Piloting of a deammonification moving bed biofilm reactor for mainstream industrial wastewater application

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Abstract

The City of Portage la Prairie is required to meet the Province of Manitoba's new effluent limits of 1 mg/L total phosphorus and 15 mg/L total nitrogen at their Water Pollution Control Facility (WPCF) and will need an upgrade to achieve this. Industrial flows to the system contribute approximately 90% of the N and P loads. To investigate methods to reduce these loads, piloting of the Ostara Pearl® struvite crystallization and Veolia ANITA^{TM}Mox deammonification systems was performed. The objective of this thesis was to pilot the ANITA^{TM}Mox system for seven months and determine the impact of the following process conditions: reduced influent temperature; increased pH; periodic high influent TSS concentrations; and modifications to the ANITA^{TM}Mox process train comprising of elimination of the pretreatment BOD removal reactor. It was found that deammonification could be an option for reducing mainstream ammonia loading from industrial flows at the WPCF.

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Nomenclature

AOB - aerobic ammonia oxidizing bacteria

BOD$_5$ - Total carbonaceous Biological Oxygen Demand, 5-day

cBOD$_5$ - Soluble carbonaceous Biological Oxygen Demand, 5-day

COD - Chemical Oxygen Demand,

DO – Dissolved Oxygen

HRT – hydraulic retention time

LRAR – Low Rate Anaerobic Reactor

NH_4-N - Soluble Ammonia

NO_2-N - Soluble Nitrites

NO_3-N - Soluble Nitrates

NOB - nitrite oxidizing bacteria

o-PO4 - Soluble Orthophosphorus

SALR – Surface Area Loading Rate

SARR – Surface Area Removal Rate

SBR - sequencing batch reactors

sCOD - Soluble Chemical Oxygen Demand,

SRT – solids retention time

TKN - Total Kjeldhal Nitrogen

TN – total nitrogen

TP – total phosphorus

TSS - Total Suspended Solids

VSS - Volatile Suspended Solids

WPCF water pollution control facility

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1 Introduction

The City of Portage la Prairie (City) is required to meet the Province of Manitoba’s new effluent limits of 1 mg/L total phosphorus (TP) and 15 mg/L total nitrogen (TN) at their Water Pollution Control Facility (WPCF). An upgrade of the existing plant will be needed to meet this new regulation. The WPCF is influenced by industrial discharges including two large potato processing plants and a pea processor. As seen in Figure 1, on average, 45% of the flow to the WPCF is from industries, accounting for 89% of the nitrogen and 94% of the phosphorus load.

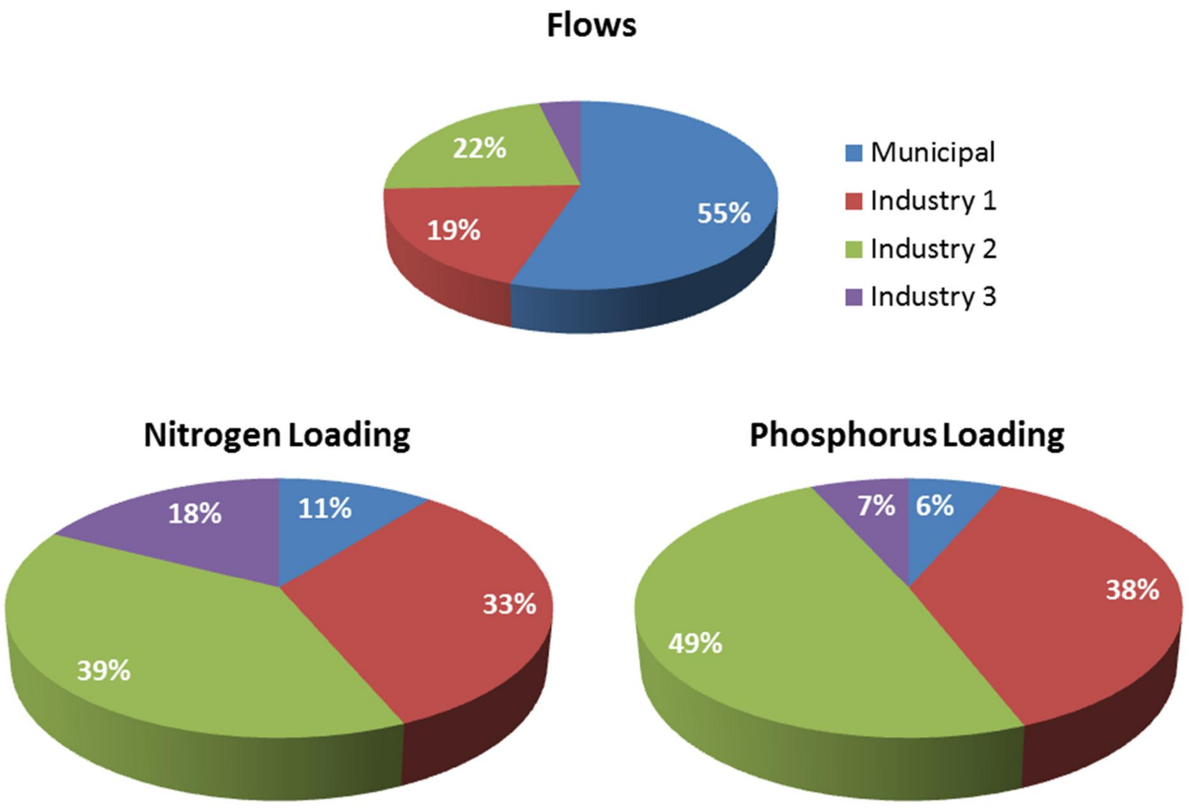

Figure 1 Influent Flow and Load Distribution Received at WPCF

Currently, the industries pretreat their wastewaters in low-rate mesophilic anaerobic reactors to remove total carbonaceous Biological Oxygen Demand, 5-day, (BOD_5) and total suspended solids, with only minimal removal of nutrients. Industrial flow is then blended with municipal flow, before final treatment in sequencing batch reactors (SBR) at the WPCF. Final effluent is disinfected through UV reactors and the wasted sludge is thickened with a belt thickener, anaerobically digested, and then stored and seasonally land applied.

1.1 Process Options Evaluation

Options for industrial pretreatment were examined through process modeling to establish capital and operating costs for meeting the new effluent limits. (AECOM 2015) As a base condition, precipitation of ortho-phosphate using aluminum sulfate (alum) addition to the SBRs was selected for meeting the TP limit. Nitrification and methanol-enhanced denitrification were selected for total nitrogen reduction. To reduce the operating cost associated with these processes (aeration energy; chemicals; sludge handling, treatment and disposal), phosphorus reduction through struvite (magnesium ammonium phosphate hexahydrate) crystallization and nitrogen ammonia reduction through deammonification (partial nitritation followed by anammox) were considered for further pretreatment of the industrial wastewaters before being combined with domestic sewage and final treatment in the SBRs. Modeling found that struvite crystallization decreased the metal salts dosing by approximately 70%, saving chemical costs and decreasing sludge production by approximately 15%. Deammonification decreased the carbon requirement by approximately 90%, the sludge production by approximately 30% and the oxygen requirement, and ultimately the energy requirements, by 85%.

Modeling results were used for estimates of both the capital and operating costs. These estimates were compared in a 20-year lifecycle cost estimate to evaluate the overall impact of the pretreatment processes. It was found that the overall lifecycle cost was very similar for all options, if the deammonification process was not heated.

Pilot testing of the deammonification and phosphorus recovery processes was recommended to confirm that these technologies should be included as part of the WPCF upgrade.

Arranging these technologies in series on a mainstream flow is not common, and the effect of their bundling needed to be confirmed, as this study is the first of its kind worldwide in an industrial mainstream application. The impact on the increased pH influent on the deammonification process would need to be confirmed. Research has shown acceptable pH ranges for deammonification up to 8.0 (van der Star, et al. 2007), 8.3 (Strous, Kuenen and Jetten 1999) and 9.0 (Egli, et al. 2001).

1.2 Objectives

The goals of this work were to demonstrate through pilot-scale studies that TP and TN from the anaerobically-pretreated industrial effluents could be reduced through struvite crystallization and deammonification processes, respectively; develop operating data to establish the most cost-effective TP and TN removal efficiencies and a basis for full-scale design and operating costs; determine the composition of the crystallized product to establish its value in the regional fertilizer market; and confirm that the desired TP and TN removal efficiencies can be maintained if the crystallization and deammonification processes are operated in series.

The deammonification technology selected to pilot at the WPCF was Veolia's ANITA™Mox process, which is the focus of this thesis.

The main objective of the Anita™Mox pilot was to produce a treated effluent with less than 35 mg N/L ammonia, and less than 20 mg N/L nitrates. Secondary objectives discussed in this thesis include:

- Studying the impact to the process when the influent temperature is reduced to 18-20^{o}C. Low influent temperatures would typically occur during the winter, most notably during the Christmas industrial shut down. Confirmation that the process would continue to meet ammonia removal goals throughout the low temperature period would allow the final system to be constructed without a costly heating system.

- Evaluating the impact of higher influent pH from bundling the Ostara Pearl® process for phosphorus recovery with the ANITA™Mox process. The struvite crystallization process increases the pH of the wastewater and it was unknown if the increased pH would affect the deammonification process.

- Determining the effect of bypassing the BOD reactor ahead of the ANITA™Mox reactor. This first MBBR reactor was used to decrease the organics in the influent wastewater prior to the deammonification process. If it could be demonstrated that this first reactor was not necessary, the capital and operational costs of the full scale system could be decreased.

- Determining the effect of high total suspended solids (TSS) on the ANITA™Mox reactor, to decide if a TSS control strategy is necessary. Due to the upstream processes malfunctioning or going into upset conditions, there are times when TSS will spike in the influent wastewater, above 1000 mg/L or greater.

2 Literature Review

2.1 Introduction

While traditional biological nutrient removal in wastewater treatment follows nitrification-denitrification pathways, the anammox bacteria convert ammonia to nitrogen gas in two steps instead of the traditional three, which has the potential to save operation costs on aeration and chemical carbon addition.

Early work in the 1960’s and earlier highlighted a gap in the nitrogen balance under anoxic conditions. The amount of ammonia being added into the reaction did not equal the total nitrogen components being produced when compared to nitrification plus denitrification reactions. It was not until the 1990’s with work done by Mulder and Van de Graaf that this nitrogen balance could be explained with the presence of a microbiological process (Ward, Arp and Klotz 2011). Mulder et al. discovered the anaerobic ammonium oxidation in a lab scale anaerobic fluidized denitrifying bed used in treating effluent from a methanogenic reactor. While nitrate consumption and the nitrogen gas production were elevated, noticeable amounts of ammonia were decreasing from the reactor. (Mulder, et al. 1995) Later, van de Graaf et al. observed that nitrite was the preferred electron acceptor for the process. (van de Graaf, et al. 1995)

Since 2004 when the first full-scale deammonification plant was successfully implemented at Strass wastewater treatment plant (B. Wett 2007) there have been many deammonification processes put into operation, with the majority as side-stream treatment for ammonia reduction in centrate.

2.1.1 Traditional nitrification-denitrification

Traditionally, ammonia is removed through the nitrification-denitrification steps. Nitrification occurs by autotrophs in the presence of oxygen to convert NH_4-N to NO_2-N by nitritation by aerobic ammonia oxidizing bacteria (AOB). This is followed by the conversion of NO_2-N to NO_3 by nitritation by aerobic nitrite oxidizing bacteria (NOB), according to the reactions below:

$$2NH_4^+ + 3O_2 \rightarrow 2NO_2^- + 4H^+ + 2H_2O$$

$$2NO_2^- + O_2 \rightarrow 2NO_3^-$$

Denitrification to reduce nitrates to nitrogen gas in the absence of dissolved oxygen occurs by heterotrophic bacteria through the following reaction:

$$NO_3 + 6H^+ + 10e^- \rightarrow \frac{1}{2}N_2$$

where the electron donor will be a degradable organic carbon such as methanol, or can include sulfate, or nitrites (AECOM 2013). The overall reaction, including oxygen and carbon demand is shown in Figure 2.

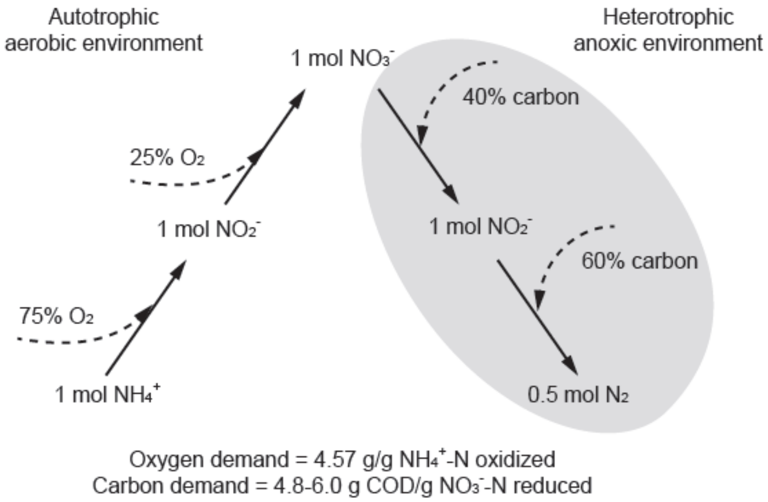

Figure 2: Nitrification-Denitrification Pathway for Inorganic Nitrogen Removal (Bowden 2013)

2.1.2 Deammonification

Biological deammonification is a two-step process, as seen in Figure 3. The first reaction uses oxygen to convert a portion of the ammonia to nitrite by aerobic AOB, while NOB reactions are suppressed. This reaction, partial nitritation, accounts for 55-60% of the ammonia conversion (Tchobanoglous, et al. 2014) (AECOM 2013). The second reaction, called anaerobic ammonium oxidation, or anammox, oxidizes NH_4-N in a limited oxygen condition, with autotrophic bacteria using nitrites from the partial nitritation stage as the electron acceptor. These autotrophic bacteria are referred to as anammox bacteria.

The amount of oxygen and carbon required to complete deammonification is less than that required for nitrification – denitrification. The oxygen consumption is lower as full nitrification is not necessary. Only partial nitration is needed to produce nitrites, resulting in approximately 60% less oxygen required. When comparing the overall reactions, deammonification requires almost 90% less carbon than nitrification, as there are only 0.11 mol nitrate for every mol ammonia. This minimal carbon needed for deammonification is found within the wastewater, and eliminates the need for supplemental carbon addition (Tchobanoglous, et al. 2014). (Graaf, et al. 1996) (Bowden 2013) (AECOM 2013).

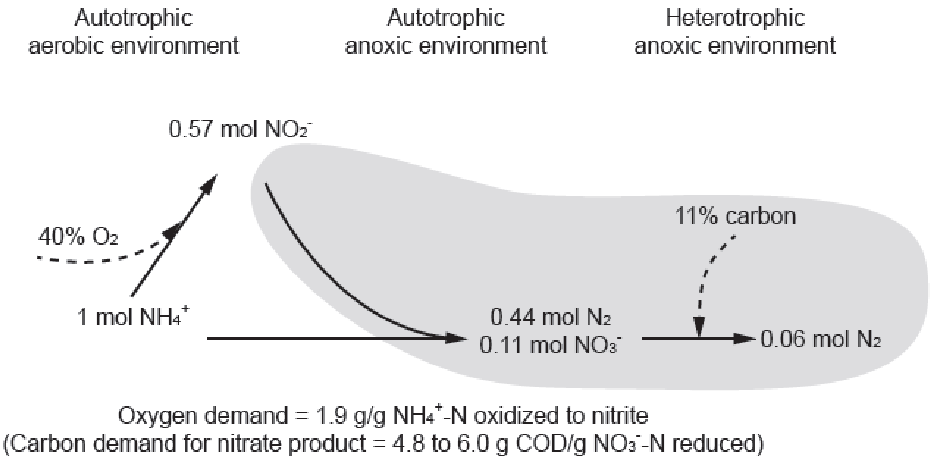

Figure 3: Partial Nitritation – Anaerobic Ammonium Oxidation (Deammonification) Pathway for Inorganic Nitrogen Removal (Bowden 2013)

The Anammox Reaction is written as (Strous, Heijnen, et al. 1998):

$$NH_4^+ + 1.32NO_2^- + 0.066HCO_3^- + 0.13H^+ \rightarrow 0.26NO_3^- + 1.02N_2 + 0.066CH_2O_{0.5}N_{0.15} + 2.03H_2O$$

The nitrogen cycle is shown in Figure 4, with deammonification shown as a shortcut.

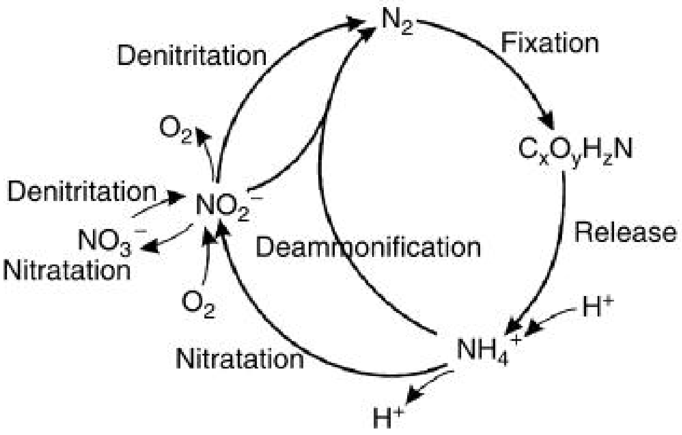

Figure 4: Nitrogen cycle demonstrating deammonification as a short cut of N-conversion. (B. Wett 2007)

2.2 Anammox Bacteria Understanding

To develop a stable ammonia removal system using anammox bacteria, the conditions that promote their growth and ammonia removal performance need to be understood. Although this research has been going on since the 1990's, (Ward, Arp and Klotz 2011) gaps in knowledge remain as this process is brought into full scale systems, including its use in mainstream treatment. A large portion of the research seems to have focused on ammonia removal of centrate sidestreams, with mesophilic temperatures (30-38°C) and low carbon.

The anammox bacteria was first identified by Strous et al. (1999) as being autotrophic under the order *Planctomycetales* in the phylogenetic tree. As research developed, anammox bacteria have been found to be abundant and frequently observed in biological wastewater treatment facilities, and in marine and fresh water sediments. It has been estimated that 50% of the dinitrogen gas formed in the marine environment is derived from anammox activity (Ward, Arp and Klotz 2011).

2.2.1 Growth Rates and Biomass

Growth rates of anammox are slow compared to aerobic AOB, however, they also have slow decay rates. (Bowden 2013). At 30°C, the maximum specific growth rate of anammox is less than 10 percent that of AOB (Tchobanoglous, et al. 2014). As temperature decreases, the SRT requirement is longer since their growth rate declines. Doubling times have been reported at 11 days (Tsushima, et al. 2007), and as long as 21 days (Jetten, et al. 2001), which becomes an important consideration to full scale implementation for the anammox process. To assist with the long start-up periods, seeding reactors from other existing systems or farms is common, and has been successful (Veolia Water Solutions & Technologies 2014). The slow decay rate of anammox allows the seed sludge to remain active during long transportation and storage.

