CEE 426

## Wastewater Treatment Plant Design

## Fall 2010

Department of Civil and Environmental Engineering

University of Wisconsin – Madison

December 15, 2010

# Beloit Wastewater Treatment Plant

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## *I. Introduction and Problem Statement*

The City of Beloit Water Pollution Control Facility is an activated sludge wastewater treatment plant commissioned in November 1991. The plant treats on average 4.6 million gallons of waste per day, and discharges their effluent into the Rock River. With the help of Harry Mathos, WRD Operations Supervisor, Scott Varney and Jerry MeKeel, Instrumentation and Control Technicians at the plant, and consultant Tom Jenkins, our group was called upon to analyze the dissolved oxygen concentration along the plant's aeration basins.

The wastewater at this plant follows a general treatment process. It is first pumped to preliminary treatment, where it is run through mechanical bar screens. The wastewater then follows the grit separation process, and next primary clarification. The solids collected at primary clarification are sent to gravity belt thickeners which remove water from the solids and reduces its volume. These solids are then sent to anaerobic digestion, where they are stabilized, and methane is produced, which is used to heat the digesters and other various locations at the plant. Following primary clarification, the wastewater is pumped to the anoxic selector, and then to the aeration basins, which will be the focus of our analysis. These aeration basins provide an aerobic environment, where the activated sludge process occurs. The Beloit plant uses multi-stage centrifugal blowers with variable frequency drives to provide airflow to the basins. The treatment continues at this facility with secondary clarification, disinfection, and finally discharge of the effluent.

The group was brought to the Beloit Wastewater Treatment Facility with the purpose of analyzing the dissolved oxygen profile along the aeration basins. Using DO Probes, the current dissolved oxygen levels could be measured. Next, we could use the plant layout and typical influent values to calculate the minimum level of dissolved oxygen needed to aerate. By determining what dissolved oxygen level the plant could run at and comparing them with the plant's current values, we could determine the amount of savings the plant could potentially achieve by lowering and/or tapering their current dissolved oxygen levels along the aeration basin.

## *II. Initial Evaluations for the Aeration Basins*

### *a. Plant Data and DO Profile*

To monitor the dissolved oxygen in the aeration basin, the Beloit Municipal Wastewater Treatment facility requested to test four DO probes from four different vendors. The four DO probes used were the Thermo Scientific RDO, MJK Oxix, ATI model Q45D-OPO, and HACH LDO. Our contact at the facility, Scott Varney, set up the four DO probes to monitor four different sections of the aeration basin. The layout of the four DO probes can be seen below in Figure 1 and is located in Appendix A as Figure 1 as well. He was able to set up the DO probes so that they all connect to a server that ATI provided us. This set up allowed us to connect to the server and get access to hourly minimum, maximum, and average DO concentrations that each of the four probes collected. The server came online November 18th.

Therefore, we choose to analyze a twelve day period of data from November 18th through November 30th.

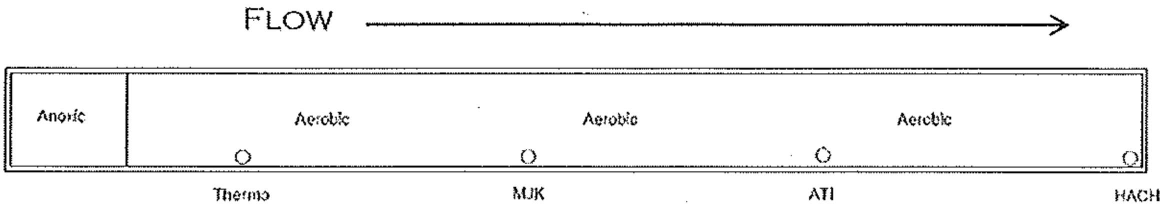

**Figure 1: DO Probe Position in Aeration Tank**

The hourly DO concentrations that were collected were averaged to display daily average, minimum, and maximum DO concentrations. The daily average, maximum, and minimum DO concentrations for the four DO probes are located in Appendix A, Table 1. Figures 2, 3, and 4 of Appendix A show the Average Daily DO concentrations, Maximum Daily DO concentrations, and Minimum Daily DO concentrations for each DO probe respectively. Figure 2, displayed below, shows the average daily DO concentration for the four DO probes.

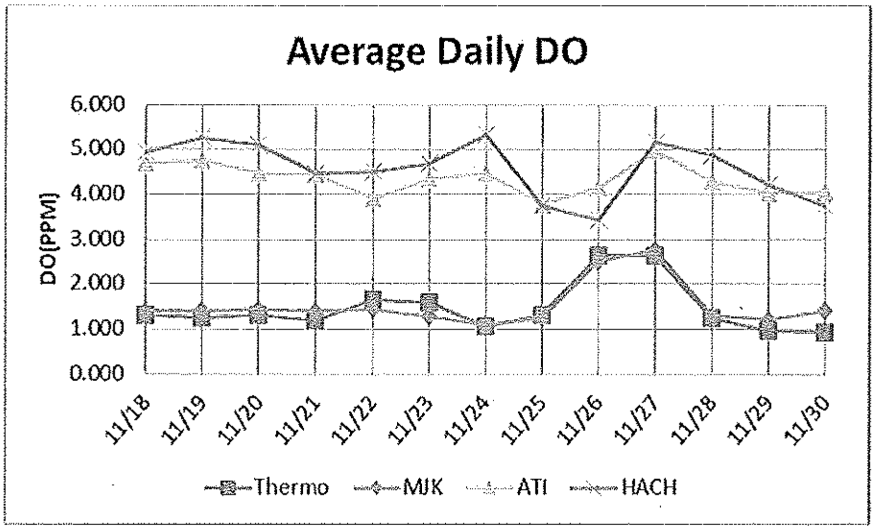

**Figure 2 - Average Daily DO Concentrations**

As you can see from the figure, the DO concentrations for the Thermo and MJK probes are lower than the DO concentrations for the ATI and HACH probes. This is further exemplified in Figure 6 of Appendix A which shows the Average DO profile for each probe for the entire twelve day period. The values for the profile are located in Table 3 of Appendix A. It is evident that at some point between the MJK and the ATI DO probes, the DO concentration increases greatly. We believe that this is where nitrification is ending. Nitrification consumes oxygen, which is why there is a larger concentration of DO in the second half of the aeration basin. Nitrifiers have stopped consuming oxygen, meaning the DO concentration will rise as shown in the profile. This increase in DO concentration has led us to investigate whether we can use tapered aeration to reduce energy costs. A graph of the potential savings can be seen in Figure 3 and Figure 7 of Appendix A and below. The feasibility and energy savings is further investigated later in this report.

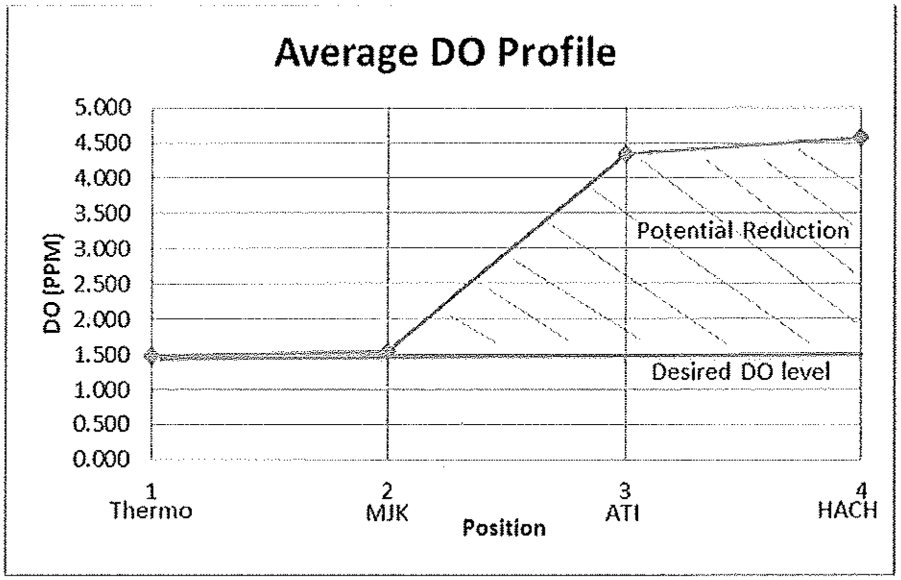

**Figure 3 - Average DO Profile with Potential Reduction**

### *b. Typical Day*

To see how the dissolved oxygen concentration varies hourly, we plotted the Average Hourly DO concentrations for a typical day, using November 28. The Average Hourly DO for November 28 is displayed below as Figure 4 and Figure 8 in Appendix A. Appendix A also contains Figures 9 and 10 which show the Maximum Hourly DO and Minimum Hourly DO for November 28. Table 4 of Appendix A is the hourly DO concentration data from November 28 used to make these figures. Once again, from Figure 4 we can see that DO concentration at the end of the tank is higher than the front end of the aeration tank. It is interesting that the Thermo and MJK probes at the front of the tank are fairly consistent where the ATI and HACH probes at the second half of the tank vary more. This could be function of nitrification continuing to slow down as we get further along in the aeration basin. The HACH probe seems to vary in concentration more than any other of the DO probes. We believe this may be because the HACH probe is the least accurate of the four measuring devices.

