Nitrogen Reduction using a Small Budget and Big Ingenuity

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ABSTRACT

This paper presents creative solutions at the Williamsburg Treatment Plant (WBTP), which reduced effluent total nitrogen (TN) from 7.4 mg/L to 2.5 mg/L on a monthly average basis. A calibrated Biowin process model was developed to assess various reactor configurations to determine the optimum process selection for the highest nutrient removal. Once the most advantageous configuration was selected, HRSD purchased, designed, and constructed all improvements required. HRSD staff utilized low cost materials to construct budget friendly baffle walls in-house, hand-built a large bubble mixing system, and modified existing equipment to implement the new configuration. Instrumentation and automation controls were integrated into the plant's distributed control system (DCS) by staff instrumentation technicians. This case study showcases the ability to optimize and implement nutrient removal strategies at low cost when the utility supports creativity and ingenuity of plant staff.

KEYWORDS: MLE, cost-effective upgrade, process modeling, biological nitrogen removal, biological phosphorus removal

INTRODUCTION

The WBTP, owned and operated by the Hampton Roads Sanitation District (HRSD), treats approximately 9 million gallons a day (MGD) (.034 Mm^3) and is located in Williamsburg, Virginia.

Liquid treatment at the WBTP consists of mechanical screening, grit removal, primary clarification, oxidation towers, biological nutrient removal (BNR), secondary clarification, chlorination, and dechlorination prior to discharging into the James River.

The plant was originally designed to fully nitrify with no nutrient removal, however modifications were implemented in 2011 to operate as a Modified Ludzak Ettinger (MLE) process. Prior to upgrades discussed in this paper the BNR process operated in a MLE configuration, with four tanks in parallel. Each tank had five cells of equal size with the first two operated anoxically.

Solids treatment at WBTP consists of in-tank gravity thickening of primary solids (PS) and gravity belt thickening of waste activated sludge (WAS). The thickened sludges are dewatered by solid bowl centrifuges and the dewatered cake is incinerated. Figure 1 depicts the original process flow at WBTP.
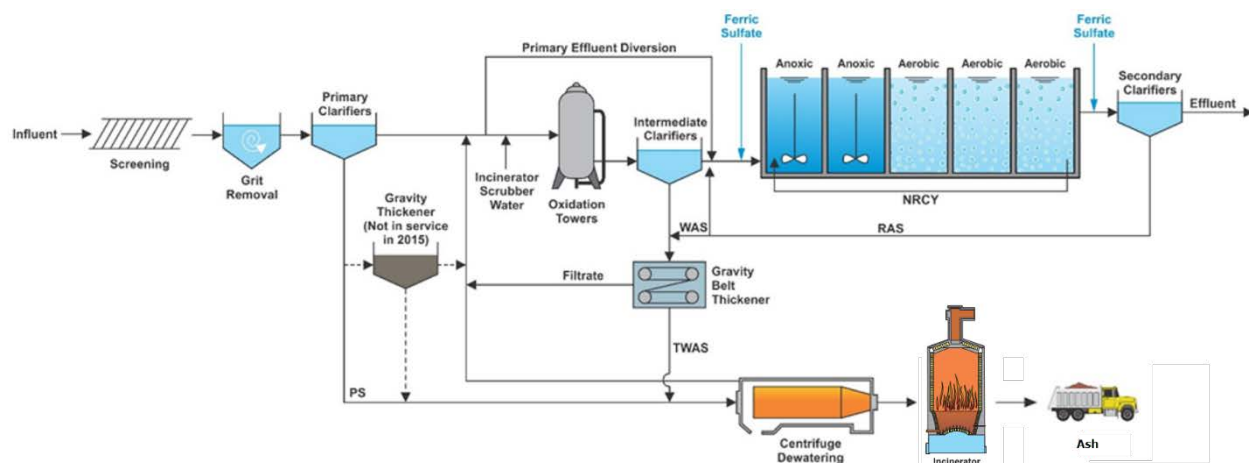
Figure 1: Process Flow Diagram Prior to Improvements (MLE configuration)

The Williamsburg Treatment Plant (WBTP) current effluent nutrient requirements are total nitrogen (TN) of 14 mg/L and total phosphorus (TP) of 2 mg/L on an annual average basis. Anticipated future nutrient goals are more stringent, including a total inorganic nitrogen (TIN) < 6 mg/L (instantaneous), TN < 4 mg/L (monthly average), and TP < 1 mg/L (monthly average). HRSD determined a plant optimization study could be utilized to evaluate if an initial idea by the WBTP plant manager could reduce effluent TN and enhance the reliability of nitrification and biological phosphorus removal.