The biomass yield of the anammox process is very low, in the same range as AOB, which produces little sludge and usually negates the need for a sludge removal process in full scale situations (Strous, Van Gerven, et al. 1997).

2.2.2 Dissolved Oxygen

While the anammox conversion from ammonia to nitrogen gas does not require oxygen, the operation of the aeration system becomes crucial in the deammonification process. Dissolved oxygen is needed for nitritation to occur. Without enough nitrite, the anaerobic ammonium oxidation cannot occur, as nitrite is the electron acceptor in the deammonification reaction. A high DO concentration may inhibit the deammonification reaction and increase the oxidation of nitrite to nitrate by bacteria as *Nitrobacter*. A low DO concentration gives low ammonium removal rates, which means that the nitritation efficiency is reduced. (Plaza, et al. 2011)

The annamox bacteria are strict anaerobes, and any DO inhibits deammonification. Experiments have shown that oxygen as low as 2 µM completely, but reversibly, inhibits anammox activity (Jetten, et al. 2001). However, as dissolved oxygen is needed for the partial nitritation step to form the nitrites needed for the anammox step, the location of the anammox growth on carriers seems to have overcome this. In one stage reactor arrangements, where partial nitritation and deammonification occur, the biofilm thickness with the AOB growth will protect the interior growth of the anammox. The AOB will grow on the outside of the biofilm, consuming the DO. The inhibitory DO concentration for the anammox will depend on the thickness of this biofilm. (Tchobanoglous, et al. 2014).

Determining the appropriate level of DO will be specific to the incoming wastewater and process setup including the use of IFAS media, and could require lengthy trial and error. Care must be taken not to have excess oxygen, as this may promote growth of aerobic nitrite oxidizing bacteria (NOB) and heterotrophic denitrifiers. Heterotrophs would dominate the autotrophic anammox. The NOB could use the nitrite and oxygen to complete nitrification into nitrates. The denitrifiers would use any available carbon to denitrify.

A study of the 500 m^2/m^3 Kaldnes media (Zubrowski-Sudol, et al. 2011) looked at different aeration strategies compared to ammonia removal and nitrite production. It found that the highest deammonification rates were achieved at an aeration strategy of aeration for 2/3 of the time, at a DO of 4 mg/L. This resulted in a maximum inorganic N removal rate of 3.33 g N m^2/d, or a removal efficiency of 69.5%.

2.2.3 Nitrifier and Anammox Relationship in a MBBR Arrangement

Studies have shown that the nitrifiers and anammox can coexist in a mutually beneficial relationship. In a one-stage arrangement where both partial nitritation and deammonification occur, the nitrifiers, growing on the outside of the media, oxidize some of the ammonia to nitrite, providing a low DO, high nitrite environment for the anammox bacteria (Leix, Drewes and Koch 2016). The anammox bacteria, growing on the inside of the media, convert the nitrite and the remaining ammonia to nitrogen gas. As anammox activity is completely inhibited by oxygen (Jetten, et al. 1998), being inside the biofilm close to the media ensures deammonification will continue even in a reactor with aeration. In a study by Leix *et al* (2016), where the K2 MBBR media was tested without any suspended sludge, a balanced deammonification occurred, suggesting the AOBs and anammox bacteria were present on the media biofilm.

The deammonification process depends on both the activity of the AOBs for the partial nitritation, as well as the diffusion of substrate and DO to the inner layers of the biofilm, as anammox are inhibited by oxygen (Strous, van Gerven, et al. 1997). It is possible to establish nitrifiers and anammox bacteria by gradually supplying increasing air into an anammox SBR reactor. (Jetten, et al. 2001). Figure 5 shows how this is relationship is established on a carrier.

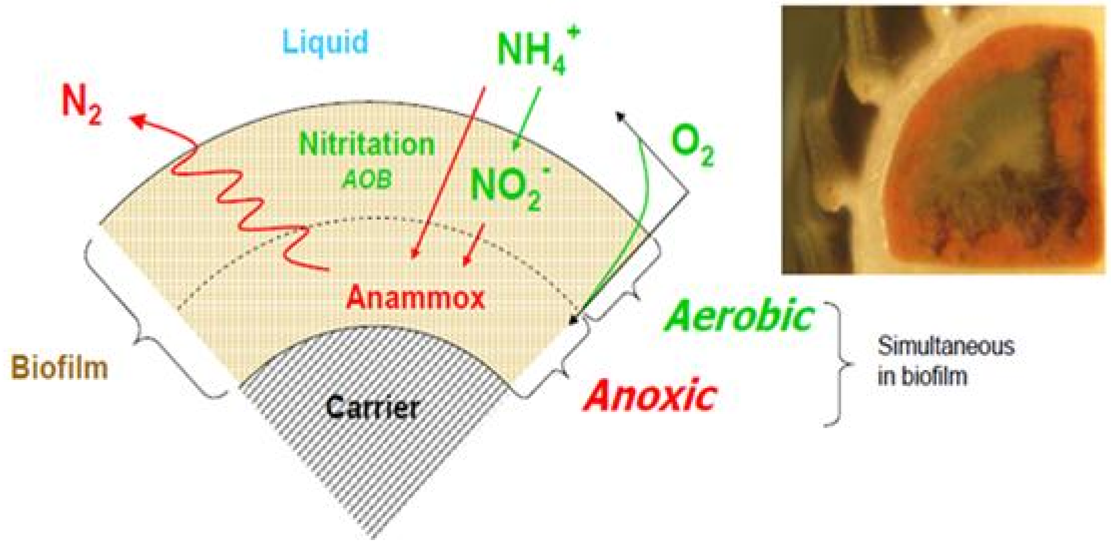

Figure 5: Deammonification in a Biofilm – Courtesy Veolia

This mutually beneficial relationship on the media permits the different sludge retention times needed by the nitrifiers and anammox bacteria. The slower growing anammox bacteria on the inside of the biofilm, where they are protected, receiving less sloughing action from shear stress and erosion from other particles and solids. The nitrifiers, with a faster growth rate, are able to withstand higher abrasion on the outside of the carrier media, and not sacrifice performance.

In a study by Lemaire *et al.* (2014) using an IFAS Anita^{TM}Mox system of 40% reactor fill with domestic wastewater, a total inorganic nitrogen removal of 70-80%, and a Surface Area Removal Rate (SARR) of 1.2-1.3 g N/m^2d in temperatures of 21-23^{o}C was observed. (Water Environment Federation 2015). In this pilot, the ratio of NO_3-Nprod/NH_4-Nrem was below 15%, which indicated successful suppression of the NOB in the IFAS system. Complete coupling of AOB and anammox activity, with suppressing nitritation by NOB, would result in a NO_3-Nprod/NH_4-Nrem ratio of 0.11. (Lotti, et al. 2014)

2.3 Temperature

While anammox activity is higher in warmer temperatures, between 30-40^{o}C (Dosta, et al. 2008), there has been renewed interest in studying the nitrogen removal abilities at low temperatures. (Tchobanoglous, et al. 2014) (Hillige, Steinle and Böhm 2012) (Lui, Horn and Muller 2012). The ability to operate the anammox system at lower temperatures could provide an opportunity for municipal systems, located in cooler climates, to benefit from the potential cost savings of decreased dissolved oxygen levels with the anammox system. (Tchobanoglous, et al. 2014) (Lotti, et al. 2014)

While growth is possible between 4-43^{O}C (Ward, Arp and Klotz 2011), temperatures ranges for ideal growth vary by study. Some were found to be between 20-43^{O}C (Strous, Kuenen and Jetten 1999), and with success at 18^{O}C (Winkler, Kleerebezem and van Loosdrecht 2012), 15^{o}C (Wett, et al. 2013), or 12^{o}C (Hu, et al. 2013).

2.3.1 Previous research

During a 15^{o}C study by Wett *et al.* (2013), a 10 L bench-scale SBR system was operated at different temperatures and different dissolved oxygen levels to test parameters applicable for full scale implementation. At full scale implementation, operation costs would be kept minimal with low DO, and no heating in the reactor. At a DO of 0.06 mg/L, nitrite availability became a limiting step, due to minimal DO for partial nitritation to occur. However, annamox activity was confirmed at 15^{o}C after spiking the reactor with nitrite.

In the 12^{o}C study by Hu *et al.* (2013), the 5 L SBR operated for 350 days, and from Day 136 onwards was at 12^{o}C, with more than average 90% removal of the supplied ammonium over the last 100 days. It was found that the ratio of nitrate production to ammonium consumption decreased from the stoichiometric ratio of 100:26 to 100:18 average for the first 68 days, and then 100:4 average for the last 158 days, indicating a higher cell maintenance activity.

A study with granular sludge by Lotti *et al.* (2014) operated the reactor down to 20°C, 15°C and then 10°C, with varying degrees of success. At 20°C and 15°C, nitrogen removal efficiencies were 86% and 73%, respectively; with nitrogen removal rates of 0.44 and 0.40 g N/L/d. At 10°C, the anammox were unstable for more than 100 days, and experienced a decrease in anammox activity and efficiency. Depending on the climate where this mainstream application could be implemented, the ammonia removal performance could be jeopardized.

Winkler *et al.*, (2012) operated a 2.9 L granular sludge SBR for 390 days, with success at temperatures as low as 18°C. The SBR was run with an aeration and anoxic cycling to promote deammonification. The first 170 days were used to acclimate the bacteria, with the remainder of the study reaching an average volumetric N conversion rate of 0.9 g N ^{2}-N/L/day as well as a COD removal rate of 0.6 g COD/L/day.

In a low temperature study with a rotating biological contactor (RBC) by de Clippeleir *et al.* (2013), the total nitrogen removal rate did not noticeably change when compared between 29°C and the lowest temperature of 15°C. At 15°C, nitrogen removal rates were 0.5 g N/L/day, and it was thought that performance was not limited by temperature, but by the RBC reactor configuration.

In a study published in 2014, a laboratory demonstration looked at temperature and deammonification. The setup had three reactors in series, with the 1.0 L fixed film deammonification reactor as the last stage. A short hydraulic retention time of 0.96 h, with a nitrogen removal rate of 0.83 g N/L/day, or 80.05% ammonia removal rate, was achieved between temperatures of 12-15°C. Even at low temperatures, fluorescence in situ hybridization imagery demonstrated high anammox bacteria growth. (Gao, Lu and Liang 2014)

2.3.2 MBBR systems

MBBR anammox systems have also shown better performance at lower temperatures, which has been attributed to the thicker biofilm which develops on the media compared to the suspended or granular sludge (Gilbert, et al. 2015).

At lower reactor temperatures and with a defined ammonium surface load, a thicker biofilm has developed in order to protect the anammox, and a higher dissolved oxygen concentration is necessary. (Plaza, et al. 2011) The higher DO concentration is needed at lower temperatures to maintain the same aerobic AOB activity as warmer temperatures (de Clippeleir, et al. 2013). In a study by Gilbert *et al.* (2015), different reactor configurations were operated at low temperatures. It was found that anammox activity in thicker biofilms was less affected than in thinner biofilms by temperatures as low as 10°C. In this study, the highest nitrogen removal, in combination with the lowest nitrite production, was from the 10 mm carrier MBBR, compared to the 2 mm carrier MBBR, suspended biomass SBR, and granular biomass SBR. Throughout the temperature decrease from 20-10°C, anammox activity within the MBBR reactors remained stable (32% for the 2 mm carriers and 45% for the 10 mm carriers) while the SBRs showed a decline in anammox activity from 16% and 25% to as low as 0.8% for the suspended and 2.7% for the granulated biomass.

In a study using an IFAS Anita^{TM}Mox system of 40% reactor fill with domestic wastewater, (Lemaire, et al. 2014) the SARR dropped from 1.2-1.3 g N/m^{2}d in temperatures of 21-23°C down to 0.8 to 0.9 g N/m^{2}d in 18°C wastewater. (Water Environment Federation 2015).

2.3.3 Operation at low temperatures

Successful operation at lower temperatures involves recognizing a longer SRT due to declining growth rate with decreasing temperature. Longer startup periods would also be expected, in order to adapt both the anammox and aerobic AOB. (Dosta, et al. 2008) (de Clippeleir, et al. 2013). In a study using an RBC, de Clippeleir *et al.* (2013) were able to achieve a similar nitrogen removal rate at 29^{O}C and 14^{O}C; however it took 255 days to acclimate the system before operating at the lower temperature.

Perez *et al.* (2014) found that particularly at low temperatures, the possibility to improve the nitritation rate in a single stage deammonification process becomes important to suppress NOB activity due to the NOB having a higher maximum growth rate than AOB at low temperature.

Bioaugmentation of anammox from sidestream, warmer processes, to the cooler mainstream treatment streams has been found to be successful in lower temperatures in order to continue treatment. (Water Environment Federation 2015). At the Strauss Wastewater Treatment Plant, when the full-scale mainstream deammonification system was established, with bioagumentation from the sidestream processes, the average nitrogen removal efficiency was 82% at water temperatures between 8.6 and 14.9^{o}C and N loads up to 0.19 kg $N/m^{3}d$. (Water Environment Federation 2015).

2.4 pH

Literature has shown acceptable pH ranges for deammonification between 7.0 and 8.0, (van der Star, et al. 2007), with maximum pH varying by experiment. Strous *et al.* (1997) (1999) (1997) found that it was pH 8.2, 8.3, and 8.5, while Egli *et al.* (2001), was able to operate without consequence at pH 9.0.

Varying pH has been proven to not impact the ammonia removal. XIE, *et al.* (2010) operated a two stage SBR partial nitrification and anammox process with influent ammonium ranging 360-400 mg/L, and average effluent ammonium of 2.7 mg/L. The pH varied between 7.5-8.3 throughout testing, which did not seem to affect the ammonia removal. Jetten *et al.* (1998) highlighted a study with a lab scale fluidized bed reactor where the pH varied between 7.0-8.5 without detriment. While operating a SBR, Jetten *et al.* (1998) found that the anammox process functioned well at pH 6.7-8.3, and best at pH 8.0.

2.5 Anammox competition (removal of BOD reactor)

While the Anita™Mox system is a one stage deammonification system, the pretreatment for organics removal in the first stage makes it a two tank process. A single-stage nitration-anammox biofilm is considered by some as a better, more convenient way to deammonify, as the capital and operational costs would be decreased. (de Clippeleir, et al. 2013). While SBR operation as a single stage process has been studied, and is implemented in the DEMON® process, a continuous mode of operation could be preferred. (Perez, et al. 2014)

One of the main challenges identified in a single-stage deammonification system is minimizing NOB growth, and thus, nitrate accumulation (de Clippeleir, et al. 2013). Heterotrophic biomass will also compete with AOB for oxygen, and with anammox for nitrite, so decreasing the COD prior to the single-stage deammonification process could be beneficial. (Perez, et al. 2014). By eliminating the organics removal reactor, the competition with the heterotrophic biomass could increase.

2.6 TSS impact on Anammox

Losing the anammox population during an event of high TSS is a possibility, however with a MBBR arrangement, the anammox are protected. The AOB, on the outside of the media will be affected the most, however they grow back quickly. AOBs such as *Nitrosomonas europaea* have a reported doubling time of 0.3-1.7 days (Prosser 1989) which aids in a rapid recovery of the system if a high inert suspended solids event washes through the tank.

In a study by Leix *et al.* (2016) where the K2 MBBR media was tested without any suspended sludge, a balanced deammonification occurred, suggesting the AOBs and anammox bacteria were present on the media biofilm, however the oxygen consumption was severely decreased, indicating that the suspended sludge is mainly represented by AOBs. The nitrogen removal capacity was also reduced by more than 50% compared to the test with the MBBR media and suspended sludge, indicating that the suspended sludge may provide additional AOBs, and thus nitrite, to aid deammonification.

While a balanced ratio between AOBs and anammox bacteria is needed, Leix *et al.* (2016) found that increasing the suspended sludge led to an abundance of AOBs, and partial nitritation, which had an increased rate of ammonia conversion by anammox.

3 Materials and Methods

3.1 Experimental Design

With the objective of meeting the Province of Manitoba's legislation which states that any wastewater facility that discharges into Lake Winnipeg must meet new limits of <15 mg/L total N and <1 mg/L total P. as well as meeting the Standards Objectives and Guidelines of the Water Protection Act where chemical addition would negatively impact the beneficial reuse of biosolids and would not be supported by Manitoba Conservation (Manitoba Water Stewardship 2011), the upgrade of the WPCF focused on deammonification and struvite crystallization of the industrial waste streams. The deammonification system piloted was Veolia's ANITA™Mox process.

The deammonification system had the main goal of producing effluent with ammonia < 35 mg/L and nitrate < 20 mg/L, however there were secondary objectives to assist with the full scale design. These secondary objectives included:

- Determining the efficiency and kinetics at low temperatures of 18-20^{o}C;
- Evaluating bundling the process with the struvite crystallization reactor upstream of the deammonification process which would result in higher influent pH wastewater to the deammonification process;
- Determining the effect of bypassing the BOD reactor located prior to the deammonification reactor in the ANITA™Mox system;
- Determining the effect of including a TSS control ahead of the deammonification process.

3.2 Equipment Setup

Both selected vendors, Veolia and Ostara, provided the pilot equipment, including control and monitoring systems. Piping and tanks upstream of and between equipment, was provided by the City of Portage la Prairie. The process flow diagram is shown in Figure 6.