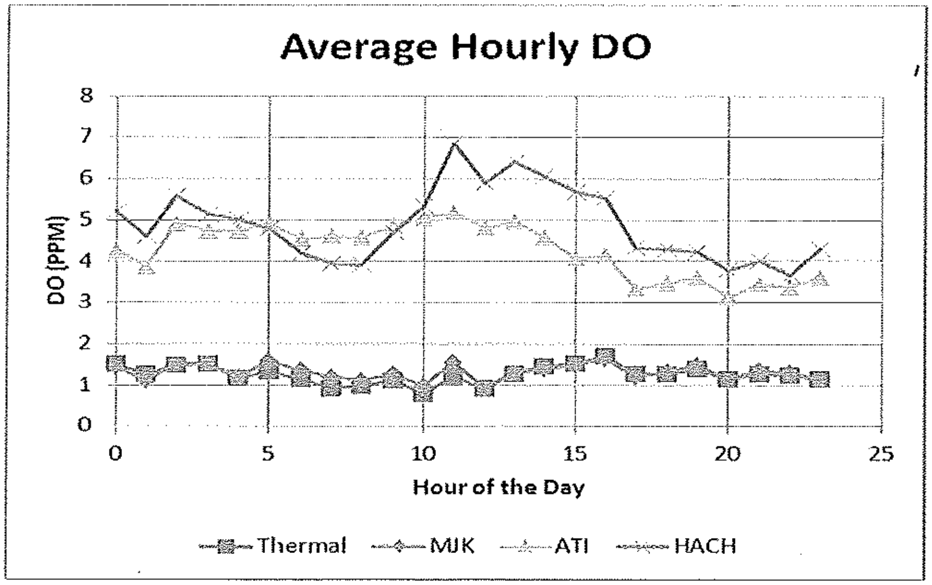

Figure 4. Average Hourly DO Concentration for November 28

**All figures in this section and all other supplemental data can be seen in Appendix A*

### c. *BioWin Model of plant*

BioWin was used to model the Plant's Aeration Tanks. In order to have DO control at specific points the aeration was initially modeled as four basins in series, however there was a concern that four basins would not behave like a plug flow reactor and instead behave like four completely stirred reactors. For this reason the model that was used for analysis was two tanks in series instead of four, with the area of the tanks adjusted. The model was configured to use the average influent concentrations that the plant typically sees to create an accurate baseline for comparison. We first ran the BioWin model with the current operating conditions, and the model produced similar effluent values to the actual plant. The reported average effluent values from the plant for ammonia and BOD were 0.29 mg/L and 5 mg/L, respectively, and the model produced values of 0.23 mg/L for ammonia and 1.3 mg/L for BOD. In both cases the model slightly over predicts the removal efficiencies of the plant. Next, many different combinations of DO set points and air flow rates were run to compare the effects of the effluent ammonia concentrations. The results of this can be seen below in Figure 5 and Appendix B Figure 1. As the air supply rate fell below 1,200 SCFM it was noticed that the ammonia concentration started to increase drastically, this is because the oxygen content in the water is limiting the ammonia oxidation. Anything below 1,320 SCFM would have been thrown out anyways because it does not meet the minimum mixing requirement for the tank (discussed in later section).

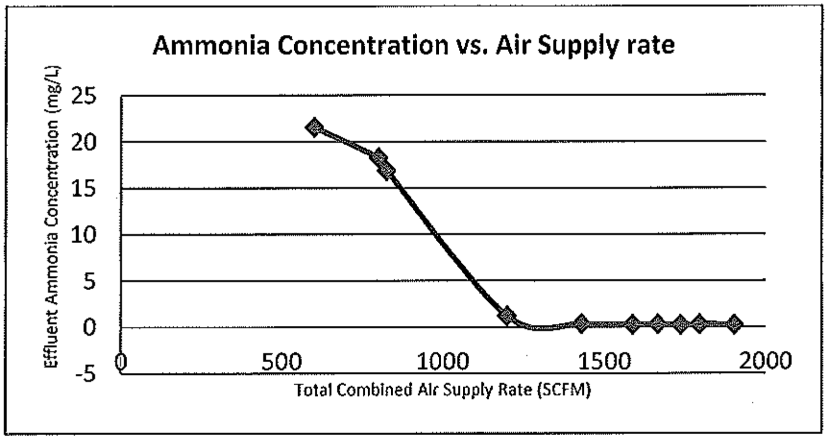

Figure 3 - Ammonia Concentration vs. Air Supply Rate

From this data six scenarios for further analysis were chosen. It is important to note that while BioWin may be a good tool for theoretically modeling the plant, it is not a perfect representation of the actual situation. This is apparent in the over prediction of removal efficiencies of BOD and ammonia. The model did however demonstrate a similar increase in DO along the length of the basin, and for this reason we consider the data drawn from BioWin for the rest of this analysis to be sufficient.

**All Tables and figures in this section along with other supplemental can be seen in Appendix B.*

### d. Alternative Aeration Options

Currently, the Beloit wastewater treatment plant treats water to the point of having effluent levels of Ammonia and BOD well below the regulation limits. Air supply rates are based on theoretical values of Oxygen demand, which are based on influent and effluent levels and can be seen in Table 1 below (Table 1 of Appendix B). Since significantly less Ammonia and BOD needs to be treated under regulation limits than the plant's current operation, the Oxygen demand is also much lower. Reducing the air supply rate would be an ideal source of energy and financial savings, while still keeping the plant's effluent levels at a safe level.

**Table 1: Influent/Effluent Concentrations and Amount to be Treated**

| | [C] mg/L in | [C] mg/L out (limit) | [C] mg/L out (typical) | [C] to be treated to achieve limit (lb/day) | [C] to be treated for typical removal (lb/day) |
|---|---|---|---|---|---|
| **Ammonia** | 22 | 17 | 0.22 | 181.2 | 789.4 |
| **BOD** | 427 | 25 | 5 | 14569.6 | 15294.4 |

These theoretical values were determined by utilizing the stoichiometric relationships that provide the requirement of 4.6 pounds of oxygen to oxidize 1 pound of ammonia and 1.1 pounds of oxygen to degrade 1 pound of BOD. The density of air and the fraction of air that is oxygen (21%) were also important factors in obtaining an air supply rate. Certain assumptions are made in these equations such as the density of air, which actually changes significantly throughout the year as temperatures change. For colder temperatures, air density is assumed to be about 0.081lb/ft^3, while it is assumed to be about 0.126 lb/ft^3 for warmer temperatures. The theoretical oxygen demand for these two values is shown below, in Table 2 and in (Appendix B Table 3), for the current typical effluent levels, regulation effluent levels, and total influent levels.

**Table 2: Density Variations**

| Theoritcal Oxygen Demand values per tank (ft^3/min) | | | |
|---|---|---|---|
| Density of Air (lb/ft^3) | Limit | Typical | All |
| 0.081 | 2164.54 | 2626.06 | 2656.36 |
| 0.126 | 1391.49 | 1688.18 | 1707.66 |

The average air supply rate for each aeration basin is measured at 2,590 ft^3/min, which is close to the value of 2,610 ft^3/min theoretically determined according to the equation below and is just under the calculated oxygen demand.

$$\mathrm{SCFM} = \frac{0.335 \cdot \mathrm{mgd}}{\mathrm{OTE}} \cdot \left(\mathrm{ppmBOD}_{\mathrm{removed}} \cdot 1.1 + \mathrm{ppmNH}_{3\mathrm{converted}} \cdot 4.6\right)$$

A desired air supply rate would be less than this typical value but higher than the demand for the regulation limits to ensure effluent concentrations are low enough during peak hours. Another factor to consider is the minimum air flow to keep the aeration basins properly mixed. We considered three mixing situations; a conservative estimate for mixing (0.12 SCFM/Sqft), a less stringent but maybe more risky estimate (0.08 SCFM/Sqft) and an average of the two estimates (0.10 SCFM/Sqft). A comparison of supply rates can be seen below in Table 3 (Appendix B Table 4).

**Table 3: Mixing Requirment**

| Mixing Requirement | Air Supply (SCFM) |
|---|---|
| **0.08 SCFM/Sq ft.** | 1322.4 |
| **0.10 SCFM/Sq ft.** | 1653 |
| **0.12 SCFM/Sq ft.** | 1983.6 |

BioWin was used to model the plant and assist in predicting an appropriate air supply rate. Several DO input concentrations were modeled. The model was run using a consistent DO set point throughout the entire aeration basin and also modeled to taper the aeration. The goal of running the BioWin model was do determine the lowest DO concentration the plant could effectively run at and to determine the air flow corresponding to that DO concentration. Using the program, it can be concluded that a DO concentration of 1mg/L can be used to achieve effluent levels and greatly reduce the air supply rate.

After taking all of these different scenarios into consideration a list of alternatives for the aeration basins and corresponding air flows has been created and can be seen in Table 4 (Appendix B Table 5). These alternatives will further be evaluated in the cost analysis section.

**Table 4: Aeration Options**

| Process | Air Supply (SCFM) | Air Supply (SCFM/Basin) |
|---|---|---|
| Current (Average) | 5180.6 | 2590.3 |
| Mixing (0.08 SCFM per sqft.) | 2644.8 | 1322.4 |
| Mixing (0.10 SCFM per sqft.) | 3306.0 | 1653.0 |
| Mixing (0.12 SCFM per sqft.) | 3967.2 | 1983.6 |
| Entire Tank DO SET of 1.0 mg/L | 3175.7 | 1587.9 |
| Entire Tank DO Set of 1.5 mg/L | 3476.3 | 1738.12 |
| Entire Tank DO Set 2.0 mg/L | 3810.7 | 1905.4 |
| Tapered DO Set 2.0 mg/L to DO Set 1.0 mg/L | 3658.4 | 1829.2 |
| Tapered DO Set 2.0 mg/L to DO Set 1.5 mg/L | 3729.2 | 1864.6 |
| Tapered DO Set 1.5 mg/L toDO Set 1.0 mg/L | 3403.8 | 1701.9 |

**All Tables and figures in this section along with other supplemental can be seen in Appendix B.*

### *III. Position of New DO Probe and Recommendation*

Dissolved Oxygen monitoring is critical for aeration system process control. Optimization of the biological process, whether it is carbonaceous removal or nitrification, depends on maintaining proper D.O. levels. In addition, controlling blowers and aerators to operate at an optimal level eliminates excess aeration and will result in large power savings for the plant. For this reason, we have decided to make recommendations stating what dissolved oxygen probes to use and at what locations of the aeration tanks.

For twelve days we monitored the minimum, maximum, and average dissolved oxygen concentrations at four locations in the tank. The four DO probes used were the MJK, Thermo, ATI, and HACH. The locations of these four meters in the aeration tank are shown in the Figure 1 (Appendix A figure 1). As shown, the Thermo and MJK are located in the first part of the tank and the ATI and HACH are located in the second part of the tank.

All of the DO probes use new technology that replaces old membranes and internal electrolytes. Using this new technology avoids having to replace membrane and chemical solutions during maintenance. Because of this, all of the models are virtually maintenance free. The HACH is the only of the four sensors that requires periodic wiping of the sensor with a wet rag for continuous measurements.

It is often an advantage to measure DO close to the surface. This is why all the models have some form of mount and/or float that keeps the DO sensor at optimum level by the surface. The accuracy and range is very good for all the models. This little difference in accuracy ranges makes our analysis more important to test the accuracy and range of measurements. From each company's specification sheets the most accurate to least accurate DO meters are the MJK, ATI, Thermo, and HACH. The accuracy and ranges are summarized below in Table 5 (Appendix A Table 5).

