Protecting Our Water Environment

Metropolitan Water Reclamation District of Greater Chicago

MONITORING AND RESEARCH DEPARTMENT

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COMPARING OPERATIONAL EFFICIENCY OF TWO DIFFERENT AERATION SYSTEMS AT THE JOHN E. EGAN WATER RECLAMATION PLANT

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LIST OF ABBREVIATIONS

Abbreviation or Acronym	Meaning
ALD	Analytical Laboratories Division
BOD	biochemical oxygen demand
CBOD	carbonaceous biochemical oxygen demand
District	Metropolitan Water Reclamation District of Greater Chicago
DO	dissolved oxygen
Egan	John E. Egan
F/M	food-to-microorganisms
FE	final effluent
$FeCl_3$	ferric chloride
ISV	interfacial settling velocity
M&R	Monitoring and Research
MG	million gallons
ML	mixed liquor
MLSS	mixed liquor suspended solids
MORs	monthly operation reports
NAB	North Aeration Battery
NH_3-N	ammonia nitrogen
NO_2-N	nitrite nitrogen
OTE_f	oxygen transfer efficiency under field conditions
OUR	oxygen uptake rate
SAB	South Aeration Battery
Sol-P	soluble phosphorus
Sol-TKN	soluble total total Kjeldahl nitrogen
$SOTE_f$	specific oxygen transfer efficiency under field conditions
SOUR	specific oxygen uptake rate
SRT	solids retention time
SS	suspended solids
SVI	sludge volume index
TKN	total Kjeldahl nitrogen
TP	total phosphorus
VSS	volatile suspended solids
WAS	waste activated sludge
WERF	Water Environment Research Foundation
WRP	water reclamation plant
Y	net yield

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DISCLAIMER

Mention of proprietary equipment and chemicals in this report does not constitute endorsement by the Metropolitan Water Reclamation District of Greater Chicago.

EXECUTIVE SUMMARY

In 2002, the aeration system in the North Aeration Battery (NAB) at the John E. Egan (Egan) Water Reclamation Plant (WRP) was replaced with a full-floor coverage, fine-pore diffuser disc system with tapered configuration such that the number of diffusers per foot of aeration tank decreases down the length of aeration tank. Adjacent to the NAB is the South Aeration Battery (SAB), which still has the original spiral roll configured aeration system using ceramic diffuser plates along one tank wall, with a constant number of diffusers per foot of aeration tank through the entire tank. This spiral roll configuration is common throughout the Metropolitan Water Reclamation District of Greater Chicago (District). The two batteries treat the same wastewater in parallel and are identical in size and shape. Due to the similarities in shape, size, and wastewater treated, these two batteries were ideal for conducting a side-by-side evaluation of the performance efficiency and the economics of operating the two different types of aeration systems. This study, conducted by the Monitoring and Research (M&R) Department from 2007 through 2010, evaluated the differences in aeration systems as well as battery performance.

The objectives of this study, along with findings and recommendations, were:

1. <u>Conduct a comprehensive comparison of the treatment efficiency and solids mass balance in each battery including characterization of the influent to each battery</u>.

   Findings: Characteristics of the primary effluent feeding the batteries were found to be statistically equivalent, verifying that the batteries receive the same flow and load. Differences in treatment performance between batteries were observed, which were likely the result of different operating conditions in the batteries.

2. <u>Measure the specific oxygen uptake rate (SOUR) at set intervals along the length of an aeration tank in each battery</u>.

   Findings: The SOURs in the two batteries showed similar trends down the length of the aeration tanks, although they were slightly higher in the SAB through the first half of the aeration tank.

3. <u>Measure the standard oxygen transfer efficiency under field conditions ($SOTE_f$) of the two different fine-bubble diffuser aeration systems under process conditions</u>.

   Findings: The $SOTE_f$ of the two aeration systems showed similar trends down the length of the aeration tanks. However the $SOTE_f$s in the NAB were consistently higher. Whether or not these higher $SOTE_f$s were due to the difference in aeration systems could not be determined from this study, as there was a significant difference in system age (the aeration system in the SAB was more than 25 years older than that in the NAB) and there is some question regarding the appropriate position of the off-gas hood during $SOTE_f$

measurements in a tank with spiral roll diffusers (off-gas is not uniform across the width of a tank with spiral roll diffusers, but testing only measured the off-gas from a portion of the width).

Recommendations: Diffuser plates in the SAB were replaced in 2012. Additional off-gas testing is recommended to compare the SAB $SOTE_f$s before and after replacement to determine the contribution age had on observed differences in SAB and NAB $SOTE_f$s. Additional off-gas testing over the entire aeration tank width in the SAB is recommended to determine the contribution the off-gas measurement method used in 2007 had on the observed differences in SAB and NAB $SOTE_f$s.

4. <u>Determine the dissolved oxygen (DO) and nitrification profiles along the aeration tanks in each battery</u>.

   Findings: Slight differences were observed in DO profiles down the length of the aeration tanks in the NAB and SAB, which were a result of different RAS return methods, possible use of anoxic zones in the beginning of the NAB aeration tank, and differences in the diffuser density down the length of NAB and SAB tanks. The ammonia nitrogen (NH_3-N) profiles showed that nitrification was completed by the end of Pass 2 in both batteries. The suspended solids (SS) and volatile SS (VSS) were consistently higher in the SAB than in the NAB, with the exception of the first half of Pass 1. These different SS and VSS concentrations are most likely a result of a leak in the SAB RAS line and possible non-ideal mixing due to the anoxic zone baffle wall or inadequate mixers if the NAB anoxic zone was in operation.

5. <u>Determine the interfacial settling velocity (ISV) of representative samples of mixed liquor (ML) from each battery</u>.

   Findings: The ISVs were not measured during this study's duration, 2007 through 2010, but limited data was available from 2005. The 2005 data showed that there are differences in the ML settling characteristics between batteries despite treating the same flow and loads and being identical in size and shape. From the limited results, the SAB ML had much better settling characteristics than the NAB.

6. <u>Evaluate the effects of these systems on oxygen uptake rate (OUR), nitrification rate, and energy consumption per pound of biochemical oxygen demand (BOD) removed</u>.

   Findings: The different aeration systems in the NAB and SAB did not appear to impact treatment performance when operating conditions were similar. However, operating conditions were not always similar, particularly due to higher sludge volume indices (SVIs) and greater filament counts in the NAB. During this study, SVIs were consistently higher in the NAB despite similar influent characteristics. It is possible that low DO in the RAS or possible dead zones in the NAB may contribute to these differences. Reliable air flow data is not available for the NAB, which prevents an energy consumption comparison from being completed for the two aeration systems.

Recommendations: A contract currently exists to replace the air flow meters in the NAB. After replacement of these meters, it is recommended that a detailed analysis of battery air usage and energy consumption be done in order to fully complete the study objective of comparing the effectiveness of the two aeration systems.

The results of this study indicate that treatment performance is similar between the NAB and SAB when operating conditions are similar. There is, however, some unidentified difference that exists which causes varying SVIs and filament counts between the batteries and prevents similar operating conditions. As for the efficiencies of the NAB and SAB aeration systems, a few outstanding questions remain, such as actual air usage by each system and investigation into the cause of differing $SOTE_f$s of systems that prevent a comparison of these two systems from being done. Additional work is recommended in order to complete this comparison.

INTRODUCTION

In 2002, the aeration system in the NAB of the Egan WRP was replaced with a full-floor coverage, fine-bubble diffuser system using ceramic discs manufactured by Sanitaire in a tapered configuration so that the amount of diffusers per foot of aeration tank decreases down the length of the tank. Adjacent to the NAB is the SAB, which still has the original spiral roll configured aeration system using ceramic diffuser plates along one tank wall, with a constant amount of diffusers per foot of aeration tank throughout the entire tank. This spiral roll configuration is common throughout the District. The two batteries, and therefore the two aeration systems, theoretically treat the same wastewater in parallel. The batteries are also identical in size and shape. Due to the similarities in shape, size, and wastewater treated, these two batteries were ideal for conducting a side-by-side evaluation of the performance efficiency and the economics of operating a full-floor coverage fine-bubble diffuser system with ceramic discs and a spiral roll configured diffuser system with ceramic plates. In December 2002, the Engineering Department requested that the M&R Department perform this evaluation comparing the two aeration systems. Due to contract work on the SAB and a Water Environment Research Foundation (WERF) nutrient study, the evaluation was postponed until 2006, when the initial request was broadened to also include evaluation and comparison of battery performance. This broader study was conducted by the M&R Department from 2007 through 2010. The results are presented in this report. It should be noted that a few operational events occurred during the completion of this project. These events include: (1) the Phosphorus Reduction Project at the Egan WRP in which ferric chloride ($FeCl_3$) was added to the ML effluent from the aeration tanks during the duration of this project, (2) excessive growth of *Nocardia* in the NAB which resulted in the formation of foam in the aeration tanks, and (3) temporary operation of an anoxic zone in the NAB in an attempt to relieve the excessive *Nocardia* growth. These events were considered while evaluating the results from this study.

BACKGROUND

John E. Egan Water Reclamation Plant Aeration Battery Configuration

North Aeration Battery Configuration. The NAB consists of two aeration tanks, with each tank having three passes. The dimensions of each pass are 375 feet long, 25 feet wide, and 15 feet deep. The volume of each pass is 1.05 million gallons (MG), or 3.16 MG per tank. The aeration system in the NAB consists of full-floor coverage fine-bubble diffusers. The diffuser discs are tapered so that the number of diffusers per foot of aeration tank decreases along the length of the tank, with the largest number of diffusers per foot occurring at the tank influent end and the lowest at the effluent end. Air flow to the diffusers is controlled using DO set points. The DO probes used to regulate air flow are located at the end of each pass.

The NAB is fed PE from two dedicated circular primary settling tanks. Typical plant operations involve splitting the total raw influent flow equally to all the aeration tanks in service. For example, if two aeration tanks in the NAB and one aeration tank in the SAB are in service, two-thirds of the total influent flow will enter the NAB primary settling tanks and then into the NAB aeration tanks. The PE enters the NAB aeration tanks via a pipe. The RAS is returned to the head of the aeration tanks via centrifugal pumps and enters the aeration tanks through its own separate pipe. Therefore, mixing of the PE and RAS occurs in the first few feet of the aeration tanks. The NAB aeration tank effluent passes into four dedicated final settling tanks.

South Aeration Battery Configuration. The SAB has two aeration tanks that are the same size and shape as those in the NAB. Key differences between the SAB and NAB include the aeration and RAS systems. The SAB aeration system is comprised of spiral roll configured ceramic plates. The ceramic plates are located along one side down the length of the tank. The number of diffuser plates per foot of aeration tank is constant throughout the tank. Air flow is controlled using DO set points at DO probes located at the end of each pass. The SAB is fed PE from two dedicated circular primary settling tanks. Unlike the NAB, in the SAB the RAS is returned to the head of the aeration tanks via air lifts. Similar to the NAB, the PE and RAS enter the SAB aeration tanks in separate pipes, so mixing is supposed to occur in the first few feet of the tanks. However, the return sludge pipe running from the exit end of Pass 1 to the influent end has four entrances to the tank, some of which may have had RAS leakage in this study. The ML flows from the aeration tanks into four dedicated final settling tanks.

OBJECTIVES

The goals of this study were to evaluate and compare not only the efficiency and economics of operating a full-floor coverage versus a spiral roll configured aeration system, but also to evaluate the treatment performance of the aeration tank batteries using these two technologies. The specific objectives included:

1. To conduct a comprehensive comparison of the treatment efficiency and solids mass balance in each battery including characterization of the influent to each battery.

2. To measure the SOUR at set intervals along the length of an aeration tank in each battery.

3. To measure and compare the field oxygen transfer efficiency (OTE_f) of the two different fine-bubble diffuser aeration systems.

4. To determine the DO and nitrification profiles along the aeration tanks in each battery.

5. To determine the ISV of representative samples of ML from each battery.

6. To evaluate the effects of these systems on OUR, nitrification rate, and energy consumption per pound of BOD removed.

MATERIALS AND METHODS

Aeration Battery Treatment Evaluation Factors

Factors used in this study to evaluate aeration battery treatment include $SOTE_f$, SOUR, solids retention time (SRT), food-to-microorganisms ratio (F/M), SVI, air to sewage flow ratio, air flow to oxygen demand (OD) ratio, and ISV. Details on each on measurement and calculation of these factors can be found in Appendix A.

Performance Evaluation of Secondary Treatment

To evaluate the secondary treatment performance of the NAB and SAB, first intensive sampling was completed for eight days from April 24, 2007, through April 27, 2007, and May 1, 2007, through May 4, 2007. The intensive sampling monitored the parameters listed in Tables 1 and 2 in 24-hour composite samples from the NAB and SAB PE and final effluent (FE), respectively. The intensive sampling was conducted to determine whether there was any difference in the influent characteristics of the two batteries. Included in the list of parameters measured during the spring intensive sampling were glass filtered and filtered/flocculated species. Glass filtered and filtered/flocculated analyses provide more detailed information on the characteristics of the influent, particularly the fractions of a specific parameter. A glass filtered sample will contain all the soluble and colloidal fractions, while the soluble sample filtered using a 0.45 micron filter may contain only a portion of the colloidal fractions along with the soluble fractions. The filtered/flocculated sample will contain only the truly soluble fraction.

Following the intensive sampling, a longer sampling event was completed in the fall, for a total of 53 weekdays, from September 5, 2007, through November 17, 2007. This fall sampling was done to evaluate the performance and treatment efficiency of the two batteries. The parameters listed in Table 3 were analyzed in 24-hour composites for the PE and secondary effluent from the NAB and SAB.

All parameters listed in Tables 1 through 3 were analyzed by the District's Analytical Laboratory Division (ALD) according to standard methods.

A mass balance on the SS of each battery was completed using the sampling results from the fall sampling along with other operating data from that time period. The mass balance used the average SS from the entire sampling period. The specific data used in calculating the solids loads for each battery included the following:

1. PE: The PE SS concentrations from the fall sampling and the raw influent flow less the primary sludge flow and divided by the number of aeration tanks in service, i.e. the treated flow.

2. Aeration Tank: Sum of the PE and RAS SS loads.

3. FE: The FE SS concentration from the fall sampling and the treated flow for that battery.

TABLE 1: PARAMETERS MEASURED DURING THE INTENSIVE SAMPLING OF THE NORTH AND SOUTH BATTERY PRIMARY EFFLUENT FROM APRIL 24, 2007, THROUGH MAY 4, 2007

North and South Battery Primary Effluent 24-Hour Composite
5-day Biochemical Oxygen Demand (BOD_5)
Total Chemical Oxygen Demand (COD_t)
Glass Filtered Chemical Oxygen Demand (COD_{gf})
Filtered, Flocculated Chemical Oxygen Demand (COD_{ff})
Total Suspended Solids (TSS)
Volatile Suspended Solids (VSS)
Total Kjeldahl Nitrogen (TKN)
Soluble Total Kjeldahl Nitrogen (Sol-TKN)
Glass Filtered Total Kjeldahl Nitrogen (TKN_{gf})
Ammonia-Nitrogen (NH_3-N)
Nitrite-Nitrogen (NO_2-N)
Nitrate-Nitrogen (NO_3-N)
Total Phosphorus (TP)
Soluble Phosphorus (Sol-TP)
Glass Filtered Total Phosphorus (TP_{gf})
Fats, Oils, and Grease (FOG)

TABLE 2: PARAMETERS MEASURED DURING THE INTENSIVE SAMPLING OF THE NORTH AND SOUTH BATTERY FINAL EFFLUENT FROM APRIL 24, 2007, THROUGH MAY 4, 2007

North and South Battery Final Effluent 24-Hour Composite
Total Chemical Oxygen Demand (COD_t)
Filtered, Flocculated Chemical Oxygen Demand (COD_{ff})
Total Suspended Solids (TSS)
Total Kjeldahl Nitrogen (TKN)
Ammonia-Nitrogen (NH_3-N)
Nitrite-Nitrogen (NO_2-N)
Nitrate-Nitrogen (NO_3-N)
Total Phosphorus (TP)

TABLE 3: PARAMETERS MEASURED DURING THE FALL SAMPLING OF THE NORTH AND SOUTH BATTERY PRIMARY EFFLUENT AND SECONDARY EFFLUENT FROM SEPTEMBER 5, 2007, THROUGH NOVEMBER 17, 2007

North and South Battery Primary Effluent and Secondary Effluent 24-hour Composite
5-day Carbonaceous Biochemical Oxygen Demand ($CBOD_5$)
Total Suspended Solids (TSS)
Volatile Suspended Solids (VSS)
Total Kjeldahl Nitrogen (TKN)
Soluble Total Kjeldahl Nitrogen (Sol-TKN)
Ammonia-Nitrogen (NH_3-N)
Nitrite-Nitrogen (NO_2-N)
Nitrate-Nitrogen (NO_3-N)
Total Phosphorus (TP)
Soluble Phosphorus (Sol-TP)
pH

4. RAS: The RAS SS concentration and the RAS flow.

5. Waste activated sludge (WAS): The RAS SS concentration and the WAS flow.

Additional parameters evaluated to compare the performance of the two batteries included SRT, SVI, and F/M. A comparison of air usage was not possible due to lack of confidence in the NAB air flow meters. The daily SRTs and SVIs were obtained from the plant monthly operating reports (MORs). The F/M was calculated daily for each battery using (1) the daily MLVSS concentrations from the MORs; (2) the treated flow to each battery, which was calculated by subtracting the primary sludge flow from the raw influent flow provided in the MOR and dividing the treated flow by the number of aeration tanks in service, which was obtained from weekly reports; (3) the volume of aeration tanks in service; and (4) the battery PE carbonaceous BOD (CBOD) from the fall sampling.

Specific Oxygen Uptake Rate

The SOUR was measured during the off-gas testing completed in September and October of 2007. Figure 1 shows the seven locations where off-gas testing and therefore SOUR measurements were taken. The SOUR was measured five to seven times at each off-gas location. Tank 2 in the NAB and SAB was consistently used for all testing. The SOUR was calculated by first measuring the OUR of the ML at each location. All OUR measurements were completed in the field immediately after sample collection. To measure the OUR, a ML sample was collected and aerated by mixing the sample in a sealed container with sufficient head space. The aerated sample was transferred to a glass BOD bottle, and a DO probe with mixer was inserted so that there were no openings to the atmosphere and no head space. A YSI BOD meter was used for all OUR measurements. The DO was monitored, and recordings were made every 30 seconds for five minutes. By plotting the DO versus time of monitoring, the OUR was obtained from the linear slope of the line. The OUR was then divided by the MLVSS concentration result from a sample collected at the same time and location. The resulting SOUR from this calculation was corrected to a temperature of 20°C so that all the results could be compared, since SOUR varies with temperature. A correction factor of 1.05 was used for temperature greater than 20°C and a factor of 1.07 for temperatures less than 20°C (USEPA, 2001).

Standard Oxygen Transfer Efficiency

The $SOTE_f$s of the aeration systems in the NAB and SAB were calculated using the off-gas method. Details regarding specific instructions for performing an off-gas test can be found in the ASCE Standard Guidelines for In-Process Oxygen Transfer Testing, which was used as a reference for conducting the tests. During the off-gas tests, an off-gas analyzer manufactured by Redmon Engineering Company was used along with a vacuum and an off-gas collection hood. The $SOTE_f$ was measured during September and October of 2007 five to seven times at each off-gas location indicated in Figure 1.

Tests completed in 2007 used a metal, square hood located along the side wall to collect off-gas from the aeration tanks, as shown in Configuration A of Figure 2. The "square" refers to

FIGURE 1: SAMPLE LOCATIONS OF THE OFF-GAS TESTING AND PROFILE SAMPLING IN THE NORTH AND SOUTH BATTERY AERATION TANKS

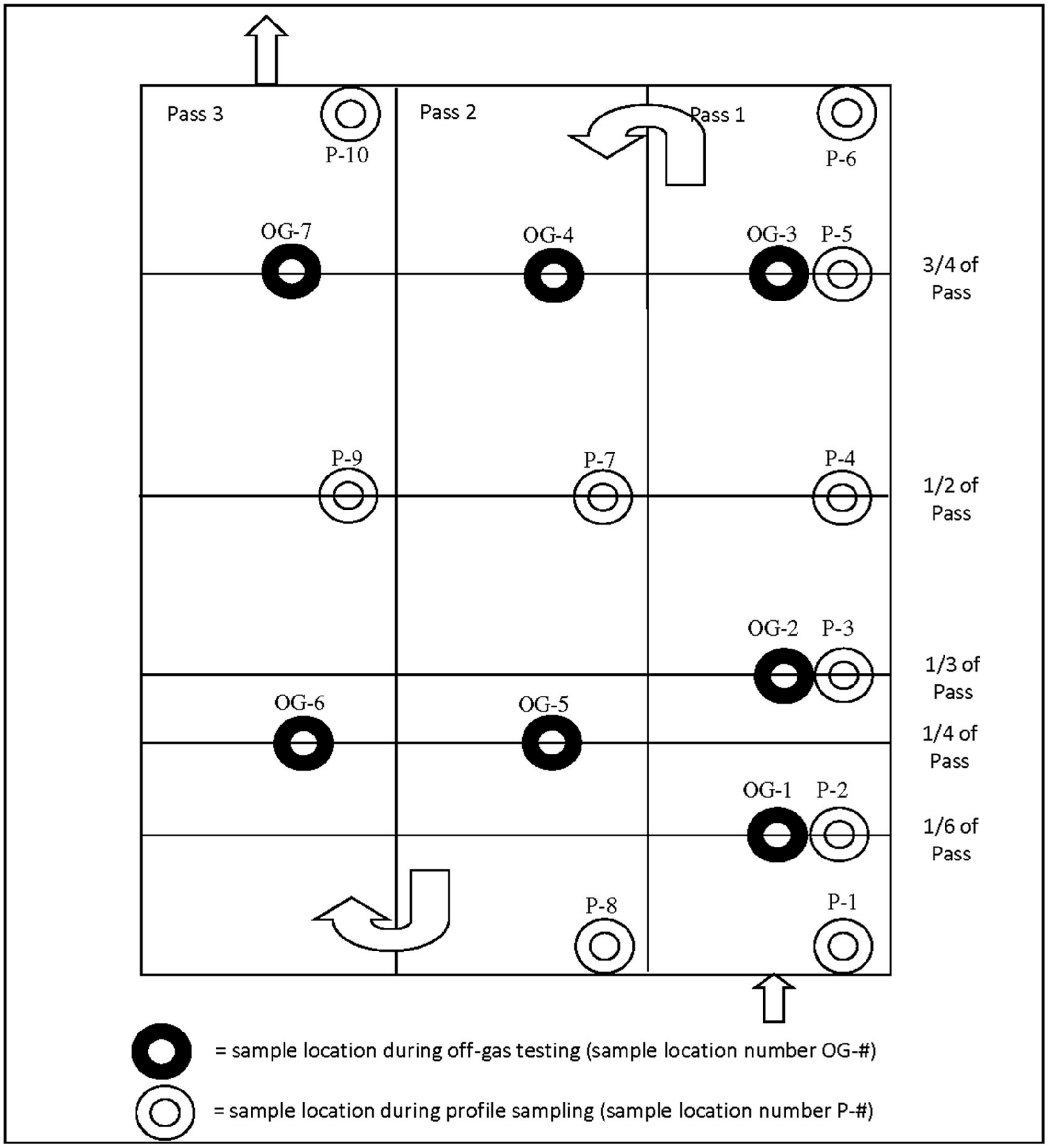
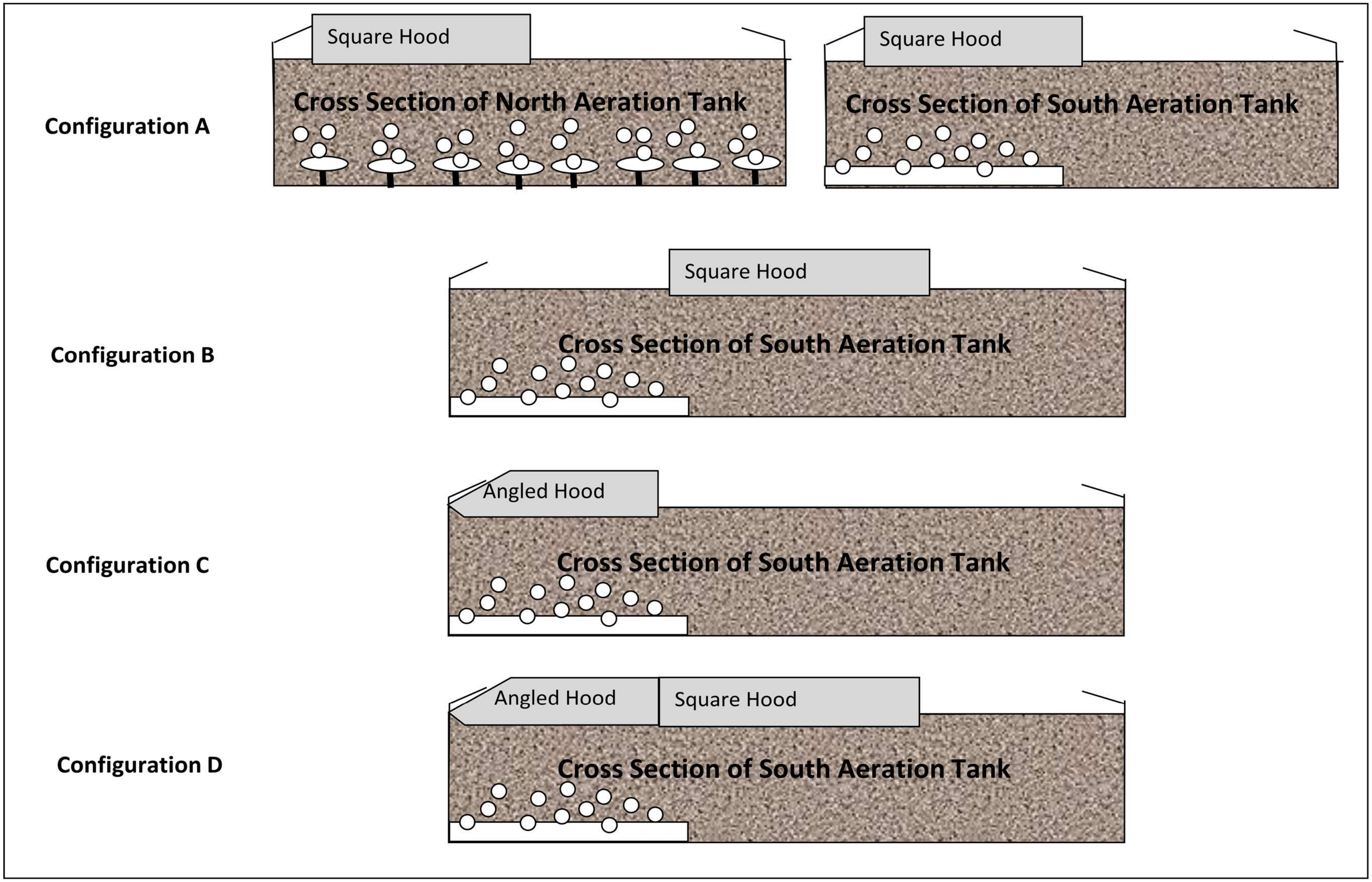


FIGURE 2: HOOD CONFIGURATIONS TESTED DURING THE 2007, 2008, 2009, AND 2010 OFF-GAS TESTING



the straight sides of the hood. The hood itself was rectangular, 10 feet long by 3 feet wide. In 2008, additional tests were completed that compared duplicate tests in the NAB and SAB, which involved running two off-gas tests using two hoods right next to each other to determine the reproducibility of the test results. These duplicate tests were completed one to three times at all seven off-gas locations. The 2008 testing also compared the results obtained using hoods of the same size but different material (metal, square hood versus wood, square hood). These tests were completed once at off-gas locations 1 through 3. In addition, the hood location in the SAB tank was evaluated (metal, square hood at side wall versus metal, square hood in middle) as the diffusers in these tanks are located only along one side wall. The metal, square hood in the middle of the aeration tank width is shown as Configuration B in Figure 2. These tests were completed two times at off-gas locations 1 through 3. In 2009 and 2010, additional off-gas tests were completed that further compared hood type and location in the SAB. Configuration C in Figure 2 shows a metal, angled hood 6 feet by 3 feet in size at the side wall, and Configuration D shows a two hood combination, which was used to calculate a weighted average $SOTE_f$ from the two hoods using the off-gas flux. The 2009 and 2010 tests were completed three to four times at off-gas locations 1 through 5. These supplemental tests provided a better understanding of the validity of the original off-gas test method used in the 2007 tests.

Tests completed in 2007 used a metal, square hood located along the side wall to collect off-gas from the aeration tanks, as shown in Configuration A of Figure 2. The “square” refers to the straight sides of the hood. The hood itself was rectangular, 10 feet long by 3 feet wide. In 2008, additional tests were completed that compared duplicate tests in the NAB and SAB, which involved running two off-gas tests using two hoods right next to each other to determine the reproducibility of the test results. These duplicate tests were completed one to three times at all seven off-gas locations. The 2008 testing also compared the results obtained using hoods of the same size but different material (metal, square hood versus wood, square hood). These tests were completed once at off-gas locations 1 through 3. In addition, the hood location in the SAB tank was evaluated (metal, square hood at side wall versus metal, square hood in middle) as the diffusers in these tanks are located only along one side wall. The metal, square hood in the middle of the aeration tank width is shown as Configuration B in Figure 2. These tests were completed two times at off-gas locations 1 through 3. In 2009 and 2010, additional off-gas tests were completed that further compared hood type and location in the SAB. Configuration C in Figure 2 shows a metal, angled hood 6 feet by 3 feet in size at the side wall, and Configuration D shows a two hood combination, which was used to calculate a weighted average $SOTE_f$ from the two hoods using the off-gas flux. The 2009 and 2010 tests were completed three to four times at off-gas locations 1 through 5. These supplemental tests provided a better understanding of the validity of the original off-gas test method used in the 2007 tests.

Dissolved Oxygen and Nitrification Profile

DO and nitrification profiles were collected four times between September and November 2007 and consisted of sampling at the ten locations shown in Figure 1. The following parameters were measured at each location: DO, total Kjeldahl nitrogen (TKN), soluble TKN (Sol-TKN), NH_3-N, NO_3-N, nitrite nitrogen (NO_2-N), total phosphorus (TP), soluble P (Sol-P), SS, and VSS. The DO measurements were made in-situ using a YSI portable DO membrane probe. All other parameters were analyzed by the District’s ALD laboratories from the collected sample.

Interfacial Settling Velocity Tests

While ISV tests were not completed during the time frame of this study, 2007 through 2010, some limited data is available from 2005. Dynamic settling tests were completed using ML samples, an eight inch inner diameter settling column with a one-rpm mixer, and upward flow of supernatant. A more detailed outline of the procedure is provided in Appendix B. The settling velocity and corresponding SS concentration were used to determine coefficients describing the settling characteristics of the ML assuming the solids settle according to the Vesilind equation as shown in Equation 1 in Appendix A.

Statistical Analyses

To compare two groups of data, either a t-test, z-test, or Kolmogorov-Smirnov test were completed. To determine which test was used, the data was first tested for normality. If there were more than 30 data points in a data set, normality was assumed as the sample size fulfilled the condition of the Central Limit Theorem. If there was fewer than 30 data points in a set, the Kolmogorov-Smirnov test was completed to check for normality. If the data was not normal, the Kolmogorov-Smirnov test was completed to compare the two groups of data. If the data was normal, the f-test was completed to check for equal variance. If variances of the two groups were equal, the t-test was used to compare the two groups. If the variances were unequal, the z-test was used to compare the two groups. A p-value of 0.05 was used in all tests.

Microsoft Excel was used to fit data to a curve, either linearly in the case of the OUR or exponentially in the case of the ISV test data.

Quality Assurance and Quality Control

All sampling and data analysis was completed with quality control in mind. All sample locations were marked during the off-gas testing and profile sampling to ensure that the same locations were sampled during each event. Samples submitted to the ALD laboratories were kept on ice from sample collection to submission. Chain of custody was documented for all samples. All instruments used in the field and in the laboratory were calibrated as needed and checked to ensure they were functioning properly. Data obtained from the study and all data analyses were reviewed for accuracy.

RESULTS AND DISCUSSION

Performance Evaluation of Secondary Treatment

The average results from the intensive sampling of the NAB and SAB PE that occurred on eight days during April 24, 2007, through May 4, 2007, are listed in Table 4. Although the averages of some of the parameters appear slightly different between batteries, there was no statistical difference between data sets for each parameter analyzed per the statistical analyses performed as described in the Materials and Methods section. These findings verify that the characteristics of the influent wastewater to the aeration tanks in each battery are equivalent. The daily results from the PE intensive sampling are provided in Appendix C. The average results from the same two-week intensive sampling of the NAB and SAB FE are listed in Table 5. Of the parameters measured, only NO_3-N was statistically different between batteries per the statistical analyses. The SAB had a consistently higher concentration of NO_3-N in the FE for the duration of the intensive sampling. The difference in NO_3-N concentrations between the SAB and NAB ranged from 1.91 to 4.27 mg/L on a given day. The higher NO_3-N concentrations in the SAB effluent cannot be attributed to greater nitrification occurring in the SAB since a difference in TKN concentrations in the effluent was not statistically observed in these results. The difference in NO_3-N concentrations in the NAB and SAB FE may be a result of the difference in RAS return methods. The SAB uses air lift to return RAS while the NAB uses centrifugal pumps. The lack of oxygen in the NAB return lines may be contributing to some denitrification. In addition, a small anoxic zone is located in the beginning of Pass 1 in the NAB aeration tank. The anoxic zone, which would further reduce the tank nitrate via denitrification, was documented as in use on October 17, 2007, and October 24, 2007, but the extent of its use, such as when it was first used and the duration of its use, is unknown. It is possible that the anoxic zone was in use during the intensive sampling, but this cannot be verified. The difference in NO_3-N concentrations was further evaluated during the fall sampling that was completed for a longer period of time. The daily results from the FE intensive sampling are provided in Appendix C.

