Evaluation of Nitrification Inhibition Using Bench-Scale Rate Measurements, Profile Sampling, and Process Simulation Modeling

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Abstract

The Hampton Roads Sanitation District (HRSD) operates thirteen treatment plants in the eastern Virginia area with a combined capacity of 231 million gallons per day (mgd). The Nansemond Treatment Plant (NTP) is one of the larger facilities, and is designed to treat 30 mgd using a 3-stage Virginia Initiative Process (VIP) biological nutrient removal (BNR) process. The majority of the influent is domestic, but there is also a large industrial contribution, particularly from a hog processing facility, landfill leachate, and significant loads from septage and grease deliveries (Bilyk et al, 2008). NTP is currently being upgraded to a 5-stage Bardenpho process to achieve improved total nitrogen (TN) removal. For several years starting in about 2001, NTP has experienced continuous and sporadic nitrification upsets that cannot be explained by plant operations events. Sporadic nitrification upsets are characterized by sharp increases in effluent ammonia and nitrite with decreases in nitrate concentrations due to reduced growth rates in bacteria. The result is reduced overall total nitrogen (TN) removal. Continuous inhibition is evidenced by a previous engineering report by Hazen and Sawyer, P.C. (2007), whereby it was suggested that the ammonia oxidizing bacteria (AOB) maximum specific growth rate ($\mu_{\text{max}}$) be reduced from 0.9 to 0.57 days$^{-1}$. This has significant implications in terms of the required aeration volume for consistent nitrification at cold temperatures.

The objective of this project was to determine whether the NTP influent wastewater does in fact exhibit inhibition to ammonia (AOB) and nitrite oxidizing bacteria (NOB), evaluated independently, and to determine the impact on polyphosphate accumulating organism activity
PAO). Because the historical operational experiences and data analysis suggested inhibited AOB and NOB activity, an investigation was initiated targeting the source of that inhibition. After conducting seventeen weeks of batch experiments the source of inhibition was not determined. Batch experiments however, did reveal other possible sources of inhibition including large amounts of chemical toilet waste received at NTP possibly containing quaternary ammonium compounds (QACs).

Due to available blower capacity during construction it was planned that nitrification would not be maintained during the fall of 2009. In an effort to stop nitrification, the solids retention time (SRT) was purposely reduced over a period of about one month (as wastewater temperature cooled) until additional blower capacity was available. This provided an opportunity to study baseline nitrification kinetics and determine the potential for continuous inhibition through profile sampling. Simulation modeling of the profile sampling and plant data was performed with Biowin 3.1 (EnviroSim, Ltd.) as a means for comparison and to generate $\mu_{\text{max}}$ values for AOB to compare with the original design $\mu_{\text{max}}$ of 0.57 $\text{day}^{-1}$.

Profile sampling was conducted from the primary effluent to the secondary effluent with samples collected along the length of the BNR process. This was being done to address the following issues:

- Conduct baseline sampling prior to a more detailed nitrification inhibition study estimated to begin in May 2010, which will include influent sampling and the operation of bench-scale sequencing batch reactors. This will be used to establish “normal” COD, nutrient and DO profiles through the VIP process without (and possibly with) the impact of inhibitory conditions, specifically with respect to N conversions and P release and uptake along the process.
• Evaluate the potential for nitrite accumulation in the process and its potential effect on aerobic phosphate uptake by phosphorus accumulating organisms (PAOs).

• Evaluate the impact of sporadic ferric chloride addition to the biological process as a means of preventing effluent TP exceedances.

• Evaluate the design $\mu_{\text{max}}$ to the actual observed $\mu_{\text{max}}$ for AOB through simulation modeling.

• Compare modeling and observed profile data for signs of any continuous nitrification inhibition.

Experimental results from batch-rate testing confirmed the sporadically inhibitory nature of NTP primary effluent when combined with other stable nitrifying biomasses. Investigation into quaternary ammonium compounds (QACs) which were contained in the chemical toilet waste suggested that QACs at higher concentrations caused some inhibition of NOB activity, but no significant impact on AOB activity. Profile sampling demonstrated no signs of sporadic or continuous nitrification inhibition or impact of nitrite accumulation and ferric chloride addition on biological treatment processes. Modeling of the profile data generated similar profiles; however, there were slight variations as the model predicted nitrification to stop earlier than what was actually observed. From the modeling it was also determined that the maximum specific growth rate ($\mu_{\text{max}}$) of ammonia oxidizing bacteria (AOB) was in the range of 0.50 – 60 days$^{-1}$. This supported batch and profile work that showed NTP PE exhibited some degree of continuous inhibition. Diurnal loadings however, were not accounted for in the modeling which could slightly underestimate the actual AOB $\mu_{\text{max}}$ value. Several suspected inhibitors were eliminated as potential causes of inhibition, including waste from a hog processing facility, landfill leachate,
the addition of ferric chloride, plant internal recycle streams, branches of the collection system, and chemical toilet disinfectants containing QACs.

References


Hazen and Sawyer. 2007. *Nansemond Treatment Plant Nutrient Reduction Improvement Technical Memorandum*. 
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Introduction

1.1 Project Background

The Nansemond Treatment Plant (NTP) is one of the larger facilities of the thirteen plants operated by the Hampton Roads Sanitation District (HRSD) with a maximum monthly design capacity of 30 million gallons per day (MGD). This facility was originally designed as a 3-stage Virginia Initiative Process (VIP) biological nutrient removal (BNR) system as shown in Figure 1.1 (Bilyk et al., 2008) and is currently being upgraded to a 5-stage Bardenpho process with external carbon addition. The majority of the influent is domestic, but there is also a large industrial contribution, particularly from a hog processing facility, landfill leachate, and significant loads from septage and grease deliveries (Bilyk et al., 2008).

![Figure 1.1 3-Stage VIP (2008) NTP Process Flow Diagram (Bilyk et al., 2008)](image)

NTP began operations as a 10 mgd secondary treatment plant in 1983. Expansions and upgrades were completed in May 1998, which converted the facility into a 30 mgd BNR facility. Since the upgrade the facility has experienced mixed success in the BNR mode (Balzer et al.,
2005). This determination was based upon the plant’s efficiency in removing nitrogen. The VIP plant in Norfolk, VA which also employs the VIP process began BNR operations approximately seven (7) years prior to similar Nansemond operations (Balzer et al., 2005). Nitrogen removal was similar at both facilities (Table 1.1) during the first two years of side-by-side operation (1999 & 2000) (Balzer et al., 2005). Nansemond experienced an unexpected decline in nitrogen removal efficiency starting in 2001, which has continued to the present (Balzer et al., 2005). This deficiency in performance has been variable and has not been consistent from 2001 to the present time.

<table>
<thead>
<tr>
<th>YEAR</th>
<th>NP [% Removal]</th>
<th>VIP [% Removal]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1999</td>
<td>69.9</td>
<td>71.5</td>
</tr>
<tr>
<td>2000</td>
<td>64.2</td>
<td>67.0</td>
</tr>
<tr>
<td>2001</td>
<td>53.1</td>
<td>66.3</td>
</tr>
<tr>
<td>2002</td>
<td>64.4</td>
<td>67.1</td>
</tr>
<tr>
<td>2003</td>
<td>45.0</td>
<td>62.5</td>
</tr>
<tr>
<td>2004</td>
<td>55.6</td>
<td>71.9</td>
</tr>
<tr>
<td>2005</td>
<td>50.6</td>
<td>67.83</td>
</tr>
<tr>
<td>2006</td>
<td>70.8</td>
<td>69.67</td>
</tr>
<tr>
<td>2007</td>
<td>68</td>
<td>65.83</td>
</tr>
<tr>
<td>2008</td>
<td>70.3</td>
<td>72.58</td>
</tr>
<tr>
<td>2009</td>
<td>50</td>
<td>60</td>
</tr>
<tr>
<td>MEAN</td>
<td><strong>60.2</strong></td>
<td><strong>67.5</strong></td>
</tr>
</tbody>
</table>

NTP achieves continuous complete nitrification during certain periods consistently meeting desired effluent limits. In spite of this, NTP has also experienced unexplained sporadic nitrification upsets for a number of years and even in summer months when compared to the VIP plant (Figure 1.2 and 1.3) and some indication of continuous nitrification inhibition, as demonstrated by calibration of a process simulation model to historical plant performance data (Hazen & Sawyer, 2007). The previous target total nitrogen (TN) treatment objective was 12 mg/L on a seasonal basis. This has changed more recently to a permitted limit of 8 mg/L TN on an annual average basis (Bilyk et al., 2008).
Figure 1.2 NTP Historical Effluent Ammonia, NOx-N, and Total Nitrogen Profile 2000-2009 (Lines represent 30-day rolling averages).

Values measured under reporting limit were plotted as half the reporting limit.

Figure 1.3 VIP Historical Effluent Ammonia, NOx-N, and Total Nitrogen Profile 2001-2009 (Lines represent 30-day rolling averages).

Values measured under reporting limit were plotted as half the reporting limit.
In addition the plant also experienced regular biological phosphorus removal upsets (Figure 1.4) which forced NTP to add large quantities of ferric chloride to avoid permit violations for effluent TP (Bilyk et al., 2008). It was the goal of NTP to meet a treatment objective of 1 mg/L of total phosphorus (TP) on an annual average basis (Bilyk et al., 2008).

1.1.1 Investigation of Inhibition

HRSD has expended considerable time and resources investigating possible sources of inhibition. It was originally presumed that contributions from industrial loads, either from a hog processing facility or landfill leachate, were the culprits for sporadic failure in nitrification and bio-P upsets. These sources were tested specifically as part of this work.

1.1.2 Facility Upgrades
In order to meet future permit limits NTP is currently being upgraded to a 5-stage Bardenpho process (Figure 1.5). This upgrade also will provide increased aeration volume/capacity to enhance both nitrification and Bio-P removal. The new upgrades will also incorporate a full-scale proprietary technology developed by Ostara that uses a fluidized bed reactor to recover phosphorus and ammonia through struvite precipitation from the centrate being generated at NTP. The harvested struvite can then be utilized as a slow release fertilizer (Ostara, 2007).

A preliminary engineering report by Hazen and Sawyer, P.C. for the current nutrient removal upgrade, suggested that the ammonia oxidizing bacteria (AOB) maximum specific growth rate ($\mu_{\text{max, AOB}}$) be reduced from the default value of 0.90 days$^{-1}$ to 0.57 days$^{-1}$ to account
for high effluent ammonia data during the calibration period (Hazen & Sawyer, 2007). This has significant implications in terms of the required aeration volume for consistent nitrification at cold temperatures. NTP along with the other HRSD James River basin facilities are required to meet a combined annual discharge limit of 6 million pounds TN to the James River – bubble permit limit (Balzer et al., 2005). It was originally assumed that NTP would nitrify year-round with this background inhibition. This would only be made possible however, by reconfiguring the BNR process to allow the 2nd anoxic zone to operate aerobically (swing zone). Removing an anoxic zone would reduce overall TN removal because the process would essentially change from the 5-stage Bardenpho process to an A2O Process. If the inhibition can be eliminated then there would no longer be a need to configure the 2nd anoxic zone to run aerobically, providing improved annual average TN removal. This would ensure that NTP and the other James River HRSD facilities meet the TN bubble permit limit with more certainty.

1.2 Research Objectives

The objectives of this study were the following:

- Establish the inhibitory characteristics of the NTP influent wastewater through bench-scale experimentation
- Study baseline nitrification kinetics and to evaluate the presence of a source of continuous inhibition
- Model the baseline nitrification kinetics and compare these values to previously calculated kinetic values.

1.2.1 Bench-scale Experimentation

The initial objectives of this research were to investigate the inhibition of nitrification at NTP through independent evaluation of ammonia oxidizing bacteria (AOB) and nitrite oxidizing
bacteria (NOB) rates, as well as, determine the impact of inhibition on polyphosphate accumulating organism activity (PAO). This was accomplished through the use of a wide variety of NTP, targeted industry, and control wastewater and biomass samples to attempt to identify possible sources of inhibition through batch rate measurements using bench-scale reactors.

1.2.2 Baseline Profile Sampling

In an effort to better understand the BNR process at the facility, profile sampling was also performed in conjunction with the bench-scale reactor experiments during the summer and fall of 2009. During the initial upgrades to the facility, nitrification was maintained; however, due to available blower capacity during construction it was planned that nitrification would not be maintained during the fall of 2009. In an effort to stop nitrification, the solids retention time (SRT) was purposely reduced over a period of about one month (as wastewater temperature cooled) until additional blower capacity was available. This coincided with the profile sampling creating an opportunity to study nitrification kinetics as the plant stopped nitrifying. Profile sampling was conducted until the plant completely ceased nitrifying in the fall of 2009. This work consisted of collecting grab samples through the BNR process and analyzing the samples for ammonia (NH$_3$-N), nitrite (NO$_2$-N), nitrate (NO$_3$-N), ortho-phosphate (PO$_4$-P), and soluble COD (sCOD), pH, and DO.

1.2.3 Biowin Simulation Modeling

The profile sampling data were combined with plant operating data and modeled using Biowin 3.1 (EnviroSim, Ltd.). The profile sampling period (7-23-09 to 11-5-09) was divided into 5 separate periods to generate a calibrated model. The modeling for four of the periods was first performed in steady-state conditions. The period in which NTP stopped nitrifying had to be calibrated with a dynamic model. A calibrated simulation was then generated over the entire
period of profile samples. These simulations were compared to data collected during the profile
sampling to better understand the level of continuous nitrification inhibition.

1.3 Thesis Organization

- Chapter two is dedicated to providing literature reviews of nitrification inhibition with
  known and suspected sources of inhibition, batch-rate measurements, and profile
  sampling.
- Chapter three provides methodologies for grab sampling, batch reactor construction,
  batch reactor operation, profile sampling, analysis of nutrients, and modeling.
- Two manuscripts were included which encompass the different aspects of this research:
  Bench-Scale Batch Testing, profile sampling, and simulation modeling of the process.
This research provides insight into measuring nitrification inhibition kinetics, evaluation of
possible inhibitors, data exhibiting a fully-nitrifying plant falling out of nitrification, and
modeling work which provides a comparison of measured plant performance data versus
simulation modeling & profile sampling data.

1.4 References

Biological Nutrient Removal at HRSD’s Nansemond Treatment Plant. NITRO Team Report.

of Biological Phosphorus Removal Upsets and Inhibited Nitrification at a 30 mgd BNR Facility.
Proceedings of the Water Environment Federation Technical Conference and Exposition,
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Hazen and Sawyer. 2007. Nansemond Treatment Plant Nutrient Reduction Improvement
Technical Memorandum.

Ostara. 2007. Proposal: Full Scale Struvite Recovery Project at the Nansemond Wastewater
2. Literature Review

2.1 Nitrification Inhibition

Biological nutrient removal processes involving nitrification are widely incorporated in wastewater treatment plants. The need for nitrification in wastewater treatment arises from water quality concerns over (1) the effect of ammonia on receiving water with respect to DO concentrations (2) the toxicity of ammonia in receiving waters to aquatic and marine life, (3) the need to provide nitrogen removal to control eutrophication, and (4) the need to provide nitrogen control for water-reuse applications including groundwater infiltration (Metcalf & Eddy, 2003). Nitrification is well recognized as the most sensitive process in biological nutrient removal (BNR) systems and is susceptible to problems arising from pH, temperature, dissolved oxygen (DO) concentrations, substrate concentrations, and chemical inhibitors (Juliastuti et al., 2003a). Conventional aerobic nitrification involves the oxidation of ammonia to nitrate by two different types of bacteria, ammonia oxidizing bacteria (AOB) and nitrite oxidizing bacteria (NOB) (Metcalf & Eddy, 2003).

\[
\text{NH}_4^+ + 1.5 \text{O}_2 \rightarrow 2 \text{H}^+ + \text{H}_2\text{O} + \text{NO}_2^- \quad (1)
\]

\[
\text{NO}_2^- + 0.5 \text{O}_2 \rightarrow \text{NO}_3^- \quad (2)
\]

The biochemical reactions above take place in nitrification processes in which ammonium is oxidized to nitrite by AOB and then nitrite is oxidized to nitrate through NOB. Based on the chemical reactions it can be noted that nitrification is an aerobic autotrophic process. Nitrification has been used for years to remove ammonia from wastewater prior to discharge.

Nitrifying bacteria have maximum specific growth rates that are much slower than heterotrophic bacteria in activated sludge processes. Generally, the minimum allowable solids
Retention time (SRT) for operation of a nitrifying activated sludge process is controlled by nitrification kinetics per the commonly used design equations presented below:

\[
\frac{1}{SRT_{\text{min}}} = \mu_a
\]

\[
\mu_a = \left( \frac{\mu_{\text{max},a} N}{K_N + N} \right) \left( \frac{DO}{K_o + DO} \right) + b_a
\]

where \( \mu_a \) is the nitrifier specific growth rate, \( \mu_{\text{max},a} \) is the nitrifier maximum specific growth rate, \( N \) is the target effluent ammonia-N concentration, \( K_N \) is the nitrifier Monod half-saturation coefficient for ammonia, \( DO \) is the aeration basin dissolved oxygen concentration, \( K_o \) is the nitrifier Monod half-saturation coefficient for oxygen, and \( b_a \) is the autotrophic decay rate (Metcalf & Eddy, 2003).

The actual SRT used for process design is typically determined by multiplying the minimum SRT for nitrification by a safety factor ranging from 1.5 to a value as high as 5.0 (extended aeration). It is commonly found that chemical inhibitors tend to reduce the nitrifier maximum specific growth rate, \( \mu_{\text{max},a} \), but can also potentially increase the nitrifier half-saturation coefficient for ammonia, \( K_N \). With the input of chemical inhibitor, the \( SRT_{\text{min}} \) would increase, possibly approaching the design SRT. If a system is operating at a given design SRT, this suggests that the presence of a chemical inhibitor may not affect process performance (effluent ammonia-N concentration) but could make the system much more susceptible to nitrification problems as a result of wastewater temperature fluctuations or peak ammonia loading events. As a result, it is critical to evaluate the effect of chemical inhibitors on nitrification kinetic parameters or on direct surrogates of those parameters (e.g. nitrate generation rate) (Kelly et al., 2004; Daigger and Sadick, 1998; Hockenbury and Grady, 1977).
Nitrification is not only used for ammonia removal, but is also commonly used in conjunction with denitrification processes for total nitrogen removal. The denitrification process is less sensitive to changes in pH, temperature, and other factors than the nitrification process; therefore it is practical to investigate the more sensitive nitrification process (Pagga et al, 2006). The specific inhibition of nitrification could have dramatic effects on a plant's ability to treat wastewater properly and discharge within permitted limits. For many of the compounds, the concentrations that inhibit the nitrifying bacteria may be an order of magnitude lower than the concentrations which inhibit the heterotrophic bacteria that remove biodegradable organic matter (Daigger and Sadick, 1998). For this reason, it is important to know the inhibition potential of substances on nitrification to prevent disturbances (Pagga et al, 2006). It is generally advised to test chemicals and wastewaters which might be considered toxic or inhibitory by suitable laboratory tests in advance (Pagga et al, 2006). Many facilities have reported experiencing biotreatment process upset conditions based on a WERF Report survey conducted in 2000 (Love and Bott, 2000). Ineffective nitrification was reported as the second most inhibited process to COD/BOD removal out of survey conducted on 110 different treatment facilities (Love and Bott, 2000). This suggests that nitrification inhibition is a widespread and common problem found at wastewater treatment facilities.

There are several types of experiments and methods used to examine nitrification inhibition. Experiments can be carried out using continuously stirred tank reactors, batch reactors, or nitrifying bioreactors in bench, pilot, and full scale studies (Hu et al, 2004). Nitrification inhibition can be measured through measuring oxygen uptake rates, also known as respirometry, and nitrate generation or ammonia uptake rate (NGR or AUR). In most cases, the experiments listed above utilize nitrifying biomass or activated sludge from a wastewater
treatment plant that is being studied and add different possible or known inhibitors to the reactors to examine oxygen, ammonia, nitrate, and nitrite uptake and generation rates. Although there is extensive literature on nitrification inhibition each situation must be independently evaluated to assess the cause of inhibition and solution to the problem. There are many potential sources of nitrification inhibition in wastewater which are discussed further in subsequent sections

2.1.1 Chemical Inhibition

Many transient upset events are known to be caused by shock loads of toxic chemicals. Furthermore, studies have shown that chemical toxins can detrimentally affect all the essential processes within an activated sludge treatment system (Henriques et al, 2007). Organic compounds at certain concentrations can promote inhibition of nitrification. According to literature it has been observed that chlorobenzene and trichloroethylene are capable of causing inhibition at much lower concentrations than phenol or ethylbenzene (Juliastuti et al, 2003a). Previous research by others has found nitrification to be highly susceptible to upset in wastewater treatment (Blum and Speece, 1991; Wood et al, 1981). Full-scale and laboratory-scale studies have shown that industrial contaminants are frequently the source of such upset events, and these sources can adversely affect the nitrification process for weeks (Hu et al, 2002; Nowak and Svardal, 1993). Literature has also shown that inhibitory chemicals can often be formed in the solids processing trains of wastewater treatment facilities (Daigger and Sadick, 1998). Numerous studies using pure cultures of nitrifying bacteria have reported that industrial toxins can be inhibitory (Anthonisen et al, 1976; Blum and Speece, 1991; Grunditz and Dalhammar, 2001). Furthermore, recovery of nitrification after an inhibitory event can take time (Stasinakis et al, 2003), leaving the treatment system vulnerable to permit violations and the downstream environment vulnerable to ecological damage (Kelly et al, 2004).
2.1.2 Impact of Heavy Metals on Biological Treatment

Metals have been found in significant concentrations in various wastewater streams. Contributions from industrial sources have been assumed as a cause of nitrification inhibition in more recent times (Hu et al., 2002). This is supported by the increasing trend of discharging industrial effluent to publicly owned treatment works (POTW) for treatment, which increases the possibility of contamination in the influent by metal ions (Stasinakis et al., 2003). Although a constant low-level exposure to metals does not typically affect microbial activity due to biomass acclimation, shock loads of metals can lead to complete failure of biological processes (Hu et al., 2004). The presence of heavy metals can also adversely affect the operation of biological treatment processes by accumulating to inhibitory concentrations. Many studies have investigated the effects of heavy metals in biological systems alone or in combination with others.

A high variation is seen in the reported inhibitory range for metals, since different experimental conditions exist in all studies (i.e. exposure time, type of buffer, pH, type and concentration of ligands) (Semerci et al., 2007). In addition to this, interpretation of results is based on different metal species such as total, labile, free or biosorbed metal. Under these circumstances, it is very difficult to compare the inhibitory concentration ranges (Semerci et al., 2007). Previous short-term studies have demonstrated that nitrification inhibition generally correlates well with the aqueous free metal cation concentration (Hu et al., 2004). There are many different types of metals which can be found in wastewaters of both municipal and industrial origin; however, nickel, cadmium, copper, and zinc are some of the more commonly found metals because of their widespread industrial use (Hu et al., 2004). Inhibition of nitrification is clear for heavy metals such as cadmium, zinc, and copper when the biomass is exposed to higher
shock load (24-hour period) concentrations of the metal (0.2 – 0.65 mg/L Cd\(^{2+}\), 0.5 – 3 mg/L Zn\(^{2+}\), 10 – 12.5 mg/L Cu\(^{2+}\)) as supported by literature (Hu et al, 2002, Kelly and Love, 2004, Semerci et al, 2007, Madoni et al, 1999). Metals also have a dual effect on microbial growth and act either as trace elements or as inhibitors (Juliastuti et al, 2003).

2.1.3 Quaternary Ammonium Compounds (QAC)

Quaternary ammonium compounds (QACs) or quaternary ammonium salts (quaternary ammines) are salts of quaternary ammonium cations with a coordinating anion (e.g. chloride). They are organic compounds that contain four functional groups attached covalently to a positively charged central nitrogen atom (R\(_4\)N\(^+\)). These functional groups (R) include at least one long chain alkyl group, and the rest are either methyl or benzyl groups. QACs are extensively used in domestic and industrial applications as surfactants, emulsifiers, fabric softeners, disinfectants and corrosion inhibitors (Tezel et al, 2007).

QACs are of importance here because it has been determined that acute inhibition of both heterotrophic COD removal and nitrification, especially the nitrite oxidation process, can be inhibited at high concentrations (Kreuzinger et al, 2007). Boethling (Boethling, 1984) suggests that at higher concentrations, for which no acclimation has occurred, the presence of QACs causes significant inhibition. There has been some investigation into the impact of QACs on biological wastewater treatment, which have found that acclimation may occur, one reason for which appears to be complexation of QACs with anionic surfactants and/or adsorption to particulate matter (Yang et al, 2008). The focus of this review is the effect of common QACs used as disinfectants and deodorants for chemical toilet liquids and their impact on aerobic biological wastewater treatment.
The Hampton Roads Sanitation District (HRSD) Nansemond Treatment Plant (NTP) receives large quantities of chemical toilet waste that are discharged to the plant in slug doses via tank truck to the septage receiving station (see Tables 2.1 and 2.2). It was hypothesized that the QACs contained in this chemical toilet waste could be a possible source for the sporadic nitrification inhibition that is experienced at the NTP.

Table 2.1 Septage Waste Received for Several HRSD WWTPs

<table>
<thead>
<tr>
<th></th>
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<tbody>
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<td>1,012</td>
<td>3,519</td>
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<td>12,130</td>
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<tr>
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<td>4,000,171</td>
<td>15.7</td>
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<tr>
<td>York River</td>
<td>2,592,031</td>
<td>76,418</td>
<td>2,730,400</td>
<td>12.9</td>
<td>209</td>
<td>7,481</td>
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</table>

Table 2.2 Septage Waste Received as a Fraction of Average Daily Plant Flow

<table>
<thead>
<tr>
<th>WWTP Loading Highest to Lowest</th>
<th>Chemical Toilet Waste [gallons/day]</th>
<th>Chemical Toilet Waste [% Avg Day Flow]</th>
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</thead>
<tbody>
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<td>Boat Harbor</td>
<td>2,336</td>
<td>0.016</td>
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<td>Williamsburg</td>
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<td>0.005</td>
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<td>0.004</td>
</tr>
<tr>
<td>York River</td>
<td>209</td>
<td>0.002</td>
</tr>
</tbody>
</table>

2.1.3.1 Impact of QACs on Biological Treatment

Relevant QACs associated with disinfectants or chemical toilet additives are BAC, DDAC, dichlorobenzyl dimethyl dodecyl ammonium chloride, cetyltrimethylammonium bromide, and laurylpyridinium methosulfate (Gerike et al, 1990). Previous research has been focused on BAC and DDAC, although one study was conducted which examined all the above QACs and the biodegradability and inhibitory threshold concentrations of these compounds (Geirke et al, 1990). It was found from this study that inhibitory effects were noted either in an oxygen consumption inhibition test (respirometry) or by comparing the degradation performance in a biological test culture with disinfectant added to a control (Gerike et al, 1990).
Study from the work of Boethling suggests that even with equivalent amounts of anionic surfactants and acclimation, slug loading which would result in temporarily high concentration in treatment plants could upset plant function and completely inhibit nitrification (Boethling, 1984). This implies that increases in QAC concentration would have a disruptive effect on sewage treatment even when anionic surfactants are also present (Boethling, 1984). This is especially true for the nitrification process, which appears to be somewhat more sensitive to inhibition by QACs than heterotrophic COD removal (Boethling, 1984).

In another study, it was determined that the second step of nitrification for which nitrite oxidizing bacteria (NOB) convert nitrite ($\text{NO}_2^-$) to nitrate ($\text{NO}_3^-$) exhibited the greatest inhibition in response to QAC loading (Kreuzinger et al, 2007). The study used both short and long term tests to look at both acute and chronic inhibition of nitrification due to exposure to QAC compounds. For acute tests, oxygen consumption for carbon removal and nitrification were measured after addition of various concentrations (0.02, 0.2, 0.5, 1, 5, 10, 25, 50, 100 mg/L) of the single QACs, BAC-$\text{C}_{12}$–$\text{C}_{16}$ and DDAC-$\text{C}_{10}$–$\text{C}_{18}$, and these data were used to estimate acute maximum autotrophic growth rates (Kreuzinger et al, 2007). Chronic inhibition was evaluated in bench-scale biological treatment systems with continuous dosage of the test substances in synthetic wastewater (peptone, meat extract, urea, NaCl, CaCl$_2$, MgSO$_4$, K$_2$HPO$_4$) for a duration of 6 months, applying final concentrations of 0.1, 1 and 2 mg/L QAC mixture described above for at least 1 month. Chronic effects were assessed by comparing COD removal and nitrification efficiency with a control that did not receive QAC (Kreuzinger et al, 2007). It was found that the following QACs and concentrations were inhibitory to nitrification; Benzyldimethyldecylammonium chloride (BDMDAC):8–22 mg/L, dichlorobenzyldimethyldecylammonium chloride (DCBMDAC):16 mg/L, and
cetyltrimethylammonium bromide (CTAB): 15 mg/L (Kreuzinger et al., 2007). These values were measured using the oxygen consumption inhibition test method.

Results from recent research on alkyl benzel dimethyl ammonium chloride (AB), using mixed aerobic and nitrifying cultures, demonstrated that the mixed aerobic cultures are able to efficiently degrade up to 50 mg/L AB when fed with dextrin and peptone (Yang et al., 2008). Nitrification was complete at a concentration 20 mg/L AB only after an acclimation period, but was almost fully inhibited at 50 mg/L (Yang et al., 2008). This supports previous work which suggests that aerobic cultures can efficiently degrade QACs if properly acclimated at lower concentrations, but at higher concentrations or slug loads can experience complete inhibition. A mixed aerobic culture was also fed only AB as the external nitrogen and carbon source and was able to achieve high AB degradation at both 20 and 50 mg/L AB (Yang et al., 2008).

Nitrifying cultures were also examined with the addition of AB from 2-20 mg/L (Yang et al., 2008). Results from this assessment showed that at lower concentrations (2 and 5 mg/L AB) there was no significant inhibition compared to the control, although the rate of the first step of nitrification (NH3-N to NO2-N) was slower than the control (Yang et al., 2008). Inhibition starting at 10-20 mg/L AB was apparent in the nitrifying cultures as ammonia was not fully utilized at 10 mg/L and complete inhibition occurred above 15 mg/L (Yang et al., 2008). An interesting finding from this study was that no nitrite accumulation was observed which suggests that in this particular work AOB were more sensitive to AB than NOB (Yang et al., 2008).

2.1.4 Impact of Nitrification Inhibition on Biological Nutrient Removal (BNR)

The inhibition of nitrification, whatever the cause may be, has a tremendous impact on BNR process performance. Ineffective nitrification can lead to nitrite accumulation which could
also have an effect on biological phosphorus removal (Bio-P) (Meinhold et al, 1999). Nitrite accumulation at higher concentrations has been found to interfere with PAO metabolism causing PHA utilization and anoxic phosphate uptake to cease (Meinhold et al, 1999). Nitrate is preferred for use during PAO metabolism as it can be utilized in both nitrogen and phosphorus removal creating a “double use” which will result in reduced sludge production. Also nitrate is preferred over oxygen as it can reduce aeration demand (Meinhold et al, 1999).

Nitrification inhibition can also create issues for denitrification. Nitrate is provided from the return activated sludge (RAS), which is recycled from the secondary clarifiers. If NOB activity is inhibited than less nitrate would be produced, thus impacting denitrifiers which utilize nitrate as a primary electron acceptor.

A typical uninhibited AOB maximum specific growth rate is 0.80-1.0 d⁻¹; however, conditions that lead to continuous nitrifier inhibition could have growth rates significantly less than this range. For process design, AOB maximum specific growth rate generally controls the minimum SRT; therefore inhibited rates can create issues with the activated sludge process in a BNR system. Increase in the minimum SRT due to slower nitrification kinetics would require larger aeration tank volumes and associated aeration in addition to potentially larger secondary clarifiers.

2.2 Bench-Rate Measurements

2.2.1 AOB & NOB Rate Measurement

AOB and NOB activity is important when reviewing a plant’s nitrification performance. The kinetic parameters associated with these rates, such as the maximum specific growth rate, are important when examining plant performance and are also a good indication of whether the plant is nitrifying properly. Traditional single-step modeling of nitrification is adequate under
sole rate limitation by \( \text{NH}_4^+ \)-N to \( \text{NO}_2^- \)-N oxidation (Chandran et al, 2000b). However, such modeling yields meaningless kinetic parameter estimates when \( \text{NO}_2^- \)-N to \( \text{NO}_3^- \)-N oxidation or both oxidation steps limit overall nitrification during periods of the test assay (Chandran et al, 2000b). Respirometry-based two step nitrification models can permit biokinetic estimation of both \( \text{NH}_4^+ \)-N to \( \text{NO}_2^- \)-N oxidation and \( \text{NO}_2^- \)-N to \( \text{NO}_3^- \)-N oxidation from a single \( \text{NH}_4^+ \)-N to \( \text{NO}_3^- \)-N oxidation respirogram (Chandran et al, 2000). However, for any nitrification design or control efforts based on batch respirometry derived biokinetic estimates, it is beneficial to identify the rate-limiting step in overall nitrification by estimating and comparing the kinetics of each step (Chandran et al, 2005).

Both full-scale and laboratory scale studies using the activated sludge process have suggested that a wide variety of industrial chemicals can inhibit the nitrification process for extended periods (Stasinakis et al, 2003; Kelly et al, 2004; Nowak et al, 1993), and that recovery from this inhibition can take a significant amount of time (Kelly et al, 2004; Stasinakis et al, 2003). Respirometry, which measures oxygen uptake rate and nitrate generation rate (NGR), which determines the nitrate production rate, are most commonly used to measure nitrification inhibition (Kelly and Love, 2004). Another common method for determining nitrification rates and inhibition is through the use of titrimetric techniques which examine nitrification rates based on the rate of base addition for pH stabilization (Kelly and Love, 2004).

The two main methods used to evaluate nitrification kinetics related to this work and, specifically the effect of chemical toxins on nitrification:

1. **Respirometry**: involves the measurement of oxygen uptake rate (OUR) for microbes associated with biological treatment. A sample of mixed liquor is removed from a full-, pilot-, or bench-scale system, placed in a sealed reactor, possibly amended with substrate
or nitrification inhibitor, and the rate of oxygen consumption is monitored over time. To evaluate nitrification kinetics, a sample of mixed liquor is added to a temperature-controlled respirometer reactor with and without (control) a chemical stressor. The mixed liquor can be supplemented with primary effluent (PE), ammonia-spiked PE, secondary effluent (SE), ammonia, or nitrite. When conducting experiments to measure nitrification kinetics it is desired to start the experiment with relatively high levels of ammonia to allow for a longer experimental run and to ensure that the maximum nitrification rate is maintained. If this is the case, careful control of pH must be maintained to ensure the pH does not drop below about 6.8-7.0 (alkalinity is typically added in the form of sodium carbonate). If organic substrate is added (e.g. PE), these experiments can be run with and without nitrification inhibitor to distinguish between heterotrophic and autotrophic oxygen uptake. Since endogenous heterotrophic oxygen uptake can occur without organic substrate addition, experiments are often run with and without nitrification inhibitor even when ammonia is the only substrate added to the mixed liquor. It is possible to calculate nitrification kinetic parameters based on specific oxygen uptake rate (SOUR) profiles (note that the term “specific” indicates that the OUR has been normalized to the biomass concentration).

2. **Nitrate/Nitrite Generation Rate**: In order to evaluate the nitrification process fully independent of heterotrophic activity, kinetic rates directly related to the consumption or production of reactants and products of the nitrification process itself can be measured, specifically nitrate/nitrite generation rate (NGR) or ammonia uptake rate (AUR). The specific nitrification rate (SNR) can be obtained by normalizing to biomass concentration, and this data can be used to determine the autotrophic kinetic parameters.
described above. For these experiments, a sample of mixed liquor is added to small
temperature controlled reactors (approximately 3.0 L). The reactor is mixed and aerated,
and the inhibitor of interest added to the stressed reactor. Once all residual organic
substrate associated with the mixed liquor sample itself is consumed, ammonia or nitrite
is spiked into the reactor, and caution must be taken to ensure that pH and alkalinity
remain within acceptable limits – preferable pH 7 to 8 at all times. The nitrate, nitrite,
and ammonia concentrations are monitored over time using typical analytical methods
(APHA, 1998). It is critical to rapidly separate the mixed liquor from the soluble
supernatant as quickly as possible after removing a sample from the reaction reactor.
Typically, samples are removed from the reaction reactors at predetermined time
intervals and rapidly centrifuged. The supernatant is poured off and immediately filtered
through a 0.45 µm membrane filter. The filtrate can then be preserved for subsequent
analysis.

Respirometry is a good method of measuring nitrification inhibition, but also has proven useful
for indicating activated sludge process stability both in lab and full-scale experimentation (Kelly
and Love, 2004). Respirometry has an advantage over NGR in that it is rapid and doesn’t require
extensive sample analyses. Unfortunately respirometry measures the total oxygen uptake rate of
a biomass. This requires several iterations of tests to determine the respiration rate of only the
nitrifying bacteria in a mixed community like mixed liquor because the nitrifying bacteria must
be specifically inhibited from other species. To do this, a total respirometry must be performed
as well as a respirometry where the biomass has been inhibited for nitrification using compounds
such as heavy metals, organic compounds, QACs or industrial wastes (Kelly and Love, 2004).
NGR provides a direct measure of the rate of nitrification, as it measures the generation of nitrate
and nitrite, the product of two-stage nitrification (Kelly and Love, 2004). This can be used to measure AOB rates based on NOx-N generation or NOB based on NO3-N generation. Although it provides a direct measure, it also requires more time to complete than respirometry.

Kelly et al (2004b) compared the use of respirometry to NGR measurement for two different chemical compounds and suggested that NGR is the preferred method for determining nitrification inhibition because the NGR test yields a direct measure of the nitrification rate through measurement of the final product while respirometry only provided indirect measurement of nitrifier activity (Kelly and Love, 2004). It was also noted that during one of the experiments in comparing respirometry and NGR measurement due to cadmium inhibition, respirometry seemed to over predict inhibition at lower concentrations and under predict inhibition at higher concentrations (Kelly and Love, 2004). NGR test results also exhibited better reproducibility within duplicate reactors (Kelly and Love, 2004).

2.2.2 Biological Phosphorus Rate Measurement

The use of enhanced biological phosphorus removal (EBPR) has been shown to be an economical and environmentally acceptable method for reducing phosphorus from wastewaters (Erdal, et al, 2006). The most common and widely used test method for measuring EBPR is the uptake and release test (URT). URTs provide a qualitative assessment of phosphorus accumulating organisms (PAO) activity in activated sludge that can be used to develop kinetic parameters for process simulation model calibration, such as the ratio of phosphate released to acetate consumed, and providing information on phosphate uptake kinetics that can be used to estimate the time required to remove quantities of phosphate in the aerobic zone (Neethling et al., 2005). By adding excess volatile fatty acids (VFA) such as sodium acetate to mixed liquor, PAO activity and the amount of stored phosphorus limit the measured phosphate release
(Neethling et al, 2005). The ratio of uptake HRT to release HRT can be used as a performance indicator as it correlates well to the observed performance in full-scale facilities according to Neethling et al (2005). Ratio between uptake and release rate can also be used as a performance indicator if data is consistent and accurate in determining aerobic contact time in full-scale treatment (Neethling et al, 2005).

There are several parameters known to influence phosphorus removal efficiency. Availability of readily biodegradable substrate in the influent of the system plays an important role in performance (Mota et al, 2001). VFAs used by PAOs are generated by fermentation under anaerobic conditions and some may be present in more septic wastewaters (Mota et al, 2001). The presence of nitrate in the anoxic stages of EBPR processes is widely recognized to have a repressive effect on phosphorus release and on net phosphorus removal (Mota et al, 2001). This is because the presence of nitrate creates a competition between denitrifying bacteria and PAOs for the VFAs which are the typical carbon source for the formation of polyhydroxyalkanoates (PHAs) (Mota et al, 2001). Studies have shown that better system performance was related to reduced competition for substrate in the non-oxic zones, which results in larger populations of PAOs, and thus, greater EBPR efficiency (Erdal et al, 2006). Solids retention time and temperature have also shown to play an important role in EBPR efficiency which has been supported by several different studies (Whang et al, 2001; Erdal et al, 2006). Other factors which can contribute to reliable EBPR performance include the role of fermenters or other processes used to enhance EBPR, the management of return flows from anaerobic solids processing steps, and chemical addition for phosphorus polishing and EBPR backup (Neethling et al, 2005).

2.3 Profile Sampling
Profile sampling of wastewater treatment plants provides an effective method for evaluating the performance of a BNR processes by sampling for species such as ammonia, nitrate, nitrite, orthophosphate, soluble COD, etc. through the treatment train. Profiles are most commonly incorporated with DO and nutrient profiles (NH$_3$-N, NO$_3$-N, etc.), but can be applied to different applications; examining different bacterial species or the solids content of a reactor. Although there is not much literature on this specific sampling method, it is very much often used in conjunction with modeling work and evaluating existing and future nutrient removal processes (Kochany et al, 2007; Scott et al, 2008; Kim et al, 2009). Profile sampling has also been used in determining the fate and transport of chemicals in wastewater treatment. There has been work conducted on the fate and transport of mercury, where samples were collected from various process locations and analyzed for mercury and methylmercury (Downing et al, 2008). When conducting profile sampling it is useful to determine what parameters need to be profiled to generate useful quantitative data. Another use for profile sampling is to determine various rates such as ammonia uptake rates, nitrate production rates, and phosphorus uptake and release rates. Grab sampling or composite sampling are both viable methods for profile sampling; however, composite sampling would require an automatic filtration system or manual composite sampling, since samples would require immediate filtration. The method for sampling is primarily based on the application, but generally involves the collection of various samples at different periods of time or various locations along the length of a treatment process.

One study used DO profiling during a feed cycle as an indication of upset conditions and monitoring SBR biomass recovery. It was found that based on DO profiling, upset conditions could be early detected and recovery measures quickly applied (Kochany et al, 2007). The same study using SBRs found that there was a correlation between the ammonia removal during a feed
cycle and the oxygen concentration in the reactors providing the same air supply (Kochany et al, 2007). This suggests that monitoring the oxygen profile (DO) can be used instead of ammonia analyses. Since DO measurements are faster as compared to ammonia analyses, determining DO profile during a feed cycle can provide useful information about efficiency of the biological system, without using expensive ammonia on-line analyzers (Kochany et al, 2007).

2.4 References


Huang, J.Y.C. Metal Inhibition of Nitrification. Industrial Waste Conference, 37, 85-93.


3. Methodology

3.1 Bench-Scale Batch Reactor Experimentation

3.1.1 Sample Collection

Batch reactor experimentation was conducted by collecting biomass samples from the aeration basin effluent of several full-scale wastewater treatment plants. Grab samples were collected unless otherwise arranged with HRSD to collect composites. All samples were collected and stored in polypropylene carboys or similar containers. These samples were then transported to the lab and stored until use with continuous aeration for no longer than approximately 48 hours at room temperature. Biomass samples were collected from NTP; the HRSD VIP plant, which uses the same BNR process as NTP but does not experience inhibition; the Henrico County WWTP, which has a fully nitrifying 5-stage BNR process; and the HRSD York River plant from the sequencing batch reactor system.

