



Utilization and Practical Approach of Ammonia-Based Aeration Control (ABAC) at Bonnybrook Wastewater Treatment Plant, Canada

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INTRODUCTION



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Agenda

1. Plant Background
2. ABAC Introduction
3. Case Study 1
4. Case Study 2
5. Case Study 3
6. Conclusions and Next Steps



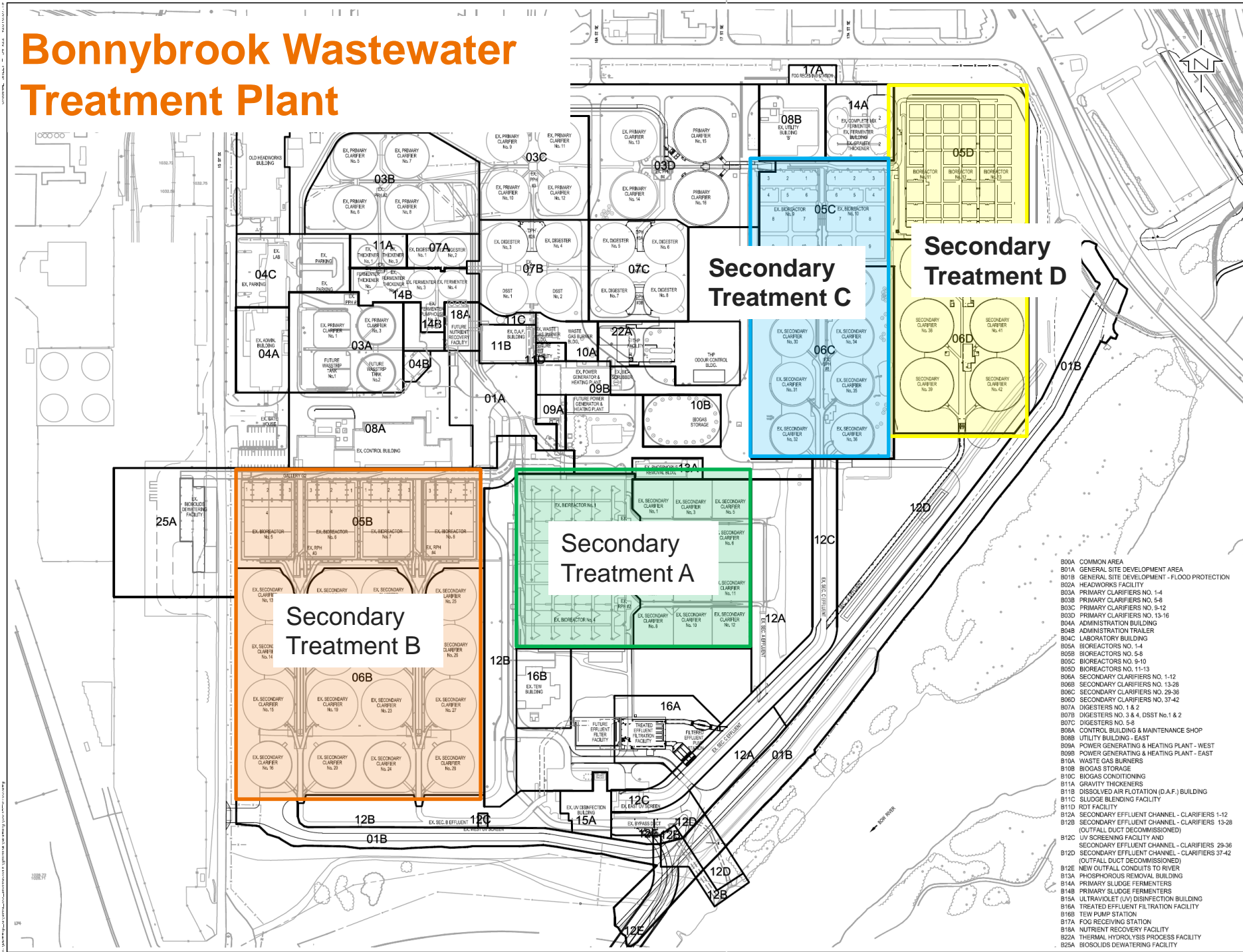
City of Calgary Plant Background

City of Calgary Plant Background



Bonnybrook Wastewater Treatment Plant

PLANT BACKGROUND

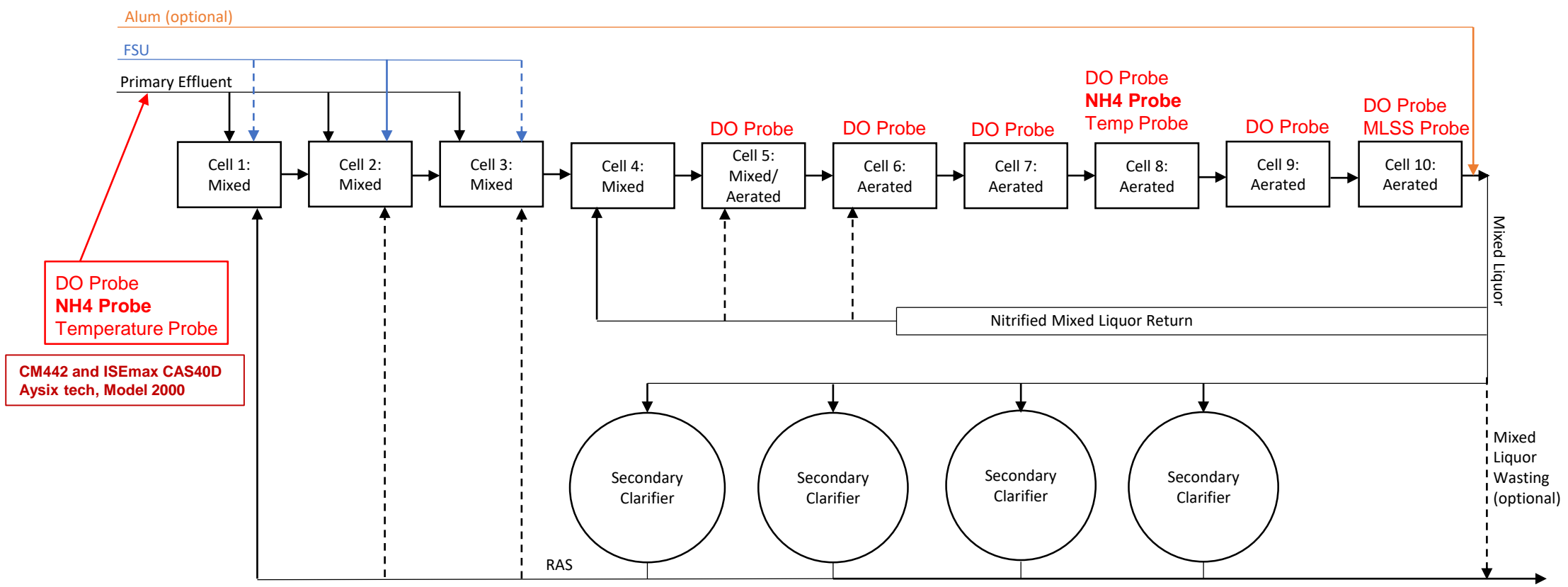


- B00A COMMON AREA
- B01A GENERAL SITE DEVELOPMENT AREA
- B01B GENERAL SITE DEVELOPMENT - FLOOD PROTECTION
- B02A HEADWORKS FACILITY
- B03A PRIMARY CLARIFIERS NO. 1-4
- B03B PRIMARY CLARIFIERS NO. 5-8
- B03C PRIMARY CLARIFIERS NO. 9-12
- B03D PRIMARY CLARIFIERS NO. 13-16
- B04A ADMINISTRATION BUILDING
- B04B ADMINISTRATION TRAILER
- B04C LABORATORY BUILDING
- B05A BIOREACTORS NO. 1-4
- B05B BIOREACTORS NO. 5-8
- B05C BIOREACTORS NO. 9-10
- B05D BIOREACTORS NO. 11-13
- B06A SECONDARY CLARIFIERS NO. 1-12
- B06B SECONDARY CLARIFIERS NO. 13-28
- B06C SECONDARY CLARIFIERS NO. 29-36
