTRL Solutions Inc.

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Outline

1. Introduction to automatic process control
2. Aeration control strategies
3. Recent advancements
4. Common control issues & solutions
5. Summary and conclusions

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What is process control?

- Process control involves maintaining a process at a desired set of conditions by adjusting selected variables within the system.
- Process control requires measurements from the process which provide feedback. These are the controlled variables.
- The adjustments to the system are made to the manipulated variables (or control handles).
- The adjustments can be made using manual actions or automatic controllers.

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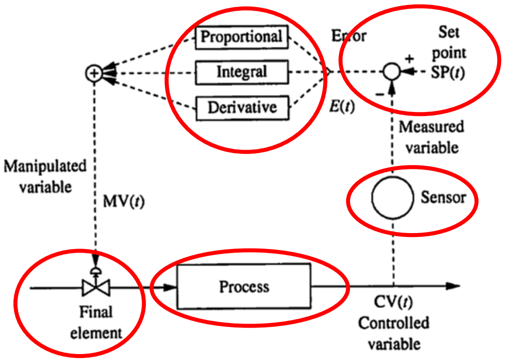
What is an automatic controller?



Marlin (2000)

$$MV_N = K_c\left[E_N + \frac{\Delta t}{T_I}\sum_{i=1}^{N} E_i - \frac{T_d}{\Delta t}(CV_N - CV_{N-1})\right] + I$$

Automatic controller: Computer algorithm that continually monitors a quantity within a system and automatically acts to correct deviations from the desired setpoint.

Elements of a feedback control system:
- Process
- Sensors
- Error calculation
- Controller (PID, model-based, etc.)
- Actuators (valves, VFD, etc.)

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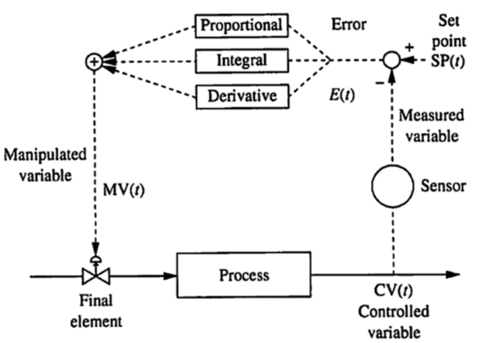
What is an automatic controller?



Marlin (2000)

$$MV_N = K_c\left[E_N + \frac{\Delta t}{T_I}\sum_{i=1}^{N} E_i - \frac{T_d}{\Delta t}(CV_N - CV_{N-1})\right] + I$$

Proportional-Integral-Derivative Controller (PID): Most common automatic controller. Algorithm based on 3 types of calculations that are added together:

Proportional action: Proportional to error

Integral action: Used to achieve zero offset from setpoint. Proportional to sum of errors.

Derivative action: Provides a correction based on the rate of change in the controlled variable.

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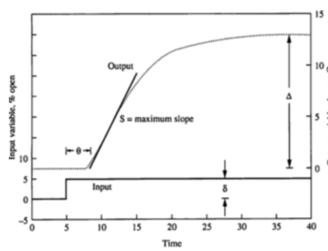
What is controller tuning?

Tuning: pick settings for controller parameters

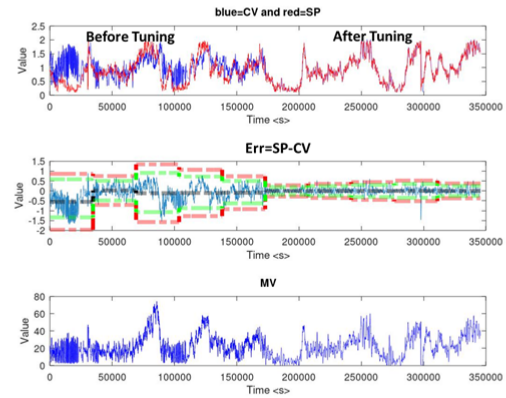
$$MV_N = K_c\left[E_N + \frac{\Delta t}{T_I}\sum_{i=1}^{N} E_i - \frac{T_d}{\Delta t}(CV_N - CV_{N-1})\right] + I$$

Methods
- Open-loop
- Closed-loop



Open Loop Method

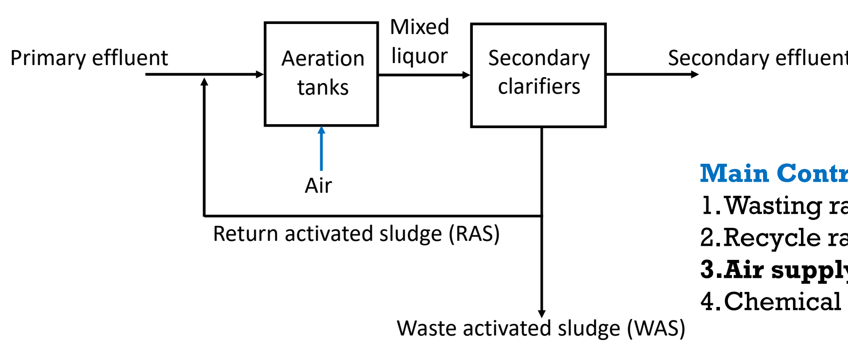
Build a model of the process being controlled and use model and tuning rules to determine tuning parameters.



Poor tuning and bad data prevent ability to track set points. Well-tuned controllers perform better.

What are the variables we can adjust?

Typical Activated Sludge Plant



Main Control Handles:
1. Wasting rate
2. Recycle rate
3. **Air supply rate**
4. Chemical addition rate

Aeration Control

- **Automatic control:**
  - Blower controller(s) used to maintain the required total air supply
  - Use DO controller(s) to adjust airflow to each basin/pass/grid to keep DO near setpoint and supply air for mixing
  - **Advantages:**
    - Lower cost for aeration energy
    - Ensures that biomass oxygen demand is met
    - Avoids operational problems associated with excessive (floc shear) or inadequate aeration (filamentous bulking)
    - Can maintain tighter control of the DO near desired setpoint

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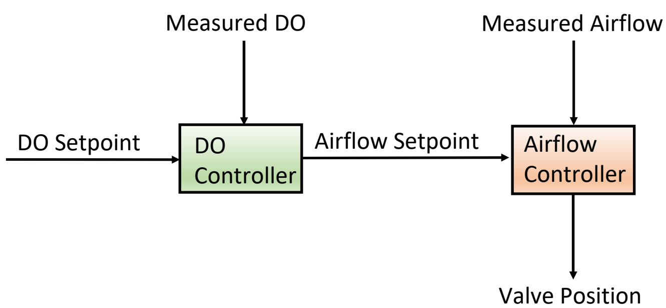
Dissolved oxygen (DO) control

Typical DO Control Loop



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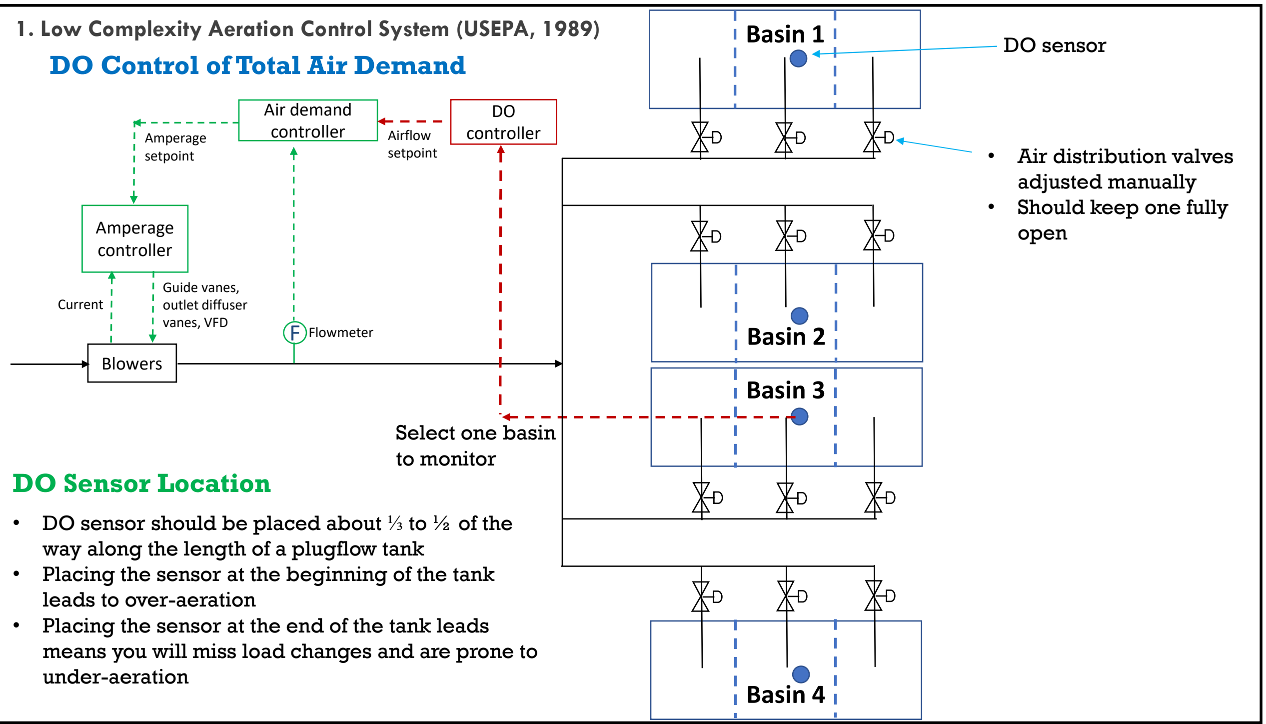
1. Low Complexity Aeration Control System (USEPA, 1989)

DO Control of Total Air Demand



DO Sensor Location

- DO sensor should be placed about ⅓ to ½ of the way along the length of a plugflow tank
- Placing the sensor at the beginning of the tank leads to over-aeration
- Placing the sensor at the end of the tank leads means you will miss load changes and are prone to under-aeration

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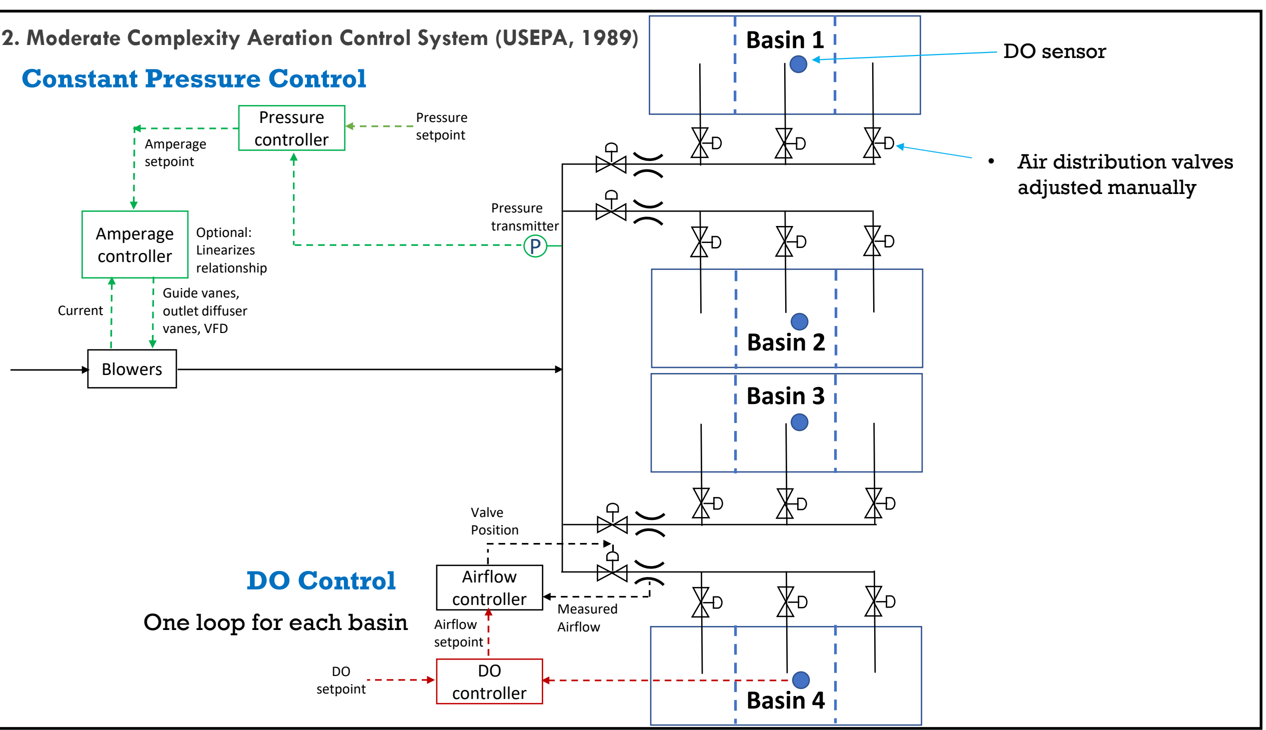
2. Moderate Complexity Aeration Control System (USEPA, 1989)

