# An Investigation into the Common Problems of Lagoon Wastewater Treatment in Kentucky

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AN INVESTIGATION INTO THE COMMON PROBLEMS OF LAGOON WASTEWATER TREATMENT IN KENTUCKY

by

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ABSTRACT

Lagoon wastewater treatment systems are commonly used in areas that do not have the available resources for typical mechanical wastewater treatment. Lagoon systems consist of multiple preliminary lagoons, but mainly rely on long-term facultative lagoons for most analyte removal. In this study, one particular lagoon wastewater treatment system (named Municipality A Wastewater Treatment Plant) is investigated due to noncompliance with governmental standards provided by the National Pollutant Discharge Elimination System (NPDES). Samples were collected by researchers at 4 different instances inside of the treatment systems. These samples were sent to an analytical laboratory for testing. The readings from these samples were used to diagnose the problem occurring within the system that is causing the noncompliance with governmental standards. It was determined that an excess of biological nutrients, nitrogen and phosphorus, was allowing for the development of harmful algal blooms in the long-term facultative lagoon. These blooms were causing a significant increase in biochemical oxygen demand (BOD) and total suspended solids (TSS) along with their percentage removal efficiencies. BOD, TSS, and their removal efficiencies are all regularly monitored by the NPDES and as such are cause for concern when the regulations are not met. When comparing with other lagoon systems in the state of Kentucky, this seemed like a common occurrence. Most other lagoon treatment systems were experiencing violations or noncompliance in the same analytes as MAWWTP. It was recommended that the wastewater treatment operators add coagulants such as lime, metal salts, or other precipitates. These coagulants are believed to react with excess phosphorus and nitrogen and significantly decrease the growth of algae in the facultative lagoon. The decrease of phosphorus and nitrogen supply should eliminate harmful algal colonies and allow the BOD and TSS levels to return to acceptable levels.

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**List of Abbreviations**

| | |
|---|---|
| APHA | American Public Health Association |
| AWWA | American Water Works Association |
| BOD | Biochemical Oxygen Demand |
| CWA | Clean Water Act |
| EPA | Environmental Protection Agency |
| MAWWTP | Municipality A Wastewater Treatment Plant |
| NPDES | National Pollutant Discharge Elimination System |
| TN | Total Nitrogen |
| TP | Total Phosphorus |
| TSS | Total Suspended Solids |
| WWTP | Wastewater Treatment Plant |

## 1. Introduction

Wastewaters are waters containing solid or liquid waste compounds that indicate this water has been previously utilized. These waters are typically transported from their area of original use to wastewater treatment plants (WWTP) via sewer systems. WWTPs are large facilities that are responsible for treatment of wastewater before they are allowed to be safely discharged into nearby bodies of water for recirculation. Wastewater management and treatment is regulated by the US Environmental Protection Agency (EPA) under the Clean Water Act (CWA). The CWA has a designated system named the National Pollutant Discharge Elimination System (NPDES) that provides discharge permits for all wastewater treatment facilities. This system is tasked with regulating the quality of water that is discharged as effluent from wastewater treatment. The NPDES monitors compliance for permitted discharge points to ensure water quality is up to EPA standards (33 USC § 1323).

Traditional methods for wastewater treatment include a combination of physical, chemical, and biological processes and operations to remove solids, organic matter, nutrients, and to a certain extent chemicals of emerging concern. Removal of these contaminants is achieved in several stages: preliminary treatment, primary treatment, occasional secondary treatment, and disinfection. Preliminary treatments, placed at the beginning of the WWTPs, involve mechanical treatments (e.g., grit chambers, bar screens, etc.) and their objective is to remove coarse solids and other large materials often found in raw wastewater. Primary treatments, placed after the preliminary treatments are typically used to settle solid material by gravity and remove it from the water. Disinfection treatment is used to eliminate all remaining bacteria after the solids have been removed.  These traditional WWTPs are commonly found in areas with sufficient funding, but they are rare in rural areas that lack resources. While these methods are the most efficient for treating wastewater, they are also the most expensive systems and cannot always be sustainable for smaller and rural municipalities.

Lagoon wastewater treatment systems are used as a cheaper alternative for wastewater treatment. These systems are often found in small, rural areas that do not have the funds for traditional WWTPs. Instead of involving a combination of physical, chemical, and biological processes and relying heavily on mechanical forms of waste removal, lagoons use detention time and aeration to remove waste from waters before discharge. In lagoon systems, water enters a short-detention lagoon followed by a long-detention lagoon, meaning the water remains stagnant for a brief time in a smaller body, and then is transferred to remain in a larger body for a longer period.

Pretreatment for lagoon or pond wastewater systems is a critical step in ensuring the plant is operating effectively. Pretreatment prolongs the life and improves the efficiency of the system by removing large objects and inorganic solids that could cause several issues in the system. Thes issues include disease-harboring or clogs (Verbyla, 2016). Pretreatment usually exists in the form of grit chambers which allow for removal of large pieces of waste that are in the raw influent water. Along with pretreatment, some type of screening is typically used to filter large objects and prevent clogs. Common screens are made of steel bars in a grid-like fashion, with openings of 20-25mm. These screens are used to filter large debris from entering biological and chemical treatment stages.

There are several different types of ponds used in lagoon systems, commonly referred to as waste stabilization ponds. The most common of these ponds are anaerobic ponds, facultative ponds, and maturation ponds. Most lagoon treatment systems, in addition to pretreatment and disinfection stages, consist of a combination of these ponds.

Anaerobic ponds are ponds with a layer of floating scum that allows no sunlight penetration. These ponds rely heavily on bacteria and algae to destroy organic matter and reduce harmful analytes. The main objective of anaerobic ponds is to target suspended solids and remove them with bacteria and algae consumption (Verbyla, 2016). It is uncommon for anaerobic ponds to act as entire treatment systems on their own. Usually, they are combined with maturation and facultative ponds to create an entire treatment system (Haandel, et al, 2006).

Facultative ponds are normally large, shallow ponds that are not mechanically mixed or aerated. Ideally, facultative ponds have two separate layers, an aerobic layer at the top and an anaerobic layer at the bottom. The aerobic layer supports organism growth and decomposition of solids, while the anaerobic layer supports sludge settling and anaerobic organismic activity. The facultative lagoon should have limited algal growth that provides increased levels of dissolved oxygen. This oxygen is used to stabilize organic material in the aerobic layer (US EPA, 2002).

Treatment Plant (MAWWTP). There are several problems occurring in this plant that are causing the water quality to suffer. The main problem indicated inside the plant is the overgrowth of algae. Algae is not harmful to lagoon efficiency alone, but blooms of algae may cause problems in the water quality.

Harmful algal blooms (HABs) form when there is an excess of nutrients for algae to grow in a body of water. When nutrients for algal organisms are too high, reproduction within these organisms begins to greatly increase, causing clusters of algae to accumulate on the surface and sometimes in the mid-lower depths of lagoons. Because they are organisms that require oxygen to survive, HABs can elevate BOD and TSS levels to a point at which noncompliance becomes possible. When HABs become so prominent that they cause compliance issues, action must be taken to remove them by physical or chemical processes. Conversely, HABs can be prevented by ensuring the removal of nutrients before replication becomes a problem (Gerardi, 2015).

The objective of this research is to monitor MAWWTP's health. Additionally, methods to mitigate the causes and negative effects of HABs on this wastewater system are suggested. Ideally, upon the implementation of the suggested procedures, MAWWTP will be fully maintaining regulations provided by the NPDES.

## 2. Materials and Methods

2.1 Existing System Operations

MAWWTP consists of 4 stages of wastewater treatment: screening, Modified Ludzack-Ettinger (MLE) lagoon, facultative lagoon, and disinfection. This system begins with two separate influent sources, one from the population which it serves, and one from an industrial park across the highway from the WWTP. Both influent sources are pumped directly into a small Modified MLE lagoon. This lagoon is divided into three zones: anoxic (or anaerobic) zone, aerobic zone, and settling zone. The influent begins in the anoxic zone, is passed through a floating barrier that acts as a sand and sedimentation filter (SSF), moves to the aerobic zone, and then passes through another floating SSF into the settling zone. A portion of the treated water in the settling zone is then pumped back to the beginning stage in the anoxic zone and receives treatment further. The remaining flow from the first MLE lagoon moves through an outlet structure into the facultative lagoon.

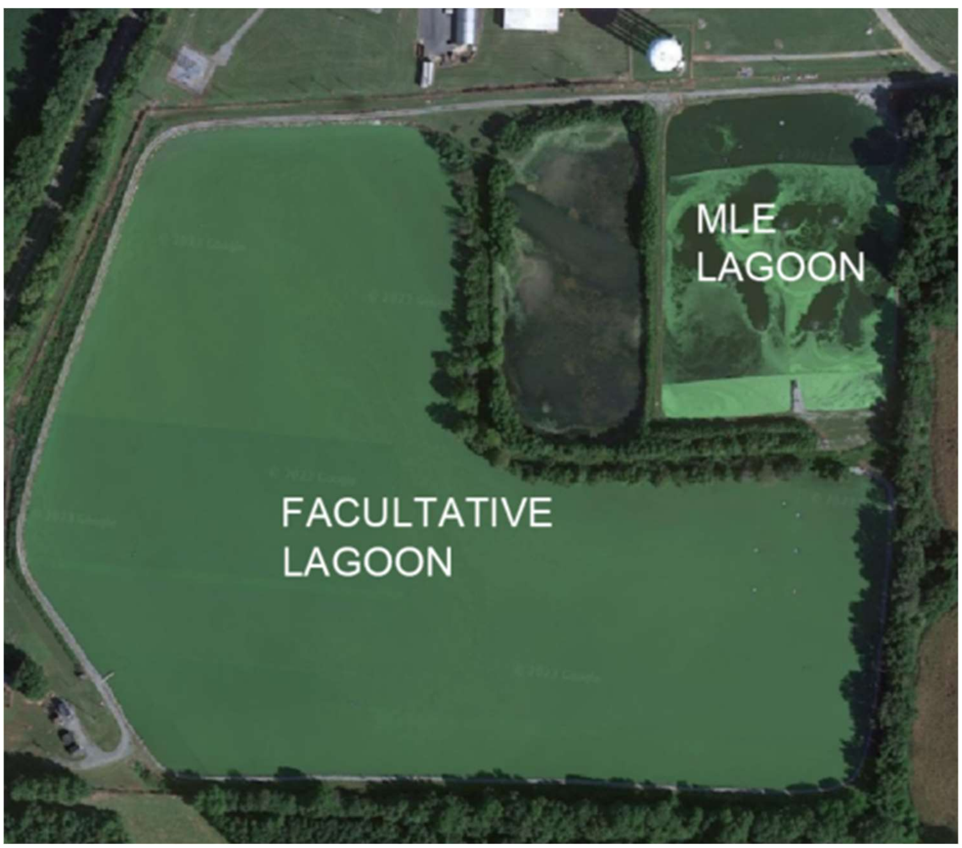


Figure 1 - Aerial Image of Plant with Specified Lagoons

The facultative lagoon has a surface area of approximately 30 acres and a depth of 4 feet throughout the entire body. Water is received from the MLE lagoon and transferred to this lagoon for long settling times. This lagoon has six (6) floating aerators of 10 Hp that provide some mixing. A floating barrier is placed to segregate the last one (1) acre of water into a quiescent zone. In this zone, water is kept still enough that solids are allowed to separate before the next stage of treatment.