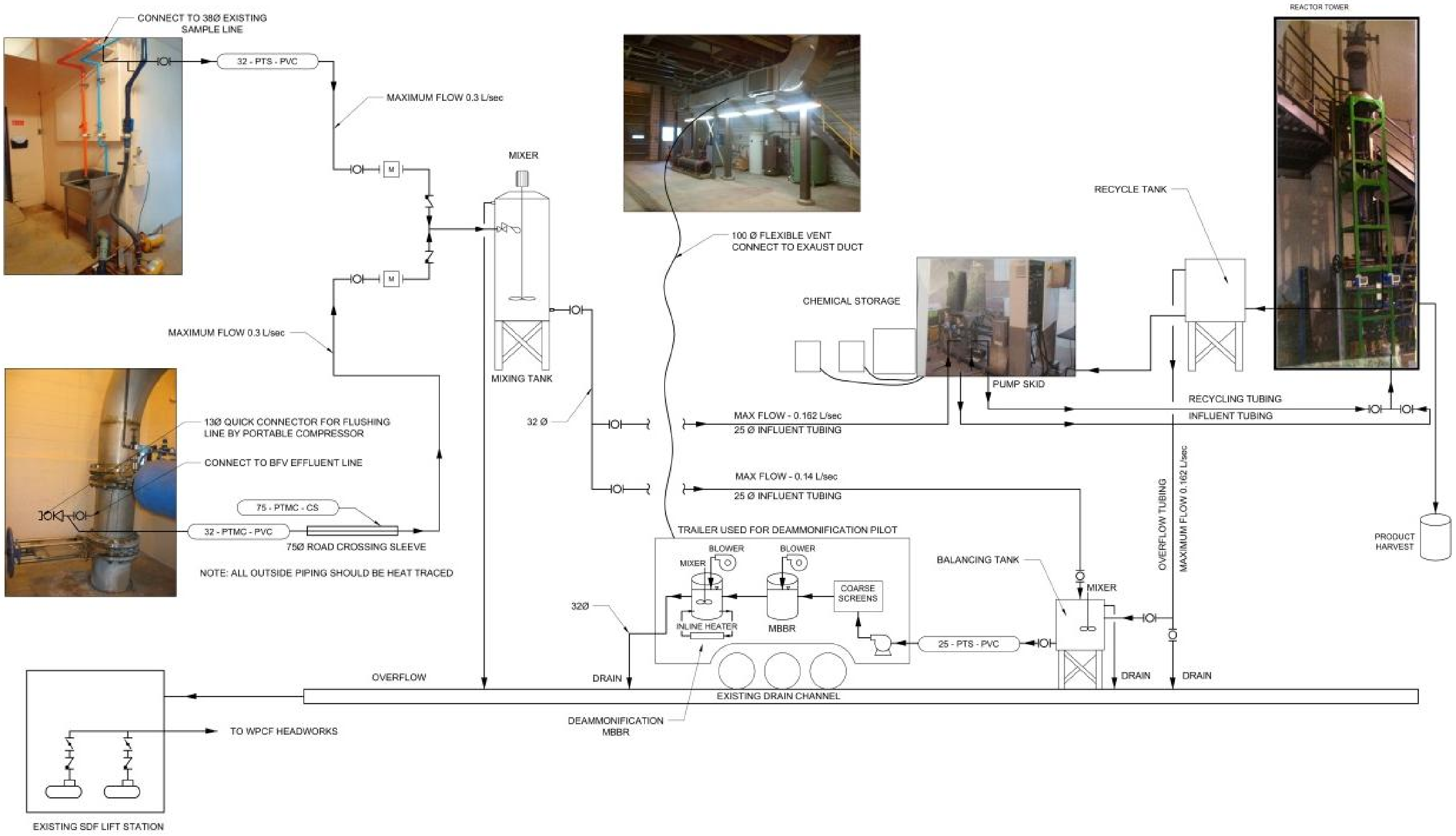

Figure 6 Deammonification and Struvite Crystallization Pilot Flow Diagram (Wilson, et al. 2015)

The influent wastewater was received from three industrial streams, and equalized and blended in two tanks as shown in Figure 7. Both tanks had mechanical mixers to prevent solids from settling; the second tank had an overflow to the drain, as well as a level sensor which shut down the Anita™Mox pilot in the event of no flow. The blending rates were balanced similar to the flow received from the industries at the WPCF.

Figure 7 Equalization and Blending Tanks

Flow through the deammonification pilot is depicted in Figure 6 and consists of centrifugal VFD pumping through 6mm coarse screens, into Reactor 1 (R1); the BOD removal reactor. Through valve modulation, flow from the BOD removal reactor entered the Anita™Mox reactor (R2), for deammonification. Excess flow from R1 not sent to R2 was sent to the drain which was mixed with the incoming wastewater flow for treatment at the WPCF. Each reactor had a blower and diffusers. R2 also had a mechanical mixer to assist mixing, as there was less airflow required in this tank. An inline water heater recirculated water in R2 to control the temperature.

Both 400 L reactors were set up as MBBR, with K5 carriers from AnoxKaldnes used for biofilm growth. The first reactor, R1, contained new media which was seeded with waste activated sludge from the WPCF process, upstream of the gravity belt thickeners. The second reactor contained media which was previously inoculated from AnoxKaldnes biofarm in Sweden, and shipped to the WPCF site. Both reactors were 50% filled with media. Figure 8 shows a photo of the reactor setup.

Figure 8 ANITA™Mox Pilot, showing BOD removal reactor (left), deammonification reactor, piping, valves, mixer and heater (Wilson, et al. 2015)

The pilot was equipped with online instrumentation, which could be observed and monitored remotely. The online monitoring is listed in Table 1.

Table 1 Online Monitoring Instruments on Deammonification Pilot (Vincent, Lamarre and Meunier 2014)

Parameters	Supplier	Model#	Range	Reactor 1	Reactor 2
Flow Rates	Krohne	N/A	0 – 1000 L/h	X	X
Dissolved oxygen	HACH	LDO	0 – 20 mg/L	X	X
Temperature			0 – 50 ^{0}C	X	X
Ammonia	HACH	Combine AN-ISE sc	0 – 200 mg N/L		X
Nitrates			0 – 200 mg N/L		X
pH	HACH	PC1R1A	0 – 14	X*	X

* Only one probe in the pilot. The probe was installed in Reactor 1 only during the pH adjustment phase of piloting.

3.3 Testing Schedule

The pilot was operated for 201 days, with all equipment set up in a building of the WPCF site. The pilot phases and durations are shown in Table 2.

Table 2 Piloting Phases

Phase	Phase Number	Beginning date	Ending date	Beginning Pilot Day	Ending Pilot Day	Length of Days
Mobilization	1	06-Jan-14	24-Jan-14	1	16	16
Acclimation	2	17-Jan-14	07-Mar-14	16	58	43
Load Increase	3	07-Mar-14	15-Apr-14	58	97	40
Steady State	4	15-Apr-14	28-Apr-14	97	110	14
Low Temperature	5	28-Apr-14	05-Jun-14	110	148	39
pH Impact	6	05-Jun-14	14-Jul-14	148	187	40
BOD Reactor Bypass	7	07-Jul-14	28-Jul-14	180	201	22
TSS Control	8	14-Jul-14	28-Jul-14	187	201	15

A description of the phases follows.

Mobilization (16d), Acclimation (43d) – In these phases, the pilot equipment was started, and the anammox were slowly introduced to the waste stream from the WPCF.

R1 was seeded with waste sludge from WPCF prior to polymer dosing on the belt filter press. Initially in batch flow, R1 was monitored for activity of organics decrease through COD testing and nitrification. As activity became noticeable, continuous flow began, and was increased. As it was not the intent for nitrification to occur within R1 throughout these phases, the flow through R1was increased to limit activity.

R2 was initially filled with media which had been seeded with anammox and shipped to site. The tank was initially run in batch mode, with continuous flow after the first few days. As ammonia decreased in R2, the flow was increased. Temperature was set at 29^{o}C in R2.

Load Increase (40d), Steady State (14d) – As the anammox began to further acclimate to the WPCF waste streams, the flow and thus the load through the reactors was increased. The load was increased until the ammonia effluent levels were within the treated water objectives, and then steady state was maintained. Temperatures were set at 29^{o}C in R2. During these phases it was determined that the dissolved oxygen set point was too low in R2 for nitritation, as there were minimal nitrite being recorded within the tank. Increasing the DO increased nitrite as well as decreased ammonia, leading to the theory that minimal nitrite had been limiting deammonification.

Low Temperature (39d) – The temperature of R2 was decreased to simulate the coldest temperatures received annually. Initially the inline water heater was turned down, however due to the time of the year the influent wastewater temperature became warmer than the target temperature of 18^{o}C of R2, with peak temperatures of 27^{o}C. Other provisions to cool the incoming wastewater included increasing the influent flow from the industry with the cooler wastewater, as well as passing the water through a heat exchanger made of aluminum and plastic piping submerged in a cool water bath. (Figure 9).

Figure 9 Heat exchanger for low temperature phase

pH impact (40d)– This phase of the work was to determine if bundling the deammonification system with a struvite crystallization reactor would be possible. The Ostara Pearl® pilot was placed ahead of the Anita™Mox system with the effluent from the Ostara system sent into the Anita™Mox pilot. Initially the pH of the Ostara effluent was adjusted with sulfuric acid to slowly increase the pH of the wastewater into the Anita™Mox pilot. In this way, the pH of the influent wastewater increased from between 7.0-7.5 up to 8.6.

BOD Reactor Bypass (22d) – This phase of the piloting took R1 offline, and the incoming flow was sent directly to R2. The first 7 days of this phase overlapped the pH impact phase.

TSS Control (15d) - This phase used the two equalization and blending tanks upstream of the pilot (Figure 7) and turned the mixer off in the second tank to promote settling of the influent prior to entering R2.

3.4 Operation

The reactor's operational parameters and control setpoints used during the pilot test are listed in Table 3.

Table 3 Operational Parameters

Parameters	**Units**	**Reactor 1 – BOD Removal**	**Reactor 2 – ANITA™Mox**
Flowrate	L/h	20 - 380	20 - 120
Hydraulic retention time	hours	1.1 – 20.5	3.33 - 20
Dissolved oxygen	mgO_2/L	1 - 5	0.5 – 4.0
Temperature	^{0}C	18 -28	18-30
Media type	-	K5	K5
Media Fill	%	50	50

3.4.1 Flow/ Load and Hydraulic Retention Time

Throughout testing, flow rates were incrementally raised to increase the ammonia load applied to both reactors until the effluent quality objectives were met.

3.4.2 Dissolved Oxygen

The amount of air injected in R1 was uncontrolled, while R2 DO was able to be controlled throughout the testing.

3.4.3 Temperature

Temperature could be increased in R2 with an online heater and recirculation pump.

3.5 Sampling

Sampling occurred 2-3 times per week on-site at the WPCF laboratory, although online monitoring was checked routinely, with any alarms sent to a cell phone. 24 hour composite samples were taken on the raw water influent, as well as from Reactor 2 using HACH SD9000 composite samplers. Grab samples were taken from Reactor 1. The parameters tested and method selected is described in Table 4.

Table 4 Laboratory Methods

Parameter	Method #	Range	Minimum Frequency
Total carbonaceous Biological Oxygen Demand, 5-day, BOD_5	STM-2002-08-3		Weekly
Soluble[1] carbonaceous Biological Oxygen Demand, 5-day, $cBOD_5$	STM-2002-08-3		Weekly
Chemical Oxygen Demand, COD	Hach 8000	20-1500 mg/L	2-3x / week
Soluble Chemical Oxygen Demand, sCOD	Hach 8000	20-1500 mg/L	2-3x / week
Soluble Ammonia, NH_4-N	Hach 10031	0.4-50.0 mg N/L	2-3x / week
Soluble Nitrates, NO_3-N	Hach 8039[2] Hach 10020	0.3-30.0 mg N/L 0.2-30.0 mg N/L	2-3x / week
Soluble Nitrites, NO_2-N	Hach 8163 Hach 8507	2-250 mgNO_2^-/L 0.002-0.300 mg N/L	2-3x / week
Total Suspended Solids, TSS	WPCF Lab SWP-Lab-08		2-3x / week
Volatile Suspended Solids, VSS	WPCF Lab SWP-Lab-25		2-3x / week
Total Kjeldhal Nitrogen, TKN	STM-2010-24-1		1x/week
Alkalinity, as $CaCO_3$	STM-2002-10-4		1x/week
Soluble Orthophosphorus, o-PO4, mg/L	Hach 8048	0.02-2.50 mgPO_4^{3-}/L	1x/week
Total Phosphorus, TP	STM-2009-22-1		1x/week

Notes

1- Soluble forms were analyzed after filtering the sample on a 0.45 µm filter.

2- This method has chloride ion over 100mg/L has an interference. Therefore, the sample dilution was high enough to decrease the interference. Several analyses for chlorides revealed a concentration over 200mg/L, so a second method was considered (#10020) which has the interference of chloride for concentration higher than 1000 mg/L.

3.6 Batch Testing

During the piloting, several batch tests were performed to confirm that deammonification was occurring. These tests were performed on a small number of media chips (100 or 150) with 1.5 L of wastewater, in a covered beaker. The beaker was sparged with nitrogen gas to keep the dissolved oxygen low. Nitrite was spiked using a concentrated sodium nitrite solution. Measurements were taken on the following:

- Dissolved oxygen
- Ammonia
- Nitrite
- Nitrate
- COD
- pH
- DO
- TKN (only a few tests)

4 Results and Discussion

4.1 Influent Water Quality

The influent water into the WPCF from the industries has high ammonia and phosphorus, and low biodegradable organic content. Mean ammonia was 139 mg/L, total phosphorus was 55.4 mg/L, while the mean soluble COD was 117 mg/L. Prior data collection at the WPCF from the year prior to sampling indicated mean ammonia of 151 mg/L and total phosphorus of 38 mg/L on the industrial stream. Municipal flows are anticipated to be on average 23.4 mg/L TKN and 3.5 mg/L total phosphorus for the new facility (AECOM 2015). Table 5 summarizes the influent water quality parameters which include sampling during operating the Ostara pilot. During this time, influent samples were taken upstream of the Anita™Mox pilot, however this flow had undergone treatment thorough the Ostara Pearl® pilot.

Peaks in solids concentrations were closely tied to changes, or operational upsets in the upstream processes, which were closely tied to peaks in COD.

Table 5 Influent Wastewater Quality Parameters

Parameter	Number of Samples	Min	Mean	95th Percentile	Max
NH_4-N, mg/L	84	51	139	177	211
NO_3-N, mg/L (HACH 8039)*	55	0.7	7.4	16.8	26.8
NO_3-N, mg/L (HACH 10020)	22	0.5	1.6	2.5	2.5
NO_2-N, mg/L	79	0	3.4	13.1	40
TKN, mg/L	62	82.7	217.7	329.7	678
TP, mg/L	49	17.4	55.4	144.2	284
o-PO4, mg/L	72	14.8	40.7	60.7	119
TSS, mg/L	76	70	933	2698	15130
VSS, mg/L	17	0	62.1	190	350
COD, mg/L	73	121	1029	2535	5594
sCOD, mg/L	79	54	117	169	479
5-day, $cBOD_5$, mg/L	21	13	79	163	178
5-day, $scBOD_5$, mg/L	19	1	18	47	53
Alkalinity, as $CaCO_3$, mg/L	66	917	1355	1548	2200
Temperature, ^{o}C	107	15.2	23	28	29
pH	63	7.4	7.9	8.7	9
Oil & Grease, mg/L	1		44		

* - Could have had chloride interference with this test method.

4.2 Hydraulic Retention Time

As described in Section 3.4, flow rates were incrementally increased in both reactors to attempt to continue to meet the effluent quality objectives. As effluent quality was met, or was stabilized, the flows and load were increased to determine if the biomass could adjust and again stabilize or meet the effluent objectives at the increased load. By the end of the piloting, the size of the reactor for the full scale application to treat the flow from the industries would be estimated by Veolia by determining the HRT achieved to meet the effluent guidelines.

For R1, nitrification was limited by monitoring for a decrease in ammonia and increase in nitrites. When this was observed, the HRT was decreased further. From the load increase phase onwards, the HRT was between 1.1 and 2.1 hours.

For R2, as the effluent objectives of ammonia <35 mg/L and nitrate <20 mg/L were met for more than one day, the flow would be increased to determine if the biomass could adjust to the higher loading. If the effluent objective was not met, but the quality stabilized, the flow and load was also increased. Figure 10 displays the HRT of both reactors throughout piloting beginning with the acclimation phase. It was found that as the piloting continued the HRT in R2 continued to decrease, while meeting performance expectations, indicating that the initial phases of 90 days meant to reach steady state may not have been long enough for the anammox to achieve this, although there was activity within the reactor. Although Christensson *et al.* (2011) found that a start-up period of 30-120 days was sufficient for a reactor where carriers were seeded, the influent COD, solids, and ammonia in the raw wastewater at the WPCF was variable, as well as the complete removal of one of the waste streams due to an upstream Low Rate Anaerobic Reactor (LRAR) biological upset; all of which may have lengthened the acclimation. There was also difficulty in determining the correct dissolved oxygen setting for the anammox reactor which may have been limiting performance due to limited nitrite.

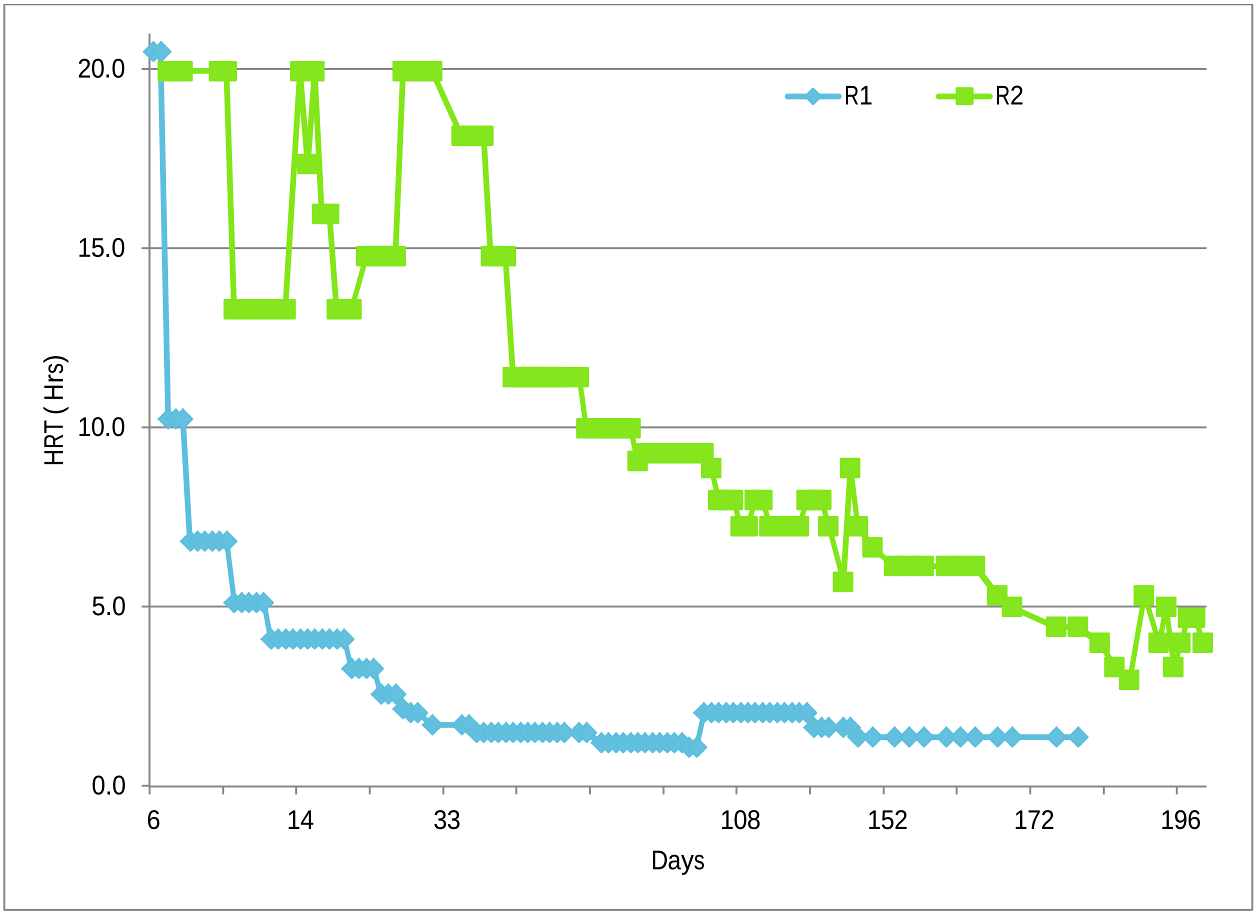

Figure 10 Hydraulic retention time (HRT) of R1 and R2 throughout piloting

4.3 Ammonia Removal

For the Anita™Mox pilot, ammonia removal through deammonification decreasing closer to a domestic wastewater concentration of ammonia <35 mg/L and nitrate <20 mg/L was the main goal of the piloting process. R1 had a decreased HRT in order for most ammonia removal to be within R2. The ammonia concentrations throughout the treatment process are shown in Figure 11. As seen, the ammonia in the raw water and R1 are similar, with the decrease in ammonia occurring in R2.