Constant Pressure Control



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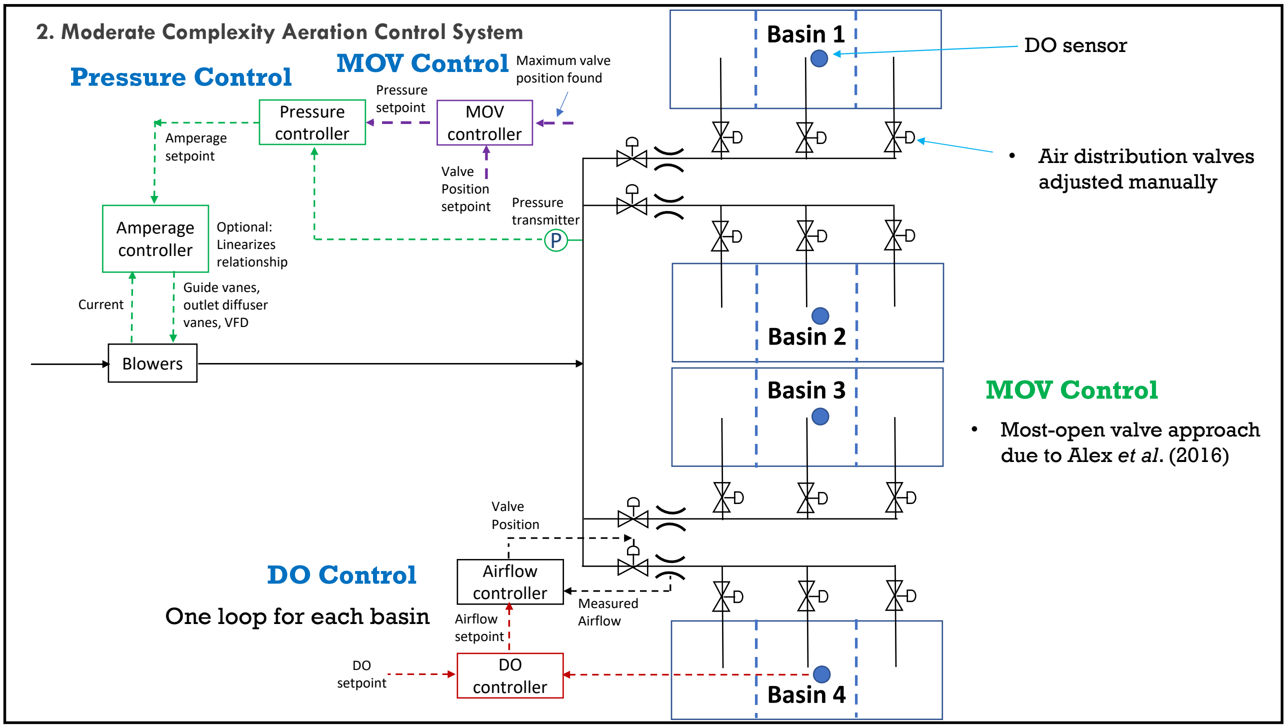
2. Moderate Complexity Aeration Control System
Pressure Control
MOV Control
Maximum valve position found
Pressure setpoint
Pressure controller
MOV controller
Amperage setpoint
Valve Position setpoint
Pressure transmitter
Amperage controller
Optional: Linearizes relationship
Current
Guide vanes, outlet diffuser vanes, VFD
Blowers
Basin 1
Basin 2
Basin 3
Basin 4
DO sensor
Air distribution valves adjusted manually
MOV Control
Most-open valve approach due to Alex et al. (2016)
Valve Position
DO Control
One loop for each basin
Airflow controller
Measured Airflow
Airflow setpoint
DO setpoint
DO controller

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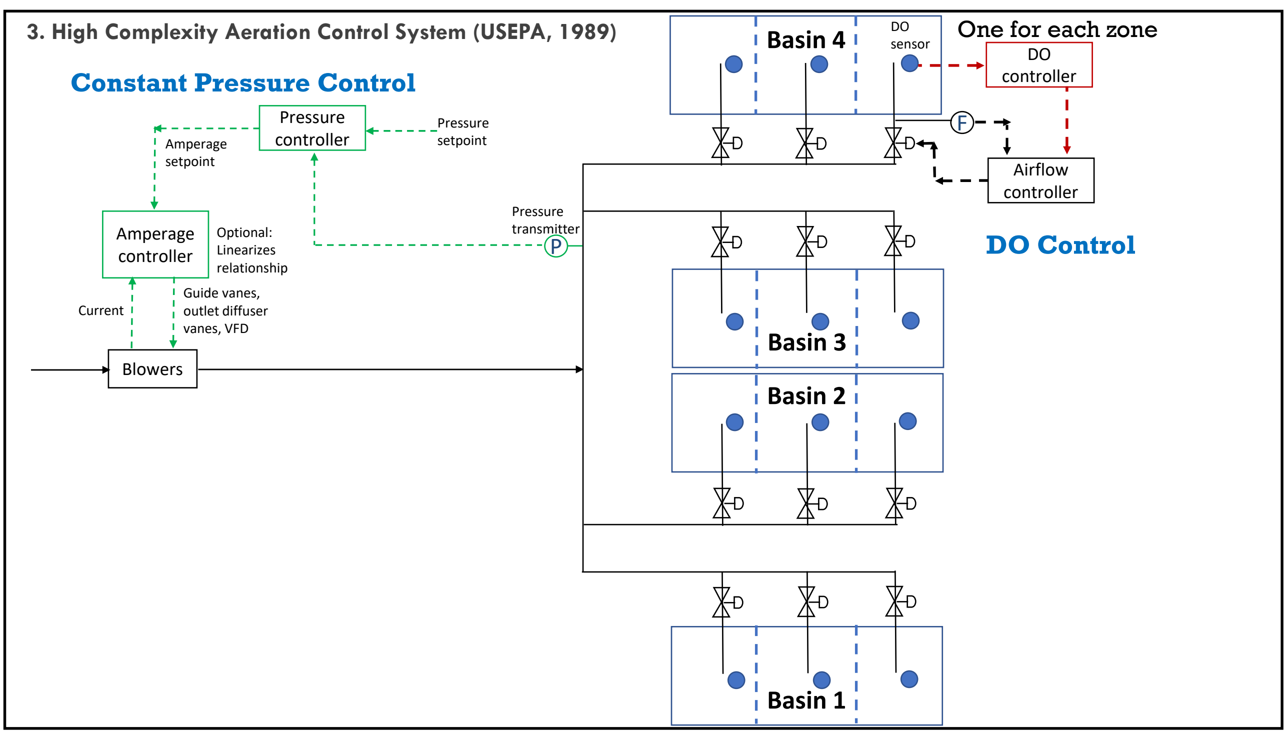
3. High Complexity Aeration Control System (USEPA, 1989)
Constant Pressure Control
Pressure controller
Pressure setpoint
Amperage setpoint
Pressure transmitter
Amperage controller
Optional: Linearizes relationship
Current
Guide vanes, outlet diffuser vanes, VFD
Blowers
Basin 4
DO sensor
One for each zone
DO controller
Airflow controller
DO Control
Basin 3
Basin 2
Basin 1

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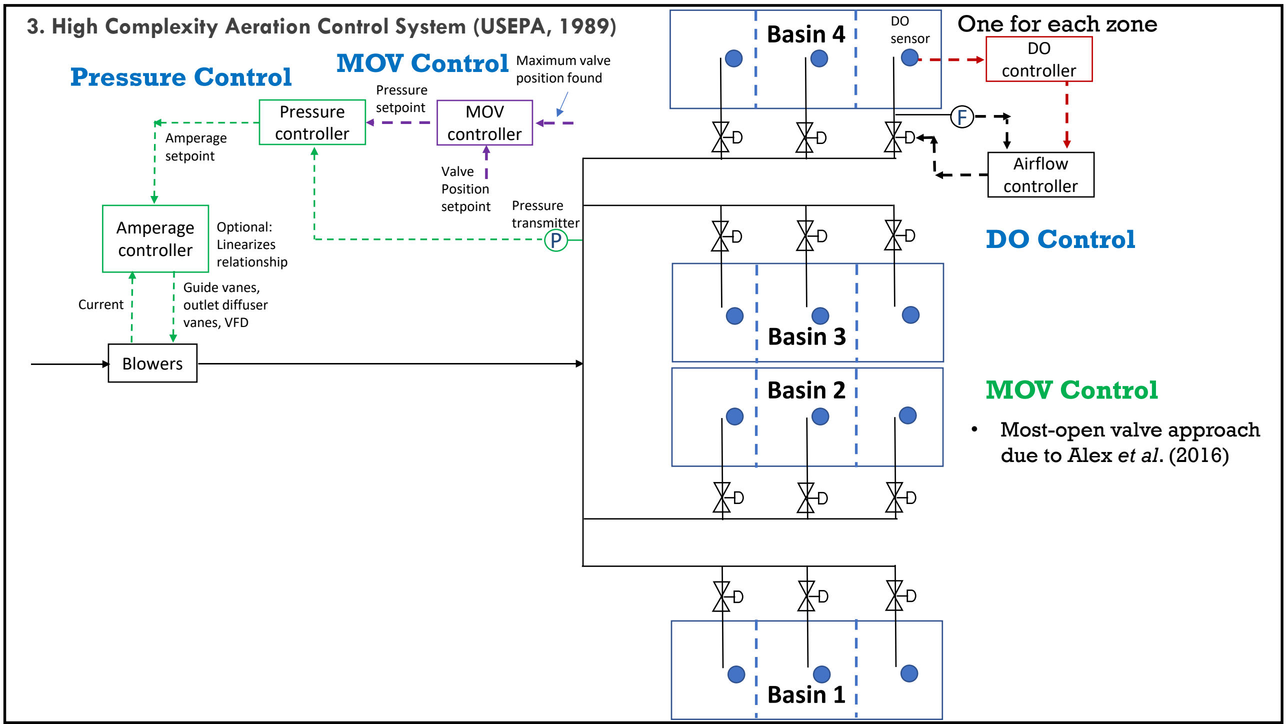