After time in the quiescent zone, water flows from the facultative lagoon to the filter pump station. The effluent is delivered to the top of the filters where it flows downward through an annular section of the filter to be introduced into the bottom of the filter. It flows upward through the filter sand and organic and inorganic impurities are removed. Afterward, the filtrate flows over a weir and is discharged through the outlet pipe. The effluent up flow filter ancillary equipment consists of a compressor which it uses to provide about 100 scfm/ft$^2$ of air for cleaning the sand by air scour. The resulting dirty slurry is removed at the top of the filter over the reject weir and into the reject pipe to an old chlorine contact basin. A grinder pump station returns the filter waste to the facultative lagoon.

The effluent pumping station consists of a duplex, submersible pump station with a design capacity of 0.94 MGD at 70 feet total dynamic head. Each pump has an 8-inch discharge pipe that manifolds together in a valve vault into a common 10-inch force main. A magnetic flow meter is contained within the valve vault for effluent flow measurement. Control of the effluent pumps is manual. The overall design is based on Hydrograph Controlled Release system that limits discharge from the MAWWTP based upon flow in the receiving stream, the Bayou de Chien. The U.S. Geological Service (USGS) maintains a flow gauge near the point of discharge. MAWWTP staff can monitor the stream flow in real-time via internet software to determine the permitted maximum effluent discharge.

Finally, water is moved to the disinfection stage. Disinfection is accomplished with the addition of PAA to the pumped effluent. Disinfection facilities include two (2) 200-gallon PAA storage tanks and two (2) small metering pumps.

### 2.2 Water Sampling

#### 2.2.1 Sampling locations

A private engineering consulting company, referred to a "Engineering Company 1" for anonymity, was hired to collect samples at different locations throughout the treatment in an effort to identify the system's problem. Engineering Company 1 performed an analysis of plant operations to decide what best practices would be for sampling water in this system. Professionals decided that the water should be sampled at four (4) points inside the system. Samples were pulled from these four points on a biweekly basis for ten (10) consecutive weeks. The sample points and their locations are shown in Table 1 and Figure 2, respectively.

Table 1: Sampling Locations, Descriptions, and Flow Path Locations

| Sample Point | Description | Location in Flow Path |
|---|---|---|
| 1 | Manhole at beginning of plant | Influent from Industrial Park |
| 2 | Pipe discharging into MLE lagoon | Influent from City |
| 3 | Pump station between MLE and facultative lagoons | After MLE treatment, before facultative treatment |
| 4 | Sampling station near quiescent zone | After MLE treatment, after facultative treatment, before filtration and disinfection |
| 5 | Final effluent water before discharge | After all stages of treatment |

*Sample point 5 was not sampled by Engineering Company 1 but was sampled by Municipality A as required reporting to the USEPA.


Figure 2 - Aerial Image of Plant with Sampling Locations (Sample Point 5 located off-site)

Sample point 1 is the influent from the city's population. This represents the wastewater inflow from all households and commercial buildings within the scope of MAWWTP treatment. Sample point 2 is a separate influent coming from an industrial park across the street from the WWTP. These influents are separate, but they are combined as they are both directly pumped into the MLE lagoon for the first stage of treatment. Sample 3 is between the two lagoons. This water has already passed through the three zones of the MLE lagoon and the preliminary treatment but has not yet been mixed with the facultative lagoon. Sample point 4 is located after the facultative lagoon, but before the up-flow pump filter station. Water collected at this sample point does not represent the final effluent that is discharged into the Bayou de Chien since it has not yet gone through the filtration and disinfection stages. Sample point 5 represents the complete effluent water that is being discharged into the Bayou de Chien.

Samples were also pulled from the effluent that discharges into the Bayou de Chien. However, since Engineering Company 1 was not the official wastewater manager established by the state of Kentucky, they were not responsible for the sampling or analysis of this sample point. Municipality A Wastewater Treatment Plant was responsible for this sampling and the data from these is included in public records.

2.2.2 Sampling protocols

Grab samples were collected from sample points 1-4 by Engineering Company 1. Water sample dipper, a telescopic water sampler, disposable gloves, a pH meter, and sampling bottles were used during each sampling event. The sampling bottles were prepared by the analytical laboratory performing the analysis, referred to as "Analytical Laboratory 1" for anonymity. The sampling personnel prepared for water sampling by first preparing sampling logs and chains of custody for each sample point. These included details regarding the sampling such as date, time, and sample identification. The sampling personnel then calibrated the field pH meter using 4 pH buffers of pH 4.01, 7.01, 9.18, and 10.01. The pH calibration readings were recorded on the sampling log and determined to be acceptable by ensuring they were inside the slope range (95%-105%).

Three sampling bottles, one containing no preservative, one bottle containing sulfuric acid ($H_2SO_4$), and one bottle containing nitric acid ($HNO_3$), were filled at each sampling location. The concentration of each of these preservatives was 1%. Sulfuric and nitric acids were used to preserve the samples at low pH ($pH<2$) that would be tested for $NH_3$ and metals, respectively. The telescopic water sampler or water dipper, depending on distance from the surface, were used to grab samples that filled these three bottles. Care was taken to ensure that the bottles were not overfilled and spilling so that none of the preservative was lost. The bottles were handled carefully with gloves to ensure no contamination took place, labeled with the sample number and the time collected and kept in a cooler at room temperature for transportation. The bottle with no preservative was taken to perform a field pH test. Additionally, pH and temperature (ºC) were measured using the field pH meter and recorded on the sampling log (Figure 2).

| pH Buffer Solution | 4.01 | 7.01 | 9.18 | 10.01 |
|---|---|---|---|---|
| pH Calibrated Value | 4.01 @ 22.3°C | 7.01 @ 22.0°C | 9.19 @ 21.9°C | 10.09 @ 22.4°C |
| Lot Number | CC722560 | CC722414 | CC727184 | CC723464 |
| Acceptable Range | 3.9 - 4.11 | 6.91 - 7.11 | 9.08 - 9.28 | 9.91 - 10.11 |
| Buffer Expiration Date | 12/15/2023 | 12/15/2023 | 3/18/2023 | 12/15/2023 |
| Slope (95-105%) | 101.3% | | | |

**Conditions / Notes**

| Sample Description | Date | Time | Notes |
|---|---|---|---|
| Sample Point 1 - Ammonia | 7/14/22 | 0715 | pH / Temp = 7.38 @ 23.2°C |
| Sample Point 1 - Metals | 7/14/22 | 0715 | |
| Sample Point 1 - BOD | 7/14/22 | 0715 | |
| | | | |
| Sample Point 2 - Ammonia | 7/14/22 | 0730 | pH / Temp = 6.82 @ 14°C |
| Sample Point 2 - Metals | 7/14/22 | 0730 | |
| Sample Point 2 - BOD | 7/14/22 | 0730 | |
| | | | |
| Sample Point 3 - Ammonia | 7/14/22 | 0700 | pH / Temp = 6.64 @ 24.8°C |
| Sample Point 3 - Metals | 7/14/22 | 0700 | |
| Sample Point 3 - BOD | 7/14/22 | 0700 | |

Figure 3 - Example Sample Log Engineering Company 1

### 2.3 Water Quality by Analyte

Seven analytes, pH, TSS, BOD, $NH_3$, Total Phosphorus (TP), and Total Nitrogen (TN), were continually tested from the samples taken at MAWWTP. Since cadmium was consistently below the analytical detection limit, it will not be discussed in this study.

#### 2.3.1 pH

pH was measured in the field as samples are collected. Because pH can change with temperature, it is the most accurate protocol to measure pH immediately after the sample was collected at each location. pH was tested in this study using a field pH meter. The glass probe was inserted into the water sample. The pH and the temperature values were allowed to stabilize on the screen of the measuring instrument. Once the values were stable and the measurement was recorded, the pH meter was removed from the water sample and rinsed with distilled and deionized (DDI) water before testing another sample.

Additionally, pH was measured by Analytical Laboratory 1 according to the American Public Health Association (APHA) and American Water Works Association (AWWA) testing guidelines. As outlined in the APHA's Standard Methods for the Examination of Water and

Wastewater, the standard for testing pH is using a pH testing probe to measure the Hydrogen ion activity in the water sample (Eaton, et al., 2005).