Table 5: Accuracy and Range for DO Probes from Specification Sheets

| | MJK | Thermo | ATI | HACH |
|---|---|---|---|---|
| Range (ppm) | 0-25 | 0-20 | 0-40 | 0-20 |
| Accuracy | ± 0.02 ppm | ± 0.1 ppm up to 8 ppm<br>± 0.2 ppm from 8 to 20 ppm | ± 0.05 ppm below 2 ppm | Below 1 ppm: ±0.1 ppm<br>Above 1 ppm: ±0.2 ppm |

Figures 11 –14 in Appendix A display the daily minimum, maximum, and average DO concentrations for the four DO probes. To see which DO meters provided the least variation from the average values, we calculated the concentration differences between the average daily value and the minimum concentration, and the average daily value and the maximum concentration. The total differences were then summed for all 12 days and the two sums below and above the average were added together. The results are summarized in Table 6 of Appendix A. As we can see from the table, the HACH and the MJK had the greatest differences at 15.197 ppm and 13.715 ppm, respectively. This is interesting as the MJK was at the front end of the plant and the HACH was at the end of the plant. The front of the plant is going to be the most likely candidate to have the greatest variation, as the Anoxic zone is right before the aeration basin where nitrification is happening. Because the Thermo and the ATI meters had the least variation at 12.064 ppm and 12.024 ppm respectfully, it may be a good idea to use these two DO meters, with one in the middle of the front half of the basin and one in the middle of the back half of the basin. The fact that the two meters that varied the least were located at the front and the end of the plant as well may further show that the location of the meter does not affect its accuracy.

Overall, we feel that all the meters are fairly accurate and will do a sufficient job in measuring the DO concentrations for blower efficiency monitoring and operation. However, we would advise not to use the HACH monitor as it is the only sensor of the four that requires periodic wiping of the sensor with a wet rag for continuous measurements. We prefer the ATI most as it has the highest range and second highest accuracy measurements according to the manufacture's specifications. Also, in our twelve day monitoring period, the ATI sensor had the lowest variation between minimum, maximum, and average daily DO concentrations.

## IV. *Plant modifications to incorporate tapered aeration*

The City of Beloit has recently put in variable frequency drives for their multi-stage centrifugal blowers. This was the major change that would have been needed to allow for DO control. Other modifications that will need to be made will be to add DO meters along the basin (at least two as previously discussed) and to install flow actuating valves, mechanical operators and flow meters on all of the air supply lines entering the basins. There will also need to be I&C changes made that allow for the SCADA system to translate from DO concentration in the aeration basin to the amount of airflow required to achieve the desired DO concentration, without violating the mixing requirements. The computer would control the amount of air flow into the basins by operating the valves and throttling back the blower.

## *V. Economic Analysis*

### *a. Energy Savings*

After analyzing the data and observing the DO profile of the aeration basin it was realized that there was much room for operational savings. Because the DO profile displays a large increase in DO concentration at the midway point of the tank, it is believed that most of the BOD has been degraded and most of the Ammonia has been oxidized, leading to the increase in DO concentration. If this is the case the plant could financially benefit by either lowering the DO concentration in the entire tank or tapering the aeration towards the end of the tank to reduce the amount of excess DO. Figure 3 above displays the amount of potentially wasted DO on the current average DO profile.

The potential savings were calculated by comparing alternative operational conditions of the aeration basin to the current operation. The alternatives considered were operating at minimum air flow for mixing (conservative, average and liberal estimates) and six different BioWin scenarios. Three of the BioWin scenarios considered a uniform DO concentration throughout the tank, and three scenarios considered tapering the aeration from a higher DO concentration to a smaller DO. Table 6 (Table 3 Appendix C) displays the nominal savings and percent airflow reduction for the different options. The average daily air flow to the basin was 2,590 SCFM, and savings were calculated by comparing to this baseline.

Table 6: Aeration Options and Nominal Savings

| Option | Air Flow Basin 1 (SCFM) | Air Flow Basin 2 (SCFM) | Total Air Flow (SCFM) | Nominal Savings (%) |
|---|---|---|---|---|
| **Constant** | | | | |
| **DO SET of 1.0 mg/L** | 1203.2 | 384.7 | 1587.9 | 38.7 |
| **DO Set of 1.5 mg/L** | 1319.9 | 418.3 | 1738.2 | 32.9 |
| **DO Set 2.0 mg/L** | 1448.7 | 456.7 | 1905.4 | 26.4 |
| **Tapered** | | | | |
| **DO Set 2.0 mg/L to DO Set 1.0 mg/L** | 1457.0 | 372.2 | 1829.2 | 29.4 |
| **DO Set 2.0 mg/L to DO Set 1.5 mg/L** | 1452.0 | 412.7 | 1864.6 | 28.0 |
| **DO Set 1.5 mg/L to DO Set 1.0 mg/L** | 1324.6 | 377.3 | 1701.9 | 34.3 |
| **Mixing Requirement** | | | | |
| **Conservative Mixing (0.12 SCFM/SQ ft)** | NA | NA | 1983.6 | 23.4 |
| **Average Mixing (0.1 SCFM/SQ ft)** | NA | NA | 1653 | 36.2 |
| **Liberal Mixing (0.08 SCFM/SQ ft)** | NA | NA | 1322.4 | 48.9 |

To obtain a better understanding of the possible financial benefits of implementing a different option, the horsepower required to deliver the airflow to the basins was determined. The difference between the current required operating horsepower and the horsepower required for each option was calculated and converted into kilowatts. Assuming that the average energy cost was $0.067 per kWh the expected cost for each alternative and expected savings associated with each alternative was calculated and can be seen in Table 7 which is a condensed version of Appendix C Table 1.

Table 7: Cost Analysis

| Process | Blower HP Required | HP Saved | Yearly Electric Cost | Yearly Savings |
|---|---|---|---|---|
| Current (Average) | 247.1 | 0.0 | $114,000 | $0 |
| Mixing (0.08 SCFM per sqft.) | 126.1 | 120.9 | $58,000 | $56,000 |
| Mixing (0.1 SCFM per sqft.) | 157.7 | 89.4 | $73,000 | $41,000 |
| Mixing (0.12 SCFM per sqft.) | 189.2 | 57.9 | $87,000 | $27,000 |
| Entire Tank DO SET of 1.0 mg/L | 151.4 | 95.6 | $70,000 | $44,000 |
| Entire Tank DO Set of 1.5 mg/L | 165.8 | 81.3 | $76,000 | $37,000 |
| Entire Tank DO Set 2.0 mg/L | 181.7 | 65.3 | $84,000 | $30,000 |
| Tapered DO Set 2.0 mg/L to DO Set 1.0 mg/L | 174.5 | 72.6 | $80,000 | $33,000 |
| Tapered DO Set 2.0 mg/L to DO Set 1.5 mg/L | 177.8 | 69.2 | $82,000 | $32,000 |
| Tapered DO Set 1.5 mg/L to DO Set 1.0 mg/L | 162.3 | 84.7 | $75,000 | $39,000 |

It can be seen from the table that every option can reduce the yearly energy costs by a minimum of $27,000. The maximum predicted savings was $56,000 using the minimum air flow for mixing, but this option leaves almost no room for safety. The BioWin model exhibited that at average flow the effluent ammonia concentration will start to increase linearly, when the air flow decreases below approximately 1200 SCFM. A large increase in flow when operating at a low air flow would provide a spike in ammonia concentration in the effluent water. This option is not recommended, but chosen to demonstrate the magnitude of possible savings. The most reasonable option and one that would provide a good factor of safety would be to taper the aeration from 2.0 mg/L in the beginning of the tank to 1.5 or 1.0 mg/L at the end of the tank. This option would provide between $32,000 and $33,000 annual savings. The complete analysis of these options can be seen in Appendix C, TABLE 1. This table includes the HP required, KW required, HP and KW saved along with the yearly costs and savings.

### b. Equipment Cost/Capital Cost

Our equipment cost analysis is a very general approximation, intended to guide further exploration into our suggested options. To make the updates we are assuming each dissolved oxygen meter and each flow meter would cost between $3,000 and $4,000, and each valve will cost about $2,000. These are only rough estimates, provided to us by other professionals. Since the City of Beloit only operates two of their four aerations basins, the costs were determined making changes to only these two basins. Four dissolved oxygen meters will need to be added, as well as eight flow meters and eight valves. It is estimated that there would need to be approximately $12,000 in instrumentation and control changes, also provided to us by other professionals. Totaling all of this we come up with an approximate capital cost between $64,000 and $76,000, for making changes to two aeration basins.

### c. Pay Back

The expected pay back has been calculated for all of the options and can be seen in Table 8 below (Appendix C Table 3).

**Table 8: Expected Return Period**

| | | Pay Back (years) | |
|---|---|---|---|
| **Process** | Yearly Savings | Capital Cost $64,000 | Capital Cost $76,000 |
| **Mixing (0.08 SCFM per sqft.)** | $55,735 | 1.1 | 1.3 |
| **Mixing (0.1 SCFM per sqft.)** | $41,202 | 1.6 | 1.8 |
| **Mixing (0.12 SCFM per sqft.)** | $26,670 | 2.4 | 2.8 |
| **Entire Tank DO SET of 1.0 mg/L** | $44,066 | 1.5 | 1.7 |
| **Entire Tank DO Set of 1.5 mg/L** | $37,458 | 1.7 | 2.0 |
| **Entire Tank DO Set 2.0 mg/L** | $30,109 | 2.1 | 2.5 |
| **Tapered DO Set 2.0 mg/L to DO Set 1.0 mg/L** | $33,456 | 1.9 | 2.2 |
| **Tapered DO Set 2.0 mg/L to DO Set 1.5 mg/L** | $31,900 | 2.0 | 2.3 |
| **Tapered DO Set 1.5 mg/L to DO Set 1.0 mg/L** | $39,054 | 1.6 | 1.9 |

The option recommended was to taper from 2.0 mg/L to 1.5 or 1.0 mg/L, and this option would result in around a 2.2 or 2.3 year pay back on the investment.

### *d. Rebates*

There are many incentives to upgrade equipment in wastewater treatment facilities. Focus on Energy is one such program in Wisconsin. Focus on Energy offers financial incentives to eligible customers for installing energy efficiency measures into their businesses. The program offers both custom and prescriptive incentives for efficiency projects. These incentives are designed to motivate customers to upgrade equipment selections, or implement energy efficiency projects. Customers complete the project and then submit a standard application form for the incentive. Projects must be one for one replacement of equipment, and customers must work with a Focus on Energy Advisor prior to project initiation, (ordering equipment or processing purchase orders) to apply for custom incentives. Grant approval will be contingent upon receipt of necessary documentation, such as energy savings calculations.

