

Planning for Explosive Growth: Leveraging Existing Infrastructure to Optimize Biological Nutrient Removal

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ABSTRACT

Delaware County Regional Sewer District (DCRSD) initiated work on a Facilities Plan for the Olentangy Environmental Control Center (OECC) in 2017. A process evaluation was performed as a part of the work to develop a comprehensive understanding of the wastewater treatment process at OECC through use of detailed sampling, process modeling and computational fluid dynamics (CFD) modeling of the clarifiers. These models were then used to identify improvements in the facility plan with a focus on energy efficiency, biological nutrient removal optimization, and repurposing existing infrastructure to help treat the anticipated future flows over the planning period. Recommendations from the study include leveraging existing tank volume to create a more reliable BNR configuration and improved settleability to meet their limits at future flows and loads. The approach utilized herein to evaluate a whole-plant process and identify low cost solutions for expanding plant capacity and providing reliable nutrient removal can be applied to other facilities facing similar challenges.

KEYWORDS: Biological Nutrient Removal, Optimization, Process Modeling, Computational Fluid Dynamics (CFD) Modeling

INTRODUCTION:

Delaware County is currently the fastest growing county in Ohio by population and among the top 15 fastest growing in the country. To serve this growing population, DCRSD initiated work on a Facilities Plan for OECC to develop recommendations for capital improvements to the facility to optimize operations for treating flow at the plant's rated capacity of 22,700 m³/d (6 mgd). OECC liquid process stream includes influent pumping, 3 pass aeration tanks, final clarifiers, tertiary filters and disinfection. Solids handling includes aerobic sludge storage and centrifuge dewatering. OECC has two separate plants within the facility. The original "North" plant (5,680 m³/d or 1.5 mgd) was taken out of service when the South plant (17,000m³/d or 4.5 mgd) was placed in service in 1996 (**Figure 1**). The North plant needs significant improvements to be placed back in service.

OECC is currently required to meet an effluent total phosphorus (TP) limit of 1 mg/L and an effluent NO₂-N+ NO₃-N limit of 4.58 mg/L on a monthly average basis. The effluent ammonia

(NH₃-N) limit is 1.28 mg/L in the winter and 0.78 mg/L in the summer on a monthly average basis. Both step feed and intermittent aeration have been implemented in the aeration tanks to accomplish denitrification to meet the permit limits. The head of the first and second passes are mixed, but not aerated providing anoxic and, at times, anaerobic conditions, resulting in limited enhanced biological phosphorus removal (EBPR). Ferric chloride is also consistently fed at the aeration tank effluent for phosphorus removal.