2.3.2 Total Suspended Solids

Total Suspended Solids (TSS) is the amount of solid waste in a water sample. TSS is measured by filtering a water sample, and heating the remaining solids left on the filter to dry them. The mass of the filter alone is taken, and the mass of the filter containing the solids is taken. The difference in the two masses divided by the volume of water filtered gives the calculated value of TSS (Equation 1).

$$TSS\left(\frac{mg}{L}\right) = \frac{mass\ of\ filter\ and\ solids(mg) - mass\ of\ empty\ filter(mg)}{volume\ of\ liquid\ filtered(L)}\quad Equation\ (1)$$

2.3.3 Biochemical Oxygen Demand

For the BOD test to remain accurate, water must be warmed or cooled to 20ºC. If the sample was refrigerated upon transport, it can be taken out of the refrigerator and allowed to warm to this temperature before the test was run. Ideally, BOD tests are performed immediately after the sample is collected to minimize changes in the number of bacteria present in the sample. The maximum holding time for water samples to test BOD is 24 hours. $BOD_5$ is measured by allowing water samples to sit in a cool, dark area for 5 days. Bacteria is allowed to perform as usual in these conditions, consuming oxygen while consuming organic matter. The dissolved oxygen (DO) of the sample is taken at the beginning and end of the 5-day period. The difference in these two values represents the $BOD_5$ value (Equation 2). Because most dissolved oxygen readers cannot read values as high as those in the undiluted water sample, the test takes place in diluted samples. The water is diluted with DDI. The DO can then be read by the meter, and the result can be multiplied by the dilution factor to create an accurate $BOD_5$ value for the sample.

$$BOD_5\left(\frac{\text{mg}}{\text{L}}\right) = (DO_{initial} - DO_5) * Dilution\ Factor \qquad \text{(Equation 2)}$$

where the dilution factor (0 – 1) is defined by the ratio between the bottle volume and the sample volume.

2.3.4 Ammonia ($NH_3$)

There are 8 acceptable testing methods for $NH_3$ listed in the APHA's Standard Methods manual. Because of the sample preservation with $H_2SO_4$, the likely method for testing is the Ammonia-Selective Electrode Method. This method for testing requires the sample to be preserved with $H_2SO_4$ as it was described in the sampling protocols section of this document. The pH of the sample was lowered to two (2) or below (Eaton, et al., 2005).

To begin the experiment, samples with known $NH_3$-N concentrations of 0.1, 1, 10, 100, and 1000 mg/L are prepared. To create a calibration curve, the millivolt (mV) potential is taken of all these samples. First, the electrode probe is placed into the sample. The samples are stirred slowly with a magnetic stirrer while 10N NaOH solution is added until the pH has risen past 11 (approximately 1 mL). The electrode probe is allowed to stabilize (about 2-3 minutes), and the potential is recorded in mV. This process is repeated for the $NH_3$ concentrations listed above. It is important that samples are kept at approximately 25°C throughout the experiment. Once the potential is known for these concentrations, a semilogarithmic curve is created, with the $NH_3$-N concentrations (mg/L) on the logarithmic horizontal axis and the potential (mV) on the linear vertical axis. This curve is used as the standard for testing the sample of unknown concentration.

The preserved sample is prepared by diluting if necessary to fall within the range of the created calibration curve. The electrode probe is inserted into the sample, and the sample is stirred with a magnetic stirrer while 10N NaOH is added to increase the pH to 11. The electrode probe is then allowed to stabilize, and the potential mV reading is recorded. This reading is plotted on the curve, and the concentration of $NH_3$-N (mg/L) is recorded from the intersection of this point with the curve (Eaton, et al., 2005).

2.3.5 Total Phosphorus (TP) and Total Nitrogen (TN)

The samples for testing TP and TP are typically prepared simultaneously using the Persulfate Method for Simultaneous Determination of Total Nitrogen and Total Phosphorus, according to the standard methods manual provided by the APHA (Eaton, et al., 2005). A calibration curve is created for this test by preparing at least 5 standard samples within the desired concentration range. Culture tubes are prepared for all standard samples and the unknown sample for testing. 6.0 mL is added to the tubes and 1.25 mL oxidizing reagent is added to the tubes. The tubes are sealed and placed in an autoclave at 120°C for 55 minutes. An autoanalyzer was water is prepared in an Erlenmeyer flask by adding the oxidation reagent to deionized water at the same ratio as it was added to the samples. This wash water is also sealed autoclaved for 55 minutes at the same temperature.

The automated ascorbic acid reduction method is performed to calculate the concentration of phosphorus in the sample. In this procedure, water is passed through a specified manifold with a heating bath, colorimeter, and data recorder. Colorimetric response occurs within this manifold and is recorded by the data recorder. Standards with known P concentrations are passed through this manifold and the responses are recorded. The data from these standards' concentrations and reactions are plotted to create a calibration curve. The sample is passed through the manifold under the same conditions, and the response is plotted on the calibration curve. The intersection of the response with the calibration curve is taken as the P concentration for that sample.

The automated cadmium reduction method is performed to calculate the concentration of nitrate-nitrogen ($NO_3$-N) in the prepared sample. Similar to the phosphorus test method, water is passed through a specified manifold with a colorimeter and data recorder. Colorimetric response occurs within this manifold and is recorded by the data recorder. Standard samples of known $NO_3$-N concentration are passed through this manifold and their responses are recorded. The responses from the standard samples are plotted against the $NO_3$-N concentrations to create a calibration curve. The unknown sample is passed through under the same circumstances and its colorimetric response is recorded. The response is plotted on the calibration curve and the $NO_3$-N is read. This measurement is taken as the TN reading as the other instances of nitrogen are only present in $NH_3$, which is recorded in a separate test (see 2.3.4) (Eaton, et al., 2005).

## 3. Results and Discussion

### 3.1 Water quality

#### 3.1.1 pH

pH is a representation of the acidity of a water sample. pH is measured on a scale of 0-14, with 0 meaning the sample is most acidic, and 14 meaning the sample is most basic. Since water is not basic or acidic, but considered neutral, the pH should remain around 7. However, the acceptable pH for wastewater ranges from 6-9. While the extremes of this scale are considered safe for organisms to survive, it is optimal for pH to remain as close to 7 as possible. There are multiple reasons that water must stay within this range. If water becomes too acidic or basic, it becomes dangerous for organisms to survive. This can be due to multiple reasons, but an example of this is the solubility of toxic metals into the water. If water is acidic, toxic metals can dissolve into the water and become harmful for organisms (USGS, 2019).

pH was measured in this plant between January 2019 and November 2022 (Figure A1). However, for this study, the pH was tested specifically at the four listed sampling locations from June to August 2022. The pH values were consistent throughout the testing period ranging between 6.93 and 7.72, 6.49 and 6.93, 6.49 and 6.92, and 6.91 and 9.84 at the first, second, third, and fourth sampling point, respectively (Figure 3). The samples collected at the listed sampling points were also tested for pH to attempt to diagnose the problem. A potential source for error in these measurements could be the refrigeration of one sample point. At sample point 2, the pipe discharging into the lagoon was mostly unreachable for the samplers. Thus, samples for this point had to be collected at an off-site location, where the water was being stored in a refrigerated tank. This water would have been warmed to room temperature upon transportation to the lab, and this could be the explanation for a discrepancy in results between the two. Data from field testing is not available for review at this time.

An interesting trend to note in pH is the high increase in pH from sample point 3 (after MLE treatment) to sample point 4 (after facultative treatment). Water after facultative treatment had a much higher pH than the water at the other sampling points. Sample point 4 (after facultative treatment) sometimes had a pH higher than 9. This is higher than the standard acceptable pH for wastewater effluent. This could be an indication that there is a factor inside the larger lagoon causing the pH to increase. Because facultative treatment is meant to be a further treatment stage, it is unintended that the pH should drastically change in this stage of treatment. Additionally, there are no basic chemicals added to the water during this stage, so there is no manmade chemical explanation for the change in pH. This could possibly be an indication that there is a factor affecting the efficiency of the plant in the larger lagoon or the facultative treatment stage.

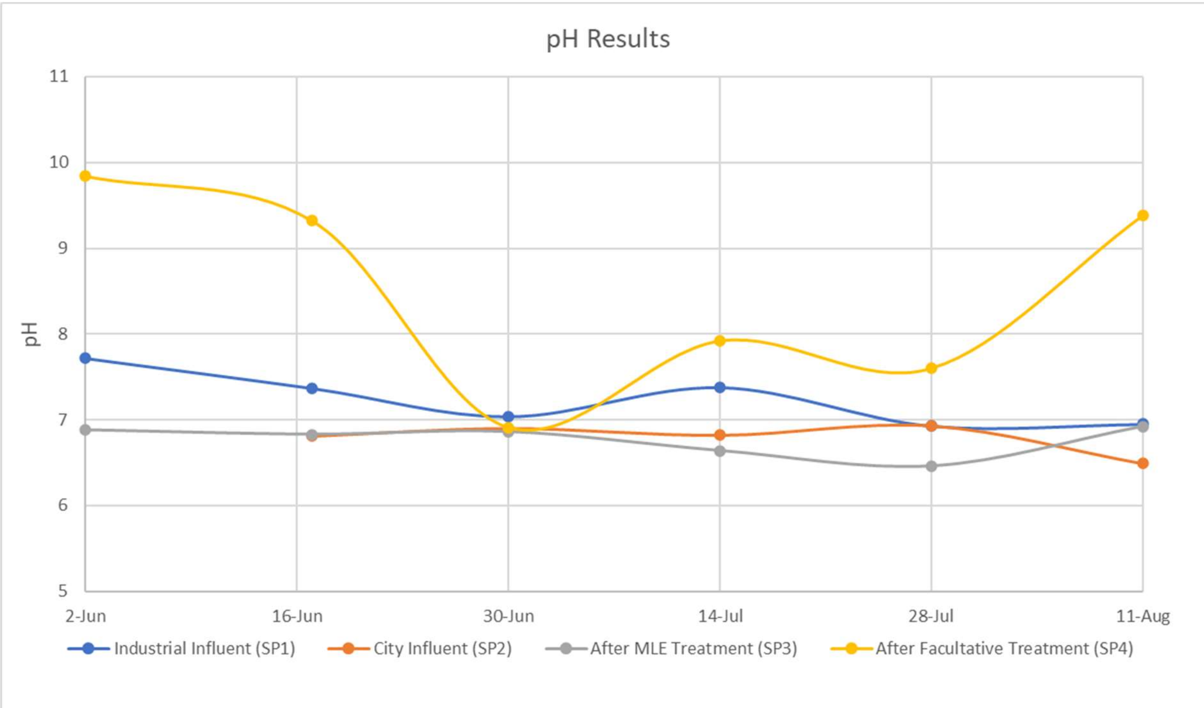


Figure 4 – pH Results from Different Sampling Points (SP 1-4)

3.1.2 Total Suspended Solids

Total Suspended Solids (TSS) is a measure of the number of solids in a wastewater sample. These solids could be organic or inorganic, but most waters have a combination of both. Examples of suspended solids in a wastewater system are silt, sand, sewage, or other solid waste forms. It is defined to be the dry weight of solids in a sample divided by the volume of the sample.