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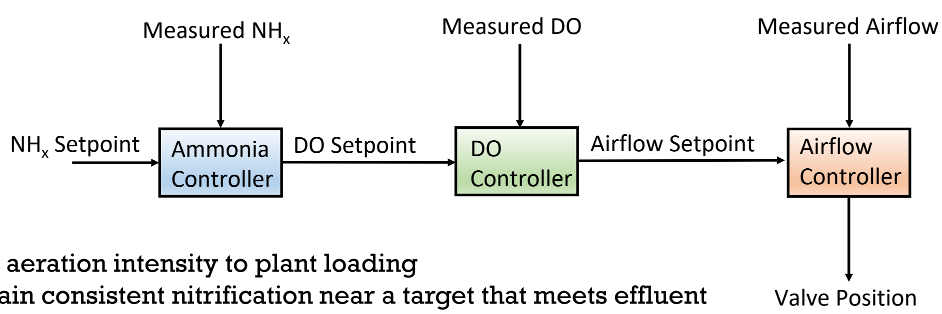
Recent advancements - ABAC

- Ammonia-based aeration control (ABAC)
- Cascaded NH_4/DO/Airflow control



Goals:
1. Tailor aeration intensity to plant loading
2. Maintain consistent nitrification near a target that meets effluent limits but minimizes energy consumption

Problems:
1. May not be able to handle peak loads if SRT is too low
2. If SRT is too high we may hit minimum airflow or DO constraints

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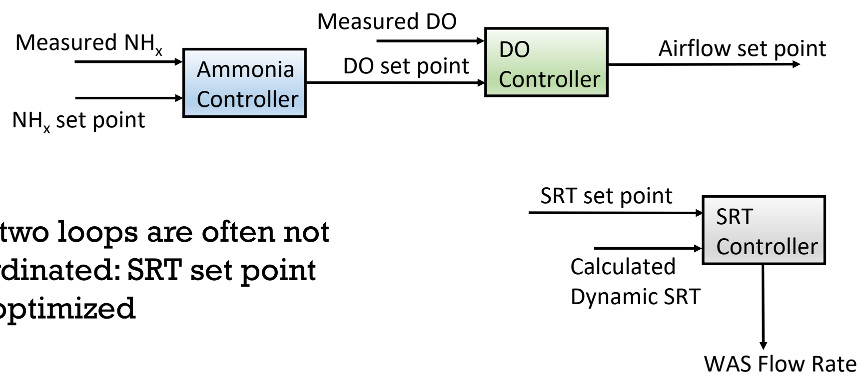
Recent advancements – ABAC-SRT

- How do we select the SRT setpoint?

ABAC-SRT Control (Schraa *et al.*, 2019)



The two loops are often not coordinated: SRT set point not optimized

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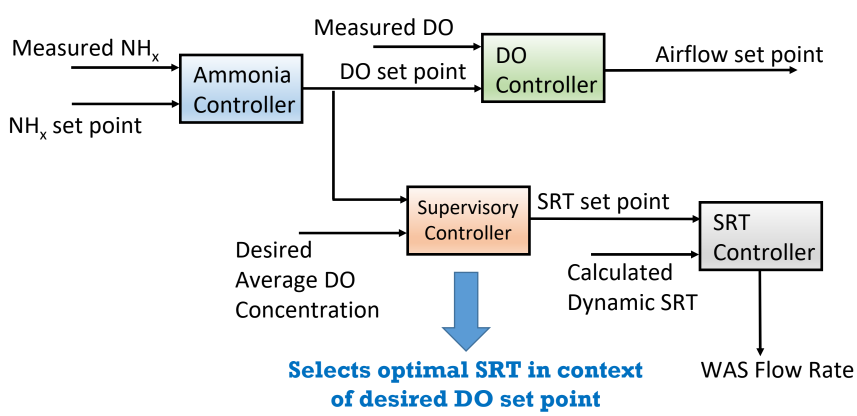
Recent advancements – ABAC-SRT

- How do we select the SRT setpoint?

ABAC-SRT Control (Schraa *et al.*, 2019)



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Common process control issues & solutions

- **Issue:** Poor controller tuning
  - Controllers tuned too aggressively will lead to oscillations in CV and MV
  - **Solution:**
    - Use plant tests and tuning rules to get initial tuning
    - Fine-tune manually or using an automated auto-tuning algorithm

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Common process control issues & solutions

- **Issue:** Valve hysteresis & deadband
  - **Hysteresis:** Same valve input signal results in different valve positions depending on whether the valve is opening or closing. Due to friction.
  - **Deadband:** Change in the input signal has no effect on the valve stem position for a certain time period. Due to friction and mechanical "play".
  - **Practical implications** are poor control performance and cycling – opening and closing valves and turning blowers on and off.
  - **Solutions:**
    - Use valve positioners
    - Add a deadband around the controller error so that the CV can deviate from its SP within a certain range and no controller action is taken.

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Common process control issues & solutions

- **Issue:** Controller encounters a bound on its output
  - A valve hits an upper or lower bound
    - When valve is on a bound the DO becomes uncontrolled
  - With an MOV strategy, some valves will be at their upper bounds. If there are valves frequently at their lower bounds, it suggests a problem with the diffuser distribution and/or valve sizing.
  - **Solutions:**
    - Change diffuser distribution to achieve better air distribution
    - May need to increase blower capacity and discharge pressure if many valves are always at their most-open position and DO setpoints are not being met.

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Common process control issues & solutions

- **Issue:** Sensor measurements drift and become unreliable
  - **Solutions:** Track sensor data against lab measurements, against sensors in other basins, and against portable meters. Make sure to clean sensors regularly.
- **Issue:** Noisy data
  - **Solutions:** Filter measurements using low-pass filters. If have regular large spikes they could be due to auto-cleaning.
- **Issue:** Sensor response time is too slow
  - May be issue with nutrient analyzers; can destabilize the control loops
  - **Solutions:** Use different type of sensor with a faster response

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Summary & Conclusions

- Introduced automatic control, PID controller algorithm, and controller tuning.
- Aeration control involves providing an adequate supply and distribution of air and maintaining desired DO concentrations and levels of mixing
- Presented low, moderate, and high complexity aeration control strategies
- Enhancements to DO control include ABAC and ABAC-SRT
- Common controller issues are:
  - Poor controller tuning
  - Valve hysteresis and deadband
  - Physical constraints that bound the controller output
  - Sensor noise and drift
  - Slow sensor response time

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Thank You

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Data, Data & More Data: Process Understanding, Optimisation and Control

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Primodal Inc. , Hamilton, ON, Canada

Acknowledgements: Edward Alchikha, Ed Ruswa, Prabhbir Pooni, Winfield Lai, Xi Wang, Roman Viveros & Emil Sekerinski

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Overview

Diving into the Details …

What is the Data Telling Me?

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What is Actually Happening

- Understanding the Control Behaviour
  - 2 goals
    - process objective (limit flow to the plant, nitrification, …)
    - control objective (maintain a control variable at a setpoint)
  - Achieving one objective doesn't guarantee the other
  - Implementation may make intuitive sense, but could lead to other issues and costs (actuator wear, added maintenance, unexpected consequences…)

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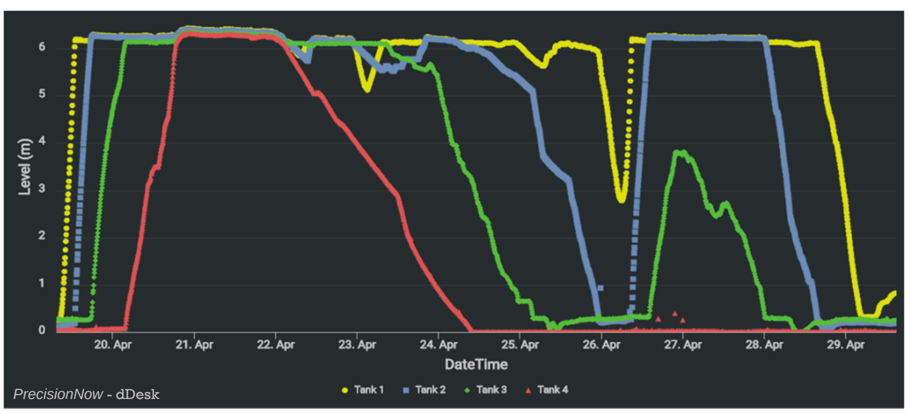
Things Are Not As They Seem …

- Wet weather
  - Sequential filling & emptying of 4 storm tanks



- Logical, and apparently working as intended

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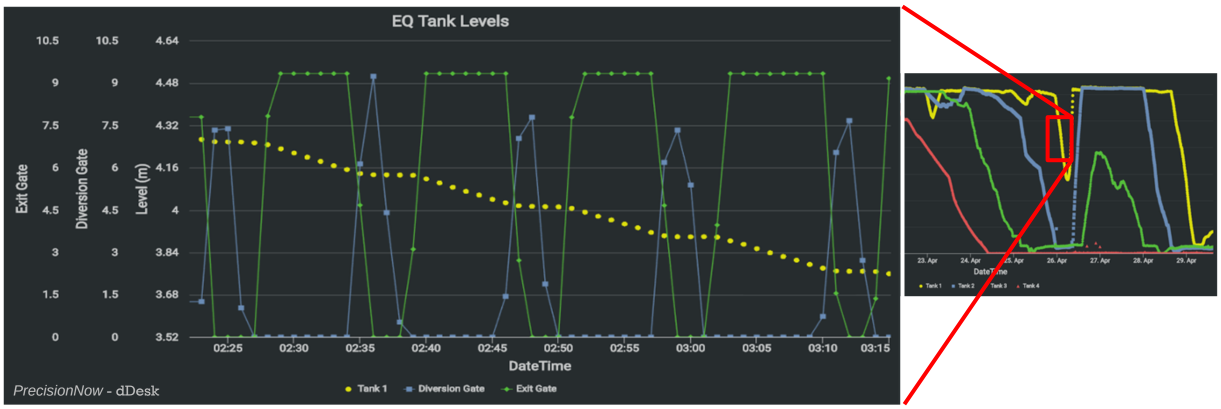
The Devil is in the Details …

- Emptying Data
  - Actual behaviour missed if data averaged or too infrequent



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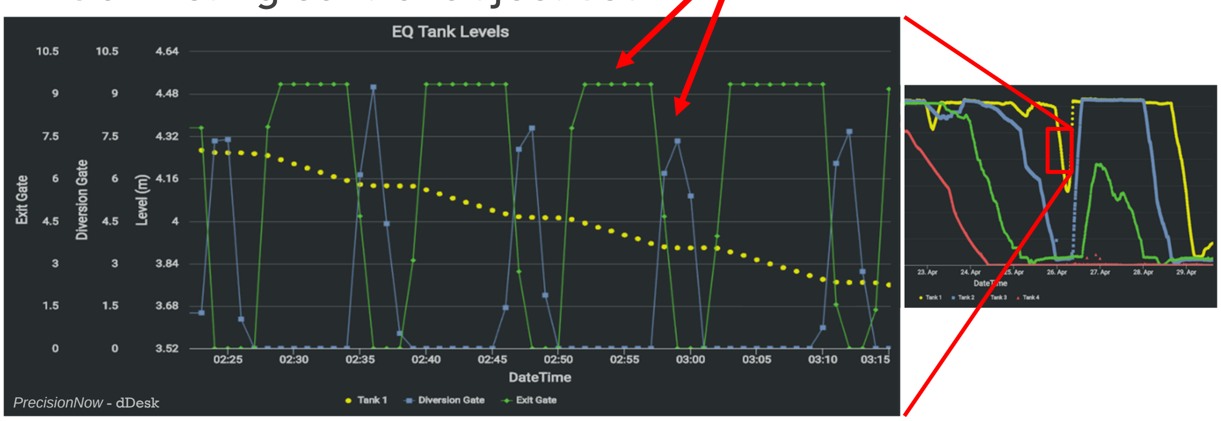
The Devil is in the Details …