Challenges at the Plant

A unique treatment technology at the WBTP is the oxidation towers. The plant receives a significant fraction of readily biodegradable chemical oxygen demand (RBCOD) from the Anheuser-Busch Brewery located in the service area. This greatly enhances the potential of the facility to remove nutrients, however, the loading from the brewery is variable. Primary effluent (PE) flow can be bypassed around the oxidation towers. The more PE bypassed, the more RBCOD is available for denitrification and biological phosphorus removal. However, the carbon source also utilizes capacity that is also needed for nitrification. The plant balances these competing interests by controlling the amount of flow sent to the oxidation towers and taking advantage of warm weather nitrification in the towers, which reduces the nitrogen load to the MLE tanks.

In addition to variable COD loading, additional nitrification issues have been linked to incinerator scrubber water. There is no formal side-stream treatment process to treat this recycle flow, however, it is directed to the oxidation towers prior to entering the aeration tanks.

METHODOLOGY

HRSD determined a plant optimization study could be utilized to optimize plant performance to consistently treat to lower effluent nutrients. Historical plant data was reviewed, a calibrated process model was developed, and the process model was used to determine simple basin configuration upgrades that could be used to treat to lower effluent limits. Hydraulic modeling was also performed to answer questions about flow distribution.

Historical Data Review

Historical data was analyzed from 2013 through 2015 to determine typical effluent concentrations from primary effluent and the intermediate clarifier effluent (ICE). Refer to Figure 1 for process flow diagram.

The influent COD concentration is greater than 800 mg/L and is primarily soluble due to the brewery waste. During particularly warm weather (summer) the towers also nitrify. The amount of flow sent to the oxidation towers is determined by the capacity to remove all the BOD and achieve some level of nitrification. In the winter it is not possible to nitrify in the towers, therefore approximately 60 percent of the influent flow is sent through the towers. In the summer, nitrification is possible in the oxidation towers but a lesser load of COD must be sent, therefore only approximately 40 percent of the influent flow is sent through the towers. Figure 2 illustrates the complex relationship between nitrification in the towers and effluent TN. An equation was also developed, Equation 1, to predict the mass of TKN in the ICE as a function of the COD load to the towers and temperature.
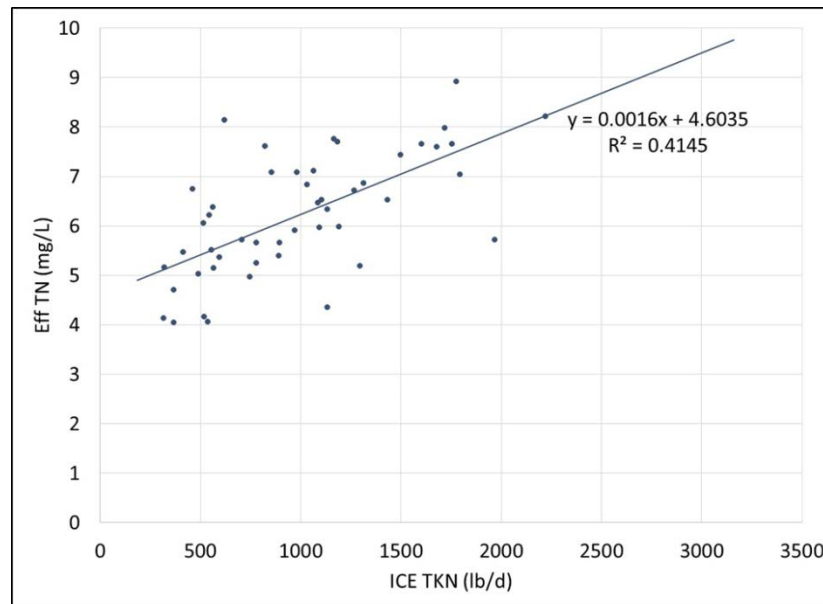

Figure 2: Relationship between Effluent TN and Intermediate Clarifier Effluent (ICE) Load

Mass of TKN in ICE = 304 + 0.04*(COD load to towers, ppd) – 19*(temp, C)   **Equation 1**

Due to the influent brewery waste, COD loading at the facility varies. Incoming COD from this waste source ranges from 0 to 55,000 lbs/day. This variability impacts flow splitting between the oxidation towers and the aeration tanks due to the performance sensitivity of COD to the oxidation towers. Ammonia loading to the aeration tanks is impacted when the amount of primary effluent bypassing the oxidation towers changes.