Wastewater sources for experimentation were also collected via grab sample or composite sampling by HRSD based on the source being tested. Wastewater samples were collected including NTP and VIP primary effluent (PE); NTP and VIP secondary effluent (SE); raw wastewater from isolated branches of the NTP collection system; and industrial waste samples from a hog processing plant and a landfill leachate stream. Waste samples were also tested from other suspected sources such as chemical toilet disinfectants (quaternary ammonium compounds).

3.1.2 Batch Reactor Construction

Four parallel batch reactors were constructed of plexiglass and configured with vinyl and polypropylene fittings and appurtenances. The first reactor served as the control while operating conditions of the other three reactors were varied. Each reactor had a volume of 3 liters with
individual ports for sampling and chemical addition (acetate, ammonia, nitrite, and phosphate) during experimentation as needed. A diffuser stone was incorporated into each reactor to provide air/oxygen or nitrogen based on the experiment. This allowed the reactors to be operated under aerobic, anoxic, or anaerobic conditions for nitrification, denitrification, and phosphorus release/uptake measurements. The reactors were configured to be air tight with a water seal on the headspace for anaerobic conditions. Mixing was provided through magnetic stir-bars and stir plates. Dissolved oxygen (DO) was kept constant using HACH LDO probes with HQ40d meters. Two probes were connected to a single HQ40d meter (total of four probes and two meters). National Instruments LabView 7.0 DO Controller was used to provide on and off control of four solenoid air supply valves with associated relays. pH was controlled and logged using Cole-Parmer pH meters/controllers connected to acid (1M H$_2$SO$_4$) and base (3M Na$_2$CO$_3$) pumps. The reactors were placed in a water bath with a circulating chiller and immersion heaters to maintain a constant temperature during experimentation. Refer to Figure 3.1, 3.2, and 3.3 for a schematic and image of an individual reactor and for a complete schematic and image of the entire reactor configuration.
Figure 3.1 Reactor Schematic and Image

Figure 3.2 Complete Reactor System Schematic
3.1.3 Batch Reactor Operation

Experimentation consisted of the evaluation AOB, NOB, and Bio-P activity. The method for evaluating each type of experiment is discussed further in subsequent sections. Temperature for experimentation was based on the temperature of the biomass sample when it was collected onsite via grab sample. The matrix of experiments developed and completed is summarized in Table 3.1. The abbreviations in the table are as follows: Nansemond (NS), VIP (VIP), Henrico (HR), York River (YR), primary effluent (PE), secondary effluent (SE), raw water influent (RWI), primary clarifier influent (PCI), primary clarifier effluent (PCE), branches of collection system (Branch 1, 2, 3), iron addition (Fe).
Table 3.1 Batch Experiment Matrix

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<th>Experiments</th>
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<td>b. VIP/PE</td>
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<td>VIP</td>
<td>c. VIP/PE</td>
<td>d. NS/PE</td>
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<td>Nansemond</td>
<td>a. NS/PE</td>
<td>b. VIP/PE</td>
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<tr>
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<td>VIP</td>
<td>c. VIP/PE</td>
<td>d. NS/PE</td>
</tr>
<tr>
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<td>a. VIP/SE + Leachate</td>
<td>b. VIP/SE</td>
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<tr>
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<td>VIP</td>
<td>c. VIP/SE + Leachate</td>
<td>d. VIP/SE</td>
</tr>
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<td>Nansemond</td>
<td>a. NS/PE</td>
<td>b. HR/PE</td>
</tr>
<tr>
<td></td>
<td>Henrico</td>
<td>c. HR/PE</td>
<td>d. NS/PE</td>
</tr>
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<tr>
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<td>c. VIP/SE + Hog Plant</td>
<td>d. VIP/SE</td>
</tr>
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<td>b. VIP/SE</td>
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<td></td>
<td>VIP</td>
<td>c. VIP/SE + Branch 2</td>
<td>d. VIP/SE + Branch 3</td>
</tr>
<tr>
<td>8</td>
<td>Nansemond</td>
<td>a. VIP/SE</td>
<td>b. VIP/SE + Branch 2a</td>
</tr>
<tr>
<td></td>
<td>VIP</td>
<td>c. VIP/SE + Branch 2b</td>
<td>d. VIP/SE + Branch 3</td>
</tr>
<tr>
<td>9</td>
<td>Nansemond</td>
<td>a. VIP/SE</td>
<td>b. VIP/SE + Cedar Ln PS</td>
</tr>
<tr>
<td></td>
<td>VIP</td>
<td>c. VIP/SE + Gum Rd. PRS</td>
<td>d. VIP/SE + Pughsville PRS</td>
</tr>
<tr>
<td>10</td>
<td>Nansemond</td>
<td>a. VIP/PE</td>
<td>b. NTP RWI</td>
</tr>
<tr>
<td></td>
<td>VIP</td>
<td>c. NTP PCI</td>
<td>d. NTP PCE</td>
</tr>
<tr>
<td>11</td>
<td>Nansemond</td>
<td>a. VIP/SE</td>
<td>b. VIP/SE + 20 mg/L Fe</td>
</tr>
<tr>
<td></td>
<td>VIP</td>
<td>c. VIP/SE + 35 mg/L Fe</td>
<td>d. VIP/SE + 50 mg/L Fe</td>
</tr>
<tr>
<td>12</td>
<td>Nansemond</td>
<td>a. VIP/SE</td>
<td>b. VIP/SE + 20 mg/L Fe</td>
</tr>
<tr>
<td></td>
<td>VIP</td>
<td>c. VIP/SE + 35 mg/L Fe</td>
<td>d. VIP/SE + 50 mg/L Fe</td>
</tr>
<tr>
<td>13</td>
<td>York River (YR)</td>
<td>a. YR/SE</td>
<td>b. YR/SE + 20 mg/L Fe</td>
</tr>
<tr>
<td></td>
<td>York River (YR)</td>
<td>c. YR/SE + 35 mg/L Fe</td>
<td>d. YR/SE + 50 mg/L Fe</td>
</tr>
<tr>
<td>14</td>
<td>York River (YR)</td>
<td>a. YR/PE</td>
<td>b. NTP RWI</td>
</tr>
<tr>
<td></td>
<td>York River (YR)</td>
<td>c. NTP PCI</td>
<td>d. NTP PCE</td>
</tr>
<tr>
<td>15</td>
<td>York River (YR)</td>
<td>a. YR/SE</td>
<td>b. YR/SE + 0.574 mL Chem Toilet Additive*</td>
</tr>
<tr>
<td></td>
<td>York River (YR)</td>
<td>c. YR/SE + 13.96 mL Chem Toilet Additive*</td>
<td>d. YR/SE + 62.84 mL Chem Toilet Additive*</td>
</tr>
<tr>
<td>16</td>
<td>York River (YR)</td>
<td>a. YR Mixed Liquor (ML)</td>
<td>b. YR ML + 15 mL Product B</td>
</tr>
<tr>
<td></td>
<td>York River (YR)</td>
<td>c. YR ML + 30 mL Product B</td>
<td>d. YR ML + 60 mL Product B</td>
</tr>
<tr>
<td>17</td>
<td>York River (YR)</td>
<td>a. YR Mixed Liquor (ML)</td>
<td>b. YR ML + 60 mL Product B</td>
</tr>
<tr>
<td></td>
<td>York River (YR)</td>
<td>c. YR ML + 120 mL Product B</td>
<td>d. YR ML + 180 mL Product B</td>
</tr>
</tbody>
</table>

*NOTE: Week 15 Experimentation – Two different Chemical Toilet Additives used for the two different days of experimentation (NatureFresh – Day 1 & Blue Works – Day 2)

3.1.3.1 AOB Experimentation
AOB activity was evaluated by spiking the reactors with ammonia and monitoring NO$_x$-N and NO$_3$-N generation rate over three hours (Kelly et al, 2004). During an AOB experiment the collected biomass was concentrated to approximately 8000 mg/L MLSS prior to experimentation. Then the reactor was filled 1/3 by volume with biomass and 2/3 by volume with a diluent (primary effluent, waste sample, etc.). Additional ammonia was added to achieve a total ammonia concentration of approximately 40 mg/L NH$_4$-N to provide sufficient ammonia during experimentation to prevent depletion. Dissolved oxygen (DO) and pH were constantly monitored and maintained within desired limits using online control systems. DO was maintained between 5-7 mg/L during experiments with a pH between 7.0-7.2. Each AOB experiment was conducted for 3 hours with 5 samples collected evenly throughout this period of time. Samples were immediately filtered through 0.45μm membrane filters after collection. AOB activity was based on NO$_x$-N generation rate.

3.1.3.2 NOB Experimentation

NOB activity was assessed by adding in nitrite (ensuring ammonia concentrations were low) and monitoring the rate of NO$_2$-N depletion and NO$_3$-N generation. NOB experimentation was conducted very similar except after the reactors were filled by volume as mentioned above they were aerated for approximately one hour to allow uptake of any residual ammonia. Samples were taken prior to starting the NOB Experimentation and analyzed for NH$_4$-N to ensure that the ammonia concentration in each reactor was <1 mg/L NH$_4$-N (detection limit of HACH TNT 831 NH$_4$-N analysis method). After it was determined that the ammonia concentration in each reactor was depleted, approximately 25 mg/L NO$_2$-N was added, and then 5 samples were collected evenly over a 3 hour test period. Samples were immediately filtered through 0.45μm membrane
filters after collection. DO and pH were maintained within the same parameters as was used for the AOB experiment. NOB activity was based on NO$_3$-N generation rate and NO$_2$-N uptake rate.

3.1.3.3 Bio-P Experimentation

Bio-P activity was determined by monitoring P uptake and release rates. Experimentation was conducted using the same concentrated biomass as in the AOB & NOB experimentation (~8000 mg/L MLSS). Experimentation was conducted in three phases: uptake, release, and a second uptake. During the first uptake (aerobic) phase, each reactor was filled with 1/3 by volume of biomass and 2/3 by volume of PE or another tested wastewater source. Then each reactor was spiked with 5 mg/L of PO$_4$-P to reach a target of 20 mg/L P in each reactor since it was presumed approximately 15 mg/L of PO$_4$-P would be present from the biomass and PE/wastewater sample. The first uptake phase was conducted for 1-2 hours and 3 samples were collected during this time with immediate filtration using 0.45μm membrane filters. During both uptake phases, pH was always controlled between 7.0-7.2 while the DO was maintained between 5-7 mg/L. After this initial uptake phase, the reactors were deaerated by sparging nitrogen (N$_2$) gas and reducing the DO to 0 mg/L which was maintained throughout the release phase. After the DO was reduced to 0 mg/L, each reactor was spiked with 200 mg/L acetate as COD. It was desired to have all NO$_3$-N and NO$_2$-N depleted, but this was not always the case. pH was controlled the same as in the uptake phase experiment and 5 samples were collected over a 1 hour period with immediate filtration using 0.45μm membrane filters. After the 1 hour release phase nitrogen was shut-off and then air/oxygen was sparged into the reactors to once again raise the DO and maintain the DO between 5-7 mg/L. As soon as the air/oxygen sparge began, 5 samples were collected over a 1-2 hour period with immediate filtration using 0.45μm membrane filters. All the samples from both uptake phases and the release phase were analyzed using the
same methods used for the AOB and NOB experiments noted in the subsequent 3.3 Analytical Methods section. Rates based on $\text{PO}_4$-$\text{P}$ release and uptake was normalized to MLVSS concentrations for each experiment.

All experimentation was conducted in this manner except for that conducted during weeks 16 & 17, during which the entire reactor volume was filled with biomass due to the biomass from the York River plant at that time being very dilute.

3.2 Profile Sampling

Profile sampling was conducted from the primary effluent to the secondary effluent with samples collected along the length of the BNR process. A total of 15 samples were collected. Analysis of soluble COD (sCOD), Ammonia (NH$_4$-N), Nitrate (NO$_3$-N), Nitrite (NO$_2$-N), ortho-phosphate (PO$_4$-P) at all sampling locations.

- Primary Clarifier Effluent (PE) - 1 Sample
- Anaerobic/Anoxic Tanks (AA1, AA2, AA3, AA4, AA5, AA6) - 6 Samples, 1 sample per cell for a single train
- Aeration Tank (AE1, AE1.25, AE1.5, AE3, AE5) - 5 samples, 1 at the beginning, 3 intermediate, 1 at the end for a single tank. The aeration tank was originally divided into 5 equal sample points along the length of the tank. AE1, AE2, AE3, AE4, AE5. Based on the data results two of the intermediate points were changed. Instead of taking 5 equally spaced points two were taken between the distance of AE1 and AE2, which became AE1.25 and AE1.5 to better capture ammonia uptake, nitrite consumption, and nitrate production. AE4 was eliminated as values were similar to AE5 (Figure 3.4).
- Clarifier Recycle (RAS) - 1 sample
Each sample was collected via grab sample from the surface of the tank using a bucket or sample dipper. The sample was allowed to settle for approximately 30 seconds to allow a supernatant layer to form. The supernatant was then aspirated and immediately filtered through 0.45μm membrane filters using a portable vacuum filtration system. DO and pH were measured and recorded when each grab sample was collected. Each sample was also collected in accordance with corresponding HRTs associated with each process. Samples were collected in two different containers; (1) 15 mL centrifuge tube for on-site analysis using HACH colorimetric test kits and (2) 40 mL VOA vial for soluble COD analysis by the HRSD Central Environmental Laboratory (CEL). All samples collected were kept chilled in a cooler on ice until they could be refrigerated to <6°C. Samples which were collected and placed into the 40 mL VOA vials were preserved with H₂SO₄ acid as soon as samples were collected and stored at a temperature of <6°C in a refrigerator until they were transported for analysis by CEL the following morning.
This process for profile sampling was performed twice a week during normal plant operation hours (0600 to 1500) for a period of approximately 2 and half months until the plant stopped nitrifying.

3.3 Analytical Methods

3.3.1 AOB, NOB, and Bio-P Analysis

Samples were analyzed for NH$_4$-N, NO$_2$-N, NO$_3$-N, and PO$_4$-P using HACH colorimetric test kits, ion chromatography (IC), and flow injection analysis (FIA) (see subsections 3.3.3, 3.3.6, 3.3.7, 3.3.8). MLSS and MLVSS were performed at the end of the experimentation per Standard Methods (APHA et al, 1995). Nitrate production rates, phosphorus uptake and release rates were calculated by normalizing the slope of each chemical constituent by the MLVSS concentration and adjusting units to mg/g MLVSS/hr.

3.3.2 Profile Sampling Analysis

Sample analysis for profile sampling was conducted both on-site and off-site. Analytes measured at NTP for each profile include: PO$_4$-P, NH$_4$-N, NO$_3$-N, NO$_2$-N which were conducted using various HACH colorimetric test kits (see subsections 3.3.3 – 3.3.6) and a HACH DR2800 spectrophotometer. Analysis of NO$_2$-N was performed the same day as sample collection, while analysis of PO$_4$-P, NH$_4$-N, and NO$_3$-N were conducted the following day. Samples were preserved by refrigeration overnight after NO$_2$-N analysis was complete. Off-site analysis by CEL consisted of soluble COD and quality assurance and quality control samples (QA/QC) of the same analytes measured on-site using Standard Methods.

3.3.3 Ammonia (NH$_4$-N) HACH Test Kit

Ammonia was analyzed using HACH Test N’ Tube (TNT) 831 kit and HACH DR2800 spectrophotometer. This method uses the salicylate method, whereby ammonium ions react with
hypochlorite and salicylate ions in the presence of sodium nitroprusside to as a catalyst form indophenol. The amount of color formed is directly proportional to the NH₄-N present.

3.3.4 Nitrate (NO₃-N) HACH Test Kit

Nitrate was analyzed using HACH TNT 835 kit. This kit incorporates the dimethylphenol method where nitrate ions in solution with sulfuric and phosphoric acids react with 2,6-dimethyphenol to form 4-nitro-2,6-dimethyphenol.

3.3.5 Nitrite (NO₂-N) HACH Test Kit

Nitrite was analyzed using NitriVer3 Nitrite Reagent Powder Pillows and 10 mL sample vials. This kit uses the diazotization method where nitrite in the sample reacts with sulfanilic acid to form a intermediate diazonium salt. This salt combined with chromotropic acid forms a pink color which is directly proportional to the amount of nitrite present.

3.3.6 Ortho-Phosphate (PO₄-P) HACH Test Kit

Ortho-Phosphate was analyzed using the HACH Reactive Phosphate TNT Reagent Kit. This test kit uses the USEPA-approved PhosVer3 method where orthophosphate reacts with molybdate in an acid to produce a mixed complex. Ascorbic acid then reduces this complex, producing an intense blue color.

3.3.7 Ion Chromatography

IC analysis was conducted for measuring nitrate only for the batch experimentation work. The IC was used in conjunction with conductivity detection (Dionex ICS-1000), an AS14A analytical column and AG14A guard column, an ASRS conductivity suppressor, and an eluent flow of 1.0 mL/min of 1.0 mM NaHCO₃ and 8.0 mM Na₂CO₃.

3.3.8 Flow Injection Analysis
FIA was conducted for measuring nitrite, nitrate, and phosphate for batch experimentation work using a SEAL Analytics auto-analyzer system. FIA analysis incorporated a volume of 2 mL of sample in sample vials and placed into a sample tray. The tray was then placed into the FIA instrument along with various reagents required for the different analyte test methods. A schedule was then configured using the associated computer software with the instrument and analyzed. QA/QC samples were measured every 10 samples and test methods were always standardized prior to analysis of actual samples. Data output was provided in concentrations in mg/L as NO$_2$-N, NO$_3$-N, and PO$_4$-P.

3.4 Biowin Modeling

Modeling was performed using Biowin version 3.1, a biological wastewater treatment simulation package developed by EnviroSim Ltd (Flamborough, Ontario, Canada) and based on the IWA activated sludge models. Biowin was incorporated into this work to compare the data generated from the profile sampling with previous work performed by Hazen and Sawyer, P.C. (H&S). The Biowin model was calibrated using recent plant performance data and previous simulation modeling work from H&S. There are various wastewater fractions (Table 3.2) which must be adjusted by the user based on the wastewater source (Primary Effluent). Wastewater fraction inputs for this work were derived from the NTP model created by H&S. The H&S NTP model was simulated with the raw influent characteristics that were generated from historical plant data and a two week special sampling study specified by H&S. The effluent data from the primary clarifier of this simulation was used to calculate wastewater fractions for the input of the simulation for the profile sampling work. Primary clarification was not simulated as part of this effort. Kinetic parameters such as maximum specific growth rate ($\mu_{\text{max},\text{AOB}}$) and nitrite half saturation concentration were changed based on the work done by H&S in addition to changes
made to fit the simulation model to the profile sampling data. A Garret wasting configuration was incorporated to simplify modeling of secondary clarification (Figure 3.5), and the waste rate was then adjusted accordingly to match the solids wasted (lbs/day) from the plant performance data within a reasonable range. Diurnal load variations were not considered as part of this modeling.

Table 3.2 Biowin Influent Wastewater Fractions

<table>
<thead>
<tr>
<th>Name</th>
<th>Default</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fbs - Readily biodegradable (including Acetate)</td>
<td>0.270</td>
<td>0.310</td>
</tr>
<tr>
<td>Fac - Acetate</td>
<td>0.150</td>
<td>0.180</td>
</tr>
<tr>
<td>Fxsp - Non-colloidal slowly biodegradable</td>
<td>0.500</td>
<td>0.610</td>
</tr>
<tr>
<td>Fus - Unbiodegradable soluble</td>
<td>0.080</td>
<td>0.155</td>
</tr>
<tr>
<td>Fup - Unbiodegradable particulate</td>
<td>0.080</td>
<td>0.169</td>
</tr>
<tr>
<td>Fna - Ammonia</td>
<td>0.750</td>
<td>0.740</td>
</tr>
<tr>
<td>Fnox - Particulate organic nitrogen</td>
<td>0.250</td>
<td>0.300</td>
</tr>
<tr>
<td>Fnus - Soluble unbiodegradable TKN</td>
<td>0.020</td>
<td>0.030</td>
</tr>
<tr>
<td>FupN - N:COD ratio for unbiodegradable part. COD</td>
<td>0.035</td>
<td>0.030</td>
</tr>
<tr>
<td>Fpo4 - Phosphate</td>
<td>0.750</td>
<td>0.820</td>
</tr>
<tr>
<td>FupP - P:COD ratio for unbiodegradable part. COD</td>
<td>0.011</td>
<td>0.009</td>
</tr>
<tr>
<td>FZbh - Non-poly-P heterotrophs</td>
<td>0.000</td>
<td>0.0001</td>
</tr>
<tr>
<td>FZbm - Anoxic methanol utilizers</td>
<td>0.000</td>
<td>0.0001</td>
</tr>
<tr>
<td>FZaob - Ammonia oxidizers</td>
<td>0.000</td>
<td>0.0001</td>
</tr>
<tr>
<td>FZnob - Nitrite oxidizers</td>
<td>0.000</td>
<td>0.0001</td>
</tr>
<tr>
<td>FZamob - Anaerobic ammonia oxidizers</td>
<td>0.000</td>
<td>0.0001</td>
</tr>
<tr>
<td>FZhp - PAOs</td>
<td>0.000</td>
<td>0.0001</td>
</tr>
<tr>
<td>FZbpa - Propionic acetogens</td>
<td>0.000</td>
<td>0.0001</td>
</tr>
<tr>
<td>FZham - Acetoclastic methanogens</td>
<td>0.000</td>
<td>0.0001</td>
</tr>
<tr>
<td>FZbhm - H2-utilizing methanogens</td>
<td>0.000</td>
<td>0.0001</td>
</tr>
</tbody>
</table>
The Biowin simulation was also reconfigured for dynamic simulation. During the profile sample period one anaerobic/anoxic (AA) train was taken offline and so the model had to be adjusted to be able to model this during the entire profile period. For this reason a separate set of AA tanks were added and the flow split between the two trains in the model. One train received 4/5 of the flow and train B received 1/5 of the flow. When all tanks were online the flow was split to each of the trains to simulate the actual 5 trains that were online in the full-scale. When the one train was shut down in the full-scale the flow split to train B (1/5 of the flow) was stopped to mimic what actually occurred (Figure 3.6).
3.4.1 Steady-State Simulations

Simulations were created for individual periods of the profile sampling as well as a simulation for the entire profile sampling period. Individual periods were created based on changes in mixed liquor suspended solids, changes in process; 5 anaerobic/anoxic trains to 4 anaerobic/anoxic trains; the Nitrate recycle (NRCY) being active and inactive, and the cease of nitrification. Steady-state simulations incorporated the use of constant input values for recycle streams, WAS, and other inputs. The entire profile sampling event was divided into 5 different periods and each period was modeled using steady-state conditions to calibrate the simulation except for the 4th period.

3.4.2 Dynamic Simulations

During the 4th period the plant was falling out of nitrification and therefore this period had to be modeled dynamically to calibrate it properly. The model for the entire profile sampling event from start to finish was modeled dynamically as well. Itineraries for influent (Primary Effluent) characteristics, temperature, recycle rates, waste rates, and clarifier removal rates were all set based on plant performance data and the steady-state & dynamic calibration models.

3.5 References


4. Manuscript 1 – Evaluation of Nitrification Inhibition Using Bench-Scale Rate Measurements

Abstract

The Nansemond Treatment Plant (NTP) operated by the Hampton Roads Sanitation District (HRSD) was originally designed as a 3-stage VIP biological nutrient removal (BNR) process (Bilyk et al., 2008). NTP is currently being upgraded to a 5-stage Bardenpho process to achieve improved total nitrogen (TN) removal. NTP has experienced unexplained sporadic nitrification upsets for a number of years and some indication of continuous nitrification inhibition, as demonstrated by calibration of a process simulation model to historical data. A preliminary engineering report by Hazen and Sawyer, P.C., suggested that the ammonia oxidizing bacteria (AOB) maximum specific growth rate ($\mu_{\text{max}}$) be reduced from 0.90 to 0.57 days$^{-1}$ to account for high effluent ammonia data during the calibration period (Hazen & Sawyer, 2007). This has significant implications in terms of the required aeration volume for consistent nitrification at cold temperatures. A study was undertaken using a wide variety of NTP, targeted industry (hog processing facility and landfill leachate), and control wastewater and biomass samples to attempt to identify possible sources of inhibition through batch rate measurements using bench-scale reactors. Biomass samples were collected from various well nitrifying facilities to compare nitrification kinetics. Experiments were carried out using four batch reactors in parallel. This batch rate testing independently evaluated AOB and NOB activity based on NO$_x$-N generation and NO$_3$-N generation/NO$_2$-N depletion, respectively. Experimental results to date have confirmed the sporadically inhibitory nature of NTP primary effluent when combined with other nitrifying biomasses; however, no specific source has been determined. NTP receives large quantities of chemical toilet waste that are discharged to the plant in slug doses via tank truck to
the septage receiving station. Investigation into quaternary ammonium compounds (QACs) which were contained in the chemical toilet waste suggested that QACs at higher concentrations caused some inhibition to NOB activity, but no significant impact on AOB activity.

4.1 Introduction

The Hampton Roads Sanitation District (HRSD) operates thirteen treatment plants in the Hampton Roads, Virginia, area with a combined capacity of 231 million gallons per day (mgd) (Bilyk et al., 2008). The Nansemond Treatment Plant (NTP) is one of the larger facilities operated by HRSD and was designed to treat 30 mgd (max monthly) using a 3-stage Virginia Imitative Process (VIP) biological nutrient removal (BNR) process (Figure 4.1 and 4.2) (Bilyk et al., 2008). The majority of the influent is domestic, but there is also a large industrial contribution, particularly from a pig processing facility, landfill leachate, and significant loads from septage and grease deliveries (Bilyk et al, 2008). NTP has had a long history of issues with nitrification after its initial upgrade to a BNR facility in 1998.

Figure 4.1 3-Stage VIP Process at NTP in 2008 (Bilyk et al., 2008).
Starting in 2001 until the present the plant has experienced continuous and sporadic nitrification upsets without much explanation. This determination was based upon the plant’s efficiency in removing nitrogen. The VIP plant in Norfolk, VA which also employs the VIP process began BNR operations approximately seven (7) years prior to similar Nansemond operations (Balzer et al., 2005). Nitrogen removal was similar at both facilities (Table 4.1) during the first two years of side-by-side operation (1999 & 2000) (Balzer et al., 2005). Nansemond experienced an unexpected decline in nitrogen removal efficiency starting in 2001 which has continued to the present (Balzer et al., 2005). This deficiency in performance has been variable and has not been consistent from 2001 to the present time.
Table 4.1 Percent TN Removal for HRSD's Nansemond and VIP Treatment Plants (1999-2009)

<table>
<thead>
<tr>
<th>PLANT</th>
<th>NP</th>
<th>VIP</th>
</tr>
</thead>
<tbody>
<tr>
<td>YEAR</td>
<td>[% Removal]</td>
<td>[% Removal]</td>
</tr>
<tr>
<td>1999</td>
<td>69.9</td>
<td>71.5</td>
</tr>
<tr>
<td>2000</td>
<td>64.2</td>
<td>67.0</td>
</tr>
<tr>
<td>2001</td>
<td>53.1</td>
<td>66.3</td>
</tr>
<tr>
<td>2002</td>
<td>64.4</td>
<td>67.1</td>
</tr>
<tr>
<td>2003</td>
<td>45.0</td>
<td>62.5</td>
</tr>
<tr>
<td>2004</td>
<td>55.6</td>
<td>71.9</td>
</tr>
<tr>
<td>2005</td>
<td>50.6</td>
<td>67.83</td>
</tr>
<tr>
<td>2006</td>
<td>70.8</td>
<td>69.66667</td>
</tr>
<tr>
<td>2007</td>
<td>68</td>
<td>65.83333</td>
</tr>
<tr>
<td>2008</td>
<td>70.3</td>
<td>72.58333</td>
</tr>
<tr>
<td>2009</td>
<td>50</td>
<td>60</td>
</tr>
<tr>
<td>MEAN</td>
<td>60.2</td>
<td>67.5</td>
</tr>
</tbody>
</table>

NTP achieves continuous complete nitrification during certain periods consistently meeting desired effluent limits. In spite of this, NTP has also experienced unexplained sporadic nitrification upsets for a number of years when compared to the VIP plant (Figure 4.3 and 4.4) and some indication of continuous nitrification inhibition, as demonstrated by calibration of a process simulation model to historical plant performance data. The previous target total nitrogen (TN) treatment objective was 12 mg/L on a seasonal basis. This has changed more recently to a permitted limit of 8 mg/L TN on an annual average basis (Bilyk et al., 2008).
Figure 4.3 NTP Historical Effluent Ammonia, NOx-N, and Total Nitrogen Profile 2000-2009 (Lines represent 30-day rolling averages).

Figure 4.4 VIP Historical Effluent Ammonia, NOx-N, and Total Nitrogen Profile 2001-2009 (Lines represent 30-day rolling averages).
In addition the plant also experienced regular biological phosphorus removal upsets (Figure 4.5) which forced NTP to add large quantities of ferric chloride to avoid permit violations for effluent TP (Bilyk et al., 2008). It was the goal of NTP to meet a treatment objective of 1 mg/L of total phosphorus (TP) on an annual average basis (Bilyk et al., 2008).

![Graph: NTP Historical Effluent TP and Ferric Chloride Addition 2000-2009](image)

This presented an issue as NTP along with other treatment facilities which discharge to the James River are required starting in 2011 to meet a combined annual discharge limit of 6 million pounds of total nitrogen (TN) (Balzer et al., 2005). Investigation as to possible contributors of nitrification inhibition has attributed the sources including industrial discharges (hog processing plant or landfill leachate) and truck-delivered waste received at the facility septage, grease, and chemical toilet waste. NTP receives large quantities of chemical toilet waste that are discharged to the plant in slug doses via tank truck to the septage receiving station (see
Tables 4.4 and 4.5). It was hypothesized that the quaternary ammonium compounds (QACs) contained in this chemical toilet waste could be a possible source for the sporadic nitrification inhibition that is experienced at the NTP.

Quaternary ammonium compounds (QACs) or quaternary ammonium salts (quaternary ammines) are salts of quaternary ammonium cations with a coordinating anion (e.g. chloride). They are organic compounds that contain four functional groups attached covalently to a positively charged central nitrogen atom (R₄N⁺). These functional groups (R) include at least one long chain alkyl group, and the rest are either methyl or benzyl groups. QACs are extensively used in domestic and industrial applications as surfactants, emulsifiers, fabric softeners, disinfectants and corrosion inhibitors (Tezel et al, 2007). QACs are of importance because it has been determined that acute inhibition of both heterotrophic COD removal and nitrification, especially the nitrite oxidation process, can be inhibited at high concentrations (Kreuzinger et al, 2007).

In order to meet future permit limits NTP is currently being upgraded to a 5-stage Bardenpho process (Figure 4.6). This will increase aeration volume/capacity and enhance both nitrification and Bio-P removal. The new upgrades will also incorporate a full-scale proprietary technology developed by Ostara that uses a fluidized bed reactor to recover phosphorus and ammonia through struvite precipitation from the centrate being generated at NTP. The harvested struvite can then be utilized as a slow release fertilizer (Ostara, 2007).
A preliminary engineering report by Hazen and Sawyer, P.C. for the current nutrient removal upgrade, suggested that the ammonia oxidizing bacteria (AOB) maximum specific growth rate ($\mu_{\text{max, AOB}}$) be reduced from the default value of 0.90 days$^{-1}$ to 0.57 days$^{-1}$ to account for high effluent ammonia data during the calibration period (Hazen & Sawyer, 2007). This has significant implications in terms of the required aeration volume for consistent nitrification at cold temperatures. It was originally assumed that NTP would nitrify year-round with this background inhibition. This would only be made possible however, by reconfiguring the BNR process to allow the 2$^{\text{nd}}$ anoxic zone to operate aerobically (swing zone). Removing an anoxic zone would reduce overall TN removal because the process would essentially change from the 5-stage Bardenpho process to an A2O Process. If the inhibition can be eliminated then there would...
no longer be a need to configure the 2\textsuperscript{nd} anoxic zone to run aerobic in cold temperature conditions, providing improved annual average TN removal. This would ensure that NTP and the other James River HRSD facilities meet the TN bubble permit limit with more certainty. The objectives of this study were the following:

- Establish the inhibitory characteristics of the NTP influent wastewater by bench-scale experiments independently evaluating ammonia oxidizing bacteria (AOB) and nitrite oxidizing bacteria (NOB) rates.
- Study and evaluate possible sources of inhibition from the industrial loads and chemical toilet waste received suspected of containing QACs and their affect on nitrification kinetics.

4.2 Methodology

4.2.1 Sample Collection

Batch reactor experiments were conducted by collecting biomass samples from the aeration basin effluent of several full-scale wastewater treatment plants. Grab samples were collected unless otherwise arranged with HRSD to collect composites. All samples were collected and stored in polypropylene carboys or similar containers. These samples were then transported to the lab and stored until use with continuous aeration for no longer than approximately 48 hours at room temperature. Biomass samples were collected from NTP; the HRSD VIP plant, which uses the same BNR process as NTP but does not experience inhibition; the Henrico County WWTP, which has a fully nitrifying 5-stage BNR process; and the HRSD York River plant from the sequencing batch reactor system.

Wastewater sources for experiments were also collected via grab sample or composite sampling by HRSD based on the source being tested. Wastewater samples were collected
including NTP and VIP primary effluent (PE); NTP and VIP secondary effluent (SE); raw wastewater from isolated branches of the NTP collection system; and industrial waste samples from a hog processing plant and a landfill leachate stream. Waste samples were also tested from other suspected sources such as chemical toilet disinfectants (quaternary ammonium compounds).

4.2.2 Batch Reactor Construction

Four parallel batch reactors were constructed of plexiglass and configured with vinyl and polypropylene fittings and appurtenances. The first reactor served as the control while operating conditions of the other three reactors were varied. Each reactor had a volume of 3 liters with individual ports for sampling and chemical addition (acetate, ammonia, nitrite, and phosphate) during experiments as needed. A diffuser stone was incorporated into each reactor to provide air/oxygen or nitrogen based on the experiment. This allowed the reactors to be operated under aerobic, anoxic, or anaerobic conditions for nitrification, denitrification, and phosphorus release/uptake measurements. The reactors were configured to be air tight with a water seal on the headspace for anaerobic conditions. Mixing was provided through magnetic stir-bars and stir plates. Dissolved oxygen (DO) was kept constant using HACH LDO probes with HQ40d meters. Two probes were connected to a single HQ40d meter (total of four probes and two meters). National Instruments LabView 7.0 DO Controller was used to provide on and off control of four solenoid air supply valves with associated relays. pH was controlled and logged using Cole-Parmer pH meters/controllers connected to acid (1M H₂SO₄) and base (3M Na₂CO₃) pumps. The reactors were placed in a water bath with a circulating chiller and immersion heaters to maintain a constant temperature during experiments. Refer to Figure 4.7, 4.8, and 4.9 for a schematic and
image of an individual reactor and for a complete schematic and image of the entire reactor configuration.

Figure 4.7 Reactor Schematic and Image

Figure 4.8 Complete Reactor System Schematic
4.2.3 Batch Reactor Operation

Experiments consisted of the evaluation AOB, NOB, and Bio-P activity. The method for evaluating each type of experiment is discussed further in subsequent sections. Temperature for experiments was based on the temperature of the biomass sample when it was collected onsite via grab sample. The matrix of experiments developed and completed is summarized in Table 4.2.
### Table 4.2 Batch Experiment Matrix

<table>
<thead>
<tr>
<th>Week #</th>
<th>Biomass Source</th>
<th>Diluents</th>
<th>Experiments</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Nansemond</td>
<td>a. NTP/PE</td>
<td>b. VIP/PE</td>
</tr>
<tr>
<td></td>
<td>VIP</td>
<td>c. VIP/PE</td>
<td>d. NTP/PE</td>
</tr>
<tr>
<td>2</td>
<td>Nansemond</td>
<td>a. NTP/PE</td>
<td>b. VIP/PE</td>
</tr>
<tr>
<td></td>
<td>VIP</td>
<td>c. VIP/PE</td>
<td>d. NTP/PE</td>
</tr>
<tr>
<td>3</td>
<td>Nansemond</td>
<td>a. VIP/SE + Leachate</td>
<td>b. VIP/SE</td>
</tr>
<tr>
<td></td>
<td>VIP</td>
<td>c. VIP/SE + Leachate</td>
<td>d. VIP/SE</td>
</tr>
<tr>
<td>4</td>
<td>Nansemond</td>
<td>a. NTP/PE</td>
<td>b. HR/PE</td>
</tr>
<tr>
<td>Henrico</td>
<td></td>
<td>c. HR/PE</td>
<td>d. NTP/PE</td>
</tr>
<tr>
<td>5</td>
<td>Nansemond</td>
<td>a. VIP/SE + Hog Plant</td>
<td>b. VIP/SE</td>
</tr>
<tr>
<td></td>
<td>VIP</td>
<td>c. VIP/SE + Hog Plant</td>
<td>d. VIP/SE</td>
</tr>
<tr>
<td>6</td>
<td>Nansemond</td>
<td>a. VIP/SE + Leachate</td>
<td>b. VIP/SE</td>
</tr>
<tr>
<td></td>
<td>VIP</td>
<td>c. VIP/SE + Leachate</td>
<td>d. VIP/SE</td>
</tr>
<tr>
<td>7</td>
<td>Nansemond</td>
<td>a. VIP/SE</td>
<td>b. VIP/SE + Branch 1</td>
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<tr>
<td></td>
<td>VIP</td>
<td>c. VIP/SE + Branch 2</td>
<td>d. VIP/SE + Branch 3</td>
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<td>Nansemond</td>
<td>a. VIP/SE</td>
<td>b. VIP/SE + Branch 2a</td>
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<tr>
<td></td>
<td>VIP</td>
<td>c. VIP/SE + Branch 2b</td>
<td>d. VIP/SE + Branch 3</td>
</tr>
<tr>
<td>9</td>
<td>Nansemond</td>
<td>a. VIP/SE</td>
<td>b. VIP/SE + Cedar Ln PS</td>
</tr>
<tr>
<td></td>
<td>VIP</td>
<td>c. VIP/SE + Gum Rd. PRS</td>
<td>d. VIP/SE + Pughsville PRS</td>
</tr>
<tr>
<td>10</td>
<td>Nansemond</td>
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<td>b. NTP RWI</td>
</tr>
<tr>
<td></td>
<td>VIP</td>
<td>c. NTP PCI</td>
<td>d. NTP PCE</td>
</tr>
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<td>11</td>
<td>Nansemond</td>
<td>a. VIP/SE</td>
<td>b. VIP/SE + 20 mg/L Fe</td>
</tr>
<tr>
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<td>VIP</td>
<td>c. VIP/SE + 35 mg/L Fe</td>
<td>d. VIP/SE + 50 mg/L Fe</td>
</tr>
<tr>
<td>12</td>
<td>Nansemond</td>
<td>a. VIP/SE</td>
<td>b. VIP/SE + 20 mg/L Fe</td>
</tr>
<tr>
<td></td>
<td>VIP</td>
<td>c. VIP/SE + 35 mg/L Fe</td>
<td>d. VIP/SE + 50 mg/L Fe</td>
</tr>
<tr>
<td>13</td>
<td>York River (YR)</td>
<td>a. YR/SE</td>
<td>b. YR/SE + 20 mg/L Fe</td>
</tr>
<tr>
<td></td>
<td>York River (YR)</td>
<td>c. YR/SE + 35 mg/L Fe</td>
<td>d. YR/SE + 50 mg/L Fe</td>
</tr>
<tr>
<td>14</td>
<td>York River (YR)</td>
<td>a. YR/PE</td>
<td>b. NTP RWI</td>
</tr>
<tr>
<td></td>
<td>York River (YR)</td>
<td>c. NTP PCI</td>
<td>d. NTP PCE</td>
</tr>
<tr>
<td>15</td>
<td>York River (YR)</td>
<td>a. YR/SE</td>
<td>b. YR/SE + 0.574 mL Chem Toilet Additive*</td>
</tr>
<tr>
<td>York River (YR) &amp; York River (YR) (YR)</td>
<td>c. YR/SE + 13.96 mL Chem Toilet Additive*</td>
<td>d. YR/SE + 62.84 mL Chem Toilet Additive*</td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>York River (YR)</td>
<td>e. YR Mixed Liquor (ML)</td>
<td>f. YR ML + 15 mL Product B</td>
</tr>
<tr>
<td>York River (YR) &amp; York River (YR) (YR)</td>
<td>g. YR ML + 30 mL Product B</td>
<td>h. YR ML + 60 mL Product B</td>
<td></td>
</tr>
<tr>
<td>17</td>
<td>York River (YR)</td>
<td>e. YR Mixed Liquor (ML)</td>
<td>f. YR ML + 60 mL Product B</td>
</tr>
<tr>
<td>York River (YR) &amp; York River (YR) (YR)</td>
<td>g. YR ML + 120 mL Product B</td>
<td>h. YR ML + 180 mL Product B</td>
<td></td>
</tr>
</tbody>
</table>

*NOTE: Week 15 Experiments – Two different Chemical Toilet Disinfectants (Product A & B) used for the two different days of experiments.

**Table Abbreviations:**

- NTP – Nansemond Treatment Plant
- VIP – Virginia Initiative Process Treatment Plant
- HR – Henrico County Treatment Plant
- YR – York River Treatment Plant
- PE – Primary Effluent
- SE – Secondary Effluent
- ML – Mixed Liquor
- RWI – Raw wastewater influent
4.2.3.1 AOB Experiments

AOB activity was evaluated by spiking the reactors with ammonia and monitoring NO$_x$-N and NO$_3$-N generation rate over three hours (Kelly et al, 2004). During an AOB experiment the collected biomass was concentrated to approximately 8000 mg/L MLSS prior to experiments. Then the reactor was filled 1/3 by volume with biomass and 2/3 by volume with a diluent (primary effluent, waste sample, etc.). Additional ammonia was added to achieve a total ammonia concentration of approximately 40 mg/L NH$_4$-N to provide sufficient ammonia during experiments to prevent depletion. Dissolved oxygen (DO) and pH were constantly monitored and maintained within desired limits using online control systems. DO was maintained between 5-7 mg/L during experiments with a pH between 7.0-7.2. Each AOB experiment was conducted for 3 hours with 5 samples collected evenly throughout this period of time. Samples were immediately filtered through 0.45μm membrane filters after collection. AOB activity was based on NO$_x$-N generation rate.