In order for the Beloit Wastewater Treatment Facility to be compensated for upgrading their equipment and using new DO meters and Flow meters, they will need to apply to the Focus on Energy Custom Incentives Program before any purchases are made. After submitting an application showing how the new equipment will save energy, they will work with an advisor to determine what type of rebate they will be offered. After the project is complete, the Beloit plant will receive their compensation.

## *VI. Conclusion and Recommendations*

After careful analysis of current plant operations and consideration of possible alternatives it has been determined that the plant could save money by lowering the air supply rate into the aeration basins. Several options were analyzed using a model in BioWin to predict the removal efficiencies of the plant when operating at different DO concentrations. It was determined that the plant would not be limited in the event of exceeding effluent ammonia concentrations but instead would be limited by the mixing requirement of the tank. The lowest predicted allowable air supply to each basin was 1322.4

SCFM which would correspond to an approximate nominal savings of 50%. This option is not recommended however, because it does not provide a good factor of safety, in the event of a large change in influent flow the treatment efficiency could drop and effluent limits for ammonia may be exceeded. More conservative options that provide adequate removal efficiency incorporate tapered aeration or a uniform DO set point for the entire basin. All options prove to offer savings in air flow.

To be able to achieve tapered aeration or a consistent DO throughout the basin some changes would need to be made. Changes include monitoring DO concentration in the middle of both the first and second halves of the aeration basin, and adding flow meters and mechanical operators to all of the air supply lines entering the basin. All of these modifications would need to be tied together with any instrumentation and control updates that could monitor DO concentration and adjust airflow to achieve the desired DO concentration.

It should be mentioned that this analysis should be considered preliminary and any observations or recommendations made should be verified by a licensed professional before any changes are made. This submittal is intended to address the possibility of energy savings and to guide future exploration into this matter.