- Emptying Data
  - Conflicting control objectives
- Flow from tank exceeds target, triggers diversion valve to open



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The Devil is in the Details …

- Pump Station Operation
  - Conflicting control objectives

- Water level rises, 2nd pump 'on'
- Pump rate increases, level drops, 2nd pump 'off'

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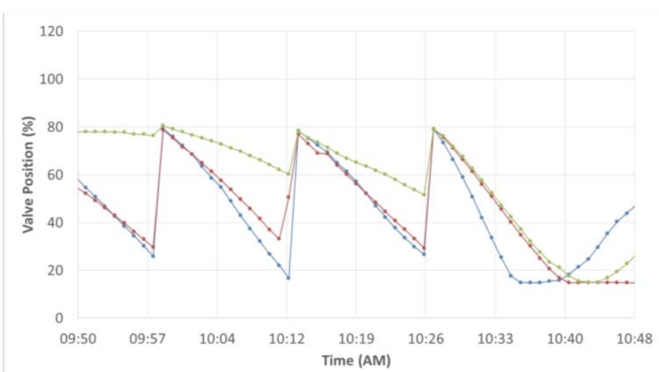
The Devil is in the Details …

- DO Control
  - 1hr of data, shows changes in the valve positions



- Implementation
  - Valves responding to DO
  - Pressure responding to valve positions

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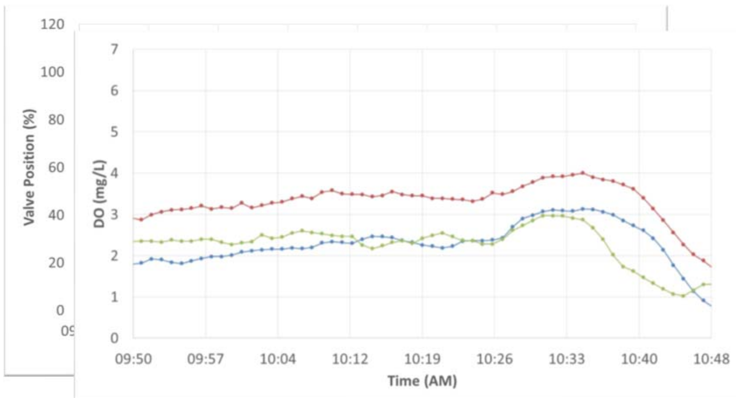
The Devil is in the Details …

- DO Control
  - 1hr of data, shows changes in the DO



- Implementation
  - Controller slow to respond, DO from <2.0 to >3.0 in under an hour (over-aeration, tail chasing)

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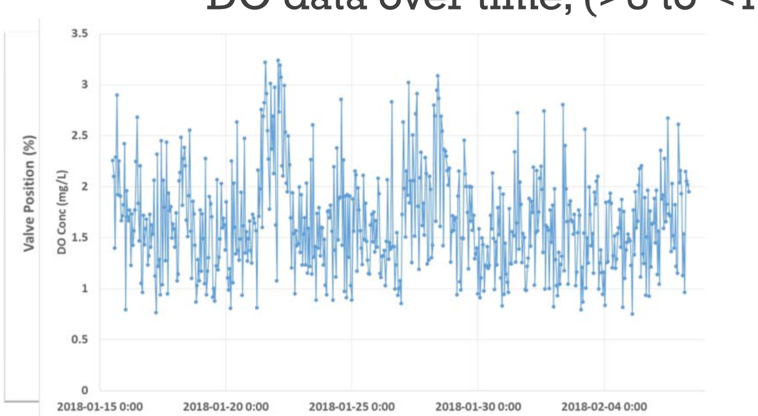
The Devil is in the Details …

- DO Control
  - DO data over time, (>3 to <1 mg/L)



- Consequences
  - Changing conditions, potential for microbial upset, over aeration, increased costs

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Control Implementation

- Analysing the Process/Control Operation
  - Does the control achieve the stated objectives?
  - Do the available control actuators (handles) have sufficient control authority? What/Where are the sensors?
  - What are the optimal setpoints?
  - Are there any conflicting control actions?
  - What behaviour is expected? What is achieved?
  - Are the 2 control objectives satisfied?

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Control Implementation

- Analysing the Process/Control Operation
  - Does the control achieve the stated objectives?
  - Do the available control actuators (handles) have sufficient control authority? What/Where are the sensors?
  - What are the optimal setpoints?
  - Are there any conflicting control actions?
  - What behaviour is expected? What is achieved?
  - Are the 2 control objectives satisfied?

  - All solvable by analysing your data …!

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What is the Data Telling Me

- Process Model Calibration

1. Process Understanding
2. Data Analysis
3. Layout & Initial Sims
4. Initial Sim Results
   - General Agreement (Yes/No)

No

YES

Re-examination of data & process understanding

Changing model parameters is not the solution

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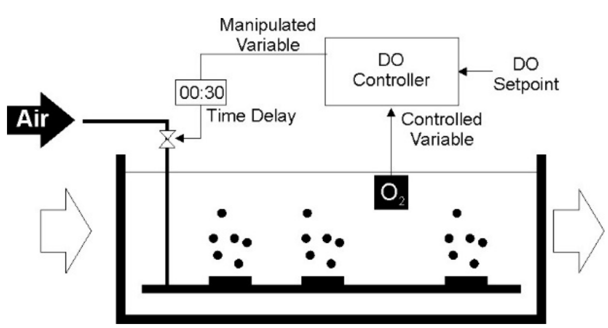
What is the Data Telling Me

- Model identified unknown delay in new aeration control response as source of effluent ammonia issue
- Without delay, model predicted no ammonia spikes



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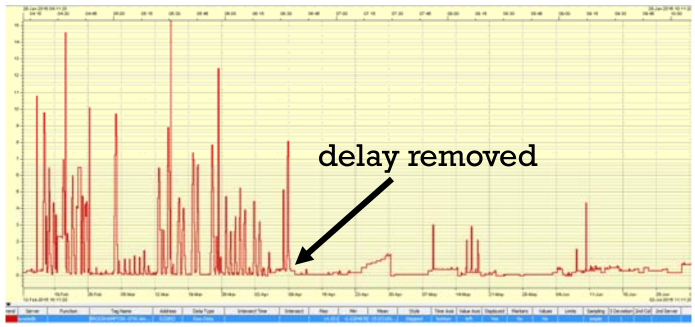
What is the Data Telling Me

- Model identified unknown delay in new aeration control response as source of effluent ammonia issue
- Without delay, model predicted no ammonia spikes
- Solution:
  remove hard-coded dampening delay



Measured Effluent Ammonia

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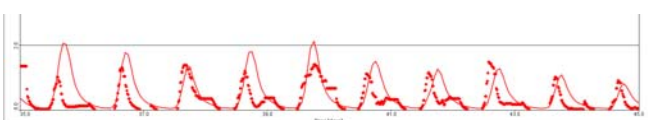
What is the Data Telling Me

- Calibration
  - Don't mistake data fitting for calibration



model parameters changed
- excellent fit to data

- *Calibrated Parameter*
  - Effluent ammonium
- *Parameter Changed*
  - Nitrifier maximum specific growth rate

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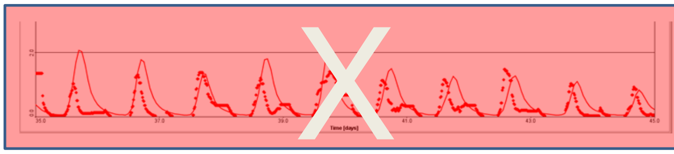
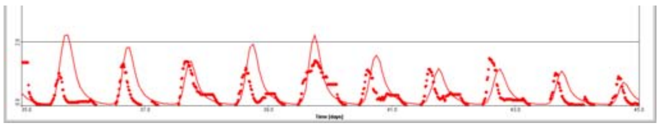
What is the Data Telling Me

- Calibration
  - Don’t mistake data fitting for process understanding



model parameters changed
- excellent fit to data



Incorporating previously unknown control behaviour
- same fit to data

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What is the Data Telling Me

- If *Incorrect* Calibration Used
  - Erroneous design decisions, problem not solved
  - Models ‘don’t work’, so potential to lower risk never realised

A 
model parameters changed

→ 16% larger
→ effluent ammonia still spiking

B 
incorporating previously unknown control behaviour

→ Correcting control issue solved effluent ammonia issue immediately,
→ no additional tanks needed near-term

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Assume The Data Is Correct …

But, A Few Things To First Consider!

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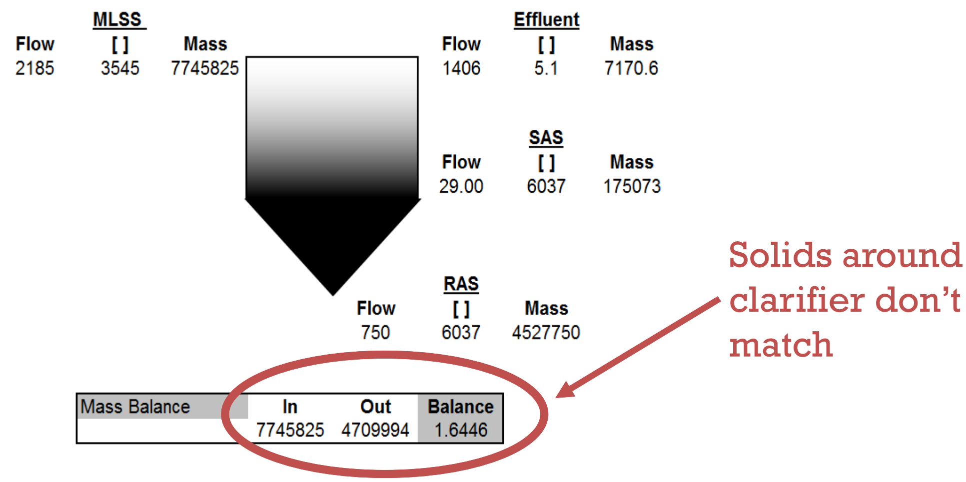
What is the Data Telling Me – Mass Balances

- Mass balances



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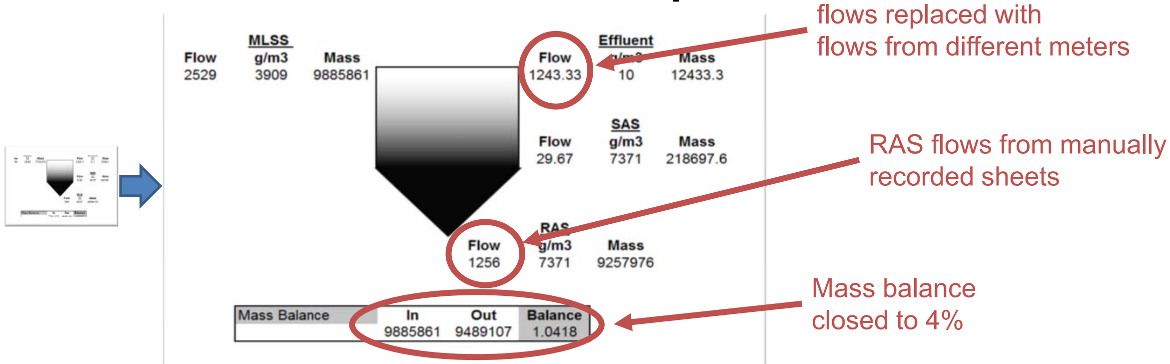
What is the Data Telling Me – Mass Balances

- **Instrumentation Issue**
  - SCADA records wrong (known by operators, not admin or engineers)
  - Concern over measurement accuracy



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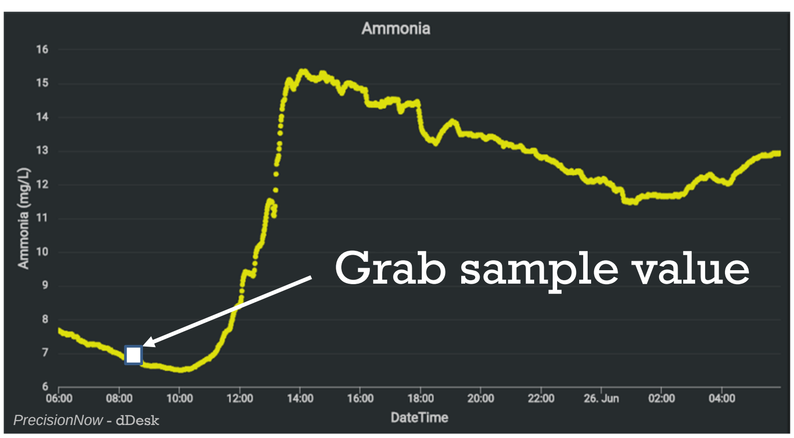
Data Source – Grab Sampling



- Issue with Grabs
  - Problem exacerbated if concentration is not representative
  - Same site, daily grabs taken, clearly underestimating the dry conc.