It was found that an effluent of ammonia <35 mg/L was possible. From the beginning of the low temperature phase on Day 110 to the end of the testing, the average overall ammonia was 36.6 mg/L. This average accounts for interruptions to the process as well as peaks in the effluent which could be attributed to pilot equipment error. These include a malfunctioning blower (Day 132, ammonia at 102 mg/L), power failures (Days 175-177), and interruptions in flow (Day 187 and 194). If the samples where the data collection may have been compromised due to mechanical error are not included, then the adjusted average effluent is 34.5 mg/L ammonia.

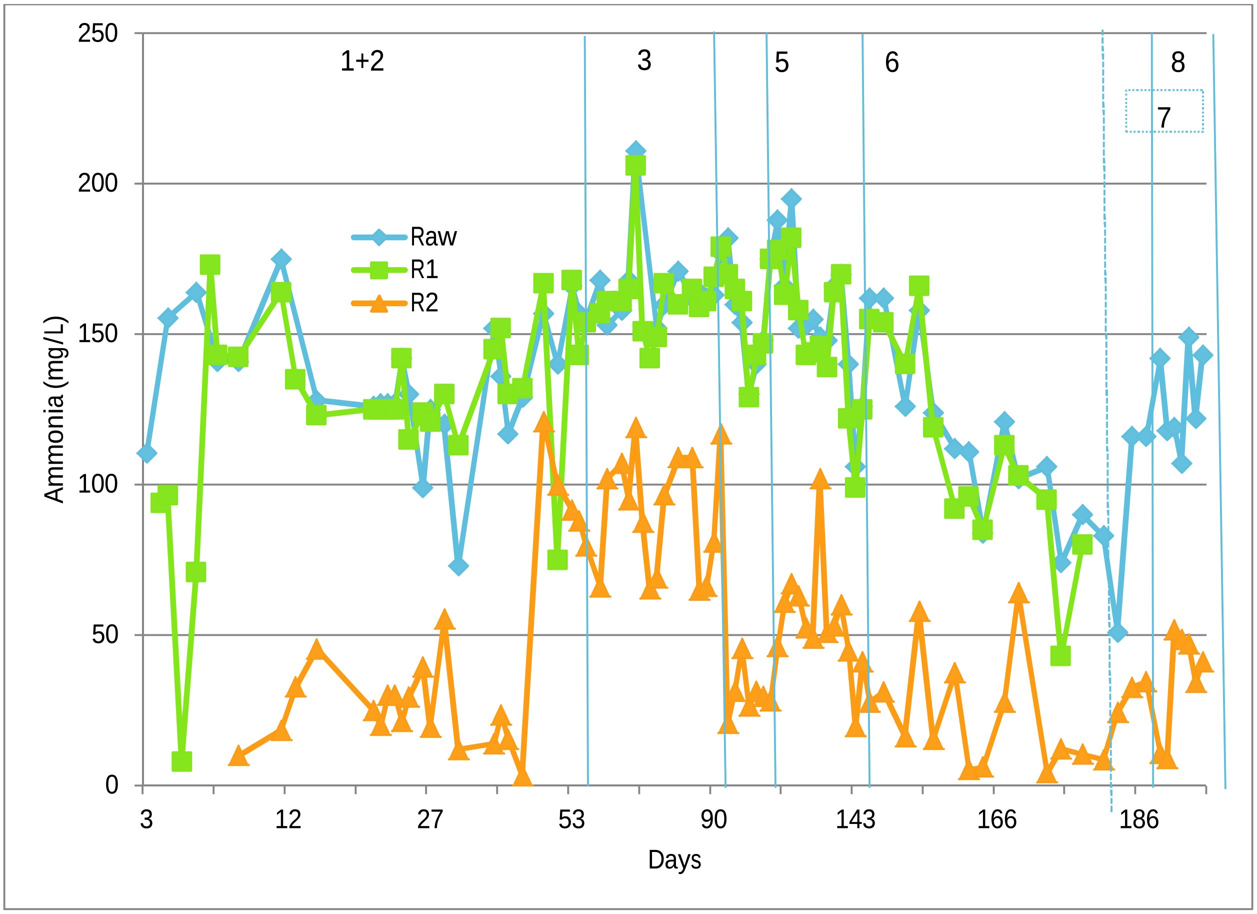

Figure 11 Soluble Ammonia decreasing through process from raw wastewater to reactor 1 and reactor 2 effluent, divided by piloting phases

Throughout the Load Increase phase (Phase 3, Days 58 -97) while the loads were increased, the removal rates did not improve. Nitrite levels were quite low, averaging 1.4 mg/L. The dissolved oxygen levels were increased, and finally the medium coarse bubble diffusers were changed to fine bubble diffusers on Day 96. The change of aeration equipment appeared to have a positive effect, with an increase of nitrite within R2 to an average of 4.3 mg/L for the remainder of testing and ammonia effluent levels decreasing from over 100 to 20 mg/L over the first day of new diffusers, as shown in Figure 11. When studying the percent removal of ammonia (Figure 12), the impact from the change in diffusers is also noticeable, with removal rates increasing from 35 to 88% after the change. This highlights the work of Plaza *et al.* (2011), who suggested that lack of dissolved oxygen could be a limiting step to deammonification, if partial nitritation efficiency was reduced.

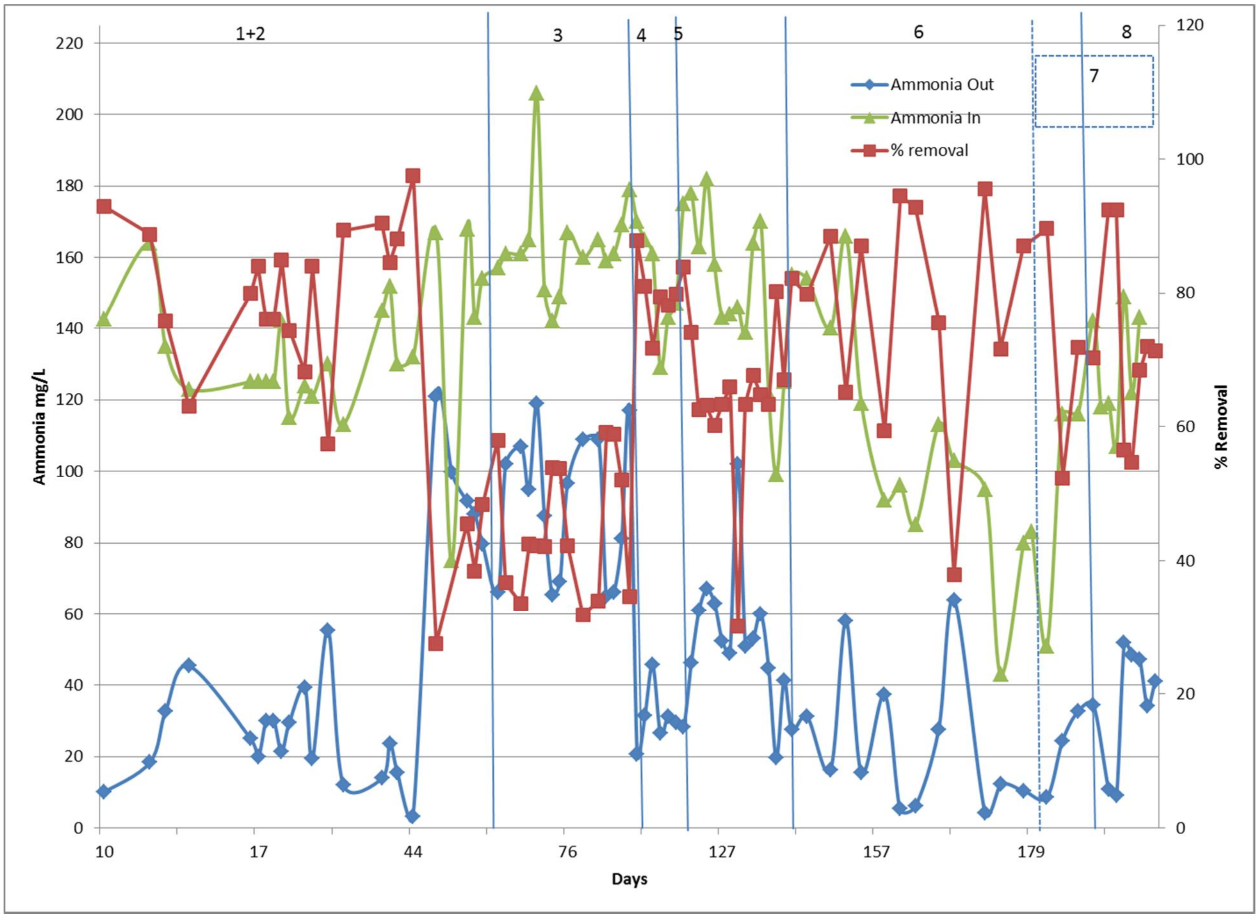

Figure 12 Ammonia percent removal throughout the pilot study, divided by piloting phases

Looking at the average ammonia percent removal (Table 6), the highest average was during the steady state phase, while the lowest was during the low temperature phase, not considering the acclimation phase. However, while the percent removal is an indicator of performance, it must be studied with other factors such as the loading to the reactor. While the percent removal was lower for the later phases of piloting, the loading was higher than during the steady state phase.

The loading in the TSS Control phase was 1.775 g soluble NH_3/m^2 media●day, compared to 1.159 g soluble NH_3/m^2 media●day during the steady state phase.

Table 6 Ammonia Average Percent Removal, by Project Phase

Pilot Phase	% Removal Ammonia, Average
Acclimation and Load Increase	62
Steady State	80
Low Temperature	67
pH Impact	77
BOD Reactor Bypass*	72
TSS Control*	72

4.4 Ammonia Loading Compared to Removal

The removal of ammonia can be expressed in terms of surface area loading rate (SALR) and removal rate (SARR) applied on the K5 media. Typically a strong indicator to the ammonia removal success is a closely matching SARR to the SALR. The overall piloting results are shown in Figure 13. While the Acclimation and Load increase phases show a separation between SALR and SARR (average 0.751 and 0.419 g NH_3/m^2 media●day), there is a noticeable improvement in SARR after the diffusers were changed to fine bubble on Day 96.

Table 7 shows the average values of SALR and SARR, organized by project phase. The highest loading to the anammox reactor occurred in the final phases of piloting, BOD Reactor Bypass and TSS Control, which was also bypassing R1. These phases were also the highest ammonia removal rates of the piloting.

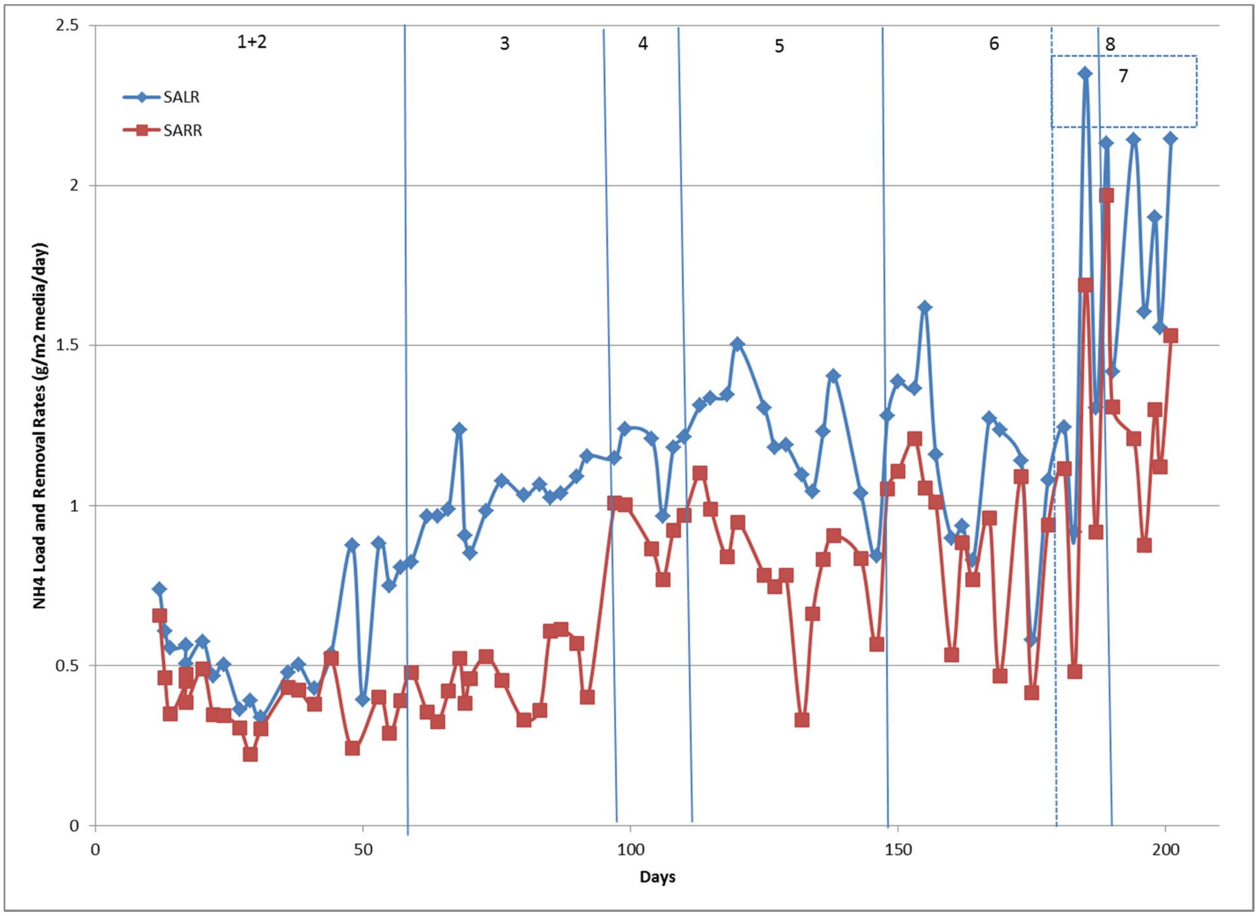

Figure 13 Ammonia SALR and SARR, Divided by Pilot Phase

These removal rates in the final phases are similar to the findings by Lemaire *et al.* (2014) when their IFAS Anita^{TM}Mox pilot, of 40% fill experienced SALR reaching 1.6 g N/m^{2}d and SARR of 1.2 to 1.3 g N/m^{2}d with temperatures of 21-23^{o}C.

Table 7 Average SALR and SARR throughout piloting, by Project Phase

Pilot Phase	Average SALR	Average SARR	Ratio SALR/SARR
	(g soluble NH_3/m^2 media/day)	(g soluble NH_3/m^2 media/day)	
Acclimation and Load Increase	0.751	0.419	1.79
Steady State	1.159	0.922	1.26
Low Temperature	1.221	0.813	1.50
pH Impact	1.207	0.915	1.32
BOD Reactor Bypass*	1.701	1.229	1.38
TSS Control**	1.775	1.279	1.39

*This phase overlapped 7 days with the pH impact phase.

**This phase overlapped with the BOD Reactor Bypass phase.

4.5 Nitrate and Nitrite in Effluent

The effluent goal for nitrate was < 20 mg NO_3-N/L throughout piloting, which was achieved, other than a few events. Throughout the mobilization and acclimation period, nitrates were above 20 mg/L on several testing days (Figure 14), which may have shown that the anammox may not have been fully established as the primary ammonia remover within the reactor. After the aeration system was changed on Day 96, the nitrate rose for a few days, and then decreased. Towards the end of the piloting, starting Day 189, three batch tests on R2 were performed over several hours (up to 14 hours), which may have aided growth of NOB in the reactor.

From the beginning of the load increase phase today 188 the nitrates concentration was an average of 8.7 mg/L, with two peaks above 20 mg/L (22.8 and 22.6 mg/L) after the diffusers were changed.