The average results from the fall sampling of the NAB and SAB PE and FE that was completed on weekdays from September 5, 2007, through November 17, 2007, are listed in Tables 6 and 7, respectively. The daily PE and FE results from this sampling are provided in Appendix D. The fall sampling analyzed fewer parameters than the intensive sampling, as only those parameters needed to evaluate treatment efficiency were included. There were no statistical differences between the parameters measured in the PE of the two batteries, except for pH and NO_2-N. The pH in the SAB was higher than the pH in the NAB roughly 74 percent of the time, but the difference between the SAB and NAB only ranged between -0.35 and 0.15 pH units on a given day. The NO_2-N concentration in the SAB PE was lower than that in the NAB roughly 68 percent of the time with the difference between the SAB and NAB ranging from -1.17 and 0.33 mg/L on a given day.

Of the parameters measured in the FE of the NAB and SAB, the following were determined to be statistically different: NO_3-N, NH_3-N, Sol-P, SS, and VSS. These differences are suspected to be a result of the operating conditions for the two batteries. The SAB had higher MLVSS concentrations (2,170 versus 1,964 mg/L), and longer SRTs (12.7 versus 7.6 days) during the first half of the fall sampling resulting in a greater nitrification capacity, which can

TABLE 4: AVERAGE RESULTS FROM THE INTENSIVE SPRING 2007 SAMPLING OF AND THE STATISTICAL DIFFERENCE BETWEEN THE NORTH AND SOUTH PRIMARY EFFLUENTS

Parameter[1]	North Battery Primary Effluent		South Battery Primary Effluent		Probability of Null Hypothesis (Equal Means)[2]
	Average	Standard Deviation	Average	Standard Deviation	
BOD_5 (mg/L)	84.1	15.4	76.0	9.0	0.218
CODt (mg/L)	196.3	31.5	176.9	26.9	0.208
CODgf (mg/L)	84.3	12.6	79.1	14.6	0.465
CODff (mg/L)	55.4	13.3	50.0	12.6	0.420
TSS (mg/L)	54.9	13.9	51.9	11.0	0.639
VSS (mg/L)	47.4	11.8	44.0	9.13	0.532
TKN (mg/L)	21.59	3.96	21.30	3.89	0.888
Sol-TKN (mg/L)	15.28	3.32	15.29	3.05	0.996
TKNgf (mg/L)	17.01	4.05	17.53	3.94	0.800
NH_3-N (mg/L)	13.79	2.73	14.16	2.85	0.794
NO_2-N (mg/L)	0.439	0.282	0.461	0.258	0.869
NO_3-N (mg/L)	1.122	0.838	1.078	0.912	0.923
TP (mg/L)	3.62	0.62	3.55	0.67	0.820
Sol-P (mg/L)	1.78	0.46	1.83	0.47	0.856
TPgf (mg/L)	1.97	0.47	2.14	0.71	0.579
FOG (mg/L)	10.9	4.6	11.6	2.8	0.734

[1]t = total; gf = glass filtered, ff = filtered flocculated.
[2]Hypothesis was identical means; $p < 0.05$ considered null hypothesis and means are different.

TABLE 5: AVERAGE RESULTS FROM THE INTENSIVE SPRING 2007 SAMPLING OF AND STATISTICAL DIFFERENCE BETWEEN THE NORTH AND SOUTH FINAL EFFLUENTS

Parameter[1]	North Battery Final Effluent		South Battery Final Effluent		Probability of Null Hypothesis (Equal Means)[2]
	Average	Standard Deviation	Average	Standard Deviation	
CODt (mg/L)	39.4	17.4	31.4	13.5	0.321
CODff (mg/L)	13.4	4.2	14.4	9.7	0.964
TSS (mg/L)	11.4	15.0	5.8	2.9	0.627
TKN (mg/L)	1.90	0.98	1.55	0.19	0.974
NH_3-N (mg/L)	0.09	0.08	0.06	0.02	0.627
NO_2-N (mg/L)	0.020	0.009	0.023	0.008	0.562
NO_3-N (mg/L)	11.48	1.58	15.07	2.19	0.002
TP (mg/L)	0.46	0.23	0.32	0.05	0.351

[1]t = total; gf = glass filtered, ff = filtered flocculated.
[2]Hypothesis was identical means; $p < 0.05$ considered null hypothesis and means are different.

TABLE 6: AVERAGE RESULTS FROM THE FALL 2007 SAMPLING OF AND STATISTICAL DIFFERENCE BETWEEN THE NORTH AND SOUTH PRIMARY EFFLUENTS

Parameter[1]	North Battery Primary Effluent Average	North Battery Primary Effluent Standard Deviation	South Battery Primary Effluent Average	South Battery Primary Effluent Standard Deviation	Probability of Null Hypothesis (Equal Means)[1]
$CBOD_5$ (mg/L)	87.1	12.5	86.4	15.0	0.795
TKN (mg/L)	25.21	2.07	24.51	2.19	0.091
Sol-TKN (mg/L)	19.04	2.38	18.56	2.14	0.278
NH_3-N (mg/L)	18.48	1.94	18.01	1.62	0.179
NO_2-N (mg/L)	0.388	0.358	0.259	0.186	0.022
NO_3-N (mg/L)	0.330	0.364	0.309	0.301	0.740
TP (mg/L)	4.99	0.64	4.93	0.59	0.591
Sol-P (mg/L)	3.23	0.67	3.27	0.59	0.737
SS (mg/L)	53.0	18.9	52.5	12.5	0.875
VSS (mg/L)	44.5	15.6	45.1	11.1	0.830
pH	7.59	0.10	7.63	0.08	0.025

[1]Hypothesis was identical means; $p < 0.05$ considered null hypothesis and means are different.

TABLE 7: AVERAGE RESULTS FROM THE FALL 2007 SAMPLING OF AND STATISTICAL DIFFERENCE BETWEEN THE NORTH AND SOUTH FINAL EFFLUENTS

Parameter[1]	North Battery Final Effluent		South Battery Final Effluent		Probability of Null Hypothesis (Equal Means)[1]
	Average	Standard Deviation	Average	Standard Deviation	
$CBOD_5$ (mg/L)	2.3	0.7	2.2	0.4	0.204
TKN (mg/L)	1.16	0.23	1.17	0.30	0.759
Sol-TKN (mg/L)	0.90	0.23	0.81	0.30	0.081
NH_3-N (mg/L)	0.12	0.05	0.07	0.03	0.000
NO_2-N (mg/L)	0.030	0.010	0.030	0.020	0.846
NO_3-N (mg/L)	14.60	1.45	17.01	1.60	0.000
TP (mg/L)	0.50	0.19	0.53	0.13	0.414
Sol-P (mg/L)	0.35	0.14	0.28	0.11	0.012
SS (mg/L)	5.7	2.8	7.5	1.7	0.000
VSS (mg/L)	4.1	2.3	4.9	1.2	0.029
pH	7.06	0.17	7.03	0.14	0.307

[1]Hypothesis was identical means; $p < 0.05$ considered null hypothesis and means are different.

explain the higher NO_3-N and lower NH_3-N in the FE of the SAB. It is also believed that the difference in RAS return methods and possible operation of an anoxic zone in the NAB aeration tank may have contributed to the lower NO_3-N in the NAB effluent. Since the MLVSS was higher in the SAB, Sol-P, a nutrient for the biomass, was most likely lower due to uptake of P during cell synthesis. The higher SS and VSS in the SAB FE may have been due to higher solids loading rates to the SAB final settling tanks, roughly 64,000 compared to 42,000 lbs/day. The SRT may have also played a role in the higher solids in the SAB effluent as floc breakup is often noted to begin when the SRT is greater than 8 days at temperatures of 20° C and higher (Rittmann and McCarty, 2001). The raw sewage temperature during the fall sampling ranged from 17.8 to 22.2°C with an average of 20.6°C, and the SAB SRT ranged from 8.5 to 19.5 days, with an average of 12.6 days. Figures 3 to 7 show daily graphs of the NO_3-N, NH_3-N, Sol-P, SS, and VSS results, which were shown to be statistically different between battery effluents.

The ML SS (MLSS), MLVSS, and SRT for the NAB and SAB during the fall sampling are shown in Figures 8 to 10, respectively. As shown in these figures, the MLSS, MLVSS, and SRT were all higher in the SAB, particularly during the first half of the fall sampling. This difference in these parameters may be the result of the excessive *Nocardia* growth that occurred in the Fall of 2007 in the NAB. The $FeCl_3$ was added to the aeration tank for a phosphorus removal study at that time. Lowered alkalinity levels in the aeration tanks may be the trigger of *Nocardia* growth. A foam developed on the water surface of the NAB in which bacteria accumulated and therefore decreased the SS in the liquid and extended actual SRT. The NAB SRT may have been shortened in order to waste more sludge and alleviate some of the excessive filament growth. Other operating parameters were reviewed for the two batteries. Figures 11 and 12 show the F/M and SVI for the two batteries. The F/M was relatively similar for the duration of the sampling, despite the accumulation of bacteria in the NAB foam, with averages of 0.13 and 0.12 kg CBOD/kg VSS for the NAB and SAB, respectively. The difference between the NAB and SAB F/M ranged from -0.06 to 0.06 kg CBOD/kg VSS on a given day. These F/M ratios measured in both the NAB and SAB are lower than typical F/M values, 0.25 to 0.5 kg CBOD/kg VSS, found in literature, but are typical of District plants. The SVI was consistently higher in the NAB throughout the duration of the fall sampling. The average SVIs in the NAB and SAB were 69 and 58 mL/g, respectively, with the difference between the NAB and SAB SVIs ranging between -0.5 and 20.0 mL/g SS on a given day.

Beginning on November 3, 2007, the MLSS, MLVSS, SRT, and F/M were relatively similar between the NAB and SAB (Figures 8 to 10). Due to the similarity in operations at this time, the battery FE results measured on or after November 3 during the fall sampling were compared. Averages of the operating and FE data are listed in Table 8. Of the FE parameters, NO_3-N, SS, and VSS were still statistically different between the two batteries despite the similarity in operations (Figures 3, 6, and 7, respectively). However, the similarity in operations resulted in equivalent NH_3-N and Sol-P concentrations in the effluents (Figures 4 and 5, respectively). The difference in effluent NO_3-N concentrations indicates that denitrification was occurring, which may be the result of the RAS return method in the NAB and/or possible use of an anoxic zone in the NAB tank. Detailed dates for anoxic zone operation are not available so denitrification due to the anoxic zone cannot be verified. It is possible that the difference in RAS return methods between the two batteries, centrifugal pump versus air lift for the NAB and SAB, respectively, plays a role in the higher NO_3-N concentration in the SAB. Even without the anoxic zone, it is possible that some denitrification occurs in the very beginning of the NAB tank due to

FIGURE 3: NITRATE NITROGEN CONCENTRATIONS IN THE FINAL EFFLUENTS DURING THE FALL 2007 SAMPLING OF THE NORTH AND SOUTH AERATION BATTERIES

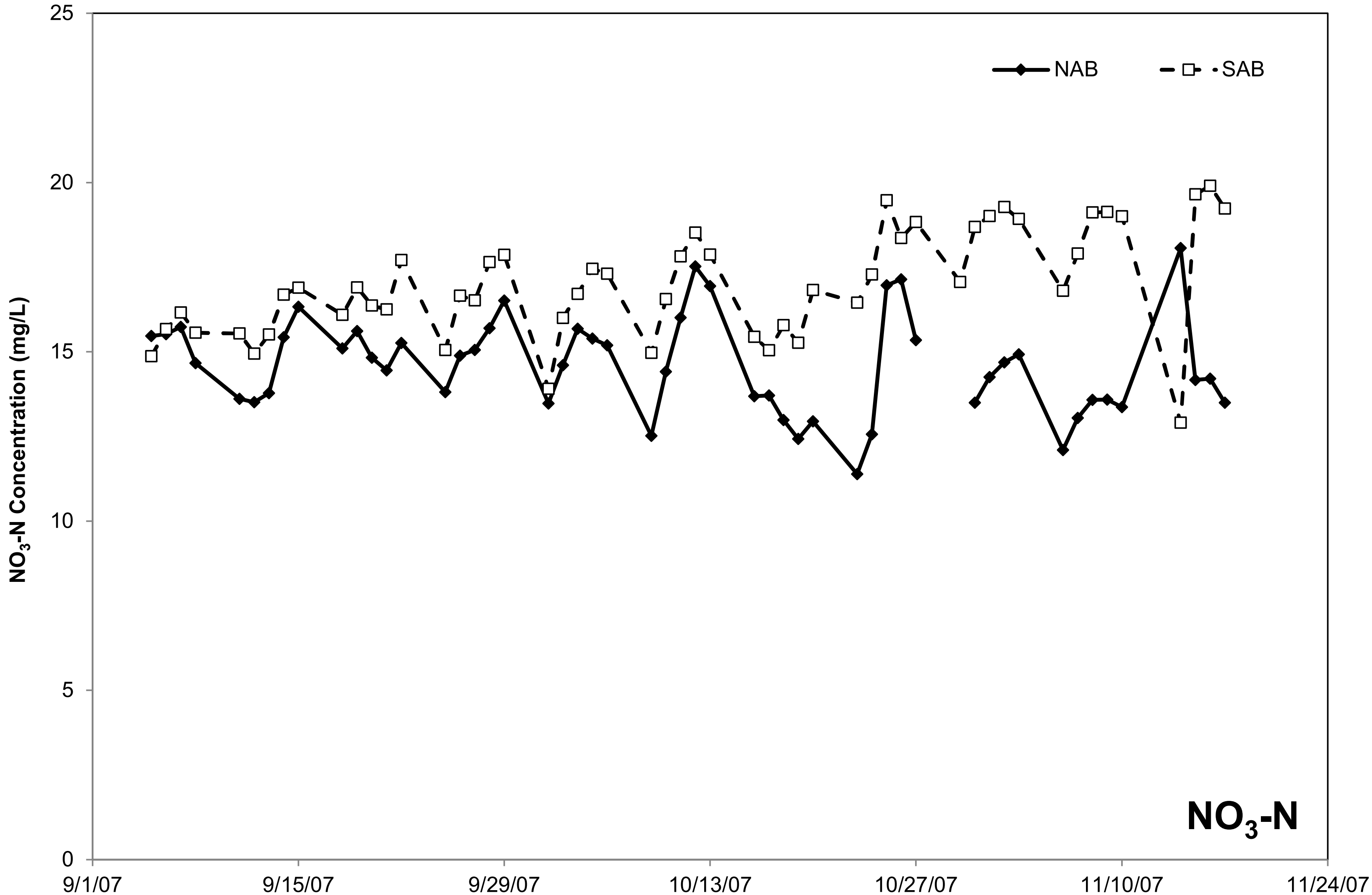


FIGURE 4: AMMONIA NITROGEN CONCENTRATIONS IN THE FINAL EFFLUENTS DURING THE FALL 2007 SAMPLING OF THE NORTH AND SOUTH AERATION BATTERIES

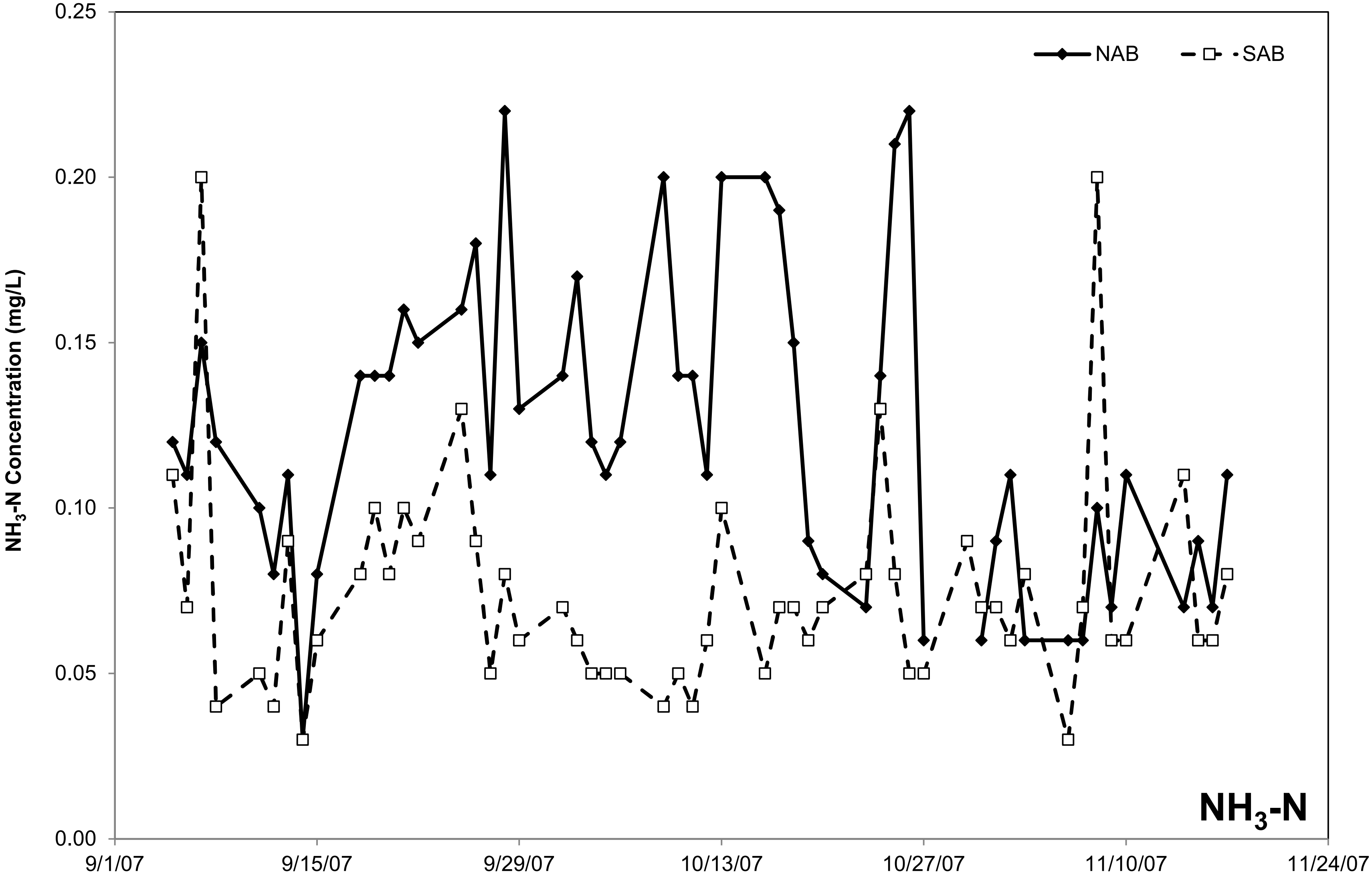


FIGURE 5: SOLUBLE PHOSPHORUS CONCENTRATIONS IN THE FINAL EFFLUENTS DURING THE FALL 2007 SAMPLING OF THE NORTH AND SOUTH AERATION BATTERIES

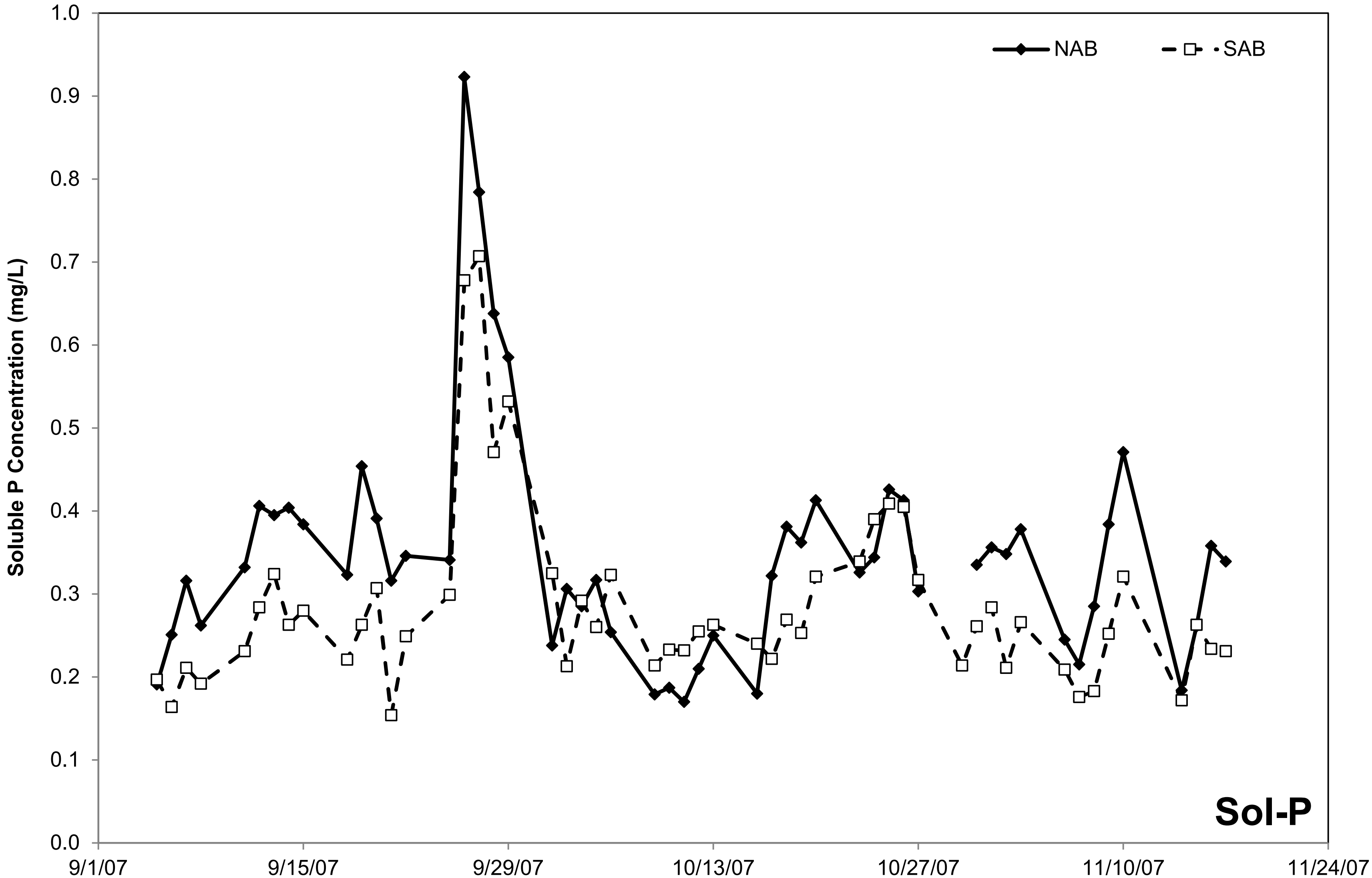


FIGURE 6: SUSPENDED SOLIDS CONCENTRATIONS IN THE FINAL EFFLUENTS DURING THE FALL 2007 SAMPLING OF THE NORTH AND SOUTH AERATION BATTERIES

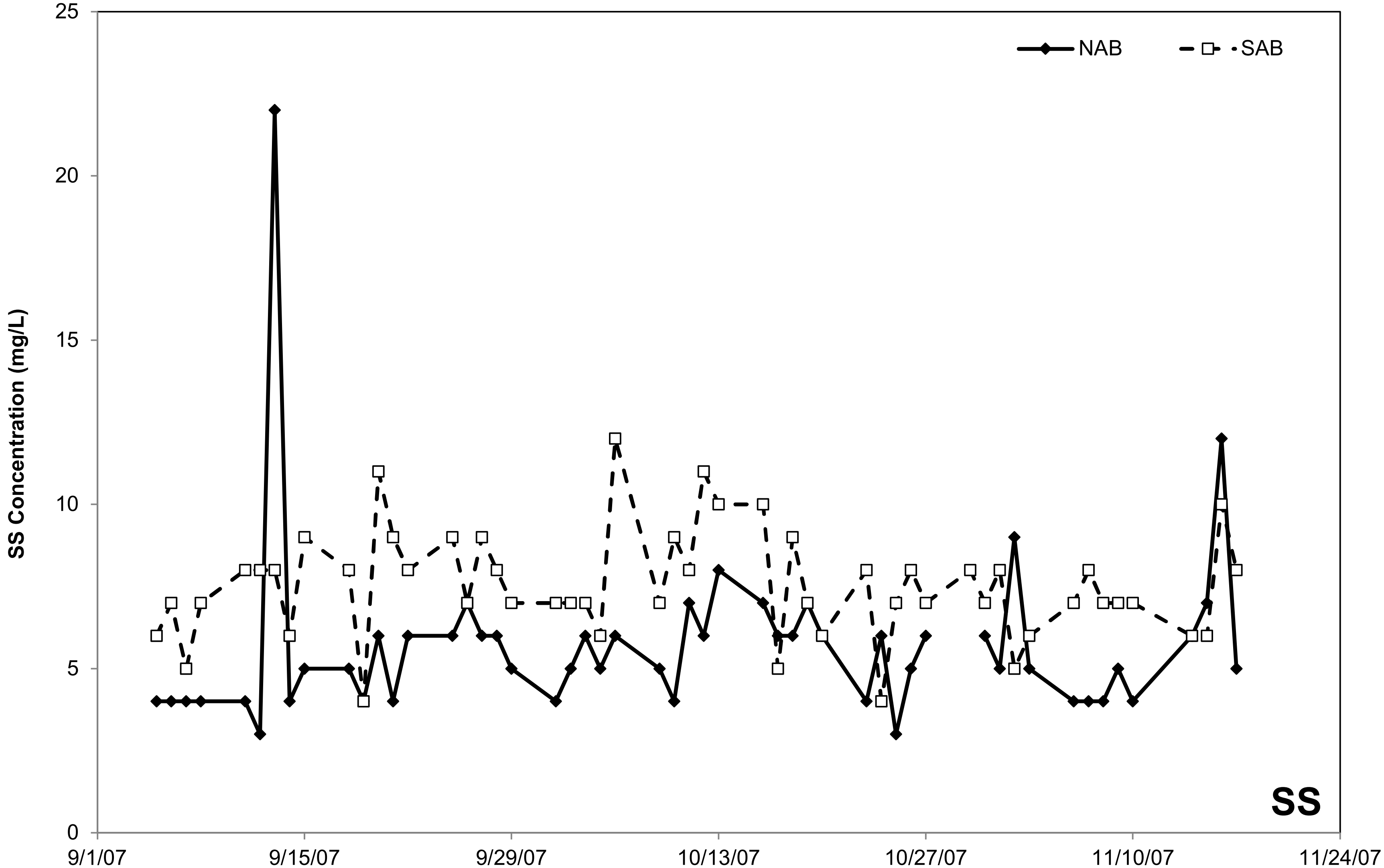


FIGURE 7: VOLATILE SUSPENDED SOLIDS CONCENTRATIONS IN THE EFFLUENTS DURING THE FALL 2007 SAMPLING OF THE NORTH AND SOUTH AERATION BATTERIES

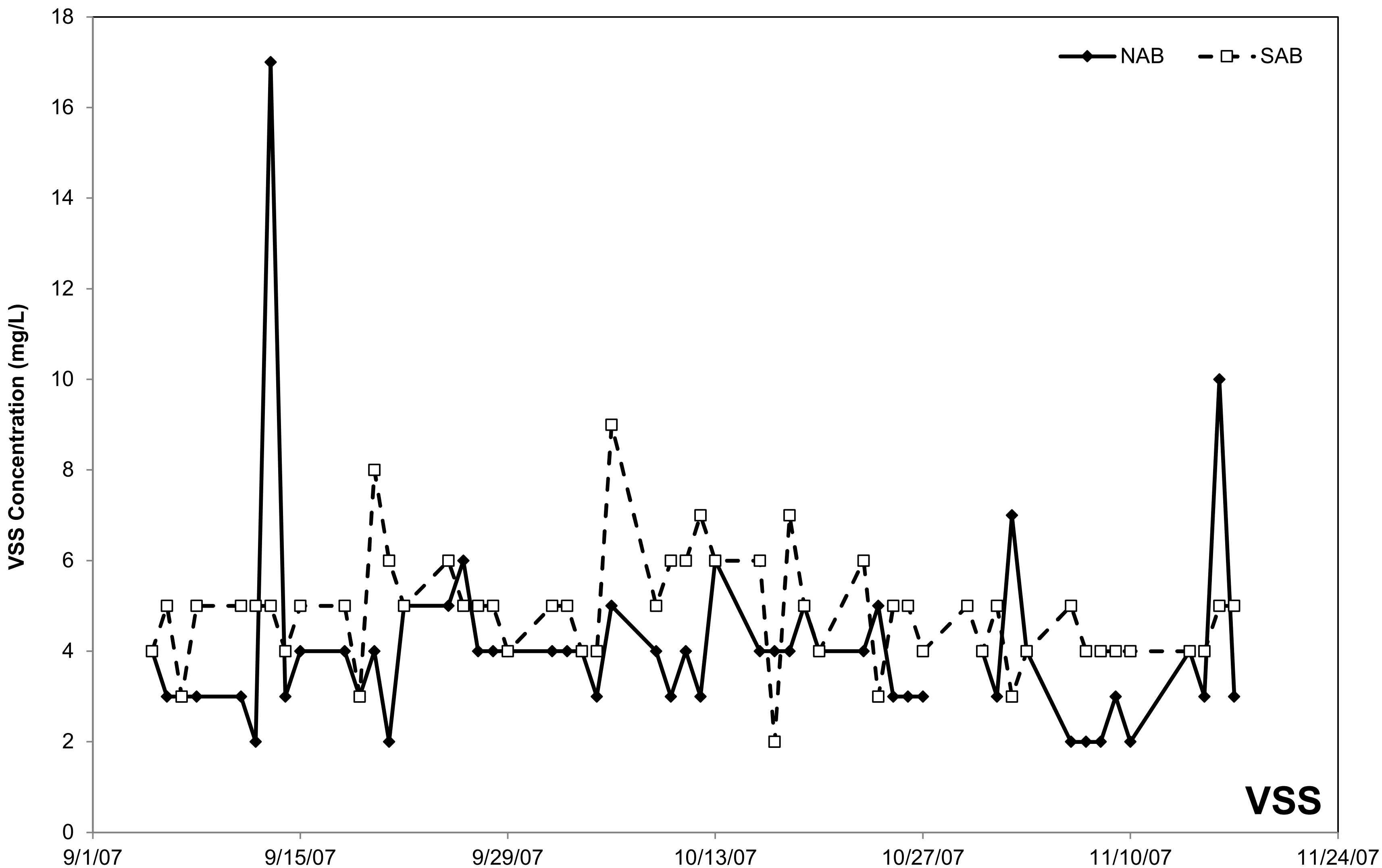


FIGURE 8: MIXED LIQUOR SUSPENDED SOLIDS IN THE NORTH AND SOUTH BATTERY AERATION TANKS DURING THE FALL 2007 SAMPLING

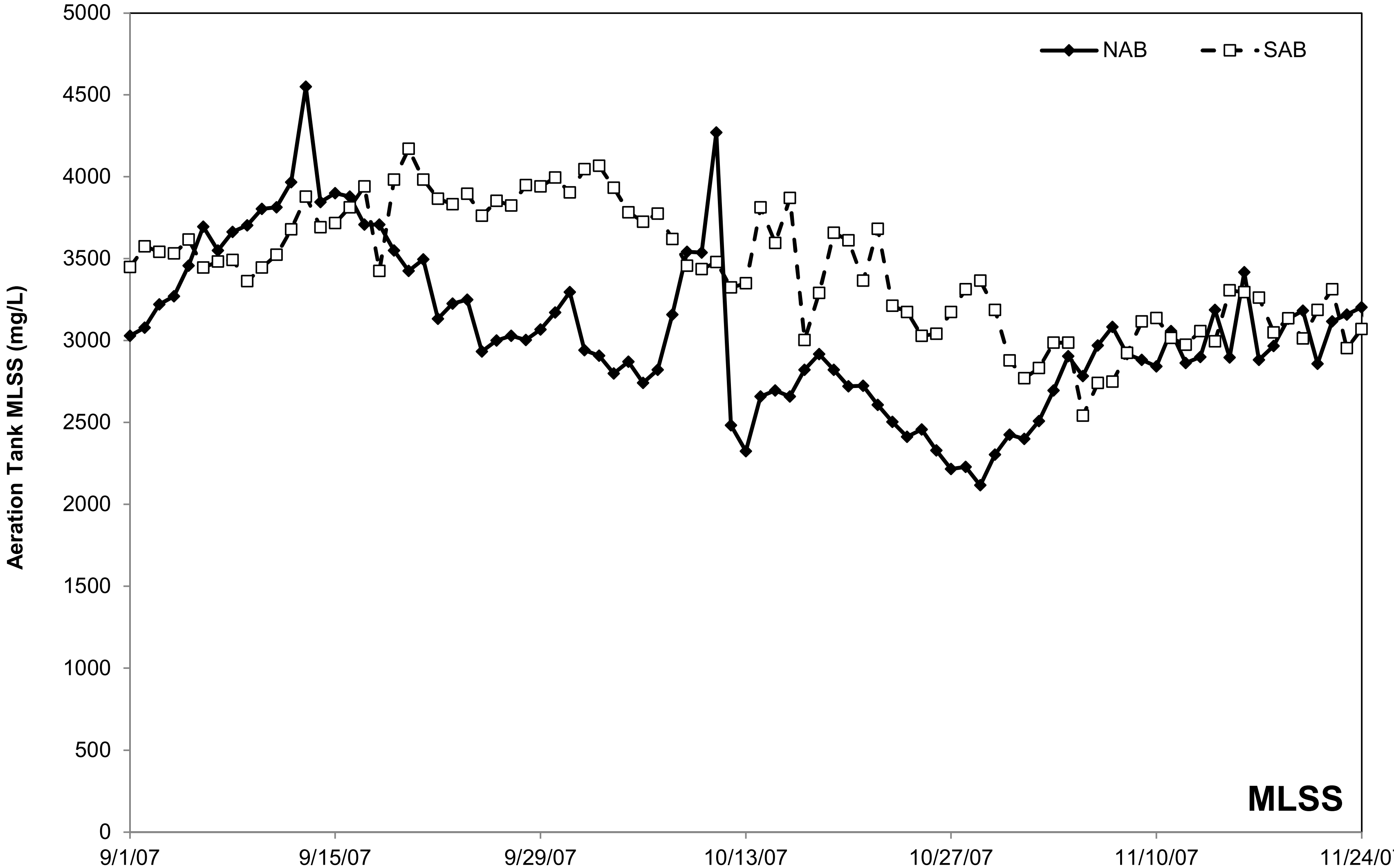


FIGURE 9: MIXED LIQUOR VOLATILE SUSPENDED SOLIDS IN THE NORTH AND SOUTH BATTERY AERATION TANKS DURING THE FALL 2007 SAMPLING