- B06D SECONDARY CLARIFIERS NO. 37-42
- B07A DIGESTERS NO. 1 & 2
- B07B DIGESTERS NO. 3 & 4, DSST No. 1 & 2
- B07C DIGESTERS NO. 5-8
- B08A CONTROL BUILDING & MAINTENANCE SHOP
- B08B UTILITY BUILDING - EAST
- B09A POWER GENERATING & HEATING PLANT - WEST
- B09B POWER GENERATING & HEATING PLANT - EAST
- B10A WASTE GAS BURNERS
- B10B BIOGAS STORAGE
- B10C BIOGAS CONDITIONING
- B11A GRAVITY THICKENERS
- B11B DISSOLVED AIR FLOTATION (D.A.F.) BUILDING
- B11C SLUDGE BLENDING FACILITY
- B11D RDT FACILITY
- B12A SECONDARY EFFLUENT CHANNEL - CLARIFIERS 1-12
- B12B SECONDARY EFFLUENT CHANNEL - CLARIFIERS 13-28 (OUTFALL DUCT DECOMMISSIONED)
- B12C UV SCREENING FACILITY AND SECONDARY EFFLUENT CHANNEL - CLARIFIERS 29-36
- B12D SECONDARY EFFLUENT CHANNEL - CLARIFIERS 37-42 (OUTFALL DUCT DECOMMISSIONED)
- B12E NEW OUTFALL CONDUITS TO RIVER
- B13A PHOSPHOROUS REMOVAL BUILDING
- B14A PRIMARY SLUDGE FERMENTERS
- B14B PRIMARY SLUDGE FERMENTERS
- B15A ULTRAVIOLET (UV) DISINFECTION BUILDING
- B16A TREATED EFFLUENT FILTRATION FACILITY
- B16B TEW PUMP STATION
- B17A FOG RECEIVING STATION
- B18A NUTRIENT RECOVERY FACILITY
- B22A THERMAL HYDROLYSIS PROCESS FACILITY
- B25A BIOSOLIDS Dewatering Facility