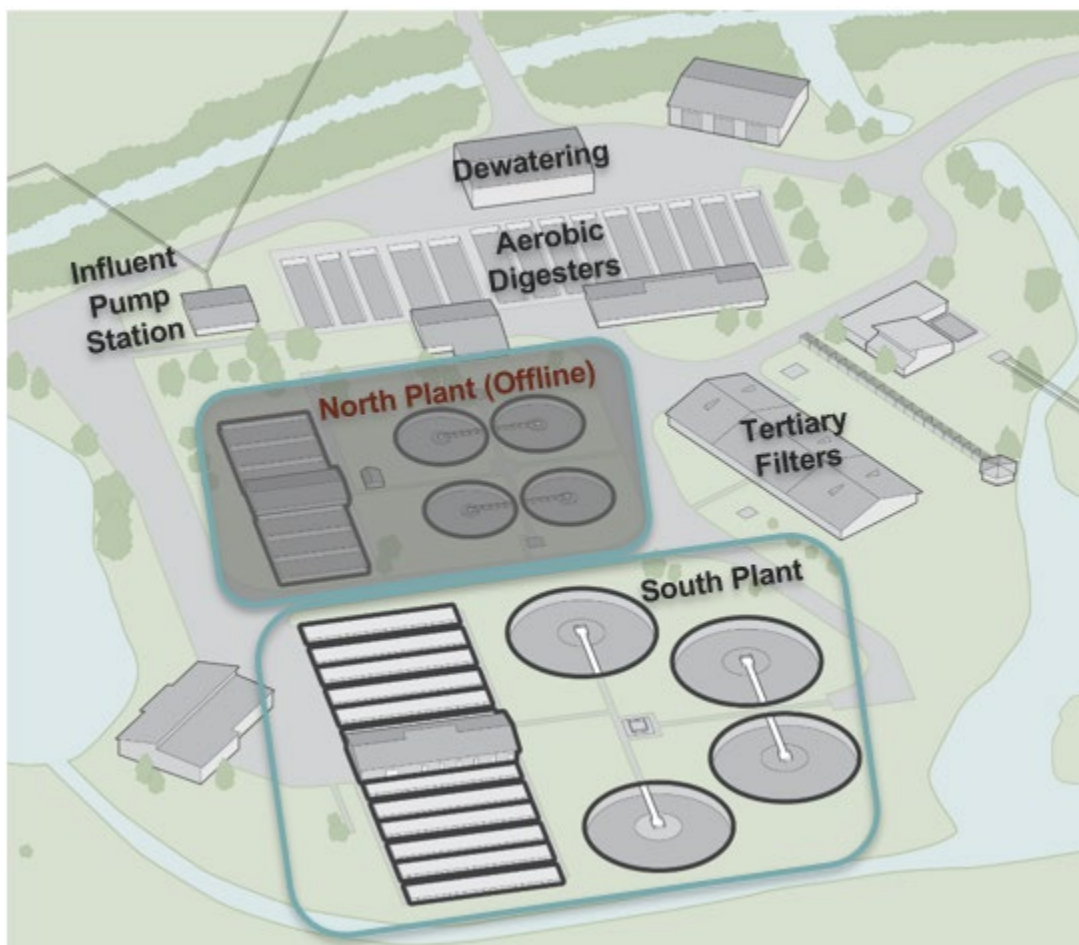


Figure 1. Existing OECC Process

METHODOLOGY

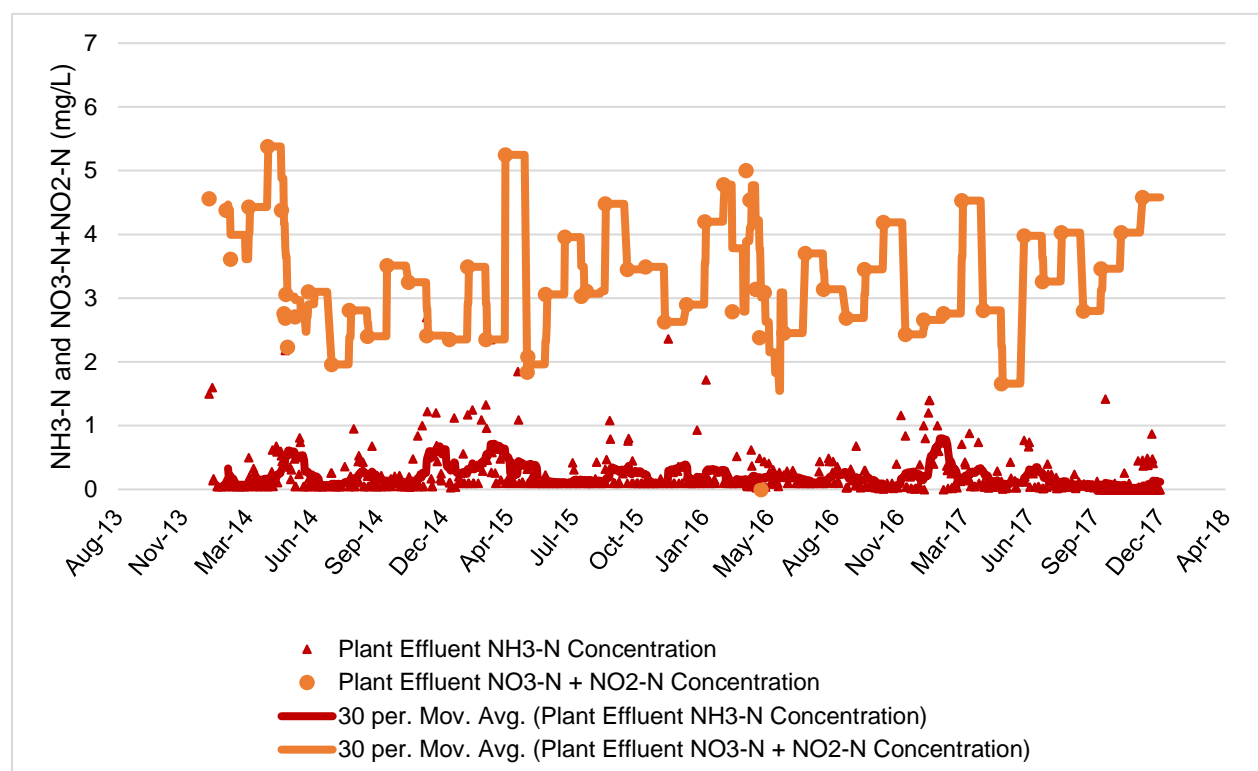
Historical Data Review and Special Sampling

Historical plant data was compiled and reviewed for 2014-2017 from the Monthly Plant Operating Reports to understand current loadings and plant nutrient removal performance. OECC currently receives an annual average flow of about 12,870 m³/day (3.4 mgd). **Table 1** summarizes the annual average measured influent flow and concentrations to OECC.