In the summer, the WBTP occasionally experiences reduced BPR. Since the oxidation towers nitrify in warm weather, further complications to BPR occur when nitrate is directed to the anoxic zone. Typically, the anoxic zone becomes an anaerobic zone due to the consumption of nitrate. This increased nitrate from the nitrifying oxidation tower reduces the effectiveness of the inadvertent anaerobic zone.

Process Modeling

A calibrated Biowin model of the WBTP was developed to evaluate alternative nitrogen removal strategies to meet current and future permit limits at current flows and loads.

The development of the calibrated model focused on primary effluent (PE) and ICE, which fed the BNR process. Three different months/temperature conditions in 2015 were used for model calibration: January (winter), July (summer), and October (spring/fall). A screenshot of the calibrated process model is presented in Figure 3. Each of these periods represents a different amount of primary effluent passing through the oxidation towers. The percent PE diverted and treated in the oxidation towers is presented in Table 1.
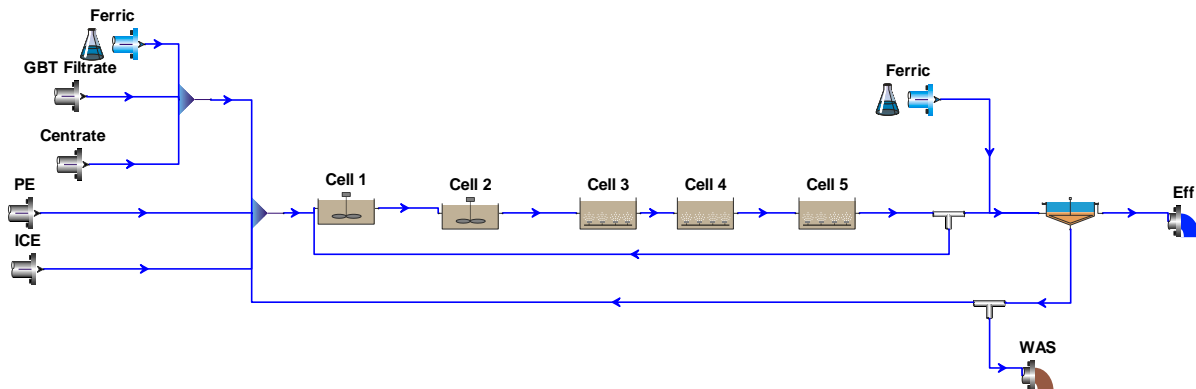

Figure 3: WBTP Calibrated Biowin Model

Table 1: Seasonal Primary Effluent Flow to Oxidation Towers

Season	Percent PE Treated in Oxidation Towers	Percent PE Diverted
Winter	60%	40%
Spring/Fall	50%	50%
Summer	40%	60%

RESULTS

Once the calibrated process model was developed, various scenarios were modeled to determine the optimum treatment scheme to upgrade the BNR tanks to reliably meet the proposed future effluent limits. Each alternative was modeled under winter conditions, which eliminated several

options, as well as spring/fall and summer conditions to simulate various operational temperatures.

Evaluation of the modeled scenarios indicated that converting the existing tanks into a 5-stage process would provide for the largest reduction in nitrogen and phosphorus. HRSD staff made these modifications in-house and had maintenance and operation staff design, internally manufacture, and install all the required equipment and upgrades for the configuration change. HRSD was able to make all required equipment upgrades and operational changes for under $200,000. Specific upgrades are discussed below.

Summary of Improvements

The selected upgrade was to convert the existing MLE process to a 5-stage process. The upgrades were divided into two phases, which are described below.