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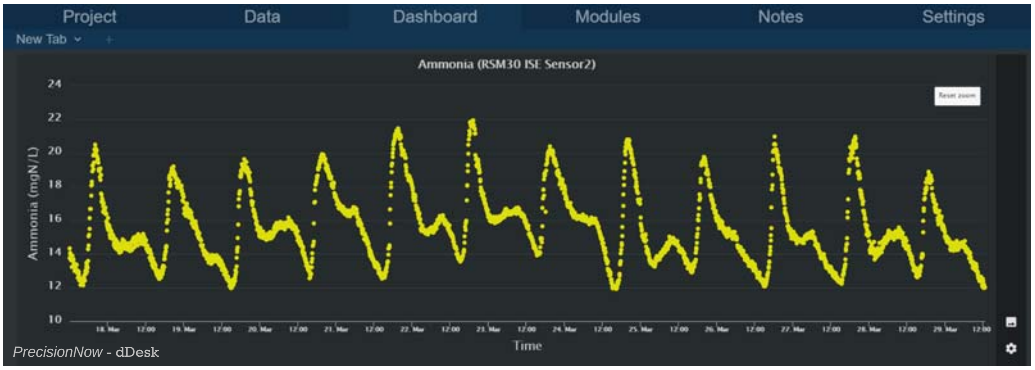
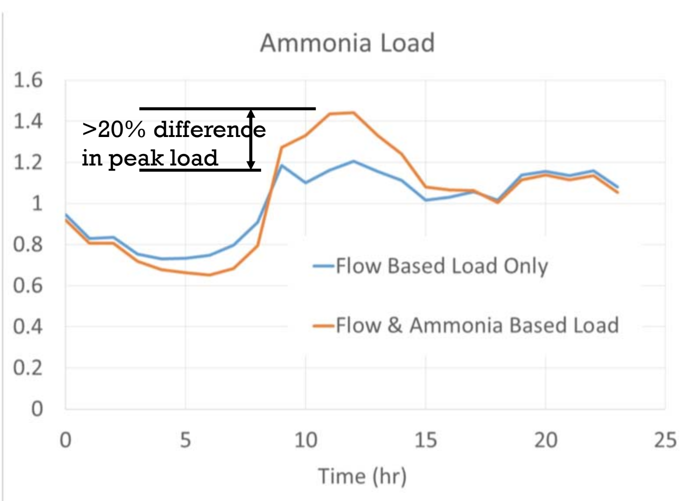
Data Source – High Frequency Sampling



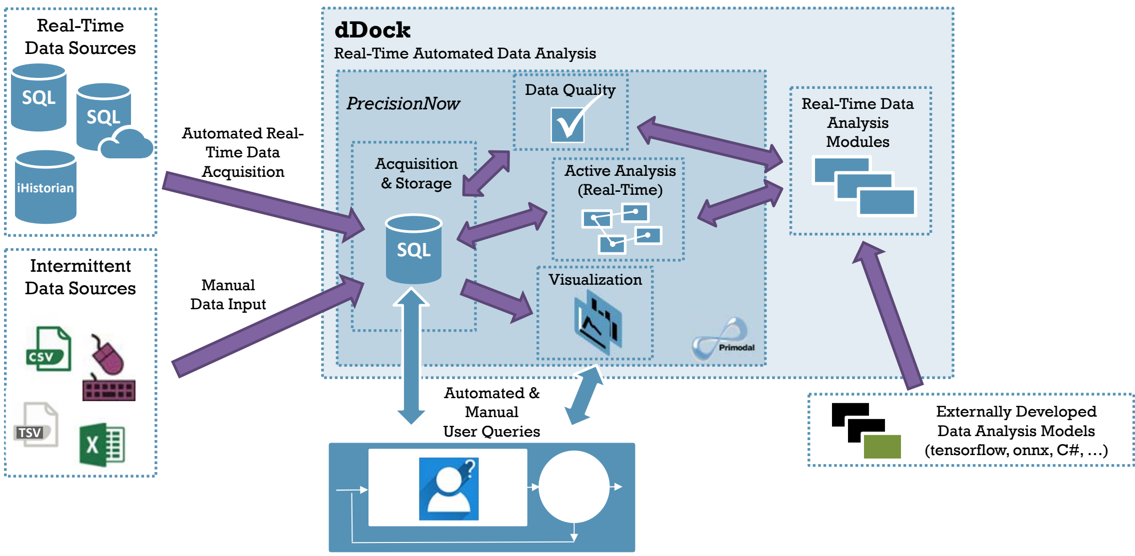
- Diurnal Ammonia
  - Determination of diurnal influent ammonia pattern

Data Source – High Frequency Sampling Benefits



- Diurnal Load
  - Not considering diurnal conc. can lead to significant underestimation of load
  - Implications for blower design and DO control

Data Quality - Current State-of-the-Art



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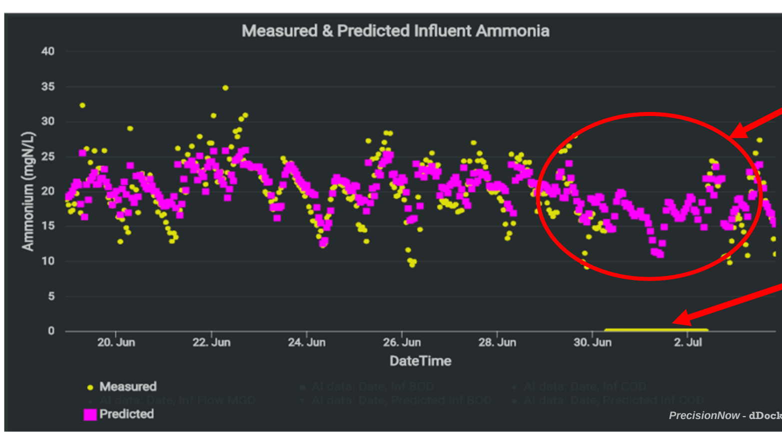
Data Quality - Current State-of-the-Art

- AI Predictive Fault Detection & Soft Sensors



Real-time soft sensors running in parallel, or alone

Sensor failure & alarm

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Conclusion

- Data Quality
  - Data Quality is essential

    You've invested in the equipment, so spending the time and money ensuring data quality will help realise the benefit
- Analyse Your Data (real-time, where possible)
  - Analysing your data in detail will provide advanced process understanding
  - Where necessary, supplement that analysis with a model for an even deeper understanding (and mitigation)
- Believe Your Data
  - It is amazing what you might learn

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Thank-you !

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Process Control Optimization

Lessons Learned from the Field

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Outline

- Overview of Ontario Clean Water Agency
- Blower Retrofit and Aeration Control Case Study
- SRT/Solids Mass Control Case Study
- Concluding Thoughts

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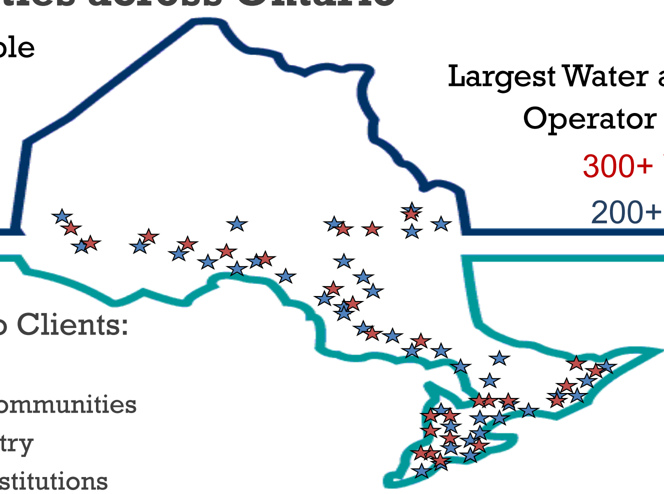
OCWA: Provincial Crown Agency that provides services to over 500 facilities across Ontario

4.5 million people drink OCWA-treated water every day

Largest Water and Wastewater Operator in Canada

300+ WTFs

200+ WWTFs



Over 300 Ontario Clients:

- Municipalities
- First Nations Communities
- Business/Industry
- Government Institutions

75% of Ontario's outsourced water treatment facilities are managed by OCWA

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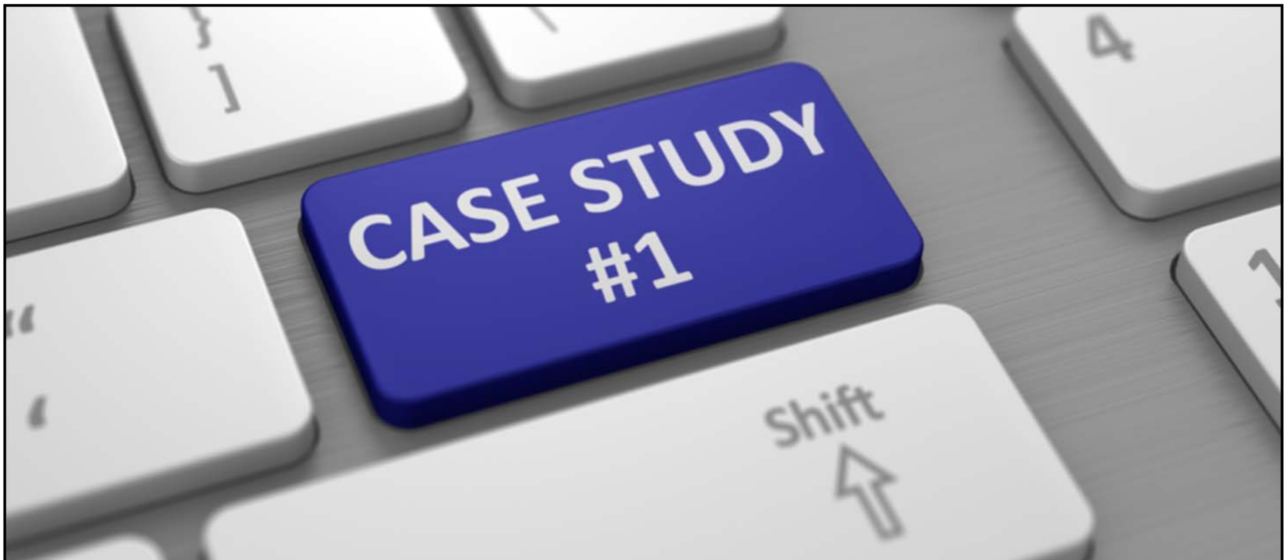