4.2.3.2 NOB Experiments

NOB activity was assessed by adding in nitrite (ensuring ammonia concentrations were low) and monitoring the rate of NO$_2$-N depletion and NO$_3$-N generation. NOB experiments was conducted very similar except after the reactors were filled by volume as mentioned above they were aerated for approximately one hour to allow uptake of any residual ammonia. Samples were taken prior to starting the NOB Experiments and analyzed for NH$_4$-N to ensure that the ammonia concentration in each reactor was <1 mg/L NH$_4$-N (detection limit of HACH TNT 831 NH$_4$-N analysis method). After it was determined that the ammonia concentration in each reactor was depleted, approximately 25 mg/L NO$_2$-N was added, and then 5 samples were collected evenly
over a 3 hour test period. Samples were immediately filtered through 0.45μm membrane filters after collection. DO and pH were maintained within the same parameters as was used for the AOB experiment. NOB activity was based on NO₃-N generation rate and NO₂-N uptake rate.

### 4.2.3.3 Bio-P Experiments

Bio-P activity was determined by monitoring P uptake and release rates. Experiments were conducted using the same concentrated biomass as in the AOB & NOB experiments (~8000 mg/L MLSS). Experiments were conducted in three phases: uptake, release, and a second uptake. During the first uptake (aerobic) phase, each reactor was filled with 1/3 by volume of biomass and 2/3 by volume of PE or another tested wastewater source. Then each reactor was spiked with 5 mg/L of PO₄-P to reach a target of 20 mg/L P in each reactor since it was presumed approximately 15 mg/L of PO₄-P would be present from the biomass and PE/wastewater sample. The first uptake phase was conducted for 1-2 hours and 3 samples were collected during this time with immediate filtration using 0.45μm membrane filters. During both uptake phases, pH was always controlled between 7.0-7.2 while the DO was maintained between 5-7 mg/L. After this initial uptake phase, the reactors were deaerated by sparging nitrogen (N₂) gas and reducing the DO to 0 mg/L which was maintained throughout the release phase. After the DO was reduced to 0 mg/L, each reactor was spiked with 200 mg/L acetate as COD. It was desired to have all NO₃-N and NO₂-N depleted, but this was not always the case. pH was controlled the same as in the uptake phase experiment and 5 samples were collected over a 1 hour period with immediate filtration using 0.45μm membrane filters. After the 1 hour release phase nitrogen was shut-off and then air/oxygen was sparged into the reactors to once again raise the DO and maintain the DO between 5-7 mg/L. As soon as the air/oxygen sparge began, 5 samples were collected over a 1-2 hour period with immediate filtration using 0.45μm membrane filters. All the samples from
both uptake phases and the release phase were analyzed using the same methods used for the AOB and NOB experiments noted in the subsequent 3.3 Analytical Methods section. Rates based on PO₄-P release and uptake was normalized to MLVSS concentrations for each experiment.

All experiments was conducted in this manner except for that conducted during weeks 16 & 17, during which the entire reactor volume was filled with biomass due to the biomass from the York River plant at that time being very dilute.

4.2.4 Analytical Methods

Samples were analyzed for NH₄-N, NO₂-N, NO₃-N, and PO₄-P using HACH colorimetric test kits, ion chromatography (IC), and flow injection analysis (FIA) (see subsections 3.3.3, 3.3.6, 3.3.7, 3.3.8). MLSS and MLVSS were performed at the end of the experiments per Standard Methods (APHA et al., 1998). Nitrate production rates, phosphorus uptake and release rates were calculated by normalizing the slope of each chemical constituent by the MLVSS. Normalizing the slope refers to the calculated slope being divided by the mixed liquor volatile suspended solids and converted into the appropriate units of mg/g MLVSS/hr.

4.2.4.1 Ammonia (NH₃-N) HACH Test Kit

Ammonia was analyzed using HACH Test N’ Tube (TNT) 831 kit and HACH DR2800 spectrophotometer. This method uses the salicylate method, whereby ammonium ions react with hypochlorite and salicylate ions in the presence of sodium nitroprusside to as a catalyst form indophenol. The amount of color formed is directly proportional to the ammonia nitrogen present.

4.2.4.2 Nitrate (NO₃-N) HACH Test Kit
Nitrate was analyzed using HACH TNT 835 kit. This kit incorporates the dimethylphenol method where nitrate ions in solution with sulfuric and phosphoric acids react with 2,6-dimethyphenol to form 4-nitro-2,6-dimethyphenol.

4.2.4.3 Nitrite (NO$_2$-N) HACH Test Kit

Nitrite was analyzed using NitriVer3 Nitrite Reagent Powder Pillows and 10 mL sample vials. This kit uses the diazotization method where nitrite in the sample reacts with sulfanilic acid to form a intermediate diazonium salt. This salt combined with chromotropic acid forms a pink color which is directly proportional to the amount of nitrite present.

4.2.4.4 Ortho-Phosphate (PO$_4$-P) HACH Test Kit

Ortho-Phosphate was analyzed using the HACH Reactive Phosphate TNT Reagent Kit. The kit analyzed 5 mL of sample in a vial. This test kit uses the USEPA PhosVer3 method where orthophosphate reacts with molybdate in an acid to produce a mixed complex. Ascorbic acid then reduces this complex, producing an intense blue color.

4.2.4.5 Ion Chromatography

IC analysis was conducted for measuring nitrate only for the batch experiments work. The IC was used in conjunction with conductivity detection (Dionex ICS-1000), an AS14A analytical column and AG14A guard column, an ASRS conductivity suppressor, and an eluent flow of 1.0 mL/min of 1.0 mM NaHCO$_3$ and 8.0 mM Na$_2$CO$_3$.

4.2.4.6 Flow Injection Analysis

FIA was conducted for measuring nitrite, nitrate, and phosphate for batch experiments work using a SEAL Analytics auto-analyzer system. FIA analysis incorporated a volume of 2 mL of sample in sample vials and placed into a sample tray. The tray was then placed into the FIA instrument along with various reagents required for the different analyte test methods. A schedule was then configured using the associated computer software with the instrument and
analyzed. QA/QC samples were measured every 10 samples and test methods were always standardized prior to analysis of actual samples. Data output was provided in concentrations in mg/L as NO₂-N, NO₃-N, and PO₄-P.

4.3 Results and Discussion

4.3.1 AOB and NOB Batch Rate Results

AOB and NOB kinetics were independently evaluated based on NOx-N production (AOB), NO₃-N production (NOB), and NO₂-N consumption rates (NOB). These rates were calculated based on a linear regression of the change in nitrogen species concentration over the experimental period (Figure 4.10). These slopes were divided by the mixed liquor volatile suspended solids (MLVSS) to normalize the rate to the biomass concentration, referred to here as the “specific” rate. The representative experiment shown below in Figure 4.10 plots the measured nitrogen species, NH₄-N, NO₂-N, NO₃-N, NOₓ-N (NO₂-N + NO₃-N), versus time. Batch experiments were conducted for a total of 17 weeks. Results from the initial batch-rate testing (Weeks 1-4) confirmed the inhibitory characteristics of NTP wastewater. Whenever NTP wastewater was combined with a stable nitrifying biomass there was an observed decrease in NOₓ-N production, nitrate production, and nitrite consumption rates (Figure 4.11).
Figure 4.10 Representative Experiment – a. AOB experiment, b. NOB experiment

The data presented from the Week 4 experiment showed some inhibition when the Henrico County (HR) WWTP biomass (control) was combined with NTP PE compared to HR
PE. Although this was true, evaluation of the 95% confidence intervals between the regression slopes revealed that it was not statistically significant as only five data points were collected. This did not provide enough data points to evaluate the regression slopes, but data such as that presented in Figure 4.11 was repeatedly seen through multiple experiments. This being the case, it was determined that NTP PE exhibited some inhibitory characteristics. When NTP biomass was combined with HR PE there was little observed improvement in AOB and NOB activity, likely because the NTP biomass had already been exposed to some degree of inhibition.

![Inhibition of AOB and NOB from Control to Stressed Reactor.](image)

**Figure 4.11** Comparisons of AOB & NOB Rates with Control (Week 4 – NTP and Henrico County). (Error bars represent the 95% confidence interval of the regression slope.)

There were several suspected wastewater sources were tested (Table 4.4). Initial testing of inhibitors was for the waste received from a hog processing facility and leachate from a landfill. Results from the testing of both wastewater sources provided no significant differences in AOB and NOB activity compared to the control (Figure 4.12 and 4.13). This was determined
based on the difference between the 95% confidence intervals of the regression slopes. Since only five data points were collected during the experiments, the error in the slopes were much greater; however, through multiple experiments of other wastewater sources similar results were observed. This supported that there was no significant difference in AOB and NOB activity from these suspected sources of inhibition. It should be noted that experiments on both of these waste streams were repeated producing similar results. In testing the two waste streams, biomass from the VIP plant was used as the control to compare to the performance of NTP biomass.

Figure 4.12 Hog Processing Plant Rate Comparison.
(Error bars represent the 95% confidence interval of the regression slope.)
Experiments with other wastewater sources generated similar results as the landfill leachate and hog processing plant. There were no significant signs of inhibition from any of the tested waste streams listed in Table 4.2 based on similar results from multiple experiments, in spite of the lack of difference in the 95% confidence interval of the slopes.

Week 14 experiments were conducted to evaluate the impact of internal recycle streams within NTP. The tested sources included the raw wastewater influent (RWI), primary clarifier influent (PCI), and primary clarifier effluent (PCE). The tested samples were composite samples collected over a four day period (Monday – Thursday) by HRSD. Two duplicate AOB experiments were conducted for each day of composite sample to examine \( \text{NO}_x\text{-N} \) (\( \text{NO}_2\text{-N} + \text{NO}_3\text{-N} \)) and \( \text{NO}_3\text{-N} \) generation for a total of eight experiments (Figure 4.14). Some mild signs of inhibition were observed between the control and other reactors. The changes in AOB rates between the different tested sources (RWI, PCI, PCE) however, were not significantly different.
This suggested that the inhibitory source was in the plant raw influent and not an internal recycle stream issue. Graphical representation suggested that the York River Biomass was affected negatively by the addition of the Nansemond RWI when compared to the Nansemond PCI and PCE. For this reason a linear regression was performed on the NOx-N rate for one of the days to examine the 95% confidence in the slopes from the different reactors (Table 4.3). The highlighted values represent the 95% confidence interval on the regression slopes between Reactor A (York River Biomass & York River PE) and Reactor B (York River Biomass & Nansemond RWI). The results suggested that the differences in slopes were not statistically different at the 95% confidence level, but were very close to this limit. This inferred that it may not have been a recycle stream issue, but it could have been an insignificant amount of truck delivered septage or grease received during the sampling week.

![Figure 4.14 AOB Comparisons for Composite Samples of NTP Internal Recycle Streams (Week 14). (Error bars represent the 95% confidence interval of the regression slope.)](image-url)
Table 4.3 Linear Regression for Calculation of 95% Confidence

<table>
<thead>
<tr>
<th>Reactor</th>
<th>Lower 95%</th>
<th>Slope (Regression)</th>
<th>Upper 95%</th>
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<td><strong>MONDAY COMPOSITE SAMPLE</strong></td>
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<td></td>
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</tr>
<tr>
<td>A</td>
<td>0.0544</td>
<td>0.0593</td>
<td>0.0643</td>
</tr>
<tr>
<td>B</td>
<td>0.0334</td>
<td>0.0457</td>
<td>0.0579</td>
</tr>
<tr>
<td>C</td>
<td>0.0371</td>
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<td>0.0643</td>
</tr>
<tr>
<td>D</td>
<td>0.0449</td>
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<table>
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<tr>
<td><strong>TUESDAY COMPOSITE SAMPLE</strong></td>
<td></td>
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</tr>
<tr>
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<th>Slope (Regression)</th>
<th>Upper 95%</th>
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<tr>
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<td>0.0335</td>
<td>0.0384</td>
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<tr>
<td>D</td>
<td>0.0309</td>
<td>0.0387</td>
<td>0.0465</td>
</tr>
</tbody>
</table>

4.3.2 Bio-P Batch Rate Results

Bio-P experiments were only conducted in conjunction with AOB and NOB experiments for four of the seventeen weeks. Bio-P experiments generated varied results. The varied results can be attributed to the fact that NTP was recovering from Bio-P upsets (FeCl₃ addition) when samples were collected. There was a noticeable effect on Bio-P performance of other biomass sources when combined with NTP PE. It was observed that when a stable biomass, in this case
VIP biomass, was combined with NTP PE there was a small decrease in phosphate uptake rate (Figure 4.15).

Figure 4.15 Bio-P Experiment with NTP and VIP Biomass and Primary Effluent. (Error bars represent the 95% confidence interval of the regression slope.)

In some cases when biomass samples were collected ferric chloride was being added to assist in phosphorus removal at NTP. For this reason experiments were also conducted examining varying ferric chloride concentrations on nitrification (Figure 4.16 and 4.17).

Experiments with ferric chloride addition were conducted for a total of three weeks (Week 11, 12, and 13). Week 11 and 12 were carried out using VIP biomass and week 13 using York River biomass. With appropriate control of pH after Fe\(^{3+}\) addition, there were no significant changes between the different concentrations of ferric chloride added (as Fe\(^{3+}\)). This suggested that there was no impact of ferric chloride addition on nitrification rates for both AOB and NOB, even at very high concentrations.
Figure 4.16 AOB Comparison with Ferric Chloride Addition (Week 13). (Error bars represent the 95% confidence interval of the regression slope. 20, 35, and 50 = mg/L as Fe$^{3+}$ added to each reactor.)

Figure 4.17 NOB Comparisons with Ferric Chloride Addition (Week 13). (Error bars represent the 95% confidence interval of the regression slope. 20, 35, and 50 = mg/L as Fe$^{3+}$ added to each reactor.)
4.3.3 QAC Batch Rate Testing

Three experiments were performed examining chemical toilet disinfectants suspected of containing QACs. Two different chemical toilet disinfectants were used for testing, Product A and Product B; however, Product A was found to contain no QACs. Various assumptions were made when determining concentrations of chemical toilet disinfectant to add to each stressed reactor. Based on the large quantity of chemical toilet waste delivered to NTP (Table 4.4 and 4.5) it was decided to use three different assumptions for calculating experiment doses.

1. NTP received trucked waste deliveries all during one month of the year, Monday – Friday only, during the normal 8 hour workday.

2. NTP received waste during two months of the summer and received the waste over 40 days, Monday – Friday, in 5 hour periods throughout the 8 hour workday.

3. NTP received waste during summer months (June, July, August) when use of portable toilets was at a peak, receiving the waste over 60 days in 6 hour periods throughout the 8 hour workday.

Table 4.4 Septage Waste Received for Several HRSD WWTPs

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Atlantic</td>
<td>501,937</td>
<td>560,258</td>
<td>1,885,655</td>
<td>40</td>
<td>1,535</td>
<td>5,166</td>
</tr>
<tr>
<td>Boat Harbor</td>
<td>90,762</td>
<td>852,656</td>
<td>1,618,515</td>
<td>14.9</td>
<td>2,336</td>
<td>4,434</td>
</tr>
<tr>
<td>Chesapeake-Elizabeth</td>
<td>454,906</td>
<td>369,426</td>
<td>1,284,278</td>
<td>13.2</td>
<td>1,012</td>
<td>3,519</td>
</tr>
<tr>
<td>Nansemond</td>
<td>1,800,999</td>
<td>1,291,602</td>
<td>4,427,292</td>
<td>18.5</td>
<td>3,539</td>
<td>12,130</td>
</tr>
<tr>
<td>Williamsburg</td>
<td>1,549,416</td>
<td>272,326</td>
<td>4,000,171</td>
<td>15.7</td>
<td>746</td>
<td>10,959</td>
</tr>
<tr>
<td>York River</td>
<td>2,592,031</td>
<td>76,418</td>
<td>2,730,400</td>
<td>12.9</td>
<td>209</td>
<td>7,481</td>
</tr>
</tbody>
</table>

Table 4.5 Septage Waste Received as a Fraction of Average Daily Plant Flow

<table>
<thead>
<tr>
<th>WWTP Loading Highest to Lowest</th>
<th>Chemical Toilet Waste [gallons/day]</th>
<th>Chemical Toilet Waste [% Avg Day Flow]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nansemond</td>
<td>3,539</td>
<td>0.019</td>
</tr>
<tr>
<td>Boat Harbor</td>
<td>2,336</td>
<td>0.016</td>
</tr>
<tr>
<td>Chesapeake-Elizabeth</td>
<td>1,012</td>
<td>0.008</td>
</tr>
<tr>
<td>Williamsburg</td>
<td>746</td>
<td>0.005</td>
</tr>
<tr>
<td>Atlantic</td>
<td>3,535</td>
<td>0.004</td>
</tr>
<tr>
<td>York River</td>
<td>209</td>
<td>0.002</td>
</tr>
</tbody>
</table>
Results from the experiments showed no significant signs of inhibition or variability in concentration of Product A (Figure 4.18).

![Figure 4.18 QAC Experiment with Product A (Week 15). (Error bars represent the 95% confidence interval of the regression slope. 0.574, 14, 63 = mL of Product A added to reactor.)](image)

It was observed in Product B experiments containing QACs, that there was a mild reduction in NOB activity at higher concentrations (Figure 4.19). This was true for the first day of experiments, but was not replicated in the second day of experiments. The decrease in NOB activity however, was consistent with literature which suggested that NOB exhibit greatest inhibition in response to QAC loading (Kreuzinger et al, 2007). Therefore it was proposed that Product B at higher concentrations may cause some inhibition of nitrification.
Further experiments in the later two weeks (week 16 and 17) using Product B generated different results from week 15 experiments. It was desired in these experiments to use Product B at higher concentrations to show more significant inhibition of NOB or some reduction in AOB rates. Results however, from week 16 and 17 showed very slight inhibition in rates at higher concentrations, but with AOB and not NOB rates (Figure 4.20). In some cases performance was better or similar with the addition of QACs.
Figure 4.20 Experiments with Chemical Toilet Additive containing QACs (Week 16). (Error bars represent the 95% confidence interval of the regression slope. 15, 30, and 60 = mL of Product B added to reactor.)

4.4 Conclusion

Based on the batch experiments, no significant inhibitor was identified as the cause of sporadic nitrification problems at NTP; the batch-rate testing did show that NTP PE was consistently inhibitory on a seemingly continuous basis. The H&S model calibration based on historical plant data suggested a reduction in AOB $\mu_{max}$ from 0.9 days$^{-1}$ to 0.57 days$^{-1}$, which supported the finding that there was some degree of continuous inhibition. It was also determined that wastewater derived from the hog processing plant and the previously suspected landfill leachate did not cause inhibition of nitrification or bio-P at least at the time the samples were collected. This does not exclude the possibility of an upset or unusual shock load event at one of these industries impacting nitrification at NTP. Evaluation of the various wastewater sources provided an opportunity to study each source independently and its inhibitory
characteristics on both AOB and NOB activity. Although there were large margins of error for some of the tests based on the 95% confidence interval of the regression slopes, data generated from the repeated experiments suggested similar findings. It was also determined that batch experiments were not sufficient to determine the source of sporadic inhibition. For this reason it was planned to reconfigure the bench-scale experiments to continuous sequencing batch reactors (SBRs) which would be run in parallel to the full-scale plant.

4.5 References


Boethling, R.S. 1984 Environmental fate and toxicity in wastewater treatment of quaternary ammonium surfactants, Water Research, 18 (9), 1061–1076.


Abstract

During the initial upgrades to the Nansemond Treatment Plant (NTP), nitrification was maintained; however, due to available blower capacity during construction it was planned that nitrification would not be maintained during the fall of 2009. In an effort to stop nitrification, the solids retention time (SRT) was purposely reduced over a period of about one month (as wastewater temperature cooled) until additional blower capacity was available. This provided an excellent opportunity to study baseline nitrification kinetics and to evaluate the presence of a source of continuous inhibition. This involved profile sampling via grab samples along the biological nutrient removal (BNR) process starting from the primary effluent to secondary effluent. Samples were immediately filtered upon collection and analyzed on-site for ammonia, nitrite, nitrate, and orthophosphate. Profile sampling was conducted until the plant completely ceased nitrifying in the fall of 2009. The profile sampling data were modeled using Biowin 3.1 (EnviroSim, Ltd.). Using plant performance data, a calibrated dynamic model was generated over the period of profile samples. These simulations were then compared to data collected during the profile sampling to better estimate the level of continuous nitrification inhibition. Results from the profile sampling showed no apparent indication of sporadic nitrification inhibition. Evaluation of the BNR process also demonstrated that there was little impact on nitrification from nitrite accumulation or sporadic addition of ferric chloride. Modeling of the profile data generated similar profiles; however, there were slight variations as the model predicted nitrification to stop earlier than what was observed. From the modeling, it was also
estimated that the maximum specific growth rate ($\mu_{max}$) of ammonia oxidizing bacteria (AOB) was approximately in the range of 0.50 – 0.60 days$^{-1}$, similar to the design value of 0.57d$^{-1}$.

5.1 Introduction

An initial investigation of nitrification inhibition was conducted at the Nansemond Treatment Plant (NTP) using bench-scale batch reactor experiments to confirm inhibition of nitrification and then identify possible sources of inhibition in the summer 2008 to summer 2009 (Yi et al., 2010). Through several weeks of batch experiments testing of various industrial sources (hog processing plant and landfill leachate), plant recycle streams, ferric chloride addition, and quaternary ammonium compounds (QACs) was conducted. Batch reactors were used to evaluate nitrification kinetics, both AOB and NOB independently; however, identification of an inhibitor for the nitrification was still inconclusive. NTP was undergoing upgrades from a 3-stage VIP process to a 5-stage Bardenpho process to achieve more stringent nutrient limits. During the initial upgrades to the facility, nitrification was maintained; however, due to available blower capacity during construction it was planned that nitrification would not be maintained during the fall of 2009. In an effort to stop nitrification, the solids retention time (SRT) was purposely reduced over a period of about one month (as wastewater temperature cooled) until additional blower capacity was available. This coincided with the profile sampling creating an opportunity to study nitrification kinetics as the plant stopped nitrifying.

NTP began operations as a 10 mgd secondary treatment plant in 1983. Expansions and upgrades were completed in May 1998, which converted the facility into a 30 mgd BNR facility. Since the upgrade the facility has experienced mixed success in the BNR mode (Balzer et al., 2005). This determination was based upon the plant’s efficiency in removing nitrogen. The VIP plant in Norfolk, VA which also employs the VIP process began BNR operations approximately
seven (7) years prior to similar Nansemond operations (Balzer et al., 2005). Nitrogen removal was similar at both facilities during the first two years of side-by-side operation (1999 & 2000) (Balzer et al., 2005). Nansemond experienced an unexpected decline in nitrogen removal efficiency starting in 2001 which has continued to the present (Balzer et al., 2005). This deficiency in performance has been variable and has not been consistent from 2001 to the present time.

Profile sampling of wastewater treatment plants provides an effective method for evaluating the performance of a BNR processes by sampling for species such as ammonia, nitrate, nitrite, orthophosphate, soluble COD, etc. through the treatment train. Profiles are most commonly incorporated with DO and nutrient profiles (NH$_3$-N, NO$_3$-N, etc.), but can be applied to different applications; examining different bacterial activities in a treatment process. Profile sampling is often used in conjunction with modeling work and evaluating existing and future nutrient removal processes (Kochany et al, 2007; Scott et al, 2008; Kim et al, 2009).

The profile sampling data were combined with plant operating data and modeled using Biowin 3.1 (EnviroSim, Ltd.). The profile sampling period (7-23-09 to 11-5-09) was divided into 5 separate periods to generate a calibrated model. The modeling for four of the periods was first performed in steady-state conditions. The period in which NTP stopped nitrifying had to be calibrated with a dynamic model. A calibrated simulation was then generated over the entire period of profile samples. These simulations were compared to data collected during the profile sampling to better understand the level of continuous nitrification inhibition.

The purpose of the baseline profile sampling and modeling was to address the following issues:

- Conduct baseline sampling prior to the more detailed nitrification inhibition study estimated to begin in March 2010, which will include influent sampling and the
operation of bench-scale sequencing batch reactors. This will be used to establish “normal” COD, nutrient and DO profiles though the VIP process without (and possibly with) the impact of inhibitory conditions, specifically with respect to N conversions and P release and uptake along the process.

- Evaluate the potential for nitrite accumulation in the process and its potential effect on aerobic phosphate uptake.

- Evaluate the impact of sporadic ferric chloride addition to the biological process as a means of preventing effluent TP exceedances.

- Evaluate the design $\mu_{\text{max}}$ to the actual observed $\mu_{\text{max}}$ for AOB through simulation modeling.

- Compare modeling and observed profile data for signs of continuous nitrification inhibition.

5.2 Methodology

Under normal circumstances, samples were collected during morning hours for 2 days of a normal business week from 7/23/09 to 11/5/09 via grab samples from the surface of each tank or reactor with a bucket. After the sample was collected it was allowed to settle for approximately 30 seconds until a supernatant layer was evident. Supernatant was then aspirated from the surface of the sample bucket using a 60 ml syringe. The sample would then be immediately filtered through the vacuum filtration system incorporating 0.45 μm membrane filters and transferred to the appropriate sample vial (see 5.2.1 Sample Preservation and Containers). DO and pH were measured and recorded when each grab sample was collected. This process was repeated for a total of two profiles per week. During each day of sampling the first sample collection point would be from the primary clarifier effluent. All successive
collection points were taken along the length of the BNR treatment process (refer to Figure 5.2) according to the actual hydraulic retention time presented in Table 5.1 (including the impact of recycle streams). The clarifier influent distribution channel sample was collected immediately following the last aeration basin sample and the RAS sample immediately after the secondary effluent sample was taken. A total of 15 samples were collected. Analysis of soluble COD (sCOD), Ammonia (NH$_4$-N), Nitrate (NO$_3$-N), Nitrite (NO$_2$-N), ortho-phosphate (PO$_4$-P) at all sampling locations.

- Primary Clarifier Effluent (PE) - 1 Sample
- Anaerobic/Anoxic Tanks (AA1, AA2, AA3, AA4, AA5, AA6) - 6 Samples, 1 sample per cell for a single train
- Aeration Tank (AE1, AE1.25, AE1.5, AE3, AE5) - 5 samples, 1 at the beginning, 3 intermediate, 1 at the end for a single tank. The aeration tank was originally divided into 5 equal sample points along the length of the tank. AE1, AE2, AE3, AE4, AE5. Based on the results, two of the intermediate points were changed. Instead of taking 5 equally spaced points, two were taken between the distance of AE1 and AE2, which became AE1.25 and AE1.5 to better capture ammonia uptake, nitrite consumption, and nitrate production. AE4 was eliminated as values were similar to AE5 (Figure 5.1).
- Clarifier Recycle (RAS) - 1 sample
- Secondary Clarifier Influent Distribution Channel (IDC) - 1 sample
- Secondary Clarifier Effluent (SE) - 1 sample
Figure 5.1 Aeration Tank Profile Sample Points

Figure 5.2 Profile Sampling Collection Points
As part of the process to stop nitrification, the nitrate recycle pump was also turned off converting all the anaerobic/anoxic cells to an anaerobic environment. Also due to upgrade efforts, the number of anaerobic/anoxic trains was reduced from 5 to 4 during the sampling period. This slightly changed the HRT in regards to sample collection; however, sample collection was still obtained based on the initial calculation of HRT from the start of the profile sampling. Profile sampling was conducted for a period of approximately 2 and half months until the plant stopped nitrifying.

### 5.2.1 Sample Preservation and Containers

After samples were collected and immediately filtered through 0.45μm membrane filters by vacuum pumps and associated filtration equipment they were placed into various containers for preservation before analysis. Table 5.2 provides a summary of the various containers, quantity of samples, and analysis methods which were used for the baseline profile sampling.

<table>
<thead>
<tr>
<th>Analysis Location:</th>
<th>NP</th>
<th>CEL</th>
<th>QA/QC by CEL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sample Container</td>
<td>15 ml centrifuge tube</td>
<td>40 ml VOA vial + H₂SO₄</td>
<td>(1) 40 ml VOA vial + H₂SO₄</td>
</tr>
<tr>
<td>(2) 40 ml VOA vial + H₂SO₄</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Analytes</td>
<td>PO₄-P</td>
<td>NH₄-N</td>
<td>NO₃-N</td>
</tr>
<tr>
<td>NO₂-N</td>
<td>sCOD</td>
<td>(1) PO₄-P</td>
<td></td>
</tr>
<tr>
<td>NO₃-N</td>
<td>NO₂-N</td>
<td>(2) NH₄-N</td>
<td></td>
</tr>
<tr>
<td>Probe/Equipment</td>
<td>DO, pH</td>
<td></td>
<td></td>
</tr>
<tr>
<td>No. Samples/week</td>
<td>15 x 2 = 30</td>
<td>15 x 2 = 30</td>
<td>2 x 2 = 4</td>
</tr>
<tr>
<td>No. Samples/month</td>
<td>120</td>
<td>120</td>
<td>16</td>
</tr>
<tr>
<td>Total No. Samples (duration of profiling)</td>
<td>480</td>
<td>480</td>
<td>64</td>
</tr>
</tbody>
</table>

*Note: The CEL sample vial used for sCOD analysis could also be used for the QA/QC sample for NH₄-N analysis.*

### 5.2.2 Analytical Methods

Sample analysis for profile sampling was conducted both on-site and off-site. Analytes measured at NTP for each profile include: PO₄-P, NH₄-N, NO₃-N, NO₂-N which were conducted using various HACH colorimetric test kits (see subsections 5.2.2.1 – 5.2.2.4) and a
HACH DR2800 spectrophotometer. Analysis of NO₂-N was performed the same day as sample collection, while analysis of PO₄-P, NH₄-N, and NO₃-N were conducted the following day. Samples were preserved by refrigeration overnight after NO₂-N analysis was complete. Off-site analysis by CEL consisted of soluble COD and quality assurance and quality control samples (QA/QC) of the same analytes measured on-site using Standard Methods.

5.2.2.1 Ammonia (NH₃-N) HACH Test Kit

Ammonia was analyzed using HACH Test N’ Tube (TNT) 831 kit and HACH DR2800 spectrophotometer. This method uses the salicylate method, whereby ammonium ions react with hypochlorite and salicylate ions in the presence of sodium nitroprusside to as a catalyst form indophenol. The amount of color formed is directly proportional to the NH₄-N present.

5.2.2.2 Nitrate (NO₃-N) HACH Test Kit

Nitrate was analyzed using HACH TNT 835 kit. This kit incorporates the dimethylphenol method where nitrate ions in solution with sulfuric and phosphoric acids react with 2,6-dimethyphenol to form 4-nitro-2,6-dimethyphenol.

5.2.2.3 Nitrite (NO₂-N) HACH Test Kit

Nitrite was analyzed using NitriVer3 Nitrite Reagent Powder Pillows and 10 mL sample vials. This kit uses the diazotization method where nitrite in the sample reacts with sulfanilic acid to form a intermediate diazonium salt. This salt combined with chromotropic acid forms a pink color which is directly proportional to the amount of nitrite present.

5.2.2.4 Ortho-Phosphate (PO₄-P) HACH Test Kit

Ortho-Phosphate was analyzed using the HACH Reactive Phosphate TNT Reagent Kit. This test kit uses the USEPA-approved PhosVer3 method where orthophosphate reacts with
molybdate in an acid to produce a mixed complex. Ascorbic acid then reduces this complex, producing an intense blue color.

5.2.3 Biowin Modeling Methodology

Modeling was performed using Biowin version 3.1, a biological wastewater treatment simulation package developed by EnviroSim Ltd (Flamborough, Ontario, Canada) and based on the IWA activated sludge models. Biowin was incorporated into this work to compare the data generated from the profile sampling with previous work performed by Hazen and Sawyer, P.C. (H&S). The Biowin model was calibrated using plant performance data from 7/23/09 to 11/5/09 period and previous simulation modeling work from H&S. Primary effluent wastewater fraction inputs for this work were derived from the NTP model created by H&S. The H&S NTP model was simulated with the raw influent characteristics that were generated from historical plant data and a two week special sampling study specified by H&S. The effluent data from the primary clarifier of this simulation was used to calculate wastewater fractions for the input of the simulation for the profile sampling work. Primary clarification was not simulated as part of this effort. Kinetic parameters such as maximum specific growth rate ($\mu_{\text{max, AOB}}$) and nitrite half saturation concentration were changed based on the work done by H&S in addition to changes made to fit the simulation model to the profile sampling data. A Garrett wasting configuration was incorporated to simplify modeling of secondary clarification (Figure 5.3), and the waste rate was then adjusted accordingly to match the solids wasted (lbs/day) from the plant performance data within a reasonable range. A Garrett wasting configuration directly wastes activated sludge from the aeration effluent, rather than wasting sludge from the secondary clarifier underflow (typical configuration). Diurnal load variations were not considered as part of this modeling.
Table 5.2 Biowin Influent Wastewater Fractions

<table>
<thead>
<tr>
<th>Name</th>
<th>Default</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fbs - Readily biodegradable (including Acetate) [gCOD/g of total COD]</td>
<td>0.270</td>
<td>0.310</td>
</tr>
<tr>
<td>Fac - Acetate [gCOD/g of readily biodegradable COD]</td>
<td>0.150</td>
<td>0.180</td>
</tr>
<tr>
<td>Fxs - Non-colloidal slowly biodegradable [gCOD/g of slowly degradable COD]</td>
<td>0.500</td>
<td>0.610</td>
</tr>
<tr>
<td>Fus - Unbiodegradable soluble [gCOD/g of total COD]</td>
<td>0.080</td>
<td>0.155</td>
</tr>
<tr>
<td>Fup - Unbiodegradable particulate [gCOD/g of total COD]</td>
<td>0.080</td>
<td>0.169</td>
</tr>
<tr>
<td>Fna - Ammonia [gNH3-N/gTKN]</td>
<td>0.750</td>
<td>0.740</td>
</tr>
<tr>
<td>Fnox - Particulate organic nitrogen [gN/g Organic N]</td>
<td>0.250</td>
<td>0.300</td>
</tr>
<tr>
<td>Fns - Soluble unbiodegradable TKN [gN/gTKN]</td>
<td>0.020</td>
<td>0.030</td>
</tr>
<tr>
<td>FupN - N:COD ratio for unbiodegradable part. COD [gN/gCOD]</td>
<td>0.035</td>
<td>0.030</td>
</tr>
<tr>
<td>Fpo4 - Phosphate [gPO4-P/gTP]</td>
<td>0.750</td>
<td>0.820</td>
</tr>
<tr>
<td>FupP - P:COD ratio for unbiodegradable part. COD [gP/gCOD]</td>
<td>0.011</td>
<td>0.009</td>
</tr>
<tr>
<td>FZbh - Non-poly-P heterotrophs [gCOD/g of total COD]</td>
<td>0.000</td>
<td>0.0001</td>
</tr>
<tr>
<td>FZbm - Anoxic methanol utilizers [gCOD/g of total COD]</td>
<td>0.000</td>
<td>0.0001</td>
</tr>
<tr>
<td>FZao - Ammonia oxidizers [gCOD/g of total COD]</td>
<td>0.000</td>
<td>0.0001</td>
</tr>
<tr>
<td>FZnb - Nitrite oxidizers [gCOD/g of total COD]</td>
<td>0.000</td>
<td>0.0001</td>
</tr>
<tr>
<td>FZamob - Anaerobic ammonia oxidizers [gCOD/g of total COD]</td>
<td>0.000</td>
<td>0.0001</td>
</tr>
<tr>
<td>FZbp - PAOs [gCOD/g of total COD]</td>
<td>0.000</td>
<td>0.0001</td>
</tr>
<tr>
<td>FZbpa - Propionic acetogens [gCOD/g of total COD]</td>
<td>0.000</td>
<td>0.0001</td>
</tr>
<tr>
<td>FZbam - Acetoclastic methanogens [gCOD/g of total COD]</td>
<td>0.000</td>
<td>0.0001</td>
</tr>
<tr>
<td>FZbhm - H2-utilizing methanogens [gCOD/g of total COD]</td>
<td>0.000</td>
<td>0.0001</td>
</tr>
</tbody>
</table>

5.2.3.1 Steady-State Simulation

Simulations were created for individual periods of the profile sampling as well as a simulation for the entire profile sampling period. Individual periods were created based on changes in mixed liquor suspended solids, changes in process; 5 anaerobic/anoxic trains to 4 anaerobic/anoxic trains; the Nitrate recycle (NRCY) being active and inactive, and the cease of nitrification. Steady-state simulations incorporated the use of constant input values. The entire profile sampling event was divided into 5 different periods and each period was modeled using steady-state conditions to calibrate the model except for the 4th period. Steady-state simulations were performed using the configuration shown in Figure 5.3.
5.2.3.2 Dynamic Simulation

Dynamic simulations were used to calibrate the model for the entire profile sampling event from start to finish. This required a reconfiguration of the model to account for dynamic simulation of one train being removed from service. This was done by creating a second anaerobic/anoxic train (train B) which only received 1/5 of the flow while the main train received 4/5 of the flow. During the period when all 5 trains were in operation the flow would be split to the 1/5 and 4/5 trains for a total of 5/5 (5 trains). Once the simulation reached the time period when one train was taken off-line, the simulation stopped the split of flow to train B (1/5) (Figure 5.4). This diverted all of the flow to the main anaerobic/anoxic train (4/5), simulating the system going from 5 to 4 anaerobic/anoxic trains. Dynamic simulations were first brought to steady-state using constant values from period 1 steady-state simulation and then simulated dynamically for the entire period. Itineraries for the various inputs were all based on plant performance data (WAS, NRCY, ARCY, RAS, Temperature, etc.).
5.3 Results and Discussion

5.3.1 Profile Sampling

During the start of the profile sampling, Anaerobic/Anoxic (AA) trains 3-7, Aeration Tanks (AE) 4 and 5, and Secondary Clarifiers 4 and 5 were being operated at NP. Based on daily plant data as of July 23, 2009, the average daily flow rate over the entire profile sampling period was 18.11 MGD (final effluent). There was one nitrate recycle (NRCY) pump active at a flow of approximately 19.5 MGD, the anoxic recycle (ARCY) flow was 19.0 MGD, and the clarifier recycle (RAS) flow for secondary clarifiers 4 and 5 was 5.7 MGD each. Traditionally NRCY rates tend to be two or three times the influent flow. However, since the plant only had one recycle pump running at a rate of about the average daily flow this suggests that denitrification performance in the anoxic tanks is limited by nitrate availability. The plant added ferric chloride on an as needed basis to the aeration basin when the effluent TP approached the treatment objective. The hydraulic retention times (HRT) at the flow during the initial profile sampling for the different treatment processes are presented in Table 5.4.
Profiling sampling started July 7, 2009 and ended on November 5, 2009. The data collected during this time period provided an overview of a BNR process coming out of nitrification as the SRT was intentionally lowered to stop nitrification. Figures 5.5 and 5.6 provide an overview of the influent (primary effluent) and secondary effluent characteristics during the entire profile sampling period. NH$_4$-N and NO$_x$-N data demonstrate that the plant began to stop nitrifying in early October, as the NH$_4$-N increased and the NO$_x$-N decreased. There was an observed steady increase in the influent phosphate which was attributed to centrate from the centrifuges and filtrate from the gravity belt thickeners.

Table 5.3 Hydraulic Retention Times at Current Average Day Flow Rate

<table>
<thead>
<tr>
<th></th>
<th>No. Units</th>
<th>Vol. Each Unit</th>
<th>Total Vol.</th>
<th>HRT w/out Recycle</th>
<th>HRT w/Recycle</th>
<th>Cumm. HRT w/RCY</th>
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<td>Anaerobic Cell 1</td>
<td>5</td>
<td>0.174</td>
<td>0.87</td>
<td>1.21</td>
<td>0.58</td>
<td>0.58</td>
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<td>0.87</td>
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<td>1.15</td>
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<tr>
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<td>0.87</td>
<td>1.21</td>
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<td>1.73</td>
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<td>0.87</td>
<td>1.21</td>
<td>0.31</td>
<td>2.04</td>
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<td>0.87</td>
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<td>0.31</td>
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<td>0.87</td>
<td>1.21</td>
<td>0.31</td>
<td>2.66</td>
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<td>Aeration Tank</td>
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<td>7.50</td>
<td>2.69</td>
<td>5.35</td>
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<tr>
<td>Secondary Clarifier</td>
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<td>2.25</td>
<td>4.5</td>
<td>6.25</td>
<td>3.77</td>
<td>9.11</td>
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</table>
Figure 5.5 Influent Characteristics (Primary Clarifier Effluent – PCE)

Figure 5.6 Secondary Effluent (SE) Characteristics
Profile sampling data were compared to the monthly plant performance data (composite samples) collected by HRSD. Results from the comparison proved to be very similar (Figure 5.7). This similarity supports the accuracy of the profile sampling data and the use of this data as a means for modeling nitrification performance to determine a maximum specific growth rate ($\mu_{\text{max}}$) for AOB to compare to design $\mu_{\text{max}}$ used for the upgrade of the facility.

![Figure 5.7 Comparison of Profile to Plant Performance Data](image)

Temperature was very consistent from day to day sampling (Figure 5.8). It was observed that temperature slowly decreased as the weather changed. The coldest temperature that was observed was 22.5°C in November. Figure 5.9 demonstrates the relationship between the WAS rate and the SRT. It was observed that as the SRT was reduced throughout the profile sampling, the WAS rate correspondingly increased, until nitrification began to fail. At this point, the SRT was increased once again and the WAS decreased. The mixed liquor suspended solids (MLSS) data are consistent with the WAS and SRT data (Figure 5.8). Figure 5.10 was generated to show
the correlation between AOB washout SRT as a function of temperature assuming DO and pH were not limiting. The $\mu_{\text{max}}$ values used for calculating the AOB washout SRT were 0.90, 0.70, 0.60, and 0.50 day$^{-1}$ (see equation (1) below). Figures 5.8 showed that nitrification began to fail around a temperature of 22°C and based on Figure 5.9 the SRT during this failure was approximately 3 to 4 days. Based on the AOB washout SRT curve, at a temperature of 22°C, the $\mu_{\text{max}}$ which predicted an SRT in the range of 3 to 4 days was approximately 0.45 to 0.41 day$^{-1}$ based on equation (2) below. In calculating the above approximately $\mu_{\text{max}}$ for AOB an SRT of 3.5 days was used at a temperature 22°C. The calculated value suggested that the approximate range of $\mu_{\text{max}}$ for AOB to be between 0.40 – 0.60 days$^{-1}$.

\[
SRT = \frac{1}{\theta_{\text{max}} \cdot \theta_{\text{max}}^{T-20} \cdot \theta_{T}^{T-20}} 
\]  

(1)

\[
\mu_{\text{max}} = \frac{1}{\theta_{\text{max}}^{T-20} \cdot \theta_{T}^{T-20}} 
\]  

(2)

Where:

SRT = solids retention time

$\mu_{\text{max}}$ = maximum specific growth rate

$\theta_{\text{max}}$ = Arrhenius temperature coefficient for growth

$b_i$ = decay rate

$\theta_i$ = Arrhenius temperature coefficient for decay

T = temperature
Figure 5.8 Mixed Liquor Suspended Solids (MLSS) and Temperature During Profile Sampling

Figure 5.9 WAS and SRT During Profile Sampling
Figure 5.10 AOB Washout SRT as a Function of Temperature - $\mu_{\text{max}} = 0.40$ to 0.90 days$^{-1}$.