## APPENDIX A: Initial Plant Data and DO Probe Analysis

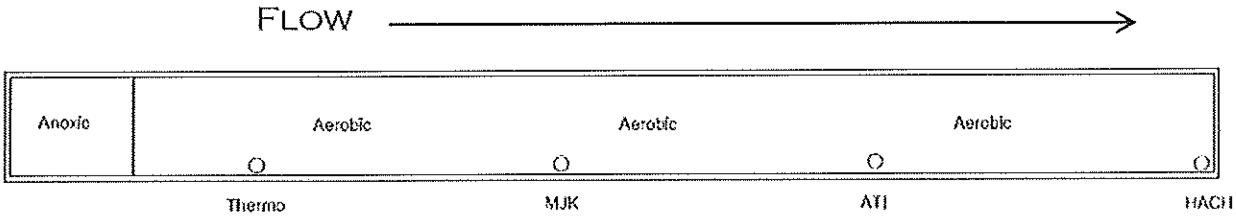

**Figure 1. DO Probe Position in Aeration Tank**

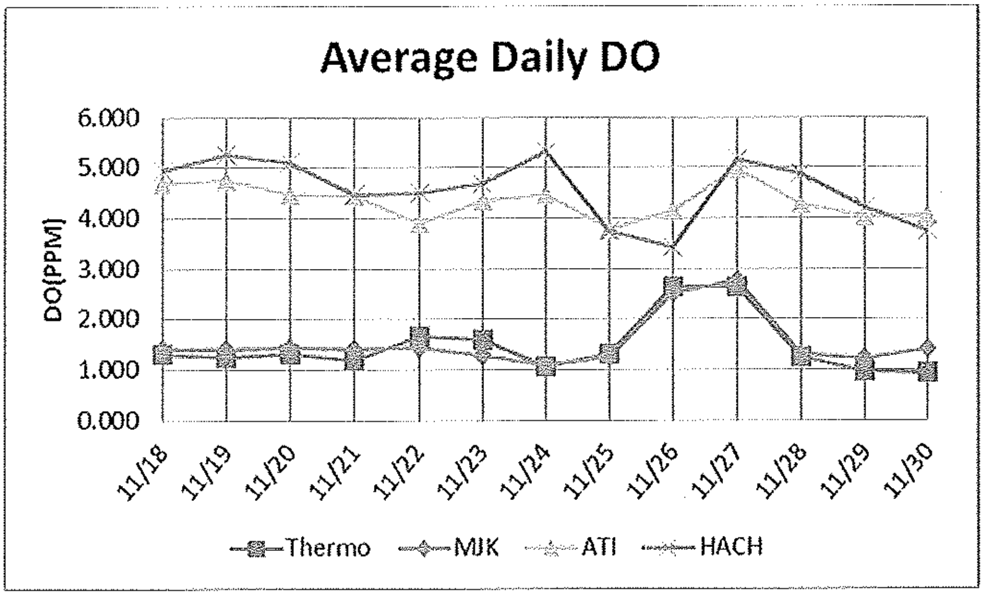

**Figure 2. Average Daily DO Concentrations**

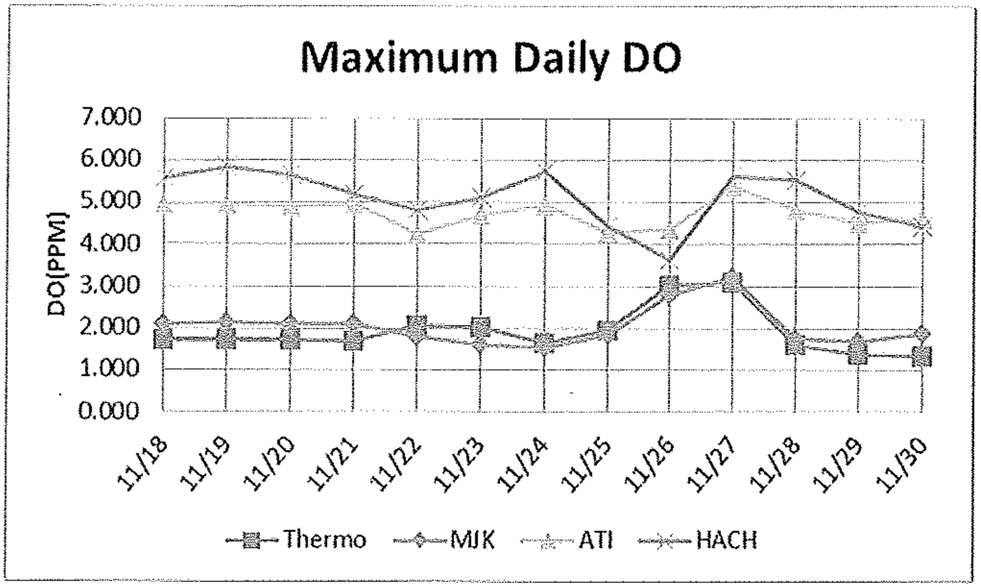

Figure 3. Maximum Daily DO Concentrations

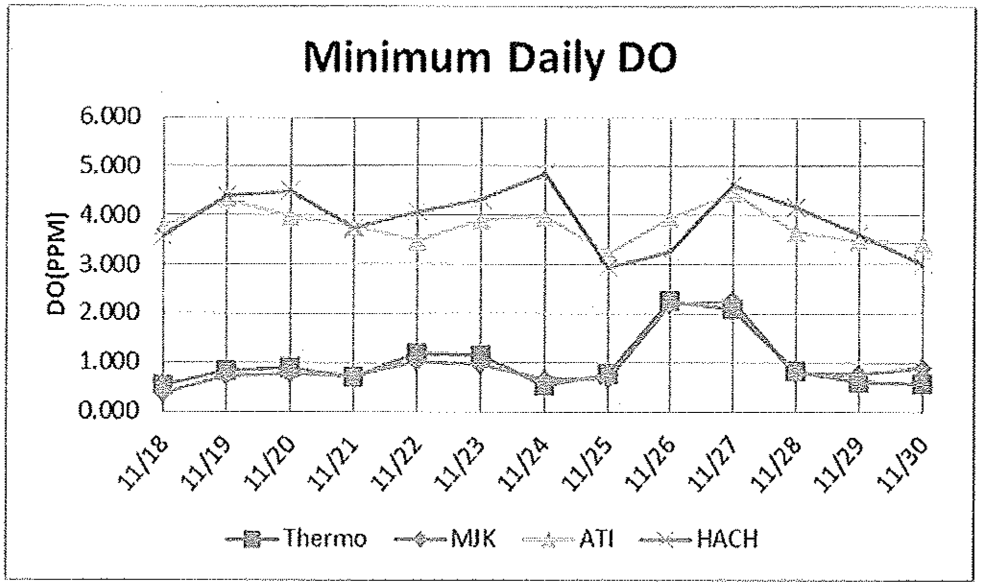

Figure 4. Minimum Daily DO Concentrations

## DO Data

Table 9. Daily Average, Maximum, and Minimum DO Concentrations

| | Air Flow | | | Thermo | | | MJK | | | ATI | | | HACH | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Day | MIN | MAX | AVG | MIN | MAX | AVG | MIN | MAX | AVG | MIN | MAX | AVG | MIN | MAX | AVG |
| 11/18/2010 | NA | NA | NA | 0.532 | 1.742 | 1.304 | 0.374 | 2.104 | 1.419 | 3.795 | 4.948 | 4.695 | 3.594 | 5.585 | 4.948 |
| 11/19/2010 | 2,725 | 4,012 | 3,452 | 0.833 | 1.726 | 1.262 | 0.731 | 2.150 | 1.405 | 4.344 | 4.948 | 4.753 | 4.415 | 5.861 | 5.248 |
| 11/20/2010 | 2,270 | 3,750 | 3,092 | 0.885 | 1.742 | 1.303 | 0.785 | 2.096 | 1.427 | 3.978 | 4.905 | 4.470 | 4.503 | 5.660 | 5.098 |
| 11/21/2010 | 1,651 | 3,422 | 2,608 | 0.696 | 1.698 | 1.190 | 0.732 | 2.091 | 1.398 | 3.785 | 4.958 | 4.429 | 3.757 | 5.176 | 4.473 |
| 11/22/2010 | 2,294 | 2,917 | 2,656 | 1.200 | 2.083 | 1.668 | 1.034 | 1.786 | 1.450 | 3.481 | 4.252 | 3.904 | 4.086 | 4.822 | 4.499 |
| 11/23/2010 | 2,182 | 2,838 | 2,522 | 1.173 | 2.026 | 1.587 | 0.957 | 1.605 | 1.283 | 3.918 | 4.698 | 4.330 | 4.343 | 5.115 | 4.707 |
| 11/24/2010 | 2,502 | 3,965 | 3,333 | 0.552 | 1.643 | 1.045 | 0.683 | 1.533 | 1.105 | 3.969 | 4.923 | 4.482 | 4.860 | 5.743 | 5.325 |
| 11/25/2010 | 1,952 | 3,313 | 2,593 | 0.780 | 1.963 | 1.319 | 0.677 | 1.857 | 1.246 | 3.246 | 4.263 | 3.786 | 2.941 | 4.428 | 3.757 |
| 11/26/2010 | 1,754 | 1,890 | 1,824 | 2.260 | 3.028 | 2.625 | 2.202 | 2.807 | 2.508 | 3.952 | 4.346 | 4.152 | 3.256 | 3.643 | 3.430 |
| 11/27/2010 | 1,800 | 2,575 | 2,257 | 2.114 | 3.103 | 2.625 | 2.273 | 3.220 | 2.770 | 4.462 | 5.383 | 4.977 | 4.631 | 5.631 | 5.165 |
| 11/28/2010 | 1,958 | 3,047 | 2,590 | 0.821 | 1.631 | 1.257 | 0.783 | 1.778 | 1.324 | 3.663 | 4.795 | 4.284 | 4.172 | 5.526 | 4.896 |
| 11/29/2010 | 2,179 | 3,155 | 2,686 | 0.618 | 1.381 | 0.975 | 0.782 | 1.689 | 1.210 | 3.508 | 4.521 | 4.014 | 3.615 | 4.777 | 4.216 |
| 11/30/2010 | 1,821 | 2,838 | 2,323 | 0.588 | 1.349 | 0.947 | 0.886 | 1.896 | 1.399 | 3.443 | 4.627 | 4.067 | 3.018 | 4.421 | 3.747 |

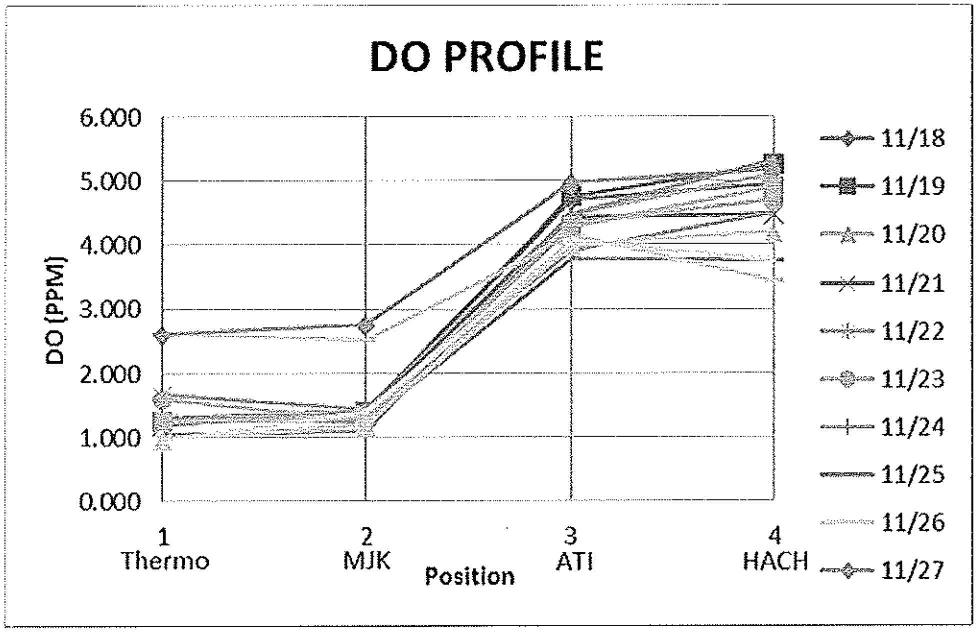

Figure 5. DO Profile

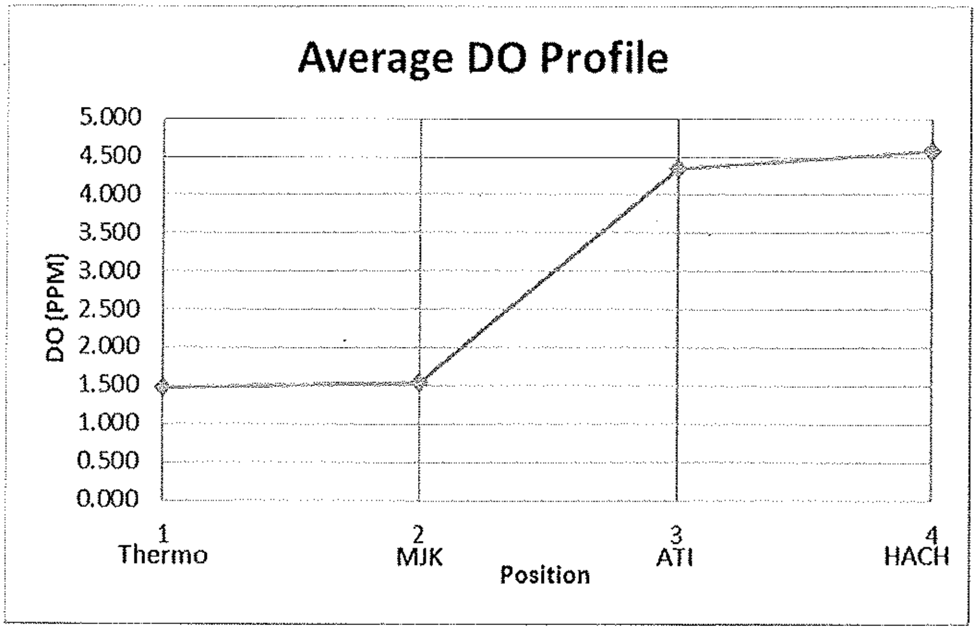

Figure 6. Average DO Profile

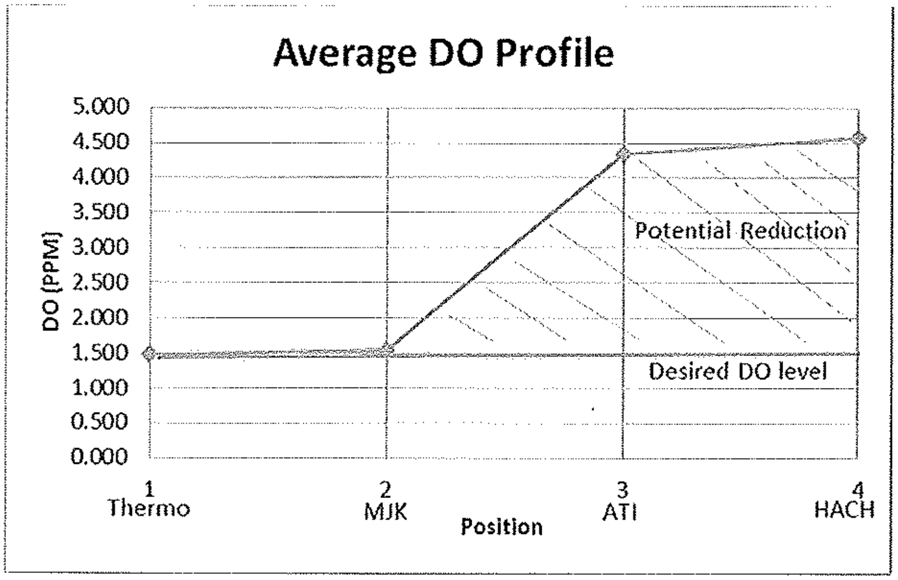

Figure 7. Average DO Profile with Potential Reduction

Table 3. Average Daily DO Concentrations

| Day | Thermo AVG | MJK AVG | ATI AVG | HACH AVG |
|---|---|---|---|---|
| **Position** | **1** | **2** | **3** | **4** |
| 11/18 | 1.304 | 1.419 | 4.695 | 4.948 |
| 11/19 | 1.262 | 1.405 | 4.753 | 5.248 |
| 11/20 | 1.303 | 1.427 | 4.470 | 5.098 |
| 11/21 | 1.190 | 1.398 | 4.429 | 4.473 |
| 11/22 | 1.668 | 1.450 | 3.904 | 4.499 |
| 11/23 | 1.587 | 1.283 | 4.330 | 4.707 |
| 11/24 | 1.045 | 1.105 | 4.482 | 5.325 |
| 11/25 | 1.319 | 1.246 | 3.786 | 3.757 |
| 11/26 | 2.625 | 2.508 | 4.152 | 3.430 |
| 11/27 | 2.625 | 2.770 | 4.977 | 5.165 |
| 11/28 | 1.257 | 1.324 | 4.284 | 4.896 |
| 11/29 | 0.975 | 1.210 | 4.014 | 4.216 |
| 11/30 | 0.947 | 1.399 | 4.067 | 3.747 |
| **AVERAGE** | **1.470** | **1.534** | **4.334** | **4.578** |