Table 1. Influent Flow and Concentration Data for 2014-2017

Parameter	2014	2015	2016	2017	2014-2017
Flow, m3/d (mgd)	11,550 (3.05)	12,260 (3.24)	12,570 (3.32)	12,870 (3.40)	12,300 (3.25)
Influent cBOD	70	78	63	66	69
Influent TSS	113	130	135	99	119
Influent NH ₃ -N	NA	19.4	17.5	18.1	18.1
Influent TP	NA	4.6	4.8	5.9	5.1

The measured influent carbonaceous biochemical oxygen demand (cBOD) and total suspended solids (TSS) concentrations are much lower than typical domestic waste concentrations. Influent NH₃-N and TP concentrations are only measured monthly, but fall in the range of typical domestic waste. Further evaluation of the historical solids production and nutrient removal performance suggested that the influent cBOD concentrations may be underestimated. Treatment performance consistently met effluent solids, organics and nutrients over the period analyzed. Effluent nutrient requirements include seasonal NH₃-N concentrations, and year-round nitrite (NO₂-N) + nitrate (NO₃-N) and TP concentrations, as shown in **Figure 2** and **3**.

**Figure 2: OECC Effluent Nitrogen Concentrations**

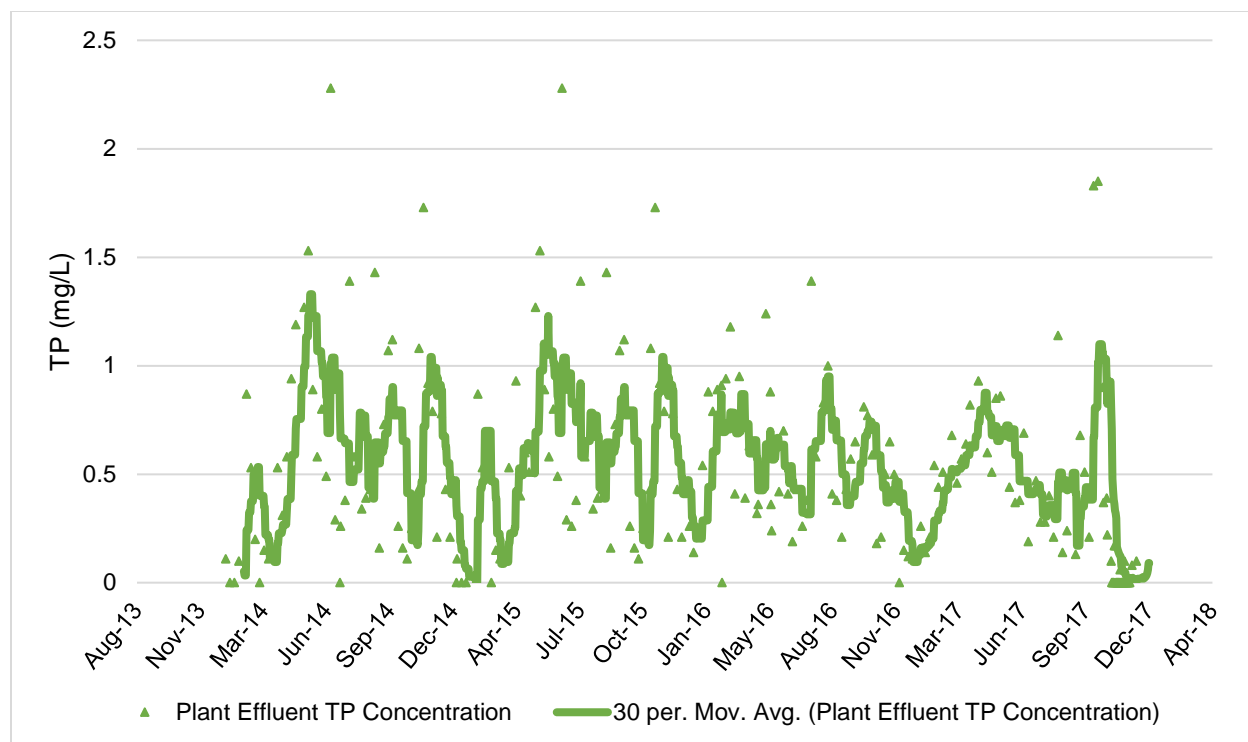


Figure 3: OECC Effluent Phosphorus Concentrations

Historically, OECC has experienced significant periods of poor settling sludge, which is a significant limitation on plant capacity and clarifier performance. Addressing sludge settleability and clarification performance and capacity was identified as a key aspect of the Facilities Plan. The historical average SVI value was approximately 169 mL/g from 2014 through 2017. This SVI value indicates poor solids settling in the secondary clarifier. Typical good settling sludge characteristics for an activated sludge process has an SVI value between approximately 100 – 120 mL/g.

Detailed process sampling and clarifier stress testing was completed in December 2017 to gather information on process performance and characterize the wastewater for model calibration. The detailed sampling and model calibration revealed several interesting findings relevant to the optimization of the plant nutrient removal performance and clarifier capacity, including:

1. Reported influent cBOD is likely higher than historically measured. Historical influent cBOD concentrations average around 70 mg/L, but the detailed sampling indicated that the influent cBOD concentrations are closer to typical domestic waste concentrations.
2. The DO concentration profiles collected during the sampling week, showed that DO remains very low along the first pass under both aerated and unaerated conditions. This is where the phosphorus release is occurring, as show in **Figures 4 and 5**. The average aeration tank effluent ammonia is below 1 mg/L, though different grab samples did show some variation. Effluent NO₃-N was consistently below 4 mg/L and effluent PO₄-P was

consistently below detection limit, indicating efficient EBPR upstream of chemical addition during this period.