Profile sampling data were also used to calculate ammonia uptake rates (AUR), specific ammonia uptake rates (SAUR), nitrate production rates (NPR), and specific nitrate production rates (SNPR). Slope regressions were performed of ammonia and nitrate concentrations over the hydraulic residence time (HRT) in the aeration tanks to determine uptake and production rates. In order to calculate the specific rates, the AUR and NPR were normalized to the mixed liquor volatile suspended solids (MLVSS). Nitrification performance was stable and rates were increasing until the SRT was purposely reduced to stop nitrification. This loss of nitrification was observed in the specific rates as time progressed from the start of the profile sampling to the end (Figure 5.11).
Figure 5.11 Specific Ammonia Uptake Rate (SAUR) and Specific Nitrate Production Rate (SNPR)

It was of interest to evaluate the potential for nitrite accumulation in the process and its potential effect on aerobic phosphate uptake by PAOs. Figure 5.12 shows aerobic nitrite concentration over the profile sampling period. The data shown represent individual profile experiments that were representative of the sampling period as a whole. It was evident that nitrite was present and accumulated to some degree as nitrification stopped. Although this was true, Figure 5.13 shows continued uptake of phosphate in the aerobic zone even after nitrification had stopped.
Figure 5.12 Aerobic NO₂-N Concentrations

Figure 5.13 Aerobic PO₄-P Uptake

Phosphate Uptake Continues Throughout
Data for late September and most of October were not shown on these figures due to the variability of this time period. Between September 30 and October 21 nitrification rates began to decrease and eventually ceased in late October/early November. This period of time was evaluated independently; however, aerobic phosphate uptake continued throughout the period of time when nitrification stopped (Figure 5.14). This suggested that there was no significant effect of nitrite accumulation on the aerobic phosphate uptake.

![Figure 5.14 Aerobic PO4-P Uptake (10/6/09 - 10/21/09)](image)

Ferric chloride was sporadically added during certain periods of the profile sampling to prevent effluent TP exceedances. Table 5.4 shows the dates during the profile sampling period in which ferric chloride was added to assist in TP removal. During these dates there was no observed change in nutrient profiles between days with and without the addition of ferric chloride. This suggested that there was no significant impact of ferric chloride on nitrogen removal.
### Table 5.4 Wastewater Characteristics during Ferric Chloride Addition

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<th>Date</th>
<th>WAS [lbs/day]</th>
<th>ANA [mg/L]</th>
<th>ANX/AER [mg/L]</th>
<th>Chem Type</th>
<th>Dose [mg/L]</th>
<th>SC EFF NH3 [mg/L]</th>
<th>FIN EFF NOx [mg/L]</th>
<th>FIN EFF T-N [mg/L]</th>
<th>FIN EFF T-P [mg/L]</th>
<th>FIN EFF OPO4 [mg/L]</th>
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### 5.3.2 Biowin Modeling

#### 5.3.2.1 Steady-State Simulations
Model calibration was first conducted for periods 1, 2, 3, and 5 using steady-state conditions. Periods 1, 2, 3, and 5 are individual time periods during the profile sampling where MLSS, SRT, primary effluent TKN, and other wastewater characteristics were similar in value (refer to Figure 5.7). The results presented from the steady-state calibration were comparable to actual profile and plant performance data in regards to nutrient and specific rate profiles (Figures 5.15 – 5.19). The results suggested that modeling kinetics were similar in value to the actual observed.

![Ammonia Comparisons for Period 1-Top (7/23/09 – 7/31/09) & 2-Bottom (8/1/09 – 8/21/09)](image-url)

*Figure 5.15 Ammonia Comparisons for Period 1-Top (7/23/09 – 7/31/09) & 2-Bottom (8/1/09 – 8/21/09)*
Figure 5.16 Ammonia Comparisons for Period 3-Top (8/22/09 – 10/2/09) & 5-Bottom (10/23/09 – 11/5/09)
Figure 5.17 Mixed Liquor and WAS Comparison for Periods 1, 2, 3, and 5

Figure 5.18 Nitrification Rate Comparisons for Periods 1, 2, 3, and 5
Although similar, the specific rates calculated from the model were generally greater than what was actually observed. This suggested either that the model predicted better performance than the observed rates or the calibration was off, thus creating the differential.

5.3.2.2 Dynamic Simulations

Dynamic simulation generated similar results to profile and plant performance data; however, some of the data were not matched perfectly to the actual observed data. Period 4 (10/3/09 to 10/22/09) was modeled dynamically, as well, since it was the period where nitrification rates declined; however, the model could not be calibrated properly for this period alone. It was speculated that periods of high PE COD and TKN caused by removing primary clarifiers from service, which were not captured by the WAS and SRT, were the main cause of the offset between the model and the observed data. Due to the high COD and TKN during this period, the MLSS concentrations in the reactors increased; however, the plant data suggested a
decline in the WAS rather than an increase. The model continued to match the SRT, but the WAS and MLSS were not well correlated due the high PE COD and TKN (Figure 5.20). The figure demonstrated the offset between the model and observed plant data. The model, in the case of all the nutrients, failed to match the observed data and constantly over predicted the effluent concentrations. There were also unknown spikes observed starting at 10/14/09 believed to be caused by the high PE COD and TKN.

Therefore, instead of modeling period 4 separately, dynamic simulations of the entire profile sampling period were developed. There were noticeable differences between the model and observed data during the period from 10/3/09 to 10/22/09 for NH₄-N, NO₃-N, MLSS, SRT, and WAS (Figure 5.21, 5.22, 5.23, 5.24). From 7/23/09 to 10/2/09 MLSS slowly decreased as the plant reduced the SRT, thus increasing the WAS. The model followed this pattern until approximately 10/3/09. After this point, it was noted that the model SRT continued to match the
plant SRT; however, large differences were observed between the MLSS and WAS in comparison to plant data. Nutrient profiles behaved similarly as they initially matched plant data and then a large variation was seen. These unknown spikes predicted by the model in solids wasting, mixed liquor, and nutrient concentrations were not observed in the actual profile and plant data. The model also continued to predict failure of nitrification sooner than the actual data, which was followed by a steady recovery. It was suspected that the origin of the issue was input data taken from the plant, as there was a large increase in the inorganic suspended solids and total kheldajl nitrogen (TKN) caused by removing primary clarifiers from service.

![Figure 5.21 Comparison of WAS and SRT Plant Data to Model Data – $\mu_{\text{max}} = 0.62 \text{days}^{-1}$](image_url)

Figure 5.21 Comparison of WAS and SRT Plant Data to Model Data – $\mu_{\text{max}} = 0.62 \text{days}^{-1}$
Figure 5.22 Mixed Liquor Suspended Solids Comparison – $\mu_{max} = 0.62\text{days}^{-1}$

Figure 5.23 Final Effluent Nitrogen Species Comparison – $\mu_{max} = 0.62\text{days}^{-1}$
Profiles of the secondary effluent ammonia concentration across the BNR process for certain dates demonstrated similar trends (Figure 5.25). The model and profile data were comparable until about 10/3/09 when a reduction in nitrification performance was observed. At this point the model predicted nitrification failure sooner than the observed data and then recovery.
Biowin modeling suggested that nitrification would stop sooner than what the actual profile data showed. The plant had intentionally stopped the NRCY and reduced the SRT to stop nitrification; however, the plant continued to nitrify for several more weeks.

Modeling provided a means of comparing the actual observed $\mu_{\text{max}}$ for AOB to the original design $\mu_{\text{max}}$. The AOB $\mu_{\text{max}}$ value used for design was 0.57 days$^{-1}$. Modeling was carried out using various $\mu_{\text{max}}$ values to determine which value best fit the profile and plant data. Despite the variation between the model and the observed, the modeling suggested an approximate $\mu_{\text{max}}$ value close to a value in the range of 0.50 to 0.60 days$^{-1}$ (Figure 5.26 and 5.27). The suggested range of $\mu_{\text{max}}$ values was determined based on the effluent NH$_4$-N and NOx-N comparisons between generated data from Biowin and profile data. Although Biowin continued to show
failure of nitrification to occur sooner than the profile data, simulations generally followed the pattern that was seen in the profile data. Diurnal load variations were not considered as part of the modeling. This suggested that the actual in situ $\mu_{\text{max}}$ for AOB might be slightly greater than the projected $\mu_{\text{max}}$. Regardless, it appeared that the suggested $\mu_{\text{max}}$ value and the original design value were similar.

Figure 5.26 Comparison of $\mu_{\text{max}}$ for AOB to $\text{NH}_4\text{-N}$
5.4 Conclusion

Based on results from the profile sampling and Biowin modeling, it was suggested that there was no significant sporadic inhibition event during the sampling period. Profile and plant data was collected which demonstrated a fully nitrifying plant ceasing to nitrify as the SRT was reduced to values below which one would not expect nitrification to be normally maintained (Figure 5.7). This allowed for the use of simulation modeling to estimate a $\mu_{\text{max}}$ for AOB which correlates with the observed data. This estimated value could then be compared to the original design value. Modeling suggested a $\mu_{\text{max}}$ for AOB to be approximately in the range of 0.50 – 0.60 days$^{-1}$, based primarily on the effluent ammonia concentrations, which was similar to the original design value of 0.57 days$^{-1}$. This supported previous batch-rate testing which suggested that there was some form of continuous inhibition present in the wastewater at NTP. Though model and profile/plant data were somewhat similar, the model did not match the profile data within a reasonable difference towards the end of the sampling. Reasoning behind the difference
was high PE COD and TKN concentrations recorded in the plant performance data. These high concentrations were caused by bad samples collected during this period where primary clarifiers were being taken in and out of service.

5.5 References


6. Engineering Significance

The purpose of this project was to identify a specific source of inhibition which would cause failure of nitrification and determine the inhibitory characteristics of NTP influent wastewater. The first objective was to attempt to find the cause of sporadic nitrification upset events at NTP, and at the outset of this work, it was hypothesized that possible sources included the hog processing facility, landfill leachate, and truck delivered septage/FOG/chemical toilet waste could be the cause. AOB and NOB batch rate testing using a range of biomass and wastewater sources suggested that there was some level of continuous inhibition, however no significant source of sporadic inhibition was observed.

The profile sampling and modeling, combined with the calibrated model developed from historical plant data by H&S seemed to indicate this as well. Based on this work, there was definitely some degree of continuous nitrification inhibition characterized by an apparent AOB $\mu_{\text{max}}$ reduction from a typical value of 0.9 days$^{-1}$ to a value approximately in the range of 0.50 – 0.60 days$^{-1}$. An evaluation of the nitrification process at the treatment plant was performed as the SRT was reduced to stop nitrification (13 days to 3-4 days). Evaluation of the profile sampling data showed that the plant ceased nitrification at an approximate SRT of 3 to 4 days and a temperature around 22°C. It was suggested that for these parameters, the AOB $\mu_{\text{max}}$ at which washout occurred would be close to a value of 0.45 to 0.41 day$^{-1}$. This was based on an AOB washout curve developed as a function of the temperature (not including rate reduction due to pH and DO).

Although the suspected inhibitors such as the hog processing facility and landfill leachate were eliminated as causes of inhibition based on this work, these sources should be reconsidered in the future. Sporadic nitrification inhibition was not observed using samples collected on one
of several days. For this reason, it was proposed in future work to configure continuous batch reactors to examine if the nitrification failure is caused over a period of time or capture the sporadic failure.

The next step was to determine the extent of the continuous nitrification inhibition. This was carried out through profile sampling of the BNR process. This provided a means for looking at nutrient concentrations through the treatment process to determine if any part of the treatment process was operating inefficiently or where issues may arise. The plant sporadically added ferric chloride to assist in meeting effluent TP limits; however, there were no observed affects on nitrification. No trends were observed in the influent received at the plant or plant process operations based on the profile sampling which would indicate an inhibition issue. The loss of nitrification was captured as the plant purposely reduced the SRT to stop nitrification.

Biowin modeling was used to calculate the $\mu_{\text{max}}$ value based on the correlation of effluent nutrient concentrations between the model and profile data. The model failed to perfectly match the observed data towards the end of the profile sampling, where there were noticeable differences. It was believed that the cause was due to primary clarifiers being taken out of service. This caused the collected samples to contain higher concentrations of COD and TKN which created a false representative sample. In spite of this, the model was still used to calculate a range of $\mu_{\text{max}}$ values which best correlated with the profile data. After several iterations with different $\mu_{\text{max}}$ values, it was determined that the range of values which best fit the observed effluent ammonia and NO$_x$-N concentrations were between 0.50 – 0.60 day$^{-1}$.
### 7.1 Appendix A

**PERIOD 1 (7/23/09 - 7/31/09)**

**SIMULATION INPUTS**

#### Primary Effluent Fractions

<table>
<thead>
<tr>
<th>Name</th>
<th>Default</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fbs - Readily biodegradable (including Acetate) [gCOD/g of total COD]</td>
<td>0.270</td>
<td>0.270</td>
</tr>
<tr>
<td>Fac - Acetate [gCOD/g of readily biodegradable COD]</td>
<td>0.150</td>
<td>0.220</td>
</tr>
<tr>
<td>Fxsp - Non-colloidal slowly biodegradable [gCOD/g of slowly degradable COD]</td>
<td>0.500</td>
<td>0.615</td>
</tr>
<tr>
<td>Fus - Unbiodegradable soluble [gCOD/g of total COD]</td>
<td>0.080</td>
<td>0.157</td>
</tr>
<tr>
<td>Fup - Unbiodegradable particulate [gCOD/g of total COD]</td>
<td>0.080</td>
<td>0.171</td>
</tr>
<tr>
<td>Fna - Ammonia [gNH3-N/gTKN]</td>
<td>0.750</td>
<td>0.744</td>
</tr>
<tr>
<td>Fnox - Particulate organic nitrogen [gN/g Organic N]</td>
<td>0.250</td>
<td>0.148</td>
</tr>
<tr>
<td>Fnus - Soluble unbiodegradable TKN [gN/gTKN]</td>
<td>0.020</td>
<td>0.033</td>
</tr>
<tr>
<td>FupN - N: COD ratio for unbiodegradable part. COD [gN/gCOD]</td>
<td>0.035</td>
<td>0.030</td>
</tr>
<tr>
<td>Fpo4 - Phosphate [gPO4-P/gTP]</td>
<td>0.750</td>
<td>0.849</td>
</tr>
<tr>
<td>FupP - P/COD ratio for unbiodegradable part. COD [gP/gCOD]</td>
<td>0.011</td>
<td>0.011</td>
</tr>
</tbody>
</table>

#### Primary Effluent Itinerary

<table>
<thead>
<tr>
<th>Flow</th>
<th>Total COD mgCOD/L</th>
<th>TKN mgN/L</th>
<th>TP mgP/L</th>
<th>NO3-N mgN/L</th>
<th>pH</th>
<th>Alk. mmol/L</th>
<th>ISS mgISS/L</th>
<th>Ca mg/L</th>
<th>Mg mg/L</th>
<th>DO mg/L</th>
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</thead>
<tbody>
<tr>
<td>18.36</td>
<td>422.10</td>
<td>46.2</td>
<td>9.56</td>
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<tr>
<td>Increased by = Original =</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>21.84</td>
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*NOTE: Values are averages of effluent data taken from Nansemond MPOR

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<tbody>
<tr>
<td>Anaerobic Tanks (3 cells per Train)</td>
<td>2.606193</td>
<td>1.17</td>
<td>un-aerated</td>
<td>5</td>
<td>-</td>
<td>-</td>
<td>-</td>
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<tr>
<td>Anoxic Tanks (3 cells per Train)</td>
<td>2.606193</td>
<td>1.17</td>
<td>un-aerated</td>
<td>5</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Aeration Tank 1</td>
<td>1.800</td>
<td>1.453</td>
<td>2</td>
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<td>-</td>
<td>-</td>
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</tr>
<tr>
<td>Aeration Tank 2</td>
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<td>1.453</td>
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<td>Aeration Tank 3</td>
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<tr>
<td>Secondary Clarifier</td>
<td>4.510</td>
<td>3.640</td>
<td>-</td>
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<td>99.9</td>
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### SPLITTERS

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<td>ARCY =</td>
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<td>NRCY ON =</td>
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<td>ARCY</td>
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<td>CRCY =</td>
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<td></td>
<td>Daily =</td>
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<td>Temperature =</td>
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### PARAMETERS (KINETIC)

#### AOB

<table>
<thead>
<tr>
<th>Name</th>
<th>Default</th>
<th>Value</th>
<th>Arrhenius</th>
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</thead>
<tbody>
<tr>
<td>Max. spec. growth rate [1/d]</td>
<td>0.9</td>
<td><strong>0.53</strong></td>
<td>1.072</td>
</tr>
<tr>
<td>Substrate (NH4) half sat. [mgN/L]</td>
<td>0.7</td>
<td>0.7</td>
<td>1</td>
</tr>
<tr>
<td>Aerobic decay rate [1/d]</td>
<td>0.17</td>
<td>0.17</td>
<td>1.029</td>
</tr>
<tr>
<td>Anoxic/anaerobic decay rate [1/d]</td>
<td>0.08</td>
<td>0.08</td>
<td>1.029</td>
</tr>
<tr>
<td>KiHNO2 [mmol/L]</td>
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<td>0.005</td>
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</table>

#### NOB

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<td>Max. spec. growth rate [1/d]</td>
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<td>Substrate (NO2) half sat. [mgN/L]</td>
<td>0.1</td>
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</tr>
<tr>
<td>Aerobic decay rate [1/d]</td>
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<td>0.17</td>
<td>1.029</td>
</tr>
<tr>
<td>Anoxic/anaerobic decay rate [1/d]</td>
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<td>0.08</td>
<td>1.029</td>
</tr>
<tr>
<td>KiNH3 [mmol/L]</td>
<td>0.075</td>
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#### SWITCHES

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<th>Value</th>
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<tbody>
<tr>
<td>Heterotrophic DO half sat. [mgO2/L]</td>
<td>0.05</td>
<td>0.05</td>
</tr>
<tr>
<td>Aerobic denit. DO half sat. [mgO2/L]</td>
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<td>0.05</td>
</tr>
<tr>
<td>Ammonia oxidizer DO half sat. [mgO2/L]</td>
<td>0.25</td>
<td>0.25</td>
</tr>
<tr>
<td>Nitrite oxidizer DO half sat. [mgO2/L]</td>
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<td>0.5</td>
</tr>
<tr>
<td>Anaerobic ammonia oxidizer DO half sat. [mgO2/L]</td>
<td>0.01</td>
<td>0.01</td>
</tr>
<tr>
<td>Anoxic NO3 half sat. [mgN/L]</td>
<td>0.1</td>
<td>0.1</td>
</tr>
<tr>
<td>Anoxic NO2 half sat. (mgN/L)</td>
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<td><strong>0.1</strong></td>
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<tr>
<td>NH3 nutrient half sat. [mgN/L]</td>
<td>1.00E-04</td>
<td>0.001</td>
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<tr>
<td>PolyP half sat. [mgP/L]</td>
<td>0.01</td>
<td>0.01</td>
</tr>
<tr>
<td>VFA sequestration half sat. [mgCOD/L]</td>
<td>5</td>
<td>5</td>
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<tr>
<td>P uptake half sat. [mgP/L]</td>
<td>0.15</td>
<td>0.15</td>
</tr>
<tr>
<td>P nutrient half sat. [mgP/L]</td>
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<td>0.001</td>
</tr>
<tr>
<td>Autotroph CO2 half sat. [mmol/L]</td>
<td>0.1</td>
<td>0.1</td>
</tr>
<tr>
<td>Heterotrophic Hydrogen half sat. [mgCOD/L]</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Propionic acetogens Hydrogen half sat. [mgCOD/L]</td>
<td>5</td>
<td>5</td>
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</table>
SUMMARY OF INPUTS

<table>
<thead>
<tr>
<th>Total</th>
<th>WAS</th>
<th>ANA</th>
<th>ANX</th>
<th>AER</th>
<th>FIN EFF TKN</th>
<th>FIN EFF NOx</th>
<th>FIN EFF T-N</th>
<th>FIN EFF T-P</th>
<th>FIN EFF TSS</th>
<th>FIN EFF NH4-N</th>
</tr>
</thead>
<tbody>
<tr>
<td>SRT [days]</td>
<td>[lbs/day]</td>
<td>[mg/L]</td>
<td>[mg/L]</td>
<td>[mg/L]</td>
<td>[mg/ L]</td>
<td>[mg/ L]</td>
<td>[mg/ L]</td>
<td>[mg/ L]</td>
<td>[mg/ L]</td>
<td></td>
</tr>
<tr>
<td>12.82</td>
<td>23418</td>
<td>1788</td>
<td>4100</td>
<td>4100</td>
<td>2.72</td>
<td>12.73</td>
<td>15.45</td>
<td>0.53</td>
<td>6.76</td>
<td>0.24</td>
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Profile Data

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<thead>
<tr>
<th>SC EFF OPO4-P</th>
<th>SC EFF NOx-N</th>
<th>SC EFF NH4-N</th>
<th>AUR [mg/g MLVSS]</th>
<th>SAUR [mg/g MLVSS]</th>
<th>NPR [mg/g MLVSS/hr]</th>
<th>SNPR [mg/g MLVSS/hr]</th>
<th>PUR [mg/g MLVSS/hr]</th>
<th>SPUR [mg/g MLVSS/hr]</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.30</td>
<td>10.59</td>
<td>&lt;1.0</td>
<td>1.65</td>
<td>0.60</td>
<td>1.90</td>
<td>0.69</td>
<td>2.241</td>
<td>0.820</td>
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</tbody>
</table>

PERIOD 2 (8/1/09 - 8/21/09)

SIMULATION INPUTS

Primary Effluent Fractions

<table>
<thead>
<tr>
<th>Name</th>
<th>Default</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fbs - Readily biodegradable (including Acetate) [gCOD/g of total COD]</td>
<td>0.270</td>
<td>0.270</td>
</tr>
<tr>
<td>Fac - Acetate [gCOD/g of readily biodegradable COD]</td>
<td>0.150</td>
<td>0.220</td>
</tr>
<tr>
<td>Fxsp - Non-colloidal slowly biodegradable [gCOD/g of slowly degradable COD]</td>
<td>0.500</td>
<td>0.615</td>
</tr>
<tr>
<td>Fus - Unbiodegradable soluble [gCOD/g of total COD]</td>
<td>0.080</td>
<td>0.157</td>
</tr>
<tr>
<td>Fup - Unbiodegradable particulate [gCOD/g of total COD]</td>
<td>0.080</td>
<td>0.171</td>
</tr>
<tr>
<td>Fna - Ammonia [gNH3-N/gTKN]</td>
<td>0.750</td>
<td>0.744</td>
</tr>
<tr>
<td>Fnox - Particulate organic nitrogen [gN/g Organic N]</td>
<td>0.250</td>
<td>0.148</td>
</tr>
<tr>
<td>Fnus - Soluble unbiodegradable TKN [gN/gTKN]</td>
<td>0.020</td>
<td>0.033</td>
</tr>
<tr>
<td>FupN - N:COD ratio for unbiodegradable part. COD [gN/gCOD]</td>
<td>0.035</td>
<td>0.030</td>
</tr>
<tr>
<td>Fpo4 - Phosphate [gPO4-P/gTP]</td>
<td>0.750</td>
<td>0.849</td>
</tr>
<tr>
<td>FupP - P:COD ratio for unbiodegradable part. COD [gP/gCOD]</td>
<td>0.011</td>
<td>0.011</td>
</tr>
</tbody>
</table>

Primary Effluent Itinerary

<table>
<thead>
<tr>
<th>Flow</th>
<th>Total COD mgCOD/L</th>
<th>TKN mgN/L</th>
<th>TP mgP/L</th>
<th>NO3-N mgN/L</th>
<th>pH</th>
<th>Alk. mmol/L</th>
<th>ISS mgISS/L</th>
<th>Ca mg/L</th>
<th>Mg mg/L</th>
<th>DO mg/L</th>
</tr>
</thead>
<tbody>
<tr>
<td>19.2</td>
<td>630.53 ↑ 23%</td>
<td>40.65</td>
<td>8.83</td>
<td>0.1</td>
<td>7</td>
<td>5.4</td>
<td>25.4</td>
<td>12</td>
<td>6</td>
<td>0</td>
</tr>
</tbody>
</table>
*NOTE: Values are averages of effluent data taken from Nansemond MPOR*

<table>
<thead>
<tr>
<th></th>
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<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Anaerobic Tanks (3 cells per Train)</td>
<td>2.606193</td>
<td>1.17</td>
<td>un-aerated</td>
<td>5</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Anoxic Tanks (3 cells per Train)</td>
<td>2.606193</td>
<td>1.17</td>
<td>un-aerated</td>
<td>5</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Aeration Tank 1</td>
<td>1.800</td>
<td>1.453</td>
<td>2</td>
<td>2</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Aeration Tank 2</td>
<td>1.800</td>
<td>1.453</td>
<td>2</td>
<td>2</td>
<td>-</td>
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<tr>
<td>Aeration Tank 3</td>
<td>1.800</td>
<td>1.453</td>
<td>2</td>
<td>2</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Secondary Clarifier</td>
<td>4.510</td>
<td>3.640</td>
<td>-</td>
<td>2</td>
<td>99.9</td>
<td>0.2</td>
<td>0.00</td>
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</tr>
</thead>
<tbody>
<tr>
<td>WAS</td>
<td>1</td>
<td>23418</td>
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<tr>
<td>NRCY</td>
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<td></td>
<td>NRCY ON =</td>
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<td>8.85</td>
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<td>CRCY =</td>
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<tr>
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<td>Daily =</td>
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<td></td>
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<td></td>
<td>Temperature =</td>
<td>27.44</td>
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**PARAMETERS (KINETIC)**

**AOB**

<table>
<thead>
<tr>
<th>Name</th>
<th>Default</th>
<th>Value</th>
<th>Arrhenius</th>
</tr>
</thead>
<tbody>
<tr>
<td>Max. spec. growth rate [1/d]</td>
<td>0.9</td>
<td>0.53</td>
<td>1.072</td>
</tr>
<tr>
<td>Substrate (NH4) half sat. [mgN/L]</td>
<td>0.7</td>
<td>0.7</td>
<td>1</td>
</tr>
<tr>
<td>Aerobic decay rate [1/d]</td>
<td>0.17</td>
<td>0.17</td>
<td>1.029</td>
</tr>
<tr>
<td>Anoxic/anaerobic decay rate [1/d]</td>
<td>0.08</td>
<td>0.08</td>
<td>1.029</td>
</tr>
<tr>
<td>KiHNO2 [mmol/L]</td>
<td>0.005</td>
<td>0.005</td>
<td>1</td>
</tr>
</tbody>
</table>

**NOB**

<table>
<thead>
<tr>
<th>Name</th>
<th>Default</th>
<th>Value</th>
<th>Arrhenius</th>
</tr>
</thead>
<tbody>
<tr>
<td>Max. spec. growth rate [1/d]</td>
<td>0.7</td>
<td>0.7</td>
<td>1.06</td>
</tr>
<tr>
<td>Substrate (NO2) half sat. [mgN/L]</td>
<td>0.1</td>
<td>0.1</td>
<td>1</td>
</tr>
<tr>
<td>Aerobic decay rate [1/d]</td>
<td>0.17</td>
<td>0.17</td>
<td>1.029</td>
</tr>
<tr>
<td>Anoxic/anaerobic decay rate [1/d]</td>
<td>0.08</td>
<td>0.08</td>
<td>1.029</td>
</tr>
<tr>
<td>KiNH3 [mmol/L]</td>
<td>0.075</td>
<td>0.075</td>
<td>1</td>
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</table>

**SWITCHES**

<table>
<thead>
<tr>
<th>Name</th>
<th>Default</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heterotrophic DO half sat. [mgO2/L]</td>
<td>0.05</td>
<td>0.05</td>
</tr>
<tr>
<td>Aerobic denit. DO half sat. [mgO2/L]</td>
<td>0.05</td>
<td>0.05</td>
</tr>
</tbody>
</table>
### SUMMARY OF INPUTS

|                          | Total | WAS   | ANA MLSS | ANX MLSS | AER MLSS | FIN EFF TKN | FIN EFF NOx | FIN EFF T-N | FIN EFF T-P | FIN EFF TSS | FIN EFF NH4-N | SC EFF OPO4-P | SC EFF NOx-N | SC EFF NH4-N | AUR [mg/g MLVSS/hr] | SAUR [mg/g MLVSS/hr] | NPR [mg/g MLVSS/hr] | SNPR [mg/g MLVSS/hr] | PUR [mg/g MLVSS/hr] | SPUR [mg/g MLVSS/hr] |
|--------------------------|-------|-------|----------|----------|----------|-------------|-------------|-------------|-------------|-------------|---------------|---------------|---------------|---------------|----------------|------------------------|----------------|----------------|----------------|----------------|----------------|----------------|
|                          | 8.85  | 32509 | 1763     | 3735     | 3735     | 1.81        | 11.83       | 13.63       | .51          | 4.1          | .42           | 0.88          | 11.17         | <1.0          | 1.55                      | 0.58                    | 2.12                      | 0.79                      | 4.91                      | 1.82                      |

### Profile Data

<table>
<thead>
<tr>
<th>SC EFF OPO4-P [mg/L]</th>
<th>SC EFF NOx-N [mg/L]</th>
<th>SC EFF NH4-N [mg/L]</th>
<th>AUR [mg/g MLVSS/hr]</th>
<th>SAUR [mg/g MLVSS/hr]</th>
<th>NPR [mg/g MLVSS/hr]</th>
<th>SNPR [mg/g MLVSS/hr]</th>
<th>PUR [mg/g MLVSS/hr]</th>
<th>SPUR [mg/g MLVSS/hr]</th>
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</thead>
<tbody>
<tr>
<td>0.88</td>
<td>11.17</td>
<td>&lt;1.0</td>
<td>1.55</td>
<td>0.58</td>
<td>2.12</td>
<td>0.79</td>
<td>4.91</td>
<td>1.82</td>
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### PERIOD 3 (8/22/09 - 10/2/09)

### SIMULATION INPUTS

### Primary Effluent Fractions

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<thead>
<tr>
<th>Name</th>
<th>Default</th>
<th>Value</th>
</tr>
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<tbody>
<tr>
<td>Fbs - Readily biodegradable (including Acetate)</td>
<td></td>
<td>[gCOD/g of total COD]</td>
</tr>
<tr>
<td>Fac - Acetate</td>
<td></td>
<td>[gCOD/g of readily biodegradable COD]</td>
</tr>
<tr>
<td>Fxsp - Non-colloidal slowly biodegradable</td>
<td></td>
<td>[gCOD/g of slowly degradable COD]</td>
</tr>
<tr>
<td>Fus - Unbiodegradable soluble</td>
<td></td>
<td>[gCOD/g of total COD]</td>
</tr>
<tr>
<td>Fup - Unbiodegradable particulate</td>
<td></td>
<td>[gCOD/g of total COD]</td>
</tr>
<tr>
<td>Fna - Ammonia</td>
<td></td>
<td>[gNH3-N/gTKN]</td>
</tr>
<tr>
<td>Fnox - Particulate organic nitrogen</td>
<td></td>
<td>[gN/g Organic N]</td>
</tr>
<tr>
<td>Parameter</td>
<td>Value</td>
<td>Value</td>
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<td>---------------------------------</td>
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<tr>
<td>Fnus - Soluble unbiodegradable TKN [gN/gTKN]</td>
<td>0.020</td>
<td>0.033</td>
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<tr>
<td>FupN - N:COD ratio for unbiodegradable part. COD [gN/gCOD]</td>
<td>0.035</td>
<td>0.030</td>
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<tr>
<td>Fpo4 - Phosphate [gPO4-P/gTP]</td>
<td>0.750</td>
<td>0.849</td>
</tr>
<tr>
<td>FupP - P:COD ratio for unbiodegradable part. COD [gP/gCOD]</td>
<td>0.011</td>
<td>0.011</td>
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### Primary Effluent Itinerary

<table>
<thead>
<tr>
<th>Flow</th>
<th>Total COD mgCOD/L</th>
<th>TKN mgN/L</th>
<th>TP mgP/L</th>
<th>NO3-N mgN/L</th>
<th>pH</th>
<th>Alk. mmol/L</th>
<th>ISS mgISS/L</th>
<th>Ca mg/L</th>
<th>Mg mg/L</th>
<th>DO mg/L</th>
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<tbody>
<tr>
<td>19.96</td>
<td>470.9</td>
<td>41.7</td>
<td>11.3</td>
<td>0.1</td>
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<td>23.71</td>
<td>12</td>
<td>6</td>
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*Note: Values are averages of effluent data taken from Nansemond MPOR*

### Process Details

<table>
<thead>
<tr>
<th>Process</th>
<th>Total Vol [MG]</th>
<th>HRT w/out recycle [hr]</th>
<th>DO-Set Point [mg/L]</th>
<th>Tanks in Service [No.]</th>
<th>% Removal [%]</th>
<th>Sludge Blanket</th>
<th>Underflow - Constant [MGD]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anaerobic Tanks (3 cells per Train)</td>
<td>2.085</td>
<td>0.91</td>
<td>un-aerated</td>
<td>4</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Anoxic Tanks (3 cells per Train)</td>
<td>2.085</td>
<td>0.91</td>
<td>un-aerated</td>
<td>4</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Aeration Tank 1</td>
<td>1.800</td>
<td>1.453</td>
<td>2</td>
<td>2</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Aeration Tank 2</td>
<td>1.800</td>
<td>1.453</td>
<td>2</td>
<td>2</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Aeration Tank 3</td>
<td>1.800</td>
<td>1.453</td>
<td>2</td>
<td>2</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Secondary Clarifier</td>
<td>4.510</td>
<td>3.640</td>
<td>-</td>
<td>2</td>
<td>99.85</td>
<td>0.2</td>
<td>0.00</td>
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### SPLITTERS

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</thead>
<tbody>
<tr>
<td>WAS</td>
<td>1.45</td>
<td>33986</td>
<td>ARCY = 17.86</td>
<td>0</td>
<td>5.59</td>
</tr>
<tr>
<td>NRCY</td>
<td>0</td>
<td></td>
<td>NRCY ON = 0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ARCY</td>
<td>17.86</td>
<td></td>
<td>CRCY = 11.92</td>
<td>Daily = 19.99</td>
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</tr>
<tr>
<td></td>
<td></td>
<td>Temperature = 26.84</td>
<td>Temperature = 26.84</td>
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### PARAMETERS (KINETIC)

<table>
<thead>
<tr>
<th>Name</th>
<th>Default</th>
<th>Value</th>
<th>Arrhenius</th>
</tr>
</thead>
<tbody>
<tr>
<td>Max. spec. growth rate [1/d]</td>
<td>0.9</td>
<td>0.53</td>
<td>1.072</td>
</tr>
<tr>
<td>Substrate (NH4) half sat. [mgN/L]</td>
<td>0.7</td>
<td>0.7</td>
<td>1</td>
</tr>
<tr>
<td>Aerobic decay rate [1/d]</td>
<td>0.17</td>
<td>0.17</td>
<td>1.029</td>
</tr>
<tr>
<td>Anoxic/anaerobic decay rate [1/d]</td>
<td>0.08</td>
<td>0.08</td>
<td>1.029</td>
</tr>
<tr>
<td>KIHNO2 [mmol/L]</td>
<td>0.005</td>
<td>0.005</td>
<td>1</td>
</tr>
</tbody>
</table>
### NOB

<table>
<thead>
<tr>
<th>Name</th>
<th>Default</th>
<th>Value</th>
<th>Arrhenius</th>
</tr>
</thead>
<tbody>
<tr>
<td>Max. spec. growth rate [1/d]</td>
<td>0.7</td>
<td>0.7</td>
<td>1.06</td>
</tr>
<tr>
<td>Substrate (NO2) half sat. [mgN/L]</td>
<td>0.1</td>
<td>0.1</td>
<td>1</td>
</tr>
<tr>
<td>Aerobic decay rate [1/d]</td>
<td>0.17</td>
<td>0.17</td>
<td>1.029</td>
</tr>
<tr>
<td>Anoxic/anaerobic decay rate [1/d]</td>
<td>0.08</td>
<td>0.08</td>
<td>1.029</td>
</tr>
<tr>
<td>KINH3 [mmol/L]</td>
<td>0.075</td>
<td>0.075</td>
<td>1</td>
</tr>
</tbody>
</table>

### SWITCHES

<table>
<thead>
<tr>
<th>Name</th>
<th>Default</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heterotrophic DO half sat. [mgO2/L]</td>
<td>0.05</td>
<td>0.05</td>
</tr>
<tr>
<td>Aerobic denit. DO half sat. [mgO2/L]</td>
<td>0.05</td>
<td>0.05</td>
</tr>
<tr>
<td>Ammonia oxidizer DO half sat. [mgO2/L]</td>
<td>0.25</td>
<td>0.25</td>
</tr>
<tr>
<td>Nitrite oxidizer DO half sat. [mgO2/L]</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td>Anaerobic ammonia oxidizer DO half sat.</td>
<td>0.01</td>
<td>0.01</td>
</tr>
<tr>
<td>Anoxic NO3 half sat. [mgN/L]</td>
<td>0.1</td>
<td>0.1</td>
</tr>
<tr>
<td>Anoxic NO2 half sat. (mgN/L)</td>
<td>0.01</td>
<td>0.1</td>
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<tr>
<td>NH3 nutrient half sat. [mgN/L]</td>
<td>1.00E-04</td>
<td>0.001</td>
</tr>
<tr>
<td>PolyP half sat. [mgP/L]</td>
<td>0.01</td>
<td>0.01</td>
</tr>
<tr>
<td>VFA sequestration half sat. [mgCOD/L]</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>P uptake half sat. [mgP/L]</td>
<td>0.15</td>
<td>0.15</td>
</tr>
<tr>
<td>P nutrient half sat. [mgP/L]</td>
<td>0.001</td>
<td>0.001</td>
</tr>
<tr>
<td>Autotroph CO2 half sat. [mmol/L]</td>
<td>0.1</td>
<td>0.1</td>
</tr>
<tr>
<td>Heterotrophic Hydrogen half sat. [mgCOD/L]</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Propionic acetogens Hydrogen half sat.</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Synthesis anion/cation half sat. [meq/L]</td>
<td>0.01</td>
<td>0.01</td>
</tr>
</tbody>
</table>

### SUMMARY OF INPUTS

| Total SRT [days] | WAS [lbs/day] | ANA MLSS [mg/L] | ANX MLSS [mg/L] | AER MLSS [mg/L] | FIN EFF TKN [mg/L] | FIN EFF NOx [mg/L] | FIN EFF T-N [mg/L] | FIN EFF T-P [mg/L] | FIN EFF TSS [mg/L] | FIN EFF NH4-N [mg/L] | FIN EFF OPO4-P [mg/L] | SC EFF NOx-N [mg/L] | SC EFF NH4-N [mg/L] | SC EFF AUR [mg/g MLVSS/hr] | SAUR [mg/g MLVSS] | NPR [mg/g MLVSS/hr] | SNPR [mg/g MLVSS/hr] | PUR [mg/g MLVSS/hr] | SPUR [mg/g MLVSS/hr] |
|------------------|--------------|-----------------|-----------------|-----------------|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|----------------------|-----------------|--------------|----------------|-----------------|----------------|----------------|
| 5.59             | 33986        | 1440            | 2710            | 2710            | 2.16              | 18.38             | 20.54             | 1.20              | 6.89              | 2.24              | 1.31              | 17                | <1.0              | 2.64               | 1.3                 | 3.65              | 1.78             | 6.35              | 3.09              |
PERIOD 5 (10/23/09 - 11/5/09)

SIMULATION INPUTS

### Primary Effluent Fractions

<table>
<thead>
<tr>
<th>Name</th>
<th>Default Value</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fbs - Readily biodegradable (including Acetate) [gCOD/g of total COD]</td>
<td>0.270</td>
<td>0.270</td>
</tr>
<tr>
<td>Fac - Acetate [gCOD/g of readily biodegradable COD]</td>
<td>0.150</td>
<td>0.220</td>
</tr>
<tr>
<td>Fxsp - Non-colloidal slowly biodegradable [gCOD/g of slowly degradable COD]</td>
<td>0.500</td>
<td>0.615</td>
</tr>
<tr>
<td>Fus - Unbiodegradable soluble [gCOD/g of total COD]</td>
<td>0.080</td>
<td>0.157</td>
</tr>
<tr>
<td>Fup - Unbiodegradable particulate [gCOD/g of total COD]</td>
<td>0.080</td>
<td>0.171</td>
</tr>
<tr>
<td>Fna - Ammonia [gNH3-N/gTKN]</td>
<td>0.750</td>
<td>0.744</td>
</tr>
<tr>
<td>Fnox - Particulate organic nitrogen [gN/g Organic N]</td>
<td>0.250</td>
<td>0.148</td>
</tr>
<tr>
<td>Fnus - Soluble unbiodegradable TKN [gN/gTKN]</td>
<td>0.020</td>
<td>0.033</td>
</tr>
<tr>
<td>FupN - N:COD ratio for unbiodegradable part. COD [gN/gCOD]</td>
<td>0.035</td>
<td>0.030</td>
</tr>
<tr>
<td>Fpo4 - Phosphate [gPO4-P/gTP]</td>
<td>0.750</td>
<td>0.849</td>
</tr>
<tr>
<td>FupP - P:COD ratio for unbiodegradable part. COD [gP/gCOD]</td>
<td>0.011</td>
<td>0.011</td>
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</tbody>
</table>

### Primary Effluent Itinerary

<table>
<thead>
<tr>
<th>Flow [mgCOD/L]</th>
<th>Total COD</th>
<th>TKN mgN/L</th>
<th>TP mgP/L</th>
<th>NO3-N mgN/L</th>
<th>pH</th>
<th>Alk. mmol/L</th>
<th>ISS mgISS/L</th>
<th>Ca mg/L</th>
<th>Mg mg/L</th>
<th>DO mg/L</th>
</tr>
</thead>
<tbody>
<tr>
<td>19.27</td>
<td>481.3</td>
<td>46.1</td>
<td>13.6</td>
<td>0.1</td>
<td>7</td>
<td>5.4</td>
<td>22</td>
<td>12</td>
<td>6</td>
<td>0</td>
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<tr>
<td>Increased by =</td>
<td>Original =</td>
<td>481.3</td>
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*NOTE: Values are averages of effluent data taken from Nansemond MPOR

### Process Status

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<tr>
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<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Anaerobic Tanks (3 cells per Train)</td>
<td>2.085</td>
<td>0.91</td>
<td>un-aerated</td>
<td>4</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Anoxic Tanks (3 cells per Train)</td>
<td>2.085</td>
<td>0.91</td>
<td>un-aerated</td>
<td>4</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Aeration Tank 1</td>
<td>1.800</td>
<td>1.453</td>
<td>2</td>
<td>2</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Aeration Tank 2</td>
<td>1.800</td>
<td>1.453</td>
<td>2</td>
<td>2</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Aeration Tank 3</td>
<td>1.800</td>
<td>1.453</td>
<td>2</td>
<td>2</td>
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<td>-</td>
</tr>
<tr>
<td>Secondary Clarifier</td>
<td>4.510</td>
<td>3.640</td>
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<td>99.8</td>
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### Rate in Side (S)

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<td>Avg. Calc.</td>
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<tr>
<td>SPLITTERS</td>
<td>[MGD]</td>
<td>[lbs/d]</td>
<td>ARCY</td>
<td>NRCY ON</td>
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<td>-----------</td>
<td>-------</td>
<td>---------</td>
<td>------</td>
<td>---------</td>
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<tr>
<td>WAS</td>
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<td>ARCY</td>
<td>16.99</td>
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</table>

**PARAMETERS (KINETIC)**

**AOB**

<table>
<thead>
<tr>
<th>Name</th>
<th>Default</th>
<th>Value</th>
<th>Arrhenius</th>
</tr>
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**NOB**

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7.2 Appendix B

Complete Simulation Dynamic (7/23/09 - 11/5/09)

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<td>Fup - Unbiodegradable particulate [gCOD/g of total COD]</td>
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## 7.3 Appendix C – Profile Sampling Data and Calculated Rates

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### 7.5 Appendix E - QAC Addition Calculation

#### Nansemond Plant

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<th>Chem. Toilet Waste [gal/day]</th>
<th>Chemical Liquid Addition</th>
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#### Chemical Stock

- 3.12 mL/L

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<td>Peak Duration</td>
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**Assumptions:**
Receive peak waste during one month of the year. Receive the waste out of the 20 days in 4 hour periods throughout the 8 hour workday.