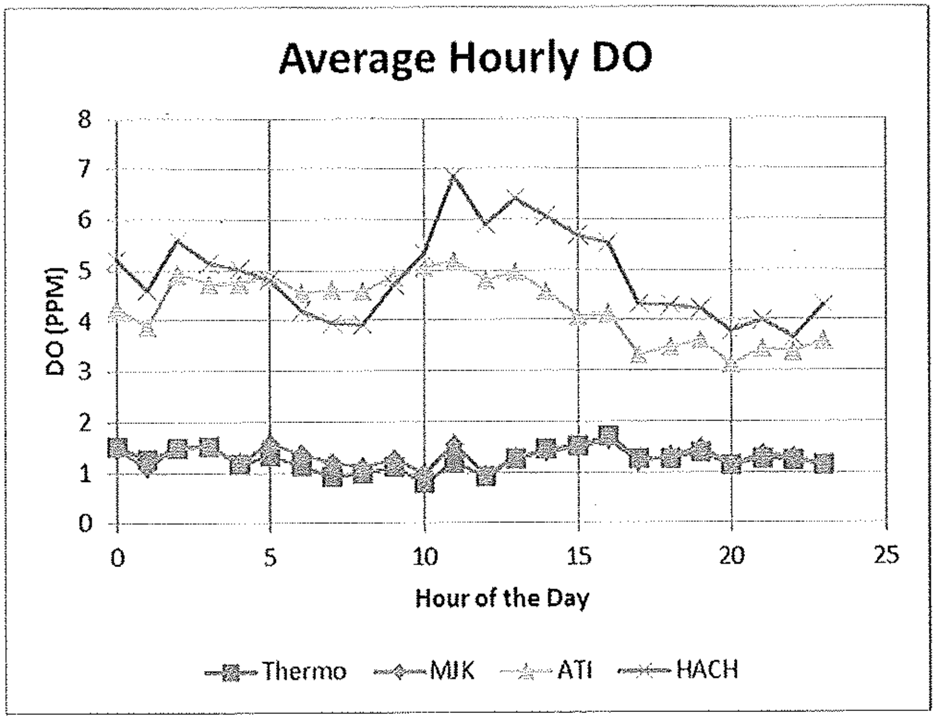

Figure 8. Average Hourly DO Concentration for November 28

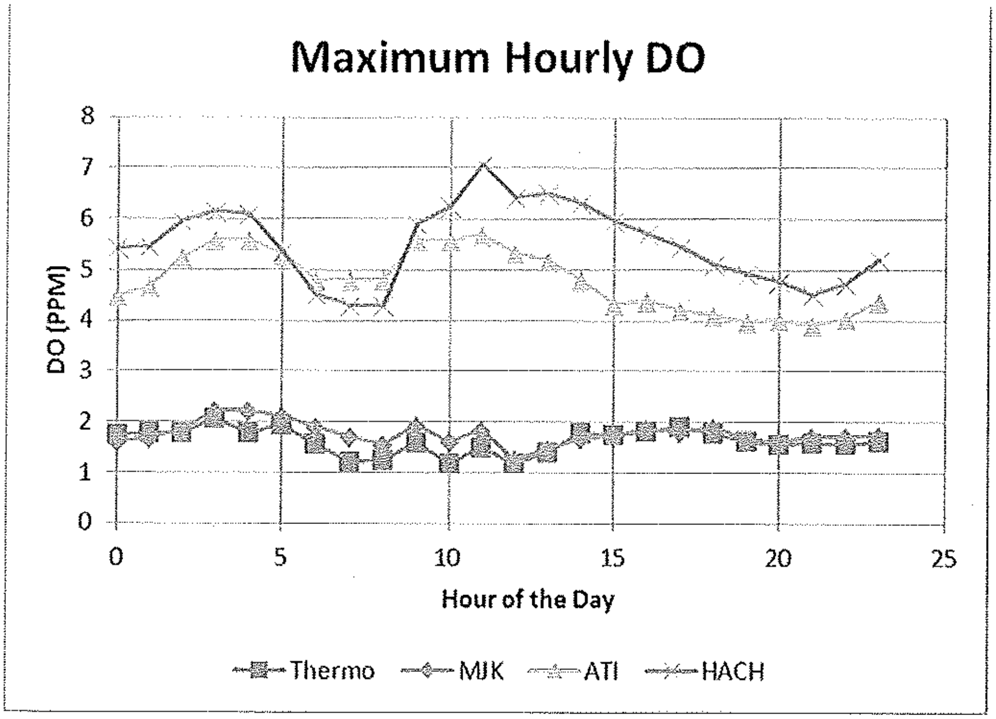

Figure 9. Maximum Hourly DO concentration for November 28

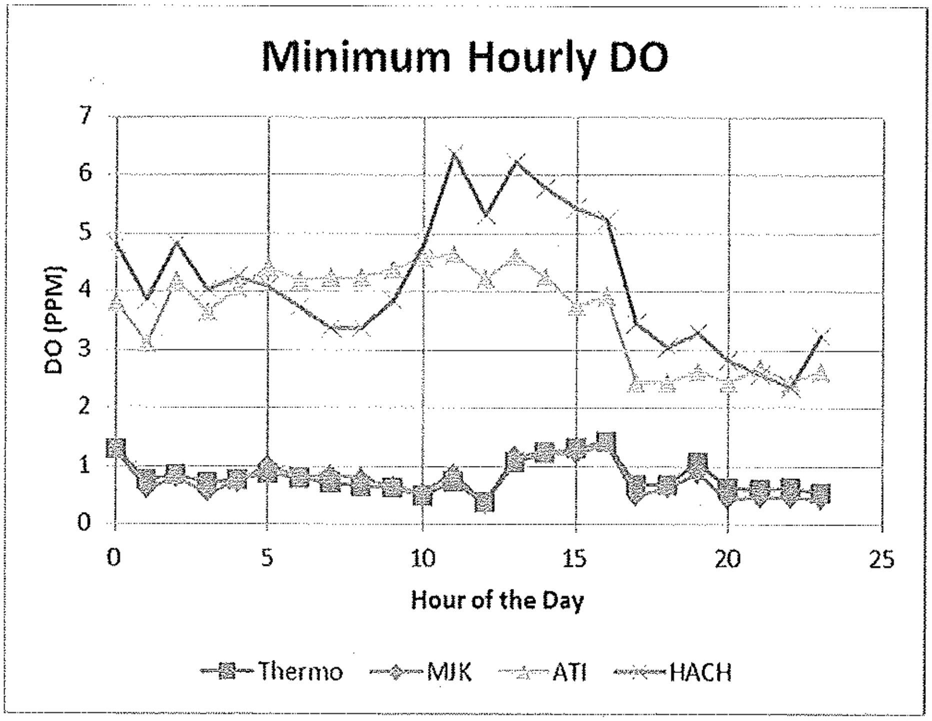

Figure 10. Minimum Hourly DO concentration for November 28

Table 4. Hourly DO Concentration Data for November 28

| | Air Flow | | | Thermo | | | MJK | | | ATI | | | HACH | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Hour | MIN | MAX | AVG | MIN | MAX | AVG | MIN | MAX | AVG | MIN | MAX | AVG | MIN | MAX | AVG |
| 0 | 2,696 | 3,221 | 3,048 | 1.29 | 1.75 | 1.52 | 1.29 | 1.64 | 1.47 | 3.82 | 4.5 | 4.27 | 4.81 | 5.45 | 5.2 |
| 1 | 1,815 | 3,197 | 2,597 | 0.76 | 1.79 | 1.26 | 0.61 | 1.69 | 1.12 | 3.1 | 4.69 | 3.9 | 3.86 | 5.47 | 4.61 |
| 2 | 1,840 | 3,185 | 2,623 | 0.85 | 1.8 | 1.48 | 0.79 | 1.85 | 1.53 | 4.2 | 5.24 | 4.92 | 4.82 | 5.96 | 5.58 |
| 3 | 1,644 | 3,209 | 2,770 | 0.72 | 2.06 | 1.53 | 0.56 | 2.24 | 1.51 | 3.64 | 5.61 | 4.73 | 4.02 | 6.17 | 5.14 |
| 4 | 1,595 | 2,732 | 2,127 | 0.78 | 1.8 | 1.18 | 0.72 | 2.22 | 1.2 | 4.06 | 5.59 | 4.73 | 4.26 | 6.11 | 5.01 |
| 5 | 1,632 | 2,940 | 1,970 | 0.89 | 1.95 | 1.32 | 1.03 | 2.12 | 1.58 | 4.42 | 5.3 | 4.9 | 4.09 | 5.36 | 4.79 |
| 6 | 1,608 | 2,378 | 1,952 | 0.79 | 1.57 | 1.15 | 0.83 | 1.91 | 1.36 | 4.19 | 4.82 | 4.55 | 3.72 | 4.53 | 4.19 |
| 7 | 1,559 | 1,938 | 1,702 | 0.72 | 1.22 | 0.94 | 0.84 | 1.72 | 1.22 | 4.25 | 4.82 | 4.6 | 3.37 | 4.31 | 3.94 |
| 8 | 1,730 | 2,256 | 1,894 | 0.67 | 1.25 | 0.99 | 0.79 | 1.58 | 1.1 | 4.25 | 4.82 | 4.58 | 3.38 | 4.3 | 3.92 |
| 9 | 1,559 | 3,075 | 2,244 | 0.62 | 1.6 | 1.11 | 0.67 | 1.93 | 1.28 | 4.38 | 5.59 | 4.88 | 3.83 | 5.9 | 4.7 |
| 10 | 1,705 | 3,160 | 2,251 | 0.51 | 1.2 | 0.8 | 0.56 | 1.64 | 0.99 | 4.58 | 5.59 | 5.05 | 4.79 | 6.25 | 5.33 |
| 11 | 1,730 | 3,221 | 2,911 | 0.75 | 1.5 | 1.22 | 0.87 | 1.85 | 1.55 | 4.63 | 5.68 | 5.17 | 6.36 | 7.08 | 6.84 |
| 12 | 1,571 | 3,221 | 2,815 | 0.4 | 1.19 | 0.91 | 0.36 | 1.29 | 0.97 | 4.22 | 5.34 | 4.81 | 5.32 | 6.44 | 5.92 |
| 13 | 3,050 | 3,258 | 3,156 | 1.08 | 1.41 | 1.26 | 1.19 | 1.47 | 1.31 | 4.6 | 5.2 | 4.97 | 6.23 | 6.5 | 6.4 |
| 14 | 2,793 | 3,197 | 3,110 | 1.23 | 1.79 | 1.46 | 1.24 | 1.68 | 1.41 | 4.25 | 4.81 | 4.58 | 5.78 | 6.31 | 6.05 |
| 15 | 2,647 | 3,221 | 3,060 | 1.31 | 1.75 | 1.53 | 1.22 | 1.71 | 1.5 | 3.77 | 4.35 | 4.07 | 5.43 | 5.96 | 5.68 |
| 16 | 2,879 | 3,197 | 3,077 | 1.44 | 1.82 | 1.7 | 1.4 | 1.89 | 1.66 | 3.92 | 4.41 | 4.14 | 5.25 | 5.72 | 5.52 |
| 17 | 1,632 | 3,209 | 2,521 | 0.69 | 1.9 | 1.28 | 0.51 | 1.83 | 1.22 | 2.43 | 4.21 | 3.32 | 3.45 | 5.48 | 4.32 |
| 18 | 1,705 | 3,233 | 2,608 | 0.7 | 1.78 | 1.27 | 0.62 | 1.91 | 1.32 | 2.43 | 4.1 | 3.48 | 3.05 | 5.13 | 4.31 |
| 19 | 2,818 | 3,197 | 3,068 | 1.08 | 1.63 | 1.41 | 0.87 | 1.69 | 1.49 | 2.62 | 4 | 3.6 | 3.29 | 4.94 | 4.25 |
| 20 | 1,656 | 3,209 | 2,575 | 0.64 | 1.58 | 1.16 | 0.45 | 1.64 | 1.16 | 2.43 | 4.03 | 3.12 | 2.82 | 4.77 | 3.81 |
| 21 | 1,656 | 3,233 | 2,631 | 0.61 | 1.61 | 1.28 | 0.46 | 1.71 | 1.36 | 2.68 | 3.94 | 3.44 | 2.57 | 4.54 | 4.03 |
| 22 | 1,925 | 3,221 | 2,941 | 0.62 | 1.57 | 1.24 | 0.48 | 1.71 | 1.31 | 2.43 | 4.06 | 3.4 | 2.37 | 4.74 | 3.66 |
| 23 | 1,546 | 3,221 | 2,516 | 0.56 | 1.62 | 1.16 | 0.43 | 1.75 | 1.15 | 2.62 | 4.39 | 3.6 | 3.25 | 5.21 | 4.3 |
| AVERAGE | 1,958 | 3,047 | 2,590 | 0.82 | 1.63 | 1.26 | 0.78 | 1.78 | 1.32 | 3.66 | 4.80 | 4.28 | 4.17 | 5.53 | 4.90 |
| STD | 506.21 | 348.24 | 424.43 | 0.27 | 0.23 | 0.21 | 0.30 | 0.21 | 0.19 | 0.80 | 0.58 | 0.63 | 1.11 | 0.75 | 0.86 |