The change of aeration system on Day 96 also increased the nitrate concentration from less than 2 mg/L to routinely between 2-6 mg/L. This corresponds to reduced ammonia (Figure 11), increased ammonia percent removal (Figure 12), and increased ammonia SARR (Figure 13) after the aeration system change. This indicates that the deammonification process may have been limited by a shortage of nitrite prior to the aeration system being changed, and the ammonia removal showing a significant dependency on the nitrite concentration. This dependency of the deammonification process on nitrite or other substrates has been shown to be common. (Ni, Lee and Sung 2010), (Jaroszynski, et al. 2012)

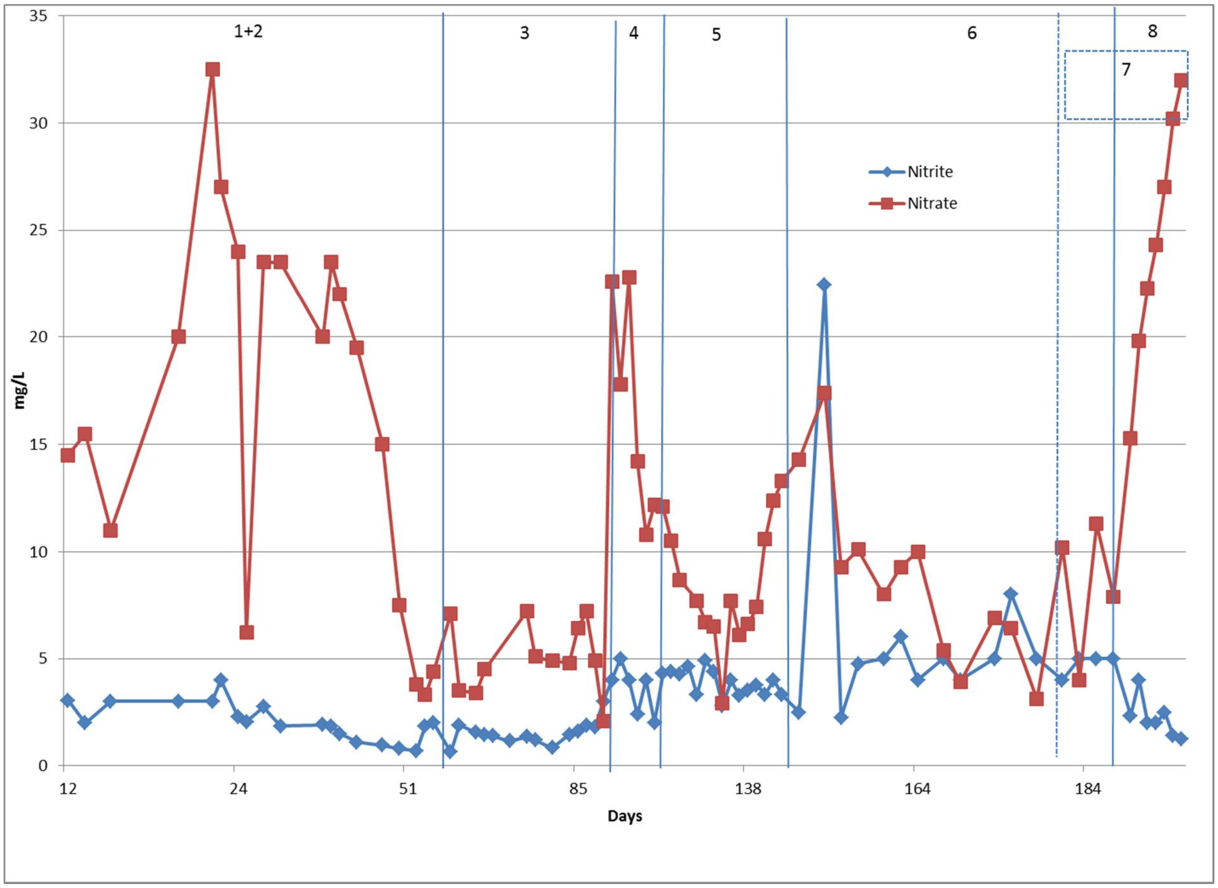

Figure 14 Nitrate and Nitrite in the Deammonification Reactor throughout piloting

4.6 Decrease in influent temperature

One of the secondary objectives was determining if the Anita™Mox process would continue to meet ammonia removal goals without supplemental heating throughout the low temperatures typically encountered during the industries Christmas shut down. This phase of the piloting lasted 38 days where the temperature in R2 was gradually decreased. Figure 15 displays the ammonia influent and effluent from R2, with the temperatures shown. The temperature was initially 30°C, and decreased down to 19°C by the end of the testing period. Unfortunately due to the timing of this phase, the pilot could not be run at the lowest temperature for more than one day, as the incoming wastewater was increasing in temperature, and the cooling system was at it maximum output.

Unlike other phases, the effluent was not stabilised at the goal outputs before decreasing the temperature further, due to the time constraints of this phase. Flows varied between 45-55 L/h in R2 for most of this phase, other than one day (Day 143) when the influent ammonia had decreased, so flow was increased to 70 L/h to increase loading. The average SALR throughout this testing was 1.22 g soluble NH_3/m^2 media/day.

The overall average percent removal throughout this testing period was 67%, and the SALR/SARR ratio was 1.5. Percent removal throughout this testing period is shown in Figure 16. As the temperature was initially decreased, the ammonia removal also decreased from about 80% to 60% removal. Other than a mechanical error with the mixer on Day 132, the removal was maintained between 60-70% until the end when there was a spike in removal, possibly due to a decrease in influent ammonia loading.

While the temperature was between 19-23^{o}C, the average ammonia effluent was 46.2 mg/L. The nitrate effluent objectives of <20 mg/L were met in this phase, with an average nitrate effluent of 8.5 mg/L.

The SARR in the low temperature phase, shown in Table 7, are similar to the findings by Lemaire *et al*. (2014) when their IFAS Anita^{TM}Mox pilot, of 40% fill experienced SARR of 0.8 to 0.9 g N/m^{2}d with a temperature of 18^{o}C.

As shown in Table 6 and Table 7, this phase had the lowest percent removal and the highest ratio of SALR/SARR, outside of the acclimation and load increase phases. This indicates that this phase may have been the most difficult for the anammox to remove ammonia.

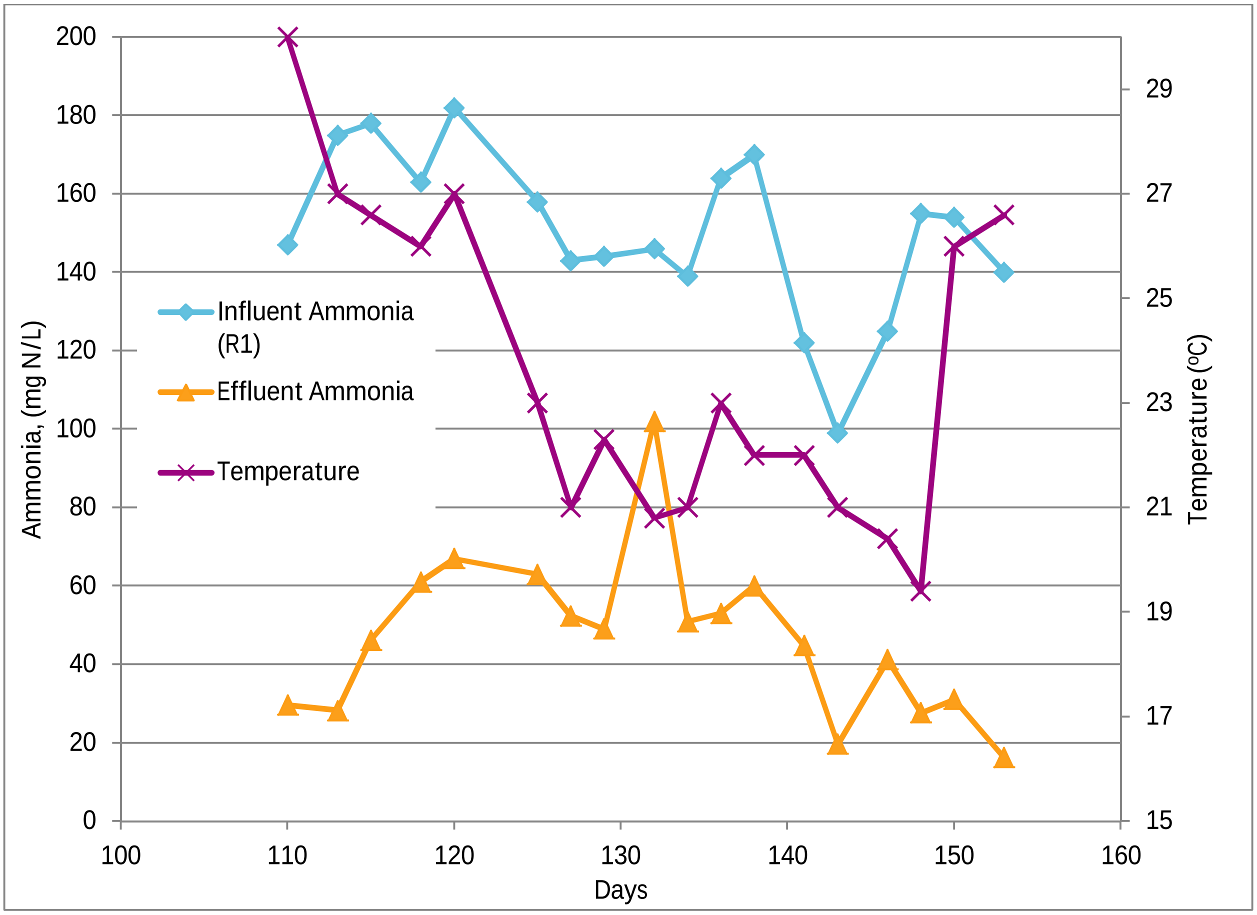

Figure 15 Ammonia measured into and from the Anita™Mox Reactor, during low temperature testing

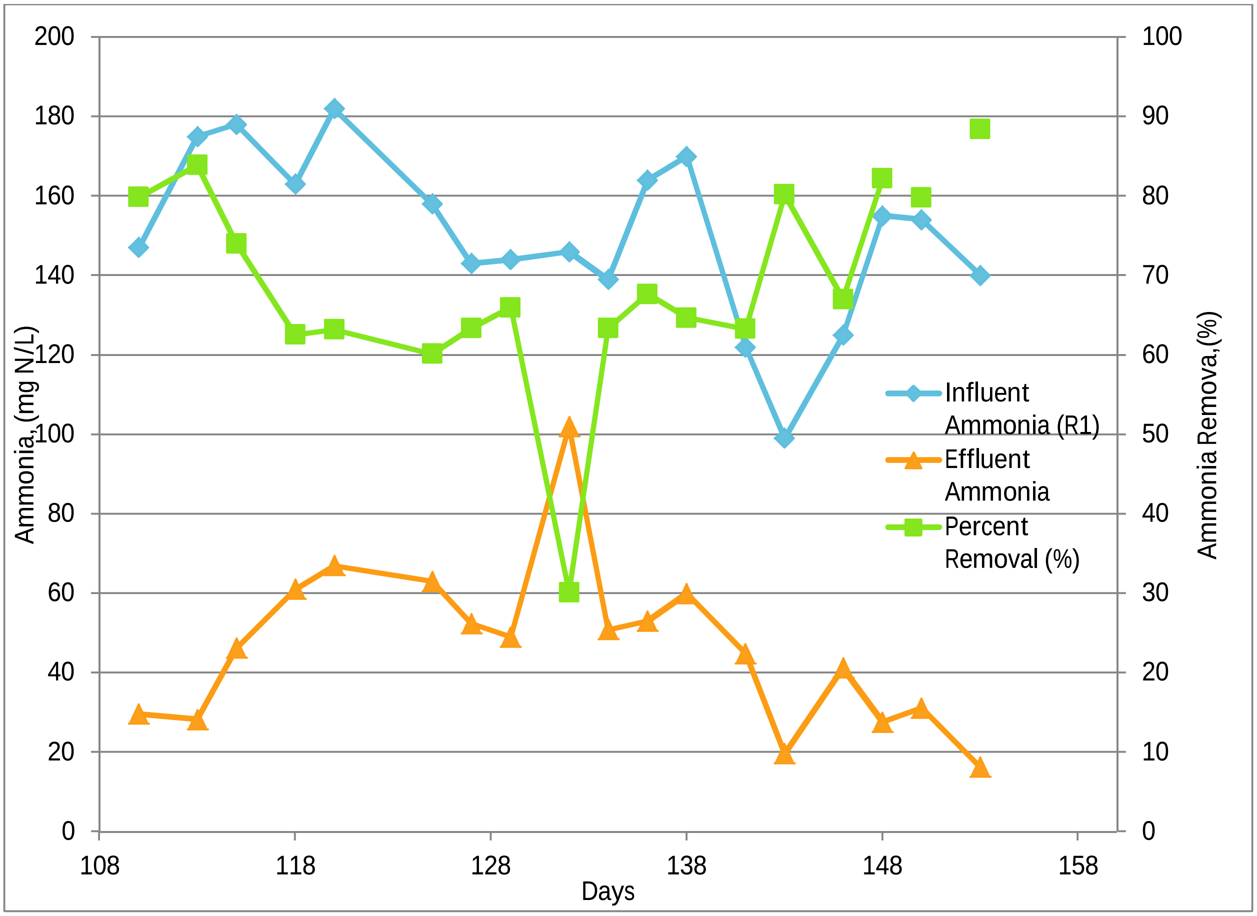

Figure 16 Ammonia measured into and from the Anita™Mox Reactor, with percent removal shown during low temperature testing

4.7 Increase in influent pH

Bundling the Ostara Pearl® process for phosphorus recovery with the ANITA™Mox process would only be possible if the anammox were able to continue to remove ammonia with an increased pH of the wastewater from the Ostara process upstream of the ANITA™Mox system. The struvite crystallization process increases the pH of the wastewater and it was unknown if the increased pH would affect the performance of the deammonification process.

Throughout this 28 day phase, the pH was incrementally increased, with initial chemical adjustment of sulphuric acid dosing for the first 15 days.

There was no noticeable effect on deammonification when the reactor was fed with effluent from the struvite crystallization reactor. Figure 17 shows the pH as well as the ammonia SALR compared to the SARR, which were found to match each other closely throughout this phase, with an average load of 1.207, and removal of 0.915 gNH_3/m^2 media●day. The SALR/SARR ratio was only slightly higher than the steady state phase.

The effluent goal of <35 mg/L ammonia was met on an overall average of 24.4 mg/L. The effluent goal of < 20 mg/L nitrate was met with an overall average of 8.9 mg/L.

The influent ammonia decreased due to a few rainstorms during this phase, and the flow was limited by the Ostara pilot, which meant the overall loading decreased. Influent ammonia ranged from 43-166 mg/L, effluent ammonia averaged 24 mg/L. The average ammonia removal from the pilot was 77%, with the highest recorded removal at 96% ammonia. This is displayed in Figure 18.

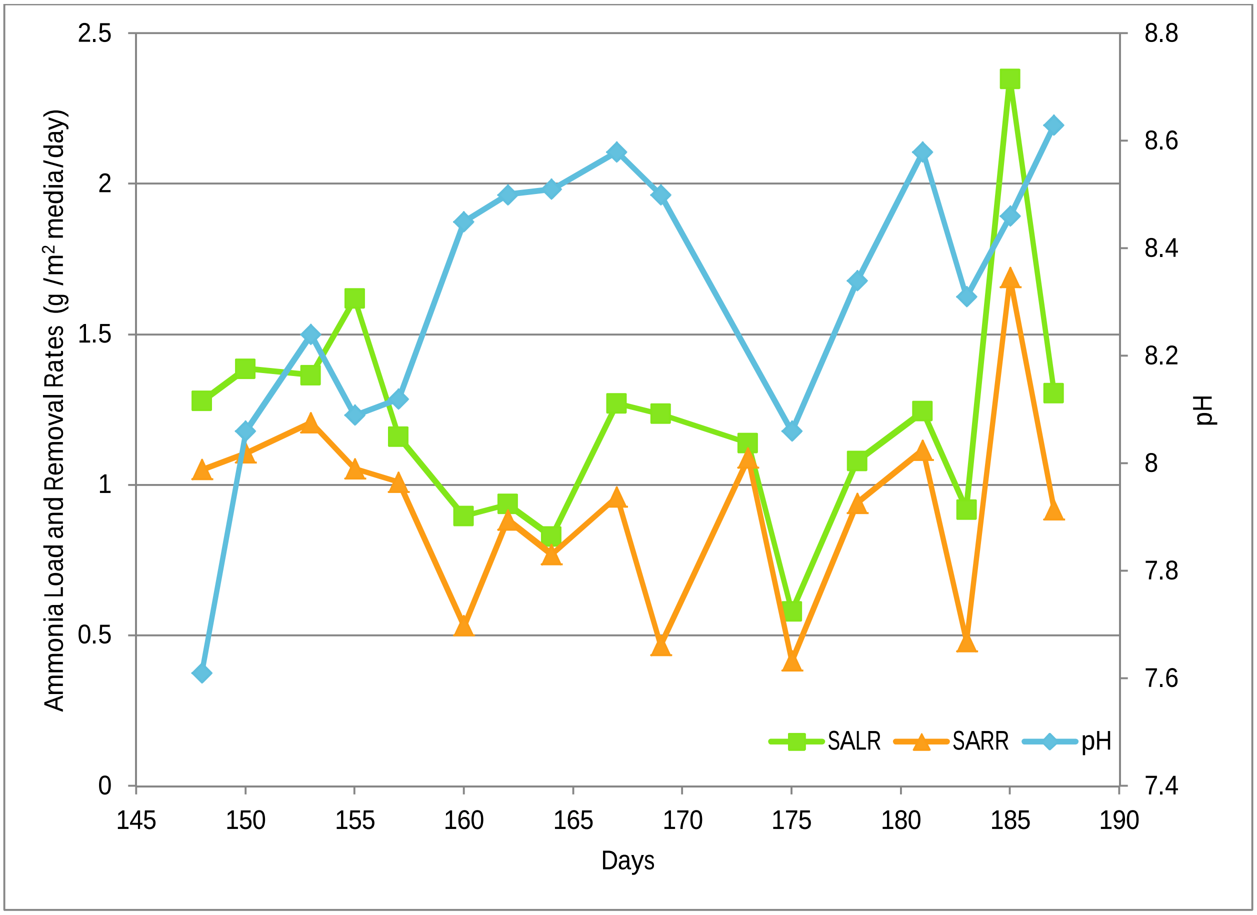

Figure 17 pH phase with Ammonia SALR and SARR

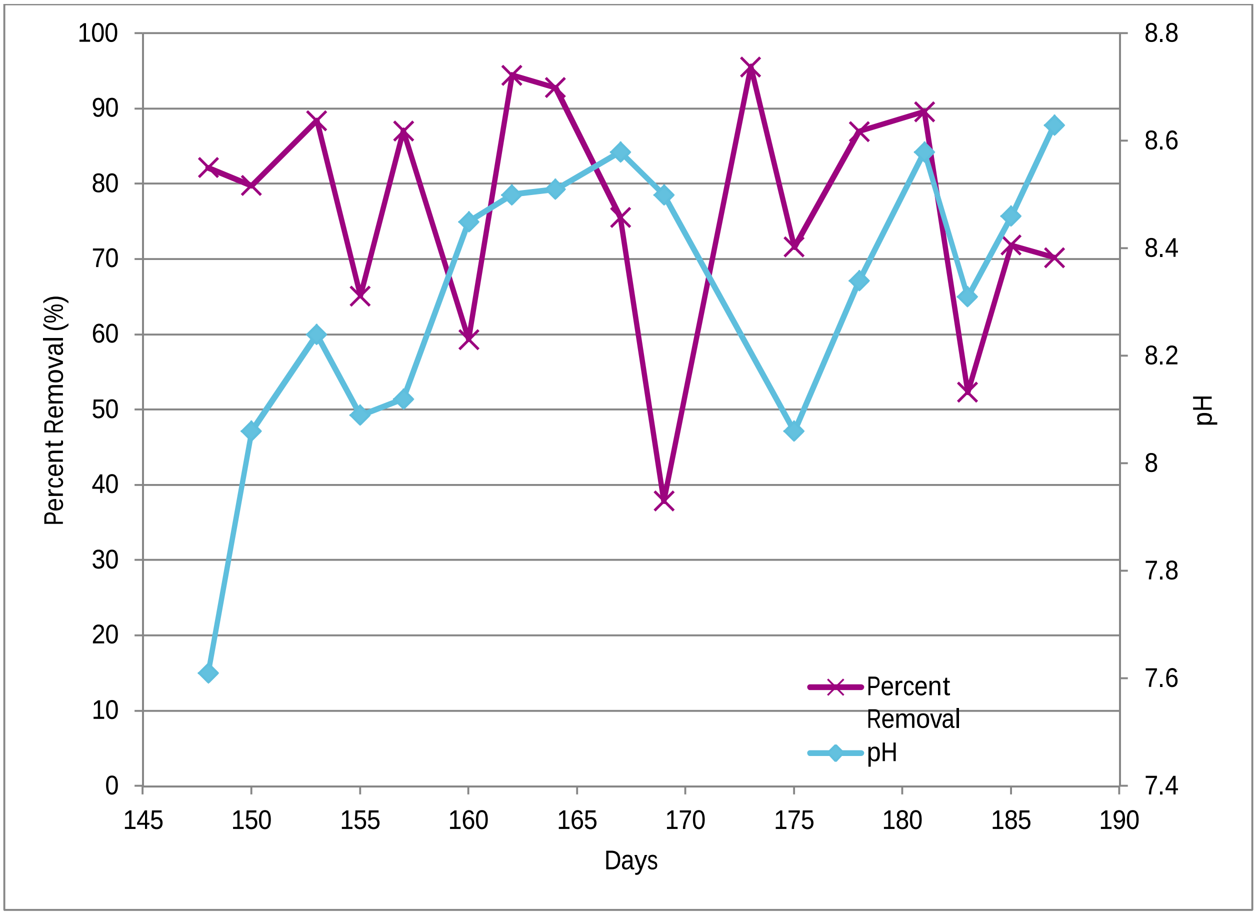

Figure 18 pH Adjustment Phase - Percent Removal

4.8 Bypassing the BOD Reactor

While the original pilot setup had two MBBR reactors, if the first reactor could be determined to be unnecessary, the capital and operational costs of the full scale system could be decreased. The first MBBR reactor was used to decrease the organics in the influent wastewater prior to the deammonification process.