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<td>Peak Duration</td>
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**Assumptions:**
Receive peak waste during two months of the summer. Receive the waste out of the 40 days in 5 hour periods throughout the 8 hour workday.

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**Assumptions:**
Receive peak waste during summer months (June, July, August) when use of portable toilets is at a peak. Receive the waste out of the 60 days in 6 hour periods throughout the 8 hour workday.
7.5 Appendix F – Iron Addition Calculation and Plan

NS Treatment plant Iron Addition

Iron addition rate = 3000 lbs/day Fe
Flow Rate = 19 MGD
Fe Dose = 18.93 mg/L Fe

FeCl₃ Stock Solution in Lab

FeCl₃ Stock = 341 g/L FeCl₃
As Fe = 117 g/L Fe

Day 1

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<th>Reactor</th>
<th>NS Mixed Liquor (L)</th>
<th>Fe Dose (mg/L Fe)</th>
<th>Fe Stock (uLs)</th>
<th>VIP SE (L)</th>
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<td>D</td>
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- Add 1.0 L NS mixed liquor to each reactor
- Add 2 L of VIP SE, and start pH and DO control
- Wait 10 Min
- Record pH
- Add FeCl₃ stock solution to Reactors B, C, D
- Add Corresponding Alkalinity
- Record pH reduction immediately after Fe Addition
- Wait 2 hours
- Start experiment as normal

Day 2

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<th>Fe Stock (uLs)</th>
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- Add 1.0 L VIP mixed liquor to each reactor
- Start aeration and wait ~10 min
- measure pH by dipping calibrated probe into top of reactor
- Add FeCl₃ stock solution to Reactors B, C, D
- Wait 2 hours
- measure pH by dipping calibrated probe into top of reactor
- Add 2 L of VIP SE, and start pH and DO control
- Wait for all pH and DO to stabilize at setpoint
- Wait at least 15-20 min
- Start experiment as normal
### 7.6 Appendix G – Weekly Profile Sampling Data

#### Week 1 – 7/23/09

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<th>Sample Number</th>
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<th>Nitrite by HACH PP</th>
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### Actual SRT

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<th>Min AER pH</th>
<th>AUR (NH4-N Slope)</th>
<th>SAUR</th>
<th>NPR (NOx-N Slope)</th>
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### Highest AER NO3-N Concentration

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<tr>
<th>Date</th>
<th>PUR (PO4-P Uptake Slope)</th>
<th>SPUR</th>
<th>Clarifier IDC NH4-N</th>
<th>Clarifier IDC NOx-N</th>
<th>Clarifier IDC PO4-P Concentration</th>
<th>Max ANA PO4-P Release</th>
<th>Avg. ANA NO3-N Concentration</th>
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### AA1 PO4-P Release Slope

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<th>AA2 PO4-P Release Slope</th>
<th>AA3 PO4-P Release Slope</th>
<th>AA4 PO4-P Release Slope</th>
<th>AA5 PO4-P Release Slope</th>
<th>AA6 PO4-P Release Slope</th>
<th>(AA1) COD Uptake Slope</th>
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### # Chem Used

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<th>ARCY Flow</th>
<th>CRCY Flow</th>
<th>NRCY Flow</th>
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### ANA MLRSS

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Week 2 – 7/27/09 & 7/29/09
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<th>Sample Number</th>
<th>Reactor Type</th>
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<th>Nitrate by HACH TNT</th>
<th>Nitrite by HACH PP</th>
<th>NOx-N by Nitrate HACH + Nitrite HACH</th>
<th>Phosphate by HACH TNT</th>
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*NOTE: These values are <1 mg/L NH4-N

QA/QC Sample: SE

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Actual SRT | Aerobic MLSS | Average AER DO | Min AER pH | AUR (NH4-N Slope) | SAUR | NPR (NOx-N Slope) | SNPR |
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Highest AER NO2-N Concentration | PUR (PO4-P Uptake Slope) | SPUR | Clarifier IDC NH4-N | Clarifier IDC NOx-N | Clarifier IDC PO4-P Concentration | Max ANA PO4-P Release | Avg. ANA NO2-N Concentration |
<p>| [mg/L] | [mg/L/hr] | [mg/g MLVSS/hr] | [mg/L] | [mg/L] | [mg/L] | [mg/L] | [mg/L] |
| 2.44 | 2.13 | 0.80 | 0.0000 | 10.5200 | 0.3 | 28.44 | 0.669 |</p>
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<th>AA1 Specific PO₄-P Release Rate</th>
<th>AA2 PO₄-P Release Slope</th>
<th>AA2 Specific PO₄-P Release Rate</th>
<th>AA3 PO₄-P Release Slope</th>
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<td>(mg/L)</td>
<td>(mg/L/hr)</td>
<td>(mg/g MLVSS/hr)</td>
<td>(mg/L/hr)</td>
<td>(mg/g MLVSS/hr)</td>
<td>(mg/L/hr)</td>
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<th>AA5 PO₄-P Release Slope</th>
<th>AA5 Specific PO₄-P Release Rate</th>
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<tr>
<td>Date</td>
<td>Sample Time</td>
<td>HRT along BNR Process (w/out Recycles)</td>
<td>Sample Number</td>
<td>Reactor Type</td>
<td>Ammonia by HACH TNT</td>
<td>Nitrate by HACH TNT</td>
<td>Nitrite by HACH TNT</td>
<td>NOx-N by Nitrate HACH + Nitrite HACH</td>
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<tr>
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*NOTE: These values are <1 mg/L NH₄-N*
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**PROFILE 1:** Train 5, Aeration Tank 5, Clarifier 5

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<th>Nitrate by HACH TNT</th>
<th>Nitrite by HACH PP</th>
<th>NOx-N by Nitrate HACH + Nitrite</th>
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*NOTE: These values are <1 mg/L NH4-N*

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## PROFILE 2: Train 4, Aeration Tank 4, Clarifier 4

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<th>Nitrate by HACH TNT</th>
<th>Nitrite by HACH TNT</th>
<th>NOx-N by HACH + Nitrite</th>
<th>Phosphate by HACH TNT</th>
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*NOTE: These values are <1 mg/L NH₄-N*

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### Highest AER NO₂⁻-N Concentration

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Profile Sampling Nutrient Levels

Concentration [mg/L]

Sample Profile Sampling Nutrient Levels

Concentration [mg/L]

Sample Profile Sampling Nutrient Levels

Concentration [mg/L]

Sample
## PROFILE 1: Train 5, Aeration Tank 5, Clarifier 5

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*NOTE: These values are <1 mg/L NH4-N*

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### Actual SRT

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<th>SAUR</th>
<th>NPR (NOx-N Slope)</th>
<th>SNPR</th>
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### Highest AER NO2-N Concentration

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<th>AA5 Specific PO₄-P Release Rate</th>
<th>AA6 PO₄-P Release Slope</th>
<th>AA6 Specific PO₄-P Release Rate</th>
<th>(AA1) COD Uptake Slope</th>
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<th>ARCY Flow</th>
<th>CRCY Flow</th>
<th>NRCY Flow</th>
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### PROFILE 2: Train 4, Aeration Tank 4, Clarifier 4

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<th>Nitrate by HACH TNT</th>
<th>Nitrite by HACH TNT</th>
<th>NOx-N by Nitrate HACH + Nitrite HACH</th>
<th>Phosphate by HACH TNT</th>
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*NOTE: These values are <1 mg/L NH4-N
*NOTE: These values are <0.23 mg/L NO3-N

### QA/QC Sample: IDC

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<th>SAUR</th>
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<th>SPUR</th>
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<th>Clarifier IDC NOx-N Concentration</th>
<th>Max ANA PO4-P Release</th>
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### PROFILE 1: Train 6, Aeration Tank 5, Clarifier 5

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<th>Sample Number</th>
<th>Reactor Type</th>
<th>Ammonia by HACH TNT</th>
<th>Nitrate by HACH TNT</th>
<th>Nitrite by HACH PP + Nitrite HACH</th>
<th>NOx-N by HACH</th>
<th>Phosphate by HACH TNT</th>
<th>DO</th>
<th>pH</th>
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*NOTE: These values are <1 mg/L NH₄-N*

### QA/QC Sample: SE

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### Actual SRT

- Aerobic MLSS: [mg/L]
- Average AER DO: [mg/L]
- Min AER pH: [unitless]
- AUR (NH₄-N Slope): [mg/L/min]
- SAUR: [mg/g MLVSS/hr]
- NPR (NOx-N Slope): [mg/L/min]
- SNPR: [mg/g MLVSS/hr]

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### Highest AER NO₂-N Concentration

- PUR (PO₄-P Uptake Slope): [mg/L/hr]
- SPUR: [mg/g MLVSS/hr]
- Clarifier IDC NH₄-N: [mg/L]
- Clarifier IDC NOx-N: [mg/L]
- Clarifier IDC PO₄-P Concentration: [mg/L]
- Max ANA PO₄-P Release: [mg/L]
- Avg. ANA NO₃-N Concentration: [mg/L]

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*NOTE: These values are <1 mg/L NH4-N
*NOTE: These values are <0.23 mg/L NO3-N

**QA/QC Sample:** SE

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**Actual SRT**
<p>| Aerobic MLSS | Average AER DO | Min AER pH | AUR (NH4-N Slope) | SAUR | NPR (NOx-N Slope) | SNPR |</p>
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**Highest AER NOx-N Concentration**
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**NOTE:** These values are <1 mg/L NH₄-N
**NOTE:** These values are <0.23 mg/L NO₃-N

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### PROFILE 2: Train 6, Aeration Tank 5, Clarifier 5

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**NOTE:** These values are <0.23 mg/L NO3-N

**NOTE:** These values are <1 mg/L NH4-N

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### Analytical Data

- **SRT:** 7.34 days
- **AER DO:** 1.35 mg/L
- **Min AER pH:** 6.67
- **AUR (NH4-N Slope):** 2.55 mg/L/hr
- **AUR:** 2.05 mg/L/hr/
- **SAUR:** 1.05 mg/L/min
- **SNPR:** 1.85 mg/L/hr

### Highest AER NO2-N Concentration

- **PUR (PO4-P Uptake Slope):** 0.52 mg/L/hr
- **SPUR:** 6.92 mg/L/hr
- **Clarifier IDC NH4-N:** 9.64 mg/L
- **Clarifier IDC NOx-N:** 18.8800 mg/L
- **Max AAN PO4-P Release:** 3.0 mg/L
- **Avg. ANA NO2-N Concentration:** 0.326 mg/L

### NOX-N by Nitrate HACH and + Nitrite HACH TNT

- **AA4 NOx-N:** 0.09 mg/L
- **AA4 Specific PO4-P Release Rate:** 0.09 mg/L/hr
- **AA4 Specific PO4-P Release Rate:** 0.12 mg/L/hr
- **AA4 Specific PO4-P Release Rate:** 0.05 mg/L/hr
- **AA4 Specific PO4-P Release Rate:** 1.80 mg/L/hr
- **AA4 Specific PO4-P Release Rate:** 0.74 mg/L/hr
- **AA4 Specific PO4-P Release Rate:** 42.70 mg/L/hr
- **AA4 Specific PO4-P Release Rate:** 26.83 mg/L/hr
- **AA4 Specific PO4-P Release Rate:** 0.35 mg/L/hr

### NO2-N by Nitrite HACH PP

- **AA4 NOx-N:** 0.09 mg/L
- **AA4 Specific PO4-P Release Rate:** 0.09 mg/L/hr
- **AA4 Specific PO4-P Release Rate:** 0.12 mg/L/hr
- **AA4 Specific PO4-P Release Rate:** 0.05 mg/L/hr
- **AA4 Specific PO4-P Release Rate:** 1.80 mg/L/hr
- **AA4 Specific PO4-P Release Rate:** 0.74 mg/L/hr
- **AA4 Specific PO4-P Release Rate:** 42.70 mg/L/hr
- **AA4 Specific PO4-P Release Rate:** 26.83 mg/L/hr
- **AA4 Specific PO4-P Release Rate:** 0.35 mg/L/hr
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Profile Sampling Nutrient Levels

- **COD**: Concentration [mg/L]
- **Ammonia**: Concentration [mg/L]
- **Phosphate**: Concentration [mg/L]
- **pH**: Concentration [mg/L]
- **Nitrate**: Concentration [mg/L]
- **Nitrite**: Concentration [mg/L]
- **NOx-N**: Concentration [mg/L]
- **DO**: Concentration [mg/L]
### Week 7 – 9/1/09 & 9/2/09

**PROFILE 1:** Train 4, Aeration Tank 4, Clarifier 4

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**NOTE:** These values are <1 mg/L NH4-N.

**NOTE:** These values are <0.23 mg/L NO3-N.

**QA/QC Sample:** SE

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Actual SRT Aerobic MLSS Average AER DO Min AER pH AUR (NH4-N Slope) SAUR NPR (NOx-N Slope) SNPR
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5.21 2800 1.29 6.72 2.70 1.32 4.86 2.28

Highest AER NO2-N Concentration PUR (PO4-P Uptake Slope) SPUR Clarifier IDC NH4-N Clarifier IDC NO2-N Clarifier IDC PO4-P Concentration Max ANA PO4-P Release Avg. ANA NO3-N Concentration
[mg/L] [mg/L/hr] [mg/g MLVSS/hr] [mg/L] [mg/L] [mg/L] [mg/L]
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AA4 NOx-N AA6 NOx-N AA1 PO4-P Release Slope AA1 Specific PO4-P Release Rate AA2 PO4-P Release Slope AA2 Specific PO4-P Release Rate AA3 PO4-P Release Slope AA3 Specific PO4-P Release Rate
[mg/L] [mg/L] [mg/L/hr] [mg/g MLVSS/hr] [mg/L/hr] [mg/g MLVSS/hr] [mg/L/hr] [mg/g MLVSS/hr]
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AA4 PO4-P Release Slope AA4 Specific PO4-P Release Rate AA5 PO4-P Release Slope AA5 Specific PO4-P Release Rate AA6 PO4-P Release Slope AA6 Specific PO4-P Release Rate (AA1) COD Uptake Slope (AA1) Specific COD Uptake Rate (AA1) PO4-P (AA1) COD
[mg/L/hr] [mg/g MLVSS/hr] [mg/L/hr] [mg/g MLVSS/hr] [mg/L/hr] [mg/g MLVSS/hr] [mg/L/hr] [mg/g MLVSS/hr]
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Profile Sampling Nutrient Levels

![Profile Sampling Nutrient Levels](image1)

Profile Sampling Nutrient Levels

![Profile Sampling Nutrient Levels](image2)

Profile Sampling Nutrient Levels

![Profile Sampling Nutrient Levels](image3)
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<th>Nitrite by HACH PP + Nitrate HACH</th>
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*NOTE: These values are <1 mg/L NH4-N
*NOTE: These values are <0.23 mg/L NO3-N

### QA/QC Sample: SE

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<th>PUR (PO4-P Uptake Slope)</th>
<th>SPUR</th>
<th>Clarifier IDC NH4-N</th>
<th>Clarifier IDC NOx-N</th>
<th>Clarifier IDC PO4-P Concentration</th>
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<th>Avg. ANA NOx-N Concentration</th>
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<td>(mg/g MLVSS/hr)</td>
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<th>AA6 NOx-N</th>
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<th>AA1 Specific PO4-P Release Rate</th>
<th>AA2 PO4-P Release Slope</th>
<th>AA2 Specific PO4-P Release Rate</th>
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<th>AA5 PO4-P Release Slope</th>
<th>AA5 Specific PO4-P Release Rate</th>
<th>AA6 PO4-P Release Slope</th>
<th>AA6 Specific PO4-P Release Rate</th>
<th>(AA1) COD Uptake Slope</th>
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<td>[mg/L/hr]</td>
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<td>[mg/g MLVSS/hr]</td>
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<td>FeCl3 Hrs Used</td>
<td>FeCl3 Addition</td>
<td>Active Biosolid</td>
<td>Influent Flow</td>
<td>ARCY Flow</td>
<td>CRCY Flow</td>
<td>NRCY Flow</td>
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<th>ANA MLVSS</th>
<th>ANX MLTSS</th>
<th>ANX % VOL</th>
<th>ANX MLVSS</th>
<th>AER MLTSS</th>
<th>AER % VOL</th>
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Profile Sampling Nutrient Levels

- **sCOD**
- **Ammonia**
- **Phosphate**
- **pH**
- **Nitrate**
- **Nitrite**
- **NOx-N**
- **DO**
### Week 8 – 9/9/09

**PROFILE 1: Train 6, Aeration Tank 5, Clarifier 5**

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<th>Date</th>
<th>Sample Time</th>
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<th>Sample Number</th>
<th>Reactor Type</th>
<th>Ammonia by HACH TNT</th>
<th>Nitrite by HACH TNT</th>
<th>Nitrate by HACH + Nitrite HACH TTNB</th>
<th>NOx-N by Nitrate HACH TTNB</th>
<th>Phosphate by HACH TTNB</th>
<th>DO</th>
<th>pH</th>
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<td>Anaerobic</td>
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**QA/QC Sample:** SE

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<td>NH4-N</td>
<td>NO2,3-N</td>
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**Actual SRT**

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**Highest AER NO2-N Concentration**

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<th>Avg. ANA NO2-N Concentration</th>
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**AA4 NOx-N**

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**AA4 PO4-P Release Slope**

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<td>0.06</td>
<td>1.62</td>
<td>0.84</td>
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# Chem Used

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<th>FeCl3 Hrs Used</th>
<th>FeCl3 Addition</th>
<th>Active Biosolid</th>
<th>Influent Flow</th>
<th>ARCY Flow</th>
<th>CRCY Flow</th>
<th>NRCY Flow</th>
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<tbody>
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<td>[lbs]</td>
<td>[hrs]</td>
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<td>(MGD)</td>
<td>(MGD)</td>
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<td>14.032</td>
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</table>

| ANA MLTSS   | ANA % VOL    | ANA MLVSS     | ANX MLTSS    | ANX % VOL   | ANX MLVSS | AER MLTSS | AER % VOL | AER MLVSS |
|-------------|--------------|---------------|--------------|-------------|-----------|-----------|-----------|
| [mg/L] | [%]  | [mg/L] | [%] | [mg/L] | [%] | [mg/L] | [%] | [mg/L] |
| 1140       | 77           | 878           | 2600         | 74          | 1924      | 2600      | 74        | 1924      |

---

**Profile Sampling Nutrient Levels**

- COD
- Ammonia
- Phosphate
- pH
- Nitrate
- Nitrite
- NOx-N
- DO

---

**Sample**
### PROFILE 1: Train 4, Aeration Tank 4, Clarifier 4

<table>
<thead>
<tr>
<th>Date</th>
<th>Sample Time</th>
<th>HRT along BNR Process (w/out Recycles)</th>
<th>Sample Number</th>
<th>Reactor Type</th>
<th>Ammonia by HACH TNT</th>
<th>Nitrate by HACH TNT</th>
<th>Nitrite by HACH TNT</th>
<th>NO3-N by Nitrate HACH + Nitrite HACH</th>
<th>Phosphate by HACH TNT/84</th>
<th>DO</th>
<th>pH</th>
</tr>
</thead>
<tbody>
<tr>
<td>14-Sep-09</td>
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<td>PE</td>
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<td>Aerobic</td>
<td>38.90</td>
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*NOTE: These values are <0.5 mg/L PO4-P
*NOTE: These values are <1 mg/L NH4-N
*NOTE: These values are <0.23 mg/L NO3-N

**QA/QC Sample: SE**

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<th>Clarifier IDC NOX-N</th>
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<th>AA2 PO4-P Release Slope</th>
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<th>AA6 PO4-P Release Slope</th>
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<th>ARCY Flow</th>
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<th>ANX % VOL</th>
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### Graphs

1. **Profile Sampling Nutrient Levels**
   - Sample: PE, AA1, AA2, AA3, AA4, AA5, AA6, AER1, AER1.25, AER1.5, AER3, AER5, IDC, SE, RAS
   - Y-axis: Concentration [mg/L]
   - X-axis: Sample
   - Labels: COD

2. **Profile Sampling Nutrient Levels**
   - Sample: PE, AA1, AA2, AA3, AA4, AA5, AA6, AER1, AER1.25, AER1.5, AER3, AER5, IDC, SE, RAS
   - Y-axis: Concentration [mg/L]
   - X-axis: Sample
   - Labels: Ammonia, Phosphate, pH

3. **Profile Sampling Nutrient Levels**
   - Sample: PE, AA1, AA2, AA3, AA4, AA5, AA6, AER1, AER1.25, AER1.5, AER3, AER5, IDC, SE, RAS
   - Y-axis: Concentration [mg/L]
   - X-axis: Sample
   - Labels: Nitrate, Nitrite, NO₃-N, DO
### PROFILE 2: Train 6, Aeration Tank 5, Clarifier 5

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<th>Sample Number</th>
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<th>Nitrite by HACH TNT</th>
<th>Nitrate by HACH TNT</th>
<th>NO3-N by Nitrate HACH + Nitrite HACH</th>
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*NOTE: These values are <1 mg/L NH4-N*

*NOTE: These values are <0.23 mg/L NO3-N*

*NOTE: These values are <0.5 mg/L PO4-P*

### QA/QC Sample: SE

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### Highest AER NO3-N Concentration

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<th>AA6 NO3-N</th>
<th>AA1 PO4-P Release Slope</th>
<th>AA1 Specific PO4-P Release Rate</th>
<th>AA2 PO4-P Release Slope</th>
<th>AA2 Specific PO4-P Release Rate</th>
<th>AA3 PO4-P Release Slope</th>
<th>AA3 Specific PO4-P Release Rate</th>
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<tbody>
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<td>[mg/L/hr]</td>
<td>[mg/g MLVSS/hr]</td>
<td>[mg/L/hr]</td>
<td>[mg/g MLVSS/hr]</td>
<td>[mg/L/hr]</td>
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<tr>
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<td>13.48</td>
<td>12.36</td>
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### AA4 PO4-P Release Slope

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<th>AA4 Specific PO4-P Release Rate</th>
<th>AA5 PO4-P Release Slope</th>
<th>AA5 Specific PO4-P Release Rate</th>
<th>AA6 PO4-P Release Slope</th>
<th>AA6 Specific PO4-P Release Rate</th>
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<th>(AA1) Specific COD Release Rate</th>
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PROFILE 3: Train 6, Aeration Tank 5, Clarifier 5

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<th>Date</th>
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<th>HRT along BNR Process (w/out Recycles)</th>
<th>Sample Number</th>
<th>Reactor Type</th>
<th>Ammonia by HACH TNT</th>
<th>Nitrates by HACH TNT</th>
<th>Nitrite by HACH TNT</th>
<th>NOx-N by Nitrate HACH + Nitrite HACH</th>
<th>Phosphate by HACH TNT</th>
<th>DO</th>
<th>pH</th>
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<td>8:20</td>
<td>PE</td>
<td>-</td>
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<td>7.02</td>
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<tr>
<td>18-Sep-09</td>
<td>8:34</td>
<td>AA1</td>
<td>Anaerobic</td>
<td>28.20</td>
<td>0.30</td>
<td>0.01</td>
<td>0.32</td>
<td>31.98 (mg/L)</td>
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<td>0.01</td>
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<td>37.36 (mg/L)</td>
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<tr>
<td>18-Sep-09</td>
<td>9:34</td>
<td>AA1</td>
<td>Anaerobic</td>
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<td>0.65</td>
<td>0.01</td>
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<td>AER1.5</td>
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<td>11:19</td>
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<td>Aerobic</td>
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*NOTE: These values are <1 mg/L NH4-N
*NOTE: These values are <0.23 mg/L NO3-N
*NOTE: These values are <0.5 mg/L PO4-P

**QA/QC Sample:**

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<tr>
<th>EPA 356.1</th>
<th>EPA 350.1</th>
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<td>NH4-N</td>
<td>NO2/,3-N</td>
<td>NO3-N</td>
<td>NO2-N</td>
</tr>
<tr>
<td>[mg/L]</td>
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**Actual SRT**

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<th>Average AER DO</th>
<th>Min AER pH</th>
<th>AUR (NH4-N Slope)</th>
<th>SAUR</th>
<th>NPR (NOx-N Slope)</th>
<th>SNPR</th>
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<tbody>
<tr>
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<td>[mg/L]</td>
<td>[mg/L]</td>
<td>[unitless]</td>
<td>[mg/L/hr]</td>
<td>[mg/L/min]</td>
<td>[mg/L/hr]</td>
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**Highest AER NO2-N Concentration**

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<tr>
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<th>SPUR</th>
<th>Clarifier IDC NH4-N</th>
<th>Clarifier IDC NOx-N</th>
<th>Max ANA PO4-P Release</th>
<th>Avg. ANA NO2-N Concentration</th>
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</thead>
<tbody>
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**AA4 NOx-N**

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<th>AA2 Specific PO4-P Release Rate</th>
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<td>[mg/L/hr]</td>
<td>[mg/g MLVSS/hr]</td>
<td>[mg/L/hr]</td>
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**AA4 PO4-P Release Rate**

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<th>AA4 Specific PO4-P Release Rate</th>
<th>AA5 Specific PO4-P Release Rate</th>
<th>AA6 Specific PO4-P Release Rate</th>
<th>(AA1) COD Uptake Rate</th>
<th>(AA1) Specific COD Uptake Rate</th>
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<td>[mg/L/hr]</td>
<td>[mg/g MLVSS/hr]</td>
<td>[mg/L/hr]</td>
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### # Chem Used

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<th>Primary Clarifier</th>
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### ANA MLTSS

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<th>AER MLTSS</th>
<th>AER % VOL</th>
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<td>[mg/L]</td>
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<td>[mg/L]</td>
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<td>2013</td>
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### Profile Sampling Nutrient Levels

- sCOD
- Ammonia
- Phosphate
- pH
- Nitrate
- Nitrite
- NOₓ-N
- DO
### PROFILE 1: Train 4, Aeration Tank 4, Clarifier 4

#### Date | Sample Time | HRT along BNR Process (w/o Recycles) | Sample Number | Reactor Type | Ammonia by HACH TNT | Nitrate by HACH TNT | Nitrate by HACH TNT + Nitrite HACH | NO\textsubscript{3}-N by Nitrate HACH | Phosphate by HACH TNT | D\textsubscript{O} | pH
---|---|---|---|---|---|---|---|---|---|---|---
22-Sep-09 | 7:03 | PE | - | 38.80 | 0.81 | 0.03 | 0.94 | 14.68 | 1.49 | 7.09
22-Sep-09 | 7:19 | 0.07 | AA1 | Anaerobic | 28.30 | 0.36 | 0.02 | 0.37 | 32.96 | 0.06 | 7.08
22-Sep-09 | 7:49 | 1.73 | AA2 | Anaerobic | 29.40 | 0.38 | 0.01 | 0.39 | 36.22 | 0.06 | 7.09
22-Sep-09 | 8:19 | 2.60 | AA3 | Anaerobic | 31.80 | 0.36 | 0.01 | 0.39 | 37.69 | 0.07 | 7.09
22-Sep-09 | 8:49 | 3.46 | AA4 | Anaerobic | 22.60 | 0.36 | 0.03 | 0.39 | 34.43 | 0.06 | 7.04
22-Sep-09 | 9:04 | 4.33 | AA5 | Anaerobic | 22.65 | 0.34 | 0.02 | 0.35 | 36.38 | 0.06 | 7.04
22-Sep-09 | 9:19 | 5.19 | AA6 | Anaerobic | 23.85 | 0.34 | 0.02 | 0.36 | 39.97 | 0.07 | 7.03
22-Sep-09 | 9:34 | 0.00 | AER1 | Aerobic | 23.65 | 0.34 | 0.02 | 0.36 | 38.51 | 0.06 | 7.01
22-Sep-09 | 9:42 | 0.34 | AER1.25 | Aerobic | 16.50 | 4.51 | 0.31 | 4.82 | 23.56 | 0.27 | 7.05
22-Sep-09 | 9:50 | 0.67 | AER1.5 | Aerobic | 2.59 | 7.39 | 0.46 | 7.84 | 17.54 | 3.05 | 7.03
22-Sep-09 | 10:15 | 3.35 | AER3 | Aerobic | 5.18 | 13.52 | 0.59 | 14.11 | 6.98 | 2.68 | 6.83
22-Sep-09 | 11:42 | 6.71 | AER5 | Aerobic | 0.00 | 17.82 | 0.05 | 17.87 | 0.23 | 0.40 | 6.7
22-Sep-09 | 11:47 | 0.00 | IDC | - | 18.08 | 0.02 | 18.10 | 0.18 | 3.25 | 6.74
22-Sep-09 | 14:47 | 0.00 | SE | - | 17.74 | 0.02 | 17.76 | 0.19 | 2.87 | 6.69
22-Sep-09 | 15:05 | 0.00 | RAS | - | 10.74 | 2.76 | 13.50 | 2.45 | 0.12 | 6.73

#### NOTE: These values are <1 mg/L NH\textsubscript{4}-N

### QA/QC Sample: SE

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<td>NH\textsubscript{4}-N</td>
<td>NO\textsubscript{2,3}-N</td>
<td>NO\textsubscript{3}-N</td>
<td>NO\textsubscript{2}-N</td>
</tr>
<tr>
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<th>Min AER pH</th>
<th>AUR (NH\textsubscript{4}-N Slope)</th>
<th>SAUR</th>
<th>NPR (NO\textsubscript{2}-N Slope)</th>
<th>SNPR</th>
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<tbody>
<tr>
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<td>[mg/L]</td>
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<td>[mg/L/hr]</td>
<td>[mg/g MLVSS/hr]</td>
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<table>
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<tr>
<th>Highest AER NO\textsubscript{2}-N Concentration</th>
<th>PUR (PO\textsubscript{4}-P Uptake Slope)</th>
<th>SPUR</th>
<th>Clarifier IDC NH\textsubscript{4}-N</th>
<th>Clarifier IDC NO\textsubscript{3}-N</th>
<th>Max ANA PO\textsubscript{4}-P Release</th>
<th>Avg. ANA NO\textsubscript{2}-N Concentration</th>
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<tbody>
<tr>
<td>[mg/L]</td>
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<td>[mg/g MLVSS/hr]</td>
<td>[mg/L]</td>
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<th>AA1 PO\textsubscript{4}-P Release Slope</th>
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<th>AA5 Specific PO\textsubscript{4}-P Release Rate</th>
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<th>AA6 Specific PO\textsubscript{4}-P Release Rate</th>
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**PROFILE 2: Train 6, Aeration Tank 5, Clarifier 5**

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<th>Nitrate by HACH TNT [mg/L NO₂-N]</th>
<th>Nitrite by HACH TNT [mg/L NO¹-N]</th>
<th>NOx-N by Nitrate HACH + Nitrite HACH [mg/L NOx-N]</th>
<th>Phosphate by HACH TNT [mg/L PO₄-P]</th>
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**Note:** These values are <1 mg/L NH₄-N

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<th>Min AER pH</th>
<th>AUR (NH₄-N Slope) [mg/L/hr]</th>
<th>SAUR [mg/L/min]</th>
<th>NPR (NOₓ-N Slope) [mg/L/hr]</th>
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<th>PUR (PO₄-P Uptake Slope) [mg/L/hr]</th>
<th>SPUR</th>
<th>Clarifier IDC NH₄-N [mg/L]</th>
<th>Clarifier IDC NOₓ-N [mg/L]</th>
<th>Max ANA PO₄-P Release Concentration [mg/L]</th>
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<th>AA1 Specific PO₄⁻,P Release Rate</th>
<th>AA2 PO₄⁻,P Release Slope [mg/L/hr]</th>
<th>AA2 Specific PO₄⁻,P Release Rate</th>
<th>AA3 PO₄⁻,P Release Slope [mg/L/hr]</th>
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<th>AA5 PO₄⁻,P Release Slope [mg/L/hr]</th>
<th>AA5 Specific PO₄⁻,P Release Rate [mg/L/hr]</th>
<th>AA6 PO₄⁻,P Release Slope [mg/L/hr]</th>
<th>AA6 Specific PO₄⁻,P Release Rate [mg/L/hr]</th>
<th>(AA1) COD Uptake Rate [mg/L/hr]</th>
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# Chem Used

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Profile Sampling Nutrient Levels

**sCOD**

**Profile Sampling Nutrient Levels**

- Ammonia
- Phosphate
- pH

**Profile Sampling Nutrient Levels**

- Nitrate
- Nitrite
- NOx-N
- DO
### PROFILE 1: Train 4, Aeration Tank 4, Clarifier 4

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<th>Nitrite by HACH TNT</th>
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**NOTE:** These values are <1 mg/L NH4-N

### QA/QC Sample: SE

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<td>NO2-N</td>
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<th>Average AER DO</th>
<th>Min AER pH</th>
<th>AUR (NH4-N Slope)</th>
<th>SAUR</th>
<th>NPR (NOx-N Slope)</th>
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<th>SPUR</th>
<th>Clarifier IDC NH4-N</th>
<th>Clarifier IDC NOx-N</th>
<th>Clarifier IDC PO4-P Concentration</th>
<th>Max ANA PO4-P Release</th>
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<th>A41 Specifically PO4-P Release Rate</th>
<th>A42 PO4-P Release Slope</th>
<th>A42 Specifically PO4-P Release Rate</th>
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<th>A4 Specific PO4-P Release Rate</th>
<th>A5 PO4-P Release Slope</th>
<th>A5 Specific PO4-P Release Rate</th>
<th>A6 PO4-P Release Slope</th>
<th>A6 Specific PO4-P Release Rate</th>
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<th>FeCl₃ Addition</th>
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<th>Influent Flow</th>
<th>ARCY Flow</th>
<th>CRCY Flow</th>
<th>NRCY Flow</th>
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Profile Sampling Nutrient Levels

Concentration [mg/L]

Sample

Profile Sampling Nutrient Levels

Concentration [mg/L]

Sample

Profile Sampling Nutrient Levels

Concentration [mg/L]

Sample
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<th>Date</th>
<th>Sample Time</th>
<th>HRT along BNR Process (w/o Recycles)</th>
<th>Sample Number</th>
<th>Reactor Type</th>
<th>Ammonia by HACH TNT</th>
<th>Nitrate by HACH TNT</th>
<th>Nitrite by HACH TNT</th>
<th>NOx-N by HACH TNT + Nitrite HACH</th>
<th>Phosphate by HACH TNT/BAH</th>
<th>DO</th>
<th>pH</th>
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NOTE: These values are <1 mg/L NH4-N.

### QA/QC Sample: SE

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Actual SRT

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Highest AER NO2-N Concentration

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<th>SPUR</th>
<th>Clarifier IDC NH4-N</th>
<th>Clarifier IDC NOX-N</th>
<th>Max ANA PO4-P Release</th>
<th>Avg. ANA NO3-N Concentration</th>
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<td>[mg/L/hr]</td>
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<td>[mg/L/hr]</td>
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AA4 NOx-N | AA6 NOx-N | AA1 PO4-P Release Slope | AA1 Specific PO4-P Release Rate | AA2 PO4-P Release Slope | AA2 Specific PO4-P Release Rate | AA3 PO4-P Release Slope | AA3 Specific PO4-P Release Rate |
| [mg/L] | [mg/L] | [mg/L/hr] | [mg/g MLVSS/hr] | [mg/L/hr] | [mg/L/hr] | [mg/L/hr] | [mg/L/hr] |
| 0.67 | 0.56 | 15.16 | 20.77 | 8.73 | 11.96 | 6.83 | 9.36 |

AA4 PO4-P Release Slope | AA4 Specific PO4-P Release Rate | AA5 PO4-P Release Slope | AA5 Specific PO4-P Release Rate | AA6 PO4-P Release Slope | AA6 Specific PO4-P Release Rate | (AA1) COD Uptake Slope | (AA1) Specific COD Uptake Rate | (AA1) PO4-P/COD |
| [mg/L] | [mg/L/hr] | [mg/g MLVSS/hr] | [mg/L/hr] | [mg/g MLVSS/hr] | [mg/L/hr] | [mg/L/hr] | [mg/g MLVSS/hr] | [mg/g MLVSS/hr] |
| 1.71 | 1.06 | 1.66 | 1.03 | 1.37 | 0.65 | 35.39 | 48.51 | 0.43 |

185
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<th>FeCl₃ Hrs Used</th>
<th>FeCl₃ Addition</th>
<th>Active Biosolid</th>
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<th>ARCY Flow</th>
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| ANA MLTSS   | ANA % VOL      | ANA MLVSS     | ANX MLTSS      | ANX % VOL     | ANX MLVSS | AER MLTSS | AER % VOL | AER MLVSS |
|-------------|----------------|---------------|----------------|---------------|-----------|-----------|-----------|
| 960         | 76             | 730           | 2120           | 76            | 1611      | 2120      | 76        | 1611      |

![Profile Sampling Nutrient Levels](image1)

![Profile Sampling Nutrient Levels](image2)

![Profile Sampling Nutrient Levels](image3)
<table>
<thead>
<tr>
<th>Date</th>
<th>Sample Time</th>
<th>Reactor Type</th>
<th>Ammonia by HACH TNT</th>
<th>Nitrate by HACH TNT</th>
<th>NOx-N by Nitrate HACH + Nitrite HACH</th>
<th>Phosphate by HACH TNT</th>
<th>DO</th>
<th>pH</th>
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<td>6-Oct-09</td>
<td>7:20</td>
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<td>0.02</td>
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**NOTE:** These values are <1 mg/L NH₄-N.
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<th>Nitrite by HACH TNT</th>
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### QA/QC Sample: SE

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<th>NPR (NO\textsubscript{X}-N Slope)</th>
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<th>Clarifier IDC NH\textsubscript{4}-N</th>
<th>Clarifier IDC NO\textsubscript{X}-N</th>
<th>Clarifier IDC PO\textsubscript{4}-P Concentration</th>
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<th>AA6 PO\textsubscript{4}-P Release Slope</th>
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### Profile Sampling Nutrient Levels

**Profile Sampling Nutrient Levels**

- PE
- AA1
- AA2
- AA3
- AA4
- AA5
- AA6
- AER1
- AER1.25
- AER1.5
- AER3
- AER5
- IDC
- SE
- RAS

#### Nitrate

![Nitrate Profile](image)

#### Nitrite

![Nitrite Profile](image)

#### NOₓ-N

![Nitrate Nitrite NOₓ-N Profile](image)

#### DO

![DO Profile](image)

### Ammonia

![Ammonia Profile](image)

### Phosphate

![Phosphate Profile](image)

### pH

![pH Profile](image)
**PROFILE 1: Train 5, Aeration Tank 4, Clarifier 4**

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<th>Sample Number</th>
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<th>Sample Time</th>
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<th>Nitrate by HACH TNT [mg/L]</th>
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**QA/QC Sample: SE**

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**Actual SRT**

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**Week 13 – 10/13/09 & 10/16/09**
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**Profile Sampling Nutrient Levels**

1. COD
2. Ammonia
3. Phosphate
4. pH
5. Nitrate
6. Nitrite
7. NOx-N
8. DO

**Sample**

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Profile Sampling Nutrient Levels

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**Actual SRT**  
Acidic MLSS  Average AER DO Min AER pH  AUR (NH4-N Slope)  SAUR  NPR (NOx-N Slope)  SNPR  
[days] [mg/L] [mg/L] [unitless] [mg/L/hr] [mg/L/min] [mg/L/min] [mg/L] 
4.93 1910 1.58 6.93 1.16 0.77 0.71 0.47

**Highest AER NO2-N Concentration**  
PUR (PO4-P Uptake Slope)  SPUR  Clarifier IDC NH4-N  Clarifier IDC NOx-N  Max ANA PO4-P Release  Avg. ANA NO3-N Concentration  
[mg/L] [mg/L/hr] [mg/L] [mg/L] [mg/L] [mg/L] [mg/L] 
2.04 9.71 6.43 21.0000 3.7200 0.1 21.05 0.309

**AA4 NOx-N**  
AA6 NOx-N  AA1 PO4-P Release Slope  AA1 Specific PO4-P Release Rate  AA2 PO4-P Release Slope  AA2 Specific PO4-P Release Rate  AA3 PO4-P Release Slope  AA3 Specific PO4-P Release Rate  
[mg/L] [mg/L] [mg/L] [mg/L/hr] [mg/L/hr] [mg/L/hr] [mg/L/hr] [mg/L/hr] 
0.33 0.32 0.10 0.13 9.17 11.58 6.45 8.14

**AA4 PO4-P Release Slope**  
AA4 Specific PO4-P Release Rate  AA5 PO4-P Release Slope  AA5 Specific PO4-P Release Rate  AA6 PO4-P Release Slope  AA6 Specific PO4-P Release Rate  (AA1) COD Uptake Slope  (AA1) Specific COD Uptake Rate  (AA1) PO4-P/COD  
[mg/L/hr] [mg/L/hr] [mg/L/hr] [mg/L/hr] [mg/L/hr] [mg/L/hr] [mg/L/hr] 
2.98 1.97 1.15 1.08 1.90 0.81 1.03 0.13

**QA/QC Sample:**  
EPA 365.1  EPA 350.1  EPA 353.2  EPA 353.2  EPA 353.2  EPA 353.2 

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Week 14 – 10/19/09 & 10/21/09