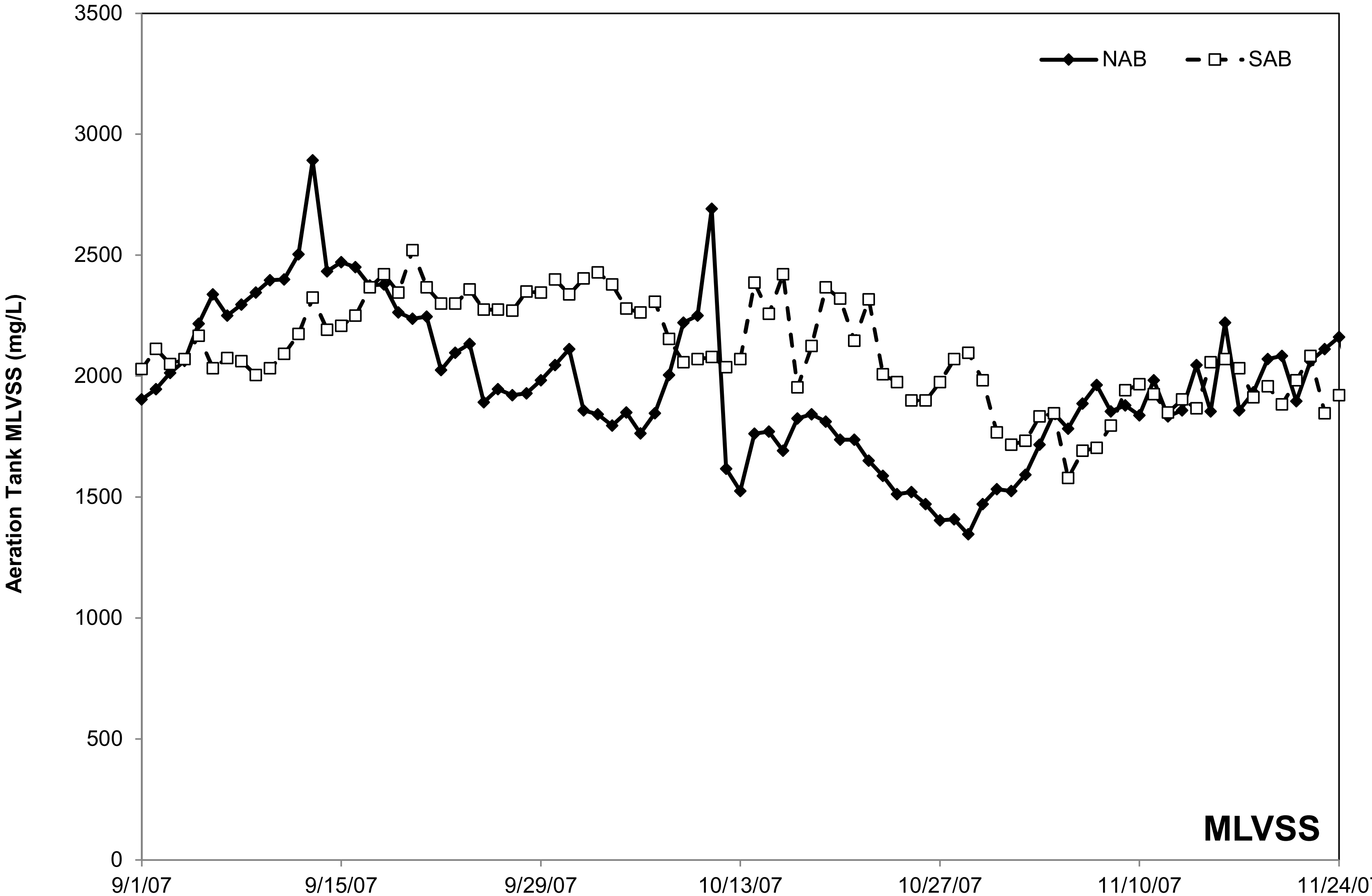


FIGURE 10: SOLIDS RETENTION TIME IN THE NORTH AND SOUTH AERATION BATTERIES DURING THE FALL 2007 SAMPLING

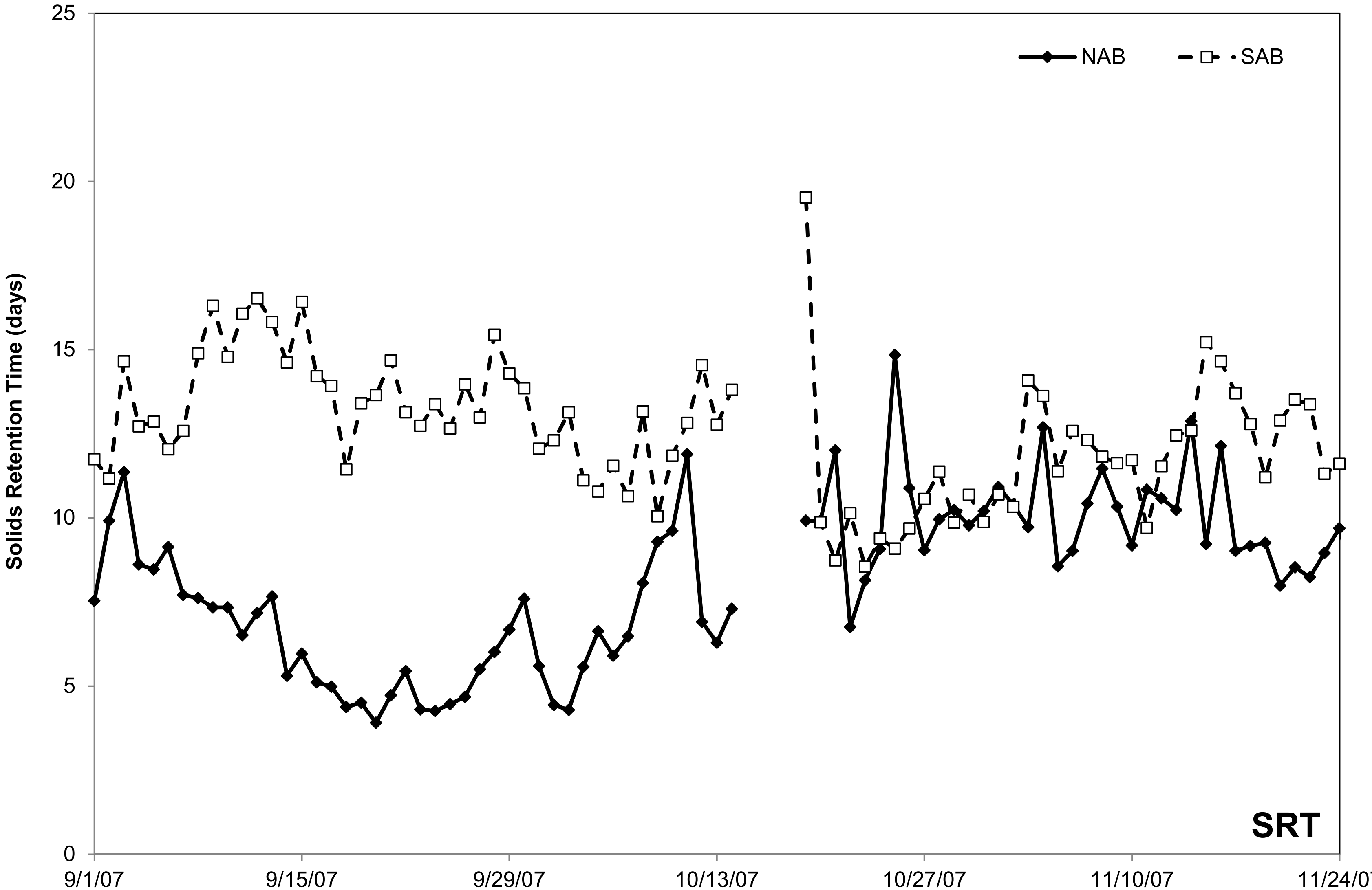


FIGURE 11: DAILY FOOD-TO-MICROORGANISM RATIO FOR THE NORTH AND SOUTH AERATION BATTERIES DURING THE FALL 2007 SAMPLING

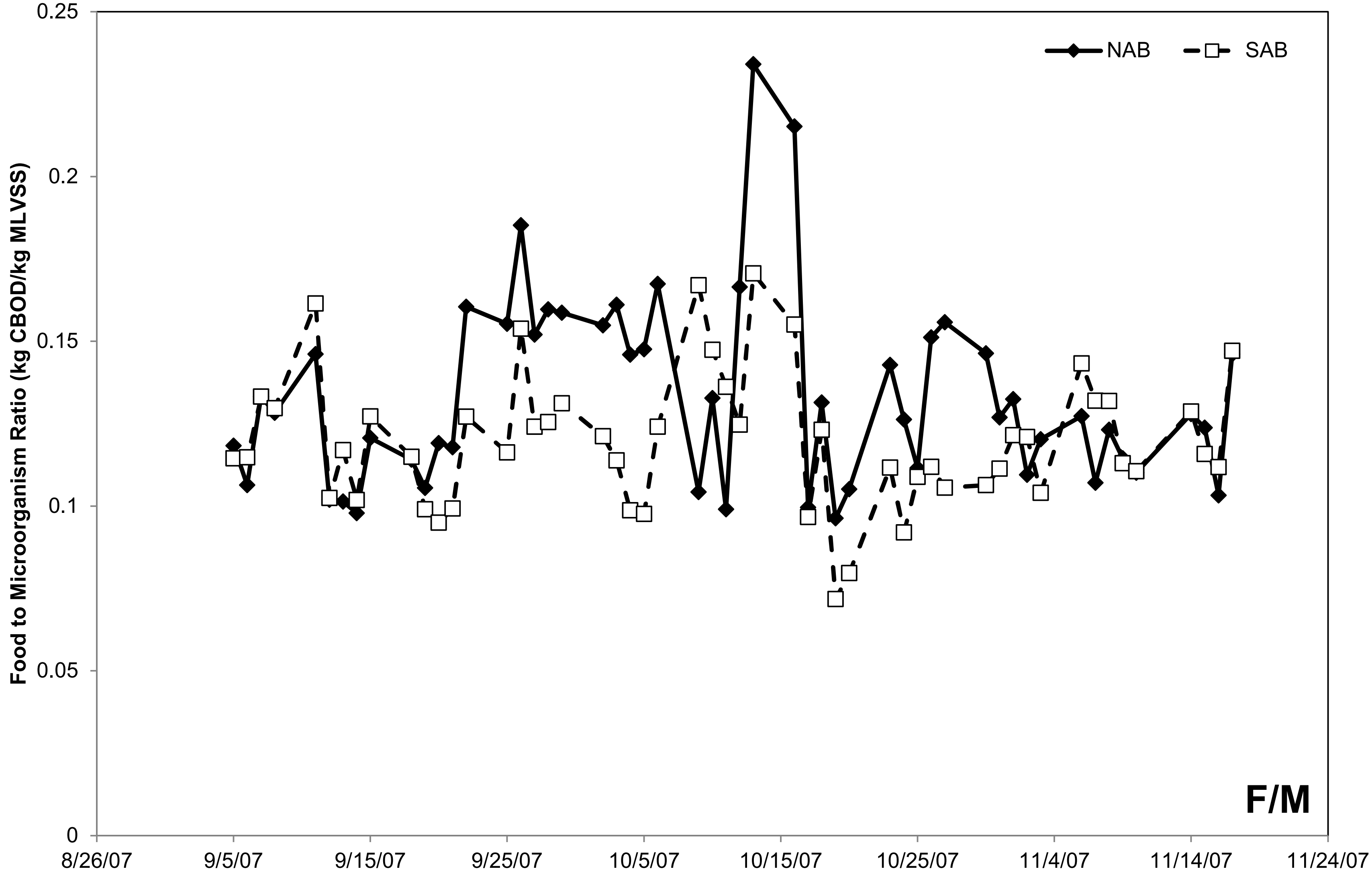


FIGURE 12: SLUDGE VOLUME INDEX OF THE NORTH AND SOUTH MIXED LIQUOR DURING THE FALL 2007 SAMPLING

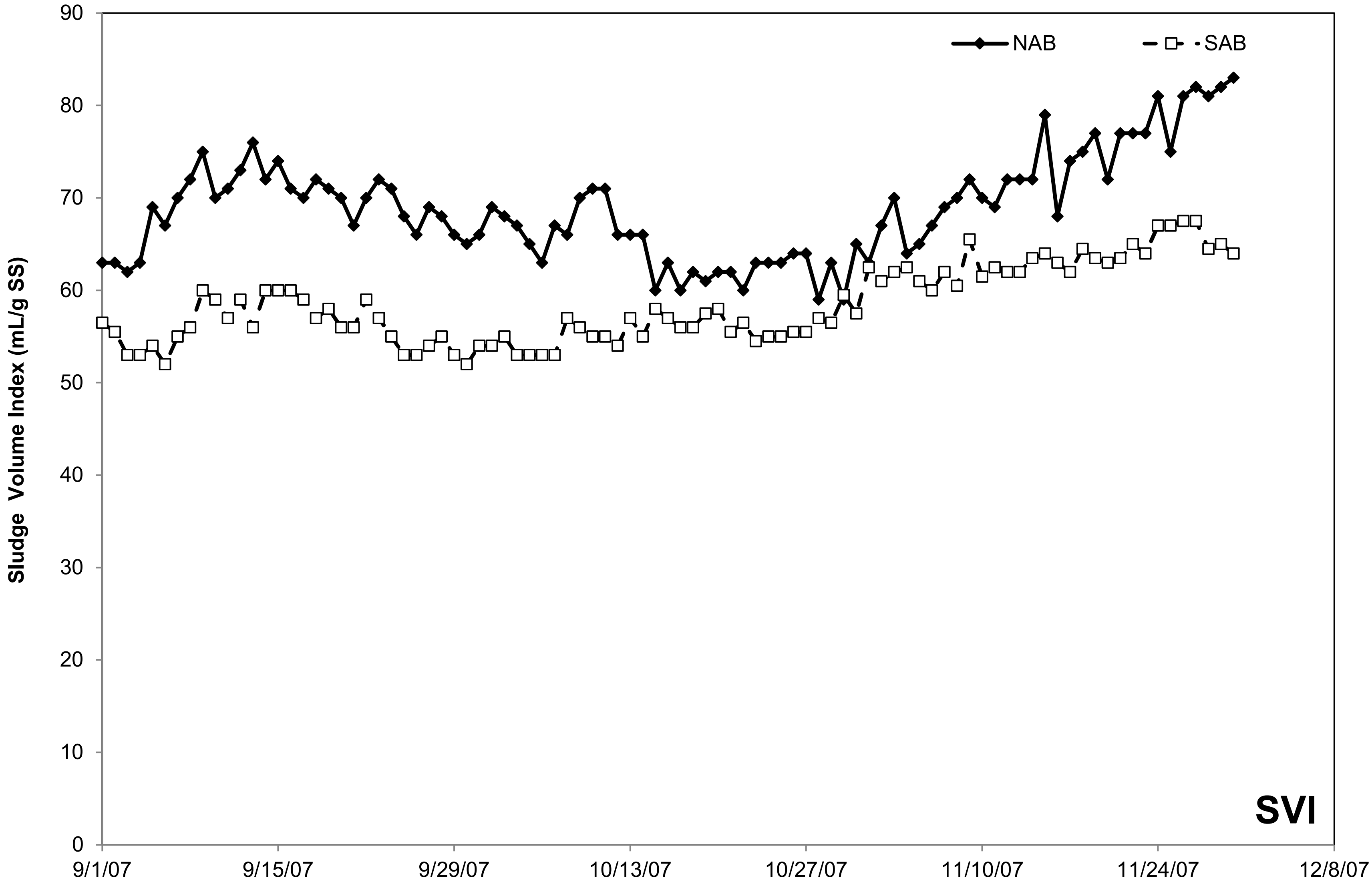


TABLE 8: OPERATING DATA AND FINAL EFFLUENT DATA FOR THE NORTH AND SOUTH AERATION BATTERIES FROM NOVEMBER 3 TO NOVEMBER 17, 2007

Parameter	North Aeration Battery		South Aeration Battery	
	Average	Standard Deviation	Average	Standard Deviation
Operating Parameters				
MLSS (mg/L)	2,952	176	3,007	213
MLVSS (mg/L)	1,895	120	1,871	140
SRT (days)	10.4	1.4	12.6	1.4
F/M (kg CBOD/kg MLVSS)	0.12	0.01	0.12	0.01
SVI (mL/g SS)	70.2	3.7	62.3	1.4
Final Effluent Concentrations				
TKN (mg/L)	1.18	0.08	1.39	0.46
Sol-TKN (mg/L)	0.90	0.15	0.93	0.54
NH_3-N (mg/L)	0.08	0.02	0.08	0.05
NO_2-N (mg/L)	0.022	0.005	0.024	0.003
NO_3-N (mg/L)	14.05	1.60	18.26	2.08
TP (mg/L)	0.45	0.09	0.47	0.09
Sol-P (mg/L)	0.31	0.09	0.23	0.05
SS (mg/L)	5.6	2.5	7.2	1.2
VSS (mg/L)	3.5	2.4	4.3	0.5
pH	7.04	0.23	7.02	0.18
CBOD	<2	-	<2	-

the low oxygen returned with the RAS. The NO_3-N through the length of the aeration tanks is further evaluated under the profile sampling results.

A solids mass balance was completed using the results from the fall sampling, other routine sampling data, and operating data. Figures 13 and 14 show the average mass balance results for the NAB and SAB, respectively, using the average SS concentrations from the fall sampling duration. The daily mass balance for each battery can be found in Appendix E. To analyze the mass balance results, the influent load was subtracted from the total effluent loads: (FE + WAS) – PE. For the NAB and SAB, the difference in solids was 6,213 and 5,313 lb/day, respectively. The difference can be partly attributed to biomass growth in the aeration tanks as well as the concurrent Phosphorus Reduction Project in which $FeCl_3$ was added to the ML aeration tank effluent resulting in additional inorganic solids formation. To further investigate the large difference in solids, the observed yield of biomass was estimated using Equation 1 and compared to typical values found in literature.

$$Biomass\ Produced = (CBOD_{5i} - CBOD_{5e}) \times Y_{obs} \qquad 1$$

where,

$Biomass\ Produced$	=	estimated based on amount of waste activated sludge (lb/day)
$CBOD_{5i}$	=	influent 5-day CBOD (lb/day)
$CBOD_{5e}$	=	effluent 5-day CBOD (lb/day)
Y_{obs}	=	observed yield coefficient (lb VSS/lb $CBOD_5$ removed)

To use Equation 1 to calculate Y_{obs}, the biomass produced was estimated using the WAS flow rate and the VSS concentration of the RAS. No VSS data is available for the RAS, but assuming the VSS/SS ratio of the ML applies to the RAS, the calculated Y_{obs} was 1.06 and 0.68 lb VSS/lb $CBOD_5$ for the NAB and SAB, respectively. The Y_{obs} for the NAB and SAB were determined to be statistically different. The higher Y_{obs} in the NAB can be attributed to shorter SRTs, an average of 8 days versus 13 days in the SAB. However, experience has shown that long SRTs in the NAB can lead to excess filamentous bacteria growth and may result in elevated SVIs, so the SRT is typically kept lower in the NAB. The daily estimated Y_{obs} are included in Appendix E.

The observed yield, Y_{obs}, is the net yield (Y) excluding the quantity from endogenous respiration. The Y can be calculated from the Y_{obs} per Equation 2.

$$Y_{obs} = {}^{Y}\!/_{(1 + bSRT)} \qquad 2$$

where,

Y	=	yield coefficient (lb VSS/lb $CBOD_5$ removed)
b	=	decay coefficient, assumed to be 0.06 /day
SRT	=	solids retention time (days)

FIGURE 13: SUSPENDED SOLIDS MASS BALANCE FOR THE NORTH AERATION BATTERY USING THE AVERAGE CONCENTRATIONS AND FLOWS FROM SEPTEMBER 5, 2007, THROUGH NOVEMBER 27, 2007

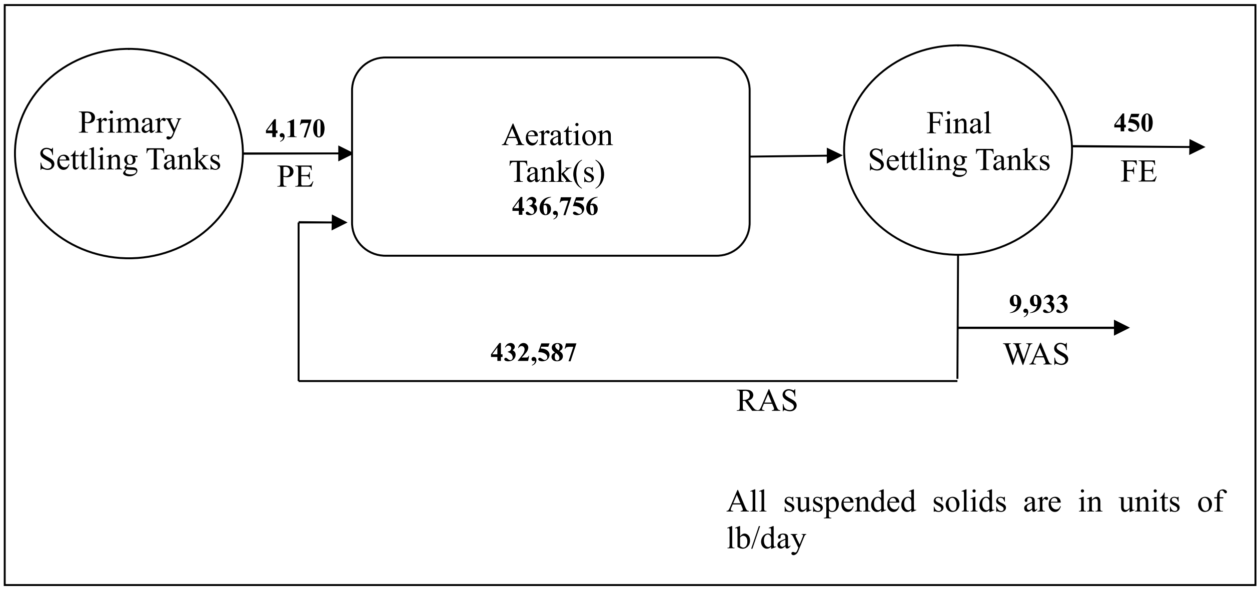
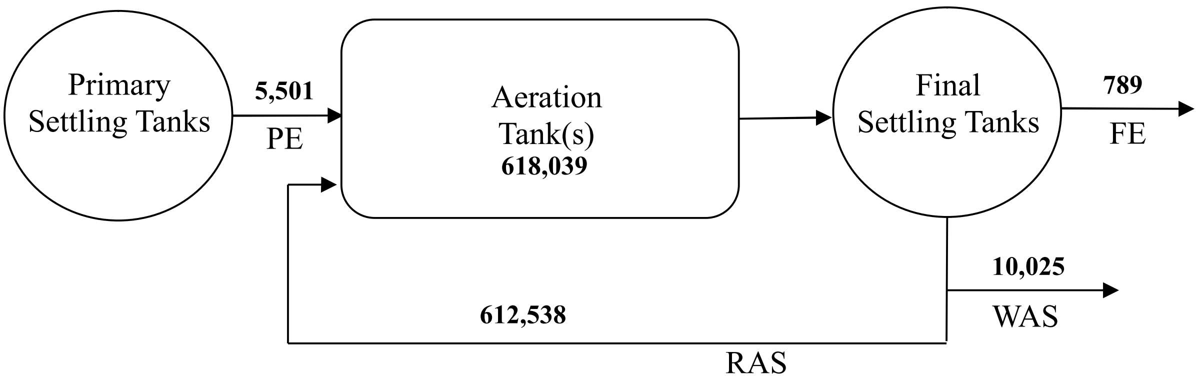


FIGURE 14: SUSPENDED SOLIDS MASS BALANCE FOR THE SOUTH AERATION BATTERY USING THE AVERAGE CONCENTRATIONS AND FLOWS FROM SEPTEMBER 5, 2007, THROUGH NOVEMBER 27, 2007



All suspended solids are in units of lb/day

Based on Equation 2, the Y was 1.58 and 1.24 for the NAB and SAB, respectively. Typical Y values found in literature range from 0.40 to 0.80 lb VSS/lb $CBOD_5$ with typical values being around 0.6 (Metcalf and Eddy, 1991). The Y calculated for the NAB and SAB during this project were higher than those typically found in literature. The reasons for the deviation are yet to be determined.

Specific Oxygen Uptake Rate

The SOURs measured during the off-gas tests were averaged and are provided in Figure 15. The SOUR in the SAB was higher than in the NAB through roughly the first half of the aeration tanks, with the difference ranging between 3.9 and 8.7 mg O_2/g VSS/hr on a given day. This is the result of a more variable MLVSS in the NAB between sample days compared to the SAB in the first half of the tank and a lower OUR. The MLVSS was higher throughout the NAB tank length on roughly half the sample days, while the MLVSS in the NAB and SAB tanks were relatively similar on the remaining days. Also during this study, it was discovered that a leak in the RAS line in the SAB allowed a portion of the RAS to enter the aeration tank at roughly ¾ down the length of Pass 1 instead of entering at the head of the tank. This resulted in a lower MLVSS in beginning of the SAB tank.

Standard Oxygen Transfer Efficiency

The average $SOTE_f$ results from the NAB and SAB are shown in Figure 16. The results compare well with typical $SOTE_f$ values found in literature, 6 to 14 percent. As expected, the $SOTE_f$s increase down the length of the tank, as it is easier to transfer oxygen into cleaner water. There was a difference between the $SOTE_f$s in the NAB and SAB. The NAB $SOTE_f$s were consistently higher, with the difference between NAB and SAB ranging between 0.017 to 0.053 on a given test day. In general, $SOTE_f$ will decrease with (1) increasing operation time due to diffuser fouling, (2) shorter SRT, (3) increasing air flow through a diffuser, and (4) increasing DO in the ML (USEPA, 1989). The SRT was shorter in the NAB for most of the study and the DO was either similar or higher in the NAB, so the difference in $SOTE_f$ cannot be attributed to SRT or DO. Reliable air flow data for the NAB is not available, so it is not possible to evaluate whether the difference in $SOTE_f$ is due to higher air flow through the diffusers.

A probable cause for the difference in $SOTE_f$s in the two batteries may be the result of the diffuser age. At the time of testing, the SAB diffuser plates were original to the plant, which went into operation in December 1975. The NAB diffuser discs, however, were put into service when the new full-floor coverage system was installed in 2002. The older diffusers and aeration system in the SAB may have leaks, etc., which can negatively affect the $SOTE_f$.

The $SOTE_f$ was measured at location 2 in Pass 1 of Tank 2 in both batteries with varying air flow rates applied to that pass. The $SOTE_f$ results versus air flow rates for the two batteries are shown in Figure 17. There was a decrease in $SOTE_f$ with increasing air flow to Pass 1 in the NAB, but no change in $SOTE_f$ was observed in the SAB. As mentioned above, there is some question on the reliability of the air flow data for the NAB, as operator experience has shown that the metering on the air pipes feeding the three passes of the NAB tanks are not accurate. It is not clear why the $SOTE_f$ did not drop with increasing air flow in the SAB, although it is possible

FIGURE 15: AVERAGE PROFILES OF THE SPECIFIC OXYGEN UPTAKE RATES AT 20 DEGREES CELSIUS IN THE NORTH AND SOUTH BATTERY AERATION TANKS DURING THE 2007 OFF-GAS TESTING

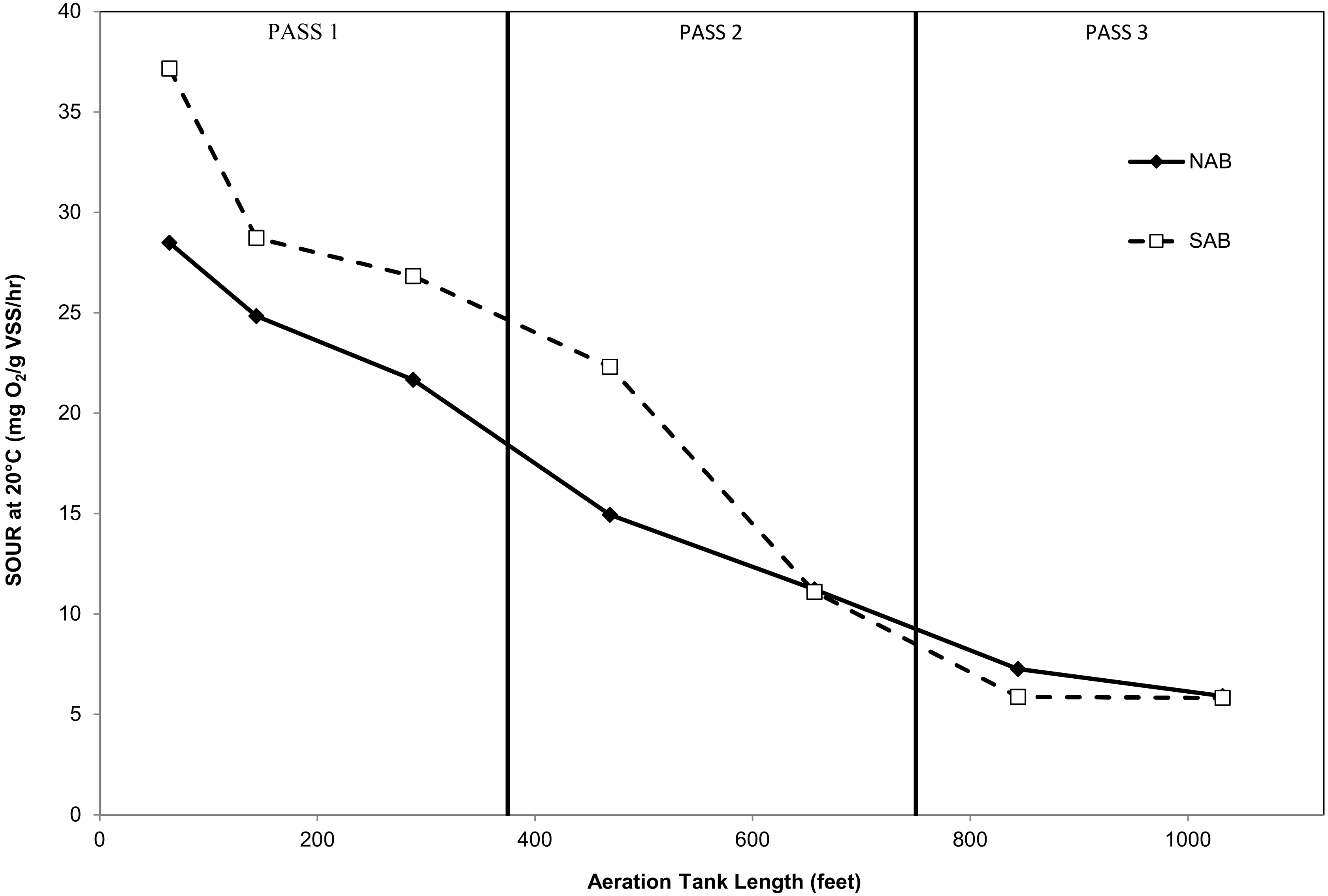


FIGURE 16: AVERAGE STANDARD OXYGEN TRANSFER EFFICIENCIES IN THE NORTH AND SOUTH BATTERY AERATION TANKS DURING THE 2007 OFF-GAS TESTING