This 21 day phase overlapped the pH adjustment phase, and through a piping modification in the pilot, had flow fed directly from the Ostara struvite crystallization process into R2.

As mentioned in Table 6, the ammonia removal averaged 72% removal throughout this phase, which was a 5% decrease from the pH impact phase. This phase also experienced among the highest ammonia loading and removal of the piloting. (Table 7). Throughout this phase the ratio of NO_3-$N_{produced}$/ NH_4-$N_{removed}$ was an average of 10.6%, not including the end of the testing when the reactor had been taken offline for the batch testing, and had difficulty recovering.

There was a noticeable change to the sBOD from R1, as shown in Figure 19. While the influent sBOD was an average of 18.4 mg/L, with a maximum of 53 mg/L, from the acclimation phase onwards, the effluent sBOD from R1 was 3.9 mg/L, with a maximum of 12 mg/L.

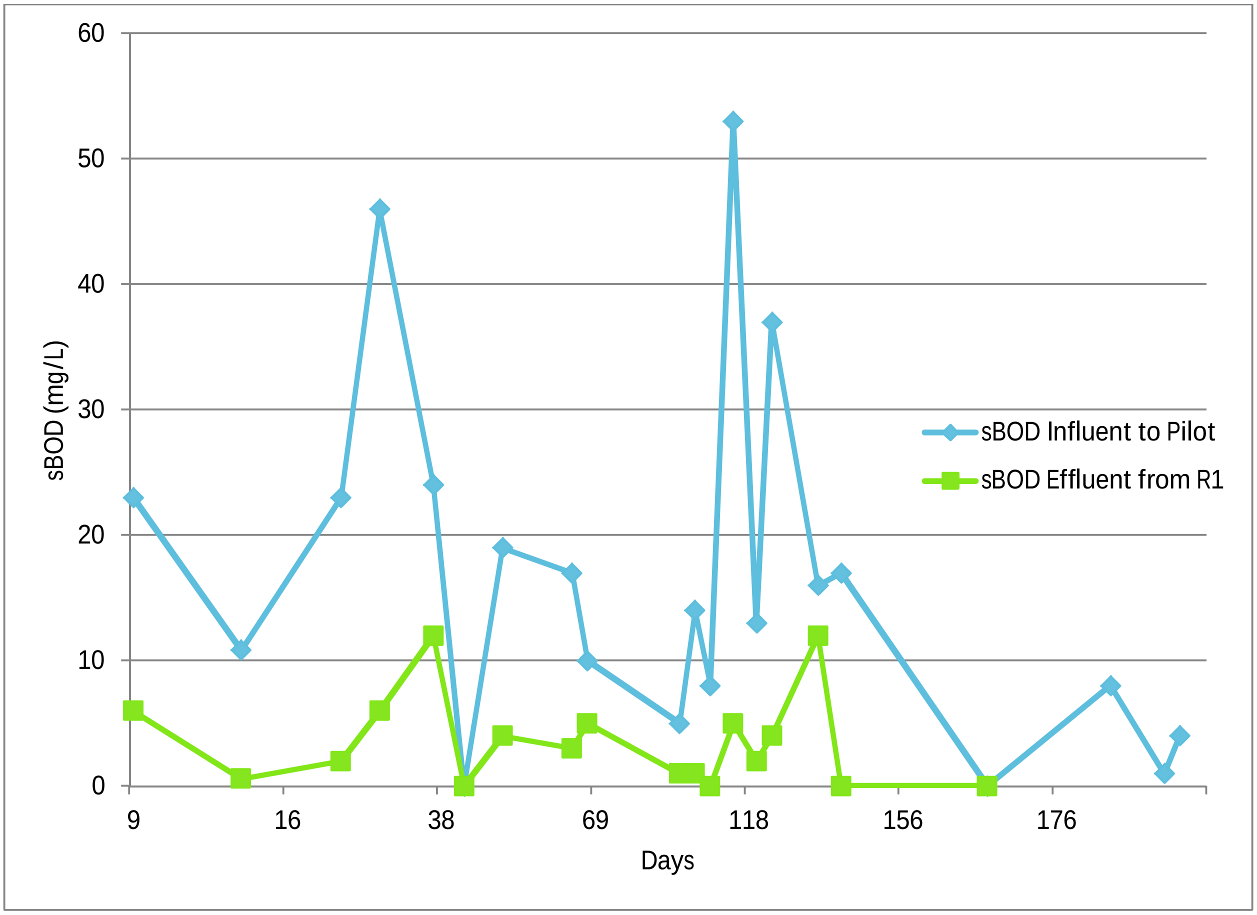

Figure 19 sBOD decreasing through R1, the organics removal MBBR

By taking R1 offline, the anammox reactor will need to adjust to the increased BOD loading. This adjustment may require longer acclimation in the full scale, or a larger full scale annamox reactor, due to the possibility of increased competition for the anammox. As the average nitrate level did increase throughout this phase compared to prior phases, there is a possibility that growth of NOB did occur throughout this phase.

4.9 TSS Spikes

After experiencing high TSS on several occasions throughout piloting, this phase of the piloting was meant to see if performance of R2 could be improved if the TSS was limited. Due to the upstream processes malfunctioning or going into upset conditions, there will be times when TSS may spike in the influent wastewater, which may trap solids within the reactor and impact performance. High TSS results also meant high COD.

If it could be shown that limiting the TSS into the reactor is beneficial, then an upstream TSS control system could be added to the full scale process. This 11 day phase overlapped the BOD Reactor Bypass phase, and through turning the mixers off in the equalization tanks prior to the pilot, solids settled out prior to entering the annamox reactor.

The ammonia removal averaged 72% throughout this phase, (Table 6) which was a 5% decrease from the pH impact phase, but no change from the BOD Reactor Bypass phase. This phase also experienced the highest ammonia loading and removal of the piloting. (Table 7). These results indicate that controlling the TSS into the pilot neither hindered or helped ammonia removal.

Spikes in TSS lasting a few days is common at the WPCF. Throughout piloting this happened several times, as shown in Figure 20. While influent TSS routinely ranged between 200-500 mg/L, it would occasionally exceed 1000 mg/L for 1-2 days, which sometimes impacted ammonia removal.

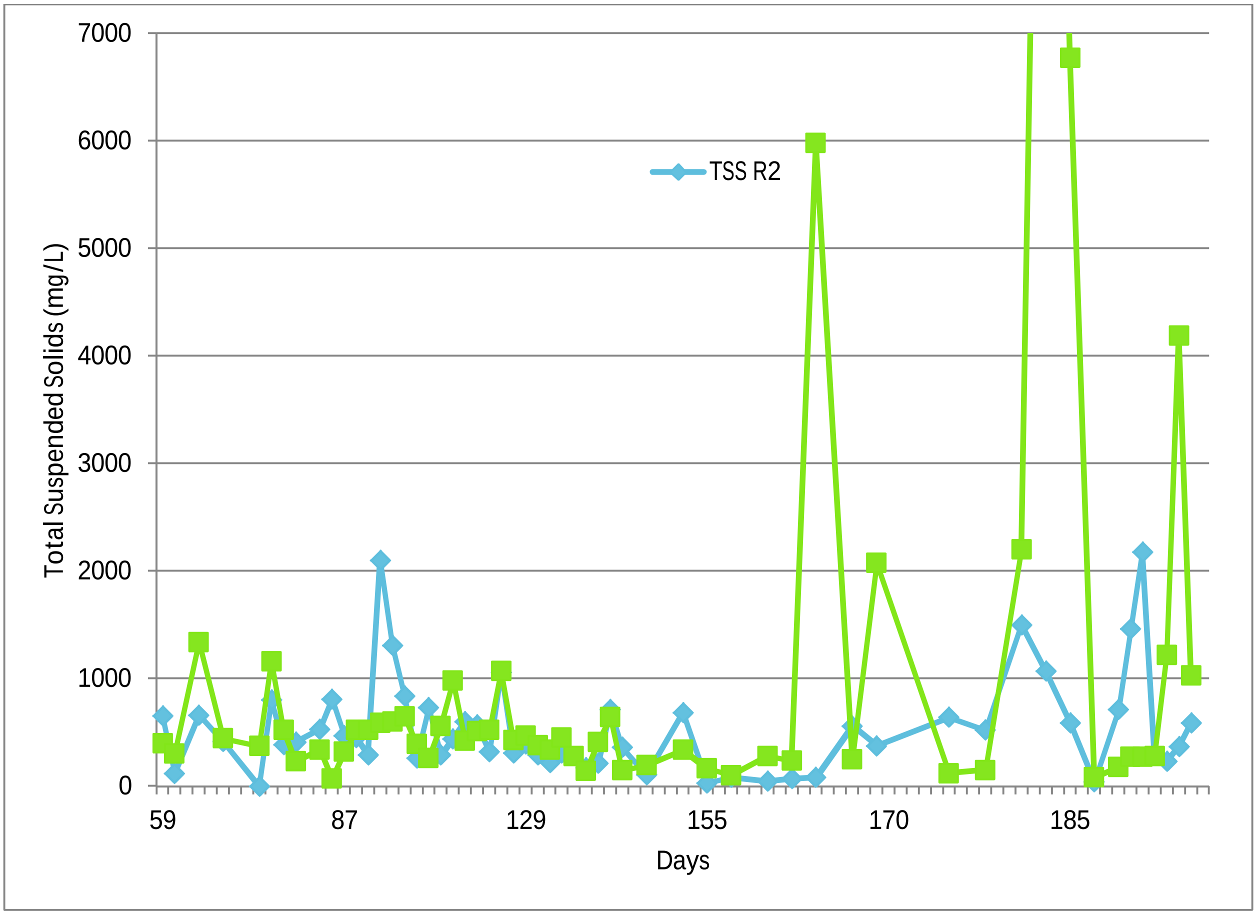

Figure 20 Total Suspended Solids (Day 183, TSS=15,130 mg/L not shown)

On Day 76, influent TSS was recorded at 1160 mg/L, and ammonia removal could have been impacted, with a decrease in ammonia removal from 50% to 42% removal. While influent sCOD had not increased from prior sampling, COD had more than doubled. However, even as the influent TSS and COD decreased four days later, the ammonia removal continued to decrease another 10%, while the TSS, and COD within R2 remained elevated compared to the influent TSS. This continued until Day 97 (April 15) when the reactor was taken down to replace the aeration grid. At that point, sludge was found in the bottom of the reactor. The aeration grid was replaced, and reactor cleaned, and the ammonia removal significantly improved.

Another high solids event occurred on Day 125, when TSS was recorded at 1070 mg/L in the influent, 1060 mg/L in R2, while COD almost doubled on the influent, and tripled in R2. Ammonia removal decreased only 3% compared to the previous sampling, and recovered by the next sampling two days later. By Day 127, TSS samples had decreased to 430 mg/L in the influent, and 310 mg/L in R2, with COD returning to average, indicating that the change in the aeration grid may have assisted in minimizing the solids from being trapped within the reactor.

The recovery within a few days from a high solids event also occurred on Day 169, influent TSS was recorded at 2075 mg/L, and ammonia removal appeared to be effected, with removal decreased to 38% from 76%. Four days later, ammonia removal improved, rising to 96% and the COD also decreased within R2.

When solids were higher than the previously noted events, recovery seemed to take longer, with an increased negative impact to ammonia removal. For example, on Day 182, one of the industries performed maintenance on their fermenter recirculation system, which caused a measured TSS in the pilot on July 10 of 15,130 mg/L. Measurements taken on Day 185, showed a decrease to the influent TSS, returning to expected levels on Day 187. In this event ammonia removal decreased from 90% to 52%, and recovered to 70% four days later. In this event the influent COD also increased almost three times, and took until the testing on Day 187 to return to normal.

While testing, an atypical event with one of the industries caused a fermenter to lose the ability to meet effluent standards for a long period, and was sending wastewater to the WPCF well in excess of their industrial service agreement. TSS was consistently above 1000 mg/L, with high

COD. The decision was made to disconnect this industry from the pilot, between Days 26 and 105, as it was not considered typical for the WPCF to routinely experience this.

When the typical TSS surges lasting 1-2 days occurred, the above-mentioned instances indicated that while ammonia removal performance may have decreased throughout the event, there was deammonification recovery in less time than the anammox would have needed to re-grow. This would indicate that performance may have been impacted by the availability of nitrite for the anammox. This agrees with Prosser (1989) in that the AOB could have been impacted by the TSS within the reactor by scouring and flushing out of the reactor, however as they are able to regrow quickly, nitrite again become available for the anammox, and deammonification continued.

4.10 Confirmation of Anammox Activity

An important parameter in testing was the confirmation of anammox activity, through the form of NOB suppression. The ratio of NO_3-$N_{produced}$/ NH_4-$N_{removed}$ indicates successful suppression of NOB activity if below the stoichiometric ratio of 11%. The ratio is shown graphically in Figure 21. The average from the beginning of the load increase phase on Day 59, to almost the end of piloting on Day 188 is 7.1%, which indicates anammox activity. Throughout the mobilization and acclimation period, the ratio was above 11%, averaging 16.8%, with a maximum at 30.6%, which may have shown that the anammox were not have been fully established and the primary ammonia remover within the reactor. After the aeration system was changed on Day 96, the ratio rose for a few days, peaking at 19.5% as the nitrate increased. Towards the end of the piloting, starting Day 189, three batch tests on R2 were performed over several hours (up to 14 hours), which may have aided the growth of NOB in the reactor.

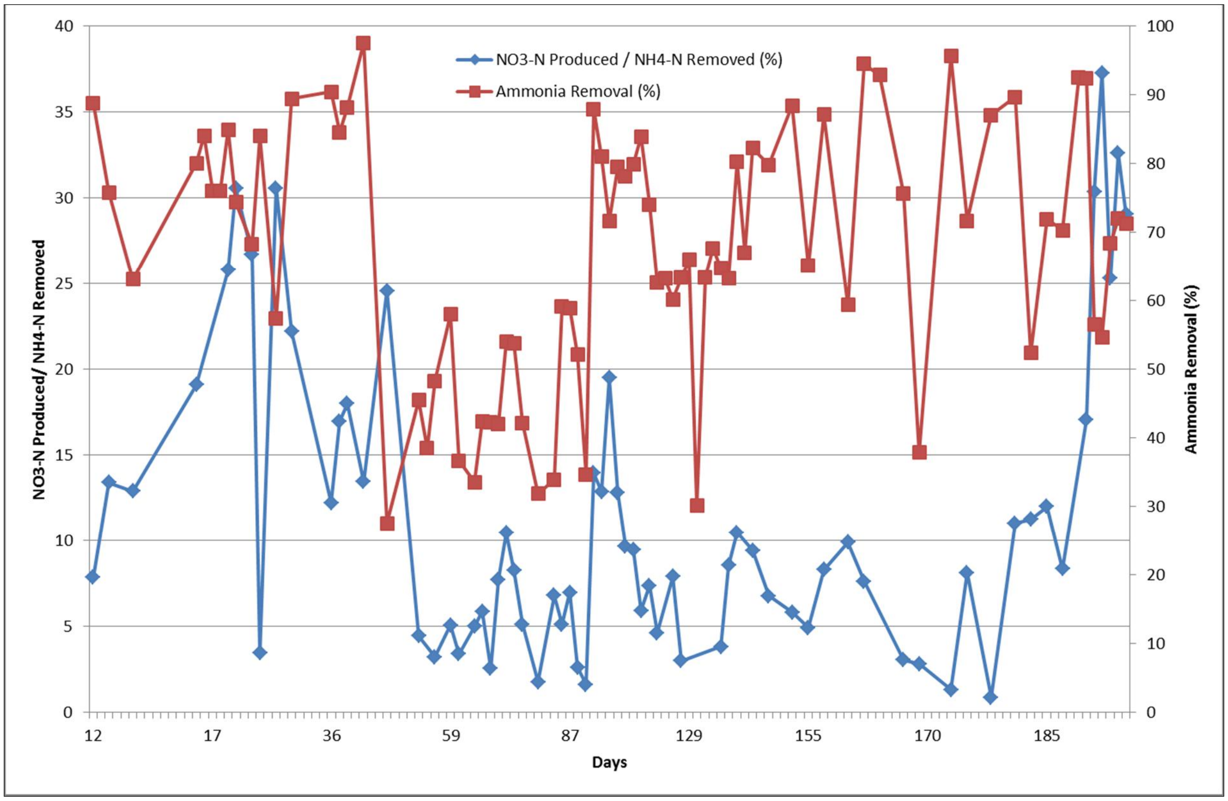

Figure 21 Confirmation of Anammox Activity through the ratio of NO_3 Produced/ NH_4 Removed

4.10.1 Batch tests

Batch tests were run for the steady state, low temperature, high pH and BOD reactor bypass phases. The stoichiometry of the anammox reaction shows that for each ammonia oxidized, 1.32 nitrite should be consumed. The ratio which resulted from the tests is shown in Table 8 below, with an average of 1.12. Yu *et al.* (2014) found that the nitrite/ammonia ratio for their SBR biofilm reactor was 1.25, while Jaroszynski *et al.* (2012) found 1.20 ± 0.27 and 1.23 ± 0.22 during the start up of the continuous flow MBBR reactors, and 1.1 ±0.1 in the same reactor, with self-regulated pH, one year later. The lower ratios may indicate that nitrites were consumed by denitrifying bacteria within the biofilm.

Table 8 Nitrite Consumed to Ammonia Ratio from Batch tests

Phase	Nitrite Consumed/Ammonia Ratio
Steady State	1.53
Low Temperature	1.13
High pH	0.95
BOD Reactor Bypass	0.86

5 Conclusions

This thesis discussed the results from operating an Anita™Mox system for industrial mainstream application at the City of Portage la Prairie. The main objective of the Anita™Mox pilot was the removal of ammonia to a treated effluent of less than 35 mg N/L ammonia and 20 mg N/L nitrates, which was achieved.