Aeration System Process Optimization and Control

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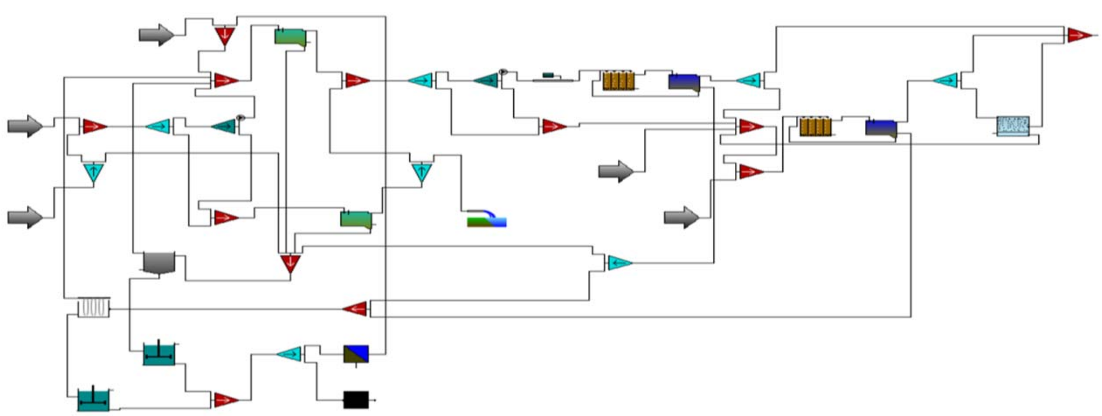
Process Analysis and Troubleshooting

A process model was useful for evaluating the impact of influent load variability on oxygen demand and plant performance:



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Process Analysis Examples

A process model was useful for evaluating the impact of influent load variability on oxygen demand and plant performance:

- St. Marys WWTP periodically experiences wastewater contributions from local food processing industries
- Wasaga Beach WWTP experiences elevated influent loading during the summer season due to an increased seasonal population
- Lakeshore West WWTP periodically wastewater contributions from local greenhouse operations and wineries

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Aeration System Process Control – Items to Consider

1. Blower Sizing and Turndown
2. Probe Location(s)
3. Dissolved Oxygen Control Strategy
4. Valves
5. Air Piping

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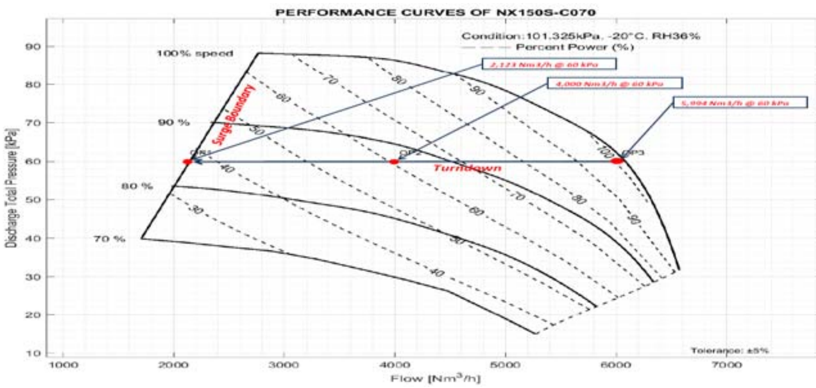
Process Analysis – Blower Sizing and Turndown

- What are the facility oxygen demands under a various loading conditions? → **what is the required blower size and turndown?**
- What are the expected blower operating points? → **now and in the future?**



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Process Control Troubleshooting

Selecting the probe location along a plug flow tank is an important consideration to achieve an adequate level of process control → **where is the ideal location?**

3-pass plug flow tank

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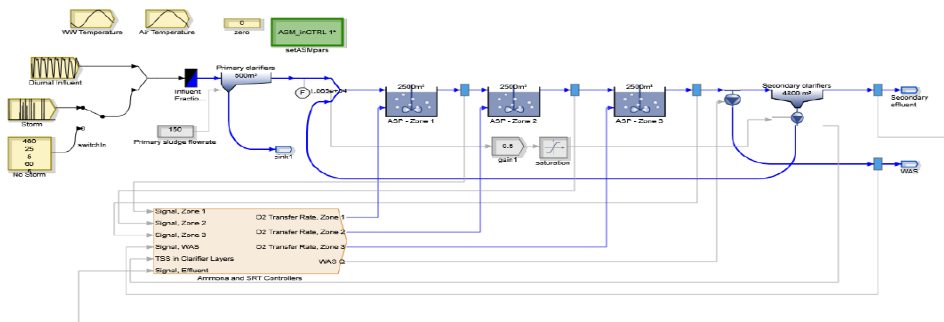
Process Control Troubleshooting

Selecting the probe location along a plug flow tank is an important consideration to achieve an adequate level of process control → **model can also be used to evaluate probe locations and fine tune process control strategies**



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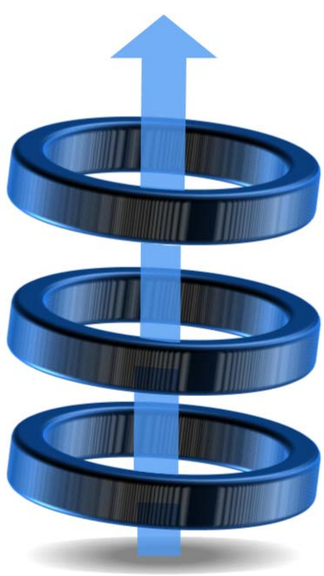
Wasaga Beach WWTP Blower Upgrade



- 600 MWh in annual energy savings
- 4.1 year payback period for project based on total project cost
- Better control over air flows to aeration tanks, improved floc formation and settleability in secondary clarifiers
- Existing DO monitoring system could be utilized to control turbo blower via PID controller

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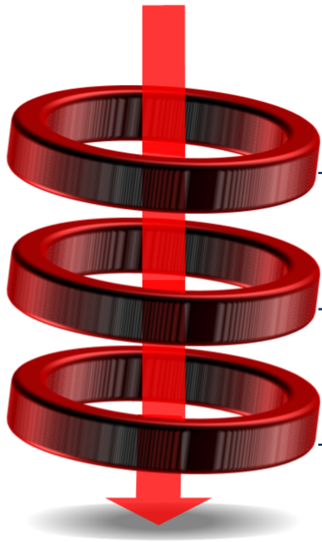
Wasaga Beach WWTP Blower Upgrade



Wasaga Beach is popular summer destination, subject to high peak loads on long weekends (Canada Day etc.)

Existing DO probes installed at the end of plug flow tank, PID controller response to peak loads was sluggish

Combination of old/broken diffusers and new fine bubble diffusers made it difficult to balance air to both tanks

Solution: DO probes moved to 1/3 length of PFT for better response, PID controller tuning was updated

Solution: Old diffusers were replaced, valves may be upgraded in future

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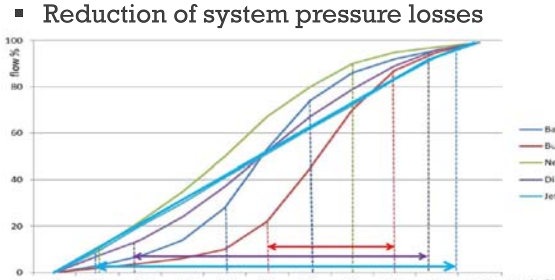
Advanced Aeration Control - Valves

- Jet/Elliptic Diaphragm Control Valves
  - Reduction of system pressure losses



  - Allows for precise control of air flow (Doody, 2017)
    - Less air is wasted, quicker response time to process
  - Has a larger stable flow/control range
  - Particularly useful for controlling the air flow split between aeration and sludge tanks when using a common blower

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Existing System Air Piping and Valve Considerations

- Non-symmetrical air piping could limit turndown range and energy savings
- Existing control valves may not provide adequate control at lower airflows
- Lower valve % Open could increase system pressure and energy consumption

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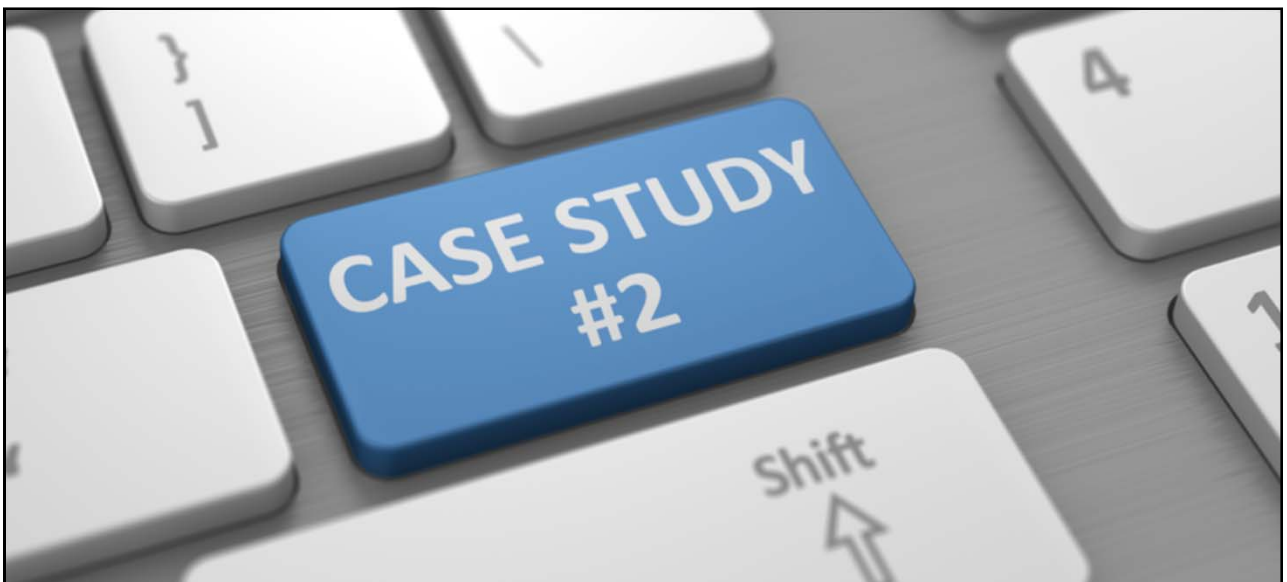

BNR Sequencing Batch Reactor – Solids Mass Control

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Sludge Wasting Controls
How Much Biomass?

Approaches to Sludge Wasting





- Settleability
- Constant MLSS
- Centrifuge/spin
- F/M
- Solids Retention Time
- Total Mass Target

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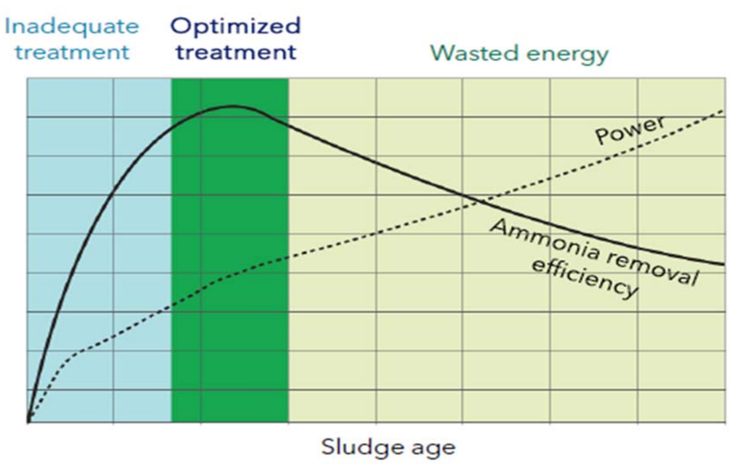
The Importance of Biomass Management



Required mass to waste to stay within the green area depend on:

- Load
- Temperature
- Ammonia requirement
- DO concentration
- Etc.