Secondary Treatment C - Trains 9 & 10

SECONDARY TREATMENT CHARACTERISTICS





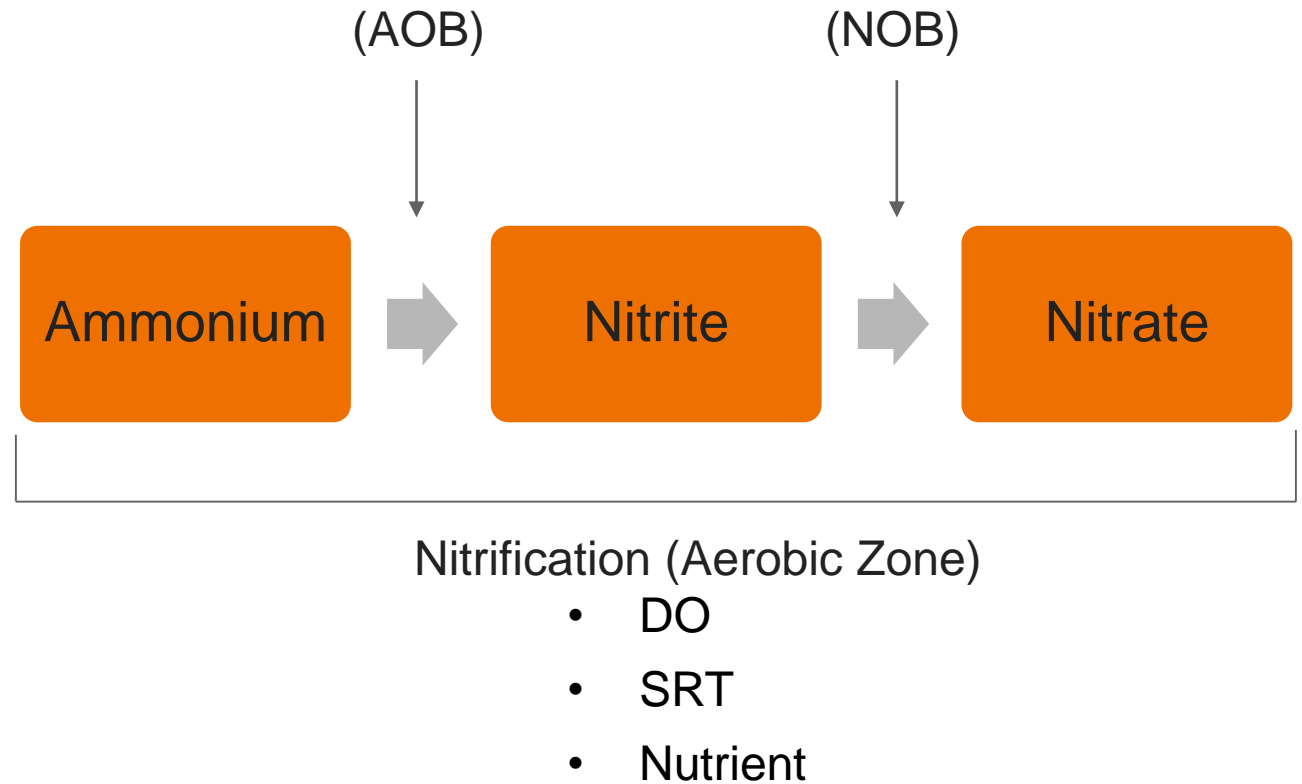
Bonnybrook WWTP Monthly Approval Limits

Parameter	Limit
CBOD	≤ 15 mg/L monthly arithmetic mean of daily composite sample
TSS	≤ 20 mg/L monthly arithmetic mean of daily composite sample
Phosphorus	≤ 1.0 mg/L monthly arithmetic mean of daily composite sample
Ammonia-Nitrogen (October 1 to June 30)	≤ 10 mg/L monthly arithmetic mean of daily composite sample
Ammonia-Nitrogen (July 1 to September 30)	≤ 5 mg/L monthly arithmetic mean of daily composite sample
Fecal Coliform Counts	≤ 200 MPN or CFU per 100 mL/monthly geometric mean of daily grab samples



Nitrification Basics

- Nitrification is a microbial process where ammonia is oxidized to nitrite and then nitrate
- Nitrification DO supplementation is between 50 to 60% of the total supplied oxygen demand.





Ammonia Based Aeration Control Introduction

ABAC Introduction



ABAC Control Strategies

	Description	Advantages	Disadvantages
Feedback	<ul style="list-style-type: none">• Measured process variable that is input to the controller.• Control action is based on difference of measured and desired value.	<ul style="list-style-type: none">• Does not require a model of the controlled system.	<ul style="list-style-type: none">• An error must exist before a control action can be taken.• Slow reactions to control actions.
Feedforward	<ul style="list-style-type: none">• Measures a process disturbance and uses a model to predict the behavior of the controlled system.	<ul style="list-style-type: none">• Fast response to ammonium load peaks.• Adequate for conditions where no “above the limit” discharge is allowed.	<ul style="list-style-type: none">• More complexity due to more sensors.• Requires an accurate process model description.• Low control authority in dry weather flow and ammonium peaks.