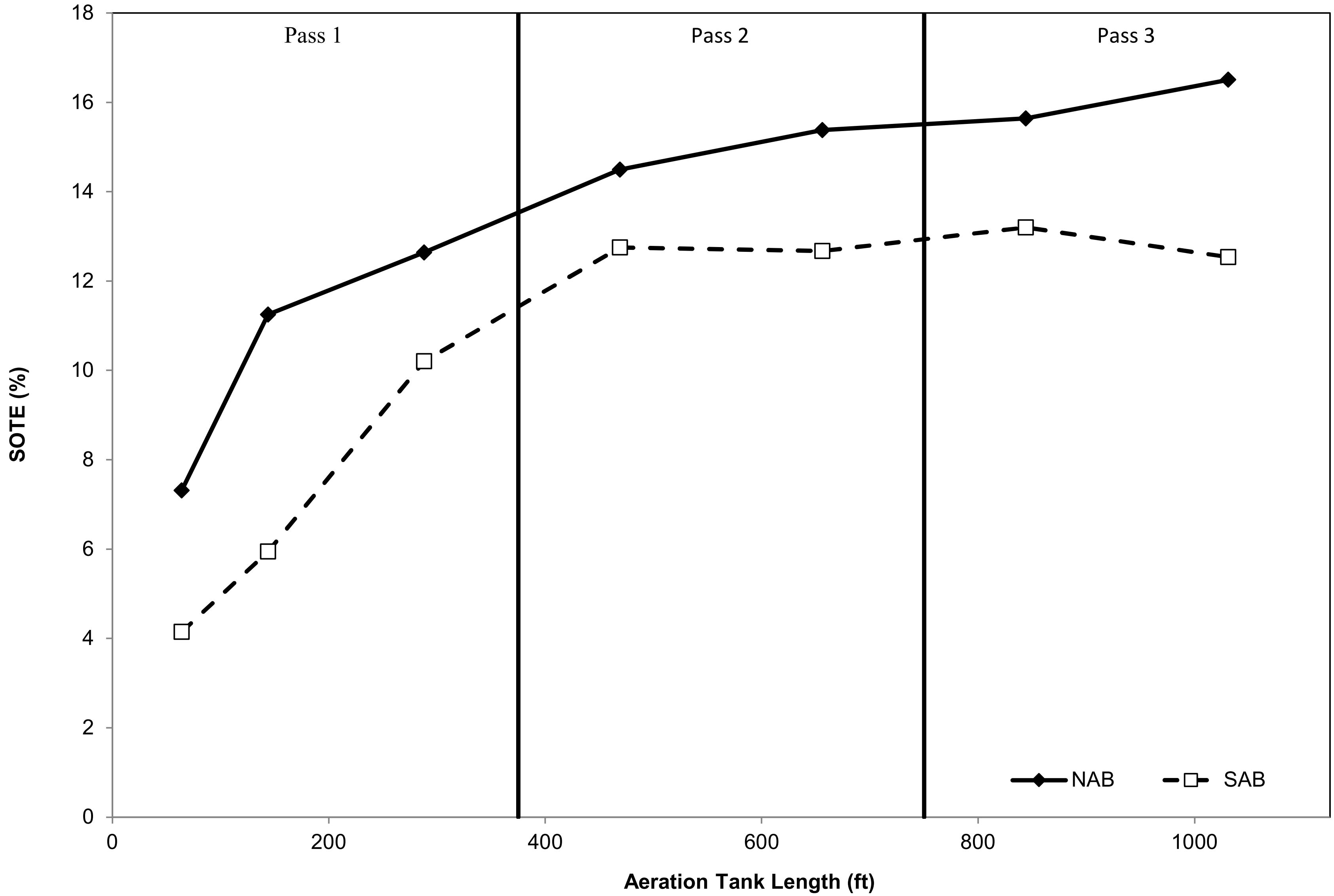
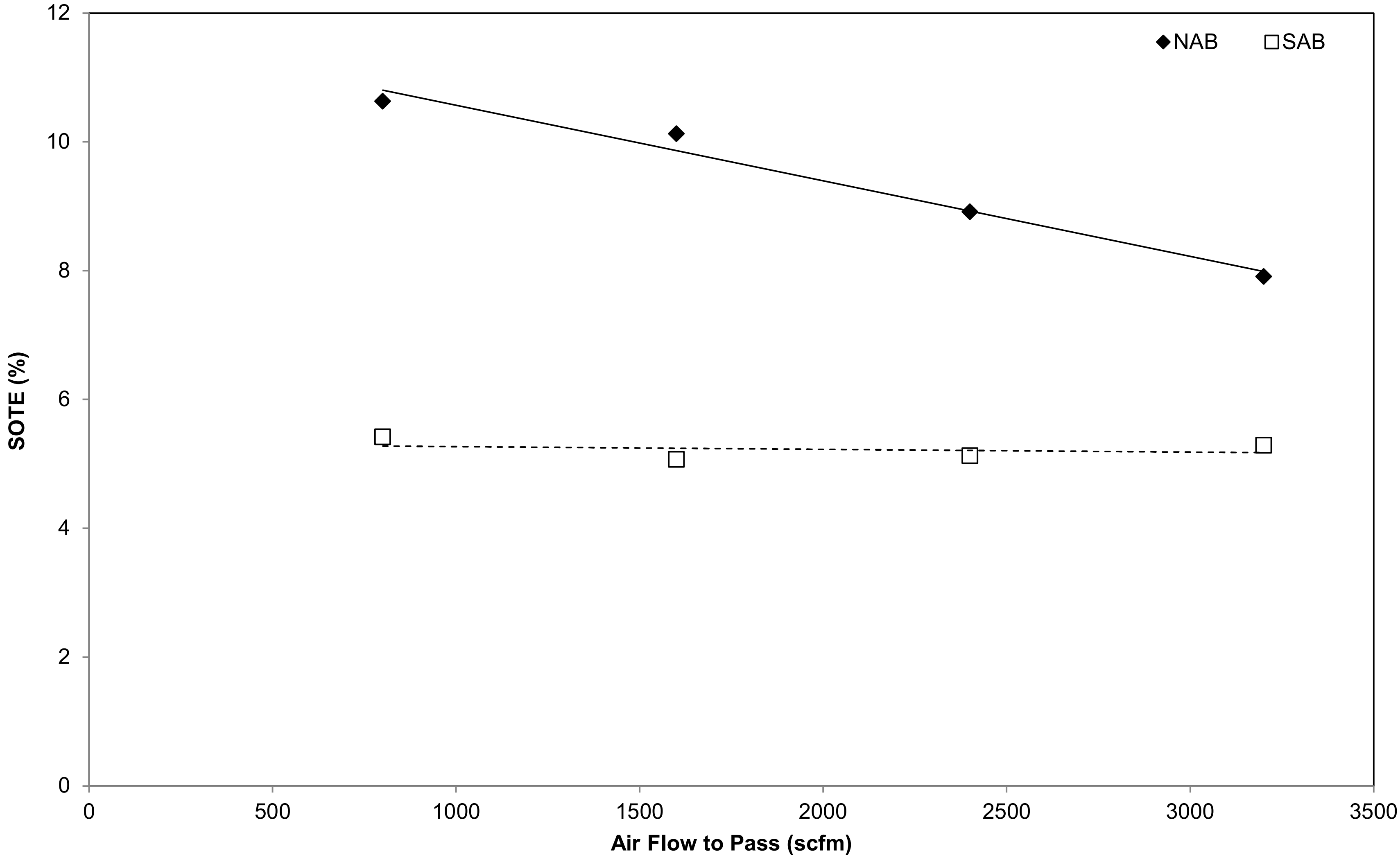


FIGURE 17: STANDARD OXYGEN TRANSFER EFFICIENCY VERSUS AIR FLOW TO THE PASS FOR THE NORTH AND SOUTH AERATION BATTERIES FROM THE 2007 OFF-GAS TESTING



that the spiral roll configuration impacted the results. Discussion below describes how the $SOTE_f$ measured in the SAB varies at a specific tank length as the off-gas hood is positioned width-wise across the tank. The $SOTE_f$ measurements versus air flow rates were measured with the off-gas hood located along the tank side wall, above the diffuser plates. Perhaps a decreasing trend in $SOTE_f$ versus air flow would have been observed if a weighted average $SOTE_f$ was calculated for the entire width of the SAB tank.

For quality assurance, duplicate off-gas tests were done in the field to verify that the test results were reproducible. The duplicate tests used two hoods side-by-side in the direction of flow. The results of the duplicate testing are shown in Figure 18 with the result from the first test on the x-axis and the result from the second test on the y-axis. Based on these results, the off-gas testing appears to be reasonably repeatable with the difference between duplicate tests less than ±0.024 and an average difference of ±0.007. In addition, the duplicate tests demonstrated that using a hood location positioned plus or minus a few feet in the direction of flow will lead to similar results. Measuring $SOTE_f$ via the off-gas method twice, one immediately following the other, will never result in the same exact result as the aeration tanks are a dynamic process and the parameters affecting the $SOTE_f$ measurement are always changing. The results from the duplicate testing were evaluated relative to off-gas flow rate, DO, and OUR, to determine if a slight change in one of these parameters may have caused the difference in the duplicate results, but no correlation was found.

Additional testing was done to compare results obtained using off-gas collection hoods of different material, metal versus wood, and results obtained from different hood positions. Evaluating the $SOTE_f$ versus varying hood positions was performed specifically for the SAB due to the diffusers only being located on one side of the tank. The off-gas testing completed in 2007 used a metal hood adjacent to the side wall located above the diffusers. In 2008, testing was completed comparing the $SOTE_f$ using a hood located along the side wall above the diffusers and the $SOTE_f$ from the hood located in the middle, width-wise, of the tank. The results comparing the hood material and hood position are shown in Figure 19. The results indicate that the hood material, metal versus wood, may not have a huge impact on the $SOTE_f$ results when used in the off-gas method. Of the three comparisons, one did show a larger difference in $SOTE_f$s of roughly 0.026, but this difference is close to that observed between duplicate tests as shown in Figure 18. The results shown in Figure 19 also indicate that the location of the hood, specifically in an aeration tank with a spiral roll configured aeration system, does impact the $SOTE_f$ results. The $SOTE_f$ measured with the off-gas hood located in the middle of the aeration tank width was consistently higher than the $SOTE_f$ measured with the hood above the diffusers and adjacent to the side wall. The difference between the $SOTE_f$ measured with middle and side hood positions ranged from 0.021 to 0.084 for a given test day.

In 2009 and 2010, additional off-gas testing was completed to further evaluate the affect of hood location on $SOTE_f$ in the SAB. Various hood configurations were evaluated as part of this testing. These configurations (Figure 2) included (1) an angled metal hood adjacent to the side wall, Configuration C, (2) a square metal hood adjacent to the side wall, Configuration A, (3) a square metal hood in the middle of the aeration tank width, Configuration B, and (4) a combination that captured roughly two-thirds of the aeration tank width with standard oxygen uptake rate (SOTE) calculated from the weighted average of the $SOTE_f$ using off-gas flux, Configuration D.

FIGURE 18: COMPARISON OF THE DUPLICATE AND CONSECUTIVE OFF-GAS STANDARD OXYGEN TRANSFER EFFICIENCY RESULTS FROM THE 2008 OFF-GAS TESTING

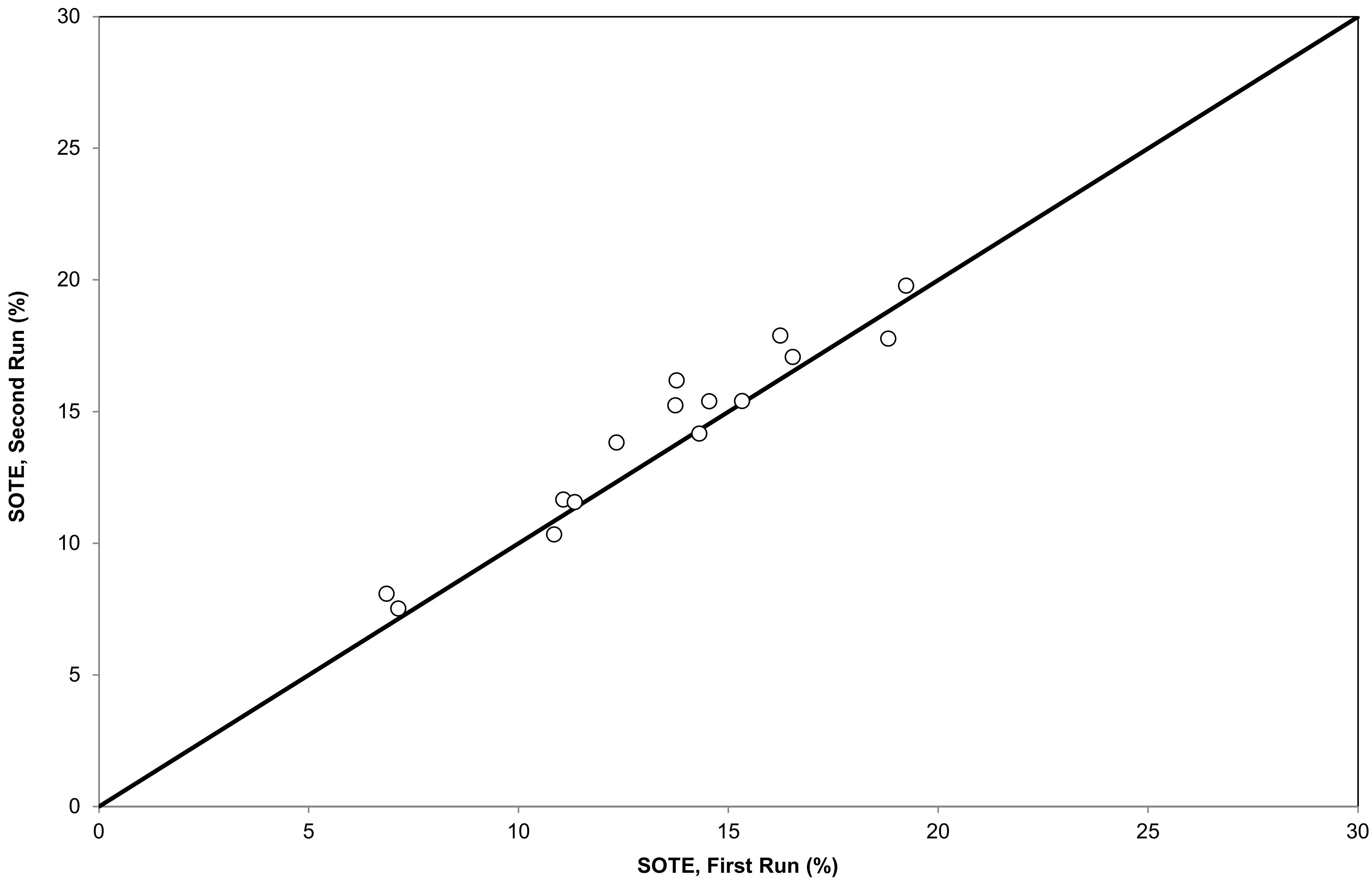
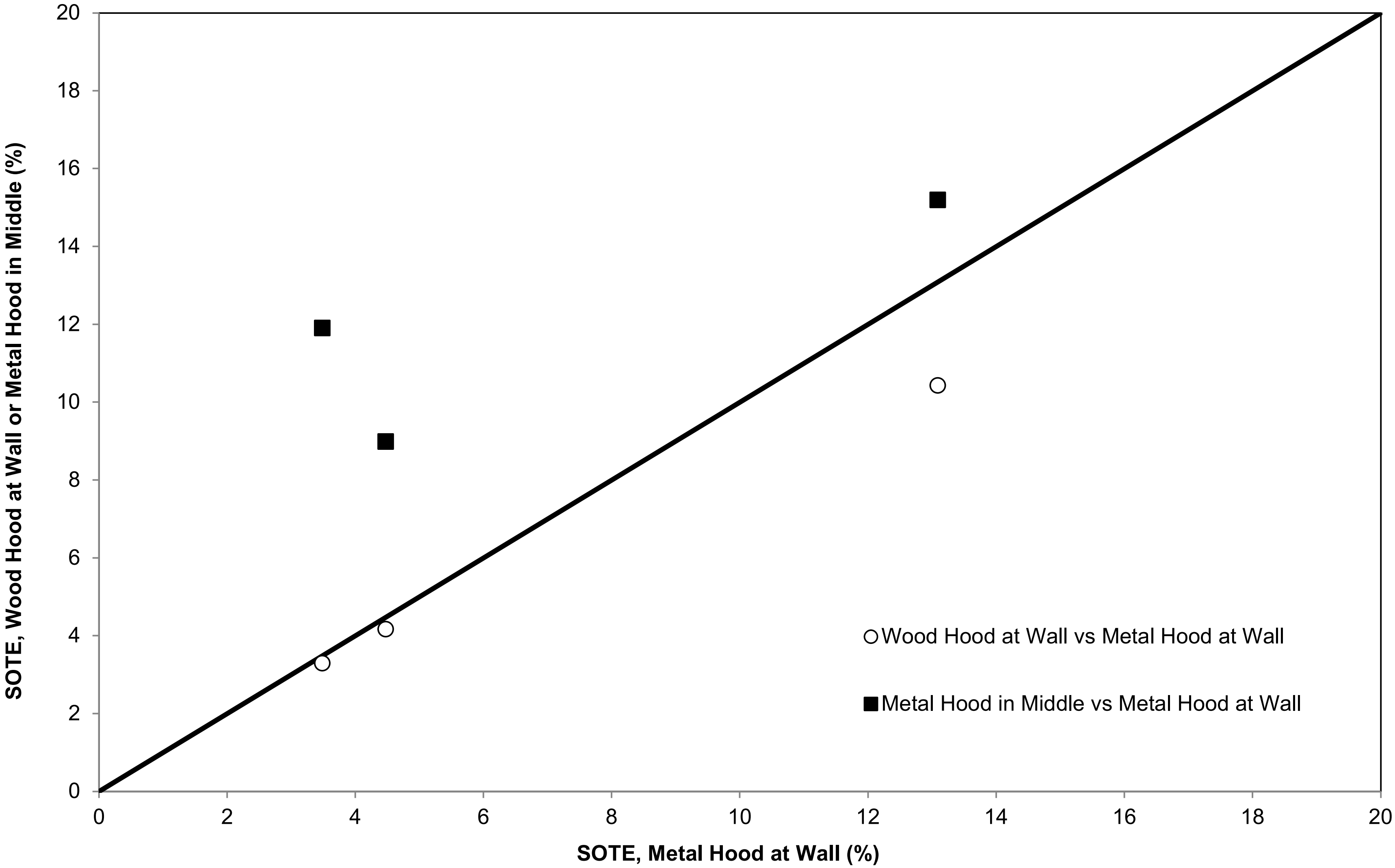


FIGURE 19: EFFECT OF THE HOOD TYPE AND LOCATION ON MEASURED STANDARD OXYGEN TRANSFER EFFICIENCIES FROM THE 2010 OFF-GAS TESTING



The results from the four configurations are shown in Figure 20. The $SOTE_f$ results from the square hood located next to the side wall compared relatively well with the $SOTE_f$ measured on the same day with angled hood located next to the side wall. The difference between the angled and square hoods along the wall ranged from -0.02 to 0.023 for a given test day, with an average of 0.004. The difference between the two hood average and the square hood at the wall ranged from -0.008 to 0.031 for a given test day, with an average of 0.005. The difference between the square hood in the middle and the square hood at the wall ranged from 0.009 to 0.058 for a given test day, with an average of 0.029.

Although the 2010 $SOTE_f$ results obtained using the square and angled hoods along the side wall compared well, the results were different than those collected in 2007. Figure 21 shows the original 2007 and 2010 $SOTE_f$ results for the SAB that were collected using the square off-gas hood located along the side wall above the diffusers. The difference between the 2007 and 2010 results are not uncommon. The USEPA's Design Manual for Fine Pore Diffusers provided $SOTE_f$ results from various plants. One set of data showed the $SOTE_f$, normalized using the submergence depth, from the same location over time varying from 0.4 to 0.9 percent/foot, which indicates the $SOTE_f$ can be variable over time at the same location. Key parameters, which included MLVSS, SOUR, and off-gas flow rate, were compared for the 2007 and 2010 off-gas tests. The SOUR data from the 2007 and 2010 testing were slightly different. The difference between corresponding locations from the 2010 and 2007 testing ranging from -1.0 to 11.5 mg O_2/g VSS/hr, but followed the same general trend down the length of the tank. The off-gas flow rate from the two time periods varied, particularly at the first three locations in the tank where the data showed different trends: decreasing off-gas flow in 2007 and increasing off-gas flow in 2010. The difference in flow between corresponding locations from the 2010 and 2007 data ranged from -14.6 and 7.1 scfm. The most notable differences were observed in the MLVSS data. The MLVSS concentration was consistently higher during the 2007 tests, with 2007 data being as much as 984 mg/L higher than the 2010 data for a particular location. A greater concentration of MLVSS, or bacteria, allows treatment to occur more rapidly, OD to drop more swiftly, and the $SOTE_f$ to increase more quickly down the length of the tank.

The 2009 and 2010 results do raise a concern regarding the proper measurement of SOTE for an aeration system utilizing the spiral roll configuration. It appears that the SOTE increases across the width of the tank with the lowest SOTE occurring above the diffuser plates. Using a two-hood configuration which collected off-gas from approximately 64 percent of the tank width, the weight average $SOTE_f$ using the off-gas flux was on average 10 percent higher than using one hood located along the side wall above the diffuser plates. For example, using one hood may result in a $SOTE_f$ of 0.050, while the two-hood configuration may result in a $SOTE_f$ of 0.055. Through rough estimates, it is believed using a weighted average $SOTE_f$ from data collected over the entire tank width may result in $SOTE_f$ values 15 to 20 percent higher than using one single hood above the diffuser plates (i.e. results of 0.06 versus 0.05). However, it is recommended that testing be conducted to verify.

All off-gas results are provided in Appendix F.

FIGURE 20: EFFECT OF THE HOOD LOCATION ON STANDARD OXYGEN TRANSFER EFFICIENCY RESULTS IN THE SOUTH AERATION BATTERY FROM THE 2010 OFF-GAS TESTING

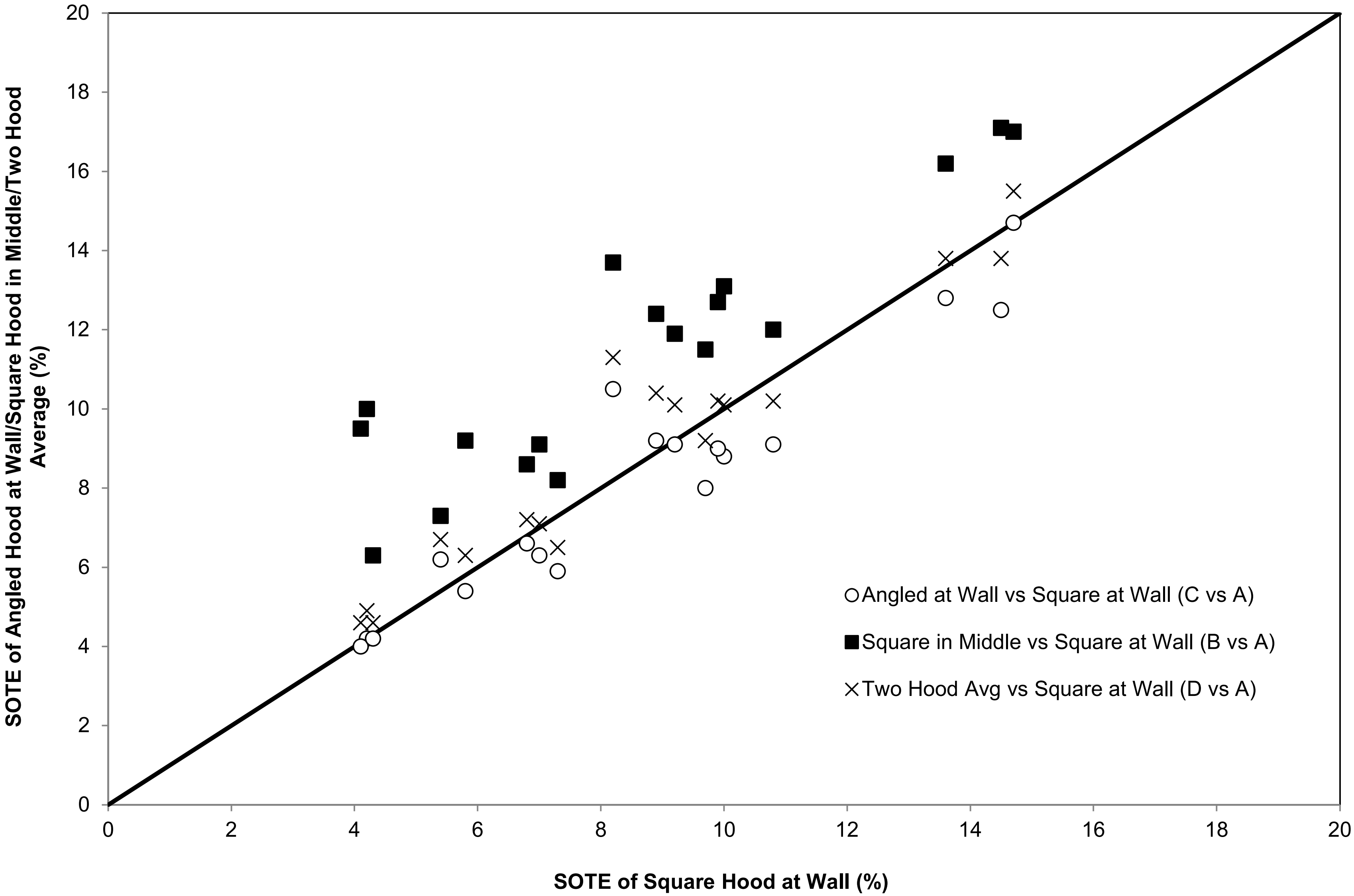
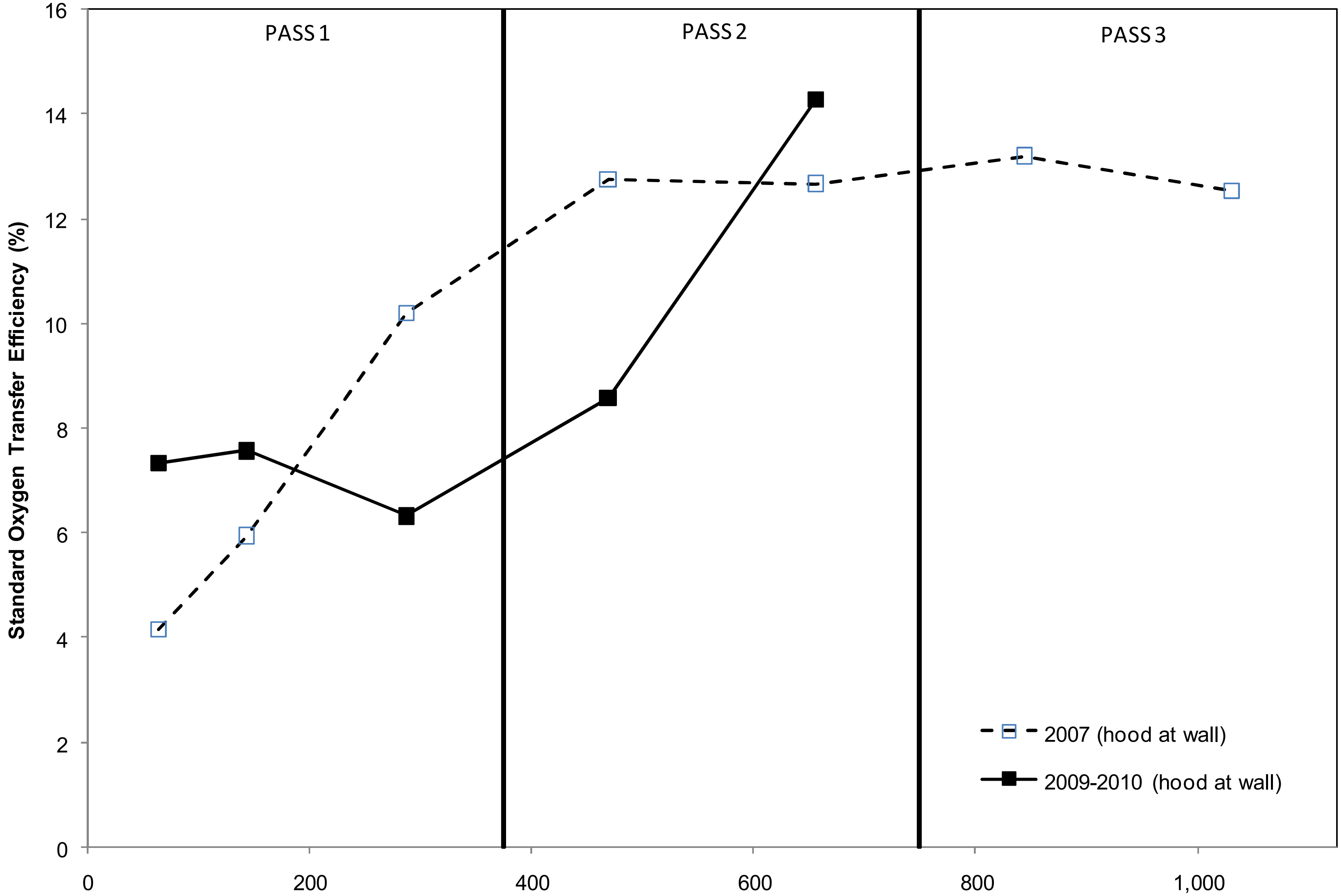


FIGURE 21: COMPARISON OF THE SOUTH AERATION BATTERY STANDARD OXYGEN TRANSFER EFFICIENCIES FROM THE 2007 AND 2010 OFF-GAS TESTING USING A METAL HOOD ABOVE THE DIFFUSERS ALONG THE SIDE WALL



Dissolved Oxygen and Nitrification Profiles

As part of the profile sampling, DO, NH_3-N, TKN, TP, NO_2-N, NO_3-N, SS, and VSS were analyzed at various locations down the length of the tank. A total of four profile sampling events were completed between September and November of 2007. All the results from the profile sampling can be found in Appendix G. Figure 22 shows the average DO results from the sampling. The average profiles are relatively similar. Major differences include the low average DO of 0.21 mg/L in the beginning of the NAB tank, the occurrence of a DO peak in Pass 1 of the NAB tank, and the higher DO at the end of the SAB tank compared to the NAB tank. The lower DO in the beginning of the NAB is due to the RAS being returned with centrifugal pumps compared to air lifts in the SAB. The low DO in the beginning of the NAB could be the reason for lower NO_3-N in the NAB effluent due to some denitrification occurring. In addition, the anoxic zone in the beginning of the NAB aeration tank was documented as being in operation twice in October 2007. While profile sampling did not fall on these two specific dates that were documented, it is believed that the anoxic zone was operated longer than the two non-consecutive days, but this cannot be verified. The remaining differences between the average DO profiles from the two batteries are a result of the distribution of diffuser plates. The SAB has a spiral roll configured aeration system in which the number of diffuser plates per foot of aeration tank remains the same for the length of the tank, roughly 2.8 diffusers/ft as shown in Figure 23. The NAB has a full-floor aeration system with the number of diffusers per foot of tank tapered down the length of the tank. The diffusers/ft in the NAB ranges from 2.2 to 8.3, as shown in Figure 23. Comparison between Figures 22 and 23 show that the battery with the higher number of diffusers/ft for a particular section of tank length has the higher DO concentration in the ML.

The average NH_3-N concentration results from the two batteries are provided in Figure 24. The increase in NH_3-N shown in the beginning of the tanks between the first and second sample location is probably a result of mixing. The RAS and PE enter the aeration tanks via two separate pipes so the two streams are not thoroughly mixed at the first location. The NH_3-N is higher through the first half of Pass 1 in the SAB. This is due to a leak in the RAS line. During this study, it was determined that a leak existed in the SAB RAS line so that part of the RAS flow entered the aeration tank half way down Pass 1 with the remainder entering at the beginning of the tank. Because of this leak, the influent NH_3-N was not as dilute in the SAB until the middle of Pass 1 when the remainder of the RAS was added to the aeration tank. Nitrification through the tanks is completed at the end of Pass 2 for both tanks, although the rate of nitrification differs in Pass 1 and 2 for the two batteries.