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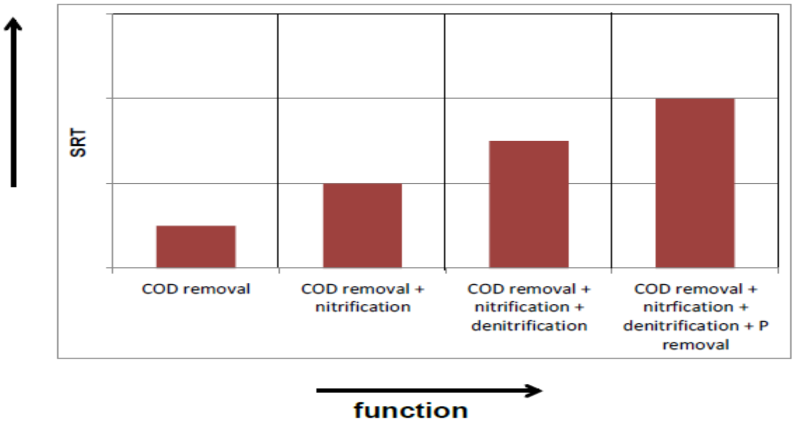
Target SRT

What are the treatment requirements?



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Petawawa WWTP

CONSTRUCTION

Constructed in early 1960's

PRIMARY/SECONDARY SYSTEMS

Plant is rated for 8.7 MLD
Chemically enhanced primary treatment plant until mid-1990's when 4-cell SBR secondary treatment system was built

OPERATIONAL CHALLENGES

Has faced operational challenges in recent years due to:

- Aging facility
- Influent loading variations (i.e. Town vs Garrison)
- Inconsistent nitrification performance
- Changing seasonal variations

OPTIMIZATION STUDY

An optimization study was recently initiated to optimize plant performance and process resiliancy

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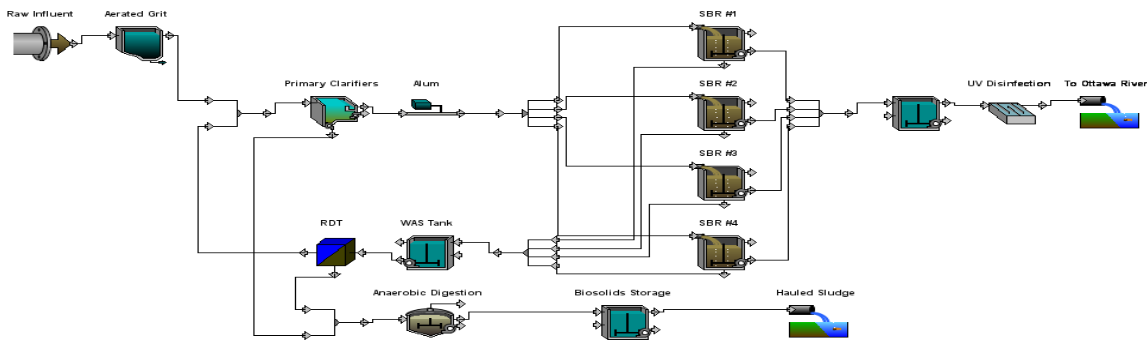
Petawawa WWTP Process Control

- A process model was developed to analyze the impact of implementing a higher level of process control with respect to solids inventory and nutrient removal



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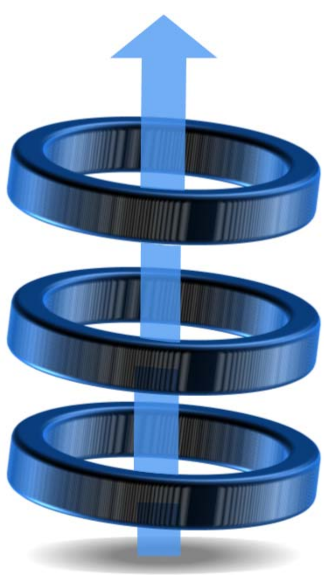
Petawawa WWTP Process Control



ON/OFF aeration cycles provides consistent total nitrogen/biological nutrient removal for most of the year

Significant amount of biological phosphorus removal from default SBR cycle settings, reduced alum required for TP removal

Energy consumption is lower on a kWh/m3 treated compared to similar sized SBR and extended air facilities

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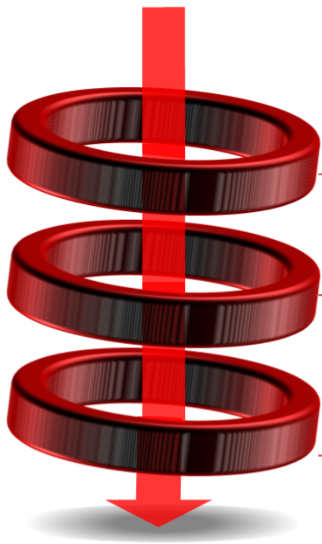
Petawawa WWTP Process Control



Inconsistent solids mass inventory and nitrification at cold weather temperatures

Default cycle settings didn't provide enough flexibility to maintain adequate aerobic SRT in extreme cold while meeting TSS limits

Solution: MLSS probe added to each basin for more precise SRT control. Default SCADA/PLC programming was modified to include Normal, Storm and Extreme Cold Weather cycle settings ✓

Solution: Anaerobic digester centrate recycle schedule was modified to equalize peak ammonia loads to biological process ✓

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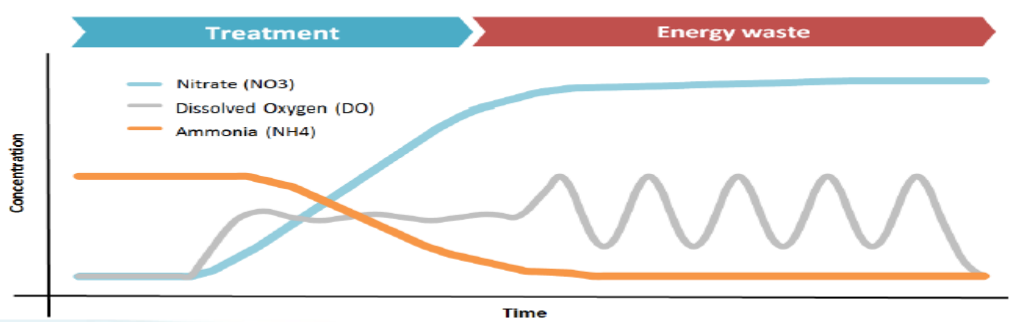
Future SBR Control Option for Further Optimization

Current Standard SBR Cycle:

- In low loaded cycles, only first part of cycle used for treatment
- Remaining treatment time and energy is wasted and control is unstable



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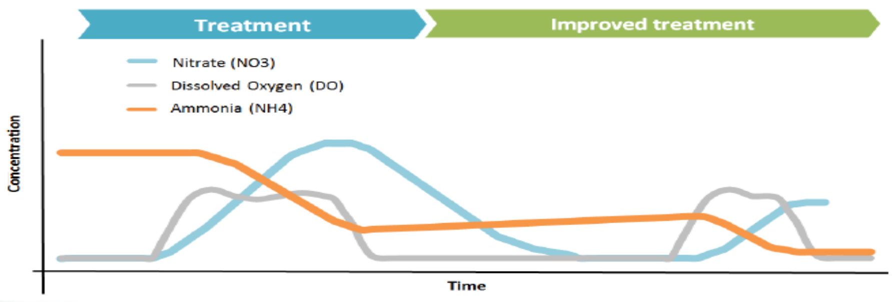
SBR with Advanced Process Control

- Detect low loaded cycles and reduce aeration
- Allow for anoxic conditions and improved denitrification
- Aeration before settle phase allows for ammonia polishing before decant



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Concluding Thoughts

- Process control retrofit projects can provide enhanced process resiliency and result in significant energy savings
  - Probes need to be in the proper location to achieve the desired level of process control
  - Physical constraints of the system need to be taken into account
  - Control system complexity should be considered relative to the benefits/payback
    - Sometimes stable and simpler control is better
  - "Rome wasn't built in a day"
    - Implement control strategies in phases to build confidence of staff

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Thank You

More Information?

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ONTARIO CLEAN WATER AGENCY
AGENCE ONTARIENNE DES EAUX

Your Total
Water Solutions
Provider

Hank Andres, P.Eng.
handres@ocwa.com
Tel: 416-575-0092

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dc water is life

Ryu Suzuki, PE
Manager, Process Engineering

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Process Control Challenges from a Utility Point of View Blue Plains AWWTP

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Presentation Outline

- Treatment objectives
- Sensor maintenance
- System and physical constraints
- Need for operator oversight

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Treatment Objectives

- Average Flow – 300 MGD (Design – 384 MGD)

Economy of scale – large vs small plants

- Stringent total nitrogen limit
  - **Mass load per calendar year** - equivalent to 3.8 mg/L total nitrogen at Design Flow

Flexibility in the discharge permit

- Nitrogen Treatment Target
  - 1 mg/L NO_3–N
  - Non-detect NH_4-N (<0.03 mg/L)
  - 1 to 1.5 mg/L TKN-N (organic nitrogen)

Are stringent limits driver or deterrent to complex control?

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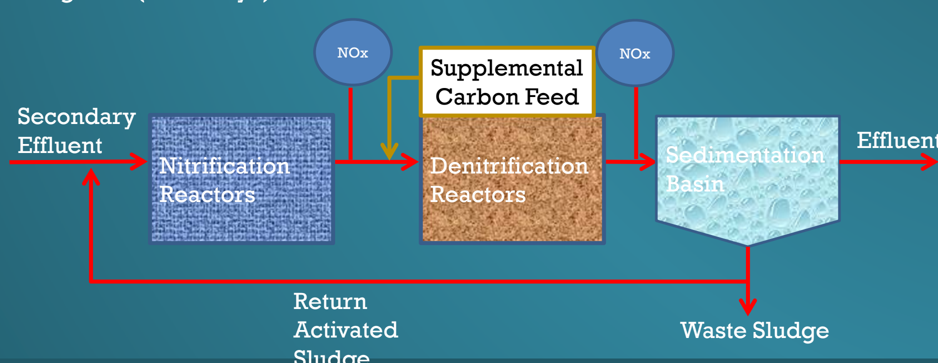
Nitrification/Denitrification at Blue Plains

- Most influent carbon removed prior to N/DN process
  - Chemically enhanced primary treatment
  - High-rate secondary treatment (1-2 day SRT)
- Long SRT (> 20 days)