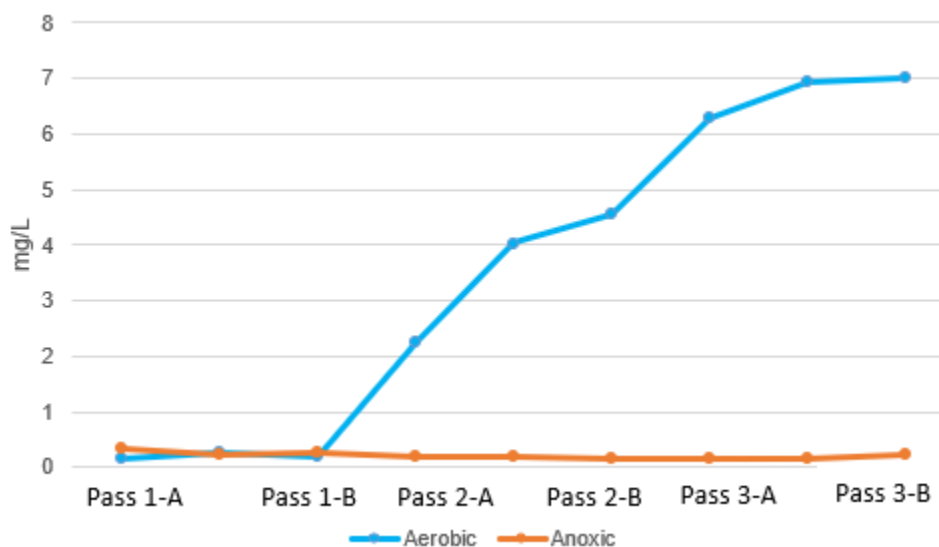


Figure 4: Average Aeration Tank DO Profile During Aerobic and Anoxic Periods

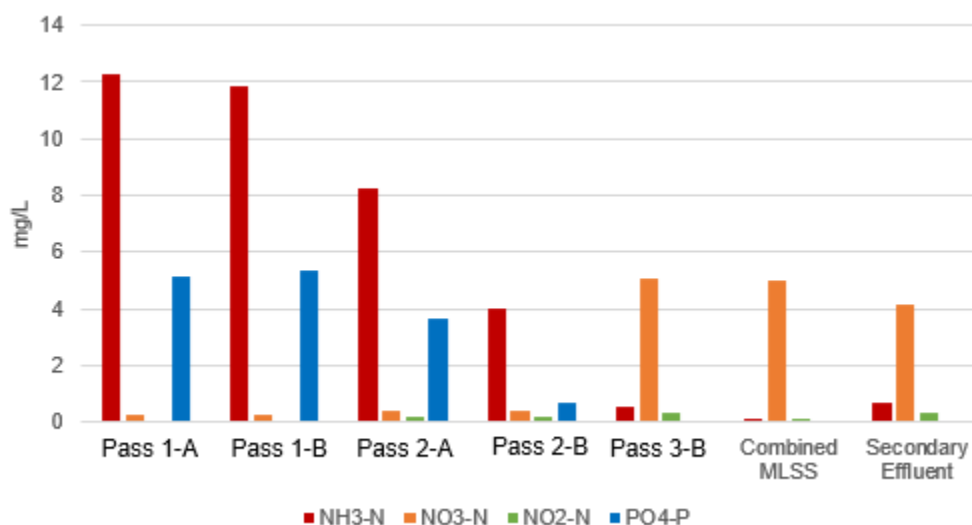


Figure 5. Sampling Week Nutrient Removal Profiles

- The existing secondary clarifiers have a flocculating center well clarifier mechanism, which is atypical for a secondary clarifier application. Based on field testing and clarifier modeling, operation of the flocculating center wells appeared to be detrimental to the clarifier performance and provide no apparent process related benefit.

Model Development

A process model was developed in BioWin™ (EnviroSim v 5.1.) to represent the conditions from the special sampling week. The process layout is shown in **Figure 6**. The model was simulated on a dynamic basis to capture the variation in nitrification/denitrification due to the intermittent aeration operation. A summary of the average calibration results are presented in **Table 2**. Overall a good match was observed on sludge production and nutrient removal.