PROFILE 1: Train 4, Aeration Tank 4, Clarifier 4
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### ANA MLTSS, ANA % VOL, ANA MLVSS, ANX % VOL, ANX MLTSS, AER MLTSS, AER % VOL, AER MLVSS

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### Profile Sampling Nutrient Levels

- **sCOD**
- **Ammonia**
- **Phosphate**
- **pH**
- **Nitrate**
- **Nitrite**
- **NOₓ-N**
- **DO**

### Diagrams

1. Profile Sampling Nutrient Levels with sCOD.
2. Profile Sampling Nutrient Levels with Ammonia, Phosphate, pH.
3. Profile Sampling Nutrient Levels with Nitrate, Nitrite, NOₓ-N, DO.
## PROFILE 2: Train 5, Aeration Tank 5, Clarifier 5

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<th>Date</th>
<th>Sample Time</th>
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<th>Sample Number</th>
<th>Reactor Type</th>
<th>Ammonia by HACH TNT</th>
<th>Nitrates by HACH TNT</th>
<th>Nitrite by HACH TNT</th>
<th>NOx-N by Nitrates HACH TNT844</th>
<th>Phosphate by HACH TNT844</th>
<th>DO</th>
<th>pH</th>
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### Actual SRT

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<th>SAUR</th>
<th>NPR (NOx-N Slope)</th>
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### Highest AER NO₂-N Concentration

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<th>SPUR</th>
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<th>Clarifier IDC NOx-N</th>
<th>Clarifier IDC PO₄-P Concentration</th>
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### AA4, AA6 NOx-N

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**QA/QC Sample: SE**

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**Actual SRT**

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<th>Min AER pH</th>
<th>AUR (NH₄-N Slope)</th>
<th>SAUR</th>
<th>NPR (NOₓ-N Slope)</th>
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<td>[unitless]</td>
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**Highest AER NO₃-N Concentration**

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<th>SPUR Clarian IDC NH₄-N</th>
<th>Clarrian IDC NOₓ-N</th>
<th>Clarrian IDC PO₄-P Concentration</th>
<th>Max AIA PO₄-P Release</th>
<th>Avg. AIA NOₓ-N Concentration</th>
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<td>[mg/L/hr]</td>
<td>[mg/g MLVSS/hr]</td>
<td>[mg/L]</td>
<td>[mg/L]</td>
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**AA4 NOₓ-N**

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<th>AA4 Specific PO₄-P Release Rate</th>
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**AA4 PO₄-P Release Slope**

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Profile Sampling Nutrient Levels

- **sCOD**
- **Ammonia**
- **Phosphate**
- **pH**
- **Nitrate**
- **Nitrite**
- **NOₓ-N**
- **DO**

Sample
## PROFILE 2: Train 5, Aeration Tank 5, Clarifier 5

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<tr>
<th>Date</th>
<th>Sample Time</th>
<th>HRT along BNR</th>
<th>Process (w/out Recycles)</th>
<th>Sample Number</th>
<th>Reactor Type</th>
<th>Ammonia by HACH TNT (mg/L)</th>
<th>Nitrate by HACH TNT (mg/L)</th>
<th>N2O-N by Nitrate HACH TNT (mg/L)</th>
<th>Phosphate by HACH TNT (mg/L)</th>
<th>DO (mg/L)</th>
<th>pH</th>
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<tbody>
<tr>
<td>27-Oct-09</td>
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<td>-</td>
<td>7.26</td>
<td>Anoxic</td>
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*NOTE: These values are <1 mg/L NH4-N
*NOTE: These values are <0.23 mg/L NO3-N

## QA/QC Sample: SE

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<td>SAUR</td>
<td>NPR (NOx-N Slope)</td>
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**PROFILE 1: Train 4, Aeration Tank 4, Clarifier 4**

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<th>HRT along BNR Process (w/o Recycles)</th>
<th>Sample Number</th>
<th>Reactor Type</th>
<th>Ammonia by HACH TNT</th>
<th>Nitrate by HACH TNT</th>
<th>NOx-N by Nitrate HACH + Nitrite HACH</th>
<th>Phosphate by HACH TNT</th>
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*NOTE: These values are <0.23 mg/L NO3-N
*NOTE: These values are <1 mg/L NH4-N

**QA/QC Sample:** SE

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**Profile Sampling Nutrient Levels**

- **COD**: 220
- **Ammonia**
- **Phosphate**
- **pH**
- **Nitrate**
- **Nitrite**
- **NOx-N**
- **DO**
PROFILE 2: Train 5, Aeration Tank 5, Clarifier 5

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*NOTE: These values are <1 mg/L NH4-N
*NOTE: These values are <0.23 mg/L NO3-N

QA/QC Sample: SE

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Actual SRT | Aerobic MLSS | Average AER DO | Min AER pH | AUR (NH4-N Slope) | SAUR | NPR (NOx-N Slope) | SNPR |
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Highest AER NOx-N Concentration

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<th>Clarifier IDC NOx-N</th>
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AA4 NOx-N | AA6 NOx-N | AA1 PO4-P Release Slope | AA1 Specific PO4-P Release Rate | AA2 PO4-P Release Slope | AA2 Specific PO4-P Release Rate | AA3 PO4-P Release Slope | AA3 Specific PO4-P Release Rate |
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<td>[mg/L/hr]</td>
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AA4 PO4_P Release Slope | AA4 Specific PO4_P Release Rate | AA5 PO4_P Release Slope | AA5 Specific PO4_P Release Rate | AA6 PO4_P Release Slope | AA6 Specific PO4_P Release Rate | (AA1) COD Uptake Slope | (AA1) Specific COD Uptake Rate | [mg/L/hr] | [mg/g MLVSS/hr] | [mg/L/hr] | [mg/g MLVSS/hr] | [mg/mg] |
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7.7 Appendix H – Batch Rate Experiment Data
Week 3 – Leachate

Sample Data Report for Nansemond Nitrification Inhibition Study

AOB & NOB Experimentation:
I. AOB
   a. Spiked four 3L reactors with 50 mg/L NH₄⁺.
   b. Each reactor is running continuously by use of stir bars.
   c. 2 L of the diluent source is added to the reactors.
   d. 1 L of concentrated biomass is added to the reactors. For this week's experiments the biomass was concentrated from 20L to 8.5 L
   e. Constant DO and pH were monitored and logged throughout the experiment.
   f. Oxygen/air blend was sparged into the reactors to maintain DO levels through solenoid valves.
   g. LabView software was used to manage DO and pH recording as well as program and maintain the solenoid valves.
   h. 5 samples were collected over a period of 3 hours through sampling ports on the reactors and filtered into sample tubes through millipore 0.45 μm filters
   i. Reactors A and C which incorporated leachate addition were spiked with 15 mL of the SPSA leachate (1:135 dilution) based on plant flow.

II. NOB
   a. Spiked four 3L reactors with 25 mg/L NO₂⁻ after ammonia levels were <2 mg/L NH₃-N which was checked through the use of HACH TNT 831 Ammonia method.
   b. Each reactor is running continuously by use of stir bars.
   c. Constant DO and pH were monitored and logged throughout the experiment.
   d. Oxygen/air blend was sparged into the reactors to maintain DO levels through solenoid valves.
   e. LabView software was used to manage DO and pH recording as well as program and maintain the solenoid valves.
   f. 5 samples were collected over a period of 3 hours through sampling ports on the reactors and filtered into sample tubes through millipore 0.45 μm filters.
   i. Reactors A and C which incorporated leachate addition were spiked with 15 mL of the SPSA leachate (1:135 dilution) based on plant flow.

Reactor A: Nansemond Activated Sludge/VIP SE + Leachate

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<th>Date</th>
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<th>Sample Number</th>
<th>Temperature °C</th>
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<th>Ammonia by AO2 SEAL mg/L NO₂-N</th>
<th>Nitrate by AO2 SEAL mg/L NOx-N</th>
<th>Nitrite by AO2 SEAL mg/L NO₃-N</th>
<th>NOx-N by AO2 SEAL mg/L NOx-N</th>
<th>Phosphate by AO2 SEAL mg/l P</th>
<th>NOx-N by Nitrate IC + Nitrite SEAL mg/L NOx-N</th>
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#### Nitrogen Species vs. Time

- **Ammonia**
- **Nitrate**
- **NOx-N**
- **Nitrite**

**Linear (Nitrate)**

**Linear (NOx-N)**

**N0x-N by AO2 SEAL**

**Nitrite by AO2 SEAL**

**Phosphate by AO2 SEAL**

**NOx-N by Nitrate IC + Nitrite SEAL**

#### Graphs:

- **Nitrogen Species vs. Time**
- **Nitrogen Species vs. Time**

- [Graph for Ammonia, Nitrate, Nitrite, NOx-N](image)
- [Graph for Ammonia, Nitrate, Nitrite, NOx-N](image)
### Reactor C: VIP Activated Sludge/VIP SE + Leachate

**Nitrogen Source:** Activated Sludge/VIP SE + Leachate

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* Nitrification rates are normalized with respect to the MLVSS concentrations in their respective reactors.
Bio-P Experimentation:
I. Bio-P
   a. Spiked four 3L reactors with 5 mg/L PO₄₃⁻·P to raise initial PO₄₃⁻·P concentration to roughly 15 mg/L PO₄₃⁻·P. (Initial PO₄₃⁻·P concentration was determined through HACH TNT PO₄₃⁻·P Tubes at the end of the AOB/NOB experimentation).
   b. The Bio-P experiment is run through an uptake/release/uptake method were the four reactors are aerobic/anaerobic/aerobic once more. During the release phase 200 mg/L of NaAc was added for COD manually to all 4 reactors.
   c. Each reactor is running continuously by use of stir bars.
   d. 2L of the diluent source is added to the reactors.
   e. 1 L of concentrated biomass is added to the reactors. For this weeks experiments the biomass was concentrated from 20L to 8.5 L.
   f. Constant DO and pH were monitored and logged throughout the experiment.
   g. Oxygen/air blend was sparged into the reactors to maintain DO levels through solenoid valves during the uptake phases and then these valves were turned off and the oxygen/air was cut-off and then the system was deaerated and the DO was allowed to drop to 0 before beginning the release phase. During the release phase nitrogen was sparged into the reactors.
   h. LabView software was used to manage DO and pH recording as well as program and implement the solenoid valves.
   i. 4 samples were collected over a period of 1.5 hours through sampling ports on the reactors and filtered into sample tubes through millipore 0.45 μm filters during both uptake phases and 4 samples were collected over a period of 1 hour for the release phase.
   j. Reactors A and C which incorporated leachate addition were spiked with 15 mL of the SPSA leachate (1:135 dilution) based on plant flow.

Reactor A: Nansemond Activated Sludge/ VIP SE + Leachate

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**Reactor C: VIP Activated Sludge/VIP SE + Leachate**

**Phosphorus Test**
- **Date**: d-mmm-yyyy
- **Sample Time**: h:mm
- **Time since initial spike**: min
- **Sample Number**: 
- **Temperature**: °C
- **Phosphate by TNT SEAL**: mg/L P
- **Phosphate by AO2 SEAL**: mg/L P
- **Nitrite by IC SEAL**: mg/L NO2-N
- **Nitrate by IC SEAL**: mg/L NO3-N
- **NOx-N by IC + Nitrite SEAL**: mg/L NOx-N

**Nitrogen Species vs. Time**
- **Ammonia**
- **Nitrate**
- **Nitrite**
- **NOx-N**

**Phosphorous Uptake/Release/Uptake Plot**
- **PO4 Concentration [mg/L -P]**
- **Time [mins]**

**Phosphorous Uptake/Release/Uptake Plot**
- **N Concentration [mg/L -N]**
- **Time [mins]**
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Week 4 – Henrico County Biomass Day 1 AOB/NOB

Sample Data Report for Nansemond Nitrification Inhibition Study

Reactor A: Nansemond Activated Sludge/Nansemond PE

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<tr>
<th>Nitrogen Source Spiked</th>
<th>Date</th>
<th>Sample Time</th>
<th>Time since initial spike</th>
<th>Sample Number</th>
<th>Temperature</th>
<th>Ammonia by AO2 SEAL mg/L NH3-N</th>
<th>Ammonia by HACH TNT mg/L NH3-N</th>
<th>Nitrate by IC mg/L NO3-N</th>
<th>NOx-N by AO2 SEAL mg/L NOx-N</th>
<th>Nitrite by AO2 SEAL mg/L NO2-N</th>
<th>Nitrite by AO2 SEAL mg/L NO2-N</th>
<th>Phosphate by AO2 SEAL mg P</th>
<th>NOx-N by Nitrate IC + Nitrite SEAL mg/L NOx-N</th>
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AOB & NOB Experimentation:

I. AOB
a. Spiked four 3L reactors with 25 mg/L NH4.
b. Each reactor is running continuously by use of stir bars.
c. 2 L of the diluent source is added to the reactors.
d. 1 L of concentrated biomass is added to the reactors. For this week's experiments the biomass was concentrated from 20L to 9L.
e. Constant DO and pH were monitored and logged throughout the experiment.
f. Oxygen/air blend was sparged into the reactors to maintain DO levels through solenoid valves.
g. LabView software was used to manage DO and pH recording as well as program and implement the solenoid valves.
h. 5 samples were collected over a period of 3 hours through sampling ports on the reactors and filtered into sample tubes through millipore 0.45 μm filters.

II. NOB
a. Spiked four 3L reactors with 25 mg/L NO2- after ammonia levels were <1 mg/L NH3-N which was checked through the use of HACH TNT 831 Ammonia method. In addition all reactors were allowed to run overnight to consume all present ammonia.
b. Each reactor is running continuously by use of stir bars.
c. Constant DO and pH were monitored and logged throughout the experiment.
d. Oxygen/air blend was sparged into the reactors to maintain DO levels through solenoid valves.
e. LabView software was used to manage DO and pH recording as well as program and implement the solenoid valves.
f. 5 samples were collected over a period of 3 hours through sampling ports on the reactors and filtered into sample tubes through millipore 0.45 μm filters.
**Reactor B: Nansemond Activated Sludge/Henrico PE**

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<th>Sample Time</th>
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<th>Ammonia by AQ2 SEAL</th>
<th>Ammonia by HACH TNT</th>
<th>Nitrate by IC SEAL</th>
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<th>Nitrite by AQ2 SEAL</th>
<th>Phosphate by AQ2 SEAL</th>
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### Reactor C: Henrico Activated Sludge/Henrico PE
Nitrogen Source
Spiked

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<th>Ammonia by HACH TNT</th>
<th>Nitrate by IC SEAL</th>
<th>NOx-N by AO2 SEAL</th>
<th>Nitrite by AO2 SEAL</th>
<th>Nitrate by AO2 SEAL</th>
<th>NOx-N by Nitrate IC + Nitrite SEAL</th>
<th>Phosphate by AO2 SEAL</th>
<th>NOx-N by Nitrate IC + Nitrite SEAL</th>
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### Reactor D: Hercio Activated Sludge/Henrico PE

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<th>Time since initial spike</th>
<th>Sample Number</th>
<th>Temperature</th>
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<th>Ammonia by HACH TNT</th>
<th>Nitrate by IC</th>
<th>NOx-N by AO2 SEAL</th>
<th>Nitrite by AO2 SEAL</th>
<th>Phosphate by AO2 SEAL</th>
<th>NOx-N by Nitrile IC + Nitrite SEAL</th>
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**Nitrogen Species vs. Time**

- Ammonia
- Nitrate
- NOx-N
- Nitrite

Linear (Nitrate)
Linear (NOx-N)
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<tr>
<th>Summary</th>
<th>Experiment</th>
<th>NOx Slope</th>
<th>NO3 Slope</th>
<th>NO2 Slope</th>
<th>Nit Rate NOx*</th>
<th>Nit Rate NO3*</th>
<th>Nit Rate NO2*</th>
<th>OUR</th>
<th>SOUR</th>
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<th>MLVSS</th>
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* Nitrification rates are normalized with respect to the MLVSS concentrations in their respective reactors
## AOB & NOB Experimentation:

### I. AOB

- a. Spiked four 3L reactors with 25 mg/L NH₄⁺.
- b. Each reactor is running continuously by use of stir bars.
- c. 2 L of the diluent source is added to the reactors.
- d. 1 L of concentrated biomass is added to the reactors. For this week’s experiments the biomass was concentrated from 20 L to 9 L.
- e. Constant DO and pH were monitored and logged throughout the experiment.
- f. Oxygen/air blend was sparged into the reactors to maintain DO levels through solenoid valves.
- g. LabView software was used to manage DO and pH recording as well as program and implement the solenoid valves.
- h. 5 samples were collected over a period of 3 hours through sampling ports on the reactors and filtered into sample tubes through millipore 0.45 μm filters.

### II. NOB

- a. Spiked four 3L reactors with 25 mg/L NO₂⁻ after ammonia levels were <1 mg/L NH₃-N which was checked through the use of HACH TNT 831 Ammonia method. In addition all reactors were allowed to run overnight to consume all present ammonia.
- b. Each reactor is running continuously by use of stir bars.
- c. Constant DO and pH were monitored and logged throughout the experiment.
- d. Oxygen/air blend was sparged into the reactors to maintain DO levels through solenoid valves.
- e. LabView software was used to manage DO and pH recording as well as program and implement the solenoid valves.
- f. 5 samples were collected over a period of 3 hours through sampling ports on the reactors and filtered into sample tubes through millipore 0.45 μm filters.

## Sample Data Report for Nansemond Nitrification Inhibition Study

### Reactor A: Nansemond Activated Sludge/Nansemond PE

<table>
<thead>
<tr>
<th>Nitrogen Source Spiked</th>
<th>Date</th>
<th>Sample Time</th>
<th>Time since initial spike</th>
<th>Sample Number</th>
<th>Temperature °C</th>
<th>Ammonia by AQ2 SEAL mg/L NH₃-N</th>
<th>Ammonia by HACH TNT mg/L NH₃-N</th>
<th>Nitrate by IC mg/L NO₃-N</th>
<th>NOx-N by AQ2 SEAL mg/L NO₂-N</th>
<th>Nitrite by AQ2 SEAL mg/L NO₂-N</th>
<th>Nitrite by AQ2 SEAL mg/L NO₂-N</th>
<th>Phosphate by AQ2 SEAL mg/l P</th>
<th>NOx-N by Nitrate IC + Nitrite SEAL mg/L NO₂-N</th>
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### Reactor B: Nansemond Activated Sludge/Henrico PE

**Nitrogen Source**
- Spiked

**Date**
- dd-mmm-yy

**Sample Time**
- h:mm

**Time since initial spike**
- min

**Sample Number**
- 

**Temperature**
- °C

**Ammonia by AQ2**
- mg/L NH₃-N

**Ammonia by HACH TNT**
- mg/L NH₃-N

**Ammonia by IC**
- mg/L NH₃-N

**Nitrate by IC**
- mg/L NO₃-N

**NOx-N by AQ2**
- mg/L NOx-N

**NOx-N by Nitrate IC + Nitrite SEAL**
- mg/L NOx-N

**Nitrite by AQ2**
- mg/L NO₂-N

**Nitrite by IC**
- mg/L NO₂-N

**Phosphate by AO2 SEAL**
- mg/L P

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<th>Nitrogen Source Spiked</th>
<th>Date</th>
<th>Sample Time</th>
<th>Sample Number</th>
<th>Temperature</th>
<th>Ammonia by AQ2 SEAL</th>
<th>Ammonia by HACH TNT</th>
<th>Ammonia by IC</th>
<th>Nitrate by IC</th>
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### Reactor C: Henrico Activated Sludge/Henrico PE

#### Nitrogen Source
- Spiked

<table>
<thead>
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<th>Sample Time</th>
<th>Sample Number</th>
<th>Temperature</th>
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<th>Ammonia by HACH TNT</th>
<th>Nitrate by IC SEAL</th>
<th>NOx-N by AQ2 SEAL</th>
<th>Nitrite by AQ2 SEAL</th>
<th>Nitrate by AQ2 SEAL + Nitrite SEAL</th>
<th>Phosphate by AQ2 SEAL</th>
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<td>°C</td>
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#### Nitrogen Species vs. Time

- Ammonia
- Nitrate
- NOx-N
- Nitrite

---

227
Reactor D: Henrico Activated Sludge/Henrico PE
Nitrogen Source Spiked Date Sample Time
Time since initial spike Sample Number Temperature Ammonia by AQ2 SEAL Ammonia by HACH TNT Nitrate by IC NOx-N by AQ2 SEAL NO3-N by AQ2 SEAL Nitrite by AQ2 SEAL phosphate by AQ2 SEAL NOx-N by Nitrate IC + Nitrite SEAL

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<th>Sample Number</th>
<th>Temperature °C</th>
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<th>mg/L NO3-N</th>
<th>mg/L NOX-N</th>
<th>mg/L NO2-N</th>
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### Summary

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<th>NO2 Slope</th>
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*Nitrification rates are normalized with respect to the MLVSS concentrations in their respective reactors.*
### Experiment 1

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### Experiment #1

**AOB Comparison**

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<th>NS Biomass &amp; HR PE</th>
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### Experiment #2

**AOB Comparison**

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Week 5 – Hog Processing Plant

Sample Data Report for Nansemond Nitrification Inhibition Study

AOB & NOB Experimentation:

I. AOB
   a. Spiked four 3L reactors with 30 mg/L NH₄⁺.
   b. Each reactor is running continuously by use of stir bars.
   c. 2 L of the diluent source is added to the reactors.
   d. 1 L of concentrated biomass is added to the reactors. For this weeks experiments the biomass was concentrated from 201 to 8.5 L.
   e. Constant DO and pH were monitored and logged throughout the experiment.
   f. Oxygen/air blend was sparged into the reactors to maintain DO levels through solenoid valves.
   g. LabView software was used to manage DO and pH recording as well as program and implement the solenoid valves.
   h. 5 samples were collected over a period of 3 hours through sampling ports on the reactors and filtered into sample tubes through millipore 0.45 μm filters.
   i. Reactors A and C which incorporated industrial waste addition were spiked with 200 mL of Smithfield sample (1:10 dilution).

II. NOB
   a. Spiked four 3L reactors with 25 mg/L NO₂⁻ after ammonia levels were <2 mg/L NH₃-N which was checked through the use of HACH TNT 831 Ammonia method.
   b. Each reactor is running continuously by use of stir bars.
   c. Constant DO and pH were monitored and logged throughout the experiment.
   d. Oxygen/air blend was sparged into the reactors to maintain DO levels through solenoid valves.
   e. LabView software was used to manage DO and pH recording as well as program and implement the solenoid valves.
   f. 5 samples were collected over a period of 3 hours through sampling ports on the reactors and filtered into sample tubes through millipore 0.45 μm filters.
   i. Reactors A and C which incorporated industrial waste addition were spiked with 200 mL of Smithfield sample (1:10 dilution).

Rearranged Table:

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<th>Sample Time</th>
<th>Time since initial spike</th>
<th>Sample Number</th>
<th>Temperature</th>
<th>Ammonia by AQ2 SEAL °C</th>
<th>Ammonia by HACH TNT mg/L NH₃-N</th>
<th>Nitrate by IC mg/L NO₃-N</th>
<th>NOx-N by AQ2 SEAL mg/L NOx-N</th>
<th>Nitrite by AQ2 SEAL mg/L NO₂-N</th>
<th>Phosphate by AQ2 SEAL mg/L P</th>
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Reactor B: Nansemond Activated Sludge/VIP SE

Nitrogen Source
Spiked Date Sample Time
Time since initial spike Sample Number Temperature mg/L NH₃-N mg/L NO₂-N mg/L NO₃-N mg/L NOx-N mg/l P mg/L NOx-N

Ammonia
29-Jul-08 9:21 39 B1 26.1 14.38 17.70 17.63 0.55 5.44 18.18
29-Jul-08 9:56 74 B2 27.1 14.12 16.70 14.55 3.00 8.49 17.56
29-Jul-08 10:34 112 B3 27.7 12.02 17.70 15.88 1.18 5.96 17.05
29-Jul-08 11:10 148 B4 28.1 12.67 17.75 17.04 1.12 6.02 18.17
29-Jul-08 11:47 185 B5 28.4 13.14 20.45 17.99 0.16 6.45 18.15

Nitrite
29-Jul-08 17:32 44 B6 28.4 0.00 - 19.37 21.16 14.44 40.53
29-Jul-08 18:11 83 B7 28.4 0.00 - 19.82 19.07 14.62 38.89
29-Jul-08 18:45 117 B8 28.7 0.00 - 18.69 18.77 14.72 37.47
29-Jul-08 19:16 148 B9 28.7 0.00 - 20.10 16.02 15.07 36.12
29-Jul-08 19:48 180 B10 28.7 0.00 - 21.03 14.71 15.89 35.73

Ammonia
Nitrate
NOx-N
Nitrite
Linear (Nitrate)
Linear (Nitrite)
### Reactor C: VIP Activated Sludge/VIP SE + Smithfield

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<th>Nitrogen Species vs. Time</th>
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**Nitrogen Source:** Activated Sludge/VIP SE + Smithfield

**Spiked:**

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<th>Temperature</th>
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* Nitrification rates are normalized with respect to the MLVSS concentrations in their respective reactors.
Sample Data Report for Nansemond Nitrification Inhibition Study

Reactor A: Nansemond Activated Sludge/VIP SE + Smithfield

Bio-P Experimentation:
I. Bio - P
   a. Spiked four 3L reactors with 5 mg/L PO$_4$-P to raise initial PO$_4$-P concentration to roughly 15 mg/L PO$_4$-P. (Initial PO$_4$-P concentration was determined through HACH TNT PO$_4$-Tubes at the end of the AOB/NOB experimentation).
   b. The Bio-P experiment was run through an uptake/release/uptake/release/uptake method were the four reactors are aerobic/anaerobic/aerobic once more. During the first release phase 100 mg/L of NaAc was added for COD manually to all 4 reactors and 200 mg/L of NaAc during the second release phase.
   c. Each reactor is running continuously by use of stir bars.
   d. 2 L of the diluent source is added to the reactors.
   e. 1 L of concentrated biomass is added to the reactors. For this weeks experiments the biomass was concentrated from 20L to 8.5 L.
   f. Constant DO and pH were monitored and logged throughout the experiment.
   g. Oxygen/air blend was sparged into the reactors to maintain DO levels through solenoid valves during the uptake phases and then these valves were turned off and the oxygen/air was cut-off and then the system was deaerated and the DO was allowed to drop to 0 before beginning the release phase. During the release phase nitrogen was sparged into the reactors.
   h. LabView software was used to manage DO and pH recording as well as program and implement the solenoid valves.
   i. 2 samples were collected over a period of 2 hours through sampling ports on the reactors and filtered into sample tubes through millipore 0.45 μm filters.
   j. Reactors A and C which incorporated industrial waste addition were spiked with 200 mL of Smithfield sample (1:10 dilution).

### Reactor A: Nansemond Activated Sludge/VIP SE + Smithfield

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<th>Date</th>
<th>Sample Time</th>
<th>Time since initial spike</th>
<th>Sample Number</th>
<th>Temperature</th>
<th>Phosphate by TNT</th>
<th>Phosphate by AQ2 SEAL</th>
<th>Ammonia by AQ2 SEAL</th>
<th>Nitrate by IC</th>
<th>NOx-N by AQ2 SEAL</th>
<th>Nitrite by AQ2 SEAL</th>
<th>Nitrate by AQ2 SEAL + Nitrite SEAL</th>
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Reactor B: Nansemond Activated Sludge/VIP SE

Phosphorus Test

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### Phosphorous Uptake/Release/Uptake Plot

- **Graph Title:** Phosphorous Uptake/Release/Uptake Plot
- **X-axis:** Time [mins]
- **Y-axis:** PO4 Concentration [mg/L -P]

### Nitrogen Species vs. Time

- **Graph Title:** Nitrogen Species vs. Time
- **X-axis:** Time [mins]
- **Y-axis:** N. Concentration [mg/L -N]

### Reactor C: VIP Activated Sludge/VIP SE + Smithfield Phosphorus Test

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<th>Time since initial spike</th>
<th>Sample Number</th>
<th>Temperature</th>
<th>Phosphate by TNT</th>
<th>Phosphate by AQ2 SEAL</th>
<th>Ammonia by AQ2 SEAL</th>
<th>Nitrate by IC</th>
<th>NOx-N by AQ2 SEAL</th>
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### Reactor D: VIP Activated Sludge/VIP SE

#### Phosphorus Test

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**Phosphorous Uptake/Release/Uptake Plot**

**Nitrogen Species vs. Time**

- **Ammonia**
- **Nitrate**
- **Nitrite**
- **NO$_x$-N**

---

240
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**Graphs:**
- **Day 1 AOB NOB:**
  - NS AS & VIP SE + Smithfield
  - NS AS & VIP SE
  - VIP AS & VIP SE + Smithfield
  - VIP AS & VIP SE

- **Day 2 Bio P:**
  - PO4 Release
  - PO4 Uptake

**Rate [mg/g MLVSS/hr]:**
- 0.000
- 5.000
- 10.000
- 15.000
- 20.000
- 25.000
- 30.000
- 35.000
- 40.000

**Rate [mg/g MLVSS/hr]:**
- 0.000
- 5.000
- 10.000
- 15.000
- 20.000
- 25.000
- 30.000
- 35.000
- 40.000
### Week 6 – Landfill Leachate Day 1 AOB/NOB

Sample Data Report for Nansemond Nitrification Inhibition Study

**Reactor A: Nansemond Activated Sludge/VIP SE + Leachate**

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<tr>
<th>Date</th>
<th>Sample Time</th>
<th>Time since Initial Spike</th>
<th>Sample Number</th>
<th>Temperature</th>
<th>Ammonia by AQ2 SEAL</th>
<th>Ammonia by HACH TNT</th>
<th>Nitrate by IC</th>
<th>NOx-N by AQ2 SEAL</th>
<th>Nitrite by AQ2 SEAL</th>
<th>Phosphate by AQ2 SEAL</th>
<th>NOx-N by Nitrate IC + Nitrate SEAL</th>
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**AOB & NOB Experimentation:**

I. **AOB**
   - Spiked four 3L reactors with 30 mg/L NH₄⁺.
   - Each reactor is running continuously by use of stir bars.
   - 2 L of the diluent source is added to the reactors.
   - 1 L of concentrated biomass is added to the reactors. For this week's experiments, the biomass was concentrated from 20L to 9L.
   - Constant DO and pH were monitored and logged throughout the experiment.
   - Oxygen/air blend was sparged into the reactors to maintain DO levels through solenoid valves.
   - LabView software was used to manage DO and pH recording as well as program and implement the solenoid valves.
   - 5 samples were collected over a period of 3 hours through sampling ports on the reactors and filtered into sample tubes through millipore 0.45 µm filters.
   - Reactors A and C which incorporated leachate addition were spiked with 15 mL of the SPSA leachate (1:135 dilution) based on plant flow.

II. **NOB**
   - Spiked four 3L reactors with 25 mg/L NO₂⁻ after ammonia levels were <1 mg/L NH₃-N which was checked through the use of HACH TNT B31 Ammonia method. In addition, all reactors were allowed to run overnight to consume all present ammonia.
   - Each reactor is running continuously by use of stir bars.
   - Constant DO and pH were monitored and logged throughout the experiment.
   - Oxygen/air blend was sparged into the reactors to maintain DO levels through solenoid valves.
   - LabView software was used to manage DO and pH recording as well as program and implement the solenoid valves.
   - 5 samples were collected over a period of 3 hours through sampling ports on the reactors and filtered into sample tubes through millipore 0.45 µm filters.
   - Reactors A and C which incorporated leachate addition were spiked with 15 mL of the SPSA leachate (1:135 dilution) based on plant flow.
### Reactor B: Nansemond Activated Sludge/VIP SE

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<th>Sample Time</th>
<th>Time since initial spike</th>
<th>Sample Number</th>
<th>Temperature</th>
<th>Ammonia by AQ2 SEAL</th>
<th>Ammonia by HACH TNT</th>
<th>Nitrate by IC SEAL</th>
<th>Nitrate by AQ2 SEAL</th>
<th>Nitrite by AQ2 SEAL</th>
<th>Phosphate by AQ2 SEAL</th>
<th>NOx-N by Nitrate IC + Nitrite SEAL</th>
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<td>13.93</td>
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### Reactor C: VIP Activated Sludge/VIP SE + Leachate

#### Nitrogen Source
- Activated Sludge/VIP SE + Leachate

### Spiked Data
- **Date:** 5-Aug-08
- **Sample Time:**
  - 10:10
  - 10:40
  - 11:14
  - 11:58
  - 12:49
  - 17:13
  - 17:44
  - 18:23
  - 19:22
  - 19:54

### Time since initial spike
- 17 min
- 47 min
- 81 min
- 125 min
- 176 min
- 176 min
- 176 min
- 176 min
- 176 min

### Sample Number
- C1
- C2
- C3
- C4
- C5
- C6
- C7
- C8
- C9
- C10

### Temperature
- 28.2°C
- 29.2°C
- 29.8°C
- 30.1°C
- 30.0°C
- 30.3°C
- 30.2°C
- 30.3°C
- 30.5°C
- 30.4°C

### Ammonia (mg/L)
- 28.3
- 29.25
- 29.8
- 30.2
- 30.3
- 30.3
- 30.2
- 30.4
- 30.5
- 30.4

### Nitrite (mg/L)
- 0
- 0
- 0
- 0
- 0
- 0
- 0
- 0
- 0
- 0

### Ammonia by AQ2 SEAL
- 28.3
- 29.25
- 29.8
- 30.2
- 30.3
- 30.3
- 30.2
- 30.4
- 30.5
- 30.4

### Ammonia by HACH TNT
- 23.91
- 20.47
- 16.52
- 8.71
- 0.00
- 0.00
- 0.00
- 0.00
- 0.00
- 0.00

### Nitrate by IC (mg/L)
- 20.60
- 19.30
- 16.55
- 5.28
- 3.70
- -
- -
- -
- -
- -

### NOx-N by AQ2 SEAL
- 13.17
- 14.60
- 16.62
- 21.96
- 29.08
- 17.08
- 22.40
- 27.71
- 28.44
- 26.02

### Nitrite by AQ2 SEAL
- 5.43
- 0.96
- 5.70
- 0.33
- 5.70
- -
- -
- -
- -
- -

### Nitrate by AQ2 SEAL
- 0.13
- 0.13
- 0.33
- 0.57
- 2.02
- 0.13
- 1.42
- 2.62
- 4.01
- 4.65

### Phosphate by AQ2 SEAL
- 0.00
- 0.00
- 0.00
- 0.00
- 0.00
- 0.00
- 0.00
- 0.00
- 0.00
- 0.00

### NOx-N by Nitrate IC + Nitrite SEAL
- 18.59
- 15.57
- 22.32
- 28.82
- 29.08
- 18.59
- 40.67
- 38.77
- 41.17
- 36.96
### Reactor D: VIP Activated Sludge/VIP SE

**Nitrogen Source**: Spiked

**Date**
- Ammonia: 5-Aug-08
- Nitrite: 5-Aug-08

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<th>Date</th>
<th>Sample Time</th>
<th>Time since initial spike</th>
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<th>Temperature</th>
<th>Ammonia by AO2 SEAL</th>
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**Nitrogen Species vs. Time**

- **Nitrogen Species**: Ammonia, Nitrate, Nitrite
- **Time (mins)**: 0, 50, 100, 150, 200
- **mg/L - N**: 0.00, 5.00, 10.00, 15.00, 20.00, 25.00, 30.00, 35.00
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<th>Experiment</th>
<th>NOx Slope</th>
<th>NO3 Slope</th>
<th>NO2 Slope</th>
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<th>Nit Rate NO3*</th>
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* Nitrification rates are normalized with respect to the MLVSS concentrations in their respective reactors

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Week 6 – Landfill Leachate Day 2 AOB/NOB
Sample Data Report for Nansemond Nitrification Inhibition Study

Reactor A: Nansemond Activated Sludge/VIP SE + Leachate

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AOB & NOB Experimentation:
I. AOB
a. Spiked four 3L reactors with 30 mg/L NH₄⁺.
b. Each reactor is running continuously by use of stir bars.
c. 1900 mL of the diluent source is added to the reactors.
d. 1 L of concentrated biomass is added to the reactors. For this weeks experiment the biomass was concentrated from 201 to 9 L.
e. Constant DO and pH were monitored and logged throughout the experiment.
f. Oxygen/air blend was sparged into the reactors to maintain DO levels through solenoid valves.
g. LabView software was used to manage DO and pH recording as well as program and implement the solenoid valves.
h. 5 samples were collected over a period of 3 hours through sampling ports on the reactors and filtered into sample tubes through millipore 0.45 μm filters.
i. Reactors A and C which incorporated leachate addition with 200 mL of the SPSA leachate (1:10 dilution) to simulate a slug load.

II. NOB
a. Spiked four 3L reactors with 25 mg/L NO₂⁻ after ammonia levels were <1 mg/L NH₃-N which was checked through the use of HACH TNT B31 Ammonia method. In addition all reactors were allowed to run overnight to consume all present ammonia.
b. Each reactor is running continuously by use of stir bars.
c. Constant DO and pH were monitored and logged throughout the experiment.
d. Oxygen/air blend was sparged into the reactors to maintain DO levels through solenoid valves.
e. LabView software was used to manage DO and pH recording as well as program and implement the solenoid valves.
f. 5 samples were collected over a period of 3 hours through sampling ports on the reactors and filtered into sample tubes through millipore 0.45 μm filters.
g. Reactors A and C which incorporated leachate addition with 200 mL of the SPSA leachate (1:10 dilution) to simulate a slug load.
Reactor B: Nansemond Activated Sludge/VIP SE
Nitrogen Source Spiked Date Sample Time
Time since initial spike Sample Number Temperature Ammonia by AQ2 SEAL Ammonia by HACH TNT Nitrate by IC NOx-N by AQ2 SEAL Nitrate by AQ2 SEAL Nitrite by AQ2 SEAL NOx-N by IC + Nitrite SEAL

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<th>Time since initial spike</th>
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Reactor D: VIP Activated Sludge/VIP SE
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Time since initial spike Sample Number Temperature

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<td>1.769</td>
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<td>1700.00</td>
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<tr>
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<td>Reactor C: VIP</td>
<td>Effluent</td>
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<td>Reactor D: VIP</td>
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<td></td>
<td>VIP Secondary</td>
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* Nitrification rates are normalized with respect to the MLVSS concentrations in their respective reactors.
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<th>Experiment 1</th>
<th>AOB Nox</th>
<th>AOB NO3</th>
<th>NOB NO3</th>
<th>NOB NO2</th>
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<td>Reactor D: VIP</td>
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<td>NS &amp; VIP SE+Leachate</td>
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<td>NOB Comparison</td>
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### Week 7 – Branches of Collection System Day 1 AOB/NOB

#### Sample Data Report for Nansemond Nitrification Inhibition Study

**Reactor A: Nansemond Activated Sludge/VIP SE**

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<tr>
<th>Nitrogen Source Spiked</th>
<th>Date</th>
<th>Sample Time</th>
<th>Time since initial spike</th>
<th>Sample Number</th>
<th>Temperature °C</th>
<th>Ammonia by AQ2 SEAL mg/L NH₃-N</th>
<th>Ammonia by HACH TNT mg/L NH₃-N</th>
<th>Nitrate by IC mg/L NO₃-N</th>
<th>NOx-N by AQ2 SEAL mg/L NOx-N</th>
<th>Nitrite by AQ2 SEAL mg/L NO₂-N</th>
<th>Phosphate by AQ2 SEAL mg/l</th>
<th>NOx-N by Nitrite IC + Nitrite SEAL mg/L NOX-N</th>
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<tbody>
<tr>
<td>Ammonia</td>
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**AOB & NOB Experimentation:**

I. **AOB**
- a. Spiked four 3L reactors with 20 mg/L NH₄⁺.
- b. Each reactor is running continuously by use of stir bars.
- c. 2 L of the diluent source is added to the reactors.
- d. 1 L of concentrated biomass is added to the reactors. For this week’s experiments the biomass was concentrated from 20L to 9 L.
- e. Constant DO and pH were monitored and logged throughout the experiment.
- f. Oxygen/air blend was sparged into the reactors to maintain DO levels through solenoid valves.
- g. LabView software was used to manage DO and pH recording as well as program and implement the solenoid valves.
- h. 5 samples were collected over a period of 3 hours through sampling ports on the reactors and filtered into sample tubes through millipore 0.45 μm filters.
- i. Reactors B, C, and D in the diluent source incorporated 1L of VIP SE and 1L of the associated Branch lines for each reactor.