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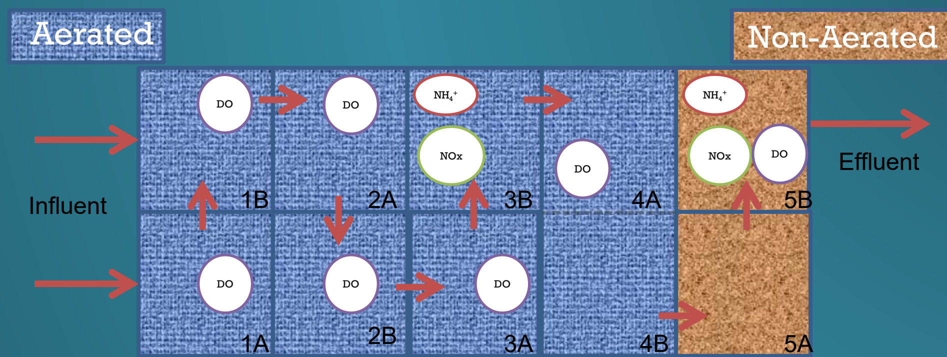
Instrumentation on Reactors 3,4, 9 and 11



- Who is going to maintain all these sensors? – Buy in from I&C group
- Certain sensors require LOTS of work – appropriate number of sensors
- Reliability – certain failure modes cause more headaches
- Balancing work order priority

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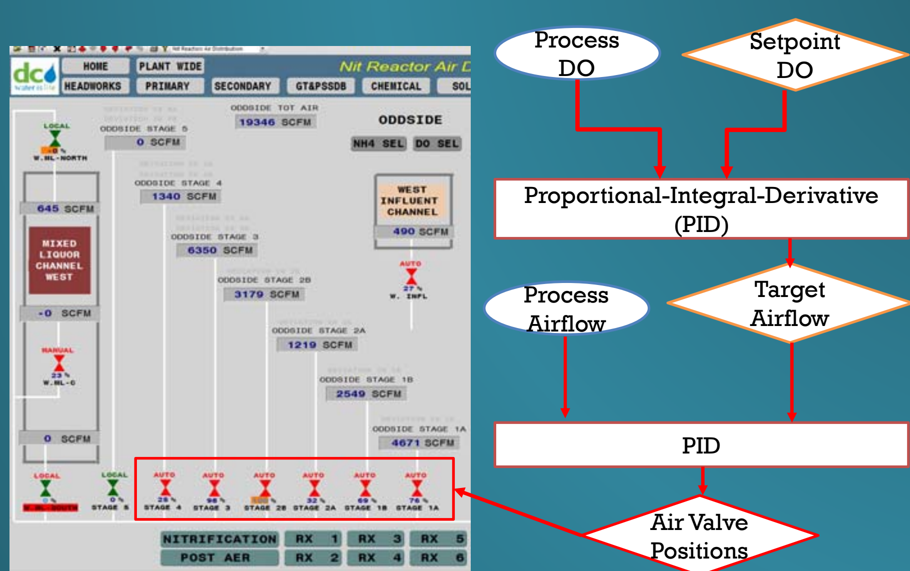
DO Based Aeration Control – Cascade



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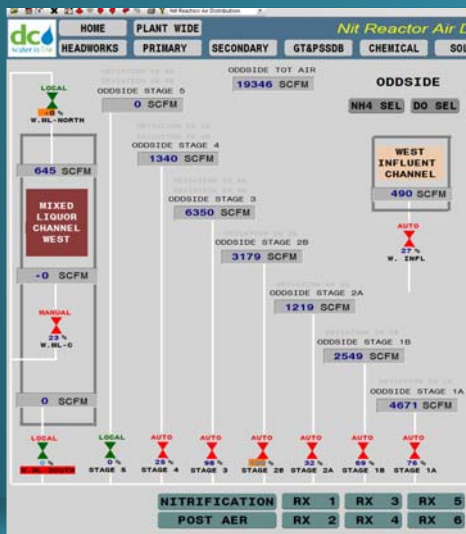
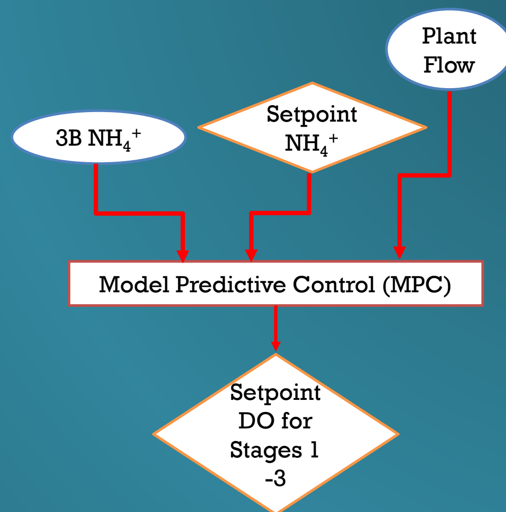
Ammonia Based Aeration Control – Triple Cascade





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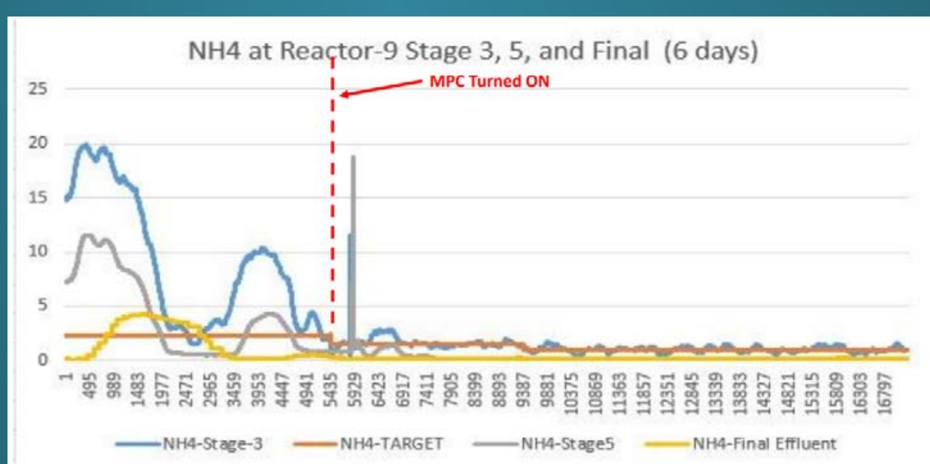
The controller works well when everything else is working well….



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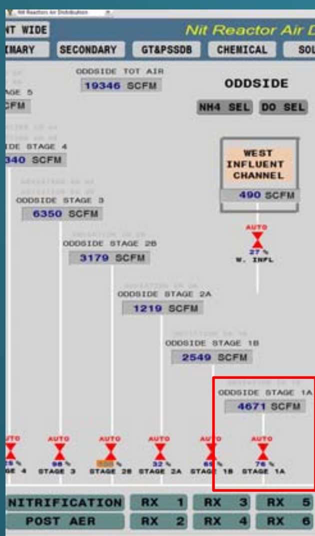
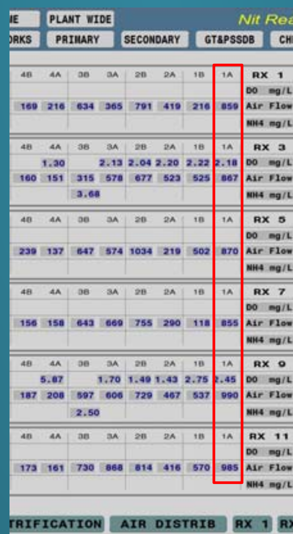
Challenges to Nitrification Aeration Control





- Proper air split at wide range of flow rates
- Fine bubble diffuser maintenance
- Seasonal changes

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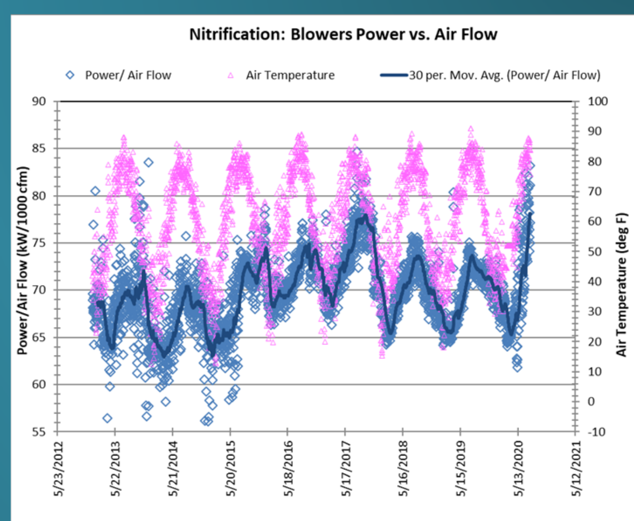
Looking at aeration system as a whole

- Two 4,000 Hp blowers servicing many process areas
  - Air demand for Nitrification (40 to 60% of blower output)
  - **OTHER**
    - Post anoxic aeration
    - Channel mixing
    - Final effluent aeration – maintain DO permit



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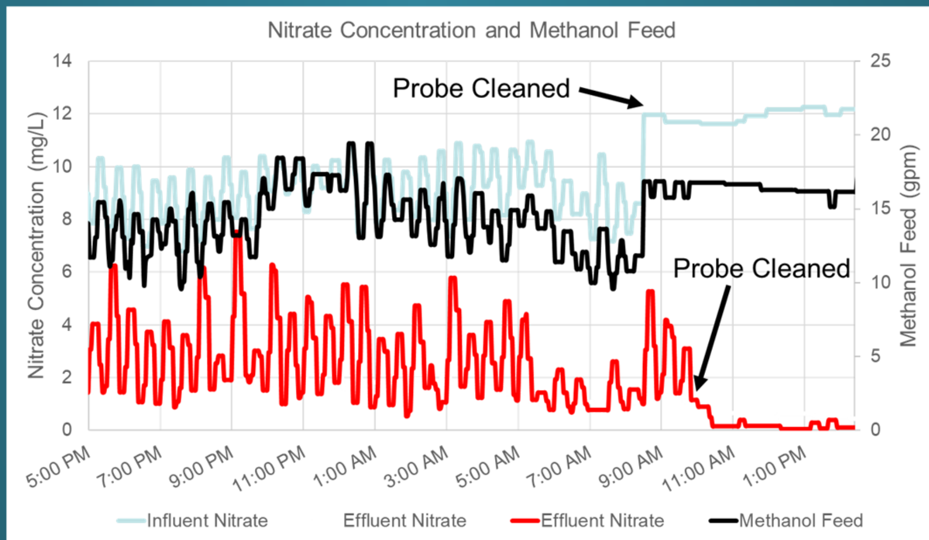
Operator oversight is always needed



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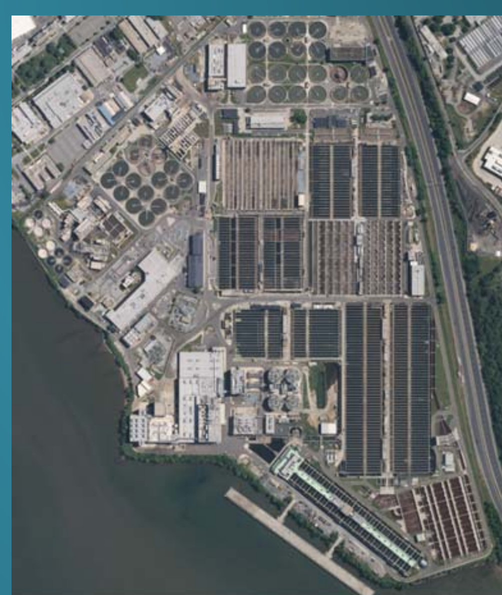
Conclusion

- Understanding drivers for automation
- Buy-in from staff to maintain system
- Physical and system constraints
- Operator oversight still required



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Control Subtleties – Mar. 11, 2021

An MRRDC Short Course:

Process Control:

Intro, Data and Lessons Learned

- Final Q & A:

Concepts	→	Oliver Schraa	inCTRL
Data	→	John Copp	Primodal
Application	→	Hanks Andres	Ontario Clean Water
Application	→	Ryu Suzuki	DC Water

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