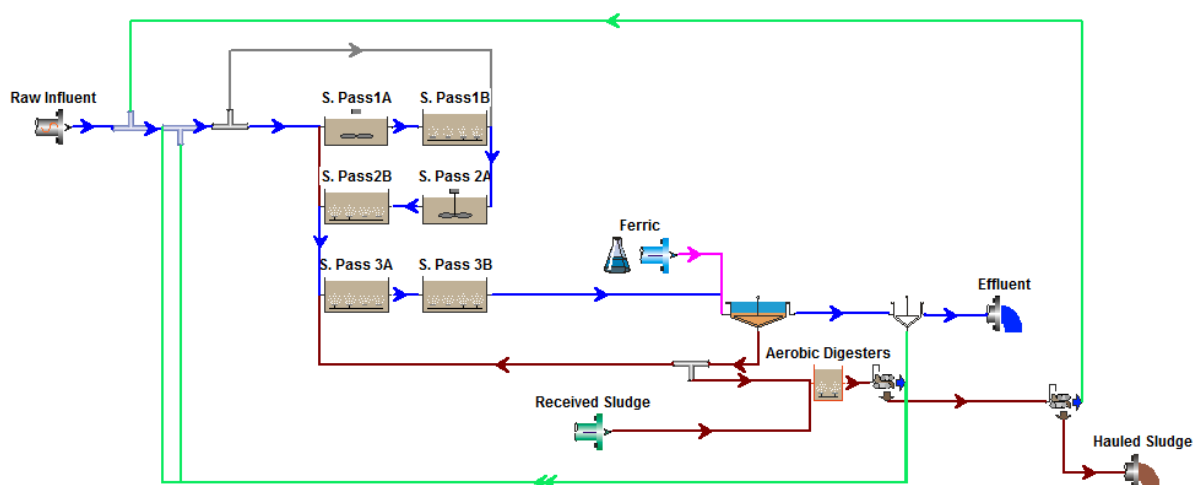


Figure 6: Process Model Layout

Table 2. Average Process Model Calibration Results

Parameters	units	Measured	Modeled	% Difference
Sludge Production				
Pass 3 MLSS	mg/L	2,190	2,010	-8%
WAS Load	Kg/d	2,550	2,410	-1%
Centrifuge Feed TSS load	Kg/d	2,910	3,340	15%
Hauled sludge	Kg/d	3,050	3,320	9%
Secondary Clarifier Effluent				
Secondary Effluent TSS	mg/L	<4.0	3.8	--
Secondary Effluent TKN	mg/L	2.0	1.96	-2%
Secondary Effluent NH3	mg/L	0.6	0.58	-2%
Secondary Effluent NO2-N+NO3-N	mg/L	4.86	5.45	12%
Secondary Effluent TP	mg/L	0.12	0.14	--
Secondary Effluent PO4-P	mg/L	0.02	0.01	--

The secondary clarifier CFD model was developed, calibrated, and validated following completion of the field tests and data analysis. The CFD model was calibrated to secondary clarifier performance during normal operation and validated with stress testing results. A summary of the calibration and validation results are presented in **Table 3** and the dynamic blanket level model predictions vs. field measurements for Day 3 are presented in **Figure 7**.

Table 3. OECC CFD Model - Calibration and Validation Results Summary

Testing Conditions	SOR (m ³ /m ² d)	ESS (mg/L)		Blanket Height (m)		Blanket + Dispersed Height (m)	
		Field Measurement	Model Prediction	Field Measurement	Model Prediction	Field Measurement	Model Prediction
Calibration	11.4	4	4	0.52	0.64	0.94	1.31
Validation	27.7	4	7	1.95	1.5	1.98	2.2
Validation	34.6	5	8	2.6	1.95	2.8	2.7