There are NPDES limitations on TSS as most solid waste materials could be hazardous to animals in the body of water that receives the discharge. Organic solid wastes could be toxic to organisms, and nonorganic solid wastes could pose other concerns. The EPA NPDES regulation for TSS is 45 mg/L as a weekly average. Wastewater treatment plants are also subject to EPA regulations for TSS removal efficiency percentages. These are calculated using the TSS from influent waters and the TSS from effluent waters (Equation 3). The percentage difference in these two values must be at least 85% for a wastewater treatment plant to remain in compliance.

$$TSS\ Removal\ Efficiency = \frac{TSS\ Influent - TSS\ Effluent}{TSS\ Influent} * 100. \qquad \text{(Equation 3)}$$

In addition to the specified sampling locations throughout the plant during June to August 2022, TSS was measured in the raw influent and final effluent waters during January 2019 to November 2022 (Figure A2). The TSS levels in MAWWTP were extremely inconsistent, ranging between 17 ppm and 93 ppm, and frequently (44.7% between January 2019 and November 2022) were above the allowable level regulated by the NPDES. While there were some instances of noncompliance in the colder months, the most common times for TSS noncompliance were during summer and early fall months. This may be an indication that the climate in this area is causing hinderances in the ability of the plant to remove TSS.

For the specified sampling locations, TSS was only above the NPDES limit once, at sampling location 4, which occurs after facultative treatment. However, two of the instances (June 30 and July 14) show an increase in TSS during facultative treatment. The primary purpose of facultative treatment is to further decrease amounts of harmful analytes, so TSS should not increase during this stage of treatment. This is a possible indication that the problem affecting the plant lies in the larger lagoon where facultative treatment occurs. Figure 5 shows the TSS levels in the specified sampling locations during the smaller diagnosis stage of this experiment.

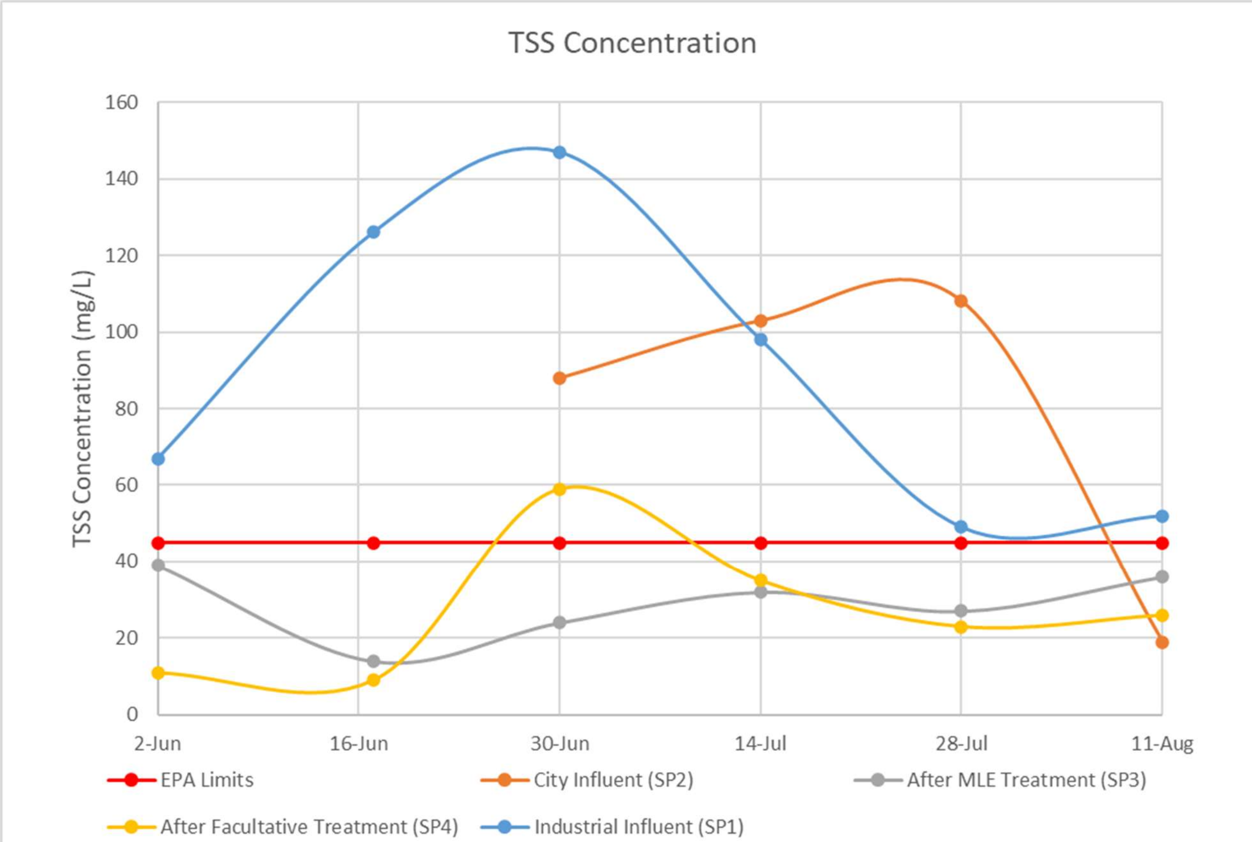


Figure 5 – TSS Results from Different Sampling Points (SP 1-4)

It is also important to note that the removal percentage of TSS is also monitored for the NPDES permit. The removal efficiencies for the final effluent waters are calculated for 2019, 2020, 2021, and 2022. TSS removal was below the minimum in 11 months of 2019, 2020, and 2022. In 2021, TSS removal was below the minimum 5 months. Combined, the TSS removal percentage was less than acceptable 78.2% of the time that was measured. These values are a strong indicator that MAWWTP is not operating as it should and that there is an ongoing problem with TSS removal. TSS removal percentages are shown in Figure B1.

3.1.3 Biochemical Oxygen Demand

Biochemical Oxygen Demand BOD is defined as the dissolved oxygen that is consumed by microorganisms in a water sample during a specific time interval. The most common of these time intervals is 5 days ($BOD_5$). BOD is important in the analysis of wastewater as it is representative of the number of microorganisms present in the water sample. The US EPA regulates the value of BOD in discharge waters via the NPDES.

The Clean Water Act and the NPDES have regulations on the amount of BOD allowed in effluent wastewater. These limits attempt to regulate the amount of organic material allowed to discharge into waters of the United States. In units of milligrams per liter (mg/L), the $BOD_5$ effluent limit is 30 mg/L as a monthly average, and 45 mg/L as a weekly average. Wastewater treatment plants are also subject to regulations on BOD removal efficiency. This is calculated the same as TSS removal, using the percent difference between effluent and influent waters. The EPA regulation is 85% removal at minimum.

BOD was tested at influent and effluent locations from January 2019 to November 2022 (Figure A3). The weekly average effluent was almost always below the EPA limits, indicating the plant is maintaining regulation standards. However, there is a significant spike in BOD in October 2022. This BOD is very high and far above the EPA limit. The BOD decreased again in November 2022. These results suggest that the plant is compliant with EPA NPDES standards regarding BOD.

BOD was tested at all 4 sampling locations described in section 2 of this report. The BOD values at each stage of treatment were commonly higher than the EPA maximum allowable limit. The BOD limits were within acceptable range after facultative treatment in 1 of the 6 sampling instances. However, in all other instances, the final effluent water after facultative treatment was above the EPA NPDES maximum limits. An important trend to note is the increase in BOD from the end of MLE treatment to the end of facultative treatment. Facultative treatment is used as a late-stage treatment and should further decrease the BOD range to lower than the maximum guideline. However, the longer-term treatment is causing an increase in BOD instead of working as intended. In some cases, the BOD levels after facultative treatment are higher than that of the raw influent water. While BOD was always within EPA NPDES limits after final treatment, this drastic increase in the facultative stage suggests the plant is not working efficiently to remove BOD via facultative treatment. There is a strong indication that the facultative stage of treatment is not operating as intended. Figure 6 shows the trend of BOD through the plant at the 6 sampling stages throughout the diagnosis period.