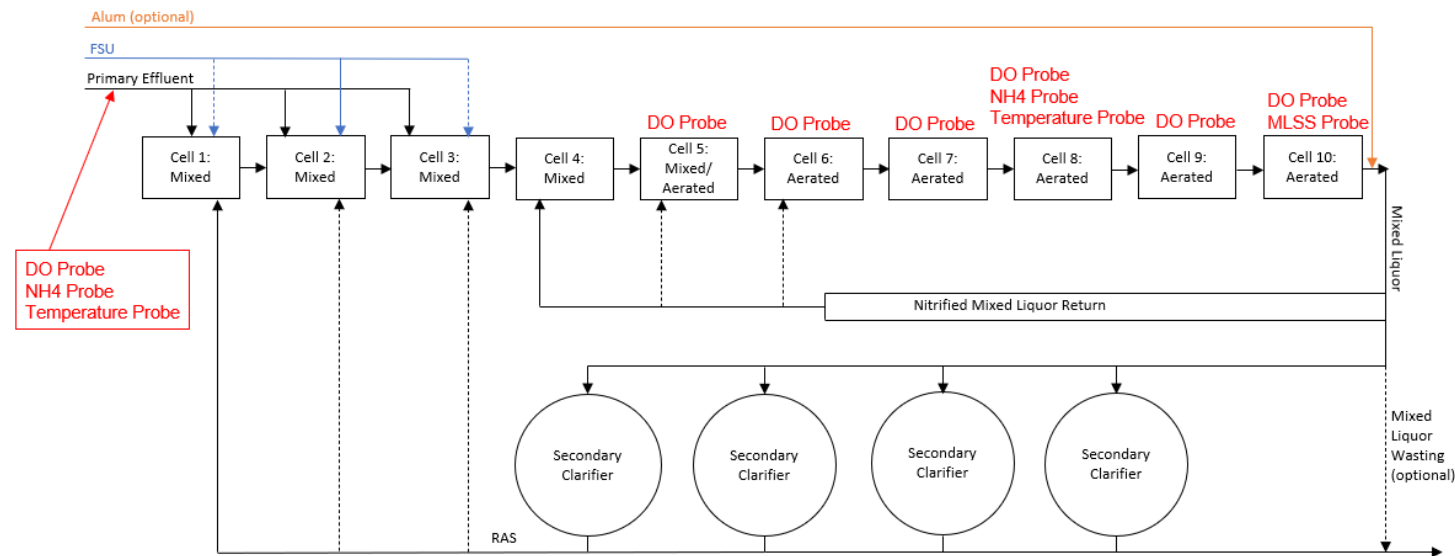


Feedforward Control

Initial DO setpoint based on influent loadings to bioreactor

$$\text{Ammonia Load } \left(\frac{T_{on}}{d} \right) = \text{Influent Flow (MGD)} \times \text{Influent NH}_3 \text{ concentration } \left(\frac{T_{on}}{MG} \right)$$

- Summer and Winter DO setpoint Matrices developed based on operational experience
- Base DO setpoint adjusted every 10 minutes to avoid system hunting





Feedforward Control DO Setpoints

$$\text{Ammonia Load } \left(\frac{\text{Ton}}{\text{d}}\right) = \text{Influent Flow (MGD)} \times \text{Influent NH}_3 \text{ concentration } \left(\frac{\text{Ton}}{\text{MG}}\right)$$

Primary Effluent Ammonium Loads (Ton/d)	DO (mg/L)					
	Cell 5*	Cell 6	Cell 7	Cell 8	Cell 9	Cell 10
Summer Mode DO Setpoints						
<0.5	1.50	1.50	1.20	1.00	0.50	0.50
=>0.5 and <1	1.70	1.70	1.40	1.10	0.75	0.50
=>1 and <1.5	1.90	1.90	1.70	1.30	0.90	0.50
=>1.5 and <1.75	2.00	2.00	2.00	1.50	1.00	0.50
=>1.75 and <2	2.25	2.25	2.25	1.75	1.25	0.75
=> 2	2.50	2.50	2.50	2.25	1.50	1.50



Feedback Control

- The aim of feedback control to maintain an ammonia concentration setpoint in Cell 8
- Cell 8 setpoint chosen to achieve 1-2 mg/L in secondary effluent
- The deviation of the measured ammonia concentration in Cell 8 to the setpoint determines the amount of trim to be applied
- A maximum trim of 0.5 mg/L can be applied to Cells 5 to 8
- Cells 9 and 10 are limited by minimum air valve positions and a maximum DO of 3.0 mg/L.
- DO trim is continuously updated by the ABAC programming.



Sequencing and Implementation Methodology

Case 1: Existing ABAC logic applied in Secondary C. Feedforward-feedback control based on the ammonia loading and Cell 8 Ammonia setpoint. Reviewed for control and energy savings available

Case 2: BioWin® model of Feedforward-feedback logic as described, based on existing hourly plant data and available ammonia profile. Existing model calibration and optimization

Case 3: Calibrated BioWin® model used to develop new feedforward control logic dependent on microbial kinetics to maintain ammonia setpoint of desired cell. Reviewed for control and additional energy savings