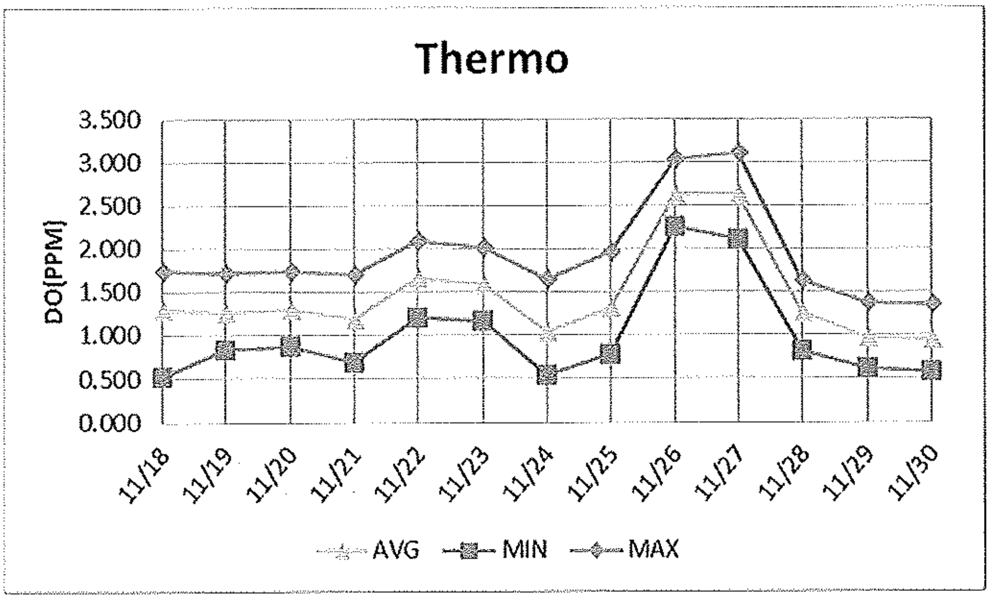

Figure 41: Thermo Daily DO Concentrations

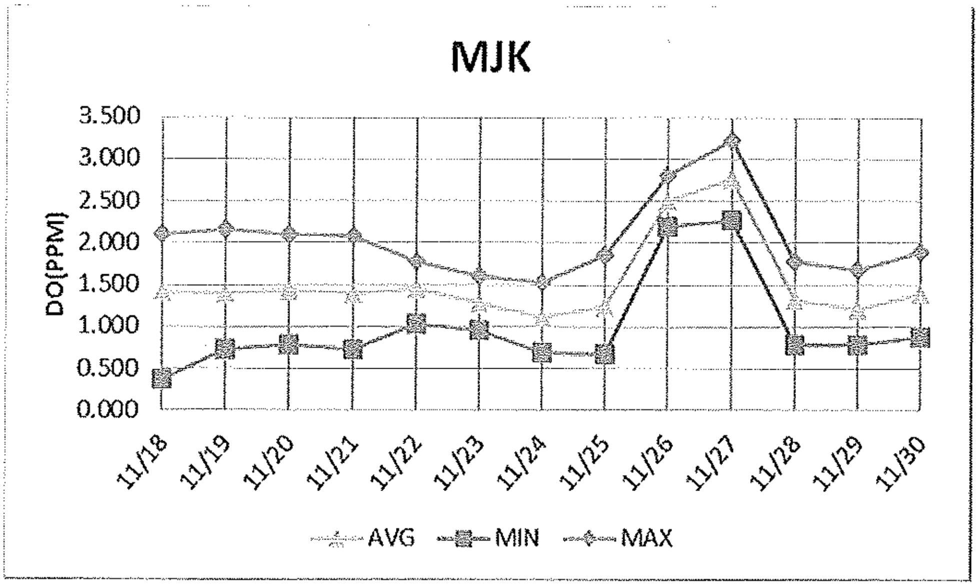

**Figure 15: MJK Daily DO Concentrations**

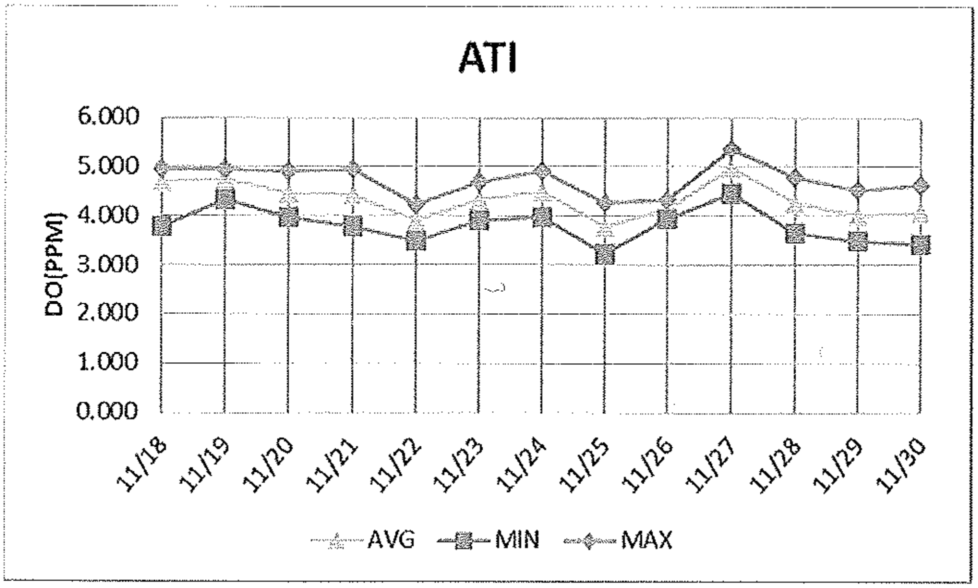

**Figure 13. ATI Daily DO Concentrations**

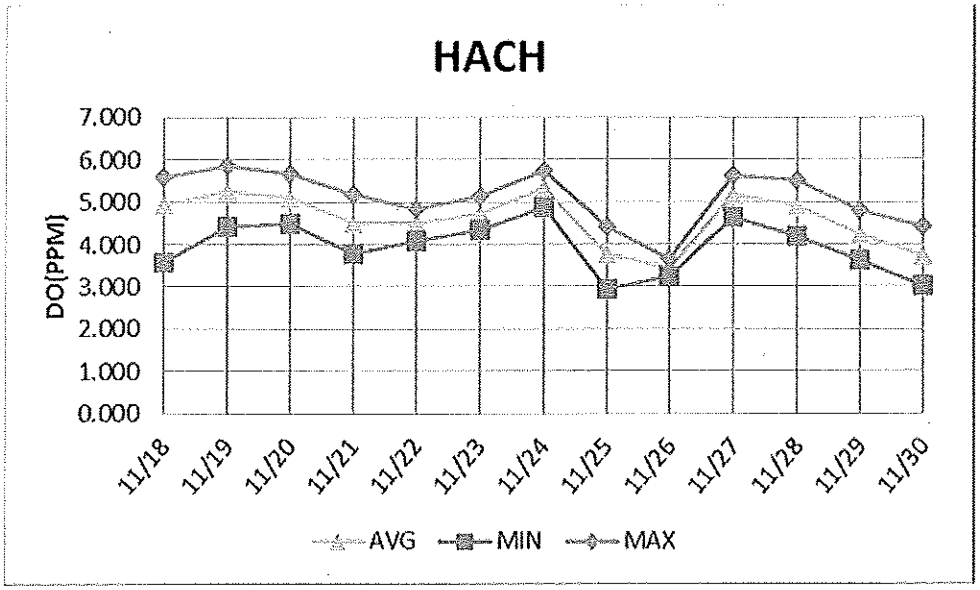

**Figure 14. HACH Daily DO Concentrations**

**Table 5. Accuracy and Range for DO Probes from Specification Sheets**

| | MJK | Thermo | ATI | HACH |
|---|---|---|---|---|
| Range (ppm) | 0-25 | 0-20 | 0-40 | 0-20 |
| Accuracy | ± 0.02 ppm | ± 0.1 ppm up to 8 ppm<br>± 0.2 ppm from 8 to 20 ppm | ± 0.05 ppm below 2 ppm | Below 1 ppm: ±0.1 ppm<br>Above 1 ppm: ±0.2 ppm |

Table 6. Variation of Daily Average DO concentration from Minimum and Maximum DO concentrations.