II. **NOB**
- a. Spiked four 3L reactors with 25 mg/L NO₂⁻ after ammonia levels were <1 mg/L NH₄⁺-N which was checked through the use of HACH TNT B31 Ammonia method. In addition all reactors were allowed to run overnight to consume all present ammonia.
- b. Each reactor is running continuously by use of stir bars.
- c. Constant DO and pH were monitored and logged throughout the experiment.
- d. Oxygen/air blend was sparged into the reactors to maintain DO levels through solenoid valves.
- e. LabView software was used to manage DO and pH recording as well as program and implement the solenoid valves.
- f. 5 samples were collected over a period of 3 hours through sampling ports on the reactors and filtered into sample tubes through millipore 0.45 μm filters.
- g. Reactors B, C, and D in the diluent source incorporated 1L of VIP SE and 1L of the associated Branch lines for each reactor.
<table>
<thead>
<tr>
<th>Nitrogen Source Spiked</th>
<th>Date (dd-mm-yy)</th>
<th>Sample Time (h:mm)</th>
<th>Time since Initial Spike (min)</th>
<th>Sample Number</th>
<th>Temperature (°C)</th>
<th>Ammonia by AQ2 SEAL mg/L NH3-N</th>
<th>Ammonia by HACH TNT mg/L NH3-N</th>
<th>Nitrate by IC mg/L NO3-N</th>
<th>NOx-N by AQ2 SEAL mg/L NOx-N</th>
<th>Nitrite by AQ2 SEAL mg/L NO2-N</th>
<th>Phosphate by AQ2 SEAL mg/L P</th>
<th>NOx-N by Nitrate IC + Nitrite SEAL mg/L NOx-N</th>
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### Nitrogen Species vs. Time

**Date:**
- 12-Aug-08
- 13-Aug-08

**Sample Time:**
- 8:44
- 9:26
- 10:13
- 10:58
- 11:28
- 6:54
- 7:37
- 8:21
- 9:02
- 9:45

**Time since initial spike:**
- 19 min
- 61 min
- 108 min
- 153 min
- 183 min
- 9 min
- 52 min
- 96 min
- 137 min
- 180 min

### Nitrogen Source
- Ammonia
- Nitrite

### Nitrogen Species
- Ammonia by AQ2 SEAL
- Ammonia by HACH TNT
- Nitrate by IC
- NOx-N by AQ2 SEAL
- Nitrite by AQ2 SEAL
- Phosphate by AQ2 SEAL
- NOx-N by Nitrate IC + Nitrite SEAL

### Nitrogen Levels

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<th>Date</th>
<th>Sample Time</th>
<th>Time since initial spike</th>
<th>Sample Number</th>
<th>Temperature</th>
<th>Ammonia by AQ2 SEAL</th>
<th>Ammonia by HACH TNT</th>
<th>Nitrate by IC</th>
<th>NOx-N by AQ2 SEAL</th>
<th>Nitrite by AQ2 SEAL</th>
<th>Phosphate by AQ2 SEAL</th>
<th>NOx-N by Nitrate IC + Nitrite SEAL</th>
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### Reactor D: Nansemond Activated Sludge/VIP SE + Branch 3

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<th>Nitrogen Source</th>
<th>Date</th>
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<th>Sample Number</th>
<th>Temperature</th>
<th>Ammonia by AQ2 SEAL</th>
<th>Ammonia by HACH TNT</th>
<th>Nitrate by IC</th>
<th>NOx-N by AQ2 SEAL</th>
<th>Nitrite by AQ2 SEAL</th>
<th>NOx-N by Nitrate IC + Nitrite SEAL</th>
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<td>25.01 mg/L NH3-N</td>
<td>23.70 mg/L NO3-N</td>
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<td>0.54 mg/L NOx-N</td>
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<tr>
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<tr>
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<td>9:47</td>
<td>D10</td>
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<td>-</td>
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Summary

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<tr>
<th>Experiment</th>
<th>NOx Slope</th>
<th>NO3 Slope</th>
<th>NO2 Slope</th>
<th>Nit Rate NOx*</th>
<th>Nit Rate NO3*</th>
<th>Nit Rate NO2*</th>
<th>OUR</th>
<th>SOUR</th>
<th>MLSS</th>
<th>MLVSS</th>
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<tr>
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<td>0.051</td>
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<td>2.090</td>
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<td>VIP SE</td>
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* Nitrification rates are normalized with respect to the MLVSS concentrations in their respective reactors

Note: Reactor D was extremely difficult to filter, lot of foaming, very low DO (samples D9 and D10 DO was below 2), and very greasy
Sample Data Report for Nansemond Nitrification Inhibition Study

Reactor A: VIP Activated Sludge/VIP SE

<table>
<thead>
<tr>
<th>Nitrogen Source Spiked</th>
<th>Date</th>
<th>Sample Time</th>
<th>Time since initial spike</th>
<th>Sample Number</th>
<th>Temperature</th>
<th>Ammonia by AQ2 SEAL (mg/L NH3-N)</th>
<th>Ammonia by HACH TNT (mg/L NH3-N)</th>
<th>Nitrate by IC (mg/L NO3-N)</th>
<th>NOx-N by AQ2 SEAL (mg/L NOx-N)</th>
<th>Nitrite by AQ2 SEAL (mg/L NO2-N)</th>
<th>Nitrate by AQ2 SEAL (mg/L NO3-N)</th>
<th>Phosphate by AQ2 SEAL (mg/l P)</th>
<th>NOx-N by Nitrate IC + Nitrite SEAL (mg/L NOx-N)</th>
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<tbody>
<tr>
<td>Ammonia</td>
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<td>17</td>
<td>A1</td>
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<td>65.85</td>
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AOB & NOB Experimentation:
I. AOB
   a. Spiked four 3L reactors with 20 mg/L NH4-
   b. Each reactor is running continuously by use of stir bars.
   c. 1900 mL of the diluent source is added to the reactors.
   d. 1 L of concentrated biomass is added to the reactors. For this weeks experiments the biomass was concentrated from 20 L to 9 L.
   e. Constant DO and pH were monitored and logged throughout the experiment.
   f. Oxygen/air blend was sparged into the reactors to maintain DO levels through solenoid valves.
   g. LabView software was used to manage DO and pH recording as well as program and implement the solenoid valves.
   h. 5 samples were collected over a period of 3 hours through sampling ports on the reactors and filtered into sample tubes through millipore 0.45 μm filters. i. Reactors B, C, and D in the diluent source incorporated 1L of VIP SE and 1L of the associated Branch lines for each reactor.

II. NOB
   a. Spiked four 3L reactors with 25 mg/L NO2- after ammonia levels were <1 mg/L NH4-N which was checked through the use of HACH TNT 831 Ammonia method. In addition all reactors were allowed to run overnight to consume all present ammonia.
   b. Each reactor is running continuously by use of stir bars.
   c. Constant DO and pH were monitored and logged throughout the experiment.
   d. Oxygen/air blend was sparged into the reactors to maintain DO levels through solenoid valves.
   e. LabView software was used to manage DO and pH recording as well as program and implement the solenoid valves.
   f. 5 samples were collected over a period of 3 hours through sampling ports on the reactors and filtered into sample tubes through millipore 0.45 μm filters.
   g. Reactors B, C, and D in the diluent source incorporated 1L of VIP SE and 1L of the associated Branch lines for each reactor.
<table>
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<tr>
<th>Nitrogen Species vs. Time</th>
<th>Nitrogen Species vs. Time</th>
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<td>Reactor B: VIP Activated Sludge/VIP SE + Branch 1</td>
<td>Reactor B: VIP Activated Sludge/VIP SE + Branch 1</td>
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<td>Nitrogen Source Spiked</td>
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<tr>
<td>Date</td>
<td>Sample Time</td>
</tr>
<tr>
<td>dd-mm-yyyy</td>
<td>h:mm</td>
</tr>
<tr>
<td>Ammonia</td>
<td>13-Aug-08</td>
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</tr>
<tr>
<td>Nitrite</td>
<td>14-Aug-08</td>
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</table>
Reactor D: VIP Activated Sludge/VIP SE + Branch 3
Nitrogen Source Spiked Date Sample Time Time since initial spike Sample Number Temperature °C Ammonia by AQ2 SEAL mg/L NH3-N Nitrate by IC NOx-N by AQ2 SEAL mg/L NOx-N Phosphate by AQ2 SEAL mg/l P NOx-N by Nitrate IC + Nitrite SEAL mg/L NOx-N
Ammonia 13-Aug-08 12:50 19 D1 30.4 24.70 27.80 13.22 0.92 15.93 0.00
Ammonia 13-Aug-08 14:06 95 D3 29.65 22.67 18.90 19.62 5.77 10.59 25.40
Ammonia 13-Aug-08 14:45 134 D4 29.7 21.39 15.40 20.45 7.49 11.94 27.94
Ammonia 13-Aug-08 15:32 181 D5 29.6 0.00 9.18 22.85 7.33 11.98 30.17
Ammonia 13-Aug-08 16:56 17 D6 29.9 0.00 - 2.14 20.07 4.08 22.21
Nitrite 14-Aug-08 7:27 48 D7 30.1 0.00 - 2.71 17.54 3.41 20.26
Nitrite 14-Aug-08 8:18 99 D8 30.1 0.00 - 4.11 8.21 3.67 12.32
Nitrite 14-Aug-08 8:59 140 D9 30.1 0.00 - 3.49 1.43 1.19 4.92
Nitrite 14-Aug-08 9:43 184 D10 30.1 0.00 - 0.31 0.00 0.58 0.31
**Summary**

<table>
<thead>
<tr>
<th>Summary</th>
<th>Experiment</th>
<th>NOx Slope</th>
<th>NO3 Slope</th>
<th>NO2 Slope</th>
<th>Nit Rate NOx*</th>
<th>Nit Rate NO3*</th>
<th>Nit Rate NO2*</th>
<th>OUR</th>
<th>SOUR</th>
<th>MLSS</th>
<th>MLVSS</th>
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<tbody>
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<td>0.073</td>
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<tr>
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<tr>
<td>Branch 1</td>
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<td>1.982</td>
<td>1.010</td>
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<td>3030.00</td>
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<tr>
<td>VIP SE</td>
<td>Nitrite</td>
<td>-0.006</td>
<td>-0.133</td>
<td>-0.119</td>
<td>-2.633</td>
<td>0.846</td>
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<td>3030.00</td>
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<td></td>
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<tr>
<td>Reactor C: VIP Activated sludge</td>
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* Nitrification rates are normalized with respect to the MLVSS concentrations in their respective reactors
### Experiment 1

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### Week 8 – Pump/Pressure Reducing Stations Day 1 AOB/NOB

Sample Data Report for Nansemond Nitrification Inhibition Study

**AOB & NOB Experimentation:**

**I. AOB**
- a. Spiked four 3L reactors with 20 mg/L NH₄.<br>
- b. Each reactor is running continuously by use of stir bars.<br>
- c. 2 L of the diluent source is added to the reactors.<br>
- d. 1 L of concentrated biomass is added to the reactors. For this week’s experiments the biomass was concentrated from 20L to 9 L.<br>
- e. Constant DO and pH were monitored and logged throughout the experiment.<br>
- f. Oxygen/air blend was sparged into the reactors to maintain DO levels through solenoid valves.<br>
- g. LabView software was used to manage DO and pH recording as well as program and implement the solenoid valves.<br>
- h. 5 samples were collected over a period of 3 hours through sampling ports on the reactors and filtered into sample tubes through millipore 0.45 μm filters.<br>
- i. Reactors B, C, and D in the diluent source incorporated 1L of VIP SE and 1L of the associated interceptor lines for each reactor.

**II. NOB**
- a. Spiked four 3L reactors with 25 mg/L NO₂⁻ after ammonia levels were <1 mg/L NH₃-N which was checked through the use of HACH TNT 831 Ammonia method. In addition all reactors were allowed to run overnight to consume all present ammonia.<br>
- b. Each reactor is running continuously by use of stir bars.<br>
- c. Constant DO and pH were monitored and logged throughout the experiment.<br>
- d. Oxygen/air blend was sparged into the reactors to maintain DO levels through solenoid valves.<br>
- e. LabView software was used to manage DO and pH recording as well as program and implement the solenoid valves.<br>
- f. 5 samples were collected over a period of 3 hours through sampling ports on the reactors and filtered into sample tubes through millipore 0.45 μm filters.<br>
- g. Reactors B, C, and D in the diluent source incorporated 1L of VIP SE and 1L of the associated interceptor lines for each reactor.

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<th>Nitrogen Source</th>
<th>Date</th>
<th>Sample Time</th>
<th>Time since initial spike</th>
<th>Sample Number</th>
<th>Temperature °C</th>
<th>Ammonia by AQ2 SEAL mg/L NH₃-N</th>
<th>Ammonia by HACH TNT mg/L NH₃-N</th>
<th>Nitrate by IC mg/L NO₃-N</th>
<th>NO₃-N by AQ2 SEAL mg/L NO₃-N</th>
<th>Nitrite by AQ2 SEAL mg/L NO₂-N</th>
<th>Nitrate by IC mg/L NO₃-N</th>
<th>Phosphate by AQ2 SEAL mg/L P</th>
<th>NOx-N by Nitrate IC + Nitrite SEAL mg/L NOx-N</th>
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### Reactor B: Nansemond Activated Sludge/VIP SE + Cedar Lane PS

#### Nitrogen Source Spiked:
- Date: dd-mmm-yy
- Sample Time: h:mm
- Temperature: °C
- Sample Number
- Time since initial spike: min
- Ammonia by AQ2 SEAL
- Ammonia by HACH TNT
- Nitrate by IC
- NOx-N by AQ2 SEAL
- Nitrite by AQ2 SEAL
- Phosphate by AQ2 SEAL
- NOx-N by Nitrate IC + Nitrite SEAL
- mg/L NH3-N
- mg/L NH3-N
- mg/L NO3-N
- mg/L NO3-N
- mg/L NO3-N
- mg/l P
- mg/L NOx-N

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<th>Date</th>
<th>Sample Time</th>
<th>Time since initial spike</th>
<th>Sample Number</th>
<th>Temperature</th>
<th>Ammonia by AQ2 SEAL</th>
<th>Ammonia by HACH TNT</th>
<th>Nitrate by IC</th>
<th>NOx-N by AQ2 SEAL</th>
<th>Nitrite by AQ2 SEAL</th>
<th>Phosphate by AQ2 SEAL</th>
<th>NOx-N by Nitrate IC + Nitrite SEAL</th>
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### Graphs:
- **Nitrogen Species vs. Time**
- **Time (mins)**
- **mg/L - N**

Diagrams show the trend of Nitrogen Species over time with different markers representing Ammonia, Nitrate, and NOx-N. The graphs use linear regression lines to illustrate the changes in concentration over time.
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<th>Date</th>
<th>Sample Time</th>
<th>Time since initial spike</th>
<th>Sample Number</th>
<th>Temperature</th>
<th>Ammonia by AQ2 SEAL</th>
<th>Ammonia by HACH TNT</th>
<th>Nitrate by IC SEAL</th>
<th>NOx-N by AQ2 SEAL</th>
<th>Nitrite by AQ2 SEAL</th>
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* Nitrification rates are normalized with respect to the MLVSS concentrations in their respective reactors
## Week 8 – Pump/Pressure Reducing Stations Day 2 AOB/NOB

### Sample Data Report for Nansemond Nitrification Inhibition Study

**Reactor A: VIP Activated Sludge/VIP SE**

**Nitrogen Source Spiked**

<table>
<thead>
<tr>
<th>Nitrogen Source Spiked</th>
<th>Date</th>
<th>Sample Time</th>
<th>Time since initial spike</th>
<th>Sample Number</th>
<th>Temperature °C</th>
<th>Ammonia by AQ2 SEAL mg/L</th>
<th>Ammonia by HACH TNT mg/L</th>
<th>Nitrite by IC mg/L</th>
<th>NOx-N by AQ2 SEAL mg/L</th>
<th>NOx-N by IC + Nitrite SEAL mg/L</th>
<th>Nitrate by IC mg/L</th>
<th>Phosphate by AQ2 SEAL mg/L</th>
<th>NOx-N by Nitrate IC + Nitrate SEAL mg/L</th>
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### AOB & NOB Experimentation:

**I. AOB**

a. Spiked four 3L reactors with 20 mg/L NH₄⁺.
b. Each reactor is running continuously by use of stir bars.
c. 1900 mL of the diluent source is added to the reactors.
d. 1 L of concentrated biomass is added to the reactors. For this week's experiments the biomass was concentrated from 20L to 9L.
e. Constant DO and pH were monitored and logged throughout the experiment.
f. Oxygen/air blend was sparged into the reactors to maintain DO levels through solenoid valves.
g. LabView software was used to manage DO and pH recording as well as program and implement the solenoid valves.
h. 5 samples were collected over a period of 3 hours through sampling ports on the reactors and filtered into sample tubes through millipore 0.45 μm filters.
i. Reactors B, C, and D in the diluent source incorporated 1L of VIP SE and 1L of the associated interceptor lines for each reactor.

**II. NOB**

a. Spiked four 3L reactors with 25 mg/L NO₂⁻ after ammonia levels were <1 mg/L NH₃-N which was checked through the use of HACH TNT 831 Ammonia method. In addition all reactors were allowed to run overnight to consume all present ammonia.
b. Each reactor is running continuously by use of stir bars.
c. Constant DO and pH were monitored and logged throughout the experiment.
d. Oxygen/air blend was sparged into the reactors to maintain DO levels through solenoid valves.
e. LabView software was used to manage DO and pH recording as well as program and implement the solenoid valves.
f. 5 samples were collected over a period of 3 hours through sampling ports on the reactors and filtered into sample tubes through millipore 0.45 μm filters.
g. Reactors B, C, and D in the diluent source incorporated 1L of VIP SE and 1L of the associated interceptor lines for each reactor.
### Reactor B: VIP Activated Sludge/VIP SE + Cedar Lane PS

**Nitrogen Source Spiked**

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<th>Date</th>
<th>Sample Time</th>
<th>Time since initial spike (min)</th>
<th>Sample Number</th>
<th>Temperature (°C)</th>
<th>Ammonia by AQ2 SEAL mg/L NH₃-N</th>
<th>Ammonia by HACH TNT mg/L NH₃-N</th>
<th>Nitrate by IC mg/L NO₃-N</th>
<th>NOx-N by AQ2 SEAL mg/L NOx-N</th>
<th>Nitrate by AQ2 SEAL mg/L NOx-N</th>
<th>Phosphate by AQ2 SEAL mg/L P</th>
<th>NOx-N by Nitrate IC + Nitrite SEAL mg/L NOx-N</th>
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Reactor C: VIP Activated Sludge/VIP SE + Gum Road PRS

Nitrogen Source
Spiked
Date
Sample Time
Time since initial spike
Sample Number
Temperature
Ammonia by AO2 SEAL
Ammonia by HACH TNT
Nitrate by IC
NOx-N by AO2 SEAL
Nitrite by AO2 SEAL
Nitrate by AO2 SEAL + Nitrite SEAL
Phosphate by AO2
NOx-N by Nitrate IC

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<th>Sample Number</th>
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<th>mg/L NO3-N</th>
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<th>mg/L NOx-N</th>
<th>mg/l P</th>
<th>mg/L NOx-N</th>
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## Reactor D: VIP Activated Sludge/VIP SE + Pughsville PRS

### Nitrogen Species vs. Time

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<th>Ammonia by AQ2 SEAL</th>
<th>Ammonia by HACH TNT</th>
<th>Nitrate by IC</th>
<th>NOx-N by AQ2 SEAL</th>
<th>Nitrite by AQ2 SEAL</th>
<th>Phosphate by AQ2 SEAL</th>
<th>NOx-N by Nitrate IC + Nitrite SEAL</th>
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<td>NO2 Slope</td>
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<td>Nit Rate NO3*</td>
<td>Nit Rate NO2*</td>
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<td>SOUR</td>
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<td>MLVSS</td>
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* Nitrification rates are normalized with respect to the MLVSS concentrations in their respective reactors
## Experiment 1

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**AOB Comparison**

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<td>Cedar Lane PS AS</td>
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<td>Gum Road PRS AS</td>
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<td>3.833</td>
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## Experiment 2

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<td>Reactor C: VIP</td>
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**NOB Comparison**

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<td>Gum Road PRS AS</td>
<td>4.858</td>
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<tr>
<td>Pughsville PRS AS</td>
<td>5.894</td>
</tr>
</tbody>
</table>

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**Rate [mg/g MLVSS/hr]**

**AOB Comparison**

- AOB NOx NS AS
- AOB NO3 NS AS
- AOB NOx VIP AS
- AOB NO3 VIP AS

**NOB Comparison**

- NOB NO3 NS AS
- NOB NO2 NS AS
- NOB NO3 VIP AS
- NOB NO2 VIP AS
Week 9 – Pump/Pressure Reducing Stations (RERUN) Day 1 AOB/NOB

Sample Data Report for Nansemond Nitrification Inhibition Study

Reactor A: Nansemond Activated Sludge/VIP SE

AOB & NOB Experimentation:
I. AOB
   a. Spiked four 3L reactors with 20 mg/L NH₄⁺.
   b. Each reactor is running continuously by use of stir bars.
   c. 2 L of the diluent source is added to the reactors.
   d. 1 L of concentrated biomass is added to the reactors. For this week's experiments the biomass was concentrated from 20L to 9L.
   e. Constant DO and pH were monitored and logged throughout the experiment.
   f. Oxygen/air blend was sparged into the reactors to maintain DO levels through solenoid valves.
   g. LabView software was used to manage DO and pH recording as well as program and implement the solenoid valves.
   h. 5 samples were collected over a period of 3 hours through sampling ports on the reactors and filtered into sample tubes through millipore 0.45 μm filters.
   i. Reactors B, C, and D in the diluent source incorporated 1L of VIP SE and 1L of the associated interceptor lines for each reactor.

II. NOB
   a. Spiked four 3L reactors with 25 mg/L NO₂⁻ after ammonia levels were <1 mg/L NH₃-N which was checked through the use of HACH TNT 831 Ammonia method. In addition all reactors were allowed to run overnight to consume all present ammonia.
   b. Each reactor is running continuously by use of stir bars.
   c. Constant DO and pH were monitored and logged throughout the experiment.
   d. Oxygen/air blend was sparged into the reactors to maintain DO levels through solenoid valves.
   e. LabView software was used to manage DO and pH recording as well as program and implement the solenoid valves.
   f. 5 samples were collected over a period of 3 hours through sampling ports on the reactors and filtered into sample tubes through millipore 0.45 μm filters.
   g. Reactors B, C, and D in the diluent source incorporated 1L of VIP SE and 1L of the associated interceptor lines for each reactor.

<table>
<thead>
<tr>
<th>Nitrogen Source Spiked</th>
<th>Date</th>
<th>Sample Time</th>
<th>Time since initial spike</th>
<th>Sample Number</th>
<th>Temperature °C</th>
<th>Ammonia by AQ2 SEAL mg/L NH₃-N</th>
<th>Ammonia by HACH TNT mg/L NH₃-N</th>
<th>Nitrate by IC mg/L NO₃-N</th>
<th>NOx-N by AQ2 SEAL mg/L NOx-N</th>
<th>Nitrite by AQ2 SEAL mg/L NO₂-N</th>
<th>Phosphate by AQ2 SEAL mg/l P</th>
<th>NOx-N by Nitrate IC + Nitrite SEAL mg/L NOx-N</th>
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Reactor B: Nansemond Activated Sludge/VIP SE + Cedar Lane PS

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<th>Nitrate by IC</th>
<th>NOx-N by AO2 SEAL</th>
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<td>mg/L NO₂-N</td>
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Reactor C: Nansemond Activated Sludge/VIP SE + Gum Road PRS

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<th>Date</th>
<th>Sample Time</th>
<th>Time since initial spike</th>
<th>Sample Number</th>
<th>Temperature</th>
<th>Ammonia by AQ2 SEAL</th>
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<th>Nitrate by IC</th>
<th>NOx-N by AQ2 SEAL</th>
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### Reactor D: Nansemond Activated Sludge/VIP SE + Pughsville PRS

**Nitrogen Source Spiked**
- Date
- Sample Time
- Time since initial spike
- Sample Number
- Temperature
- Ammonia by AQ2 SEAL
- Ammonia by HACH TNT
- Nitrate by IC
- NOx-N by AQ2 SEAL
- Nitrite by AQ2 SEAL
- Phosphate by AQ2 SEAL
- NOx-N by Nitrate IC + Nitrite SEAL

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<th>NOx-N by AQ2 SEAL</th>
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* Nitrification rates are normalized with respect to the MLVSS concentrations in their respective reactors

---

**Summary**: Experiment NOx Slope NO3 Slope NO2 Slope Nit Rate NOx* Nit Rate NO3* Nit Rate NO2* OUR SOUR MLSS MLVSS

---

**Plot**: Nitrogen Species vs. Time

---

**Diagram**: Nitrogen Species vs. Time
Week 9 – Day 2 AOB/NOB

Sample Data Report for Nansemond Nitrification Inhibition Study

AOB & NOB Experimentation:

I. AOB
   a. Spiked four 3L reactors with 20 mg/L NH₄⁺.
   b. Each reactor is running continuously by use of stir bars.
   c. 1900 mL of the diluent source is added to the reactors.
   d. 1 L of concentrated biomass is added to the reactors. For this week’s experiments the biomass was concentrated from 20L to 9 L.
   e. Constant DO and pH were monitored and logged throughout the experiment.
   f. Oxygen/air blend was sparged into the reactors to maintain DO levels through solenoid valves.
   g. LabView software was used to manage DO and pH recording as well as program and implement the solenoid valves.
   h. 5 samples were collected over a period of 3 hours through sampling ports on the reactors and filtered into sample tubes through millipore 0.45 μm filters.
   i. Reactors B, C, and D in the diluent source incorporated 1L of VIP SE and 1L of the associated interceptor lines for each reactor.

II. NOB
   a. Spiked four 3L reactors with 25 mg/L NO₃ after ammonia levels were <1 mg/L NH₄-N which was checked through the use of HACH TNT 831 Ammonia method. In addition all reactors were allowed to run overnight to consume all present ammonia.
   b. Each reactor is running continuously by use of stir bars.
   c. Constant DO and pH were monitored and logged throughout the experiment.
   d. Oxygen/air blend was sparged into the reactors to maintain DO levels through solenoid valves.
   e. LabView software was used to manage DO and pH recording as well as program and implement the solenoid valves.
   f. 5 samples were collected over a period of 3 hours through sampling ports on the reactors and filtered into sample tubes through millipore 0.45 μm filters.
   g. Reactors B, C, and D in the diluent source incorporated 1L of VIP SE and 1L of the associated interceptor lines for each reactor.

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<th>Time since initial spike</th>
<th>Sample Number</th>
<th>Temperature °C</th>
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<th>Ammonia by HACH TNT mg/L NH₃-N</th>
<th>Nitrate by IC mg/L NO₃-N</th>
<th>NOx-N by AQ2 SEAL mg/L NO₂-N</th>
<th>Nitrite by AQ2 SEAL mg/L N₂O-N</th>
<th>Nitrate by AQ2 SEAL mg/L NO₃-N</th>
<th>Phosphate by AQ2 SEAL mg/L P</th>
<th>NOx-N by Nitrate IC + Nitrite SEAL mg/L NOx-N</th>
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Reactor B: VIP Activated Sludge/VIP SE + Cedar Lane PS
Nitrogen Source 
Spiked Date Sample Time
Time since initial ... 150 200
mg/L - N
time (mins)
Nitrogen Species vs. Time
Ammonia
Nitrate
Nitrite
Linear (Nitrate)
Linear (Nitrite)

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* Nitrification rates are normalized with respect to the MLVSS concentrations in their respective reactors.
### Experiment 1

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### Experiment 2

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### Experiment # 1

![Graph 1](image1.png)

### Experiment # 2

![Graph 2](image2.png)

### AOB Comparison

![Graph 3](image3.png)

### NOB Comparison

![Graph 4](image4.png)
AOB & NOB Experimentation:
I. AOB
   a. Spiked four 3L reactors with 25 mg/L NH₄⁺
   b. Each reactor is running continuously by use of stir bars.
   c. 2 L of the diluent source is added to the reactors.
   d. 1 L of concentrated biomass is added to the reactors. For this week’s experiments the biomass was concentrated from 20L to 9 L.
   e. Constant DO and pH were monitored and logged throughout the experiment.
   f. Oxygen/air blend was sparged into the reactors to maintain DO levels through solenoid valves.
   g. LabView software was used to manage DO and pH recording as well as program and implement the solenoid valves.
   h. 5 samples were collected over a period of 3 hours through sampling ports on the reactors and filtered into sample tubes through millipore 0.45 μm filters.
   i. Reactors B, C, and D in the diluent source incorporated 1L of VIP SE and 1L of the associated interceptor lines for each reactor.

II. NOB
   a. Spiked four 3L reactors with 25 mg/L NO₂⁻ after ammonia levels were <1 mg/L NH₃-N which was checked through the use of HACH TNT 831 Ammonia method. In addition all reactors were allowed to run overnight to consume all present ammonia.
   b. Each reactor is running continuously by use of stir bars.
   c. Constant DO and pH were monitored and logged throughout the experiment.
   d. Oxygen/air blend was sparged into the reactors to maintain DO levels through solenoid valves.
   e. LabView software was used to manage DO and pH recording as well as program and implement the solenoid valves.
   f. 5 samples were collected over a period of 3 hours through sampling ports on the reactors and filtered into sample tubes through millipore 0.45 μm filters.
   g. Reactors B, C, and D in the diluent source incorporated 1L of VIP SE and 1L of the associated interceptor lines for each reactor.

### Reactor A: Nansemond Activated Sludge/VIP PE

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<th>Sample Number</th>
<th>Temperature °C</th>
<th>Ammonia by AQ2 SEAL mg/L NH₃-N</th>
<th>Ammonia by HACH TNT mg/L NH₃-N</th>
<th>Nitrate by IC mg/L NO₃-N</th>
<th>NOx-N by AQ2 SEAL mg/L NOx-N</th>
<th>Nitrite by AQ2 SEAL mg/L N₂O-N</th>
<th>Phosphate by AQ2 SEAL mg/l P</th>
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*Nitrification rates are normalized with respect to the MLVSS concentrations in their respective reactors
### Sample Data Report for Nansemond Nitrification Inhibition Study

**Reactor A: VIP Activated Sludge/VIP PE**

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<th>Sample Number</th>
<th>Temperature °C</th>
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<th>Ammonia by HACH TNT mg/L</th>
<th>Nitrate by IC mg/L</th>
<th>NOx-N by AE2 SEAL mg/L</th>
<th>Nitrite by AE2 SEAL mg/L</th>
<th>Phosphate by AE2 SEAL mg/L</th>
<th>NOx-N by Nitrate IC + Nitrite SEAL mg/L</th>
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**AOB & NOB Experimentation:**

**I. AOB**
- Spiked four 3L reactors with 10 mg/L NH₄⁺.
- Each reactor is running continuously by use of stir bars.
- 1900 mL of the diluent source is added to the reactors.
- 1 L of concentrated biomass is added to the reactors. For this week’s experiments the biomass was concentrated from 20L to 9 L.
- Constant DO and pH were monitored and logged throughout the experiment.
- Oxygen/air blend was sparged into the reactors to maintain DO levels through solenoid valves.
- LabView software was used to manage DO and pH recording as well as program and implement the solenoid valves.
- 5 samples were collected over a period of 3 hours through sampling ports on the reactors and filtered into sample tubes through millipore 0.45 μm filters.
- Reactors B, C, and D in the diluent source incorporated 1L of VIP SE and 1L of the associated interceptor lines for each reactor.

**II. NOB**
- Spiked four 3L reactors with 25 mg/L NO₂⁻ after ammonia levels were <1 mg/L NH₃-N which was checked through the use of HACH TNT 831 Ammonia method.
- Each reactor is running continuously by use of stir bars.
- Constant DO and pH were monitored and logged throughout the experiment.
- Oxygen/air blend was sparged into the reactors to maintain DO levels through solenoid valves.
- LabView software was used to manage DO and pH recording as well as program and implement the solenoid valves.
- 5 samples were collected over a period of 3 hours through sampling ports on the reactors and filtered into sample tubes through millipore 0.45 μm filters.
- Reactors B, C, and D in the diluent source incorporated 1L of VIP SE and 1L of the associated interceptor lines for each reactor.
Reactor B: VIP Activated Sludge/NS Raw
Nitrogen Source: Spiked
Date
Sample Time
Time since initial spike
Sample Number
Temperature
Ammonia by AQ2 SEAL
Ammonia by HACH TNT
Nitrate by IC
NOx-N by AQ2 SEAL
Nitrite by AQ2 SEAL
Nitrate by AQ2 SEAL
Phosphate by AQ2 SEAL
NOx-N by Nitrate IC + Nitrite SEAL

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<th>Time since initial spike</th>
<th>Sample Number</th>
<th>Temperature</th>
<th>Ammonia by AQ2 SEAL</th>
<th>Ammonia by HACH TNT</th>
<th>Nitrate by IC</th>
<th>NOx-N by AQ2 SEAL</th>
<th>Nitrite by AQ2 SEAL</th>
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| Nitrite        | 14-Dec-08  | 22:56       | 45                       | C7            | 19.5        | 0.00                                           | -                                           | 38.39                                     | 23.89                                     |                                  |                                  | 1.57                                     |
| Nitrite        | 14-Dec-08  | 23:36       | 85                       | C8            | 19.6        | 0.00                                           | -                                           | 39.08                                     | 23.32                                     |                                  |                                  | 1.91                                     |
| Nitrite        | 14-Dec-08  | 0:18        | 127                      | C9            | 19.6        | 0.00                                           | -                                           | 43.28                                     | 21.07                                     |                                  |                                  | 2.23                                     |
| Nitrite        | 14-Dec-08  | 1:05        | 174                      | C10           | 19.6        | 0.00                                           | -                                           | 38.84                                     | 19.87                                     |                                  |                                  | 2.80                                     |</p>
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<td>Nit Rate NO3*</td>
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* Nitrification rates are normalized with respect to the MLVSS concentrations in their respective reactors.
### Experiment 1

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<th>Reactor</th>
<th>Type</th>
<th>O2 Concentration</th>
<th>NO2 Concentration</th>
<th>NO3 Concentration</th>
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<td>VIP</td>
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<td>2.032</td>
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### AOB Comparison

- **NOx**
  - NS AS
  - VIP AS

- **NO3**
  - NS AS
  - VIP AS

### NOB Comparison

- **NO3**
  - NS AS
  - VIP AS

- **NO2**
  - NS AS
  - VIP AS
### AOB & NOB Experimentation:

**I. AOB**
- a. Spiked four 3L reactors with 20 mg/L NH₄⁺.
- b. Each reactor is running continuously by use of stir bars.
- c. 2 L of the diluent source is added to the reactors.
- d. 1 L of concentrated biomass is added to the reactors. For this week's experiments the biomass was concentrated from 20L to 9 L.
- e. Constant DO and pH were monitored and logged throughout the experiment.
- f. Oxygen/air blend was sparged into the reactors to maintain DO levels through solenoid valves.
- g. LabView software was used to manage DO and pH recording as well as program and implement the solenoid valves.
- h. 5 samples were collected over a period of 3 hours through sampling ports on the reactors and filtered into sample tubes through millipore 0.45 μm filters.
- i. Reactors B, C, and D in the diluent source incorporated varying concentrations of FeCl₃ calculated based on an as Fe basis relative to the 1L Biomass.
- j. A two hour period was allowed after FeCl₃ addition to monitor pH adjustment due to FeCl₃ addition.

**II. NOB**
- a. Spiked four 3L reactors with 25 mg/L NO₂⁻ after ammonia levels were <1 mg/L NH₃- N which was checked through the use of HACH TNT 831 Ammonia method. In addition all reactors were allowed to run overnight to consume all present ammonia.
- b. Each reactor is running continuously by use of stir bars.
- c. Constant DO and pH were monitored and logged throughout the experiment.
- d. Oxygen/air blend was sparged into the reactors to maintain DO levels through solenoid valves.
- e. LabView software was used to manage DO and pH recording as well as program and implement the solenoid valves.
- f. 5 samples were collected over a period of 3 hours through sampling ports on the reactors and filtered into sample tubes through millipore 0.45 μm filters.
- g. Reactors B, C, and D in the diluent source incorporated varying concentrations of FeCl₃ calculated based on an as Fe basis relative to the 1L Biomass.
- h. A two hour period was allowed after FeCl₃ addition to monitor pH adjustment due to FeCl₃ addition.

### Sample Data Report for Nansemond Nitrification Inhibition Study

**Reactor A: Nansemond Activated Sludge/VIP SE**

<table>
<thead>
<tr>
<th>Nitrogen Source Spiked</th>
<th>Date</th>
<th>Sample Time</th>
<th>Time since initial spike</th>
<th>Sample Number</th>
<th>Temperature</th>
<th>Ammonia by AQ2 SEAL</th>
<th>Ammonia by HACH TNT</th>
<th>Nitrate by IC NOx-N by AQ2 SEAL</th>
<th>Nitrate by AQ2 SEAL</th>
<th>Nitrate by AO2 SEAL + Nitrite SEAL</th>
<th>Phosphate by AO2 SEAL</th>
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<td>min</td>
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<td>°C</td>
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<td>mg/L NH₃-N</td>
<td>mg/L NO₂-N</td>
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Reactor C: Nansemond Activated Sludge/VIP SE + 35 mg/L Fe
Nitrogen Source Spiked
Date Sample Time Time since initial spike Sample Number Temperature Ammonia by AQ2 SEAL Ammonia by HACH TNT Nitrate by IC NOx-N by AQ2 SEAL Nitrite by AQ2 SEAL Phosphate by AQ2 SEAL NOx-N by Nitrate IC Phosphate by HACH TNT

<table>
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<tr>
<th>Nitrogen Source Spiked</th>
<th>Date</th>
<th>Sample Time</th>
<th>Time since initial spike</th>
<th>Sample Number</th>
<th>Temperature</th>
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<th>Ammonia by HACH TNT</th>
<th>Nitrate by IC</th>
<th>NOx-N by AQ2 SEAL</th>
<th>Nitrite by AQ2 SEAL</th>
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<th>NOx-N by Nitrate IC</th>
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<td>Nitrate by IC</td>
<td>NOx-N by AQ2 SEAL</td>
<td>Nitrite by AQ2 SEAL</td>
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<td>Phosphate by AQ2 SEAL</td>
<td>Phosphate by HACH TNT</td>
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* Nitrification rates are normalized with respect to the MLVSS concentrations in their respective reactors.
Week 11 – Day 2 AOB/NOB
Sample Data Report for Nansemond Nitrification Inhibition Study

AOB & NOB Experimentation:
I. AOB
  a. Spiked four 3L reactors with 20 mg/L NH₄.
  b. Each reactor is running continuously by use of stir bars.
  c. 1900 mL of the diluent source is added to the reactors.
  d. 1 L of concentrated biomass is added to the reactors. For this weeks experiments the biomass was concentrated from 20L to 9 L.
  e. Constant DO and pH were monitored and logged throughout the experiment.
  f. Oxygen/air blend was sparged into the reactors to maintain DO levels through solenoid valves.
  g. LabView software was used to manage DO and pH recording as well as program and implement the solenoid valves.
  h. 5 samples were collected over a period of 3 hours through sampling ports on the reactors and filtered into sample tubes through millipore 0.45 μm filters.
  i. Reactors B, C, and D in the diluent source incorporated varying concentrations of FeCl₃ calculated based on an as Fe basis relative to the 1L Biomass.
  j. A two hour period was allowed after FeCl₃ addition to monitor pH adjustment due to FeCl₃ addition.

II. NOB
  a. Spiked four 3L reactors with 25 mg/L NO₂ after ammonia levels were <1 mg/L NH₃-N which was checked through the use of HACH TNT 831 Ammonia method. In addition all reactors were allowed to run overnight to consume all present ammonia.
  b. Each reactor is running continuously by use of stir bars.
  c. Constant DO and pH were monitored and logged throughout the experiment.
  d. Oxygen/air blend was sparged into the reactors to maintain DO levels through solenoid valves.
  e. LabView software was used to manage DO and pH recording as well as program and implement the solenoid valves.
  f. 5 samples were collected over a period of 3 hours through sampling ports on the reactors and filtered into sample tubes through millipore 0.45 μm filters.
  g. Reactors B, C, and D in the diluent source incorporated varying concentrations of FeCl₃ calculated based on an as Fe basis relative to the 1L Biomass.
  h. A two hour period was allowed after FeCl₃ addition to monitor pH adjustment due to FeCl₃ addition.

<table>
<thead>
<tr>
<th>Reactor A: VIP Activated Sludge/VIP SE</th>
<th>Nitrogen Source Spiked</th>
<th>Date</th>
<th>Sample Time</th>
<th>Time since initial spike</th>
<th>Sample Number</th>
<th>Temperature</th>
<th>Ammonia by AQ2 SEAL mg/L NH₃-N</th>
<th>Ammonia by HACH TNT mg/L NH₃-N</th>
<th>Nitrates by IC mg/L NO₃-N</th>
<th>NOx-N by AQ2 SEAL mg/L NOx-N</th>
<th>Nitrate by AQ2 SEAL mg/L NO₃-N</th>
<th>Phosphate by AQ2 SEAL mg/L PO₄-P</th>
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NOTE NOB EXPERIMENT WAS NOT RUN DURING DAY 2 EXPERIMENTATION
## Reactor B: VIP Activated Sludge/VIP SE + 20 mg/L Fe

### Nitrogen Species vs. Time

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<th>Time since initial spike</th>
<th>Sample Number</th>
<th>Temperature</th>
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<th>NOx-N by AO2 SEAL</th>
<th>Nitrite by AO2 SEAL</th>
<th>NOx-N by Nitrate IC + Nitrite SEAL</th>
<th>Phosphate by AO2 SEAL</th>
<th>NOx-N by Nitrate IC</th>
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### Nitrogen Species vs. Time Graphs

- **Ammonia**
- **Nitrate**
- **NOx-N**
- **Nitrite**
- **Linear (Nitrate)**
- **Linear (NOx-N)**

**Time (mins)**

- 0
- 50
- 100
- 150
- 200

**mg/L - N**

- 0
- 5.00
- 10.00
- 15.00
- 20.00
- 25.00
<table>
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<tr>
<th>Nitrogen Source Spiked</th>
<th>Date</th>
<th>Sample Time</th>
<th>Time since initial spike</th>
<th>Sample Number</th>
<th>Temperature</th>
<th>Ammonia by AQ2 SEAL</th>
<th>Ammonia by HACH TNT</th>
<th>Nitrate by IC</th>
<th>NOx-N by AQ2 SEAL</th>
<th>Nitrite by AQ2 SEAL</th>
<th>Nitrate by AQ2 SEAL + Nitrite SEAL</th>
<th>Phosphate by AQ2 SEAL</th>
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Reactor D: VIP Activated Sludge/VIP SE + 50 mg/L Fe
Nitrogen Source 
Spiked Date Sample Time
Time since initial spike Sample Number Temperature
Ammonia by AQ2 SEAL Ammonia by HACH TNT Nitrate by IC NOx-N by AQ2 SEAL Nitrate by AQ2 SEAL Nitrite by AQ2 SEAL Phosphate by AQ2 SEAL NOx-N by Nitrate IC + Nitrite SEAL Phosphate by HACH TNT

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<th>Date</th>
<th>Sample Time</th>
<th>Time since initial spike</th>
<th>Sample Number</th>
<th>Temperature</th>
<th>Ammonia by AQ2 SEAL mg/L NH3-N</th>
<th>Ammonia by HACH TNT mg/L NH3-N</th>
<th>Nitrate by IC mg/L NO3-N</th>
<th>NOx-N by AQ2 SEAL mg/L NOx-N</th>
<th>Nitrate by AQ2 SEAL mg/L NO3-N</th>
<th>Nitrite by AQ2 SEAL mg/L NO2-N</th>
<th>Phosphate by AQ2 SEAL mg/l P</th>
<th>NOx-N by Nitrate IC + Nitrite SEAL mg/L NOx-N</th>
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### Summary

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<th>Experiment</th>
<th>NOx Slope</th>
<th>NO3 Slope</th>
<th>NO2 Slope</th>
<th>Nit Rate NOx*</th>
<th>Nit Rate NO3*</th>
<th>Nit Rate NO2*</th>
<th>OUR</th>
<th>SOUR</th>
<th>MLSS</th>
<th>MLVSS</th>
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* Nitrification rates are normalized with respect to the MLVSS concentrations in their respective reactors

**NOTE NOB EXPERIMENT WAS NOT RUN DURING DAY 2 EXPERIMENTATION**
### Experiment 1

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<th>NOB NO3</th>
<th>NOB NO2</th>
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<tr>
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### Experiment 2

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### Experiment #1

**AOB Comparison**

- **Rate [mg/g MLVSS/hr]**
  - Reactor A: NS
  - Reactor B: NS
  - Reactor C: NS
  - Reactor D: NS

### Experiment #2

**NOB Comparison**

- **Rate [mg/g MLVSS/hr]**
  - Reactor A: NS
  - Reactor B: NS
  - Reactor C: NS
  - Reactor D: NS
### AOB & NOB Experimentation:

I. **AOB**
   a. Spiked four 3L reactors with 20 mg/L NH₄⁺.
   b. Each reactor is running continually by use of stir bars.
   c. 2 L of the diluent source is added to the reactors.
   d. 1 L of concentrated biomass is added to the reactors. For this week's experiments the biomass was concentrated from 20 L to 9 L.
   e. Constant DO and pH were monitored and logged throughout the experiment.
   f. Oxygen/air blend was sparged into the reactors to maintain DO levels through solenoid valves.
   g. LabView software was used to manage DO and pH recording as well as program and implement the solenoid valves.
   h. 5 samples were collected over a period of 3 hours through sampling ports on the reactors and filtered into sample tubes through 0.45 μm filters.
   i. Reactors B, C, and D in the diluent source incorporated varying concentrations of FeCl₃ calculated based on an as Fe basis relative to the 1L Biomass.
   j. A two hour period was allowed after FeCl₃ addition to monitor pH adjustment due to FeCl₃ addition.