Secondary objectives included studying the impact on the process of: influent temperature reduced to 18-20^{o}C; increased influent pH; elimination of the BOD reactor ahead of the Anita™Mox reactor; and the effect of high TSS in the influent.

Although the effluent goals of < 35 mg NH_3-N/L were not met throughout the low temperatures phase, it was decided that supplemental heating on the full scale ANITA™Mox process would not be required to meet the final effluent goals at WPCF. The higher ammonia effluent could be treated with additional chemicals in the downstream SBR system for a lower cost to the City than the high capital cost of deammonification reactor heating. This phase had the lowest percent removal and the highest ratio of SALR/SARR, outside of the acclimation and load increase phases. This indicated that this phase may have been the most difficult for the anammox to remove ammonia. This was in agreement with the expectations found in literature that anammox do not grow at ideal rates at temperatures lower than the mesophilic range. The overall average percent removal throughout this testing period was 67%, and the SALR/SARR ratio was 1.5. While the temperature was between 19-23^{o}C, the average ammonia effluent was 46.2 mg/L. The nitrate effluent objectives of <20 mg NO_3-N /L were met in this phase, with an average nitrate effluent of 8.5 mg NO_3-N/L.

Testing higher influent pH, found that there was no impact to deammonification, so bundling with the Ostara Pearl process could be practical in full scale. This was in agreement with the expectations found in the literature review. The effluent goal of <35 mg/L ammonia was met on an overall average of 24.4 mg/L while the effluent goal of < 20 mg/L nitrate was met with an overall average of 8.9 mg/L. The average ammonia removal from the pilot was 77%, with the highest recorded removal at 96% ammonia. The SALR/SARR ratio was found to be 1.32.

It was found that removing the BOD reactor (R1) prior to the ANITA™Mox reactor had only a slight impact on performance when compared with the previous phase. However with an increase to loading during this phase, the results could be argued to be not noticeable, therefore making the full scale arrangement with only one MBBR reactor a strong possibility. The average effluent ammonia was 31.1 mg NH_3-N/L and average nitrate was 18.6 mg NO_3-N /L. Ammonia removal was 72% removal, with a SALR/SARR of 1.38. While the effluent goals were met, the average nitrate was higher than most other phases, indicating that competition from other bacteria, including NOB could be something that needs to be considered in full scale implementation.

When studying the impact of higher TSS, it was found that when a settling basin prior to the process was used, performance was not affected. Occasional incidents of high TSS did impact ammonia removal, with complete recovery taking several days. Due to the recovery time it is suspected that it is not the anammox which are most affected, but the AOB, growing on the outside of the MBBR media biofilm. These results are in agreement with literature where it was shown that the AOB are likely to be scoured off the biofilm before the anammox.

5.1 Recommendations

From this piloting of the ANITA™Mox system, it was found that implementing this process, without the BOD removal MBBR pretreatment could remove ammonia from the industrial stream discharged into the WPCF.

The testing of the deammonification process under increased pH and without the pretreatment BOD removal reactor occurred towards the end of the pilot study, after the anammox bacteria were well established on the media. Full scale implementation of the ANITA™Mox reactor, without a BOD removal reactor, in series with an upstream Ostara Pearl® process should consider a longer acclimation period and maintaining a lower pH in the deammonification reactor until the anammox biomass is fully established.

While the time constraints of this piloting work may not have allowed for steady state in the phases to occur, future piloting and testing could extend the time provided for each of the testing phases in order to confirm results.

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Appendix – A

Data

DAY #	DATE	TIME (central time, MB)	VOLUME OF TANK (L)		VOLUME OF MEDIA (L)		FILLING %		FLOW (L/h)			HYD. RES. TIME (h)		DISSOLVED OXYGEN (mg/L)		TEMPERATURE (degC)	
#	*yyyy-mm-dd*	*hh:mm*	*TK1*	*TK2*	*TK1*	*TK2*	*TK1*	*TK2*	*P%*	*TK1*	*TK2*	*TK1*	*TK2*	*TK1*	*TK2*	*TK1*	*TK2*
0	08/01/2014	16:00	410	399	160	0	39	0	0	0	0			5.2		19	
1	09/01/2014	8:15	410	399	160	0	39	0	0	0	0			9.12		15.2	
1	09/01/2014	13:00	410	399	160	0	39	0	0	0	0						
1	09/01/2014	17:00	410	399	160	0	39	0	0	0	0						
2	10/01/2014	9:00	410	399	160	0	39	0	0	0	0			8.9		17	
2	10/01/2014	14:00	410	399	160	0	39	0	0	0	0						
2	10/01/2014	15:00	410	399	205	0	50	0	0	0	0			7.51		17	
3	11/01/2014	9:45	410	399	205	0	50	0	0	0	0			4.65		19	
3	11/01/2014	11:30	410	399	205	0	50	0	18	20	0	20.5		3.24		19	
4	12/01/2014	14:30	410	399	205	0	50	0	0	0	0						
4	12/01/2014	14:45	410	399	205	0	50	0	0	0	0			6.55		20	
5	13/01/2014	8:45	410	399	205	0	50	0	0	0	0			7.96		19	
5	13/01/2014	15:45	410	399	205	0	50	0	0	0	0			3.56		19	
6	14/01/2014	8:45	410	399	205	0	50	0	0	0	0			8		17	
6	14/01/2014	9:00	410	399	205	0	50	0	18	20	0	20.5		5.82			
7	15/01/2014	8:45	410	399	205	0	50	0	18	20	0	20.5		6.9		17.5	
7	15/01/2014	15:00	410	399	205	0	50	0	13	40	20	10.3	19.95	6.9		17.5	
8	16/01/2014	11:00	410	399	205	0	50	0	13	40	20	10.3	19.95	7.4	0	17	17.5

DAY #	DATE	TIME (central time, MB)	VOLUME OF TANK (L)		VOLUME OF MEDIA (L)		FILLING %		FLOW (L/h)			HYD. RES. TIME (h)		DISSOLVED OXYGEN (mg/L)		TEMPERATURE (degC)	
#	*yyyy-mm-dd*	*hh:mm*	*TK1*	*TK2*	*TK1*	*TK2*	*TK1*	*TK2*	*P%*	*TK1*	*TK2*	*TK1*	*TK2*	*TK1*	*TK2*	*TK1*	*TK2*
9	17/01/2014	9:45	410	399	205	0	50	0	13	40	20	10.3	19.95	7.41	0.61	19	29
9	17/01/2014	16:00	410	399	205	200	50	50	18	60	0	6.8		5.65	0.8	18	25
10	18/01/2014	7:30	410	399	205	200	50	50	18	60	0	6.8		4.08	1.1	20.5	29
10	18/01/2014	9:00	410	399	205	200	50	50	18	60	0	6.8		4.08	1.1	20.5	29
10	18/01/2014	12:00	410	399	205	200	50	50	18	60	0	6.8		8.51	0.76	19	24.4
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11	19/01/2014	15:30	410	399	205	200	50	50	18	60	20	6.8	19.95	3	1.1	23	30
11	19/01/2014	21:30	410	399	205	200	50	50	18	80	30	5.1	13.3	3.05	0.8	23	29
12	20/01/2014	7:30	410	399	205	200	50	50	18	80	30	5.1	13.3	3.15	0.5	21	28
12	20/01/2014	9:30	410	399	205	200	50	50	18	80	30	5.1	13.3	3.2	1.13	21.5	28.7
12	20/01/2014	14:40	410	399	205	200	50	50	18	80	30	5.1	13.3	2.5	1.25	20.6	28.4
13	21/01/2014	9:30	410	399	205	200	50	50	18	80	30	5.1	13.3	4.45	0.8	20	30
13	21/01/2014	11:00	410	399	205	200	50	50	18	100	30	4.1	13.3			21	30
13	21/01/2014	18:30	410	399	205	200	50	50	17	100	30	4.1	13.3	2.7	1.2	21	30
14	22/01/2014	8:15	410	399	205	200	50	50	16	100	30	4.1	13.3	2.85	1.2	20	29
14	22/01/2014	12:00	410	399	205	200	50	50	16	100	0	4.1		2.73	1.69	20	30
14	22/01/2014	15:15	410	399	205	200	50	50	16	100	20	4.1	20.0	6.4	1.54	20	29
15	23/01/2014	8:45	410	399	205	200	50	50	16	100	23	4.1	17.3	4.01	1	18	28

DAY #	DATE	TIME (central time, MB)	VOLUME OF TANK (L)		VOLUME OF MEDIA (L)		FILLING %		FLOW (L/h)			HYD. RES. TIME (h)		DISSOLVED OXYGEN (mg/L)		TEMPERATURE (degC)	
#	*yyyy-mm-dd*	*hh:mm*	*TK1*	*TK2*	*TK1*	*TK2*	*TK1*	*TK2*	*P%*	*TK1*	*TK2*	*TK1*	*TK2*	*TK1*	*TK2*	*TK1*	*TK2*
15	23/01/2014	13:30	410	399	205	200	50	50	16	100	20	4.1	20.0	3.11	1	18	30
15	23/01/2014	17:00	410	399	205	200	50	50	17	100	25	4.1	16.0	3.13	0.5	19	29.5
16	24/01/2014	10:45	410	399	205	200	50	50	17	100	25	4.1	16.0	2.99	1.04	19	29.7
16	24/01/2014	10:50	410	399	205	200	50	50	17	100	30	4.1	13.3	2.99	1.04	19	29.7
17	25/01/2014	9:20	410	399	205	200	50	50	17	100	30	4.1	13.3	2.75	1.08	18	28.5
17	25/01/2014	15:35	410	399	205	200	50	50	17	125	30	3.3	13.3				
17	25/01/2014	18:15	410	399	205	200	50	50	17	125	0	3.3					
17	25/01/2014	23:45	410	399	205	200	50	50	17	125	27	3.3	14.8				
20	28/01/2014	9:25	410	399	205	200	50	50		125	27	3.3	14.77778	1.59	1.41	17.7	28.7
22	30/01/2014		410	399	205	200	50	50		160	27	2.6	14.77778	1.71	1.78	17.3	27
23	31/01/2014	9:15	410	399	205	200	50	50		160	27	2.6	14.77778	1.07	1.66	19.7	28
24	01/02/2014	10:30	410	399	205	200	50	50		160	27	2.6	14.77778	1.31	1.32	23.5	27.1
27	04/02/2014	9:45	410	399	205	200	50	50		190	20	2.2	19.95	8.8	1.27	24.1	27.4
28	05/02/2014	15:00	410	399	205	200	50	50		200	20	2.1	19.95	0.5	1	24.3	30
29	06/02/2014	9:30	410	399	205	200	50	50		200	20	2.1	19.95	1.12	1.1	23.3	26.9
30	07/02/2014																

DAY #	DATE	TIME (central time, MB)	VOLUME OF TANK (L)		VOLUME OF MEDIA (L)		FILLING %		FLOW (L/h)			HYD. RES. TIME (h)		DISSOLVED OXYGEN (mg/L)		TEMPERATURE (degC)	
#	*yyyy-mm-dd*	*hh:mm*	*TK1*	*TK2*	*TK1*	*TK2*	*TK1*	*TK2*	*P%*	*TK1*	*TK2*	*TK1*	*TK2*	*TK1*	*TK2*	*TK1*	*TK2*
31	08/02/2014	10:00	410	399	205	200	50	50		240	20	1.7	19.95	1.51	1.03	22.9	28.8
32	09/02/2014																
33	10/02/2014																
34	11/02/2014																
35	12/02/2014	16:00	410	399	205	200	50	50	17	240	22	1.7	18.13636	1.05	0.95	26.6	30
36	13/02/2014	9:00	410	399	205	200	50	50	17	240	22	1.7	18.13636	0.73	0.94	27	29
38	15/02/2014	9:00	410	399	205	200	50	50	17	275	22	1.5	18.13636	3.64	1.05	28	29
41	18/02/2014	9:30	410	399	205	200	50	50		275	22	1.5	18.13636	3.21	1.22	29	28.2
42	19/02/2014	8:30	410	399	205	200	50	50		275	27	1.5	14.77778	2.93	1.15	28	27
44	21/02/2014	9:30	410	399	205	200	50	50		275	27	1.5	14.77778	6.35	1.29	25.5	28.3
46	23/02/2014	19:30	410	399	205	200	50	50		275	27	1.5	14.77778	5.2	0.97	27.6	27.9
47	24/02/2014	10:35	410	399	205	200	50	50		275	35	1.5	11.4	5.2	1.04	27	28.6
48	25/02/2014	11:00	410	399	205	200	50	50		275	35	1.5	11.4	4.9	1.13	28	28.7
49	26/02/2014	7:41	410	399	205	200	50	50		275	35	1.5	11.4	4.5	1.08	28	29
50	27/02/2014		410	399	205	200	50	50		275	35	1.5	11.4	5	0.99	27	29
51	28/02/2014	8:00	410	399	205	200	50	50		275	35	1.5	11.4	4.3	0.9	27	29

DAY #	DATE	TIME (central time, MB)	VOLUME OF TANK (L)		VOLUME OF MEDIA (L)		FILLING %		FLOW (L/h)			HYD. RES. TIME (h)		DISSOLVED OXYGEN (mg/L)		TEMPERATURE (degC)	
#	*yyyy-mm-dd*	*hh:mm*	*TK1*	*TK2*	*TK1*	*TK2*	*TK1*	*TK2*	*P%*	*TK1*	*TK2*	*TK1*	*TK2*	*TK1*	*TK2*	*TK1*	*TK2*
53	02/03/2014	9:00	410	399	205	200	50	50		275	35	1.5	11.4	5.1	0.96	25	27
55	04/03/2014	9:00	410	399	205	200	50	50		275	35	1.5	11.4	9.6	1.1	18	24.9
57	06/03/2014	15:27	410	399	205	200	50	50		275	35	1.5	11.4	3	0.97	28	28
58	07/03/2014		410	399	205	200	50	50									
59	08/03/2014	10	410	399	205	200	50	50		275	35	1.5	11.4	3.1	1.01	27	29
62	11/03/2014	9:45	410	399	205	200	50	50		275	40	1.5	9.975	3.87	1	28	28
	12/03/2014																
64	13/03/2014	9:40	410	399	205	200	50	50		340	40	1.2	9.975	2.4	1.1	29	29
66	15/03/2014	10:30	410	399	205	200	50	50		340	40	1.2	9.975	3.6	1.2	28	27
68	17/03/2014	10:00	410	399	205	200	50	50	18.7	340	40	1.2	9.975	3.77	1.28	28.2	28.3
69	18/03/2014	8:15	410	399	205	200	50	50	18.7	340	40	1.2	9.975		1.4	26	26
70	19/03/2014	8:30	410	399	205	200	50	50	16.9	340	40	1.2	9.975	2.41	1.42	27.2	29.6
71	20/03/2014	13:20	410	399	205	200	50	50	18.6	340	40	1.2	9.975	3.19	1.42	26.7	29.2
73	22/03/2014		410	399	205	200	50	50.13		340	44	1.2	9.068182	4.15	1.43	26	30
76	25/03/2014	9:15	410	399	205	200	50	50		340	43	1.2	9.27907	4.2	1.5	27	30
78	27/03/2014		410	399	205	200	50	50		340	43	1.2	9.27907				
80	29/03/2014	7:00	410	399	205	200	50	50		340	43	1.2	9.27907	5.1	1.5	27	28
81	30/03/2014	7:30	410	399	205	200	50	50		340	43	1.2	9.27907	4.6	1.6	29	31
83	01/04/2014	9:00	410	399	205	200	50	50		340	43	1.2	9.27907	5.3	1.87	28	30
85	03/04/2014	9:30	410	399	205	200	50	50		340	43	1.2	9.27907	3.96	2.5	27	31

DAY #	DATE	TIME (central time, MB)	VOLUME OF TANK (L)		VOLUME OF MEDIA (L)		FILLING %		FLOW (L/h)			HYD. RES. TIME (h)		DISSOLVED OXYGEN (mg/L)		TEMPERATURE (degC)	
#	*yyyy-mm-dd*	*hh:mm*	*TK1*	*TK2*	*TK1*	*TK2*	*TK1*	*TK2*	*P%*	*TK1*	*TK2*	*TK1*	*TK2*	*TK1*	*TK2*	*TK1*	*TK2*
87	05/04/2014	9:30	410	399	205	200	50	50		380	43	1.1	9.27907	3.75	3.12	27	26
90	08/04/2014	9:30	410	399	205	200	50	50		380	43	1.1	9.27907	1	2.8	27.6	30.5
92	10/04/2014	9:30	410	399	205	200	50	50		200	43	2.1	9.3	3.3	2.96	27	26.5
97	15/04/2014	8:30	410	399	205	200	50	50		200	45	2.1	8.9	4.85	2.8	23	30
99	17/04/2014	10	410	399	205	200	50	50		200	50	2.05	7.98	3.6	3.6	24.1	30
104	22/04/2014	9:15	410	399	205	200	50	50		200	50	2.05	7.98	3.3	3	24	30
106	24/04/2014	9:00	410	399	205	200	50	50		200	50	2.05	7.98	3.5	3.48	20.4	31
108	26/04/2014	10:00	410	399	205	200	50	50		200	55	2.05	7.254545	4.15	3.5	21	30
110	28/04/2014	9:15	410	399	205	200	50	50		200	55	2.05	7.254545	3.8	3.4	21	30
113	01/05/2014	9:40	410	399	205	200	50	50		200	50	2.05	7.98	5	3.5	21.2	27
115	03/05/2014	10:00	410	399	205	200	50	50		200	50	2.05	7.98	2.14	3.5	26	26.6
118	06/05/2014	11:00	410	399	205	200	50	50		200	55	2.05	7.254545	2.12	3.5	27	26
120	08/05/2014	9:00	410	399	205	200	50	50		200	55	2.05	7.254545	2.6	3.33	26	27

DAY #	DATE	TIME (central time, MB)	VOLUME OF TANK (L)		VOLUME OF MEDIA (L)		FILLING %		FLOW (L/h)			HYD. RES. TIME (h)		DISSOLVED OXYGEN (mg/L)		TEMPERATURE (degC)	
#	yyyy-mm-dd	hh:mm	TK1	TK2	TK1	TK2	TK1	TK2	P%	TK1	TK2	TK1	TK2	TK1	TK2	TK1	TK2
125	13/05/2014	9:30	410	399	205	200	50	50		200	55	2.05	7.254545	2.73	3.8	23	23
127	15/05/2014	9:30	410	399	205	200	50	50		200	55	2.05	7.254545	2.8	4	20	21
129	17/05/2014	8:45	410	399	205	200	50	50		200	55	2.05	7.254545	4.7	3.3	20.5	22.3
132	20/05/2014	9:05	410	399	205	200	50	50		200	50	2.05	7.98	4.5	1.06	20.9	20.8
134	22/05/2014	10:00	410	399	205	200	50	50		250	50	1.64	7.98	2.45	3.9	23	21
136	24/05/2014	9:30	410	399	205	200	50	50		250	50	1.64	7.98	4.7	3	23	23
138	26/05/2014	10:15	410	399	205	200	50	50		250	55	1.64	7.254545	2.05	3.35	24	22
141	29/05/2014	9:30	410	399	205	200	50	50									
143	31/05/2014	8:30	410	399	205	200	50	50		250	70	1.64	5.7		3.5	20	21