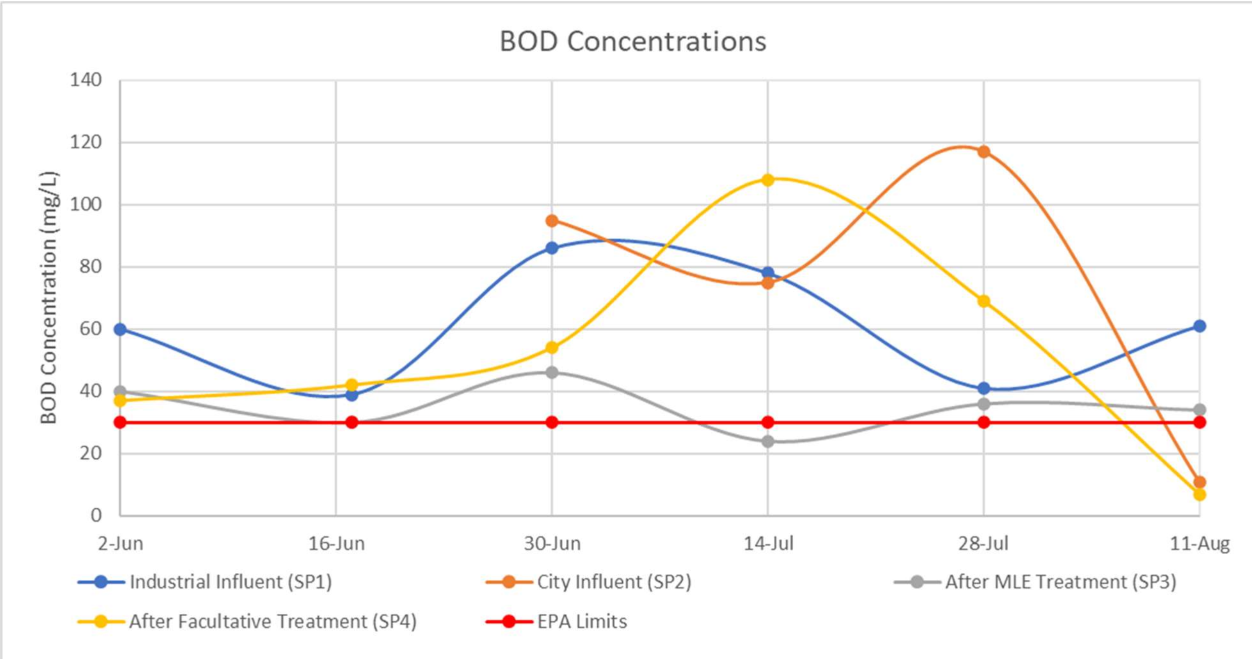


Figure 6 – BOD Results from Different Sampling Points (SP 1-4)

It is also important to analyze the BOD removal efficiency of the plant. BOD efficiency removal was measured from final effluent monthly from January 2019 to November 2022. In 2022, BOD removal was only in the acceptable range for 2 of the 10 measured months. Samples from final effluent were unable to be collected due to staff changes during the month of July. While BOD levels in final effluent waters were under the maximum limit set by the NPDES, the removal, which is heavily dependent on the influent waters as well, was not meeting the regulations. The plant is not operating as intended, and this is an indication that facultative treatment is not removing BOD as efficiently as it should. BOD removal percentages are shown in Figure B1.

3.1.4 Ammonia

Ammonia is typically derived from waste and found in wastewaters. Ammonia in its unionized form ($NH_3$) is what is tested for in this study. This form of $NH_3$ is more toxic than its ionized form. $NH_3$ is dangerous to the life and health of fish in discharge waters. While $NH_3$ can cause the death of fish, it more commonly creates problems in fish species that do not lead to death but cause serious decline in fish health. Unionized $NH_3$ levels can be indicated by a higher water pH. $NH_3$ can also increase BOD in wastewaters and elevate plant growth because of its nutritional properties. Algae specifically is encouraged to grow by the presence of $NH_3$.

Because $NH_3$ is dangerous to fish and other aquatic wildlife, the EPA and NPDES give specific regulations on this water analyte. $NH_3$ is not to exceed concentrations of 15 and 23 mg/L in monthly and weekly averages, respectively. Failure to limit $NH_3$ to these concentrations can result in non-compliance.

$NH_3$ was tested in final effluent waters monthly from January 2019 to November 2022 (Figure A4). $NH_3$ concentrations are always significantly lower than the EPA regulation and have no instances of spikes or noncompliance. The EPA regulation for $NH_3$ is 23 mg/L. The $NH_3$ concentrations in this study were almost always below 2 mg/L and in many cases below 1 mg/L. There is no problem that can be diagnosed by excess $NH_3$ in this plant. The plant is operating efficiently and as intended as far as $NH_3$ removal.

In the specified sampling locations throughout the plant in the summer of 2022, $NH_3$ concentrations stayed consistent with being below the maximum number for regulations. There are no compliance issues with $NH_3$ in this plant. However, there is an increase in $NH_3$ levels after facultative treatment. Facultative treatment should ideally decrease $NH_3$, indicating that it is not working as intended. This is an indication that the problem with the treatment system is in the facultative lagoon, but the problem is not a result of overwhelming amounts of $NH_3$. Figure 7 demonstrates the $NH_3$ levels at sampling points throughout the system.

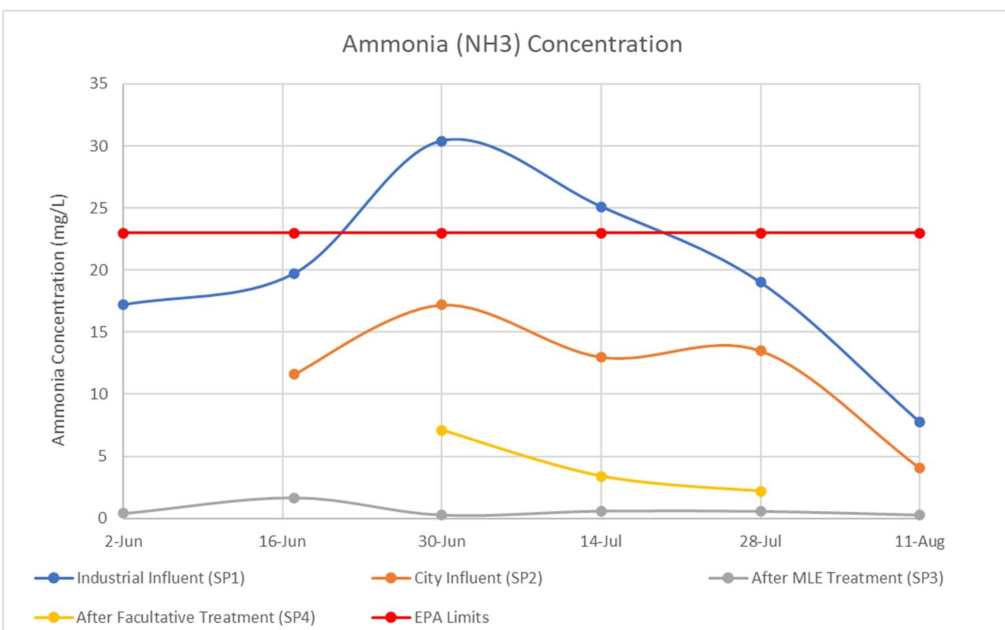


Figure 7 – $NH_3$ Results from Different Sampling Points (SP 1-4)

### 3.1.5 Total Phosphorus

TP is an essential nutrient for plant life in wastewater lagoons and in discharge waters. TP becomes dangerous when there is too much of it in water because it can permit eutrophication. Eutrophication is dangerous in wastewater lagoons because it can cause excessive growth of algae, which in turn causes difficulties in wastewater treatment. HABs can cause BOD to increase in wastewater, causing non-compliance and other efficiency problems within the plant. TP is harmful in the same regard in discharge waters. Not only can algae decrease effective waste removal, but it also can degrade the quality of water and be dangerous to fish and aquatic wildlife. HABs can significantly decrease the health of aquatic ecosystems.

Due to potentially harmful effects of HABs or eutrophication, TP is quantitatively limited by the EPA and NPDES. The limit for TP is 1 mg/L in weekly and monthly average. Failure to remain below this limit can result in noncompliance.

TP was measured in final effluent waters from January 2019 to November 2022 (Figure A5). During this period, TP was significantly higher than the limit in several months. The weekly average TP levels were above acceptable regulation amounts in 23 of the 46 monitored months. The noticed trend in these levels is the significant increase in TP numbers in the warmer months. Warmer temperatures allow TP levels to remain increased. It is likely that elevated TP numbers are a cause of the HABs that continue to grow in this system. TP is a major cause for concern in the functionality and effectiveness of this treatment system.

TP was also measured at multiple stages throughout the plant in the summer of 2022. In all stages, the TP was above the allowable limit for NPDES permitting. While the TP was decreasing from influent waters to waters in the treatment stages, it was not usually below the limit. Additionally, there was an increase in TP after the facultative stage at the warmest of these dates, June 30, 2022. This means that the increase in TP was heavily dependent on weather. However, the TP level was below the EPA limit 2 of the 6 times. This is not consistent enough to be considered an effectively functioning treatment. TP is likely a cause of the noncompliance issues in MAWWTP. Figure 8 demonstrates TP levels throughout different treatment stages.

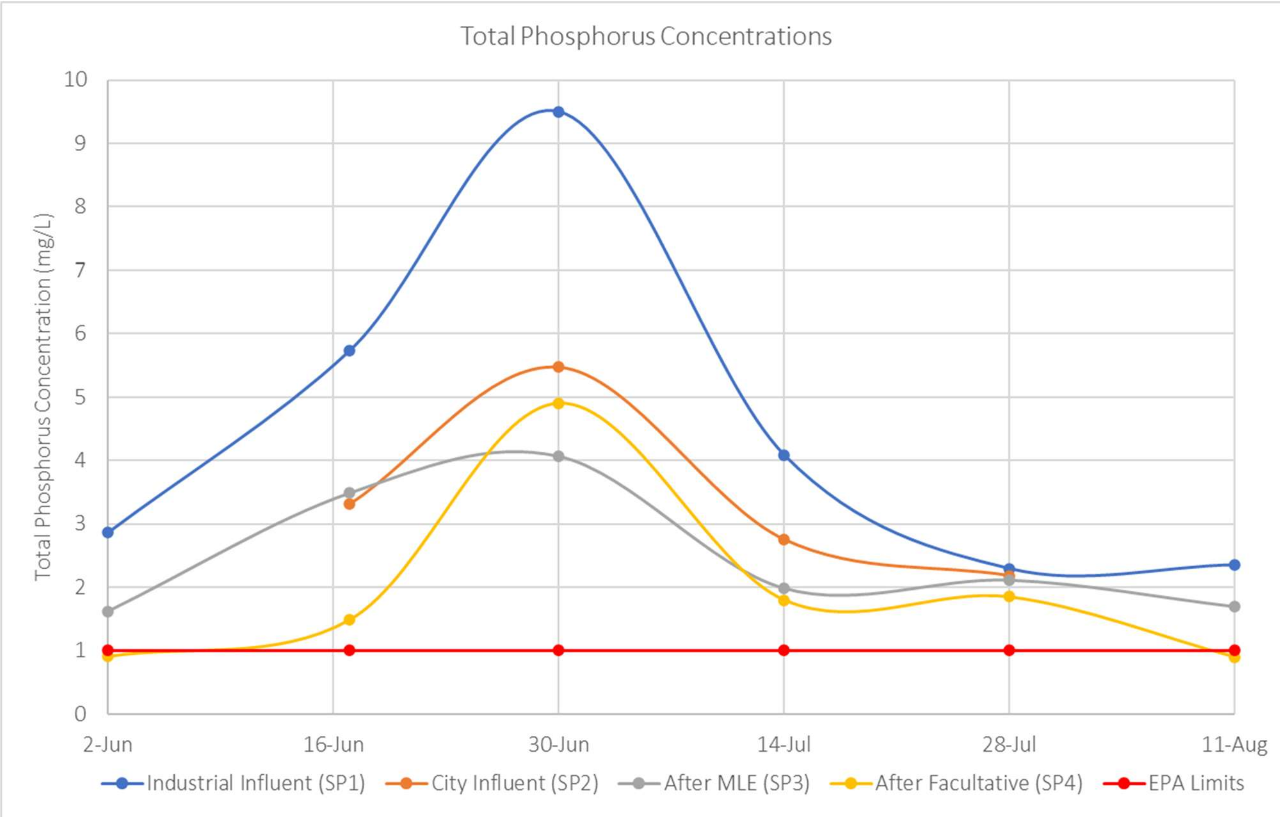


Figure 8 – TP Results from Different Sampling Points (SP 1-4)