II. **NOB**
   a. Spiked four 3L reactors with 25 mg/L NO₂⁻ after ammonia levels were <1 mg/L NH₃-N which was checked through the use of HACH TNT 831 Ammonia method. In addition all reactors were allowed to run overnight to consume all present ammonia.
   b. Each reactor is running continually by use of stir bars.
   c. Constant DO and pH were monitored and logged throughout the experiment.
   d. Oxygen/air blend was sparged into the reactors to maintain DO levels through solenoid valves.
   e. LabView software was used to manage DO and pH recording as well as program and implement the solenoid valves.
   f. 5 samples were collected over a period of 3 hours through sampling ports on the reactors and filtered into sample tubes through 0.45 μm filters.
   g. Reactors B, C, and D in the diluent source incorporated varying concentrations of FeCl₃ calculated based on an as Fe basis relative to the 1L Biomass.
   h. A two hour period was allowed after FeCl₃ addition to monitor pH adjustment due to FeCl₃ addition.

### Sample Data Report for Nansemond Nitrification Inhibition Study

Reactor A: Nansemond Activated Sludge/VIP SE

<table>
<thead>
<tr>
<th>Time since initial spike</th>
<th>Sample Number</th>
<th>Temperature °C</th>
<th>Ammonia by AQ2 SEAL mg/L NH₃-N</th>
<th>Ammonia by HACH TNT mg/L NH₃-N</th>
<th>Nitrate by IC mg/L NO₃-N</th>
<th>NOx-N by AQ2 SEAL mg/L NOx-N</th>
<th>Nitrite by AQ2 SEAL mg/L NO₂-N</th>
<th>Nitrite by AQ2 SEAL mg/L NO₂-N</th>
<th>Phosphate by AQ2 SEAL mg/L P</th>
<th>NOx-N by Nitrate IC + Nitrite SEAL mg/L NOx-N</th>
<th>Phosphate by HACH TNT mg/L PO₄-P</th>
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## Reactor B: Nansemond Activated Sludge/VIP SE + 20 mg/L Fe

### Nitrogen Source
- Spiked

### Date
- d/m/m-yy

### Sample Time
- h:mm

### Temperature
- °C

### Sample Number
- min

### Ammonia by AQ2 SEAL
- mg/L NH₃-N

### Ammonia by HACH TNT
- mg/L NH₃-N

### Nitrate by IC
- mg/L NO₃-N

### NOx-N by AQ2 SEAL
- mg/L NOx-N

### Nitrite by AQ2 SEAL
- mg/L NO₂-N

### Phosphate by AQ2 SEAL
- mg/l P

### NOx-N by Nitrate IC + Nitrite SEAL
- mg/L NOx-N

### Phosphate by HACH TNT
- mg/L PO₄-P

### Nitrogen Species vs. Time

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<tr>
<th>Nitrogen Source Spiked</th>
<th>Date</th>
<th>Sample Time</th>
<th>Time since initial spike</th>
<th>Sample Number</th>
<th>Temperature</th>
<th>Ammonia by AQ2 SEAL</th>
<th>Ammonia by HACH TNT</th>
<th>Nitrate by IC</th>
<th>NOx-N by AQ2 SEAL</th>
<th>Nitrite by AQ2 SEAL</th>
<th>Phosphate by AQ2 SEAL</th>
<th>NOx-N by Nitrate IC + Nitrite SEAL</th>
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<th>Ammonia by AQ2 SEAL</th>
<th>Ammonia by HACH TNT</th>
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<th>NOx-N by AQ2 SEAL</th>
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### Reactor D: Nansemond Activated Sludge/VIP SE + 50 mg/L Fe

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<th>NOx-N by AQ2 SEAL</th>
<th>Phosphate by AQ2 SEAL</th>
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#### Nitrogen Species vs. Time

- **Ammonia**
- **Nitrate**
- **NOx-N**
- **Nitrite**
  - Linear (Nitrate)
  - Linear (NOx-N)
  - Linear (Nitrite)

---

### Diagrams

1. **Nitrogen Species vs. Time**
   - Ammonia
   - Nitrate
   - NOx-N
   - Nitrite
     - Linear (Nitrate)
     - Linear (NOx-N)
     - Linear (Nitrite)

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### Summary

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<th>NOx Slope</th>
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<th>NO2 Slope</th>
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<th>Nit Rate NO3*</th>
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<th>SOUR</th>
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* Nitrification rates are normalized with respect to the MLVSS concentrations in their respective reactors.
## Sample Data Report for Nansemond Nitrification Inhibition Study

### NOB EXPERIMENT WAS NOT RUN DURING DAY 2 EXPERIMENTATION

**AOB & NOB Experimentation:**

I. **AOB**
   a. Spiked four 3L reactors with 20 mg/L NH₄⁺.
   b. Each reactor is running continuously by use of stir bars.
   c. 1900 mL of the diluent source is added to 9 L of the reactors.
   d. 1 L of concentrated biomass is added to the reactors. For this week’s experiments the biomass was concentrated from 20 L to 9 L.
   e. Constant DO and pH were monitored and logged throughout the experiment.
   f. Oxygen/air blend was sparged into the reactors to maintain DO levels through solenoid valves.
   g. LabView software was used to manage DO and pH recording as well as program and implement the solenoid valves.
   h. 5 samples were collected over a period of 3 hours through sampling ports on the reactors and filtered through millipore 0.45 μm filters.
   i. Reactors B, C, and D in the diluent source incorporated varying concentrations of FeCl₃ calculated based on an as Fe basis relative to the 1L Biomass.
   j. A two hour period was allowed after FeCl₃ addition to monitor pH adjustment due to FeCl₃ addition.

II. **NOB**
   a. Spiked four 3L reactors with 25 mg/L NO₂⁻ after ammonia levels were <1 mg/L NH₃-N which was checked through the use of HACH TNT 831 Ammonia method. In addition all reactors were allowed to run overnight to consume all present ammonia.
   b. Each reactor is running continuously by use of stir bars.
   c. Constant DO and pH were monitored and logged throughout the experiment.
   d. Oxygen/air blend was sparged into the reactors to maintain DO levels through solenoid valves.
   e. LabView software was used to manage DO and pH recording as well as program and implement the solenoid valves.
   f. 5 samples were collected over a period of 3 hours through sampling ports on the reactors and filtered through millipore 0.45 μm filters.
   g. Reactors B, C, and D in the diluent source incorporated varying concentrations of FeCl₃ calculated based on an as Fe basis relative to the 1L Biomass.
   h. A two hour period was allowed after FeCl₃ addition to monitor pH adjustment due to FeCl₃ addition.

### Reactor A: VIP Activated Sludge/VIP SE

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<th>Time since initial spike</th>
<th>Sample Number</th>
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<th>Ammonia by AQ2 SEAL</th>
<th>Ammonia by HACH TNT</th>
<th>Nitrate by IC</th>
<th>NOx-N by AQ2 SEAL</th>
<th>Nitrite by AQ2 SEAL</th>
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<th>Phosphate by AQ2 SEAL</th>
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Reactor C: VIP Activated Sludge/VIP SE + 35 mg/L Fe
Nitrogen Source: Spiked

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<th>Ammonia by HACH TNT</th>
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<th>NOx-N by AQ2 SEAL</th>
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### Reactor D: VIP Activated Sludge/VIP SE + 50 mg/L Fe

**Nitrogen Source**
- Spiked Date
- Sample Time
- Time since initial spike
- Sample Number
- Temperature

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* Nitrification rates are normalized with respect to the MLVSS concentrations in their respective reactors

**NOTE NOB EXPERIMENT WAS NOT RUN DURING DAY 2 EXPERIMENTATION**
### Experiment 1

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### Experiment 2

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### NOB Comparison

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Week 13 – FeCl3 Addition with York River Biomass Day 1 AOB/NOB

Sample Data Report for Nansemond Nitrification Inhibition Study

Reactor A: YR A.S. / YR SE

Nitrogen Source Spiked

<table>
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<tr>
<th>Ammonia</th>
<th>Date</th>
<th>Sample Time</th>
<th>Time since initial spike</th>
<th>Sample Number</th>
<th>Temperature</th>
<th>Ammonia by AQ2 SEAL</th>
<th>Ammonia by HACH TNT</th>
<th>Nitrate by IC NOx-N by AQ2 SEAL</th>
<th>Nitrite by AQ2 SEAL</th>
<th>Nitrate by IC NOx-N by AQ2 SEAL</th>
<th>Phosphate by AQ2 SEAL</th>
<th>Phosphate by HACH TNT</th>
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AOB & NOB Experimentation:
I. AOB
a. Spiked four 3L reactors with 25 mg/L NH4.

b. Each reactor is running continuously by use of stir bars.

c. 2 L of the diluent source is added to the reactors.

d. 1 L of concentrated biomass is added to the reactors. For this weeks experiments the biomass was concentrated from 20 L to 9 L.

e. Constant DO and pH were monitored and logged throughout the experiment.

f. Oxygen/air blend was sparged into the reactors to maintain DO levels through solenoid valves.

g. LabView software was used to manage DO and pH recording as well as program and implement the solenoid valves.

h. 5 samples were collected over a period of 3 hours through sampling ports on the reactors and filtered into sample tubes through millipore 0.45 μm filters

i. Reactors B, C, and D in the diluent source incorporated varying concentrations of FeCl3 calculated based on an as Fe basis relative to the Biomass

j. A two hour period was allowed after FeCl3 addition to monitor pH adjustment due to FeCl3 addition.

k. Alkalinity was added to each reactor according to the Fe dose added to keep the pH from dropping to low.

II. NOB
a. Spiked four 3L reactors with 15 mg/L NO2 after ammonia levels were <1 mg/L NH3-N which was checked through the use of HACH TNT 831 Ammonia method.

In addition all reactors were allowed to run overnight to consume all present ammonia.

b. Each reactor is running continuously by use of stir bars.

c. Constant DO and pH were monitored and logged throughout the experiment.

d. Oxygen/air blend was sparged into the reactors to maintain DO levels through solenoid valves.

e. LabView software was used to manage DO and pH recording as well as program and implement the solenoid valves.

f. 5 samples were collected over a period of 3 hours through sampling ports on the reactors and filtered into sample tubes through millipore 0.45 μm filters.

g. Reactors B, C, and D in the diluent source incorporated varying concentrations of FeCl3 calculated based on an as Fe basis relative to the Biomass

h. A two hour period was allowed after FeCl3 addition to monitor pH adjustment due to FeCl3 addition.

i. Alkalinity was added to each reactor according to the Fe dose added to keep the pH from dropping to low.
Reactor B: YR A.S./YR SE + 20 mg/L Fe

<table>
<thead>
<tr>
<th>Nitrogen Source Spiked</th>
<th>Date</th>
<th>Sample Time</th>
<th>Time since initial spike</th>
<th>Sample Number</th>
<th>Temperature</th>
<th>Ammonia by AQ2 SEAL</th>
<th>Ammonia by HACH TNT</th>
<th>Nitrate by IC</th>
<th>NOx-N by AQ2 SEAL</th>
<th>Nitrite by AQ2 SEAL</th>
<th>Nitrate by AQ2 SEAL + Nitrite SEAL</th>
<th>Phosphate by AQ2 SEAL</th>
<th>NOx-N by Nitrate IC</th>
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Reactor C: YR A.S./YR SE + 35 mg/L Fe

Nitrogen Species vs. Time

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<th>Ammonia by HACH TNT</th>
<th>Nitrate by IC</th>
<th>NOx-N by AQ2 SEAL</th>
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<th>Phosphate by HACH TNT</th>
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Nitrogen Source Spiked Date Sample Time Temperature Ammonia by AQ2 SEAL Ammonia by HACH TNT Nitrate by IC NOx-N by AQ2 SEAL Nitrate by AQ2 SEAL Phosphate by AQ2 SEAL NOx-N by Nitrate IC + Nitrite SEAL Phosphate by HACH TNT

Reactor C: YR A.S./YR SE + 35 mg/L Fe
Reactor D: YR A.S./YR SE + 50 mg/L Fe

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<th>Sample Time</th>
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<th>NOx-N by AQ2 SEAL</th>
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### Summary

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<th>NO2 Slope</th>
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<th>Nit Rate NO3*</th>
<th>Nit Rate NO2*</th>
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<th>SOUR</th>
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* Nitrification rates are normalized with respect to the MLVSS concentrations in their respective reactors.
## Week 13 – Day 2 AOB/NOB

Sample Data Report for Nansemond Nitrification Inhibition Study

### AOB & NOB Experimentation:

I. AOB
- a. Spiked four 3L reactors with 25 mg/L NH₄⁻.
- b. Each reactor is running continuously by use of stir bars.
- c. 2 L of the diluent source is added to the reactors.
- d. 1 L of concentrated biomass is added to the reactors. For this week's experiments the biomass was concentrated from 20L to 9 L.
- e. Constant DO and pH were monitored and logged throughout the experiment.
- f. Oxygen/air blend was sparged into the reactors to maintain DO levels through solenoid valves.
- g. LabView software was used to manage DO and pH recording as well as program and implement the solenoid valves.
- h. 5 samples were collected over a period of 3 hours through sampling ports on the reactors and filtered into sample tubes through millipore 0.45 μm filters.
- i. Reactors B, C, and D in the diluent source incorporated varying concentrations of FeCl₃ calculated based on an as Fe basis relative to the Biomass.
- j. A two hour period was allowed after FeCl₃ addition to monitor pH adjustment due to FeCl₃ addition.
- k. Alkalinity was added to each reactor according to the Fe dose added to keep the pH from dropping to low.

II. NOB
- a. Spiked four 3L reactors with 15 mg/L NO₂⁻ after ammonia levels were <1 mg/L NH₃-N which was checked through the use of HACH TNT 831 Ammonia method. In addition all reactors were allowed to run overnight to consume all present ammonia.
- b. Each reactor is running continuously by use of stir bars.
- c. Constant DO and pH were monitored and logged throughout the experiment.
- d. Oxygen/air blend was sparged into the reactors to maintain DO levels through solenoid valves.
- e. LabView software was used to manage DO and pH recording as well as program and implement the solenoid valves.
- f. 5 samples were collected over a period of 3 hours through sampling ports on the reactors and filtered into sample tubes through millipore 0.45 μm filters.
- g. Reactors B, C, and D in the diluent source incorporated varying concentrations of FeCl₃ calculated based on an as Fe basis relative to the Biomass.
- h. A two hour period was allowed after FeCl₃ addition to monitor pH adjustment due to FeCl₃ addition.
- i. Alkalinity was added to each reactor according to the Fe dose added to keep the pH from dropping to low.

### Reactor A: YR A.S./YR SE

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<tr>
<th>Nitrogen Source Spiked</th>
<th>Date</th>
<th>Sample Time</th>
<th>Time since initial spike</th>
<th>Sample Number</th>
<th>Temperature</th>
<th>Ammonia by AO2 SEAL</th>
<th>Ammonia by HACH TNT</th>
<th>Nitrate by IC</th>
<th>NOx-N by AO2 SEAL</th>
<th>Nitrile by AO2 SEAL</th>
<th>Nitrate by AO2 SEAL</th>
<th>Phosphate by AO2 SEAL</th>
<th>NOx-N by Nitrile IC + Nitrile SEAL</th>
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Reactor B: YR A.S./YR SE + 20 mg/L Fe

Nitrogen Source Spiked Date Sample Time
Spiked Date Sample Time
Time since initial spike Sample Number Temperature °C mg/L NH₃-N mg/L NO₃-N mg/L NOx-N mg/l P mg/L NOx-N mg/L PO₄-P

Ammonia 7-Feb-09 16:53 3 B1 12.5 23.29 22.80 23.30 0.07 0.22 23.37 0.05
Ammonia 7-Feb-09 17:41 51 B2 13.1 22.01 21.45 24.55 0.50 0.39 25.04 0.39
Ammonia 7-Feb-09 18:23 93 B3 13.4 21.11 20.15 25.35 0.87 1.18 26.23 0.09
Ammonia 7-Feb-09 19:02 132 B4 13.5 19.91 18.95 23.56 1.22 1.45 24.78 0.08
Ammonia 7-Feb-09 19:56 186 B5 13.6 18.14 17.10 25.97 1.68 1.31 27.65 0.06

Nitrite 8-Feb-09 9:31 3 B6 12.36666667 0.00 - 23.48 15.22 1.31 38.70 0.08
Nitrite 8-Feb-09 10:14 46 B7 13.12 0.00 - 24.54 14.21 1.21 38.75 0.05
Nitrite 8-Feb-09 10:59 91 B8 13.9 0.00 - 26.49 13.31 1.31 39.61 0.07
Nitrite 8-Feb-09 11:44 136 B9 14.4 0.00 - 26.58 11.87 1.09 38.44 0.06
Nitrite 8-Feb-09 12:26 178 B10 14.35 0.00 - 27.88 10.07 1.01 37.75 0.07
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<th>Nitrate by IC</th>
<th>NOx-N by AQ2 SEAL</th>
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### Diagrams

**Nitrogen Species vs. Time**

- **Reactor C: YR A.S./YR SE + 35 mg/L Fe**
- **Spiked Date**: dd-mm-yy
- **Sample Time**: h:mm
- **Temperature**: °C
- **Ammonia by AQ2 SEAL**: mg/L NH₃-N
- **Nitrate by IC**: mg/L NO₃-N
- **NOx-N by AQ2 SEAL**: mg/L NOₓ-N
- **Nitrite by AQ2 SEAL**: mg/L NO₂-N
- **Phosphate by AQ2 SEAL**: mg/l P
- **Phosphate by HACH TNT**: mg/l PO₄-P

**Ammonia**

- 7-Feb-09 16:53: 23.99 mg/L NH₃-N
- 7-Feb-09 17:41: 21.41 mg/L NH₃-N
- 7-Feb-09 18:23: 19.48 mg/L NH₃-N
- 7-Feb-09 19:02: 17.44 mg/L NH₃-N
- 7-Feb-09 19:56: 15.14 mg/L NH₃-N

**Nitrate**

- 8-Feb-09 9:31: 22.97 mg/L NO₃-N
- 8-Feb-09 10:14: 24.28 mg/L NO₃-N
- 8-Feb-09 10:59: 26.24 mg/L NO₃-N
- 8-Feb-09 11:44: 26.65 mg/L NO₃-N
- 8-Feb-09 12:26: 27.42 mg/L NO₃-N

**Nitrite**

- 8-Feb-09 9:31: 0.00 mg/L NO₂-N
- 8-Feb-09 10:14: 0.00 mg/L NO₂-N
- 8-Feb-09 10:59: 0.00 mg/L NO₂-N
- 8-Feb-09 11:44: 0.00 mg/L NO₂-N
- 8-Feb-09 12:26: 0.00 mg/L NO₂-N

**NOx-N**

- 8-Feb-09 9:31: 15.14 mg/L NOₓ-N
- 8-Feb-09 10:14: 13.84 mg/L NOₓ-N
- 8-Feb-09 10:59: 12.63 mg/L NOₓ-N
- 8-Feb-09 11:44: 11.29 mg/L NOₓ-N
- 8-Feb-09 12:26: 10.61 mg/L NOₓ-N
### Reactor D: YR A.S./YR SE + 50 mg/L Fe

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<tr>
<th>Nitrogen Source</th>
<th>Date</th>
<th>Sample Time</th>
<th>Time since initial spike</th>
<th>Sample Number</th>
<th>Temperature</th>
<th>Ammonia by AQ2 SEAL</th>
<th>Ammonia by HACH TNT</th>
<th>Nitrate by IC</th>
<th>NOx-N by AQ2 SEAL</th>
<th>Nitrate by AQ2 SEAL</th>
<th>Phosphate by AQ2 SEAL + Nitrate SEAL</th>
<th>Phosphate by HACH TNT</th>
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---

**Diagram:**

- Nitrogen Species vs. Time
- Graph showing the concentration of Ammonia, Nitrate, NOx-N, and Nitrite over time.

---

**Table:**

- Nitrogen Source: Ammonia and Nitrite
- Spiked Date: 7-Feb-09 and 8-Feb-09
- Sample Time: Ranges from 3 to 136 minutes
- Temperature: Ranges from 12.4°C to 13.6°C
### Summary

<table>
<thead>
<tr>
<th>Experiment</th>
<th>Ammonia NOx Slope</th>
<th>Ammonia NO3 Slope</th>
<th>Ammonia NO2 Slope</th>
<th>Nitrate NOx*</th>
<th>Nitrate NO3*</th>
<th>Nitrate NO2*</th>
<th>OUR</th>
<th>SOUR</th>
<th>MLSS</th>
<th>MLVSS</th>
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<tr>
<td>Reactor A: YR Activated sludge</td>
<td>Ammonia 0.020</td>
<td>0.013</td>
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<td>0.891</td>
<td>0.133</td>
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<td>1.596</td>
<td>-1.940</td>
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<td>Reactor B: YR Activated Sludge</td>
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<td>0.110</td>
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<td>Reactor D: YR 35 mg/L Fe Activated Sludge</td>
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* Nitrification rates are normalized with respect to the MLVSS concentrations in their respective reactors.
### Experiment 1

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<tr>
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<td>1.363</td>
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<td>50 mg/L Fe</td>
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### Week 14 – NTP Raw, PCI, PCE Composite Samples Day 1 AOB

**Sample Data Report for Nansemond Nitrification Inhibition Study**

Reactor A: YR A.S. / YR PE

#### Nitrogen Source Spiked

<table>
<thead>
<tr>
<th>Date</th>
<th>Sample Time</th>
<th>Time since initial spike</th>
<th>Sample Number</th>
<th>Temperature</th>
<th>Ammonia by AQ2 SEAL</th>
<th>Ammonia by HACH TNT</th>
<th>Nitrate by IC</th>
<th>NOx-N by AQ2 SEAL</th>
<th>Nitrate by AQ2 SEAL</th>
<th>Nox-N by Nitraten IC + Nitrate SEAL</th>
<th>Phosphate by AQ2 SEAL</th>
<th>Phosphate by HACH TNT</th>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>°C</td>
<td>mg/L NH3-N</td>
<td>mg/L NH3-N</td>
<td>mg/L NO3-N</td>
<td>mg/L NO2-N</td>
<td>mg/L NO3-N</td>
<td>mg/L NOx-N</td>
<td>mg/l P</td>
<td>mg/L PO4-P</td>
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<td>Ammonia-M</td>
<td>20-Mar-09</td>
<td>21:09</td>
<td>15 A1</td>
<td>19.7</td>
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<td>1.60</td>
<td>11.78</td>
<td>1.60</td>
<td>11.78</td>
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AOB Experimentation:

I. AOB
a. Spiked four 3L reactors with 25 mg/L NH₄.
b. Each reactor is running continuously by use of stir bars.
c. 2 L of the diluent source is added to the reactors.
d. 1 L of concentrated biomass is added to the reactors. For this week's experiments the biomass was concentrated from 20 L to 9 L.
e. Constant DO and pH were monitored and logged throughout the experiment.
f. Oxygen/air blend was sparged into the reactors to maintain DO levels through solenoid valves.
g. LabView software was used to manage DO and pH recording as well as program and implement the solenoid valves.
h. 5 samples were collected over a period of 3 hours through sampling ports on the reactors and filtered into sample tubes through millipore 0.45 μm filters.
i. Reactors B, C, and D in the diluent source incorporated 2L of the associated composite samples taken for each day respectively.
<table>
<thead>
<tr>
<th>Nitrogen Source Spiked</th>
<th>Date</th>
<th>Sample Time</th>
<th>Time since initial spike</th>
<th>Sample Number</th>
<th>Temperature</th>
<th>Ammonia by AQ2 SEAL</th>
<th>Ammonia by HACH TNT</th>
<th>Nitrate by IC</th>
<th>NOx-N by AQ2 SEAL</th>
<th>Nitrte by AQ2 SEAL</th>
<th>NOx-N by Nitrate IC + Nitrte SEAL</th>
<th>Phosphate by AQ2 SEAL</th>
<th>Phosphate by HACH TNT</th>
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<tbody>
<tr>
<td>Ammonia-M</td>
<td>20-Mar-09</td>
<td>21:09</td>
<td>15</td>
<td>B1</td>
<td>17.5</td>
<td>39.12 mg/L</td>
<td>35.00 mg/L</td>
<td>5.48</td>
<td>1.54 mg/L</td>
<td>2.52 mg/L</td>
<td>6.29 mg/L</td>
<td>0.81 mg/L</td>
<td>2.76 mg/L</td>
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<td>60</td>
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* Nitrification rates are normalized with respect to the MLVSS concentrations in their respective reactors.
### Sample Data Report for Nansemond Nitrification Inhibition Study

**Reactor A: YR A.S. / YR PE**

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<th>Sample Number</th>
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<th>Ammonia by HACH TNT mg/L NH₃-N</th>
<th>Nitrate by IC mg/L NO₃-N</th>
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### Reactor C: YR A.S. / NS PCI

#### Nitrogen Source
- Spiked

#### Date
- Ammonia-W: 21-Mar-09
- Ammonia-TR: 21-Mar-09

#### Sample Time
- 5:50, 6:35, 7:18, 8:00, 8:42, 9:58, 10:40, 11:23, 12:05, 12:47

#### Temperature
- 15.5, 16.0, 15.8, 15.7, 16.1, 15.9, 15.8, 15.8, 15.8, 15.8

#### Sample Number
- C1, C2, C3, C4, C5, C6, C7, C8, C9, C10

#### Nitrogen Species
- Ammonia by AQ2 SEAL
- Ammonia by HACH TNT
- Nitrate by IC
- NOx-N by AQ2 SEAL
- Nitrite by AQ2 SEAL
- Nitrate by AQ2 SEAL
- Phosphate by AQ2 SEAL
- Nitrate by IC + Nitrite SEAL
- Phosphate by HACH TNT

#### Nitrogen Species vs. Time

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*Nitrification rates are normalized with respect to the MLVSS concentrations in their respective reactors.
Monday & Tuesday

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**Week 15 – QACs Day 1 AOB/NOB**

Sample Data Report for Nansemond Nitrification Inhibition Study

AOB & NOB Experimentation:

I. AOB
   a. Spiked four 3L reactors with 25 mg/L NH$_4$-
   b. Each reactor is running continuously by use of stir bars.
   c. 2 L of the diluent source is added to the reactors.
   d. 1 L of concentrated biomass is added to the reactors. For this weeks experiments the biomass was concentrated from 20 L to 9 L.
   e. Constant DO and pH were monitored and logged throughout the experiment.
   f. Oxygen/air blend was sparged into the reactors to maintain DO levels through solenoid valves.
   g. LabView software was used to manage DO and pH recording as well as program and implement the solenoid valves.
   h. 5 samples were collected over a period of 3 hours through sampling ports on the reactors and filtered into sample tubes through millipore 0.45 μm filters.

II. NOB
   a. Spiked four 3L reactors with 15 mg/L NO$_2$-
      after ammonia levels were <1 mg/L NH$_3$-
      which was checked through the use of HACH TNT 831 Ammonia method.
      In addition all reactors were allowed to run overnight to consume all present ammonia.
   b. Each reactor is running continuously by use of stir bars.
   c. Constant DO and pH were monitored and logged throughout the experiment.
   d. Oxygen/air blend was sparged into the reactors to maintain DO levels through solenoid valves.
   e. LabView software was used to manage DO and pH recording as well as program and implement the solenoid valves.
   f. 5 samples were collected over a period of 3 hours through sampling ports on the reactors and filtered into sample tubes through millipore 0.45 μm filters.
   g. Reactors B, C, and D in the diluent source incorporated varying concentrations of Nature Fresh Chemical Toilet Additive based on different assumptions

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### Reactor C: YR A.S./YR SE + 14 mL NF

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<th>Temperature</th>
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<th>NOx-N by AQ2 SEAL</th>
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### Nitrogen Species vs. Time

- **Ammonia**
- **Nitrate**
- **NOx**
- **Nitrite**

#### Linear Trends
- **Linear (Nitrate)**
- **Linear (NOx)**
- **Linear (Series2)**
- **Linear (Nitrite)***

---

343
Reactor D: YR A.S./YR SE + 63 mL NF

Nitrogen Source
Spiked
Date
Sample Time
Time since initial spike
Sample Number
Temperature
Ammonia by AQ2 SEAL
Ammonia by HACH TNT
Nitrate by IC
NOx-N by AQ2 SEAL
Nitrite by AQ2 SEAL
Phosphate by AQ2
Phosphate by HACH TNT

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* Nitrification rates are normalized with respect to the MLVSS concentrations in their respective reactors.
### Week 15 – Day 2 AOB/NOB

#### Sample Data Report for Nansemond Nitrification Inhibition Study

**Reactor A: YR A.S./YR SE**

#### Nitrogen Source Spiked

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<th>Time since initial spike</th>
<th>Sample Number</th>
<th>Temperature</th>
<th>Ammonia by AQ2 SEAL</th>
<th>Ammonia by HACH TNT</th>
<th>Nitrate by IC</th>
<th>NOx-N by AQ2 SEAL</th>
<th>Nitrate by AQ2 SEAL</th>
<th>Nitrate by IC</th>
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**AOB & NOB Experimentation:**

**I. AOB**

a. Spiked four 3L reactors with 25 mg/L NH₄-

b. Each reactor is running continuously by use of stir bars.

c. 2 L of the diluent source is added to the reactors.

d. 1 L of concentrated biomass is added to the reactors. For this week's experiments the biomass was concentrated from 20 L to 9 L.

e. Constant DO and pH were monitored and logged throughout the experiment.

f. Oxygen/air blend was sparged into the reactors to maintain DO levels through solenoid valves.

g. LabView software was used to manage DO and pH recording as well as program and implement the solenoid valves.

h. 5 samples were collected over a period of 3 hours through sampling ports on the reactors and filtered into sample tubes through millipore 0.45 μm filters.

i. Reactors B, C, and D in the diluent source incorporated varying concentrations of Blue Works Chemical Toilet Additive based on different assumptions.

[See Additive Dose Calculation worksheet]

**II. NOB**

a. Spiked four 3L reactors with 15 mg/L NO₂⁻ after ammonia levels were <1 mg/L NH₃-N which was checked through the use of HACH TNT 831 Ammonia method.

In addition all reactors were allowed to run overnight to consume all present ammonia.

b. Each reactor is running continuously by use of stir bars.

c. Constant DO and pH were monitored and logged throughout the experiment.

In addition all reactors were allowed to run overnight to consume all present ammonia.

d. Oxygen/air blend was sparged into the reactors to maintain DO levels through solenoid valves.

e. LabView software was used to manage DO and pH recording as well as program and implement the solenoid valves.

f. 5 samples were collected over a period of 3 hours through sampling ports on the reactors and filtered into sample tubes through millipore 0.45 μm filters.

g. Reactors B, C, and D in the diluent source incorporated varying concentrations of Blue Works Chemical Toilet Additive based on different assumptions.

[See Additive Dose Calculation worksheet]
## Nitrogen Species vs. Time

**Reactor B: YR A.S./YR SE + 0.574 mL BW**

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<th>Date</th>
<th>Sample Time</th>
<th>Time since initial spike</th>
<th>Sample Number</th>
<th>Temperature</th>
<th>Ammonia by AQ2 SEAL</th>
<th>Ammonia by HACH TNT</th>
<th>Nitrate by IC</th>
<th>NOx-N by AQ2 SEAL</th>
<th>Nitrate by AQ2 SEAL</th>
<th>Nitrite by AQ2 SEAL</th>
<th>Phosphate by AQ2 SEAL</th>
<th>NOx-N by Nitrite SEAL</th>
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Reactor C: YR A.S./YR SE + 14 mL BW

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<th>Temperature</th>
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<th>Nitrate by IC</th>
<th>NOx-N by AQ2 SEAL</th>
<th>Nitrite by AQ2 SEAL</th>
<th>Nitrate by AQ2 SEAL + Nitrite SEAL</th>
<th>Phosphate by AQ2 SEAL</th>
<th>NOx-N by Nitrate SEAL + Nitrite SEAL</th>
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Reactor D: YR A.S./YR SE + 63 mL BW

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<th>Nitrate by IC</th>
<th>NOx-N by AQ2 SEAL</th>
<th>Nitrite by AQ2 SEAL</th>
<th>Phosphate by AQ2 SEAL</th>
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### Summary Experiment NOx Slope NO3 Slope NO2 Slope Nit Rate NOx* Nit Rate NO3* Nit Rate NO2* OUR SOUR MLSS MLVSS

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<th>NO2 Slope</th>
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<th>Nit Rate NO3*</th>
<th>Nit Rate NO2*</th>
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* Nitrification rates are normalized with respect to the MLVSS concentrations in their respective reactors.
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### Experiment # 1

#### AOB Comparison

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### Experiment # 2

#### NOB Comparison

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**Week 16 – QAC Product B Day 1 AOB/NOB**

Sample Data Report for Nansemond Nitrification Inhibition Study

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<th>Sample Time</th>
<th>Time since initial spike</th>
<th>Sample Number</th>
<th>Temperature</th>
<th>Ammonia by AQ2 SEAL</th>
<th>Ammonia by HACH TNT</th>
<th>Nitrate by HACH TNT</th>
<th>NOx-N by AQ2 SEAL</th>
<th>Nitrate by HACH TNT</th>
<th>NOx-N by HACH TNT + Nitrate HACH</th>
<th>Phosphate by HACH TNT</th>
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AOB & NOB Experimentation:
I. AOB
   a. Spiked four 3L reactors with 25 mg/L NH₄⁺.
   b. Each reactor is running continuously by use of stir bars.
   c. 2 L of the diluent source is added to the reactors.
   d. 1 L of concentrated biomass is added to the reactors. For this week’s experiments the biomass was concentrated from 20L to 9 L.
   e. Constant DO and pH were monitored and logged throughout the experiment.
   f. Oxygen/air blend was sparged into the reactors to maintain DO levels through solenoid valves.
   g. LabView software was used to manage DO and pH recording as well as program and implement the solenoid valves.
   h. 5 samples were collected over a period of 3 hours through sampling ports on the reactors and filtered into sample tubes through 0.45 µm filters.
   i. Reactors B, C, and D in the diluent source incorporated varying concentrations of Blue Works Chemical Toilet Additive based on different assumptions.

II. NOB
   a. Spiked four 3L reactors with 20 mg/L NO₂⁻ after ammonia levels were <1 mg/L NH₃-N which was checked through the use of HACH TNT 831 Ammonia method.
   In addition all reactors were allowed to run overnight to consume all present ammonia.
   b. Each reactor is running continuously by use of stir bars.
   c. Constant DO and pH were monitored and logged throughout the experiment.
   d. Oxygen/air blend was sparged into the reactors to maintain DO levels through solenoid valves.
   e. LabView software was used to manage DO and pH recording as well as program and implement the solenoid valves.
   f. 5 samples were collected over a period of 3 hours through sampling ports on the reactors and filtered into sample tubes through 0.45 µm filters.
   g. Reactors B, C, and D in the diluent source incorporated varying concentrations of Blue Works Chemical Toilet Additive based on different assumptions.

[See Additive Dose Calculation worksheet]
Reactor B: YR A.S./YR SE + 15 mL BW

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<th>Nitrogen Species vs. Time</th>
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<td>Nitrate + NOx-N</td>
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<table>
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<th>Sample Number</th>
<th>Temperature °C</th>
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<th>Ammonia by HACH TNT mg/L NH3-N</th>
<th>Nitrate by HACH TNT mg/L NO3-N</th>
<th>NOx-N by AQ2 SEAL mg/L NOx-N</th>
<th>Nitrite by HACH PP mg/L</th>
<th>Phosphate by AQ2 SEAL mg/L PO4-P</th>
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Reactor C: YR A.S./YR SE + 30 mL BW

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<th>Temperature</th>
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<th>Nitrate by HACH TNT</th>
<th>NOx-N by AQ2 SEAL</th>
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Reactor D: YR A.S./YR SE + 60 mL BW

Nitrogen Species vs. Time

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### Summary

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<th>NO2 Slope</th>
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<th>Nit Rate NO3*</th>
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* Nitrification rates are normalized with respect to the MLVSS concentrations in their respective reactors.
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![Graph of Experiment # 1](image-url)
Week 17 – QAC Product B Higher Concentration

Sample Data Report for Nansemond Nitrification Inhibition Study

AOB & NOB Experimentation:
I. AOB
a. Spiked four 3L reactors with 25 mg/L NH₄⁺.
b. Each reactor is running continuously by use of stir bars.
c. 2 L of the diluent source is added to the reactors.
d. 1 L of concentrated biomass is added to the reactors. For this week's experiments the biomass was concentrated from 20 L to 9 L.
e. Constant DO and pH were monitored and logged throughout the experiment.
f. Oxygen/air blend was sparged into the reactors to maintain DO levels through solenoid valves.
g. LabView software was used to manage DO and pH recording as well as program and implement the solenoid valves.
h. 5 samples were collected over a period of 3 hours through sampling ports on the reactors and filtered into sample tubes through millipore 0.45 μm filters.
i. Reactors B, C, and D in the diluent source incorporated varying concentrations of Blue Works Chemical Toilet Additive based on different assumptions.
(See Additive Dose Calculation worksheet)

II. NOB
a. Spiked four 3L reactors with 20 mg/L NO₂⁻ after ammonia levels were <1 mg/L NH₃-N which was checked through the use of HACH TNT 831 Ammonia method.
In addition all reactors were allowed to run overnight to consume all present ammonia.
b. Each reactor is running continuously by use of stir bars.
c. Constant DO and pH were monitored and logged throughout the experiment.
d. Oxygen/air blend was sparged into the reactors to maintain DO levels through solenoid valves.
e. LabView software was used to manage DO and pH recording as well as program and implement the solenoid valves.
f. 5 samples were collected over a period of 3 hours through sampling ports on the reactors and filtered into sample tubes through millipore 0.45 μm filters.
g. Reactors B, C, and D in the diluent source incorporated varying concentrations of Blue Works Chemical Toilet Additive based on different assumptions.
(See Additive Dose Calculation worksheet)

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<th>Date</th>
<th>Sample Time</th>
<th>Time since initial spike</th>
<th>Sample Number</th>
<th>Temperature</th>
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<th>Ammonia by HACH TNT</th>
<th>Nitrate by HACH TNT</th>
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Reactor B: YR A.S./YR SE + 60 mL BW

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### Reactor C: YR A.S./YR SE + 120 mL BW

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<th>Time since initial spike</th>
<th>Sample Number</th>
<th>Temperature</th>
<th>Ammonia by AQ2 SEAL</th>
<th>Ammonia by HACH TNT</th>
<th>Nitrate by HACH TNT</th>
<th>NO\textsubscript{x}-N by AQ2 SEAL</th>
<th>Nitrate by AQ2 SEAL</th>
<th>Nitrite by HACH PP</th>
<th>Phosphate by AQ2 SEAL</th>
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Reactor D: YR A.S./YR SE + 180 mL BW
Nitrogen Source: Spiked Date
Sample Time Time since initial spike Sample Number Temperature Ammonia by AQ2 SEAL Ammonia by HACH TNT Nitrate by HACH TNT NOx-N by AQ2 SEAL Nitrite by HACH PP Nitrite by AQ2 SEAL NOx-N by HACH + Nitrite Phosphate by AQ2 SEAL Phosphate by HACH TNT

<p>| Nitrogen Source | Date     | Sample Time | Time since initial spike | Sample Number | Temperature | mg/L NH3-N | mg/L NH3-N | mg/L NO3-N | mg/L NO2-N | mg/L NO3-N | mg/L NO2-N | mg/L NO3-N | mg/L NO2-N | mg/L PO4-P |
|-----------------|----------|-------------|--------------------------|----------------|-------------|------------|------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|
| Ammonia         | 23-Jun-09| 14:02       | 22                       | D1             | 22.5        | 20.40      | 19.14      | 0.92        | 20.06       | 29.14       | 36.52       | 42.50       | 40.80       | 46.40       |
| Ammonia         | 23-Jun-09| 14:45       | 58                       | D2             | 23.9        | 12.90      | 24.20      | 4.94        | 24.14       | 39.14       | 45.70       | 43.80       | 44.60       | 49.00       |
| Ammonia         | 23-Jun-09| 15:28       | 96                       | D3             | 24.5        | 5.05       | 27.40      | 9.12        | 36.52       | 42.50       | 40.80       | 46.40       | 44.60       | 49.00       |
| Ammonia         | 23-Jun-09| 16:09       | 135                      | D4             | 24.7        | 0.00       | 32.00      | 10.50       | 42.50       | 40.80       | 46.40       | 44.60       | 49.00       | 43.80       |
| Ammonia         | 23-Jun-09| 16:49       | 175                      | D5             | 24.8        | 0.00       | 33.60      | 7.20        | 42.50       | 40.80       | 46.40       | 44.60       | 49.00       | 43.80       |
| Nitrite         | 24-Jun-09| 8:35        | 12                       | D6             | 22.5        | -          | 30.40      | 16.00       | 46.40       | 44.70       | 44.10       | 43.80       | 44.60       | 49.00       |
| Nitrite         | 24-Jun-09| 9:16        | 95                       | D7             | 22.9        | -          | 31.20      | 13.50       | 44.70       | 44.10       | 43.80       | 44.60       | 49.00       | 43.80       |
| Nitrite         | 24-Jun-09| 9:58        | 95                       | D8             | 23.1        | -          | 33.00      | 11.10       | 44.70       | 44.10       | 43.80       | 44.60       | 49.00       | 43.80       |
| Nitrite         | 24-Jun-09| 10:49       | 135                      | D9             | 24.5        | -          | 36.20      | 7.60        | 44.60       | 44.10       | 43.80       | 44.60       | 49.00       | 43.80       |
| Nitrite         | 24-Jun-09| 11:31       | 176                      | D10            | 24.7        | -          | 39.00      | 5.60        | 44.60       | 44.10       | 43.80       | 44.60       | 49.00       | 43.80       |</p>
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<th>Experiment</th>
<th>NOx Slope</th>
<th>NO3 Slope</th>
<th>NO2 Slope</th>
<th>Nit Rate NOx*</th>
<th>Nit Rate NO3*</th>
<th>Nit Rate NO2*</th>
<th>OUR</th>
<th>SOUR</th>
<th>MLSS</th>
<th>MLVSS</th>
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<td>3180.00</td>
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* Nitrification rates are normalized with respect to the MLVSS concentrations in their respective reactors.
Experiment 1

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Rate [mg/g MLVSS/hr]