ABAC Case Study 1

Case Study 1



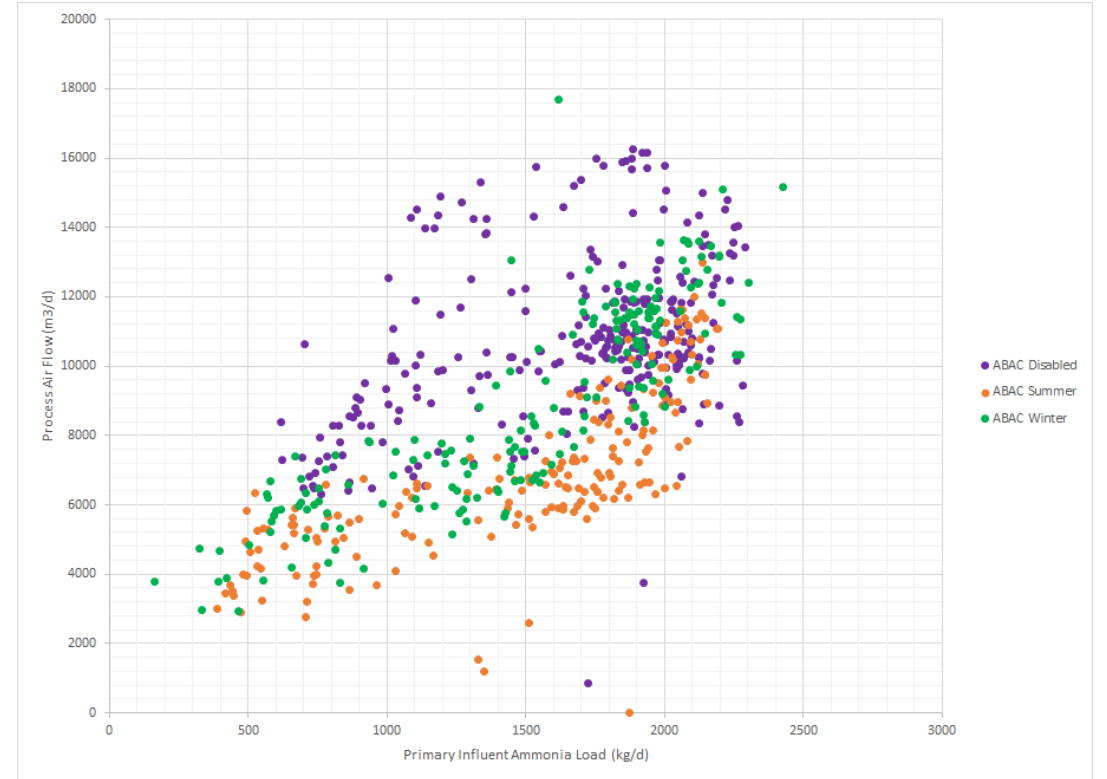
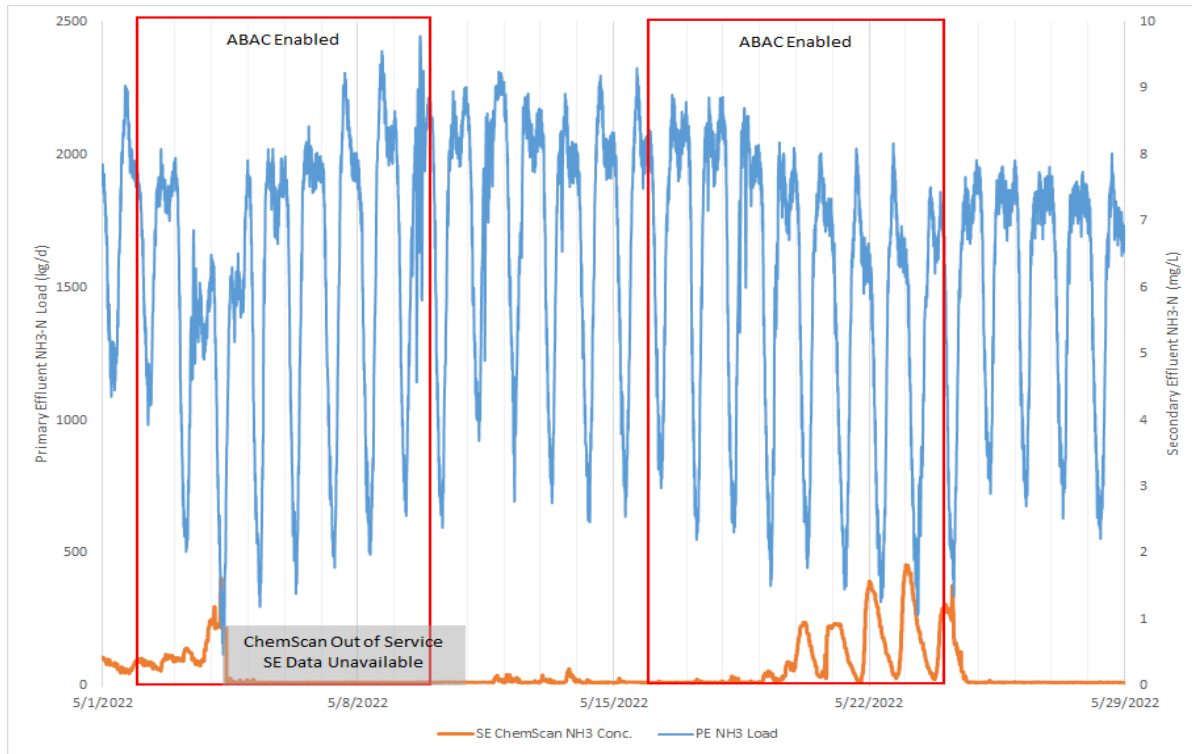
Case 1: ABAC Testing Bioreactor 10

Dates	Aeration Mode	Influent Temperature (F)	Influent Flow (MGD)	Average PE TKN Concentration (mg/L)	DO Setpoints (mg/L)				
					Cell 6	Cell 7	Cell 8	Cell 9	Cell 10
May 2 to May 9	ABAC Winter	55.58	9.47	56.6	ABAC Controlled with Cell 8 ammonia setpoint of 7.0 mg/L				
May 10 to 12	ABAC Disabled	55.76	9.64	55.0	2.5	2.5	2.5	2.0	1.5
May 13 to 15					2.0	2.0	2.0	2.0	1.5
May 16 to May 23	ABAC Summer	55.94	8.28	51.1	ABAC Controlled with Cell 8 ammonia setpoint of 4.5 mg/L (May 16 to 18 th) and 5.5 mg/L (May 19 th to 23 rd)				
May 24 to May 28	ABAC Disabled	57.02	8.78	52.7	2.0	2.0	2.0	2.0	1.5