3.1.6 Total Nitrogen

Total Nitrogen (TN) is a measure of the nitrogen in the water that is not taken by $NH_3$. Most of this nitrogen is in nitrates (NO3) and nitrites (NO2). Decaying organic matter and fertilizers are the most common sources of nitrogen in wastewater (WEF, 2013). TN acts as a nutrient for microorganisms such as algae, bacteria, and fungi, in most wastewater treatment systems. While it is not as predominant a nutrient as TP, it still is a contributing factor to the microbiological life in MAWWTP's lagoons.

The CWA and the US EPA have allowed the respective state's environmental department to provide the limits for nitrogen on a case-by-case basis. The specific TN limit given to MAWWTP in their NPDES permit was not able to be obtained for this study. However, a normal acceptable range for TN in wastewater systems is approximately 2-6 mg/L.

TN was measured weekly in effluent water from January 2019 to November 2022 (Figure A6). TN was above the normal limit in 4 of the 10 months measured in 2022. While the specific limit for TN is unknown for this plant, it is likely that above 6 mg/L would be cause for noncompliance. However, if the level is higher than 6 mg/L and the plant remains in compliance, there still should be cause for concern of these higher levels. TN acts as a nutrient for most microorganisms that can survive in wastewater lagoons. High levels of TN can allow HABs to form, causing increased BOD which can lead to noncompliance and negative effects of discharge waters.

TN was also measured throughout different stages of the plant at the 4 specified sampling locations. The concentrations of TN were usually within acceptable range after MLE treatment, but significantly increased during facultative treatment. This is an indication that there is too much nitrogen in the facultative lagoon. Nitrogen can harbor growth of HABs and is likely one of the primary causes of the BOD and TSS increases in the facultative stage. Figure 9 demonstrates the TN levels throughout MAWWTP's stages of treatment.

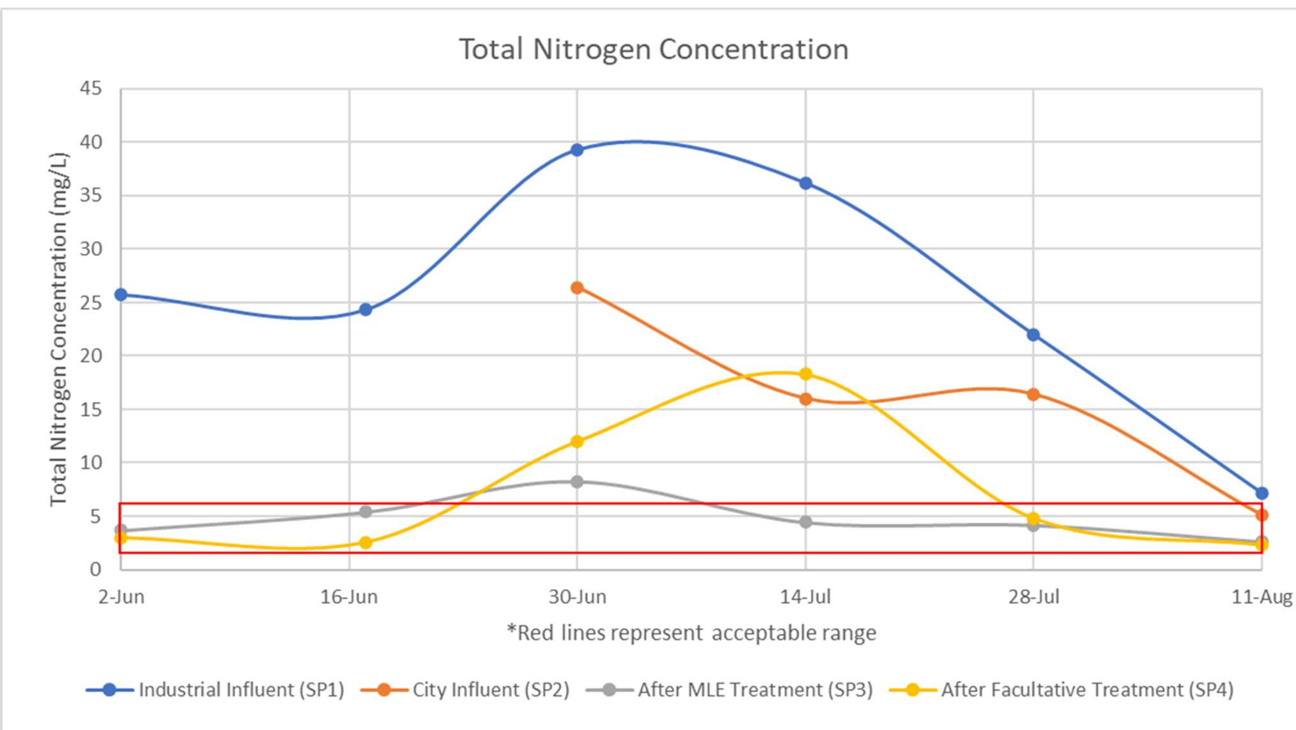


Figure 9 – TN Results from Different Sampling Points (SP 1-4)

3.2 Comparison to other lagoons in Kentucky

The US EPA identified 10 lagoon systems throughout the state of Kentucky, not including MAWWTP, in 2022. Of these 10 systems, 6 had violated the CWA and their NPDES permit during the time that they were active. Every violation listed was due to either BOD or TSS levels being higher than the allowed limit. Table 2 shows the violations of BOD, TSS, and their percentage removals from the 10 identified systems.

Table 2 – Violations in Other Lagoon Systems in Kentucky [Source: US EPA, 2022]

| Plant Location/Name | Violation Importance | BOD5 | BOD5 percent removal | Carbonaceous BOD | Carb. BOD Percent Removal | TSS | TSS percent removal |
|---|---|---|---|---|---|---|---|
| Kuttawa | Violation | No | Yes | No | No | Yes | Yes |
| Hardin | Violation | No | No | Yes | Yes | Yes | Yes |
| Brandenburg | Violation | No | No | No | No | Yes | Yes |
| Clinton | Non-compliance | No | No | Yes | Yes | Yes | Yes |
| Lewis County | Violation | No | No | No | No | Yes | Yes |
| Wingo | Non-compliance | No | No | Yes | Yes | Yes | Yes |

It is important to note that the EPA monitors all violations, but significant non-compliance is defined as "chronic violations of wastewater discharge limits" (Code of Federal Regulations, Title 40, Part 403 2019). More specifically, the same analyte must be above the maximum limit 66% of the time over a period of 6 months for a system to be considered in significant non-compliance. Two of the above-mentioned wastewater treatment systems are in significant non-compliance as they have met this criterium.

While BOD specifically does not seem to be a consistent problem in other lagoon systems in Kentucky, it is quite common that carbonaceous BOD (CBOD) is in violation. BOD and CBOD are not comparable entirely, however, CBOD is a subgroup of BOD and can be an indication that BOD problems may arise later. CBOD can also be an adequate indicator that HABs are occurring in these plants. This data suggests that microorganism activity could be taking place at a higher rate than desired. CBOD was not tested in the specific tests ran for MAWWTP.

The percent removal problem that occurs in MAWWTP's BOD is also occurring in other lagoon systems' CBOD. It seems that lagoon treatment is not adequately removing BOD and CBOD in Kentucky. The lack of removal of BOD is a common problem across the state of Kentucky in regard to lagoon wastewater treatment.

TSS levels and TSS percent removal is a common analyte between every violation in the state of Kentucky. Kentucky's lagoon systems, including MAWWTP, are neither effective nor efficient in removing TSS from influent wastewaters. It is likely that there are multiple problems occurring within the different plants. However, it is likely that MAWWTP is not the only Kentucky lagoon system with HABs hindering the effectiveness of their treatment. The results from the data collected at MAWWTP and the violations of other similar systems are consistent. HABs are likely the issue in many of these plants, demonstrated by the remarkably similar violation analytes.

3.3 Problems and solution recommendations

It is believed that the main cause of MAWWTP's high BOD and TSS levels are from HABs. While TN is elevated and could be a cause for concern, HABs are likely caused by the excess phosphorus in the lagoons. While BOD and TSS levels decrease after the MLE treatment, they rise back to unacceptable concentrations while in the facultative lagoon. This is likely because the treatment methods in the MLE lagoon are effective in decreasing concentrations of BOD and TSS, but the HABs present in the facultative lagoon are causing these concentrations to rise again. As seen in the trends in DMR data, when the phosphorus is increased, the TSS and BOD levels follow in elevation. It is likely that the increased phosphorus is the cause of the HABs, thus the cause of the TSS and BOD noncompliance.