| | Thermo | | MJK | | ATI | | HACH | |
|---|---|---|---|---|---|---|---|---|
| **Concentration Difference between Average and** | MIN | MAX | MIN | MAX | MIN | MAX | MIN | MAX |
| **Day** | | | | | | | | |
| 11/18/2010 | 0.772 | 0.438 | 1.045 | 0.685 | 0.901 | 0.253 | 1.355 | 0.636 |
| 11/19/2010 | 0.428 | 0.465 | 0.675 | 0.745 | 0.409 | 0.195 | 0.833 | 0.612 |
| 11/20/2010 | 0.419 | 0.439 | 0.642 | 0.669 | 0.491 | 0.435 | 0.596 | 0.561 |
| 11/21/2010 | 0.495 | 0.508 | 0.666 | 0.693 | 0.644 | 0.530 | 0.716 | 0.703 |
| 11/22/2010 | 0.469 | 0.415 | 0.417 | 0.336 | 0.423 | 0.348 | 0.413 | 0.323 |
| 11/23/2010 | 0.413 | 0.439 | 0.327 | 0.322 | 0.411 | 0.369 | 0.363 | 0.408 |
| 11/24/2010 | 0.493 | 0.598 | 0.422 | 0.428 | 0.512 | 0.442 | 0.465 | 0.418 |
| 11/25/2010 | 0.539 | 0.644 | 0.569 | 0.611 | 0.540 | 0.478 | 0.816 | 0.671 |
| 11/26/2010 | 0.365 | 0.403 | 0.306 | 0.299 | 0.200 | 0.194 | 0.174 | 0.213 |
| 11/27/2010 | 0.511 | 0.478 | 0.497 | 0.450 | 0.515 | 0.406 | 0.534 | 0.466 |
| 11/28/2010 | 0.435 | 0.374 | 0.541 | 0.454 | 0.620 | 0.512 | 0.724 | 0.630 |
| 11/29/2010 | 0.357 | 0.406 | 0.428 | 0.480 | 0.506 | 0.507 | 0.601 | 0.560 |
| 11/30/2010 | 0.359 | 0.402 | 0.513 | 0.497 | 0.624 | 0.561 | 0.729 | 0.674 |
| SUM | 6.056 | 6.008 | 7.047 | 6.668 | 6.796 | 5.229 | 8.319 | 6.878 |
| Total | 12.064 | | 13.715 | | 12.024 | | 15.197 | |

## APPENDIX B: Aeration Analysis

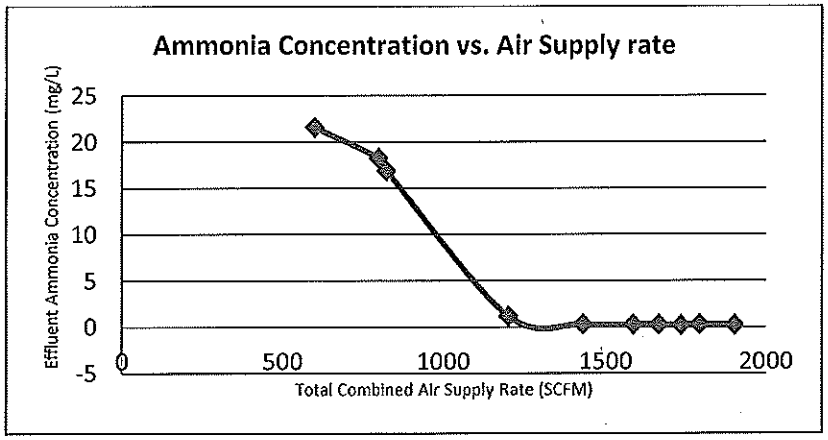

Figure 6: Air Supply and Ammonia Relationship

Table 10: Influent/Effluent Concentrations and Amount to be Treated

| | [C] mg/L in | [C] mg/L out (limit) | [C] mg/L out (typical) | [C] to be treated to achieve limit (lb/day) | [C] to be treated for typical removal (lb/day) |
|---|---|---|---|---|---|
| Ammonia | 22 | 17 | 0.22 | 181.2 | 789.4 |
| BOD | 427 | 25 | 5 | 14569.6 | 15294.4 |

Table 11: Theoretical Air Supply Requirements

| | *Oxygen Demand (lb O2/day)* | *Air Demand (lb air/day)* | *Total Air Suply (SCFM)* | *Air Supply Per Basin (SCFM)* |
|---|---|---|---|---|
| *To Achieve Limit* | *16860.1* | *80286.1* | *4329.1* | *2164.5* |
| *To Achieve Typical Values* | *20454.9* | *98528.3* | *5312.7* | *2656.4* |

Table 12: Density Variations

|  | Theoritcal Oxygen Demand values per tank (ft^3/min) |  |  |
|---|---|---|---|
| Density of Air (lb/ft^3) | Limit | Typical | All |
| 0.081 | 2164.54 | 2626.06 | 2656.36 |
| 0.126 | 1391.49 | 1688.18 | 1707.66 |

Table 13: Air Supply Mixing Requirements

| Mixing Requirement | Air Supply (SCFM) |
|---|---|
| **0.08 SCFM/Sq ft.** | 1322.4 |
| **0.10 SCFM/Sq ft.** | 1653 |
| **0.12 SCFM/Sq ft.** | 1983.6 |

Table 14: Aeration Options

| Process | Air Supply (SCFM) | Air Supply (SCFM/Basin) |
|---|---|---|
| **Current (Average)** | 5180.6 | 2590.3 |
| **Mixing (0.08 SCFM per sqft.)** | 2644.8 | 1322.4 |
| **Mixing (0.10 SCFM per sqft.)** | 3306.0 | 1653.0 |
| **Mixing (0.12 SCFM per sqft.)** | 3967.2 | 1983.6 |
| **Entire Tank DO SET of 1.0 mg/L** | 3175.7 | 1587.9 |
| **Entire Tank DO Set of 1.5 mg/L** | 3476.3 | 1738.12 |
| **Entire Tank DO Set 2.0 mg/L** | 3810.7 | 1905.4 |
| **Tapered DO Set 2.0 mg/L to DO Set 1.0 mg/L** | 3658.4 | 1829.2 |
| **Tapered DO Set 2.0 mg/L to DO Set 1.5 mg/L** | 3729.2 | 1864.6 |
| **Tapered DO Set 1.5 mg/L toDO Set 1.0 mg/L** | 3403.8 | 1701.9 |

# APPENDIX C: Cost Analysis

**Table 1: Yearly Savings**

| Process | Blower HP Needed | HP Saved | KiloWatts | KiloWatts Saved | Yearly Electric Cost | Yearly Savings |
|---|---|---|---|---|---|---|
| Current (Average) | 247.06 | 0.00 | 194.01 | 0.00 | $113,866.43 | $0.00 |
| Design | 198.71 | 48.35 | 156.04 | 37.97 | $91,581.09 | $22,285.34 |
| Mixing (0.08 SCFM per sqft.) | 126.13 | 120.93 | 99.04 | 94.96 | $58,131.28 | $55,735.15 |
| Mixing (0.1 SCFM per sqft.) | 157.66 | 89.40 | 123.81 | 70.20 | $72,664.10 | $41,202.33 |
| Mixing (0.12 SCFM per sqft.) | 189.19 | 57.87 | 148.57 | 45.44 | $87,196.92 | $26,669.51 |
| Entire Tank DO SET of 1.0 mg/L | 151.45 | 95.61 | 118.93 | 75.08 | $69,800.18 | $44,066.26 |
| Entire Tank DO Set of 1.5 mg/L | 165.78 | 81.27 | 130.18 | 63.82 | $76,408.08 | $37,458.35 |
| Entire Tank DO Set 2.0 mg/L | 181.73 | 65.33 | 142.71 | 51.30 | $83,757.13 | $30,109.30 |
| Tappered DO Set 2.0 mg/L to DO Set | 174.47 | 72.59 | 137.00 | 57.00 | $80,410.10 | $33,456.33 |
| Tappered DO Set 2.0 mg/L to DO Set | 177.84 | 69.21 | 139.65 | 54.35 | $81,966.25 | $31,900.18 |
| Tappered DO Set 1.5 mg/L toDO Set 1 | 162.32 | 84.74 | 127.47 | 66.54 | $74,812.81 | $39,053.62 |

**Table 2. Pay Back Periods**

| | | Pay Back (years) | |
|---|---|---|---|
| Process | Yearly Savings | Capital Cost $64,000 | Capital Cost $76,000 |
| Mixing (0.08 SCFM per sqft.) | $55,735 | 1.1 | 1.3 |
| Mixing (0.1 SCFM per sqft.) | $41,202 | 1.6 | 1.8 |
| Mixing (0.12 SCFM per sqft.) | $26,670 | 2.4 | 2.8 |
| Entire Tank DO SET of 1.0 mg/L | $44,066 | 1.5 | 1.7 |
| Entire Tank DO Set of 1.5 mg/L | $37,458 | 1.7 | 2.0 |
| Entire Tank DO Set 2.0 mg/L | $30,109 | 2.1 | 2.5 |
| Tappered DO Set 2.0 mg/L to DO Set 1.0 mg/L | $33,456 | 1.9 | 2.2 |
| Tappered DO Set 2.0 mg/L to DO Set 1.5 mg/L | $31,900 | 2.0 | 2.3 |
| Tappered DO Set 1.5 mg/L toDO Set 1.0 mg/L | $39,054 | 1.6 | 1.9 |

**Table 3. Savings in Percent**

| Option | Air Flow Basin 1 (SCFM) | Air Flow Basin 2 (SCFM) | Total Air Flow (SCFM) | Nominal Savings (%) |
|---|---|---|---|---|
| Constant | | | | |
| DO SET of 1.0 mg/L | 1203.2 | 384.7 | 1587.9 | 38.7 |
| DO Set of 1.5 mg/L | 1319.9 | 418.3 | 1738.2 | 32.9 |
| DO Set 2.0 mg/L | 1448.7 | 456.7 | 1905.4 | 26.4 |
| Tappered | | | | |
| DO Set 2.0 mg/L to DO Set 1.0 mg/L | 1457.0 | 372.2 | 1829.2 | 29.4 |
| DO Set 2.0 mg/L to DO Set 1.5 mg/L | 1452.0 | 412.7 | 1864.6 | 28.0 |
| DO Set 1.5 mg/L toDO Set 1.0 mg/L | 1324.6 | 377.3 | 1701.9 | 34.3 |
| Mixing Requirment | | | | |
| Conservative Mixing (0.12 SCFM/SQ ft) | NA | NA | 1983.6 | 23.4 |
| Average Mixing (0.1 SCFM/SQ ft) | NA | NA | 1653 | 36.2 |
| Liberal Mixing (0.08 SCFM/SQ ft) | NA | NA | 1322.4 | 48.9 |