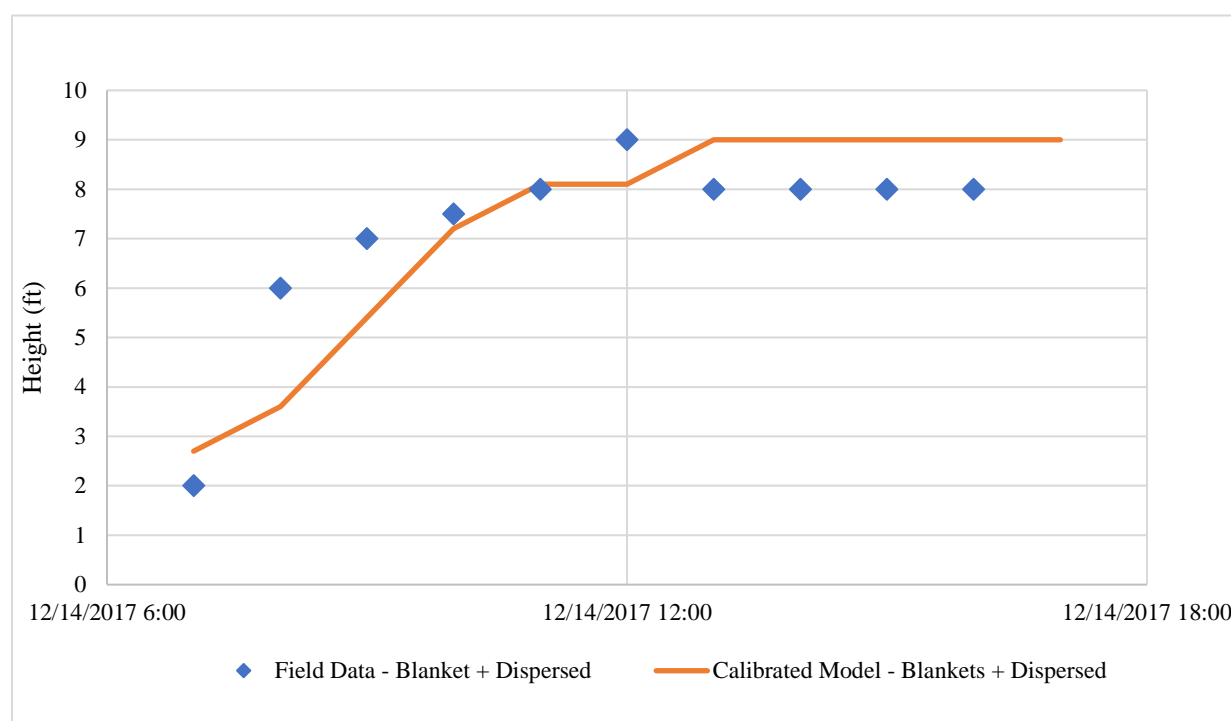


Figure 1. OECC Secondary Clarifier Model Validation - Blanket Comparison

Process Evaluation:

The calibrated models were then used to evaluate current capacity and alternative process configurations to optimize nutrient removal at the design capacity.

Design Criteria

There was uncertainty associated with the influent concentrations, so additional sampling was performed in December 2018 and March 2019. Based on the additional sampling, the influent cBOD was determined to be higher than the historical average, but still considered a weak strength wastewater. The annual average design criteria were selected to design the Facilities Plan improvements is presented in **Table 4**. A maximum month peaking factor of 1.25 was applied to the loads for the process evaluation and simulated under minimum week temperatures.

Table 4. Influent Concentrations for Alternative Analysis

Parameter	Historical (2014-2017)	Sampling Week	Design Concentrations
cBOD (mg/L)	69	187	125
TSS (mg/L)	119	167	112
TKN (mg/L)	--	34.3	23.0
NH ₃ -N (mg/L)	18.1	23.9	16.0
TP (mg/L)	5.10	4.72	3.16
PO ₄ -P (mg/L)	--	2.37	1.59

The models were used to evaluate improvements needed to meet 3 annual average flow conditions:

- Existing 22,700 m³/d (6 mgd) capacity
- Capacity Expansion to 34,100 m³/d (9 mgd)
- Capacity Expansion to 45,400 m³/d (12 mgd)

In the existing configuration at future flows and loads, the modeled effluent nitrogen concentrations were extremely sensitive to control of the intermittent aeration and ultimately this strategy was not recommended to reliably meet the effluent NO₂+NO₃-N limit. Improvements to the process layout were explored utilizing the existing infrastructure in the South and North Aeration Basins. A four or five stage process were determined to be the best alternative to optimize nitrogen and phosphorus removal. Schematics of these process configurations are shown in **Figure 8**.