The two methods that could solve the present issue are lowering the excess phosphorus levels or removing the HABs. Both solutions would allow TSS and BOD levels to return to normal, but phosphorus control is needed to meet its quantitative EPA and NPDES requirements. It is recommended that a metal salt (precipitate) or lime is added to the water to decrease the phosphorus levels (Buzzell, 1967). Metal salts or precipitates can be used as coagulants for phosphorus so that it becomes filterable. Adding metal salts, precipitates, or lime can allow phosphorus to be removed from the water in the filtering stage. This removes the food source for HABs and should decrease the number of algae blooms in the lagoon. This solution should decrease the algae blooms over time. However, if an immediate decrease in algae is needed, the plant could add a 635 drip as an algicide. This is not recommended as a long-term solution on its own, as it does not decrease phosphorus levels. However, it could be used in addition to metal precipitates to further decrease the algal blooms. These two solutions together should provide a safe long-term solution for MAWWTP. It is recommended that MAWWTP continue to monitor DMR data as they implement these solutions should the problems not be resolved.

## 4. Conclusion

The system investigated in this study was MAWWTP located in western Kentucky. The objective of this research was to monitor the health of the system and to suggest alternative solutions to mitigate the violations in NPDES permit regulations.

MAWWTP has violations in BOD, TSS, their percentage removals, TN, and TP. The TN and TP elevated levels are likely the cause of HABs that are creating excess BOD and TSS. The system is not performing as desired due to excessive amounts of nutrients in the facultative lagoon allowing overgrowth of algae. MAWWTP is not alone in this problem, as many other lagoon wastewater systems in the state of Kentucky have the same or similar issues with compliance. The recommended solution for MAWWTP is the addition of metal salts, precipitates, or lime. These additions will react with the excess nutrients and cause solids to form. These solids will be allowed to settle and access to them by microorganisms will be limited. This will stop the overgrowth of algae and formation of HABs. Thus, this approach should decrease the violations in all 4 of the elevated analytes.

The addition of lime, metal salts, or other precipitates will not cause harm to the marine life in the discharge body, as most will settle into sludge after reacting with the nutrients. The materials suggested are low in cost and easy to administer, making them an ideal solution to improve the effectiveness of MAWWTP.