The average NO_2-N and NO_3-N concentration results from the two batteries are provided in Figures 25 and 26, respectively. The average NO_2-N concentrations through the tanks in the NAB and SAB follow similar trends. However, there are differences in the first two passes, which may be the result of the RAS leak in the SAB. It is also possible that the differences in mixing intensity of the two batteries impacts the nitrification rate by affecting how well the NH_3-N and NO_2-N can diffuse into the bacteria floc. The SAB experiences a circular mixing in the vertical and horizontal directions as a result of the spiral roll configuration, while the NAB experiences only mixing in the vertical direction as a result of the full-floor configuration. The difference in NO_3-N concentrations down the length of the tank can be attributed to using centrifugal pumps to return the RAS in the NAB compared to air lifts in the SAB. The resulting low DO in the upstream end of the aeration tank and the low DO in the RAS lines may promote

FIGURE 22: AVERAGE DISSOLVED OXYGEN CONCENTRATIONS ALONG THE LENGTH OF THE AERATION TANKS IN THE NORTH AND SOUTH AERATION BATTERIES DURING THE 2007 PROFILE SAMPLING

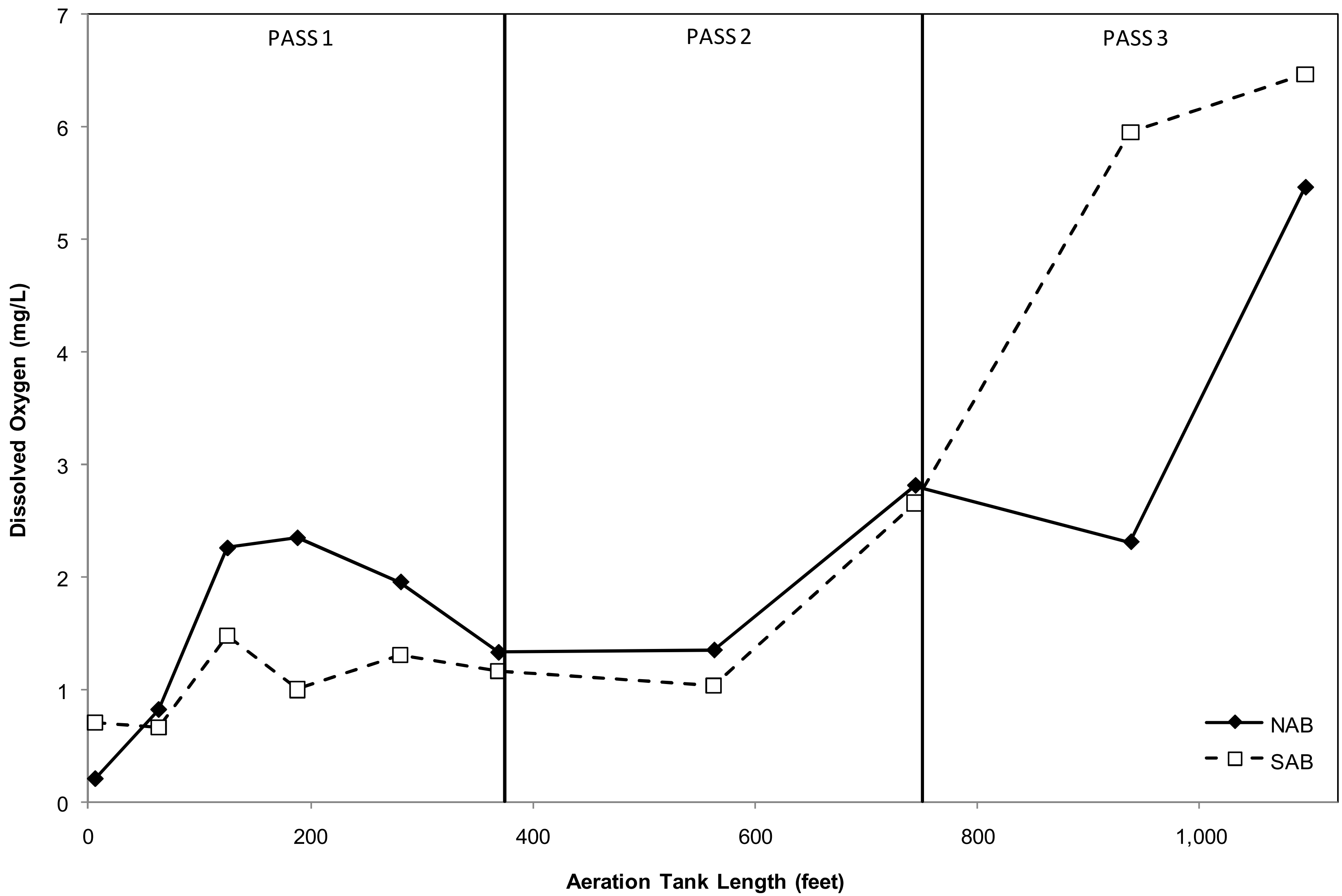


FIGURE 23: DISTRIBUTION OF DIFFUSER PLATES IN THE NORTH AERATION BATTERY AND SOUTH AERATION BATTERY AERATION TANKS

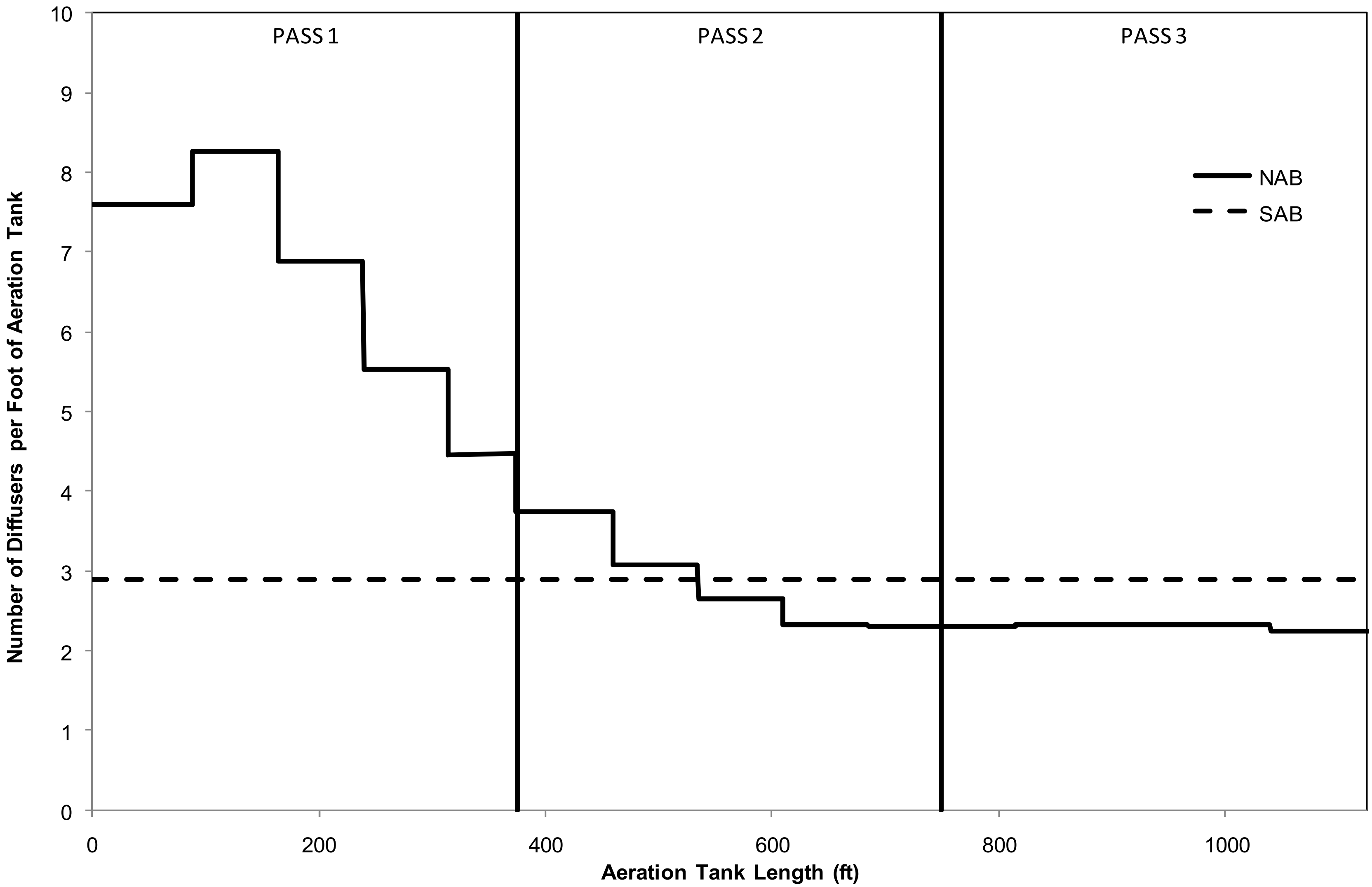


FIGURE 24: AVERAGE AMMONIA NITROGEN CONCENTRATIONS ALONG LENGTH OF THE AERATION TANKS IN THE NORTH AND SOUTH AERATION BATTERIES DURING THE 2007 PROFILE SAMPLING

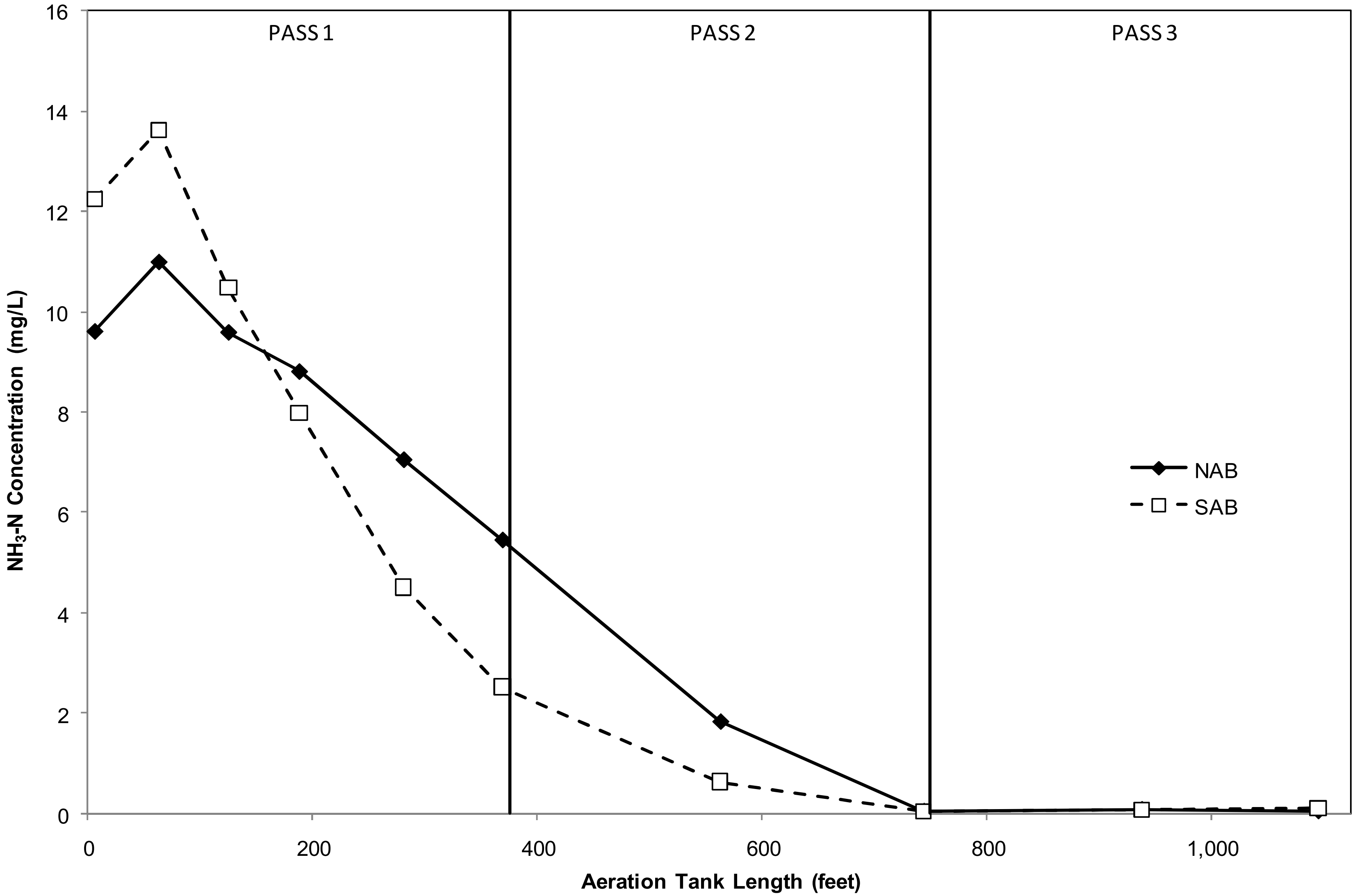


FIGURE 25: AVERAGE NITRITE NITROGEN CONCENTRATIONS ALONG THE LENGTH OF THE AERATION TANKS IN THE NORTH AND SOUTH AERATION BATTERIES DURING THE 2007 PROFILE SAMPLING

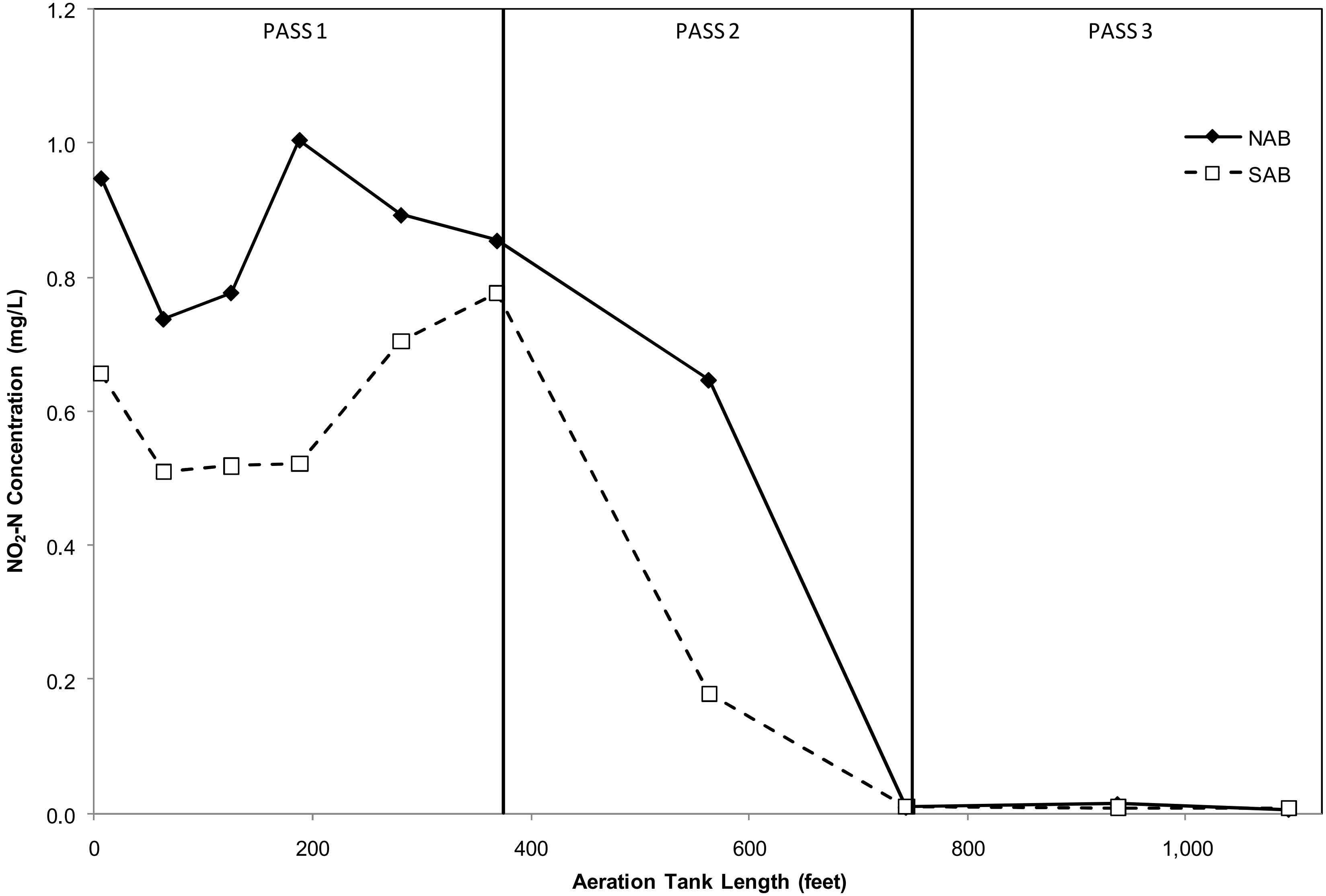
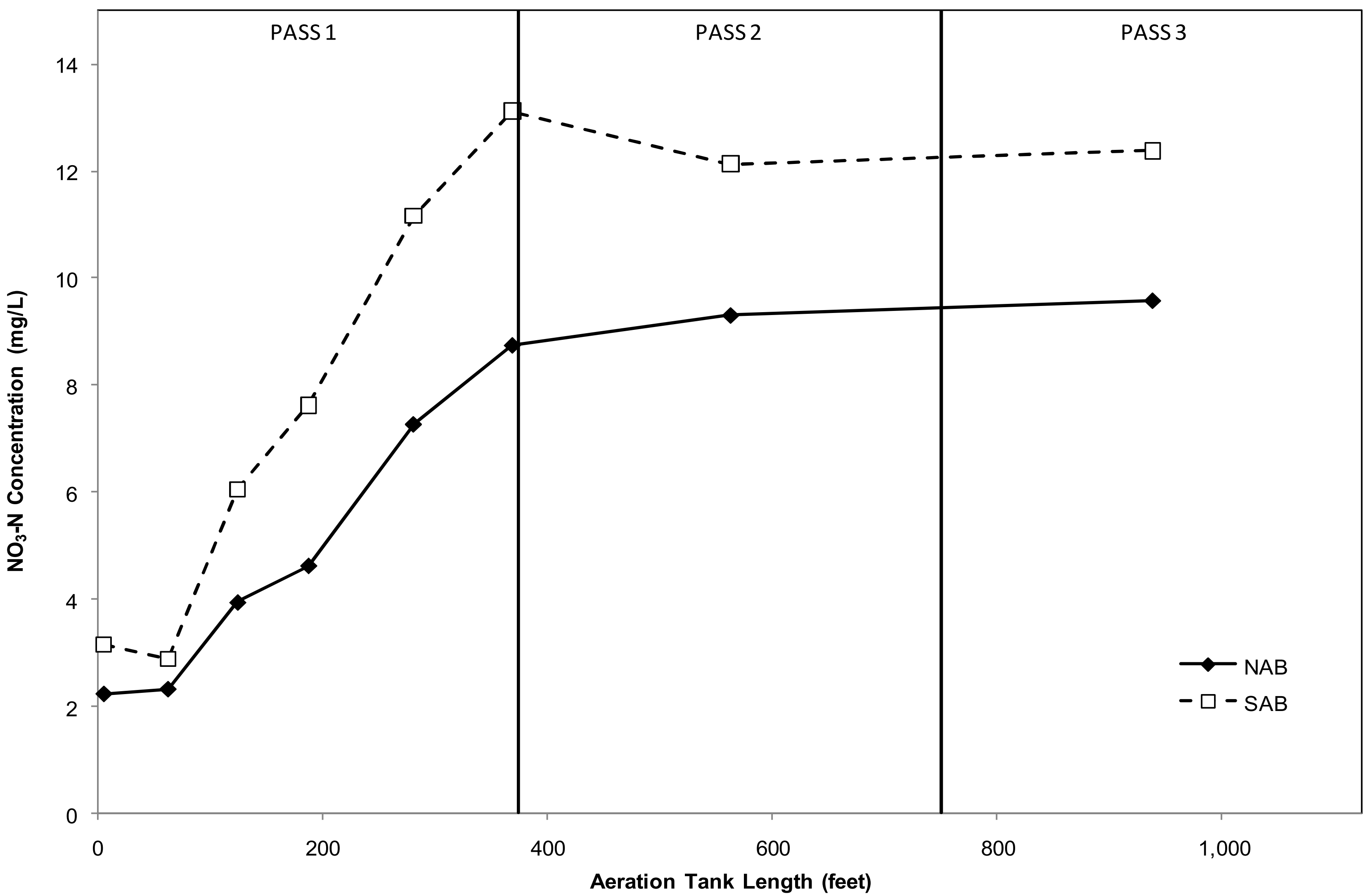


FIGURE 26: AVERAGE NITRATE NITROGEN CONCENTRATIONS ALONG THE LENGTH OF THE AERATION TANKS IN THE NORTH AND SOUTH AERATION BATTERIES DURING THE 2007 PROFILE SAMPLING



some denitrification. It is also believed that the anoxic zone in the NAB was operated at some point during this study, which would further reduce the NO_3-N concentrations in the NAB. The concentrations are relatively similar at the second location, but this may be due to the RAS leak. A portion of the RAS enters the tank further down Pass 1 in the SAB tank, so all the NO_3-N return is not present at the second sampling location.

The average SS and VSS concentration results from the two batteries are provided in Figure 27. The SS and VSS concentrations should be relatively constant through the length of the tank, with minor fluctuation and perhaps a minor increase due to biomass growth. The profiles for the SAB show the low SS and VSS in the beginning of Pass 1 due to the RAS leak. The SAB SS and VSS increase by the end of Pass 1 and are relatively constant through the remainder of the tank length. The SS and VSS in the NAB are also a little low in the beginning of Pass 1 and then are relatively stable the remainder of the length. If the anoxic zone was in fact operating, this may indicate that there was some settling occurring in the anoxic zone of the NAB tank and ideal mixing was not achieved. There is also a baffle wall separating the anoxic zone from the aerobic zone, so the baffle wall could be contributing to some solids settling or non-ideal mixing.

Interfacial Settling Velocity

ISV tests were not completed during 2007 through 2010, however some limited data is available from testing that was completed in 2005. The results are presented here simply to show that although the NAB and SAB treat the same wastewater and are identical in shape and size, there does appear to be a difference between the ML settling in the two batteries. Figure 28 shows a settling flux curve for the NAB and SAB using settling coefficients determined through the dynamic settling tests: a V_o and k, of 44.03 ft/hr and 0.000515 L/mg and 69.86 ft/hr and 0.000439 L/mg for the NAB and SAB, respectively. The detailed results are provided in Appendix H. These V_o and k settling coefficients are comparative to those found in literature, which typically range from 17.3 to 42.9 ft/hr and 0.00019 to 0.000650 L/mg, respectively (Vanderhasselt et al., 2000; Ramalingam et al., 2007). The SAB had a higher and wider flux curve than the NAB, indicating the SAB has better settling characteristics. A detailed description of flux curves and how they can be used in a state point analysis can be found in projects 00-CTS-1 and 04-CTS-5 by WERF (Wahlberg, 2001; Reddy and Pagilla, 2009).

Aeration System Effects on Oxygen Uptake, Nitrification, and Energy Consumption

The aeration systems in the NAB and SAB did not seem to cause any major differences in the treatment performance of the batteries. The SOURs were relatively similar, and when the batteries were operating with similar SRTs, MLVSS, and F/M, the treatment performance was equivalent. If these operating parameters are different, the battery performances will change, such as in the beginning of the fall sampling when SRT and MLVSS were higher in the SAB resulting in better nitrification performance. The observed difference in effluent NO_3-N concentrations indicates that some denitrification was occurring in the NAB, due to the RAS return via centrifugal pumps instead of air lifts and/or possible operation of the anoxic zone in the beginning of the NAB tank, which was documented as occurring on two days during this study. It is possible that the anoxic zone was operated on more days than the two documented.

FIGURE 27: AVERAGE TOTAL SUSPENDED SOLIDS AND VOLATILE SUSPENDED SOLIDS ALONG THE LENGTH OF THE AERATION TANKS IN THE NORTH AND SOUTH AERATION BATTERIES DURING THE 2007 PROFILE SAMPLING

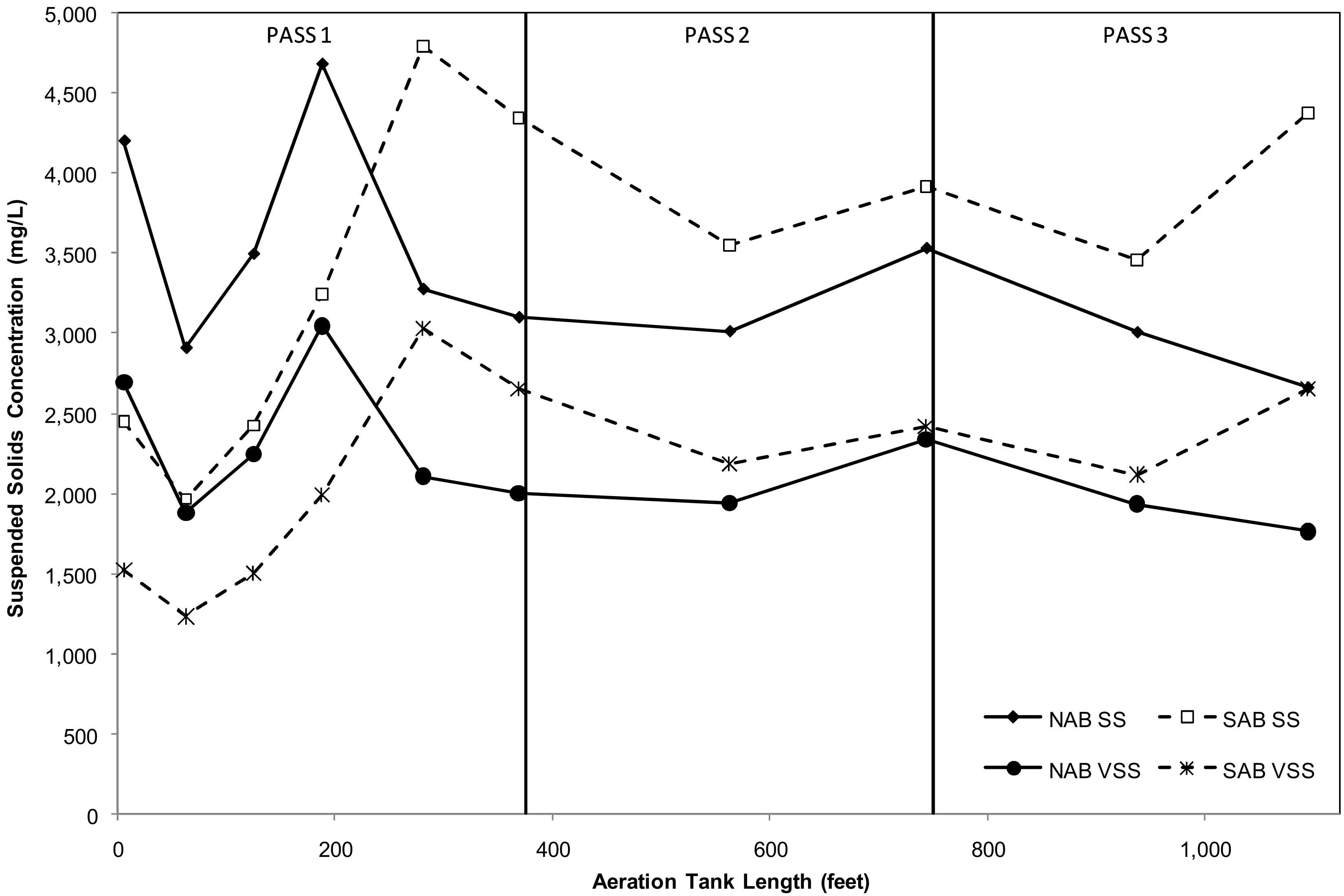
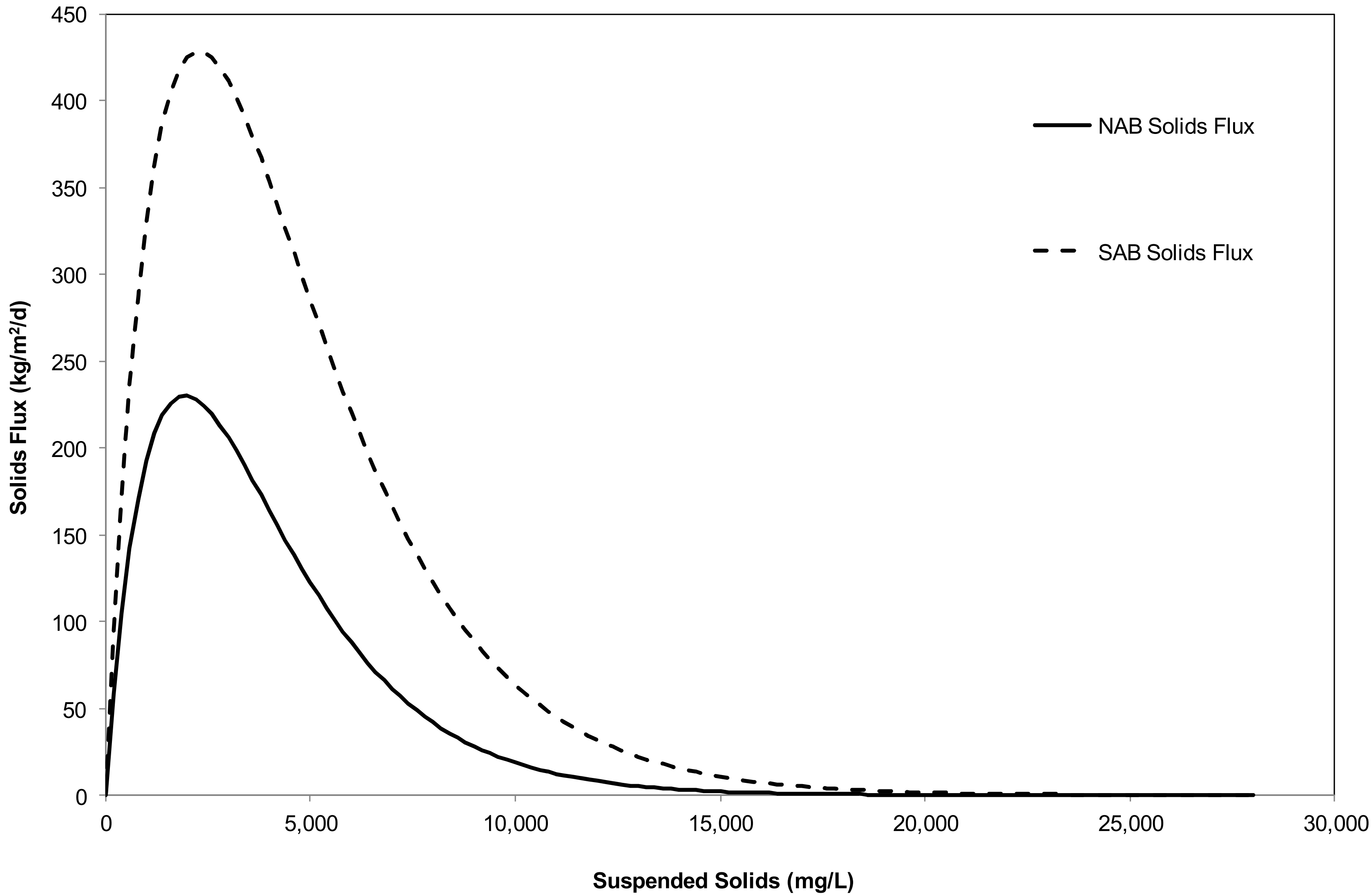


FIGURE 28: SOLIDS FLUX CURVES FOR THE MIXED LIQUOR FROM THE NORTH AND SOUTH AERATION BATTERIES FROM THE INTERFACIAL SETTLING VELOCITY TESTING COMPLETED IN 2005



Based on operator experience, it is not always possible to maintain similar SRTs and MLSS concentrations in the batteries, so nitrification performance may differ. The NAB typically experiences much higher SVIs than the SAB due to filament growth. The difference in SVIs during the fall sampling was shown in Figure 12, where the NAB SVI was consistently higher than NAB. The high SVI results in settling impairments and requires that the MLSS inventory be reduced to prevent solids from leaving in the NAB FE. The intensive sampling showed that the influent characteristics are the same for the two batteries, so the influent is not the cause for the difference in filaments and SVI. Possible causes may include the RAS return methods and differences in aeration systems in the two batteries. The NAB, with the centrifugal pumps for the RAS, may limit the amount of oxygen in the return, creating a low DO environment susceptible to filament growth. The NAB also has the full-floor aeration system. This system does not achieve the horizontal, circular mixing that the spiral roll system does in the SAB. This can lead to possible dead zones in the NAB which can also result in environments susceptible to filament growth.

One major drawback to this study is the fact that there is no reliable air flow data for the NAB. Without this data, it is impossible to compare air usage and therefore energy consumption of the two aeration systems. There is, however, reliable air flow data for the SAB. The SAB air flow data was used to calculate the ratios of air/sewage flow and air/OD. The average results from the fall sampling are provided in Table 9 along with average results from 2010 sampling completed at the James C. Kirie (Kirie) WRP, which is provided for comparison, as it is one of the more efficient plants at the District in terms of air usage for secondary treatment. The Kirie WRP also has a similar aeration system to the SAB.

The SAB air/sewage results compared well with the Kirie WRP results, and ratios from both plants were within the typical range of 0.4 to 1.6 cf/gal. The air/OD ratio was a bit higher for the SAB compared with the results from the Kirie WRP, but this could be a result of different DO setpoints for aeration tanks or the use of any post aeration systems downstream of the final tanks.

TABLE 9: AVERAGE RATIO OF THE AIR TO SEWAGE FLOW AND THE AIR TO OXYGEN DEMAND FROM THE SOUTH AERATION BATTERY DURING THE 2007 FALL SAMPLING AND FROM THE 2010 FALL SAMPLING COMPLETED AT THE JAMES C. KIRIE WATER RECLAMATION PLANT

Plant and Tank	Air to Sewage Flow[1] (scf/gal)	Air to Oxygen Demand[2] (scf/lb O_2)
Egan WRP[3]		
South Battery, Tank 1	0.79	504
South Battery, Tank 2	0.75	506
Kirie WRP[4]		
Battery A, Tank 1	0.78	410
Battery A, Tank 2	1.00	523
Battery A, Tank 3	0.72	385
Battery A, Tank 4	0.77	402
Battery A, Tank 5	0.83	434
Battery A, Tank 6	0.76	400

[1]Calculated by dividing average daily air flow to the tank by sewage flow to the tank.
[2]Calculated by diving average daily air flow to tank by estimated oxygen demand of the influent to the tank (oxygen demand = (1 lb O_2/lb CBOD x CBOD lb/d) + (4.57 lb O_2/lb TKN x (TKN lb/d – CBOD lb/day x 0.05) (USEPA, 1989).
[3]From fall sampling of the south aeration battery, September 5 to November 17, 2007.
[4]From fall sampling of Battery A at the Kirie WRP during a step feed study, August 28 to December 24, 2010.

CONCLUSIONS AND RECOMMENDATIONS

Based on the results of this study comparing battery performance and aeration system efficiency at the Egan WRP, the following conclusions can be made:

1. The spring 2007 intensive sampling of the PE entering and the FE leaving the two batteries were statistically equivalent, which verified that the batteries receive the same wastewater and achieve equivalent treatment.

2. The fall 2007 sampling showed that there are some differences in treatment performance between batteries, but these differences are due to operating conditions. When the SRT and MLVSS were similar, the batteries had equivalent NH_3-N and Sol-P effluent concentrations. There appeared to be some dentirfication occurring in the NAB, either due to the RAS return method (centrifugal pumps for the NAB and air lifts for the SAB) or due to possible operation of an anoxic zone in the NAB that was documented as in use two days in October 2007. Finally, the SS and VSS concentrations were slightly higher in the SAB effluent, but this may be the result of higher MLSS and longer SRT in the SAB.

3. The SOUR results showed similar trends through the length of the NAB and SAB aeration tanks. The SOURs were slightly higher in the SAB than the NAB in the first half of the aeration tanks. This was a result of differences in MLVSS concentrations and instantaneous food to biomass ratios in the first half of the aeration tanks.

4. The SOTE of the two aeration systems in the NAB and SAB followed the same trend down the length of the aeration tanks; however, the SOTEs in the NAB were consistently higher. This may be a result of the age of the SAB aeration system, which was original to the plant and put in operation in December 1975. There is also some question as to the proper hood location for obtaining SOTE measurements from an aeration tank with spiral roll configured diffuser plates in which the diffuser plates are only located along one side. Testing indicates that using a hood located in the middle of the tank results in higher SOTE results than using a hood located along the side wall above the diffusers. No tests were done with a hood located along the side wall opposite the diffuser plates.