The original MLE configuration is shown in Figure 4. The modifications were installed in two phases.
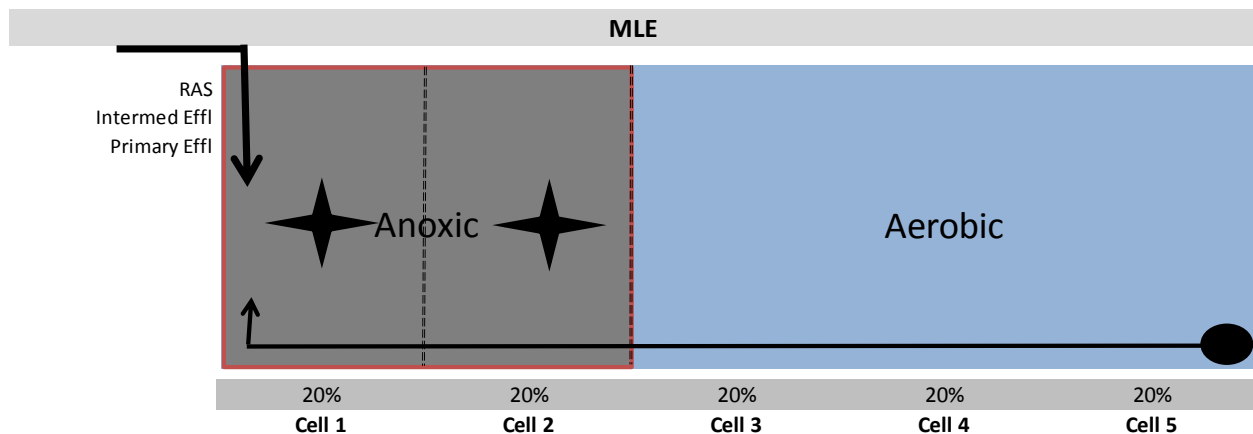

Figure 4: Original MLE Configuration

Phase I upgrades are shown in Figure 5 and included the installation of three baffles walls, which are shown by yellow dashed lines below, in each of the four trains and flow split adjustment to incorporate step feed of MLSS. To complete the anoxic operation of cell 4, the mixer located in cell 2 was moved to cell 4.
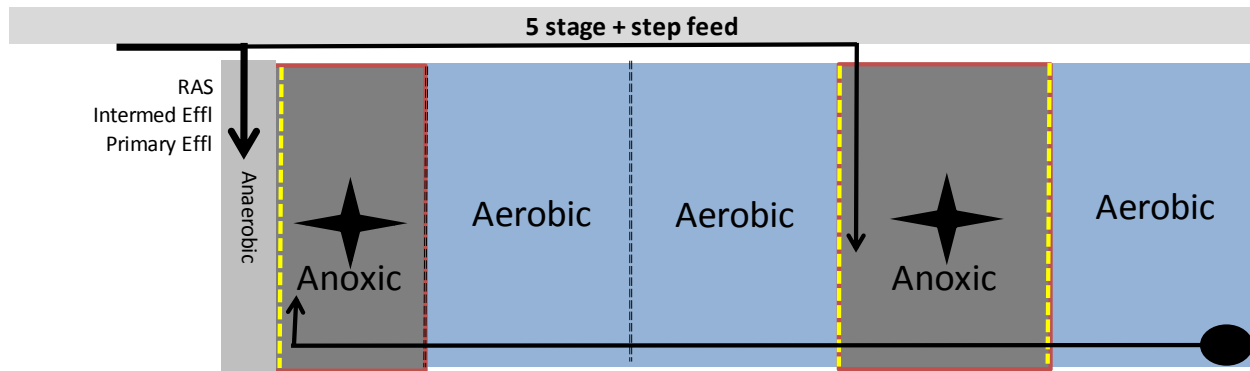
Figure 5: 5-Stage Upgrades (Phase 1)