Case 1: Results

CASE STUDY 1





Case 1: Results and Savings

CASE STUDY 1

- ABAC summer mode: 26% process air savings/mass of ammonia-N
- ABAC winter mode: 7% process air savings/mass of ammonia-N
- Overall, ABAC control achievable 17% savings

Aeration Mode	Process Air per kg Ammonia-N ($\text{m}^3/\text{kgNH}_3\text{-N}$)	Process air per Influent Flow (m^3/MGD)	Power savings (MWhr)	Annual savings (US\$)
ABAC Avg.	5.7	67.4	~1136	~121k
<i>Summer</i>	<i>5.1</i>	<i>63.2</i>	~1738	~185k
<i>Winter</i>	<i>6.4</i>	<i>71.9</i>	~468	~50k
ABAC Disabled	6.9	82.5	-	-



ABAC Case Study 2

Case Study 2



Case 2: Existing BioWin® Simulation

Press F1 for help

Controller list

- Blower Controller
- Air Distributor
- NH3 FF 1 Controller
- NH3 FB Controller
- DO Valve Cell 6
- DO Valve Cell 7
- DO Valve Cell 8
- DO Valve Cell 9
- DO Valve Cell 10
- DO Setting Cell 6
- DO Setting Cell 7
- DO Setting Cell 8
- DO Setting Cell 9
- DO Setting Cell 10
- NH3 FF 2 Controller
- NH3 FF 3 Controller
- NH3 FF 4 Controller
- NH3 FF 5 Controller

Add Remove

Note: Unchecking a controller holds the manipulated variable at its last position.

Controller input/output

Select measured variable...

Measured element:
PC 1 to 14

Measured variable:
N - Ammonia (mass rate)

Select manipulated variable...

Manipulated element:
User defined variable

Manipulated variable:
DOSettingFF1

Controller type

On/Off [High/Low] P

Multi-step PI

Ratio PID

User Defined Controller

Selector/Combiner Air Distribution Tool

Controller parameters - Multi-step

Number of settings: 6

Start controller at: Setting 1

Hysteresis: 0.00

Output

Setting	Output
1	1.2
2	1.5
3	2.4
4	2.6
5	2.8
6	3

Switching Criteria

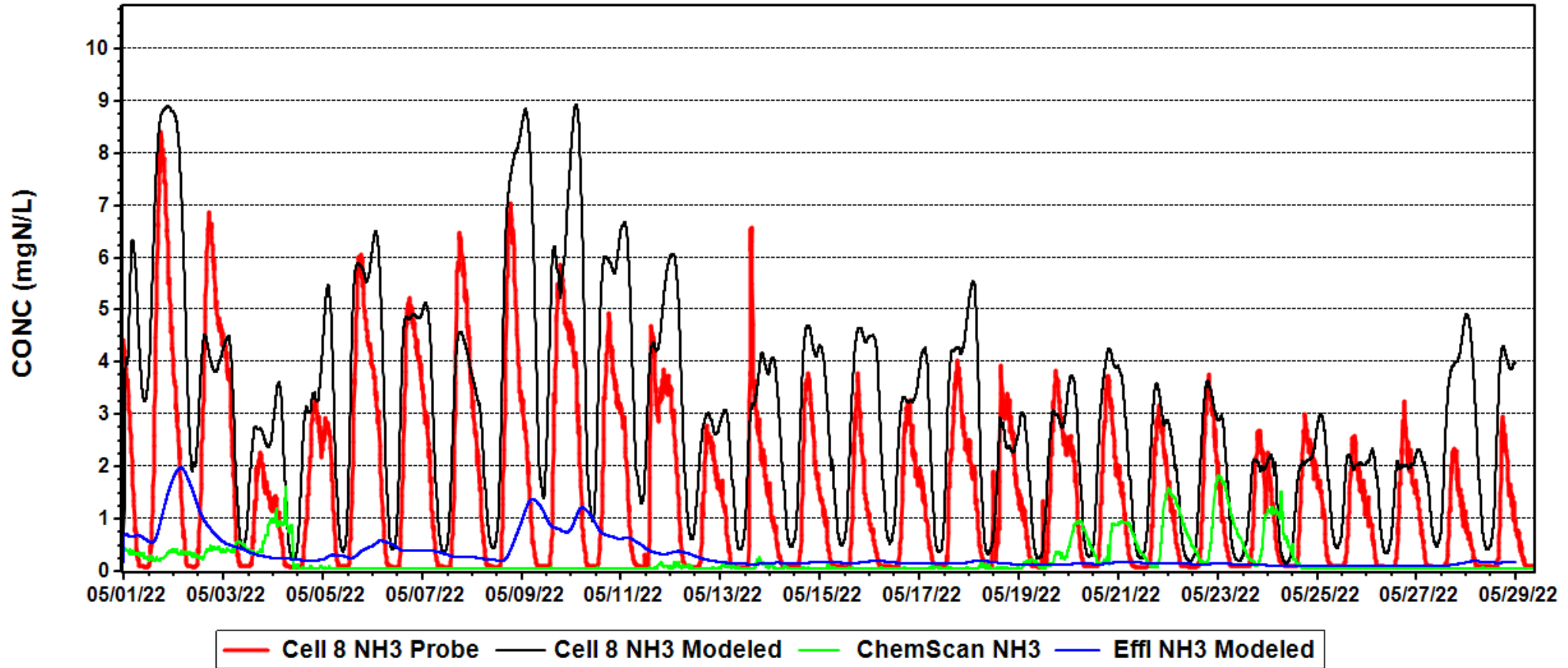
For increasing N - NH3:		For decreasing N - NH3:	
Step	Switch at [kg N/d]	Step	Switch at [kg N/d]
1 -> 2	1000	2 -> 1	1000
2 -> 3	1250	3 -> 2	1250
3 -> 4	1500	4 -> 3	1500
4 -> 5	1750	5 -> 4	1750
5 -> 6	2000	6 -> 5	2000