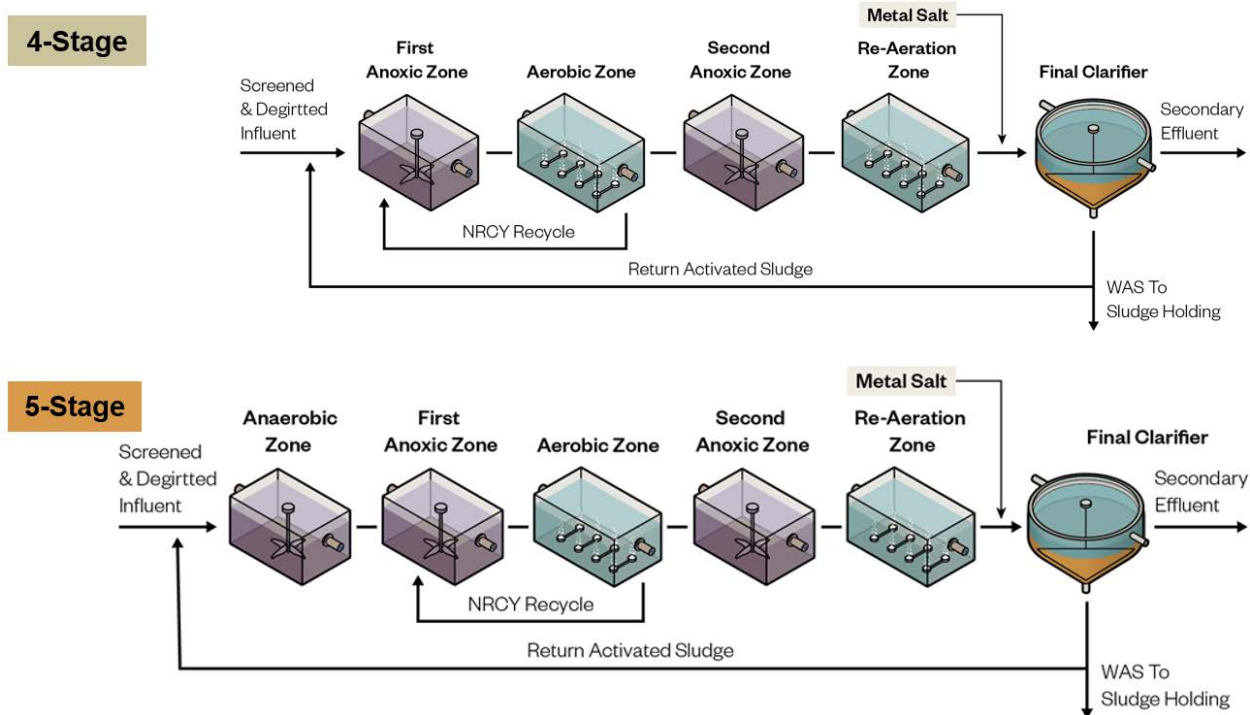


Figure 8 – Four or Five Stage Process Schematic

Based upon the process modeling evaluation, the existing South Plant aeration tanks can be modified to a 4-Stage/5-Stage configuration to improve treatment efficiency and enhance reliability up to 22,700 m³/d (6 mgd). The South Plant process improvements are summarized below.

- Installation of axial flow pumps to facilitate nitrified recycle (NRCY) flows for enhanced nitrogen removal and discontinue the use of intermittent aeration.
- Replacement of two of the five existing 20-year old multi-stage centrifugal blowers with two air- or magnetic-bearing blowers for improved efficiency and turndown at design conditions.
- Replacement of existing diffusers with tube diffusers in aerobic and swing zones
- Replacement of existing mixers with a compressed air (large bubble) mixing system in anaerobic, anoxic, and swing zones

The South Plant Process improvements are expected to allow OECC to treat up to 34,100 m³/d (9 mgd) annual average capacity, as long as peak flows through biological treatment do not exceed 114,000 m³/d (30 mgd). As future influent loads increase, either due to consistent flow increase or strength of wastewater, an expansion in capacity would be facilitated by a conversion of the Old North Plant to an upgraded biological treatment system.

Creation of dedicated anaerobic and anoxic zones using the North tanks and operating the two plants in series will allow for treatment of annual average flows up to 45,400 m³/d (12 mgd). The North tanks would serve as the anaerobic zone (if 5 stage) and anoxic, and the South would have the last 3 stages. A new wet pit submersible nitrified recycle (NRCY) pump station, as well as yard piping and distribution structures, are included in the Facilities Plan to facilitate the 4-Stage / 5-Stage configuration between the Old North Plant and South Plant aeration tanks. The existing Old North Plant clarifiers will be demolished to make room for the NRCY pump station. A supplemental carbon feed facility was also evaluated for enhanced denitrification, but BioWin modeling results did not indicate a need for supplemental carbon under current influent conditions. A summary of the process model results for the process operated as a four-stage process are presented in **Table 5**, including the anticipated required chemical addition for nitrogen and phosphorus removal.

Table 5 – Process Evaluation Modeling Results

Parameter	Current Monthly Limits	Annual Average Model Results		
		6.0	9.0	12.0
Supplemental Carbon		NA	NA	NA
Metal for P removal, lpd		1,320	1,800	2,080
Effluent BOD (mg/L)		1.3	1.4	1.6
Effluent TSS (mg/L)		1.7	1.7	2
Effluent NH ₃ -N (mg/L)	0.78/1.28	0.2	0.2	0.2
Effluent NO ₂ -N+NO ₃ -N (mg/L)	4.58	1.9	1.8	1.8
Effluent TP (mg/L)	1	0.6	0.6	0.7

The calibrated and validated secondary clarifier CFD model was used to evaluate existing secondary clarifier capacity at current and projected design conditions. Future clarifier loadings were evaluated based on the projected future MLSS of 2,200 mg/L at annual average conditions and 2,900 mg/L at maximum month conditions. The results from the capacity analysis are presented in **Table 6**.

Table 6. OECC Secondary Clarifier Capacity Analysis - Annual Average and Maximum Month Conditions

Design Condition	MLSS Concentration	SOR (m ³ /m ² d)	SVI (mL/g)	ESS (mg/L)	Sludge Blanket Height (m)	Sludge Blanket + Dispersed Layer (m)	Pass/Fail
Design Annual Average	2,200	12.8	165	<15	0.3	4	Pass
			200	<15	0.6	1.5	Pass
Current Max Month	2,900	9.0	165	<15	0.6	1.5	Pass
			200	<15	1.5	1.8	Pass
Design Max Month	2,900	16.3	165	<15	1.5	2.1	Pass
			200	>30	>3	>3	Fail

In summary, the existing secondary clarifiers do not appear to have adequate reliability for future peak flow conditions with the existing settleability characteristics. An SVI range of 100-140 mL/g was established as the required performance criteria at the peak flow condition, which is expected to be achievable with the implementation of an anoxic selector zone in a four or five stage configuration. For expected flow and load conditions over the next ten years, the performance and conditions of the existing secondary clarifiers are expected to be sufficient. Historical challenges with settling at OECC are expected to improve with the biological treatment improvements. As annual average flows increase, or if sludge settleability improvements are not realized, additional clarifier capacity is recommended.