Phase 2 upgrades are shown in Figure 6 and include additional baffle walls to incorporate a swing zone into each of the four trains after the second anoxic zone, addition of large bubble mixing in the swing zone, aeration grid modifications, and modification to the nitrified recycle (NRCY). The swing zone was added to be able to further enhance denitrification when the process has fully nitrified or offer additional nitrification when needed. A nitrate and ammonia probe are used in the aeration effluent to determine if the swing zone is to be operated as anoxic, low DO, or in ammonia-based aeration control (ABAC) for additional nitrogen removal.
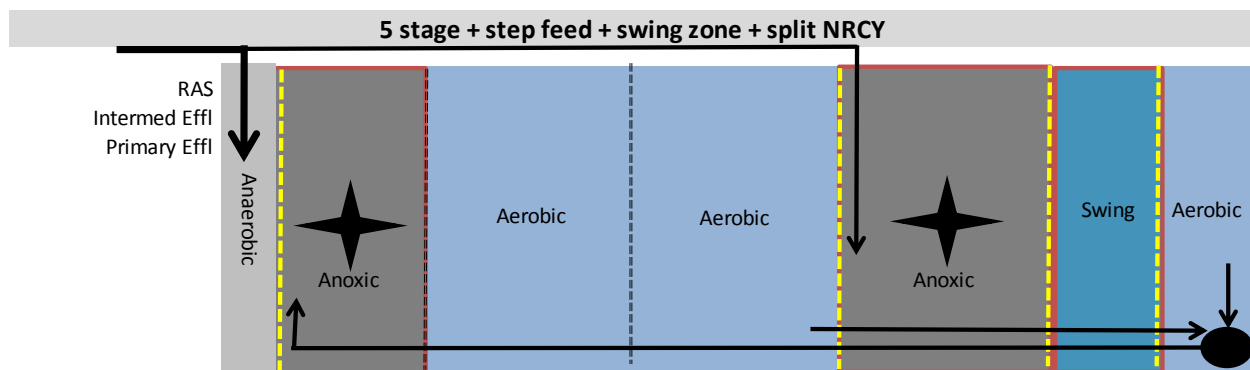

Figure 6: 5-Stage Upgrades (Phase 2)

Baffle Walls

Four baffle walls were installed in each of the four trains to modify the original tank and create additional zones for a 5-stage process. The location of each baffle wall is indicated in yellow in Figures 5 and 6. Material to construct each baffle wall was approximately $4,000 each using fiberglass and 1/8" PVC roofing panels and stainless-steel accessories shown in Figure 7. Fabrication and installation was performed by HRSD maintenance staff.

Figure 7: Baffle Walls constructed utilizing fiberglass framing and PVC roofing panels

Flow Splitting

Each of the phased upgrades required modifications to the existing process flow. Phase 1 implemented step feed which was achieved through extending the existing influent feed flow piping through Cell 4 in each tank. Phase 2 implemented a NRCY split, allowing NRCY to be obtained from both cells 3 and 5. Piping modifications were completed by HRSD maintenance staff.

Swing Zone

To mix the new swing zone when it is unaerated, plant staff built six large bubble mixers out of PVC piping for each swing zone. An air header was tapped to provide a drip of air into the PVC chamber, releasing big air bubbles when the chamber fills with air. The handcrafted big bubble mixers are shown in Figure 8. Half of the diffuser grid in Cell 5 was joined to the grid from Cell 4 and an actuator was added to be able to automatically turn air on and off as needed to achieve the desired effluent nitrogen.

Figure 8: Photos of in-house constructed large bubble mixers

Automation

Automation was added for the actuator to the air supply of the swing zone. This actuator runs based on the feedback from the aeration effluent nutrient probes and the plant influent flow meter. Under normal conditions, the swing zone operates at a DO setpoint of 0.25 mg/L. If effluent nitrate increases, the air is turned off to provide additional anoxic capacity. If effluent ammonia increases, the actuator runs based on an ammonia setpoint (ABAC). During high influent plant flow (wet weather mode), the swing zone operates at a DO setpoint of 2 mg/L. The control logic has three control modes. They operate in the following order of priority: (1) wet weather model, (2) nutrient control (ammonia and nitrate) and ABAC and (3) nitrate control.

Cost of Improvements

The initial phase of improvements cost $78,000 for all four tanks. The second iteration cost $100,000 total.