5. The profile sampling provided insight on DO and nitrification down the length of the aeration tanks. The DO profiles were slightly different as a result of (1) the difference in RAS return methods, (2) the possible use of an anoxic zone in the beginning of the NAB aeration tank, and (3) differences in the number of diffusers per foot down the length of the aeration tanks in the NAB and SAB. The NH_3-N profiles showed that nitrification was completed by the end of Pass 2 in both batteries. On the days of profile sampling, the SS and VSS concentrations were consistently higher in the SAB than in the NAB, with the exception of the first half of Pass 1. For the SAB, the downstream leak in the

RAS line resulted in lower SS and VSS concentrations in the first half of Pass 1. In the NAB, the presence of a baffle wall and/or possible operation of an anoxic zone could have resulted in variable SS and VSS concentrations in the first half of Pass 1 due to inefficient or variable mixing and settling.

6. Although ISVs were not measured during this study's duration, from 2007 through 2010, limited data from 2005 was available. The data was presented merely to show that although the batteries treat the same wastewater and are the same size and shape, there are settling differences in the ML in the batteries. From the limited results, the SAB ML had much better settling characteristics than the NAB.

7. The different aeration systems in the NAB and SAB did not seem to impact treatment performance when operating conditions were similar between the batteries, such as SRT and MLVSS. When these were different, the treatment performance was different between batteries. It is not always possible to keep these operating conditions similar, particularly due to a higher SVI and greater filament counts in the NAB. During the fall 2007 sampling, the SVI in the NAB was consistently higher than the SAB despite similar influent characteristics. A high SVI indicates poorer settling and may require a reduction in the MLSS, and therefore MLVSS, in the aeration tank. The causes of greater filaments in the NAB are complex and have not been fully understood.

8. Reliable air flow data is not available for the NAB, which is a major setback for comparing air usage and therefore energy consumption of the two aeration systems. The air flow for the SAB was available and was used to calculate the ratios of air flow to sewage flows and air/OD. The SAB results compared well with results from the Kirie WRP, with the air/OD ratio being slightly higher. Kirie WRP data was used as a comparison due to its known efficiency in terms of air usage for secondary treatment.

The following are recommended based on the results of this study:

1. The diffuser plates in Tank 2 of the SAB were replaced in 2012. Additional off-gas testing is recommended to compare the SAB $SOTE_f$ before and after diffuser plate replacement. These results would help determine the contribution the aged diffuser plates had on the differences in SOTEs between the SAB and NAB. The additional testing should also evaluate how calculating a weighted average SOTE from off-gas measurement over the entire width of the SAB tanks compares to using one single hood located along the side wall above the diffuser plates. This full-width testing would help determine the contribution the off-gas measurement method used in 2007 had on the differences in SOTEs between the SAB and NAB.

2. A contract is in place to replace the air flow meters in the NAB. When this has been completed, it is recommended that a detailed analysis on the air usage and energy consumption of the two batteries be completed to complete the

study objective of comparing the effectiveness of the two aeration systems on energy consumption.

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APPENDIX A

AERATION BATTERY TREATMENT EVALUATION FACTORS

AERATION BATTERY TREATMENT EVALUATION FACTORS

Oxygen Transfer Efficiency

The oxygen transfer efficiency (OTE_f) of an aeration system in a WRP is the amount of oxygen that is transferred from the supplied air to the ML in an aeration tank under process conditions. Measured OTE_fs can be used to assess the condition and effectiveness of an aeration system and can also be used to compare the performance of different types of aeration systems. With aeration systems responsible for greater than 50 percent of a WRP's total electricity usage, a system with a higher OTE_f is desired for economic reasons.

OTE_f is dependent on site-specific conditions including barometric pressure, temperature, wastewater characteristics, and DO in the wastewater. In order to compare OTE_f measurements, it is necessary to convert the OTE_f to a $SOTE_f$ for standard conditions of 20°C, zero DO in the liquid, and with clean water. According to results presented in the Design Manual for Fine Pore Aeration Systems by the United States Environmental Protection Agency (USEPA), typical $SOTE_f$s in aeration tanks using fine-pore diffusers under process conditions range between 6 and 14 percent, depending on loading, flow scheme, location, etc. (USEPA, 1989).

The American Society of Civil Engineers (ASCE) provides a standard guideline for a number of proven methods for measuring oxygen transfer under process conditions, such as the non-steady state model, off-gas method, and tracer measurement (ASCE, 1997). In this guideline, ASCE evaluated a number of studies that have been conducted comparing side-by-side oxygen transfer measurements obtained using the three methods, and the field oxygen transfer coefficients ($K_L a_f$), defined below, were within ± 10 percent of each other. ASCE concluded that the choice of method will depend on economics and treatment plant site constraints. For diffused air aeration systems, the off-gas method is (1) precise, (2) not sensitive to variations in flow, loads, and DO, and (3) ranked medium in terms of manpower, analytical, and capital costs. Due to these reasons, the off-gas method was chosen for measuring $SOTE_f$.

The off-gas method directly measures OTE_f of diffused air aeration systems using a gas-phase mass balance approach. This method requires the use of an analyzer to measure the relative gas-phase oxygen content of ambient air and off-gas exiting the liquid surface from an aeration tank (ASCE, 1997). A fixed or floating hood is also required to collect off-gas from the surface and send it to the analyzer.

Equation 1 is the gas-phase mass balance for oxygen over liquid where the oxygen reduced in the gas is equal to the oxygen absorbed by the liquid. The rate of air supplied must be known to determine the mass of oxygen transferred, but the fraction transferred to the liquid can be determined without the gas flow rate.

$$\rho(q_i Y_i - q_e Y_e) = K_L a_f \left(C^*_{\infty f} - C\right) V \qquad (1)$$

where,

ρ = the density of oxygen at temperature and pressure of gas, lb/ft^3

q_i, q_e	=	total volumetric gas flow rate into (i) and out of (e) the test volume, ft^3/day
Y_i, Y_e	=	mole fraction of oxygen in the inlet (i) and outlet (e) gas
$K_L a_f$	=	apparent volumetric mass transfer coefficient of oxygen in process water at temperature T, 1/day ($K_L a_f = \propto K_L a$)
$C^*_{\infty f}$	=	value of steady-state DO saturation concentration at infinite time in process water, lb/ft^3
C	=	DO concentration of process water, lb/ft^3
V	=	liquid volume, ft^3

To estimate $K_L a_f$, measurements must be made of the mole fractions of oxygen in the inlet and outlet gas, total gas flow rate, and DO. Additionally, an estimate of $C^*_{\infty f}$ under test conditions is needed, which can be estimated from Equation 2.

$$C^*_{\infty f} = C^*_{\infty 20} \times P_b/P_s \times \beta \times C_s/C_{s20} \qquad (2)$$

where,

$C^*_{\infty 20}$	=	steady state DO saturation concentration in clean water at infinite time and 20°C, mg/L
P_b	=	ambient barometric pressure during test, atm
P_s	=	standard barometric pressure of 1.0 atm
β	=	ratio of C^*_∞ in process water to clean water at equivalent temperature and pressure, unitless
C_s	=	surface saturation value of DO at 1.0 atm pressure and 100% relative humidity, mg/L
C_{s20}	=	DO saturation concentration at 20°C, 1.0 atm, and 100% relative humidity, mg/L

To estimate $C^*_{\infty f}$, $C^*_{\infty 20}$ must be known, which is typically measured during clean water tests or is calculated using comparable full-scale test data. $C^*_{\infty 20}$ is primarily dependent on diffuser submergence and diffuser type. The USEPA provides Equation 3 as a means of estimating $C^*_{\infty 20}$ (USEPA 1989) and provides graphs, Figures 2-13 and 2-14, of $C^*_{\infty 20}$ versus diffuser submergence for various diffuser types.

$$C^*_{\infty 20} = C_s\,[(P_b - P_{vT} + 0.007\gamma_w d_e)/(P_s - P_{vT})] \qquad (3)$$

where,

P_{vT}	=	saturated vapor pressure of water at temperature T, lb/ft^2
γ_w	=	specific weight of water at temperature T, lb/ft^3
d_e	=	effective saturation depth, ft (typically between 21 and 44 percent of water depth)

Based on Equation 3, assuming an average effective saturation depth of 33 percent, and the graphs provided in the manual, a reasonable assumption for $C^*_{\infty 20}$ for fine-pore diffusers with a submergence depth between 14 and 14.5 feet is 10.5 mg/L.

By expressing gas transfer as a fraction and using molar ratios of inlet and outlet oxygen to inert gas fractions, gas flow measurements can be omitted to calculate the OTE_f, resulting in Equation 4.

$$OTE_f = (MR_i - MR_e)/M\,R_i \tag{4}$$

where,

MR_i	=	oxygen molar ratio of the inlet, $Y_i/(1 - Y_i - Y_{CD_i} - Y_{W_i})$, unitless
MR_e	=	oxygen molar ratio of the outlet, $Y_e/(1 - Y_e - Y_{CD_e} - Y_{W_e})$, unitless
Y_i	=	mole fraction of oxygen in the inlet gas, $0.2095(1 - Y_v)$, unitless
Y_v	=	mole fraction of vapor constituents other than air such as carbon dioxide (CO_2) and water vapor, unitless
Y_e	=	mole fraction of oxygen in the outlet gas, $Y_i\ (MV_e/M\,V_i)$, unitless
$Y_{CD_{i,e}}$	=	mole fraction of CO_2 in the inlet and outlet gas respectively, unitless
$Y_{W_{i,e}}$	=	mole fraction of water vapor in the inlet and outlet gas respectively, unitless

Removing CO_2 and water vapor upstream of the oxygen analyzer allows the direct calculation of OTE_f from Equation 5.

$$OTE_f = 1 - Y_e(1 - Y_i)/Y_i(1 - Y_e) \tag{5}$$

If a proportional voltage output analyzer is used, Equation 5 can be rewritten as Equation 6 using the direct current (DC) millivolt (MV) output from the DO analyzer, where MV_e is the DC MV output of the off-gas and MV_i is the DC MV output of the ambient, influent air.

$$OTE_f = 1 - \frac{MV_e}{MV_i}(1 - 0.2095)\Big/(1 - \frac{MV_e}{MV_i}0.2095) \tag{6}$$

Finally, the conversion of OTE_f to $SOTE_f$ is shown in Equation 7.

$$SOTE_f = \frac{OTE_f}{(C^*_{\infty f} - C)} \times 1.024^{(20-T)} \times C^*_{\infty 20} \times \beta \tag{7}$$

Solids Retention Time

The SRT is the amount of time that solids are held in the system. The waste activated sludge (WAS) flow is adjusted to maintain an SRT setpoint, as shown in Equation 8. Typically short SRTs are needed for organic matter oxidation, between four and ten days when balancing removal and economics (Rittmann and McCarty, 2001). Longer SRTs are needed for ammonia oxidation, typically between eight and 20 days (Metcalf and Eddy, 1991). The wastewater temperature also plays a role in determining the appropriate SRT, with lower temperatures resulting in the need for longer SRTs due to lowered biomass activity at lower temperatures.

$$Q_{WAS} = (MLSS \times Volume)/(SRT \times RASSS) \quad (8)$$

where,

Q_{WAS}	=	waste activated sludge flow, million gallons per day (MGD)
$MLSS$	=	mixed liquor suspended solids concentration, mg/L
$Volume$	=	volume of aeration tank, MG
$RASSS$	=	return activated sludge suspended solids concentration, mg/L

Food-to-Microorganisms Ratio

The F/M ratio is the ratio of the amount of food being supplied to the aeration tank to the number of microorganisms in the tank. For a conventional activated sludge process, typical F/M ratios range from 0.25 to 0.5 kg five-day BOD (BOD_5)/kg MLVSS, which generally results in reliable BOD_5 removal of about 90 percent (Rittman and McCarty, 2001). The daily F/M can be calculated using Equation 9.

$$F/_{M} = (Flow \times BODinf \times 8.34)/(Volume \times MLVSS \times 8.34) \quad (9)$$

where,

$Flow$	=	influent flow to the aeration tank, MGD
$BODinf$	=	biochemical oxygen demand of the influent, mg/L
8.34	=	conversion factor, lb/MG x mg/L
$Volume$	=	volume of aeration tank, MG
$MLVSS$	=	mixed liquor volatile suspended solids concentration, mg/L

Sludge Volume Index

The SVI is a measurement of the volume in milliliters (mL) occupied by 1 gram (g) of SS after 30 minutes of settling and can be calculated using Equation 10. The range of SVI values that are considered appropriate vary and are specific to each WRP. A high SVI can be an indication of sludge bulking due to filamentous growth, which may negatively affect settling in the final clarifiers.

$$SVI = V_{30} \times (1{,}000/(MLSS \times V_t)) \quad (10)$$

where,

SVI	=	sludge volume index, mL/g suspended solids
V_{30}	=	volume of settled sludge after 30 minutes of settling, mL
1,000	=	conversion factor, mg/g
V_t	=	total sample volume used in test, L

Air-to-Sewage Ratio

The air-to-sewage (air/sewage) ratio is calculated using Equation 11.

$$\frac{Air}{Sewage} = Q_{air}/Q \tag{11}$$

where,

Q_{air} = the air flow rate supplied to aeration tank, cf/day
Q = sewage flow entering the aeration tank, gal/day

The air/sewage ratio normalizes the air flow so that the air usage can be compared between aeration tanks. Typical values for the air/sewage ratio range between 0.4 and 1.6 cf/gal.

Air to Oxygen Demand Ratio

The air/OD ratio is another way to compare air usage between aeration tanks. The air/OD ratio is calculated by dividing the air flow by the theoretical amount of oxygen required to oxidize the influent carbonaceous and nitrogenous demands, as shown in Equation 12.

$$\frac{Air}{OD} = Q_{air}/[(1.0 \times CBOD_5) + (4.57 \times (TKN - CBOD_5 \times 0.05)] \tag{12}$$

where,

1.0 = lb oxygen required to remove 1 lb of CBOD
$CBOD_5$ = 5-day carbonaceous oxygen demand in aeration tank influent, lb/day
4.57 = lb oxygen required to remove 1 lb of TKN
TKN = total Kjeldahl nitrogen in aeration tank influent, lb/day
0.05 = nitrogen used during synthesis, (lb TKN/lb VSS)(lb VSS/lb $CBOD_5$)
VSS = volatile suspended solids, lb/day

Interfacial Settling Velocity

The ISV continuous flow tests are completed to determine coefficients that describe the settling characteristics of a ML. By varying the upflow rate in a settling column and analyzing the SS concentration of the settled sludge, the settling coefficients can be determined by fitting the resulting velocity and SS data to the Vesilind equation, as shown in Equation 13.

$$V_s = V_o\, e^{-k(X)} \tag{13}$$

where,

V_s = ISV, ft/hr
V_o = settling coefficient for particular mixed liquor, ft/hr

k = settling coefficient for particular mixed liquor, L/mg
X = suspended solids concentration, mg/L

A good settling sludge will have a large V_o and a small k, while a poor settling sludge will have low V_o and a large k.

APPENDIX B

INTERFACIAL SETTLING VELOCITY TEST PROCEDURE

INTERFACIAL SETTLING VELOCITY TEST PROCEDURE

1. A well-mixed twenty-five gallon mixed liquor (ML) sample will be transferred to a plastic drum and air will be bubbled through the bottom of the reservoir to ensure adequate aeration. Simultaneously, a propeller mixer will be placed in the drum to ensure mixing.

2. A pump will be used to transfer the ML from the drum into the bottom of the settling column. The settling column is 64 inches high with an inner diameter of eight inches and nine ports spaced along the length of the column. Once filled, the pump will be stopped, and the ML will be allowed to settle for one hour.

3. A storage container (carboy) will be filled with four liters of secondary effluent.

4. Upon standing for one hour, the supernatant liquid above the settled sludge blanket will be withdrawn from the top of the column via a recirculation pump into the partially filled carboy and returned through the bottom of the settling column for 20 minutes at a rate of 100–200 mL/min.

5. The exact recirculation pump rate will be measured by placing the supernatant feed line into a graduated cylinder. The time needed to pump 1,000 mL supernatant will be used to compute the pumping rate. Once the pumping rate has been recorded, the recycle will be put back on line.

6. The height of the solid-liquid interface will be measured in the column in parallel with the recirculation rate. The pumping rate and interface height will be measured at five-minute intervals until both are constant.

7. Once steady state has been reached, the middle port will be opened, and a 100-mL sample will be withdrawn and wasted. A second 100 mL will be collected and transferred to a 200-mL boron bottle for suspended solids analysis and labeled accordingly.

8. Steps 4–7 will be repeated at seven to ten different recirculation rates.

9. The upflow velocity will then be plotted versus suspended solids concentration to obtain the settling coefficients, assuming the settling follows the Vesilind equation.

APPENDIX C

SPRING 2007 INTENSIVE SAMPLING RESULTS

TABLE C-1: NORTH BATTERY PRIMARY EFFLUENT SPRING 2007 INTENSIVE SAMPLING RESULTS

Parameter[1]	04/24/07	04/25/07	04/26/07	04/27/07	05/01/07	05/02/07	05/03/07	05/04/07
BOD_5 (mg/L)	109	79	93	72	73	70	103	74
CODt (mg/L)	231	225	170	231	157	159	192	205
CODgf (mg/L)	103	98	87	68	76	70	83	89
CODff (mg/L)	74	66	46	70	44	37	54	52
TSS (mg/L)	62	62	70	50	44	27	62	62
VSS (mg/L)	54	60	46	42	41	24	56	56
TKN (mg/L)	25.75	25.32	16.61	15.41	19.35	23.28	24.02	22.95
SolTKN (mg/L)	18.43	15.76	11.61	9.91	13.18	16.95	17.98	18.45
TKNgf (mg/L)	20.83	19.69	10.06	12.80	15.93	19.42	16.01	21.36
NH_3-N (mg/L)	16.65	15.19	10.11	9.47	12.54	15.21	15.37	15.76
NO_2-N (mg/L)	0.069	1.029	0.331	0.264	0.440	0.349	0.441	0.587
NO_3-N (mg/L)	0.037	1.797	2.346	1.173	1.989	0.445	0.682	0.504
TP	4.27	4.24	2.96	2.77	3.11	3.54	4.31	3.76
Sol-P	2.32	1.81	1.30	1.14	1.44	1.86	2.39	2.00
TPgf	1.34	2.45	1.46	1.51	2.02	2.24	2.50	2.25
FOG	16	13	9	7	4	8	17	13

[1]t = total, gf = glass filtered, ff = filtered and flocculated.

TABLE C-2: NORTH BATTERY FINAL EFFLUENT SPRING 2007 INTENSIVE SAMPLING RESULTS

Parameter[1]	04/24/07	04/25/07	04/26/07	04/27/07	05/01/07	05/02/07	05/03/07	05/04/07
CODt (mg/L)	35	61	46	46	57	26	7	37
CODff (mg/L)	16	20	13	15	11	<6	11	15
TSS (mg/L)	3	47	12	6	2	13	6	2
TKN (mg/L)	1.28	4.17	2.33	1.52	1.48	1.68	1.23	1.47
NH_3-N (mg/L)	0.04	0.28	0.09	<0.03	0.05	0.03	0.09	0.08
NO_2-N (mg/L)	0.019	0.041	0.025	0.011	0.016	0.015	0.020	0.016
NO_3-N (mg/L)	11.48	12.97	10.50	8.57	10.69	11.59	12.50	13.54
TP (mg/L)	0.23	0.97	0.55	0.34	0.40	0.46	0.33	0.40

[1]t = total, ff = filtered and flocculated.

TABLE C-3: SOUTH BATTERY PRIMARY EFFLUENT SPRING 2007 INTENSIVE SAMPLING RESULTS

Parameter[1]	04/24/07	04/25/07	04/26/07	04/27/07	05/01/07	05/02/07	05/03/07	05/04/07
BOD_5 (mg/L)	85	75	65	69	81	68	91	74
CODt (mg/L)	205	216	159	142	161	153	196	183
CODgf (mg/L)	96	101	68	63	70	65	85	85
CODff (mg/L)	63	61	41	41	44	30	57	63
TSS (mg/L)	54	42	54	50	55	32	60	68
VSS (mg/L)	50	38	40	40	48	28	52	56
TKN (mg/L)	25.50	24.72	16.93	14.89	19.06	22.15	23.34	23.84
Sol-TKN (mg/L)	18.57	16.92	11.41	10.24	14.20	16.32	17.86	16.82
TKNgf (mg/L)	21.18	18.83	10.59	12.71	16.62	19.37	19.93	21.00
NH3-N (mg/L)	16.87	15.53	10.27	9.64	12.95	15.59	15.91	16.51
NO2-N (mg/L)	0.563	1.042	0.236	0.242	0.452	0.372	0.359	0.425
NO3-N (mg/L)	0.331	1.608	2.759	1.208	1.727	0.149	0.431	0.414
TP	4.09	4.03	2.79	2.44	3.30	3.45	4.32	3.94
Sol-P	2.27	2.04	1.31	1.08	1.61	1.82	2.42	2.03
TPgf	2.72	2.48	0.74	1.53	2.00	2.27	2.92	2.48
FOG	15	13	7	N/A	9	11	14	12

[1]t = total, gf = glass filtered, ff = filtered and flocculated, N/A = no sample collected.

TABLE C-4: SOUTH BATTERY FINAL EFFLUENT SPRING 2007 INTENSIVE SAMPLING RESULTS

Parameter[1]	04/24/07	04/25/07	04/26/07	04/27/07	05/01/07	05/02/07	05/03/07	05/04/07
CODt (mg/L)	24	50	15	26	26	54	26	30
CODff (mg/L)	29	29	6	15	13	6	6	11
TSS (mg/L)	5	11	6	6	<2	7	2	7
TKN (mg/L)	1.39	1.60	1.44	1.81	1.32	1.48	N/A	1.79
NH_3-N (mg/L)	0.04	0.07	0.04	0.05	0.05	0.05	0.08	0.07
NO_2-N (mg/L)	0.023	0.041	0.015	0.015	0.018	0.026	0.022	0.024
NO_3-N (mg/L)	15.75	17.63	12.40	11.74	13.92	15.51	16.25	17.39
TP (mg/L)	0.27	0.34	0.31	0.35	0.29	0.28	N/A	0.42

[1]t = total, ff = filtered and flocculated, N/A = no sample collected.

APPENDIX D

FALL 2007 SAMPLING RESULTS

TABLE D-1: FALL 2007 SAMPLING RESULTS FOR THE NORTH AERATION BATTERY PRIMARY EFFLUENT

Date	TKN (mg/L)	Sol-TKN (mg/L)	NH_3-N (mg/L)	NO_2-N (mg/L)	NO_3-N (mg/L)	TP (mg/L)	Sol-P (mg/L)	SS (mg/L)	VSS (mg/L)	pH	$CBOD_5$ (mg/L)
09/05/07	23.26	13.68	16.65	1.363	0.090	3.68	1.33	38	30	7.48	74
09/06/07	23.84	17.29	16.77	0.043	<0.020	4.76	2.45	56	50	7.51	65
09/07/07	22.80	15.27	16.44	0.049	0.020	4.19	1.86	68	56	7.43	77
09/08/07	21.58	15.67	15.77	0.043	0.036	4.37	2.25	86	70	7.62	76
09/11/07	22.98	18.94	15.50	0.373	0.749	4.96	2.59	84	74	7.52	82
09/12/07	24.02	14.47	14.61	0.328	0.243	4.67	2.45	52	38	7.61	71
09/13/07	25.86	18.56	16.23	0.035	<0.020	5.00	2.84	76	60	7.45	83
09/14/07	23.33	17.22	15.83	0.688	0.259	4.37	2.64	52	42	7.52	64
09/15/07	26.98	18.73	17.86	0.039	<0.020	5.11	3.01	96	78	7.71	86
09/18/07	25.55	19.29	17.88	0.564	0.055	5.11	3.27	108	87	7.62	79
09/19/07	26.56	19.72	18.14	0.138	<0.020	5.48	3.57	56	46	7.49	75
09/20/07	27.02	19.68	18.94	0.125	<0.020	5.13	3.22	82	66	7.60	79
09/21/07	25.55	20.45	18.09	0.467	0.383	4.87	2.97	64	52	7.58	80
09/22/07	24.13	17.07	18.18	0.037	0.022	5.42	3.55	60	52	7.50	90
09/25/07	25.23	19.42	18.32	0.235	0.025	6.28	4.29	62	56	7.60	80
09/26/07	23.52	18.19	17.19	0.044	<0.020	7.43	5.57	60	56	7.55	103
09/27/07	25.32	19.67	17.83	0.467	0.120	5.72	3.87	68	48	7.56	85
09/28/07	25.14	18.40	19.36	0.617	0.672	5.66	3.91	52	40	7.60	94
09/29/07	25.04	19.88	18.49	0.067	0.057	5.35	3.52	88	82	7.59	92
10/02/07	22.10	17.33	16.21	0.669	0.344	3.96	2.68	44	36	7.51	78
10/03/07	22.59	19.61	17.99	0.029	<0.020	4.52	3.23	42	32	7.61	88
10/04/07	23.32	16.70	17.23	0.912	0.260	5.02	3.25	54	44	7.56	77
10/05/07	24.13	18.42	17.14	0.900	0.329	4.80	2.91	54	50	7.48	81
10/06/07	23.47	16.17	16.45	0.034	0.040	4.85	3.04	72	62	7.66	83
10/09/07	24.13	17.49	17.06	0.870	0.687	4.60	2.82	62	52	7.58	66

TABLE D-1 (Continued): FALL 2007 SAMPLING RESULTS FOR THE NORTH AERATION BATTERY PRIMARY EFFLUENT

Date	TKN (mg/L)	Sol-TKN (mg/L)	NH_3-N (mg/L)	NO_2-N (mg/L)	NO_3-N (mg/L)	TP (mg/L)	Sol-P (mg/L)	SS (mg/L)	VSS (mg/L)	pH	$CBOD_5$ (mg/L)
10/10/07	23.79	17.75	18.66	1.001	0.556	4.40	2.66	42	36	7.59	90
10/11/07	24.98	18.80	18.54	0.819	0.926	4.43	3.02	36	34	7.55	81
10/12/07	25.58	18.59	18.68	1.072	1.145	4.41	2.81	34	30	7.63	89
10/13/07	24.97	15.54	17.78	0.543	1.737	5.62	3.29	54	48	7.48	102
10/16/07	26.07	18.91	19.01	0.522	0.207	5.26	3.39	40	30	7.60	96
10/17/07	21.42	15.94	16.01	1.325	0.852	3.73	2.25	42	38	7.76	75
10/18/07	24.20	18.31	18.17	0.435	0.580	4.35	2.72	48	36	7.51	87
10/19/07	20.85	15.54	15.85	0.554	0.684	3.94	2.55	36	34	7.66	77
10/20/07	23.20	18.23	18.23	0.423	0.240	5.11	3.66	50	46	7.39	77
10/23/07	26.25	21.31	19.46	0.433	0.675	4.86	3.33	30	26	7.58	93
10/24/07	24.38	19.77	18.72	0.385	0.612	4.63	3.20	38	36	7.59	83
10/25/07	25.98	22.12	21.32	0.039	<0.020	4.74	3.69	24	20	7.55	82
10/26/07	25.26	19.83	19.19	1.016	<0.020	4.83	3.43	50	40	8.05	92
10/27/07	25.57	18.31	18.35	0.153	0.067	5.23	3.42	66	56	7.66	86
10/30/07	26.31	20.74	18.89	0.375	0.382	5.01	3.51	30	24	7.61	99
10/31/07	25.27	21.33	18.81	0.303	0.460	5.08	3.70	28	26	7.77	83
11/01/07	25.33	19.46	18.73	0.505	0.880	5.00	3.48	40	36	7.70	92
11/02/07	27.40	19.18	20.22	0.147	0.596	4.83	2.98	24	22	7.62	79
11/03/07	27.72	21.59	20.26	0.154	0.275	5.71	4.08	56	44	7.65	91
11/06/07	29.08	22.65	21.51	0.044	<0.020	5.13	3.47	28	26	7.64	110
11/07/07	27.72	21.40	21.84	0.248	<0.020	5.16	3.41	38	28	7.66	100
11/08/07	29.72	23.53	22.93	0.047	<0.020	5.58	3.90	38	34	7.62	106
11/09/07	27.73	22.81	20.67	0.228	0.685	5.77	4.31	56	48	7.62	97
11/10/07	27.30	21.24	20.25	0.041	0.027	5.44	3.69	68	56	7.53	93
11/14/07	28.69	24.38	22.97	0.205	0.235	5.37	3.59	36	28	7.62	122

TABLE D-1 (Continued): FALL 2007 SAMPLING RESULTS FOR THE NORTH AERATION BATTERY PRIMARY EFFLUENT

Date	TKN (mg/L)	Sol-TKN (mg/L)	NH_3-N (mg/L)	NO_2-N (mg/L)	NO_3-N (mg/L)	TP (mg/L)	Sol-P (mg/L)	SS (mg/L)	VSS (mg/L)	pH	$CBOD_5$ (mg/L)
11/15/07	29.85	23.99	21.53	0.144	0.368	5.60	3.78	36	32	7.64	104
11/16/07	26.84	20.00	21.16	0.211	0.636	4.99	3.25	40	38	7.65	104
11/17/07	27.32	20.70	21.36	0.033	0.043	5.01	3.30	64	50	7.54	118

TABLE D-2: FALL 2007 SAMPLING RESULTS FOR THE NORTH AERATION BATTERY FINAL EFFLUENT

Date	TKN (mg/L)	Sol-TKN (mg/L)	NH_3-N (mg/L)	NO_2-N (mg/L)	NO_3-N (mg/L)	TP (mg/L)	Sol-P (mg/L)	SS (mg/L)	VSS (mg/L)	pH	$CBOD_5$ (mg/L)
09/05/07	1.06	1.20	0.12	0.023	15.468	0.30	0.19	4	4	7.02	4
09/06/07	0.80	1.13	0.11	0.028	15.524	0.34	0.25	4	3	7.24	<2
09/07/07	1.24	0.97	0.15	0.041	15.735	0.44	0.32	4	3	7.03	2
09/08/07	1.01	0.91	0.12	0.071	14.664	0.37	0.26	4	3	7.42	3
09/11/07	1.22	0.75	0.10	0.037	13.609	0.46	0.33	4	3	7.04	4
09/12/07	1.21	0.94	0.08	0.026	13.511	0.55	0.41	3	2	7.25	3
09/13/07	0.95	0.93	0.11	0.038	13.777	0.52	0.40	22	17	7.29	5
09/14/07	1.01	0.74	<0.03	0.029	15.429	0.51	0.40	4	3	7.15	3
09/15/07	1.06	0.74	0.08	0.022	16.333	0.53	0.38	5	4	7.57	3
09/18/07	1.16	0.59	0.14	0.048	15.104	0.45	0.32	5	4	7.08	3
09/19/07	1.38	1.02	0.14	0.066	15.613	0.60	0.45	4	3	6.99	3
09/20/07	0.67	0.81	0.14	0.037	14.825	0.50	0.39	6	4	6.99	3
09/21/07	1.04	0.86	0.16	0.034	14.454	0.41	0.32	4	2	7.05	2
09/22/07	1.44	0.65	0.15	0.039	15.259	0.55	0.35	6	5	7.16	3
09/25/07	1.30	0.59	0.16	0.037	13.813	0.46	0.34	6	5	6.97	2
09/26/07	1.24	0.93	0.18	0.037	14.889	1.04	0.92	7	6	7.07	<2
09/27/07	0.90	1.02	0.11	0.030	15.054	0.91	0.78	6	4	7.09	<2
09/28/07	1.46	1.08	0.22	0.027	15.697	0.83	0.64	6	4	7.03	<2
09/29/07	1.16	1.01	0.13	0.026	16.516	0.74	0.59	5	4	7.23	<2
10/02/07	1.15	0.44	0.14	<0.003	13.474	0.33	0.24	4	4	6.95	<2
10/03/07	1.42	0.78	0.17	0.030	14.602	0.38	0.31	5	4	7.12	<2
10/04/07	0.50	0.99	0.12	0.022	15.681	0.38	0.29	6	4	6.86	<2
10/05/07	1.46	1.20	0.11	0.028	15.392	0.54	0.32	5	3	6.88	2
10/06/07	1.24	1.08	0.12	0.032	15.189	0.38	0.25	6	5	7.07	<2
10/09/07	1.32	0.71	0.20	<0.003	12.521	0.32	0.18	5	4	6.83	<2

TABLE D-2 (Continued): FALL 2007 SAMPLING RESULTS FOR THE NORTH AERATION BATTERY FINAL EFFLUENT

Date	TKN (mg/L)	Sol-TKN (mg/L)	NH_3-N (mg/L)	NO_2-N (mg/L)	NO_3-N (mg/L)	TP (mg/L)	Sol-P (mg/L)	SS (mg/L)	VSS (mg/L)	pH	$CBOD_5$ (mg/L)
10/10/07	1.14	1.05	0.14	0.028	14.413	0.29	0.19	4	3	6.96	<2
10/11/07	0.83	0.83	0.14	0.020	16.006	0.29	0.17	7	4	6.92	<2
10/12/07	1.38	0.99	0.11	0.021	17.518	0.39	0.21	6	3	7.10	<2
10/13/07	1.41	1.56	0.20	0.037	16.942	0.34	0.25	8	6	7.14	3
10/16/07	1.12	0.60	0.20	0.047	13.688	0.28	0.18	7	4	6.95	<2
10/17/07	1.35	1.28	0.19	0.027	13.707	0.49	0.32	6	4	7.05	3
10/18/07	0.79	0.22	0.15	0.027	12.984	0.50	0.38	6	4	6.92	<2
10/19/07	1.37	0.95	0.09	0.024	12.428	0.49	0.36	7	5	6.97	<2
10/20/07	1.17	0.95	0.08	0.023	12.947	0.55	0.41	6	4	7.28	2
10/23/07	1.22	0.65	0.07	0.018	11.388	0.46	0.33	4	4	6.82	<2
10/24/07	0.83	0.72	0.14	0.016	12.564	0.46	0.34	6	5	6.92	<2
10/25/07	0.99	0.72	0.21	0.029	16.961	0.56	0.43	3	3	6.91	<2
10/26/07	1.70	1.36	0.22	0.049	17.138	0.61	0.41	5	3	7.10	<2
10/27/07	1.23	1.12	0.06	0.022	15.347	1.33	0.30	6	3	7.25	<2
10/30/07	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
10/31/07	1.25	0.99	0.06	0.021	13.495	0.49	0.34	6	4	7.15	2
11/01/07	0.85	0.80	0.09	0.020	14.249	0.55	0.36	5	3	7.04	<2
11/02/07	1.39	1.08	0.11	0.022	14.689	0.56	0.35	9	7	7.05	2
11/03/07	1.15	0.97	0.06	0.020	14.926	0.50	0.38	5	4	7.52	<2
11/06/07	1.15	0.59	0.06	0.029	12.101	0.36	0.25	4	2	7.10	2
11/07/07	1.08	0.99	0.06	0.017	13.044	0.37	0.22	4	2	6.92	<2
11/08/07	0.96	1.04	0.10	0.019	13.582	0.42	0.29	4	2	6.81	<2
11/09/07	1.46	0.96	0.07	0.019	13.586	0.57	0.38	5	3	6.81	<2
11/10/07	1.21	0.91	0.11	0.022	13.364	0.61	0.47	4	2	7.27	2
11/14/07	1.43	1.01	0.07	0.032	18.061	0.41	0.18	6	4	6.78	<2

TABLE D-2 (Continued): FALL 2007 SAMPLING RESULTS FOR THE NORTH AERATION BATTERY FINAL EFFLUENT

Date	TKN (mg/L)	Sol-TKN (mg/L)	NH_3-N (mg/L)	NO_2-N (mg/L)	NO_3-N (mg/L)	TP (mg/L)	Sol-P (mg/L)	SS (mg/L)	VSS (mg/L)	pH	$CBOD_5$ (mg/L)
11/15/07	0.93	0.74	0.09	0.022	14.171	0.37	0.26	7	3	6.95	<2
11/16/07	1.31	1.02	0.07	0.018	14.208	0.48	0.36	12	10	7.07	2
11/17/07	1.09	0.78	0.11	0.017	13.499	0.41	0.34	5	3	7.15	<2

N/A = No sample collected.