In addition, the existing clarifiers have flocculating center wells installed, and clarifier testing and modeling found that the additional turbulence imparted by the flocculator arms negatively impacted clarifier performance during peak flows. Disabling the flocculating center well and long-term replacement of the clarifier mechanisms could provide additional clarifier capacity.

A schematic of this suggested layout of the proposed biological improves including both design and capacity expansions is shown in **Figure 9**.

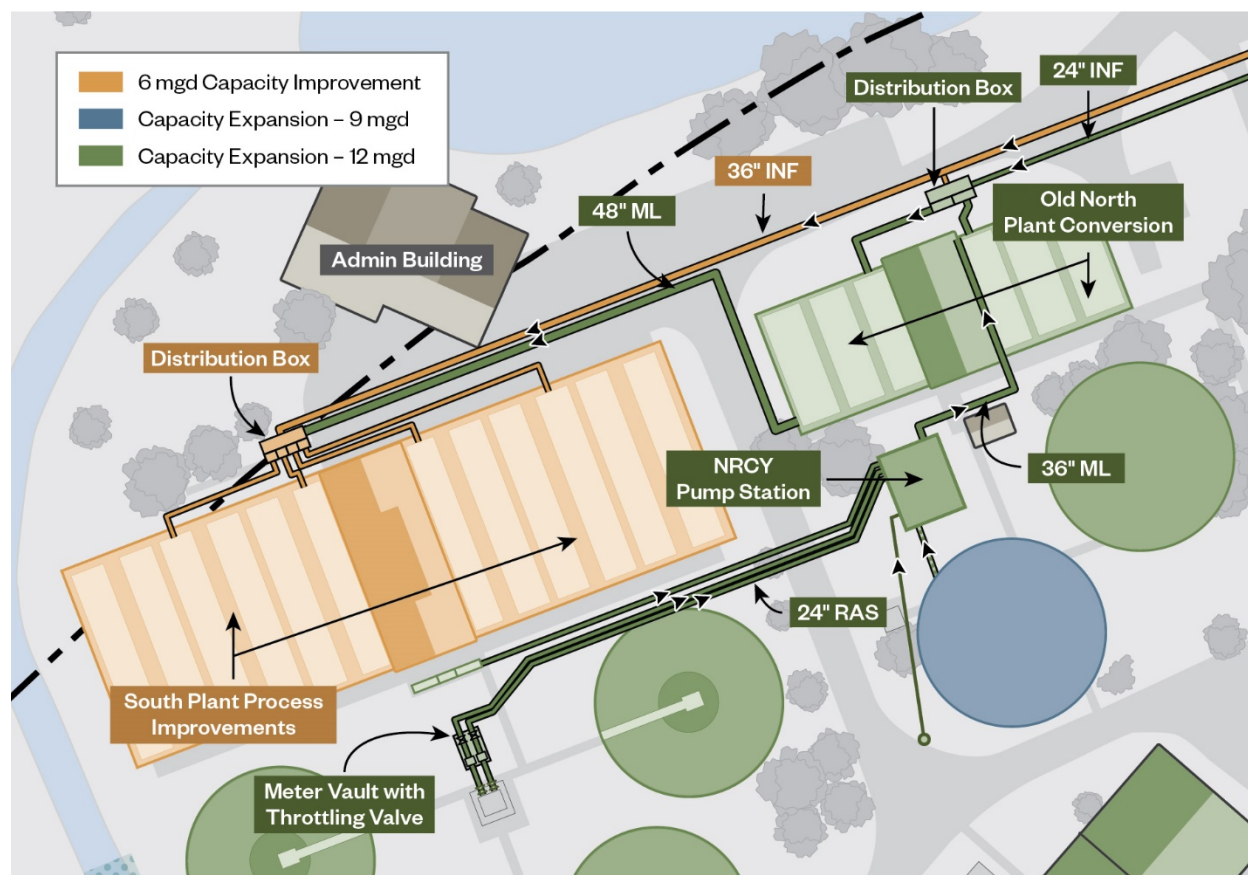


Figure 9. Recommended Secondary Improvements for Design and Capacity Expansions

RESULTS:

Process and CFD models served as valuable tools in the Facilities Plan to determine the capacity of the existing process and evaluate different potential process solutions. For both 22,700 m³/d (6 mgd) Improvements and Capacity Expansion projects, BioWin modeling results indicate that the ability to operate in both a 4-stage and 5-stage configuration using aerated/unaerated “swing” zones will be beneficial to treatment performance, energy efficiency, and operational flexibility. DCRSD will be able to leverage that existing tank volume in the South Plant and eventually in the North plant to create a more reliable BNR configuration and improved settleability to meet their limits at future flows and loads.