Control interval: 30.00 minute(s)

- Existing control logic was simulated in BioWin® and BioWin Controller®
- Feedforward with Feedback trim, adjusting a floating DO setpoint at a similar time interval
- 28-day simulation was completed
- The input highlights that as the ammonia load changes the DO setpoint also changes



Case 2: Simulation Results





ABAC Case Study 3

Case Study 3



Case 3: Modified ABAC Control Logic

- Modified control logic was developed
- Controllers maintains a desired ammonia objective by considering microbial kinetics, total mass load of nitrifiers, and the incoming ammonia load

$$\frac{K_{DO}}{\left(\frac{(X_{AOB} \cdot \mu_{max@20} \cdot \theta^{T-20} \cdot Vol_{Aer}[m^3]) / Y_{AOB}}{NitFac \cdot \frac{kgNH_3N INF}{d} \cdot 1000} - 1 \right)} - 0.1$$

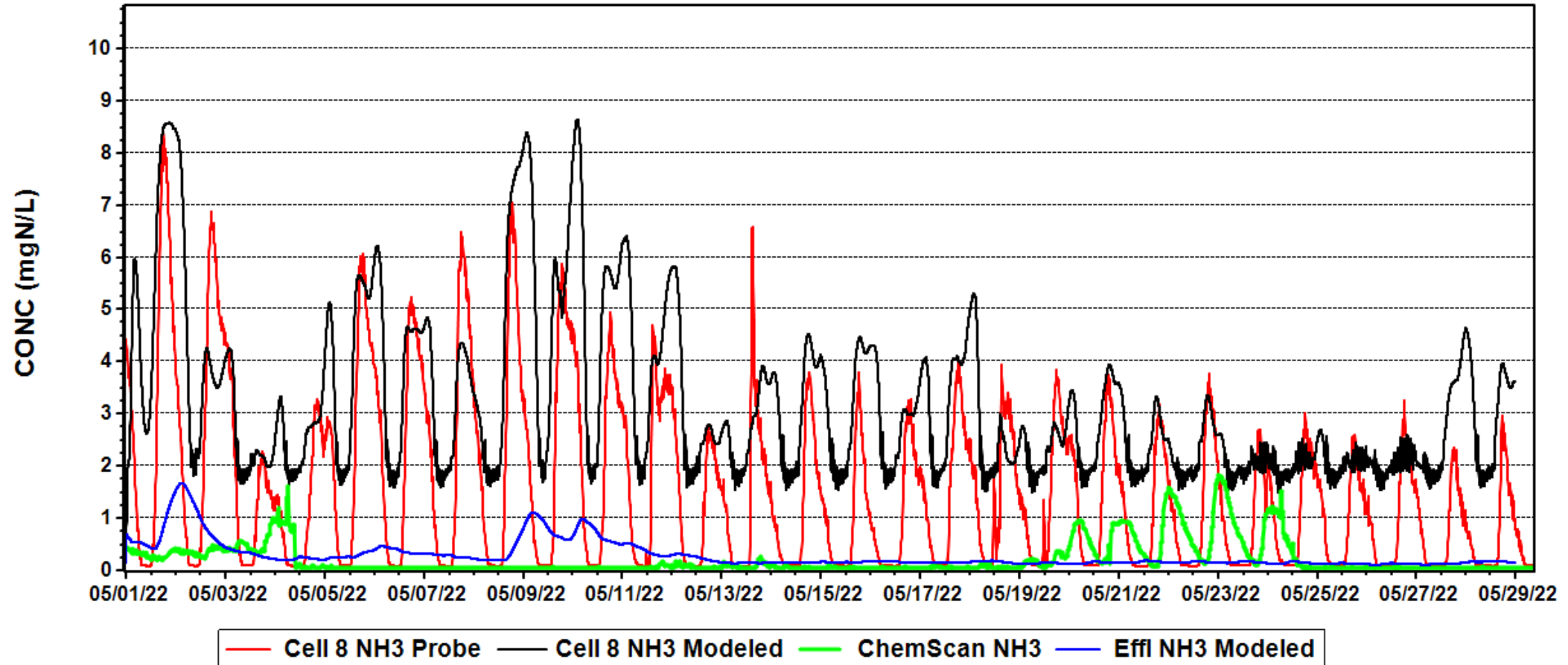
The screenshot shows the 'BW Controller - BB C9 2028 Controller FFModel-FBPID.bcf' window. The 'Controller list' on the left includes 'Blower Controller', 'NH3 FF Controller' (selected), 'Air Distributor', 'NH3 FB Controller', and several 'DO Valve Cell' and 'DO Setting Cell' items. The 'Controller input/output' section shows 'Manipulated element' as 'User defined variable' and 'Manipulated variable' as 'DOSettingFF'. The 'Controller parameters - User Defined Controller' section displays the 'Controller formula' as $\text{Max}(K_{DO} / (((X_{AOB} \cdot \text{Temp. Depend.}(\mu_{max_20}, \text{Theta_mue}, [\text{Cell 8.Temp.]}) \cdot \text{Vol_aer}) / Y_{AOB}) / (\text{Nit_Factor} * [\text{PC 1 to 14.N - NH3 (mass rate)]} * 1000) - 1) - 0.1, 0)$. Below the formula is a 'Constants' table:

	Name	Value	Notes
Add...	X_AOB	70	
Edit...	mue_max_20	0.7	
	Theta_mue	1.072	
Remove	Y_AOB	0.15	
	Vol_aer	14074	

Additional parameters include 'Lower bound' (0.00), 'Upper bound' (2.00), and 'Control interval' (2.00 minute(s)). The 'Controller type' is set to 'User Defined Controller'.



Case 3: Simulation Results





Conclusion and Next Steps

Next Steps

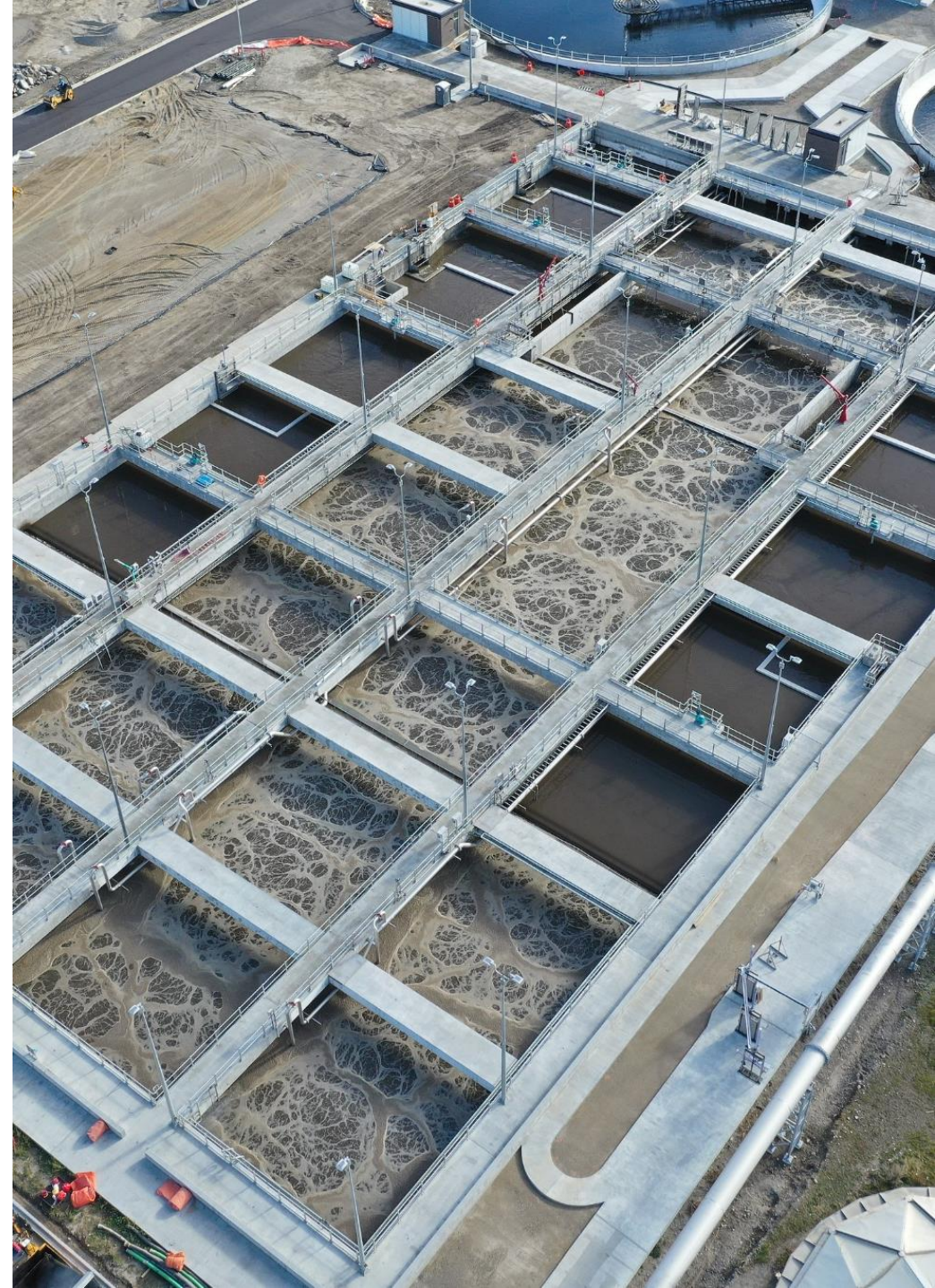


Conclusion

- ABAC has been widely applied in WWTP but not optimized
- Any advance control optimization may result in investing time, labor and possible disruption to system
- Optimized simulation yield to time and capitol savings and operation disturbance protection

Next Steps

- Program a second modified controller for testing
- Implement in Secondary D





Thank you!

Discussion