TABLE D-3: FALL 2007 SAMPLING RESULTS FOR THE SOUTH AERATION BATTERY PRIMARY EFFLUENT

Date	TKN (mg/L)	Sol-TKN (mg/L)	NH_3-N (mg/L)	NO_2-N (mg/L)	NO_3-N (mg/L)	TP (mg/L)	Sol-P (mg/L)	SS (mg/L)	VSS (mg/L)	pH	$CBOD_5$ (mg/L)
09/05/07	22.60	11.98	16.54	0.195	0.830	3.53	1.62	60	50	7.62	70
09/06/07	26.60	17.76	16.97	0.045	<0.020	4.72	2.87	44	40	7.57	61
09/07/07	21.04	16.07	16.92	0.380	0.052	3.87	2.32	46	42	7.56	71
09/08/07	20.69	15.29	15.91	0.061	0.057	4.03	2.35	62	56	7.70	69
09/11/07	21.66	15.88	16.68	0.170	0.369	4.34	2.82	42	40	7.63	79
09/12/07	22.35	14.84	14.63	0.117	0.077	4.32	2.63	44	38	7.68	62
09/13/07	24.48	18.14	15.83	0.032	<0.020	4.74	2.98	50	46	7.60	77
09/14/07	22.61	15.75	15.24	0.222	0.455	4.39	2.63	48	46	7.66	60
09/15/07	24.28	18.83	16.91	0.036	0.023	4.71	3.01	70	60	7.70	81
09/18/07	25.98	19.20	17.72	0.198	0.138	4.97	3.28	100	87	7.68	81
09/19/07	25.40	20.05	17.73	0.042	<0.020	5.15	3.61	54	52	7.62	73
09/20/07	25.79	19.29	18.34	0.040	<0.020	4.93	3.22	58	48	7.67	71
09/21/07	25.71	16.60	17.33	0.447	0.079	4.75	2.69	60	46	7.66	71
09/22/07	24.57	17.77	17.62	0.036	<0.020	5.31	3.47	44	38	7.52	81
09/25/07	22.63	17.17	17.61	0.227	0.381	5.35	3.88	46	42	7.66	72
09/26/07	19.29	16.67	16.93	0.041	<0.020	6.48	5.13	54	52	7.63	100
09/27/07	22.73	18.17	17.25	0.048	<0.020	5.52	4.16	58	48	7.62	82
09/28/07	23.94	18.15	18.63	0.346	0.381	5.60	3.89	42	40	7.61	90
09/29/07	24.36	18.00	17.66	0.034	0.067	5.55	3.59	74	66	7.58	90
10/02/07	21.91	16.23	16.04	0.287	0.056	4.04	2.56	54	48	7.55	79
10/03/07	22.50	18.89	17.53	0.029	0.021	4.45	2.98	50	44	7.42	82
10/04/07	22.24	16.53	16.83	0.438	0.200	4.53	3.04	46	36	7.69	69
10/05/07	22.98	17.18	16.93	0.631	0.164	4.52	2.93	46	34	7.59	66
10/06/07	22.79	17.31	16.37	0.026	0.031	4.59	3.11	66	62	7.69	79
10/09/07	24.24	18.02	17.54	0.308	0.164	4.64	2.97	64	44	7.60	98

TABLE D-3 (Continued): FALL 2007 SAMPLING RESULTS FOR THE SOUTH AERATION BATTERY PRIMARY EFFLUENT

Date	TKN (mg/L)	Sol-TKN (mg/L)	NH_3-N (mg/L)	NO_2-N (mg/L)	NO_3-N (mg/L)	TP (mg/L)	Sol-P (mg/L)	SS (mg/L)	VSS (mg/L)	pH	$CBOD_5$ (mg/L)
10/10/07	23.23	18.95	18.77	0.298	0.053	4.38	2.86	40	32	7.68	92
10/11/07	24.68	19.54	18.85	0.217	0.419	4.50	3.08	36	34	7.65	86
10/12/07	25.68	19.62	19.25	0.347	0.548	4.60	3.05	44	42	7.73	84
10/13/07	25.47	19.01	18.71	0.114	0.320	5.67	3.80	52	44	7.60	101
10/16/07	26.67	18.87	18.81	0.445	0.103	5.37	3.29	46	38	7.65	99
10/17/07	22.08	17.96	16.97	0.594	0.513	3.78	2.41	38	36	7.69	78
10/18/07	23.62	17.81	17.34	0.409	0.804	4.44	2.87	58	48	7.59	94
10/19/07	20.24	14.99	14.92	0.788	0.670	4.12	2.62	42	36	7.65	75
10/20/07	23.10	18.55	17.67	0.353	0.216	5.48	3.79	64	62	7.25	78
10/23/07	26.38	21.11	19.42	0.429	0.632	4.89	3.31	40	36	7.58	92
10/24/07	23.88	19.54	19.21	0.383	0.524	4.68	3.20	42	38	7.64	79
10/25/07	25.46	20.79	19.55	0.363	0.167	4.93	3.54	42	38	7.66	100
10/26/07	25.31	20.11	19.23	0.647	0.657	4.96	3.51	44	38	7.70	88
10/27/07	25.55	18.82	17.56	0.054	0.029	5.44	3.62	72	62	7.64	82
10/30/07	26.11	20.61	18.28	0.341	0.515	5.20	3.60	42	36	7.60	97
10/31/07	23.30	19.42	16.98	0.377	0.529	4.98	3.54	48	34	7.73	84
11/01/07	25.29	19.16	18.34	0.407	0.735	5.26	3.56	52	42	7.79	95
11/02/07	28.53	16.99	17.06	0.431	0.783	5.46	2.79	50	48	7.75	95
11/03/07	26.07	19.79	18.75	0.270	0.717	5.67	3.88	66	52	7.67	84
11/06/07	27.79	21.86	20.61	0.169	<0.020	5.18	3.56	38	28	7.66	111
11/07/07	26.63	22.20	20.90	0.389	0.322	5.17	3.66	48	38	7.69	107
11/08/07	28.55	22.62	21.58	0.272	0.020	5.64	3.95	46	42	7.68	110
11/09/07	27.10	21.57	19.80	0.301	0.898	5.77	4.20	52	40	7.66	99
11/10/07	25.78	20.07	18.98	0.062	0.022	5.46	3.69	72	58	7.68	100
11/14/07	27.41	21.51	21.49	0.327	0.545	5.27	3.38	46	36	7.52	112

TABLE D-3 (Continued): FALL 2007 SAMPLING RESULTS FOR THE SOUTH AERATION BATTERY PRIMARY EFFLUENT

Date	TKN (mg/L)	Sol-TKN (mg/L)	NH_3-N (mg/L)	NO_2-N (mg/L)	NO_3-N (mg/L)	TP (mg/L)	Sol-P (mg/L)	SS (mg/L)	VSS (mg/L)	pH	$CBOD_5$ (mg/L)
11/15/07	27.90	22.65	20.59	0.169	0.948	5.47	4.01	44	38	7.63	108
11/16/07	26.85	20.29	20.53	0.284	0.911	5.18	3.36	54	38	7.65	105
11/17/07	26.85	19.68	20.48	0.034	0.049	5.15	3.28	82	72	7.62	130

TABLE D-4: FALL 2007 SAMPLING RESULTS FOR THE SOUTH AERATION BATTERY FINAL EFFLUENT

Date	TKN (mg/L)	Sol-TKN (mg/L)	NH_3-N (mg/L)	NO_2-N (mg/L)	NO_3-N (mg/L)	TP (mg/L)	Sol-P (mg/L)	SS (mg/L)	VSS (mg/L)	pH	$CBOD_5$ (mg/L)
09/05/07	1.17	0.96	0.11	0.019	14.872	0.39	0.20	6	4	6.96	3
09/06/07	0.75	0.93	0.07	0.045	15.670	0.37	0.16	7	5	7.15	<2
09/07/07	1.14	1.10	0.20	0.121	16.162	0.44	0.21	5	3	6.86	<2
09/08/07	1.14	0.95	0.04	0.084	15.563	0.39	0.19	7	5	7.25	3
09/11/07	1.38	0.90	0.05	0.016	15.540	0.56	0.23	8	5	6.99	3
09/12/07	1.22	1.11	0.04	0.020	14.951	0.57	0.28	8	5	7.11	3
09/13/07	0.63	0.78	0.09	0.015	15.515	0.52	0.32	8	5	7.21	4
09/14/07	1.14	0.81	0.03	0.020	16.689	0.49	0.26	6	4	7.08	3
09/15/07	1.14	0.81	0.06	0.014	16.898	0.58	0.28	9	5	7.43	3
09/18/07	1.08	0.77	0.08	0.020	16.094	0.41	0.22	8	5	7.04	3
09/19/07	1.00	0.82	0.10	0.021	16.900	0.49	0.26	4	3	6.92	2
09/20/07	1.01	0.78	0.08	0.026	16.366	0.71	0.31	11	8	7.02	3
09/21/07	1.18	<0.06	0.10	0.026	16.254	0.50	0.15	9	6	7.00	<2
09/22/07	1.31	0.72	0.09	0.033	17.712	0.46	0.25	8	5	7.03	2
09/25/07	1.29	0.86	0.13	0.029	15.054	0.42	0.30	9	6	6.97	<2
09/26/07	1.19	0.63	0.09	0.038	16.659	0.90	0.68	7	5	7.04	<2
09/27/07	0.89	0.90	0.05	0.023	16.518	0.91	0.71	9	5	7.02	<2
09/28/07	1.36	0.64	0.08	0.018	17.648	0.78	0.47	8	5	6.95	<2
09/29/07	1.20	0.75	0.06	0.013	17.862	0.82	0.53	7	4	7.23	<2
10/02/07	1.04	0.81	0.07	0.014	13.907	0.47	0.33	7	5	7.06	<2
10/03/07	1.45	0.75	0.06	0.016	16.001	0.60	0.21	7	5	7.17	<2
10/04/07	0.32	0.80	0.05	0.023	16.713	0.31	0.29	7	4	6.84	<2
10/05/07	1.17	0.32	0.05	0.030	17.450	0.49	0.26	6	4	6.86	<2
10/06/07	1.44	0.91	0.05	0.022	17.307	0.70	0.32	12	9	7.31	2
10/09/07	1.14	0.78	0.04	<0.003	14.968	0.42	0.21	7	5	6.90	<2

TABLE D-4 (Continued): FALL 2007 SAMPLING RESULTS FOR THE SOUTH AERATION BATTERY FINAL EFFLUENT

Date	TKN (mg/L)	Sol-TKN (mg/L)	NH_3-N (mg/L)	NO_2-N (mg/L)	NO_3-N (mg/L)	TP (mg/L)	Sol-P (mg/L)	SS (mg/L)	VSS (mg/L)	pH	$CBOD_5$ (mg/L)
10/10/07	1.06	0.57	0.05	0.029	16.558	0.48	0.23	9	6	6.97	<2
10/11/07	0.86	0.91	0.04	0.039	17.816	0.53	0.23	8	6	7.01	<2
10/12/07	1.33	0.77	0.06	0.018	18.520	0.61	0.26	11	7	7.01	<2
10/13/07	1.27	1.00	0.10	0.016	17.873	0.48	0.26	10	6	7.04	<2
10/16/07	1.07	0.73	0.05	0.019	15.443	0.42	0.24	10	6	7.05	<2
10/17/07	0.97	0.57	0.07	0.018	15.046	0.52	0.22	5	<2	7.00	<2
10/18/07	0.94	0.63	0.07	0.068	15.786	0.49	0.27	9	7	6.93	<2
10/19/07	1.22	0.59	0.06	0.042	15.270	0.47	0.25	7	5	6.87	<2
10/20/07	1.11	1.36	0.07	0.033	16.825	0.53	0.32	6	4	7.13	<2
10/23/07	1.27	0.95	0.08	0.034	16.449	0.48	0.34	8	6	6.82	<2
10/24/07	0.92	0.63	0.13	0.028	17.286	0.58	0.39	4	3	6.94	<2
10/25/07	0.95	0.78	0.08	0.020	19.476	0.62	0.41	7	5	6.96	<2
10/26/07	1.53	0.78	0.05	0.023	18.362	0.69	0.41	8	5	7.13	<2
10/27/07	1.24	1.04	0.05	0.030	18.835	0.56	0.32	7	4	7.22	<2
10/30/07	1.38	0.88	0.09	0.030	17.064	0.48	0.21	8	5	6.95	<2
10/31/07	1.25	0.65	0.07	0.031	18.693	0.49	0.26	7	4	7.04	<2
11/01/07	0.77	0.57	0.07	0.028	19.010	0.52	0.28	8	5	7.07	<2
11/02/07	1.36	0.57	0.06	0.025	19.278	0.48	0.21	5	3	6.95	<2
11/03/07	1.16	0.93	0.08	0.026	18.928	0.50	0.27	6	4	7.44	<2
11/06/07	1.27	0.91	0.03	0.027	16.801	0.47	0.21	7	5	7.06	<2
11/07/07	1.24	0.65	0.07	0.022	17.905	0.43	0.18	8	4	6.98	<2
11/08/07	1.06	1.08	0.20	0.025	19.115	0.44	0.18	7	4	6.93	<2
11/09/07	1.46	0.62	0.06	0.026	19.134	0.52	0.25	7	4	6.95	<2
11/10/07	1.23	0.95	0.06	0.023	19.004	0.61	0.32	7	4	7.20	<2
11/14/07	1.41	0.79	0.11	0.023	12.908	0.29	0.17	6	4	6.91	<2

TABLE D-4 (Continued): FALL 2007 SAMPLING RESULTS FOR THE SOUTH AERATION BATTERY FINAL EFFLUENT

Date	TKN (mg/L)	Sol-TKN (mg/L)	NH_3-N (mg/L)	NO_2-N (mg/L)	NO_3-N (mg/L)	TP (mg/L)	Sol-P (mg/L)	SS (mg/L)	VSS (mg/L)	pH	$CBOD_5$ (mg/L)
11/15/07	2.66	2.33	0.06	0.026	19.656	0.57	0.26	6	4	6.85	<2
11/16/07	1.36	0.34	0.06	0.022	19.908	0.50	0.23	10	5	6.89	<2
11/17/07	1.08	0.72	0.08	0.017	19.232	0.39	0.23	8	5	7.00	<2

APPENDIX E

NORTH AND SOUTH AERATION BATTERY MASS BALANCE RESULTS

TABLE E-1: MASS BALANCE RESULTS FOR THE NORTH AERATION BATTERY

	Flows (MGD)			Suspended Solids (mg/L)				Solids Loads (lb/day)					Biomass	Observed
Date	NAB Inf	RAS	WAS	PE	ML	RAS	FE	PE	RAS	FE	WAS	Eff - Inf	Produced (lb/day)	Yield (lb VSS/lb $CBOD_5$)
09/05/07	11.2	9.0	0.117	38	3,458	10,260	4	3,550	770,116	374	10,012	6,835	6,908	1.59
09/06/07	12.1	9.3	0.127	56	3,696	9,370	4	5,646	726,756	403	9,925	4,682	6,649	1.62
09/07/07	12.3	9.1	0.129	68	3,550	10,490	4	6,977	796,128	410	11,286	4,719	7,900	1.50
09/08/07	12.3	9.2	0.140	86	3,663	10,100	4	8,788	774,953	409	11,793	3,414	8,491	1.66
09/11/07	13.5	10.2	0.162	84	3,813	10,620	4	9,468	903,422	451	14,348	5,331	10,187	1.61
09/12/07	11.4	8.4	0.162	52	3,967	10,040	3	4,927	703,362	284	13,565	8,922	9,902	2.20
09/13/07	11.2	8.4	0.183	76	4,550	9,540	22	7,074	668,334	2,048	14,560	9,534	11,066	2.22
09/14/07	11.8	9.0	0.194	52	3,846	10,990	4	5,099	824,909	392	17,781	13,074	12,803	2.82
09/15/07	11.0	8.2	0.194	96	3,900	9,910	5	8,773	677,725	457	16,034	7,718	11,865	2.12
09/18/07	10.9	7.8	0.237	108	3,708	10,500	5	9,779	683,046	453	20,754	11,428	14,943	2.74
09/19/07	10.1	7.2	0.274	56	3,550	8,450	4	4,697	507,406	336	19,310	14,948	13,710	2.88
09/20/07	10.7	7.4	0.269	82	3,425	9,570	6	7,288	590,622	533	21,470	14,715	15,029	2.75
09/21/07	10.5	7.6	0.272	64	3,496	7,990	4	5,582	506,438	349	18,125	12,892	12,144	2.29
09/22/07	11.4	8.2	0.219	60	3,133	7,720	6	5,708	527,955	571	14,100	8,963	9,870	1.58
09/25/07	11.6	8.4	0.236	62	2,933	8,190	6	6,002	573,759	581	16,120	10,699	10,962	1.84
09/26/07	11.1	8.9	0.213	60	3,000	8,850	7	5,533	656,900	646	15,721	10,834	10,376	1.43
09/27/07	10.9	7.8	0.195	68	3,029	8,300	6	6,157	539,932	543	13,498	7,884	9,314	1.65
09/28/07	10.4	8.0	0.179	52	3,004	8,210	6	4,492	547,771	518	12,256	8,283	8,334	1.43
09/29/07	10.8	7.5	0.179	88	3,067	7,540	5	7,931	471,627	451	11,256	3,775	7,429	1.28
10/02/07	11.7	6.7	0.215	44	2,942	9,070	4	4,278	506,813	389	16,263	12,375	11,222	1.92
10/03/07	10.7	7.7	0.209	42	2,908	9,530	5	3,733	611,998	444	16,611	13,323	11,296	1.86
10/04/07	10.8	7.9	0.189	54	2,800	7,820	6	4,845	515,229	538	12,326	8,020	8,259	1.64
10/05/07	10.7	7.5	0.176	54	2,871	7,230	5	4,797	452,237	444	10,612	6,260	6,898	1.37
10/06/07	11.2	8.0	0.171	72	2,742	7,990	6	6,746	533,093	562	11,395	5,211	7,179	1.28

TABLE E-1 (Continued): MASS BALANCE RESULTS FOR THE NORTH AERATION BATTERY

Date	Flows (MGD)			Suspended Solids (mg/L)				Solids Loads (lb/day)					Biomass Produced (lb/day)	Observed Yield (lb VSS/lb $CBOD_5$)
	NAB Inf	RAS	WAS	PE	ML	RAS	FE	PE	RAS	FE	WAS	Eff - Inf		
10/09/07	11.1	7.9	0.166	62	3,542	6,750	5	5,732	444,731	462	9,345	4,075	6,541	1.72
10/10/07	10.5	7.7	0.172	42	3,538	6,290	4	3,673	403,931	350	9,023	5,700	6,406	1.31
10/11/07	10.4	7.8	0.166	36	4,271	6,360	7	3,123	413,731	607	8,805	6,289	6,252	1.56
10/12/07	9.6	5.8	0.163	34	2,483	6,480	6	2,710	313,451	478	8,809	6,577	5,814	1.19
10/13/07	11.1	8.4	0.161	54	2,325	6,750	8	4,980	472,878	738	9,063	4,822	5,982	0.90
10/16/07	12.0	4.5	0.083	40	2,658	7,430	7	3,998	278,848	700	5,143	1,845	3,240	N/A
10/17/07	7.7	5.4	0.017	42	2,821	6,040	6	2,682	272,017	383	856	(1,442)	514	N/A
10/18/07	8.8	6.3	0.124	48	2,917	5,590	6	3,521	293,710	440	5,781	2,700	3,584	N/A
10/19/07	7.2	5.2	0.115	36	2,821	7,270	7	2,150	315,285	418	6,973	5,241	4,253	1.51
10/20/07	7.5	5.6	0.111	50	2,721	7,280	6	3,124	340,005	375	6,739	3,990	4,178	1.42
10/23/07	7.7	5.4	0.122	30	2,504	7,410	4	1,928	333,717	257	7,540	5,869	4,750	1.21
10/24/07	7.3	3.1	0.122	38	2,413	6,410	6	2,304	165,724	364	6,522	4,581	4,109	1.29
10/25/07	6.5	1.5	0.119	24	2,458	4,090	3	1,309	51,166	164	4,059	2,914	2,557	1.11
10/26/07	7.6	5.6	0.118	50	2,329	5,330	5	3,185	248,932	319	5,245	2,379	3,357	0.97
10/27/07	8.0	5.7	0.113	66	2,217	6,380	6	4,424	303,292	402	6,013	1,990	3,848	1.05
10/30/07	6.9	5.6	0.118	30	2,304	5,870	6	1,719	274,152	344	5,777	4,401	3,408	0.95
10/31/07	7.4	5.3	0.119	28	2,425	5,870	6	1,729	259,466	371	5,826	4,467	3,787	1.22
11/01/07	6.9	5.0	0.121	40	2,400	5,340	5	2,315	222,678	289	5,389	3,363	3,395	1.08
11/02/07	7.0	6.3	0.114	24	2,508	6,220	9	1,395	326,811	523	5,914	5,042	3,962	1.44
11/03/07	7.2	5.4	0.112	56	2,696	7,280	5	3,349	327,862	299	6,800	3,750	4,760	1.42
11/06/07	6.9	5.0	0.117	28	2,971	8,280	4	1,612	345,276	230	8,079	6,698	5,413	1.34
11/07/07	6.6	4.9	0.117	38	3,083	7,430	4	2,105	303,634	222	7,250	5,367	5,003	1.50
11/08/07	6.8	5.4	0.117	38	2,917	6,390	4	2,157	287,780	227	6,235	4,306	4,365	1.25
11/09/07	7.0	5.3	0.116	56	2,883	7,070	5	3,272	312,508	292	6,840	3,860	4,925	1.44

TABLE E-1 (Continued): MASS BALANCE RESULTS FOR THE NORTH AERATION BATTERY

Date	Flows (MGD)			Suspended Solids (mg/L)				Solids Loads (lb/day)					Biomass Produced (lb/day)	Observed Yield (lb VSS/lb $CBOD_5$)
	NAB Inf	RAS	WAS	PE	ML	RAS	FE	PE	RAS	FE	WAS	Eff - Inf		
11/10/07	6.9	5.3	0.118	68	2,842	7,710	4	3,900	340,797	229	7,588	3,917	5,311	1.58
11/14/07	6.8	5.1	0.127	36	3,188	5,730	6	2,035	243,720	339	6,069	4,373	4,370	1.14
11/15/07	7.0	5.1	0.127	36	2,896	7,270	7	2,094	309,222	407	7,700	6,014	6,083	1.59
11/16/07	7.0	5.1	0.132	40	3,417	6,270	12	2,325	266,688	697	6,903	5,275	4,694	1.37
11/17/07	7.3	5.2	0.136	64	2,883	6,910	5	3,880	299,673	303	7,838	4,261	5,800	1.27
Average	9.4	6.7	0.155	53	3,066	7,694	6	4,170	432,587	450	9,933	6,213	7,045	1.58

Estimated biomass produced assumed to be equal to the solids in the WAS.
Observed yield calculated using the SRT and assuming a decay rate of 0.06 /day.
N/A = Either sample not collected or cannot be calculated due to missing data.
NAB = North Aeration Battery.
RAS = Return Activated Sludge.
WAS = Waste Activated Sludge.
PE = Primary Effluent.
ML = Mixed Liquor.
FE = Final Effluent.
Eff = Effluent.
Inf = Influent.

TABLE E-2: MASS BALANCE RESULTS FOR THE SOUTH AERATION BATTERY

Date	Flows (MGD)			Suspended Solids (mg/L)				Solids Loads (lb/day)					Biomass Produced (lb/day)	Observed Yield (lb VSS/lb $CBOD_5$)
	SAB Inf	RAS	WAS	PE	ML	RAS	FE	PE	RAS	FE	WAS	Eff - Inf		
09/05/07	11.2	8.6	0.111	60	3,617	7,980	6	5,606	572,358	561	7,387	2,342	4,426	1.25
09/06/07	12.1	9.2	0.111	44	3,446	8,120	7	4,436	623,031	706	7,517	3,787	4,435	1.28
09/07/07	12.3	9.1	0.109	46	3,483	8,000	5	4,720	607,152	513	7,272	3,066	4,333	1.07
09/08/07	12.3	9.2	0.106	62	3,492	6,970	7	6,335	534,794	715	6,162	542	3,638	1.02
09/11/07	13.5	10.2	0.098	42	3,525	7,050	8	4,734	599,729	902	5,762	1,930	3,420	0.78
09/12/07	11.4	8.4	0.095	44	3,679	7,380	8	4,169	517,013	758	5,847	2,436	3,457	1.23
09/13/07	11.2	8.4	0.097	50	3,879	7,960	8	4,654	557,646	745	6,439	2,530	3,860	1.11
09/14/07	11.8	9.0	0.096	48	3,692	8,290	6	4,707	622,247	588	6,637	2,519	3,941	1.32
09/15/07	11.0	8.2	0.096	70	3,717	7,430	9	6,397	508,123	822	5,949	374	3,534	0.98
09/18/07	10.9	7.9	0.098	100	3,425	9,620	8	9,055	633,823	724	7,863	(468)	5,558	1.33
09/19/07	10.1	7.3	0.106	54	3,983	8,830	4	4,529	537,588	336	7,806	3,612	4,598	1.39
09/20/07	10.7	7.4	0.109	58	4,171	8,830	11	5,155	544,952	978	8,027	3,850	4,852	1.46
09/21/07	10.5	7.6	0.113	60	3,983	7,560	9	5,233	479,183	785	7,125	2,677	4,234	1.32
09/22/07	11.4	8.2	0.115	44	3,867	8,060	8	4,186	551,207	761	7,730	4,306	4,598	1.09
09/25/07	11.6	8.4	0.115	46	3,763	8,140	9	4,453	570,256	871	7,807	4,225	4,720	1.23
09/26/07	11.1	8.5	0.112	54	3,854	7,760	7	4,980	550,106	646	7,248	2,914	4,279	0.87
09/27/07	10.9	7.8	0.109	58	3,825	8,510	9	5,252	553,593	815	7,736	3,299	4,593	1.13
09/28/07	10.4	8.0	0.106	42	3,950	7,600	8	3,628	507,072	691	6,719	3,782	3,997	1.01
09/29/07	10.8	8.5	0.109	74	3,942	7,970	7	6,670	564,993	631	7,245	1,206	4,312	1.01
10/02/07	11.7	9.8	0.118	54	4,046	8,780	7	5,250	717,607	681	8,641	4,071	5,134	1.19
10/03/07	10.7	8.5	0.118	50	4,067	8,260	7	4,444	585,551	622	8,129	4,307	4,855	1.22
10/04/07	10.8	7.9	0.123	46	3,933	9,060	7	4,127	596,927	628	9,294	5,795	5,622	1.56
10/05/07	10.7	7.5	0.127	46	3,783	8,700	6	4,086	544,185	533	9,215	5,662	5,551	1.61

TABLE E-2 (Continued): MASS BALANCE RESULTS FOR THE SOUTH AERATION BATTERY

Date	Flows (MGD)			Suspended Solids (mg/L)				Solids Loads (lb/day)					Biomass Produced (lb/day)	Observed Yield (lb VSS/lb $CBOD_5$)
	SAB Inf	RAS	WAS	PE	ML	RAS	FE	PE	RAS	FE	WAS	Eff - Inf		
10/06/07	11.2	8.0	0.128	66	3,725	7,940	12	6,184	529,757	1,124	8,476	3,416	5,149	1.21
10/09/07	11.1	7.9	0.128	64	3,458	8,470	7	5,917	558,054	647	9,042	3,772	5,381	0.97
10/10/07	10.5	8.3	0.123	40	3,437	7,430	9	3,498	514,319	787	7,622	4,911	4,593	1.00
10/11/07	10.4	7.8	0.111	36	3,479	7,700	8	3,123	500,900	694	7,128	4,699	4,260	1.03
10/12/07	9.6	8.6	0.114	44	3,325	6,320	11	3,507	453,296	877	6,009	3,379	3,681	1.05
10/13/07	11.1	8.4	0.112	52	3,350	7,380	10	4,795	517,013	922	6,894	3,020	4,262	0.82
10/16/07	12.0	13.8	0.038	46	3,871	7,830	10	4,598	901,170	1,000	2,481	(1,117)	1,552	N/A
10/17/07	15.3	13.5	0.000	38	3,004	3,060	5	4,853	344,525	639	0	N/A	0	N/A
10/18/07	17.6	18.2	0.115	58	3,292	7,470	9	8,509	1,133,856	1,320	7,164	(24)	4,625	N/A
10/19/07	14.3	10.7	0.124	42	3,658	9,520	7	5,016	849,546	836	9,845	5,665	6,371	1.59
10/20/07	15.0	11.0	0.246	64	3,612	9,370	6	7,999	859,604	750	19,224	11,975	12,353	2.07
10/23/07	15.4	10.8	0.264	40	3,213	8,970	8	5,141	807,946	1,028	19,750	15,637	12,343	1.61
10/24/07	14.5	13.6	0.257	42	3,175	8,290	4	5,094	940,285	485	17,769	13,160	11,053	1.85
10/25/07	13.1	13.3	0.253	42	3,029	8,300	7	4,580	920,653	763	17,513	13,696	10,985	1.59
10/26/07	15.3	11.1	0.254	44	3,042	7,790	8	5,606	721,151	1,019	16,502	11,916	10,307	1.49
10/27/07	16.1	11.4	0.263	72	3,175	7,200	7	9,653	684,547	939	15,793	7,078	9,824	1.50
10/30/07	13.7	10.3	0.261	42	3,187	7,200	8	4,814	618,494	917	15,673	11,776	9,752	1.47
10/31/07	14.8	10.9	0.272	48	2,879	6,750	7	5,928	613,616	865	15,312	10,248	9,398	1.48
11/01/07	13.9	10.1	0.272	52	2,771	6,000	8	6,019	505,404	926	13,611	8,518	8,434	1.29
11/02/07	13.9	12.5	0.261	50	2,833	6,620	5	5,814	690,135	581	14,410	9,177	8,815	1.32
11/03/07	14.3	10.7	0.253	66	2,987	5,280	6	7,895	471,177	718	11,141	3,964	6,837	1.29
11/06/07	13.8	10.0	0.240	38	2,742	5,720	7	4,375	477,048	806	11,449	7,880	7,065	0.99
11/07/07	13.3	9.7	0.241	48	2,750	5,840	8	5,317	472,444	886	11,738	7,307	7,273	1.09

TABLE E-2 (Continued): MASS BALANCE RESULTS FOR THE SOUTH AERATION BATTERY

Date	Flows (MGD)			Suspended Solids (mg/L)				Solids Loads (lb/day)					Biomass Produced (lb/day)	Observed Yield (lb VSS/lb $CBOD_5$)
	SAB Inf	RAS	WAS	PE	ML	RAS	FE	PE	RAS	FE	WAS	Eff - Inf		
11/08/07	13.6	10.4	0.244	46	2,925	6,390	7	5,221	554,243	795	13,003	8,577	7,984	1.11
11/09/07	14.0	10.3	0.244	52	3,117	6,920	7	6,077	594,442	818	14,082	8,823	8,774	1.31
11/10/07	13.8	10.6	0.237	72	3,138	7,120	7	8,258	629,436	803	14,073	6,618	8,822	1.34
11/14/07	13.6	10.2	0.224	46	2,996	6,690	6	5,200	569,105	678	12,498	7,976	7,788	1.10
11/15/07	13.9	10.3	0.224	44	3,308	6,110	6	5,118	524,861	698	11,414	6,995	7,101	1.10
11/16/07	13.9	10.2	0.225	54	3,296	6,300	10	6,277	535,928	1,162	11,822	6,708	7,428	1.17
11/17/07	14.5	10.4	0.230	82	3,263	6,520	8	9,942	565,519	970	3,535	12,507	7,792	0.92
Average	12.6	9.7	0.160	52	3,456	7,535	8	5,501	612,538	789	5,313	10,025	6,074	1.24

Estimated biomass produced assumed to be equal to the solids in the WAS.
Observed yield calculated using the SRT and assuming a decay rate of 0.06 /day.
N/A = Either sample not collected or cannot be calculated due to missing data.
NAB = North Aeration Battery.
RAS = Return Activated Sludge.
WAS = Waste Activated Sludge.
PE = Primary Effluent.
ML = Mixed Liquor.
FE = Final Effluent.
Eff = Effluent.
Inf = Influent.