Table 2: Cost Breakdown by Phase

Phase	Modifications per Treatment Train	Total Cost
I	- Addition of 3 baffle walls - Shortened NRCY discharge pipe - Extended internal step feed pipe - Moved anoxic mixer location - Changed diffuser grid	$78,000
II	- Modified NRCY intake locations - Addition of 1 more baffle wall - Changed diffuser grid - Added actuators for DCS control of swing zone - Added mixing in swing zone	$100,000
	Total	**$178,000**

RESULTS AND DISCUSSION

Effluent Quality

Total nitrogen from the plant has decreased as a result of the improvements. Historical effluent TN has decreased from a monthly average of 7.4 to 2.5 mg/L. Historical daily effluent TN concentrations are displayed in Figure 9. As shown on the figure, there is a clear decrease in effluent TN concentrations. Figure 10 is included to compare effluent TN for February and October, which typically represent worst and best months for nitrification in the towers, respectively. The figure clearly shows a significant decrease in both months in 2017 due to the changes in configuration. Figure 11 presents effluent TN concentration for each phase. The

average effluent TN concentration with all tanks updated to include Phase II improvements is 2.5 mg/L for the two months of available operation data.
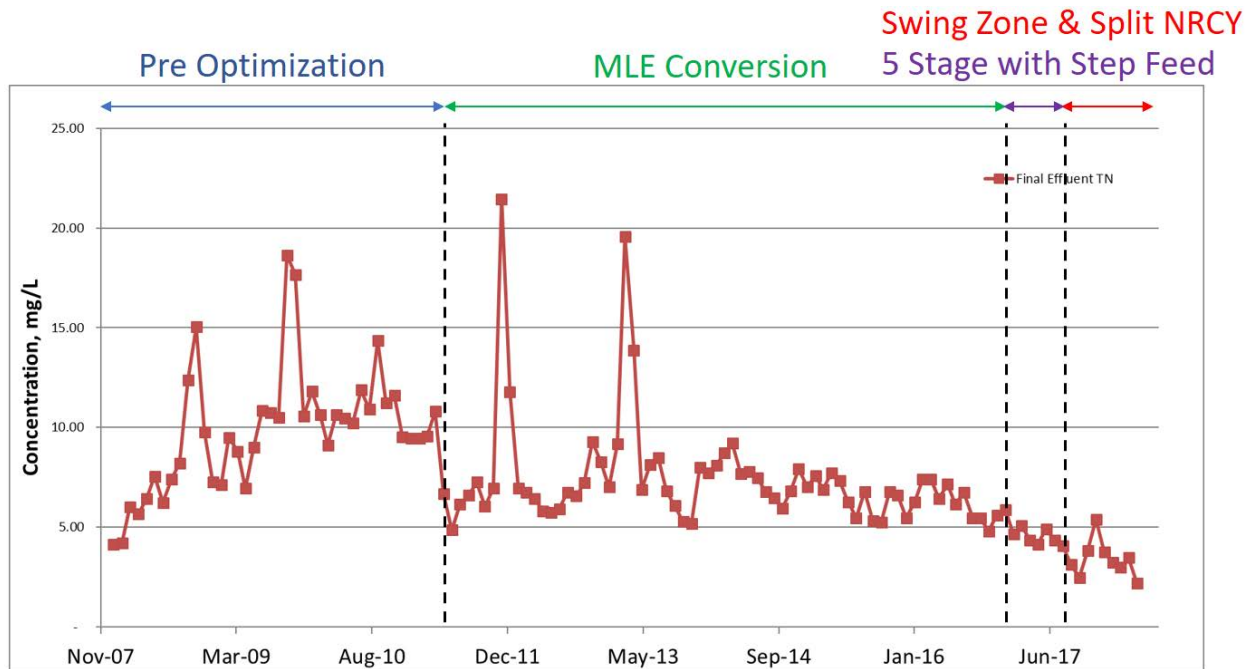

Figure 9: Historical Effluent TN

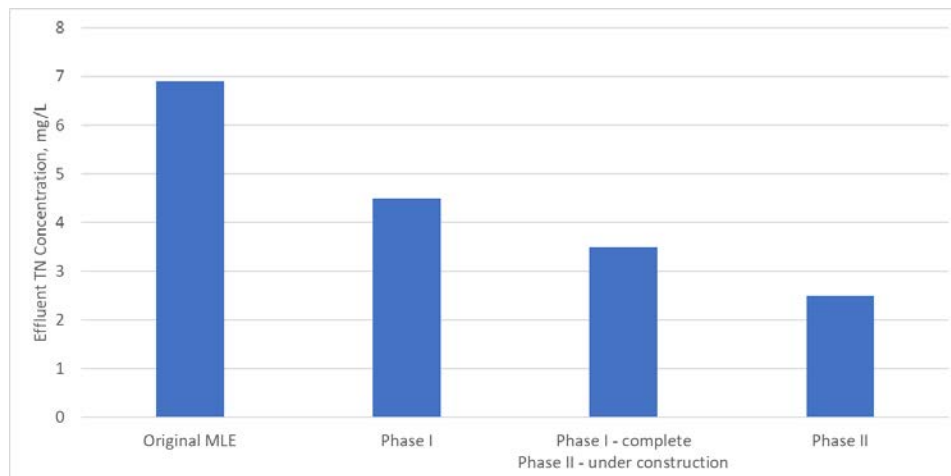Figure 10: Comparison of Effluent TN by Month