## 5. Appendices

### Appendix A – Final Effluent Results (2019-2022)

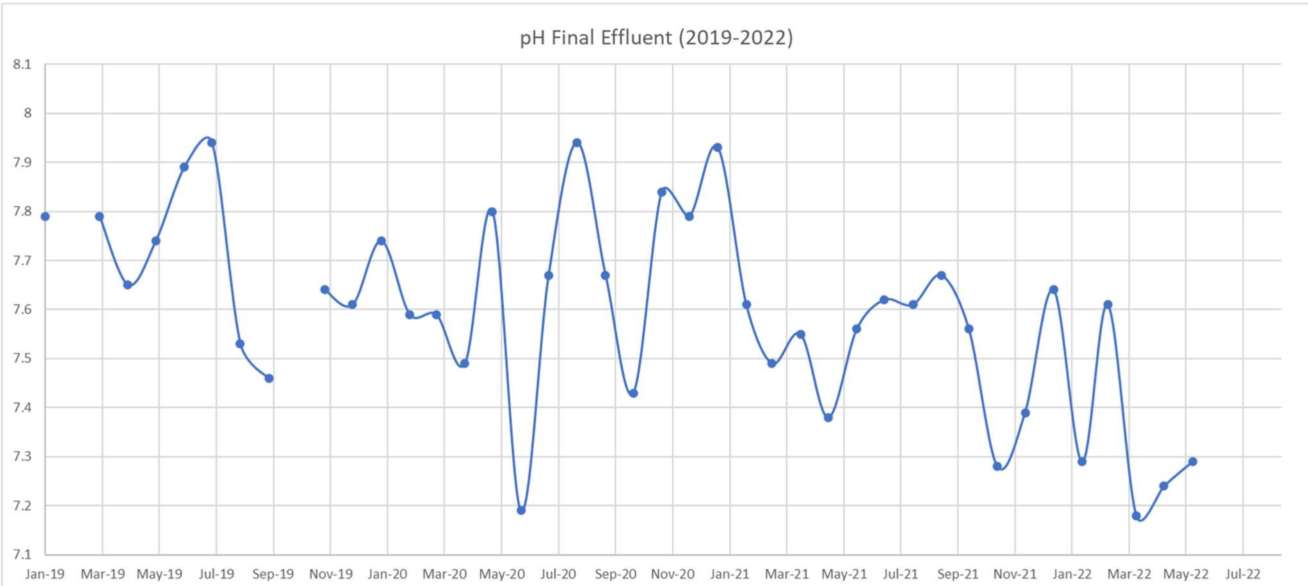


Figure A1 – Final Effluent pH in 2019-2022

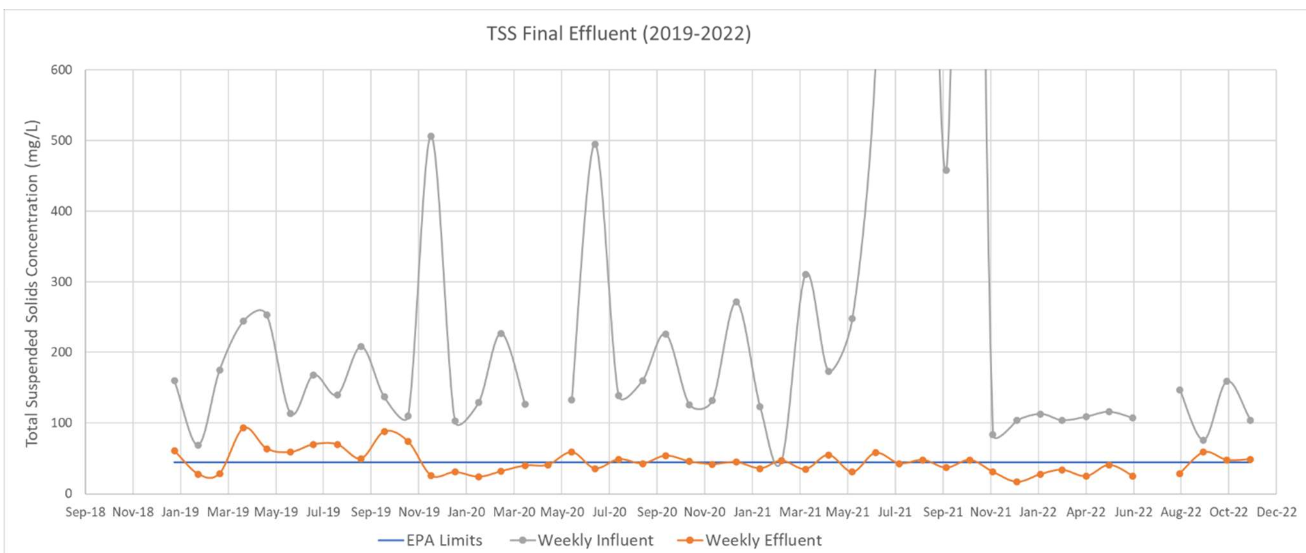


Figure A2 – Final Effluent TSS in 2019-2022

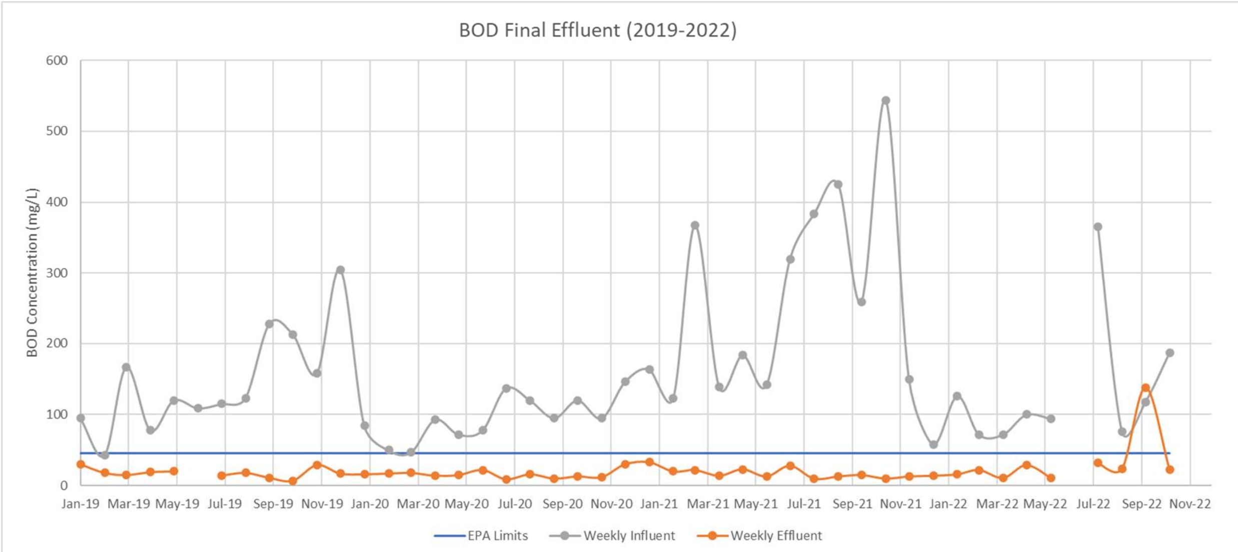


Figure A3 – Final Effluent BOD in 2019-2022

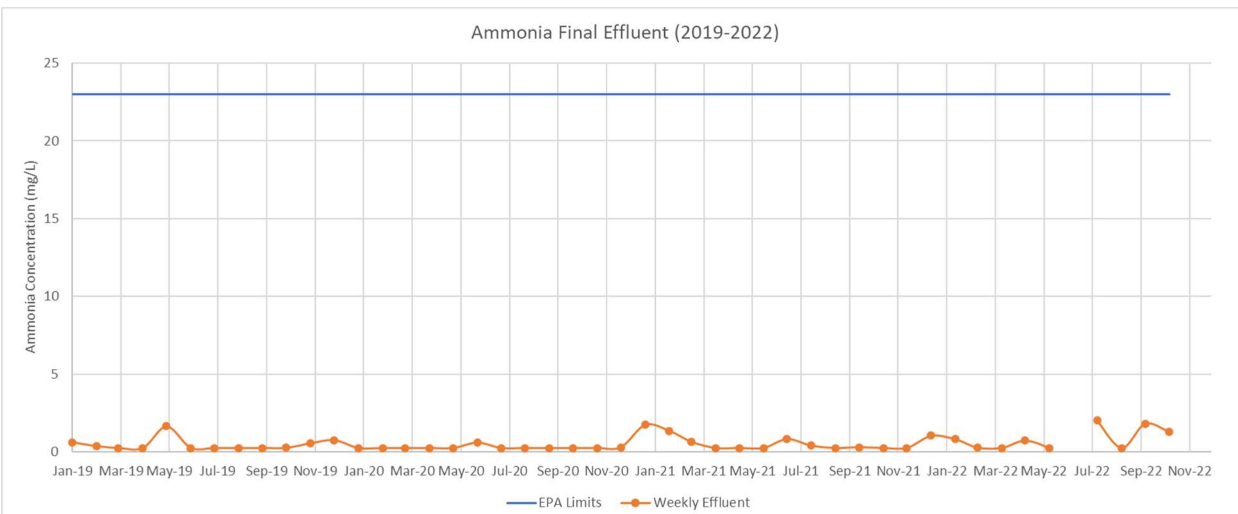


Figure A4 – Final Effluent Ammonia in 2019-2022

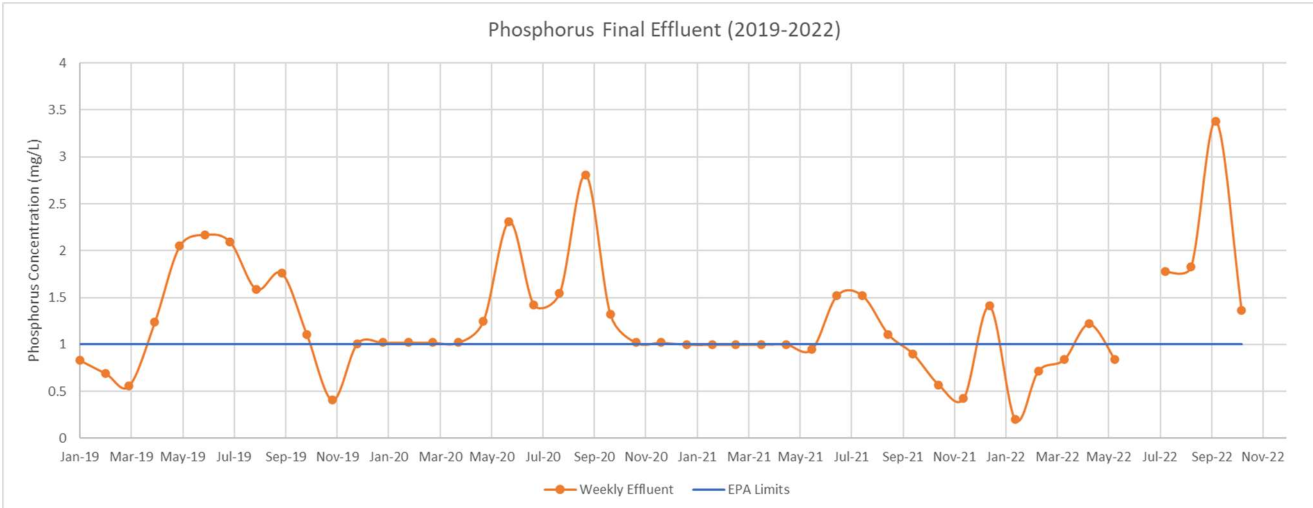


Figure A5 – Final Effluent Total Phosphorus in 2019-2022

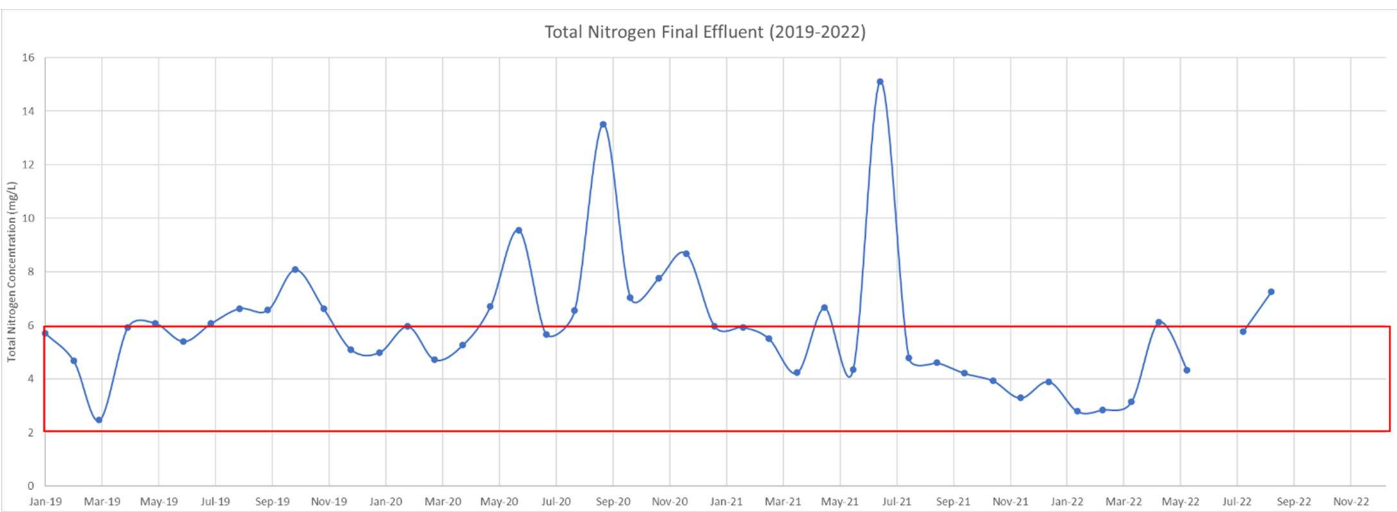


Figure A6 – Final Effluent Total Nitrogen in 2019-2022

## Appendix B – Removal Efficiencies

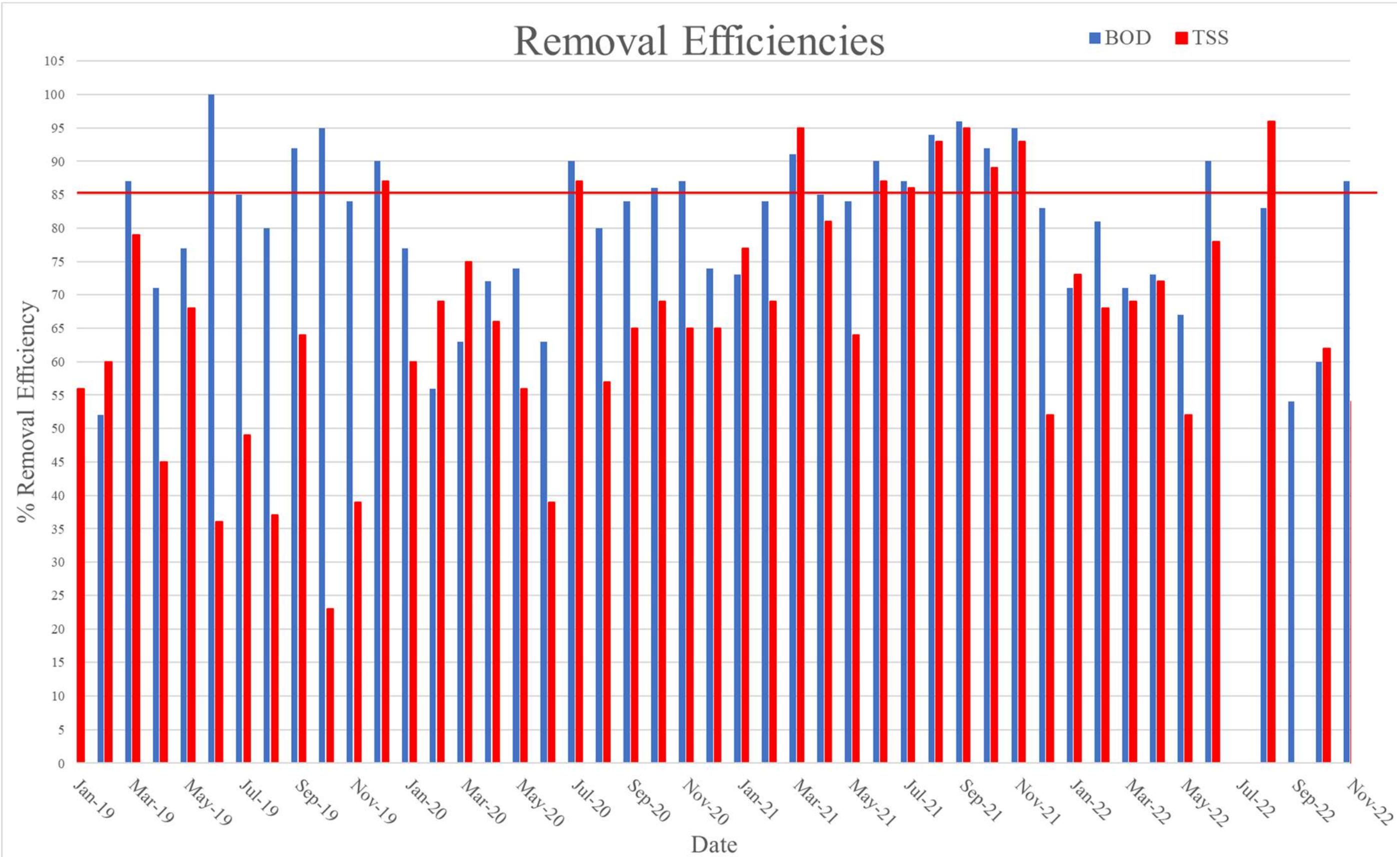


Figure B1 – Removal Efficiencies for TSS and BOD in 2019-2022

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