APPENDIX F

OFF-GAS RESULTS

TABLE F-1: 2007 OFF-GAS RESULTS FOR THE NORTH AERATION BATTERY

Date	OTE_f	OTE_{sp20}	SOTE	Off-Gas (scfm)	DO (mg/L)	Temp (°C)	OUR (mg/L/hr)	MLVSS (mg/L)	SOUR (mg/g/hr)
Location 1									
09/04/07	0.079	0.0082	0.086	16.7	0.88	21.77	93.1	2,442	38.1
09/13/07	0.083	0.0086	0.089	20.9	0.74	21.50	88.2	3,808	23.2
09/20/07	0.067	0.0065	0.068	14.3	0.28	21.80	123.3	3,300	37.4
09/26/07	0.063	0.0061	0.064	13.3	0.27	21.70	56.1	1,696	33.1
10/02/07	0.059	0.0057	0.060	11.8	0.19	21.40	52.3	1,829	28.6
Location 2									
09/04/07	0.059	0.0125	0.130	23.4	5.54	21.80	81.9	2,400	34.1
09/13/07	0.075	0.0121	0.125	19.6	4.18	21.60	80.4	2,704	29.7
09/20/07	0.077	0.0102	0.106	17.5	2.84	21.83	66.5	2,533	26.3
09/26/07	0.082	0.0102	0.106	13.8	2.33	21.74	47.8	1,675	28.5
10/02/07	0.072	0.0087	0.090	14.6	2.13	21.40	49.4	1,963	25.2
10/17/07	0.097	0.0106	0.110	9.7	1.26	21.00	39.7	1,929	20.6
10/24/07	0.081	0.0089	0.092	10.9	1.32	20.50	35.6	1,638	21.7
Location 3									
09/04/07	0.092	0.0119	0.124	10.6	2.70	21.80	69.1	2,646	26.1
09/13/07	0.097	0.0125	0.130	10.4	2.69	21.66	59.6	2,354	25.3
09/20/07	0.098	0.0114	0.118	9.3	1.83	22.00	60.8	2,738	22.2
09/26/07	0.105	0.0123	0.128	6.7	1.86	21.80	46.7	1,746	26.8
10/02/07	0.108	0.0118	0.122	6.0	1.26	21.50	53.3	1,817	29.3
10/17/07	0.131	0.0135	0.140	3.7	0.67	21.07	29.9	1,942	15.4
10/24/07	0.112	0.0118	0.122	4.8	0.95	20.39	33.7	1,850	18.2
Location 4									
09/13/07	0.141	0.0160	0.166	2.7	1.63	21.80	18.9	2,425	7.8
09/20/07	0.149	0.0161	0.168	4.5	1.24	22.03	27.2	2,683	10.1
09/26/07	0.099	0.0114	0.119	5.8	1.77	21.90	46.9	1,758	26.7
10/02/07	0.110	0.0130	0.135	6.0	2.02	21.60	37.8	1,800	21.0
10/17/07	0.085	0.0141	0.147	7.0	4.26	21.20	30.9	2,079	14.9
10/24/07	0.119	0.0130	0.135	4.0	1.31	20.40	34.8	2,196	15.8
Location 5									
09/13/07	0.129	0.0157	0.163	4.3	2.22	21.80	22.7	3,887	5.8
09/20/07	0.134	0.0139	0.145	5.8	0.91	22.20	25.2	2,771	9.1
09/26/07	0.129	0.0141	0.147	7.1	1.30	22.00	44.5	2,054	21.7
10/02/07	0.137	0.0145	0.151	4.4	1.04	21.80	26.7	1,763	15.1
10/17/07	0.127	0.0143	0.149	4.4	1.51	21.20	22.9	2,300	9.9
10/24/07	0.148	0.0162	0.169	2.0	1.33	20.40	12.2	2,217	5.5

TABLE F-1 (Continued): 2007 OFF-GAS RESULTS FOR THE NORTH AERATION BATTERY

Date	OTE_f	OTE_{sp20}	SOTE	Off-Gas (scfm)	DO (mg/L)	Temp (°C)	OUR (mg/L/hr)	MLVSS (mg/L)	SOUR (mg/g/hr)
Location 6									
09/13/07	0.078	0.0130	0.135	6.6	4.33	21.90	17.7	2,213	8.0
09/20/07	0.105	0.0147	0.153	4.1	3.22	22.28	19.5	5,950	3.3
09/26/07	0.156	0.0155	0.161	3.2	0.38	22.00	32.5	1,767	18.4
10/02/07	0.141	0.0149	0.155	2.2	1.02	21.90	13.3	1,808	7.3
10/17/07	0.147	0.0162	0.169	1.9	1.31	21.20	13.8	3,229	4.3
10/24/07	0.163	0.0160	0.166	1.4	0.26	20.59	11.3	1,842	6.1
Location 7									
09/20/07	0.089	0.0152	0.158	4.5	4.45	22.30	17.9	2,471	7.2
09/26/07	0.136	0.0159	0.166	3.9	1.89	22.04	15.3	1,838	8.3
10/02/07	0.130	0.0159	0.165	2.5	2.27	21.90	13.0	2,067	6.3
10/17/07	0.130	0.0163	0.169	2.3	2.40	21.21	7.8	1,929	4.0
10/24/07	0.138	0.0161	0.167	1.5	1.90	20.57	9.9	1,592	6.2

TABLE F-2: 2007 OFF-GAS RESULTS FOR THE SOUTH AERATION BATTERY

Date	OTE_f	OTE_{sp20}	SOTE	Off-Gas (scfm)	DO (mg/L)	Temp (°C)	OUR (mg/L/hr)	MLVSS (mg/L)	SOUR (mg/g/hr)
Location 1									
09/05/07	0.046	0.0049	0.051	24.1	1.16	21.68	51.1	1,175	43.50
09/11/07	0.021	0.0023	0.024	24.7	1.25	21.60	44.5	—	—
09/17/07	0.042	0.0043	0.045	27.3	0.66	21.20	49.8	1,575	31.61
09/21/07	0.042	0.0043	0.044	22.4	0.63	21.70	39.8	892	44.57
09/27/07	0.044	0.0045	0.047	22.5	0.58	21.50	44.8	850	52.69
09/28/07	0.040	0.0040	0.042	23.1	0.48	21.30	39.3	1,158	33.97
10/04/07	0.039	0.0039	0.041	21.9	0.48	21.26	45.7	1,096	41.67
10/12/07	0.037	0.0037	0.039	20.5	0.56	20.60	34.1	1,029	33.16
Location 2									
09/05/07	0.062	0.0078	0.081	18.3	2.39	21.97	61.7	1,758	35.1
09/11/07	0.025	0.0031	0.032	11.9	2.06	21.60	53.9	—	—
09/17/07	0.061	0.0071	0.074	17.6	1.91	21.33	52.1	1,546	33.7
09/21/07	0.062	0.0067	0.070	16.4	1.26	21.81	51.7	1,496	34.5
09/27/07	0.049	0.0053	0.055	21.5	1.13	21.56	45.0	1,533	29.3
09/28/07	0.051	0.0054	0.056	17.5	1.06	21.40	46.8	1,592	29.4
10/04/07	0.052	0.0055	0.058	17.5	1.08	21.40	51.2	1,683	30.4
10/12/07	0.046	0.0049	0.051	17.6	0.96	20.70	34.0	1,533	22.2
Location 3									
09/05/07	0.092	0.0078	0.125	18.3	2.71	22.08	66.5	2,129	31.2
09/11/07	0.037	0.0043	0.045	10.9	1.84	21.50	55.0	—	—
09/17/07	0.083	0.0098	0.102	17.7	1.95	21.50	65.9	1,492	44.2
09/21/07	0.099	0.0108	0.112	12.7	1.25	22.00	64.9	2,229	29.1
09/27/07	0.097	0.0103	0.107	13.9	1.04	21.60	56.4	2,250	25.1
09/28/07	0.097	0.0104	0.109	13.3	1.22	21.50	56.9	2,250	25.3
10/04/07	0.103	0.0110	0.114	11.7	1.10	21.50	65.5	2,321	28.2
10/12/07	0.092	0.0098	0.102	12.4	1.06	20.80	42.2	2,033	20.8
Location 4									
09/11/07	0.035	0.0042	0.044	3.6	2.01	21.70	56.9	—	—
09/17/07	0.132	0.0136	0.141	8.3	0.78	21.70	43.4	2,208	19.7
09/21/07	0.129	0.0131	0.136	8.4	0.67	22.20	58.7	2,358	24.9
09/27/07	0.120	0.0125	0.130	11.2	0.91	21.70	53.2	2,129	25.0
09/28/07	0.128	0.0132	0.137	8.7	0.83	21.60	54.5	2,208	24.7
10/04/07	0.154	0.0153	0.159	4.9	0.42	21.60	60.0	2,246	26.7
10/12/07	0.139	0.0139	0.145	5.8	0.45	20.80	36.5	2,054	17.8

TABLE F-2 (Continued): 2007 OFF-GAS RESULTS FOR THE SOUTH AERATION BATTERY

Date	OTE_f	OTE_{sp20}	SOTE	Off-Gas (scfm)	DO (mg/L)	Temp (°C)	OUR (mg/L/hr)	MLVSS (mg/L)	SOUR (mg/g/hr)
Location 5									
09/17/07	0.119	0.0141	0.147	5.0	2.04	21.80	21.7	2,162	10.0
09/21/07	0.122	0.0135	0.140	8.7	1.43	22.30	22.5	2,371	9.5
09/27/07	0.109	0.0114	0.119	10.4	0.86	21.76	36.1	3,008	12.0
09/28/07	0.104	0.0112	0.117	12.0	1.22	21.80	32.4	2,300	14.1
10/04/07	0.111	0.0116	0.121	10.0	0.89	21.80	32.4	2,317	14.0
10/12/07	0.108	0.0112	0.117	11.2	0.88	20.93	24.5	1,921	12.8
Location 6									
09/21/07	0.042	0.0121	0.125	14.1	6.67	22.30	19.0	2,308	8.2
09/27/07	0.096	0.0135	0.140	7.3	3.21	21.80	14.4	2,167	6.6
09/28/07	0.099	0.0149	0.155	6.8	3.76	21.80	15.2	2,267	6.7
10/04/07	0.070	0.0137	0.143	8.9	5.22	21.80	17.7	2,329	7.6
10/12/07	0.052	0.0093	0.097	11.1	4.77	20.97	5.9	2,004	2.9
Location 7									
09/21/07	0.021	0.0127	0.132	19.5	8.38	22.40	19.6	2,358	8.3
09/27/07	0.055	0.0128	0.133	9.1	5.93	21.80	16.2	2,221	7.3
09/28/07	0.058	0.0143	0.149	10.1	6.25	21.90	14.9	2,325	6.4
10/04/07	0.037	0.0124	0.129	12.6	7.25	21.90	17.4	2,317	7.5
10/12/07	0.027	0.0081	0.084	15.0	7.03	20.93	5.1	2,017	2.5

TABLE F-3: 2007 OFF-GAS RESULTS VERSUS AIR FLOW

	Location 2							
Date	OTE_f	OTE_{sp20}	SOTE	Off-Gas (scfm)	DO (mg/L)	Temp (°C)	OUR (mg/L/hr)	Air Flow (scfm)
South Aeration Battery								
11/08/07	0.053	0.0052	0.054	10.1	0.30	19.30	29.0	800
11/08/07	0.048	0.0049	0.051	15.1	0.62	19.30	28.8	1,600
11/08/07	0.044	0.0049	0.051	18.2	1.42	19.30	28.7	2,400
11/08/07	0.038	0.0051	0.053	21.8	2.90	19.40	27.4	3,200
North Aeration Battery								
11/08/07	0.105	0.0102	0.106	5.3	0.14	19.60	37.1	800
11/08/07	0.095	0.0097	0.101	10.0	0.64	19.60	39.3	1,600
11/08/07	0.072	0.0086	0.089	15.0	1.96	19.60	43.2	2,400
11/08/07	0.057	0.0076	0.079	18.0	2.92	19.60	37.8	3,200

TABLE F-4: 2008 DUPLICATE OFF-GAS RESULTS FOR THE NORTH AND SOUTH AERATION BATTERIES

		First Test					Second Test				
Location[1]	Date	SOTE (%)	Off-Gas (scfm)	DO (mg/L)	Temp (°C)	OUR (mg/L/hr)	SOTE (%)	Off-Gas (scfm)	DO (mg/L)	Temp (°C)	OUR (mg/L/hr)
N-1	09/23/08	7.1	15.9	1.77	21.13	79.1	7.5	18.7	1.77	21.14	86.5
N-1	10/13/08	6.9	16.0	1.23	20.60	82.7	8.1	18.5	1.78	20.66	84.6
S-1	11/03/08	4.0	21.1	2.56	19.70	29.0	5.3	20.1	2.78	19.70	32.0
N-2	09/23/08	11.1	11.0	3.11	21.14	57.4	11.7	11.0	3.26	21.18	59.2
N-2	10/13/08	11.3	12.2	2.38	20.80	124.7	11.6	13.4	2.55	20.78	125.3
S-2	11/03/08	5.4	22.7	2.63	19.70	42.1	6.5	18.9	2.82	19.70	35.5
N-3	10/13/08	14.3	5.5	1.05	20.69	35.8	14.2	7.0	1.22	20.70	44.9
S-3	11/03/08	9.9	11.4	1.59	19.66	59.3	8.7	13.2	1.62	19.71	41.7
N-4	10/09/08	19.2	3.6	5.27	20.00	8.4	19.8	3.8	5.06	19.98	7.8
N-4	10/16/08	16.2	3.0	2.39	20.16	26.4	17.9	3.1	2.13	20.19	26.6
N-5	10/09/08	18.8	2.9	5.80	20.03	10.5	17.8	2.7	5.47	20.08	8.3
N-5	10/10/08	14.5	3.6	4.77	20.00	7.8	15.4	2.9	4.30	20.00	8.0
N-5	10/16/08	16.5	2.4	4.85	20.30	22.8	17.1	3.2	4.85	20.30	16.7
N-6	10/10/08	10.8	2.7	4.59	19.98	5.5	10.3	2.6	4.56	20.07	7.0
N-6	10/16/08	13.8	2.2	4.41	20.29	14.9	16.2	1.8	4.32	20.36	15.7
N-7	10/09/08	15.3	2.2	4.44	19.90	10.0	15.4	2.8	4.50	19.89	6.8
N-7	10/10/08	13.7	2.5	3.11	20.30	4.6	15.2	2.5	3.25	20.32	6.3
N-7	10/16/08	12.3	2.0	3.39	20.10	8.2	13.8	2.0	3.31	20.14	18.6

[1] N = north aeration tank; S = south aeration tank.

TABLE F-5: 2008 METAL HOOD VERSUS WOOD HOOD OFF-GAS RESULTS FOR THE SOUTH AERATION BATTERY

		Metal Hood					Wood Hood				
Location	Date	SOTE	Off-Gas (scfm)	DO (mg/L)	Temp (°C)	OUR (mg/L/hr)	SOTE	Off-Gas (scfm)	DO (mg/L)	Temp (°C)	OUR (mg/L/hr)
1	10/29/08	3.5	18.7	2.22	19.1	28.2	3.3	25.2	2.21	19.2	25.8
2	10/30/08	4.5	18.5	1.93	19.2	42.8	4.2	25.5	2.56	19.3	83.1
3	10/31/08	13.1	8.7	1.34	19.1	25.3	10.4	9.7	0.96	19.4	86.9

TABLE F-6: 2008 METAL HOOD AT THE SIDE WALL AND IN THE MIDDLE OFF-GAS RESULTS FOR THE SOUTH AERATION BATTERY

Location	Date	Metal Hood at Side Wall					Metal Hood in Middle				
		SOTE	Off-Gas (scfm)	DO (mg/L)	Temp (°C)	OUR (mg/L/hr)	SOTE	Off-Gas (scfm)	DO (mg/L)	Temp (°C)	OUR (mg/L/hr)
1	10/29/08	3.5	18.7	2.22	19.1	28.2	11.9	3.7	1.89	19.1	25.5
2	10/30/08	4.5	18.5	1.93	19.2	42.8	9.0	6.5	2.23	19.2	116.5
3	10/31/08	13.1	8.7	1.34	19.1	25.3	15.2	6.8	0.98	19.4	86.9

TABLE F-7: 2010 STANDARD OXYGEN UPTAKE RATE OFF-GAS RESULTS FOR THE SOUTH AERATION BATTERY

Location	Date	Square Hood at Wall		Angled Hood at Wall		Square Hood in Middle		Two-Hood Weighted Average	
		SOTE (%)	Off-Gas (scfm)	SOTE (%)	Off-Gas (scfm)	SOTE (%)	Off-Gas (scfm)	SOTE (%)	Off-Gas (scfm)
1	06/22/09	N/A	N/A	10.5	11.13	13.7	5.90	11.3	9.87
2	07/06/09	7.0	16.52	6.3	13.15	9.6	7.03	7.1	11.70
3	07/13/09	7.3	13.77	5.9	11.85	8.2	7.11	6.5	10.60
1	09/20/10	10.0	9.08	8.8	9.16	13.1	6.72	10.1	8.41
2	09/20/10	9.9	11.98	9.0	9.51	12.7	7.18	10.2	8.79
3	09/27/10	4.2	18.69	4.2	16.95	10.0	4.12	4.9	15.32
3	09/28/10	4.1	20.41	4.0	17.68	9.5	3.97	4.6	16.05
1	10/08/10	6.8	4.42	6.6	5.46	8.6	4.26	7.2	5.07
2	10/08/10	5.8	9.94	5.4	8.77	9.2	4.63	6.3	7.78
4	10/12/10	5.4	16.27	6.2	8.25	7.3	11.36	6.7	9.66
4	10/14/10	10.8	11.38	9.1	8.50	12.0	9.10	10.2	8.73
5	10/14/10	14.7	5.03	14.7	4.65	17.0	4.36	15.5	4.55
5	10/18/10	13.6	8.08	12.8	6.25	16.2	4.55	13.8	5.73
4	10/18/10	9.2	17.08	9.1	12.15	11.9	11.41	10.1	11.90
5	10/20/10	14.5	6.57	12.5	5.88	17.1	3.63	13.8	5.27
1	10/20/10	4.3	9.48	4.2	14.10	6.3	5.42	4.6	12.50
3	10/22/10	9.7	11.29	8.0	10.32	11.5	8.23	9.2	9.64
4	10/22/10	8.9	12.91	9.2	10.67	12.4	11.67	10.4	11.07

N/A = No data available.

APPENDIX G

PROFILE SAMPLING RESULTS

TABLE G-1: PROFILE SAMPLING RESULTS FROM THE NORTH AERATION BATTERY

Date	Length (ft)	Time	Temp (°C)	DO (mg/L)	OUR (mg/L/hr)	SOUR20 (mg/g/hr)	SS (mg/L)	VSS (mg/L)	TKN (mg/L)	TP (mg/L)	Sol TKN (mg/L)	Sol P (mg/L)	NH_3-N (mg/L)	NO_2-N (mg/L)	NO_3-N (mg/L)
09/18/07	6	10:52	21.7	0.32	101.66	23.49	6,133	3,983	358	254	5.904	0.661	6.37	0.476	4.28
	63	11:13	21.7	1.70	88.63	31.23	3,996	2,612	245	168	9.592	0.908	8.79	0.694	6.199
	125	11:30	21.8	3.89	83.71	28.10	4,171	2,729	247	171	6.58	0.751	6.05	1.12	10.063
	188	11:49	21.8	1.88	74.08	28.92	3,567	2,346	204	137	7.082	0.846	7.26	1.278	11.481
	281	11:59	21.9	4.06	70.20	27.37	3,546	2,338	241	161	5.397	0.812	4.91	1.684	15.137
	369	13:32	21.9	2.04	63.61	24.24	3,646	2,392	242	163	3.156	0.767	2.7	1.859	16.731
	563	13:58	22.9	0.51	43.77	18.16	3,154	2,092	219	148	1.352	0.706	0.87	0.566	5.117
	744	14:20	22.1	2.81	20.91	8.07	3,533	2,338	244	167	0.782	0.624	0.05	0.009	0.07
	938	15:05	22.1	5.24	17.16	8.49	2,767	1,825	194	134	0.945	0.652	0.05	0.007	0.051
	1,095	15:25	22.2	5.46	16.45	8.38	2,663	1,763	195	135	0.927	0.581	0.05	0.006	0.05
10/03/07	6	10:10	21.5	0.32	78.94	20.43	5,675	3,592	291	223	9.257	0.898	9.31	1.477	3.501
	63	10:31	21.5	1.15	46.39	24.82	2,671	1,737	136	107	12.334	1.137	11.57	1.024	3.565
	125	10:48	21.5	2.79	63.82	20.48	4,538	2,896	218	175	10.307	0.911	10.2	0.981	4.912
	188	11:05	21.6	3.85	92.36	18.26	7,304	4,679	355	287	9.199	0.844	8.42	1.644	4.441
	281	11:25	21.6	1.75	51.16	19.03	3,900	2,487	184	135	7.378	0.754	7.33	1.015	7.716
	369	11:47	21.7	1.31	39.45	19.63	2,854	1,850	149	113	6.416	0.685	6.43	0.834	8.886
	563	12:50	21.7	2.13	33.60	14.82	3,258	2,087	162	124	3.086	0.63	3.24	0.989	11.807
	938	1:04	21.7	0.64	17.63	6.59	3,833	2,463	161	134	0.948	0.627	0.11	0.027	15.287
10/09/07	6	9:48	21.6	0.11	70.92	23.71	4,333	2,767	260	188	8.58	0.765	8.84	1.82	2.101
	63	10:05	21.5	0.35	45.26	26.49	2,508	1,588	133	106	12.884	1.115	11.93	1.668	1.042
	125	10:23	21.6	1.29	50.05	21.00	3,479	2,204	174	140	11.445	0.902	11.06	1.357	1.874
	188	10:40	21.6	1.98	57.37	20.38	4,075	2,604	194	159	10.492	0.817	10.03	1.184	2.892
	281	10:58	21.6	1.08	50.57	19.76	3,733	2,367	219	158	9.103	0.715	8.51	0.783	4.795
	369	11:16	21.7	1.00	48.24	18.09	3,871	2,454	230	165	7.345	0.66	7.2	0.57	6.192

TABLE G-1 (Continued): PROFILE SAMPLING RESULTS FROM THE NORTH AERATION BATTERY

Date	Length (ft)	Time	Temp (°C)	DO (mg/L)	OUR (mg/L/hr)	SOUR20 (mg/g/hr)	SS (mg/L)	VSS (mg/L)	TKN (mg/L)	TP (mg/L)	Sol TKN (mg/L)	Sol P (mg/L)	NH_3-N (mg/L)	NO_2-N (mg/L)	NO_3-N (mg/L)
	563	11:37	21.7	1.75	43.82	17.64	3,621	2,287	205	151	3.578	0.574	3.07	0.521	9.646
	938	11:58	21.7	1.41	13.55	6.31	3,104	1,975	161	127	1.067	0.468	0.12	0.015	11.263
11/05/07	6	9:27	19.7	0.08	59.14	41.14	2,271	1,467	N/S	N/S	11.241	1.888	10.67	0.434	0.188
	63	9:47	19.7	0.08	38.96	25.85	2,388	1,538	142.6	105.6	11.266	2.087	10.41	0.04	0.068
	125	10:05	19.7	1.05	34.22	22.72	2,400	1,537	132.8	100.5	10.366	1.669	9.47	0.162	0.843
	188	10:25	19.8	1.67	40.23	21.42	2,942	1,904	168.3	128.8	9.642	1.445	8.81	0.276	1.653
	281	10:45	19.8	0.91	31.21	20.09	2,450	1,575	139.2	100.3	7.568	1.198	6.87	0.334	3.283
	369	11:05	19.8	0.96	31.90	21.31	2,362	1,517	137.8	99.98	5.99	1.02	5.07	0.334	4.964
	563	11:25	19.8	1.00	17.54	11.17	2,458	1,592	N/S	N/S	1.447	0.762	0.35	0.259	9.067
	938	11:52	19.8	1.94	8.25	4.81	2,733	1,737	148.1	116.3	1.121	0.536	0.03	0.01	9.591
11/14/07	6	N/R	N/S	N/S	N/S	N/S	2,604	1,667	N/S	N/S	N/S	N/S	12.86	0.534	1.127
	63	N/R	N/S	N/S	N/S	N/S	2,992	1,925	N/S	N/S	N/S	N/S	12.26	0.264	0.762
	125	N/R	N/S	N/S	N/S	N/S	2,900	1,863	N/S	N/S	N/S	N/S	11.17	0.267	2.032
	188	N/R	N/S	N/S	N/S	N/S	5,529	3,696	N/S	N/S	N/S	N/S	9.53	0.644	2.679
	281	N/R	N/S	N/S	N/S	N/S	2,758	1,771	N/S	N/S	N/S	N/S	7.64	0.65	5.426
	369	N/R	N/S	N/S	N/S	N/S	2,775	1,779	N/S	N/S	N/S	N/S	5.86	0.677	6.954
	563	N/R	N/S	N/S	N/S	N/S	2,579	1,646	N/S	N/S	N/S	N/S	1.63	0.9	10.882
	938	N/R	N/S	N/S	N/S	N/S	2,604	1,667	N/S	N/S	N/S	N/S	0.1	0.01	11.702

SOUR20 = Specific oxygen uptake rate at standard temperature of 20°C.
N/R = Data not recorded.
N/S = Sample not collected.

TABLE G-2: PROFILE SAMPLING RESULTS FROM THE SOUTH AERATION BATTERY

Date	Length (ft)	(Time)	Temp (°C)	DO (mg/L)	OUR (mg/L/hr)	SOUR20 (mg/g/hr)	SS (mg/L)	VSS (mg/L)	TKN (mg/L)	TP (mg/L)	Sol TKN (mg/L)	Sol TP (mg/L)	NH_3-N (mg/L)	NO_2-N (mg/L)	NO_3-N (mg/L)
09/18/07	6	10:51	21.6	1.44	60.79	31.60	2,871	1,779	149	119	11.161	1.001	10.26	0.311	2.799
	63	11:11	21.6	1.05	50.85	21.88	3,437	2,150	127	89	11.075	1.126	11.62	0.377	3.4
	125	11:30	21.7	2.19	61.07	29.58	3,054	1,900	157	119	8.27	0.747	7.73	0.891	8.06
	188	11:49	21.7	1.01	64.93	21.60	4,488	2,767	119	106	6.775	0.68	7.3	0.641	5.795
	281	13:15	21.8	1.89	67.98	8.62	11,050	7,221	194	149	4.065	0.541	3.69	1.255	11.338
	369	13:32	21.9	1.66	55.85	10.00	8,333	5,092	202	149	1.643	0.527	1.49	1.604	14.555
	563	13:58	22.0	0.54	23.63	8.30	4,179	2,583	203	154	0.832	0.509	0.13	0.288	2.625
	744	14:20	22.0	2.65	17.63	6.62	3,917	2,417	195	152	0.534	0.486	0.03	0.01	0.103
	938	15:05	22.1	6.38	17.35	6.56	3,883	2,387	203	152	0.67	0.473	0.04	0.006	0.061
	1,095	15:25	22.1	6.47	15.59	5.30	4,375	2,654	210	157	0.777	0.419	0.11	0.007	0.059
10/03/07	6	10:10	21.4	0.64	57.32	29.53	2,925	1,813	130	112	11.774	1.184	10.93	0.307	3.77
	63	10:31	21.4	0.63	39.12	32.11	1,804	1,138	96	73	14.643	1.733	13.8	0.325	2.557
	125	10:48	21.4	1.37	50.44	29.44	2,567	1,600	134	107	10.468	1.116	10.63	0.436	5.081
	188	11:05	21.5	1.35	61.29	27.51	3,367	2,071	151	132	6.765	0.837	7.49	0.665	7.634
	281	11:25	21.6	1.23	65.36	24.30	4,000	2,488	195	160	4.529	0.661	4.28	0.688	10.74
	369	11:47	21.6	1.03	59.83	22.62	3,971	2,446	190	160	2.265	0.625	2.62	0.724	12.079
	563	12:20	21.7	0.76	49.13	18.49	3,946	2,446	190	162	2.029	0.611	1.17	0.246	13.868
	938	12:47	21.7	5.80	16.49	6.32	3,858	2,400	190	162	0.455	0.576	0.11	0.008	14.941
10/09/07	6	9:48	21.5	0.37	47.89	32.37	2,254	1,375	132	105	12.707	1.355	12.16	0.583	2.966
	63	10:05	21.4	0.53	38.02	40.58	1,388	875	93	66	15.987	1.941	14.33	0.565	1.613
	125	10:23	21.5	1.03	44.96	32.77	2,117	1,275	127	97	12.453	1.286	11.79	0.319	4.166
	188	10:40	21.6	0.79	52.21	28.12	2,883	1,717	147	126	8.144	0.911	8.89	0.394	6.729
	281	10:58	21.6	1.16	55.13	29.42	2,900	1,733	181	152	5.987	0.732	5.51	0.524	9.12
	369	11:16	21.7	0.98	54.80	25.32	3,313	1,992	176	145	3.552	0.695	3.47	0.617	10.948

TABLE G-2 (Continued): PROFILE SAMPLING RESULTS FROM THE SOUTH AERATION BATTERY

Date	Length (ft)	(Time)	Temp (°C)	DO (mg/L)	OUR (mg/L/hr)	SOUR20 (mg/g/hr)	SS (mg/L)	VSS (mg/L)	TKN (mg/L)	TP (mg/L)	Sol TKN (mg/L)	Sol TP (mg/L)	NH_3-N (mg/L)	NO_2-N (mg/L)	NO_3-N (mg/L)
	563	11:37	21.7	0.51	46.10	21.67	3,271	1,958	177	148	2.438	0.663	1.53	0.234	12.201
	938	11:58	21.8	6.41	14.66	6.58	3,417	2,042	185	155	0.687	0.556	0.12	0.013	14.009
11/05/07	6	9:27	19.7	0.36	15.38	13.85	1,813	1,133	102.36	70.2	13.385	1.526	12.19	0.537	3.125
	63	9:47	19.7	0.43	12.89	15.24	1,367	863	89.92	57.72	14.396	1.839	12.86	0.487	2.682
	125	10:05	19.7	1.29	11.77	9.91	1,954	1,212	111.58	78.16	11.017	1.165	9.82	0.415	5.591
	188	10:25	19.7	0.84	12.99	8.26	2,592	1,604	121.3	91.58	7.218	0.815	7.17	0.421	7.822
	281	10:45	19.7	0.92	14.52	8.06	2,954	1,838	157.94	116	4.563	0.595	3.6	0.528	11.263
	369	11:05	19.7	0.95	13.76	7.86	2,913	1,787	160.32	116.7	1.983	0.57	1.71	0.428	12.818
	563	11:25	19.7	2.30	3.29	1.80	3,029	1,862	165.9	123.4	1.232	0.522	0.06	0.01	14.187
	938	11:52	19.7	5.24	3.17	1.79	2,954	1,804	164.1	120.4	0.985	0.487	0.06	0.007	14.83
11/14/07	6	N/R	N/S	N/S	N/S	N/S	2,392	1,513	N/S	N/S	N/S	N/S	15.74	1.546	3.127
	63	N/R	N/S	N/S	N/S	N/S	1,825	1,142	N/S	N/S	N/S	N/S	15.54	0.794	4.139
	125	N/R	N/S	N/S	N/S	N/S	2,429	1,513	N/S	N/S	N/S	N/S	12.48	0.529	7.411
	188	N/R	N/S	N/S	N/S	N/S	2,892	1,792	N/S	N/S	N/S	N/S	9.05	0.485	10.143
	281	N/R	N/S	N/S	N/S	N/S	3,075	1,888	N/S	N/S	N/S	N/S	5.47	0.522	13.346
	369	N/R	N/S	N/S	N/S	N/S	3,183	1,950	N/S	N/S	N/S	N/S	3.3	0.507	15.199
	563	N/R	N/S	N/S	N/S	N/S	3,317	2,058	N/S	N/S	N/S	N/S	0.27	0.11	17.791
	938	N/R	N/S	N/S	N/S	N/S	3,163	1,958	N/S	N/S	N/S	N/S	0.03	0.007	18.047

SOUR20 = Specific oxygen uptake rate at standard temperature of 20°C.
N/R = Data not recorded.
N/S = Sample not collected.

APPENDIX H

INTERFACIAL SETTLING VELOCITY TESTS

TABLE H-1: 2005 INTERFACIAL SETTLING VELOCITY TEST RESULTS

	South Battery			North Battery	
Date	MLSS (mg/L)	Velocity (ft/d)	Date	MLSS (mg/L)	Velocity (ft/d)
08/31/05	6,410	105	09/07/05	4,460	111
	4,500	207		2,960	213
	3,830	326		2,230	313
	3,210	425		1,960	430