Figure 11: Effluent TN Concentration by Phase

Historical effluent TP is presented in Figure 12. There is an increase in effluent TP once the final phase was completed. Biological phosphorus removal suffers when oxidation tower nitrification is occurring because of the additional nitrate load entering the anaerobic zone. Figure 13 divides the winter versus summer effluent TP concentrations and a slight improvement is noted in February 2017 most likely due to the anaerobic zone. This will continue to be monitored and optimized over time.
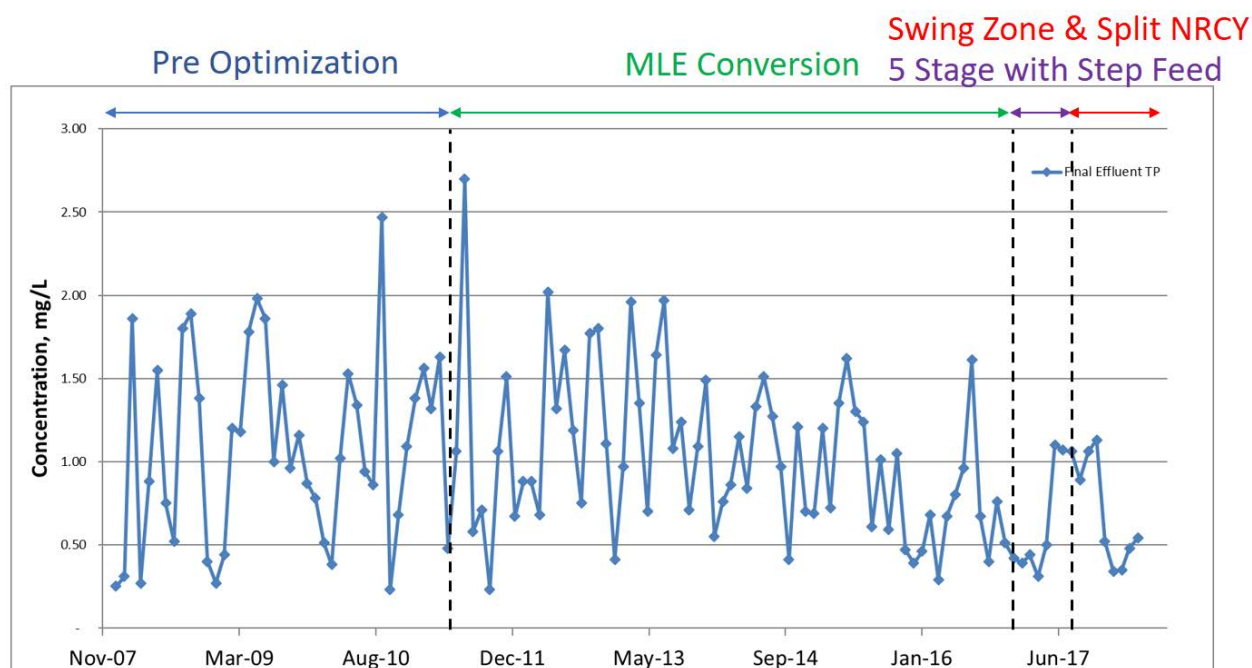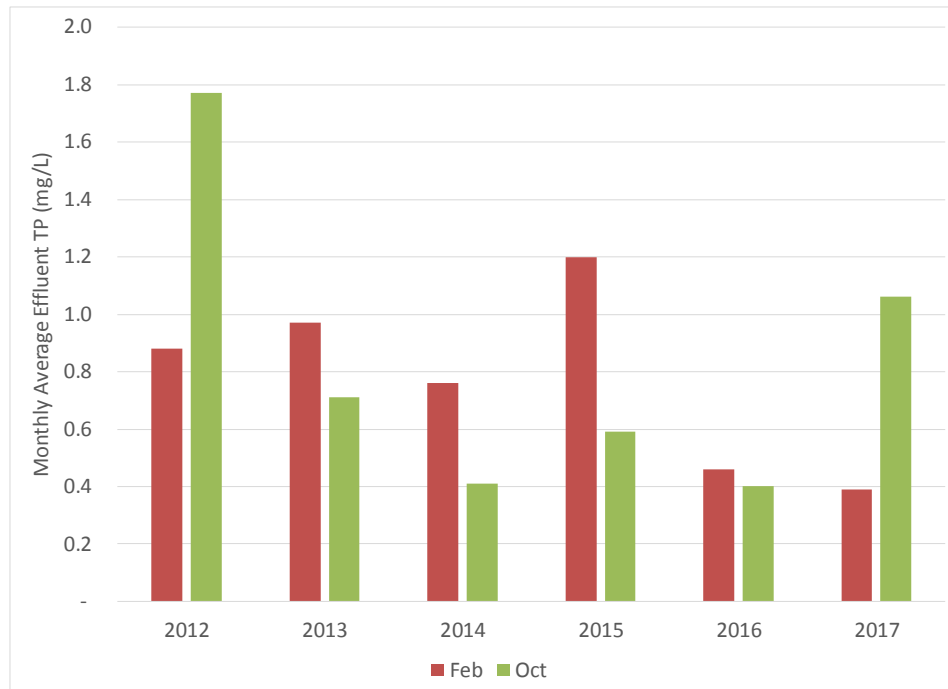

Figure 12: Historical Effluent TP

Figure 13: Comparison of Effluent TP by Month

In addition to reduced effluent nitrogen and phosphorus concentrations, the plant also noticed a decrease in power consumption as well, as shown in Figure 14.
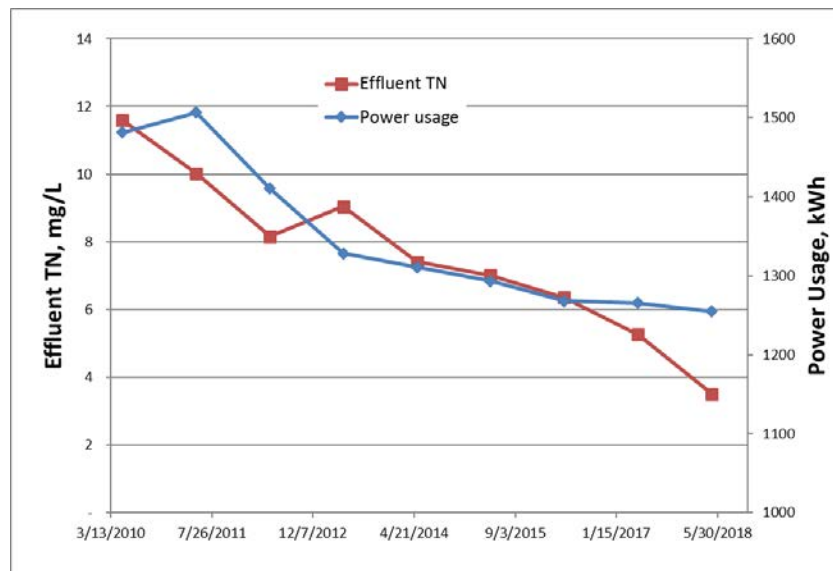

Figure 14: Effluent TN and Power Consumption

CONCLUSION

Significant improvements in nitrogen removal were proven to be achievable and affordable at this facility. Integration of historical data analysis, process modeling, in-house engineering, and mechanical ingenuity all played a role in the development of a cost-effective nutrient removal upgrade at the WBTP. All upgrades were completed in the middle of 2018. The first two full months of operation with Phase II tanks in service, the effluent total nitrogen average was 2.5 mg/L with the lowest two-week average at 1.7 mg/L. Effluent total phosphorus has also been decreased, however BPR is currently still being optimized.

ACKNOWLEDGMENTS

I would like to thank Charles Bott for his guidance and insight. Thank you to Hazen and Sawyer for their calibrated Biowin model. Also, a big thank you to the WBTP plant staff for their creativity and hard work during construction of the plant upgrades.