DAY #	DATE	TIME (central time, MB)	VOLUME OF TANK (L)		VOLUME OF MEDIA (L)		FILLING %		FLOW (L/h)			HYD. RES. TIME (h)		DISSOLVED OXYGEN (mg/L)		TEMPERATURE (degC)	
#	*yyyy-mm-dd*	*hh:mm*	*TK1*	*TK2*	*TK1*	*TK2*	*TK1*	*TK2*	*P%*	*TK1*	*TK2*	*TK1*	*TK2*	*TK1*	*TK2*	*TK1*	*TK2*
146	03/06/2014	9:15	410	399	205	200	50	50		250	45	1.64	8.866667	5.6	3.5	20	20.4
148	05/06/2014	8:45	410	399	205	200	50	50		300	55	1.36666667	7.254545	4.74	3.58	19.3	19.4
149	06/06/2014																
150	07/06/2014	9:45	410	399	205	200	50	50		300	60	1.36666667	6.65	4.44	3.39	26	26
151	08/06/2014																
152	09/06/2014																
153	10/06/2014	9:25	410	399	205	200	50	50		300	65	1.36666667	6.138462	1.14	3.6	26.5	26.6
154	11/06/2014																
155	12/06/2014	9:25	410	399	205	200	50	50		300	65	1.36666667	6.138462	1.61	3.5	27	27
156	13/06/2014																
157	14/06/2014	9:45	410	399	205	200	50	50		300	65	1.36666667	6.138462	2	3.5	25	25.5
157	15/06/2014																
157	16/06/2014																
160	17/06/2014	9:15	410	399	205	200	50	50		300	65	1.36666667	6.138462	2.1	3.1	25	25
161	18/06/2014																
162	19/06/2014	10:00	410	399	205	200	50	50		300	65	1.36666667	6.138462	1.4	2.8	27	27
163	20/06/2014																
164	21/06/2014	9:30	410	399	205	200	50	50		300	65	1.36666667	6.138462	1.35	3.18	26	26
165	22/06/2014																
166	23/06/2014																
167	24/06/2014	9:00	410	399	205	200	50	50		300	75	1.36666667	5.32	2.34	2.45	25	26
168	25/06/2014																
169	26/06/2014		410	399	205	200	50	50		300	80	1.36666667	4.9875	4.7	3.3	27.4	25.4

DAY #	DATE	TIME (central time, MB)	VOLUME OF TANK (L)		VOLUME OF MEDIA (L)		FILLING %		FLOW (L/h)			HYD. RES. TIME (h)		DISSOLVED OXYGEN (mg/L)		TEMPERATURE (degC)	
#	*yyyy-mm-dd*	*hh:mm*	*TK1*	*TK2*	*TK1*	*TK2*	*TK1*	*TK2*	*P%*	*TK1*	*TK2*	*TK1*	*TK2*	*TK1*	*TK2*	*TK1*	*TK2*
170	27/06/2014																
170	28/06/2014																
172	29/06/2014																
173	30/06/2014		410	399	205	200	50	50		300	80						
174	01/07/2014																
175	02/07/2014	10:30	410	399	205	200	50	50		300	90	1.36666667	4.433333	5.3	3.4	22	21
176	03/07/2014																
177	04/07/2014																
178	05/07/2014	8:30	410	399	205	200	50	50		300	90	1.36666667	4.433333	5	3.5	28	27
179	06/07/2014																
180	07/07/2014																
181	08/07/2014	12:35	410	399	205	200	50	50			100		3.99		3.58		23
182	09/07/2014																
183	10/07/2014	9:15	410	399	205	200	50	50			120		3.325		3.5		22
184	11/07/2014																
185	12/07/2014	9:00	410	399	205	200	50	50			135		2.955556		3.2		27
186	13/07/2014																
187	14/07/2014	9:00	410	399	205	200	50	50			75		5.32		3.67		20.2
188	15/07/2014																

DAY #	DATE	TIME (central time, MB)	VOLUME OF TANK (L)		VOLUME OF MEDIA (L)		FILLING %		FLOW (L/h)			HYD. RES. TIME (h)		DISSOLVED OXYGEN (mg/L)		TEMPERATURE (degC)	
#	*yyyy-mm-dd*	*hh:mm*	*TK1*	*TK2*	*TK1*	*TK2*	*TK1*	*TK2*	*P%*	*TK1*	*TK2*	*TK1*	*TK2*	*TK1*	*TK2*	*TK1*	*TK2*
189	16/07/2014	9:00	410	399	205	200	50	50			100		3.99		3.3		28.9
190	17/07/2014	10:00	410	399	205	200	50	50			80		4.9875		3.5		28.5
194	21/07/2014	9:30	410	399	205	200	50	50			120		3.325		2.8		30
196	23/07/2014	9:00	410	399	205	200	50	50			100		3.99		3.2		28
198	25/07/2014	9:50	410	399	205	200	50	50			85		4.694118		3.4		29
199	26/07/2014	9:00	410	399	205	200	50	50			85		4.694118		2.5		30.2
201	28/07/2014	9:00	410	399	205	200	50	50			100		3.99		3		29

DAY #	DATE	pH				Alkalinity (mgCaCO3/L)	Alkalinity (mgCaCO3/L)	Alkalinity (mgCaCO3/L)	Alkalinity (mgCaCO3/L)	Total P (mg/L)			Soluble -PO4 (city analysis)(mgP/L)			soluble o-PO4 (mgP/L)
#	*yyyy-mm-dd*	*Pre O*	*RW*	*TK1*	*TK2*	*Pre O*	*RW*	*R1*	*TK2*	*RW*	*R1*	*R2*	*RW*	*R1*	*TK2*	*RW*
0	08/01/2014		7.62													
1	09/01/2014															
1	09/01/2014			8.97												
1	09/01/2014			8.65												
2	10/01/2014			8.65												
2	10/01/2014			8.84												
2	10/01/2014			8.71												
3	11/01/2014			7.83												
3	11/01/2014		7.26													
4	12/01/2014															
4	12/01/2014			8.23												
5	13/01/2014		7.59	8.60			1486			40.67			35.46			38
5	13/01/2014															
6	14/01/2014			7.44												
6	14/01/2014															
7	15/01/2014		8.05	8.11												35
7	15/01/2014															
8	16/01/2014															

DAY #	DATE	pH				Alkalinity (mgCaCO3/L)	Alkalinity (mgCaCO3/L)	Alkalinity (mgCaCO3/L)	Alkalinity (mgCaCO3/L)	Total P (mg/L)			Soluble -PO4 (city analysis)(mgP/L)			soluble o-PO4 (mgP/L)
#	*yyyy-mm-dd*	*Pre O*	*RW*	*TK1*	*TK2*	*Pre O*	*RW*	*R1*	*TK2*	*RW*	*R1*	*R2*	*RW*	*R1*	*TK2*	*RW*
9	17/01/2014		7.6	8.32			1316									119
9	17/01/2014															
10	18/01/2014															
10	18/01/2014															
10	18/01/2014															
10	18/01/2014															
11	19/01/2014															
11	19/01/2014															
12	20/01/2014															
12	20/01/2014		7.69	8.13	7.78		1411						22.46		33.09	38
12	20/01/2014															
13	21/01/2014															
13	21/01/2014															
13	21/01/2014															
14	22/01/2014		7.55	8.05	7.98		1335			37.66			22.46		33.09	28
14	22/01/2014															
14	22/01/2014															
15	23/01/2014															

DAY #	DATE	pH				Alkalinity (mgCaCO3/L)	Alkalinity (mgCaCO3/L)	Alkalinity (mgCaCO3/L)	Alkalinity (mgCaCO3/L)	Total P (mg/L)			Soluble -PO4 (city analysis)(mgP/L)			soluble o-PO4 (mgP/L)
#	*yyyy-mm-dd*	*Pre O*	*RW*	*TK1*	*TK2*	*Pre O*	*RW*	*R1*	*TK2*	*RW*	*R1*	*R2*	*RW*	*R1*	*TK2*	*RW*
15	23/01/2014															
15	23/01/2014															
16	24/01/2014															
16	24/01/2014															
17	25/01/2014		7.36	7.84	7.82		1263.5									34.5
17	25/01/2014															
17	25/01/2014															
17	25/01/2014															
20	28/01/2014		7.56	7.93	7.9		1364			40.15						32.5
22	30/01/2014		7.66	7.85	7.84		1327.5									36
23	31/01/2014															
24	01/02/2014		8.3	7.85	7.9		1189									
27	04/02/2014		7.49	7.78	7.92		1290			X						37
28	05/02/2014															
29	06/02/2014		7.54	7.98	7.95		1259									36
30	07/02/2014															

DAY #	DATE	pH				Alkalinity (mgCaCO3/L)	Alkalinity (mgCaCO3/L)	Alkalinity (mgCaCO3/L)	Alkalinity (mgCaCO3/L)	Total P (mg/L)			Soluble -PO4 (city analysis)(mgP/L)			soluble o-PO4 (mgP/L)
#	*yyyy-mm-dd*	*Pre O*	*RW*	*TK1*	*TK2*	*Pre O*	*RW*	*R1*	*TK2*	*RW*	*R1*	*R2*	*RW*	*R1*	*TK2*	*RW*
31	08/02/2014		7.45	7.58	7.69		1111		430							27
32	09/02/2014															
33	10/02/2014															
34	11/02/2014															
35	12/02/2014															
36	13/02/2014		7.36	7.71	7.84		1402		494	X						38
38	15/02/2014		7.14	7.79	7.8		1413		560							36.5
41	18/02/2014		7.43	7.99	7.95				541							40
42	19/02/2014															
44	21/02/2014		7.67	8.27	7.84											36.5
46	23/02/2014															
47	24/02/2014															
48	25/02/2014		7.13		8.02		1526		854	40.098			31.3612	33.252		36
49	26/02/2014															
50	27/02/2014		7.7	8.13	8.13		1470	939	989				36.512	25.917	27.0906	38
51	28/02/2014															

DAY #	DATE	pH				Alkalinity (mgCaCO3/L)	Alkalinity (mgCaCO3/L)	Alkalinity (mgCaCO3/L)	Alkalinity (mgCaCO3/L)	Total P (mg/L)			Soluble -PO4 (city analysis)(mgP/L)			soluble o-PO4 (mgP/L)
#	*yyyy-mm-dd*	*Pre O*	*RW*	*TK1*	*TK2*	*Pre O*	*RW*	*R1*	*TK2*	*RW*	*R1*	*R2*	*RW*	*R1*	*TK2*	*RW*
53	02/03/2014		6.86	7.86	8		1548	1450	1069				36.838	37.49	29.5682	40
55	04/03/2014		7.7	8.3	8.2		1480	1480	1051				37.49	27.5144	28.2316	47
57	06/03/2014												34.882	46.292	45.314	
58	07/03/2014															
59	08/03/2014		6.8	7.7	7.9		1545.5	1405.5	854.5							46
62	11/03/2014		8.2	7.87	7.2		1521	1430	1020	x						62
	12/03/2014															
64	13/03/2014		7.32	7.78	8.18		1549	1451	1054	x						47
66	15/03/2014		7.27	7.82	8.21		1439	1436	1024	x						46
68	17/03/2014		7.43	7.69	8.12								47	47	28	
69	18/03/2014				7.8											
70	19/03/2014			7.7	8			1308	813							
71	20/03/2014															
73	22/03/2014		6.98	7.63	8		1477	1335	768	x						46
76	25/03/2014		7.50	7.64	8		1537	1473	964	51.88			40.09		25.03	72
78	27/03/2014															
80	29/03/2014		7	7.7	8		1605	1491	1075	46.4	44.41	36.94	40.99	38.96	26.81	48
81	30/03/2014															
83	01/04/2014		7.37	7.67	8.11		1494	1403	975	44.5	2.7	37.97	38.89	38.03	24.89	57
85	03/04/2014		7.41	7.48	8.03		1468	1349	under	44.62						

DAY #	DATE	pH				Alkalinity (mgCaCO3/L)	Alkalinity (mgCaCO3/L)	Alkalinity (mgCaCO3/L)	Alkalinity (mgCaCO3/L)	Total P (mg/L)			Soluble -PO4 (city analysis)(mgP/L)			soluble o-PO4 (mgP/L)
#	*yyyy-mm-dd*	*Pre O*	*RW*	*TK1*	*TK2*	*Pre O*	*RW*	*R1*	*TK2*	*RW*	*R1*	*R2*	*RW*	*R1*	*TK2*	*RW*
87	05/04/2014		7.32	7.45	7.89		1413	1323	770	44.52	1.22	41.97	41.28	41.1	31.69	48
90	08/04/2014		7.21	7.49	8.01		1484	1425	896	45.3			38.64	39	28.06	42.4
92	10/04/2014		7.34	7.75	8.15		1527	1527	1044	46.83			39.54	37.3	28.27	46.5
97	15/04/2014		7.3	7.8	7.57		1416	1416	757	45.54	37.42	27.74	39.14	37.42	27.74	45
99	17/04/2014		7.21	7.65	7.66		1349	1277	603	43.12			36.92	36.66	30.22	43
104	22/04/2014		7.01	7.51	7.4		1325	1253	573	39.91			34.59	33.09	27.5	44
106	24/04/2014		7.38	7.85	7.86		1234	1187	513				33.57		23.21	46
108	26/04/2014		7.6	7.9	7.7			1259	603	39.93			36.74	34.32	22.99	
110	28/04/2014		7.56	7.91	7.82		1360	1311	600	44.12			35.66	36.99	24.65	59
113	01/05/2014		7.6	7.77	7.79		1455		622	62.65			39.04	31.51	26	50
115	03/05/2014		7.23	7.73	7.78		1465	1411	689	47.76	v		42.75	41.97	28.54	47
118	06/05/2014		7.35	7.81	7.92		1474	1406	772	43.83			39.46		30.27	46
120	08/05/2014		7.45	7.83	7.88			1370	748	43.66			39.77	40.01	30.98	49

DAY #	DATE	pH				Alkalinity (mgCaCO3/L)	Alkalinity (mgCaCO3/L)	Alkalinity (mgCaCO3/L)	Alkalinity (mgCaCO3/L)	Total P (mg/L)			Soluble -PO4 (city analysis)(mgP/L)			soluble o-PO4 (mgP/L)
#	*yyyy-mm-dd*	*Pre O*	*RW*	*TK1*	*TK2*	*Pre O*	*RW*	*R1*	*TK2*	*RW*	*R1*	*R2*	*RW*	*R1*	*TK2*	*RW*
125	13/05/2014		7.31	7.76	7.78		1319	1227	721	45.91			37.1		29.66	40
127	15/05/2014		7.45	7.81	7.79		1232	1186	706	41.66			35.93		30.86	40.4
129	17/05/2014		7.08	7.71	7.7		1233	1166	713	46.05			38.14		31.97	44.4
132	20/05/2014		7.37	7.67	7.68		1182	1142	922	43.27			37.81		34.44	49.5
134	22/05/2014		7.24	7.51	7.63		1133	1110	670	41.45					35.04	44.44
136	24/05/2014		7.33	8.06	7.62		1271	1135	677	47.59			40.21		33.48	47.5
138	26/05/2014		7.48	7.66	7.73		1337	1303		42.84			39.55		34.11	42.42
141	29/05/2014		7.34	7.67	7.75		1175	1164	724	43.27			37.53		34.87	44.4
143	31/05/2014			7.6												49.5

DAY #	DATE	pH				Alkalinity (mgCaCO3/L)	Alkalinity (mgCaCO3/L)	Alkalinity (mgCaCO3/L)	Alkalinity (mgCaCO3/L)	Total P (mg/L)			Soluble -PO4 (city analysis)(mgP/L)			soluble o-PO4 (mgP/L)
#	*yyyy-mm-dd*	*Pre O*	*RW*	*TK1*	*TK2*	*Pre O*	*RW*	*R1*	*TK2*	*RW*	*R1*	*R2*	*RW*	*R1*	*TK2*	*RW*
146	03/06/2014		7.6	7.89	7.69		1193	1123	648	45.96			39.33		34.51	43.4
148	05/06/2014		7.3	7.61	7.57		1249	1221	620	43.91			41.81		37.09	46.5
149	06/06/2014															
150	07/06/2014		7.38	8.06	7.81		1235	1332	710	44.74			41.92		18.47	68.7
151	08/06/2014															
152	09/06/2014															
153	10/06/2014		9	8.24	7.77		1448	1231	632	50.42	28.52	40.63		23.2	24.27	38.4
154	11/06/2014															
155	12/06/2014		8.57	8.09	8.01		1587	1444	868	19.42			16.08		18.81	22.22
156	13/06/2014															
157	14/06/2014		8.39	8.12	8.06		1307	1194	751	24.65						23
157	15/06/2014															
157	16/06/2014															
160	17/06/2014		8.67	8.45	8		1209	1125	871							22.22
161	18/06/2014															
162	19/06/2014		8.66	8.5	7.88		1273		675	29						20.9
163	20/06/2014															
164	21/06/2014		8.6	8.51	7.94					160.87						38.76
165	22/06/2014															
166	23/06/2014															
167	24/06/2014		8.88	8.58	8.09		1273	1166	950	17.42						15.3
168	25/06/2014															
169	26/06/2014			8.5						119.13						23.46

DAY #	DATE	pH				Alkalinity (mgCaCO3/ L)	Alkalinity (mgCaCO3/L)	Alkalinity (mgCaCO3/L)	Alkalinity (mgCaCO3/L)	Total P (mg/L)			Soluble -PO4 (city analysis)(mgP/L)			soluble o-PO4 (mgP/L)
#	*yyyy-mm-dd*	*Pre O*	*RW*	*TK1*	*TK2*	*Pre O*	*RW*	*R1*	*TK2*	*RW*	*R1*	*R2*	*RW*	*R1*	*TK2*	*RW*
170	27/06/2014															
170	28/06/2014															
172	29/06/2014															
173	30/06/2014									52.19						15.81
174	01/07/2014															
175	02/07/2014		8.58	8.06	8		917	757	767	23.88					19.17	19.38
176	03/07/2014															
177	04/07/2014															
178	05/07/2014	7.16	8.67	8.34	8.02	961.5	1199	1101	814	21.86	34.79		15.16		19.24	16.32
179	06/07/2014															
180	07/07/2014															
181	08/07/2014	7.35	8.58		7.89		1281		714							15.81
182	09/07/2014															
183	10/07/2014	7.49	8.31		7.89	736	1290		555	273.16						14.79
184	11/07/2014															
185	12/07/2014	7.45	8.46		8	1109	2200		891	283.98						18.36
186	13/07/2014															
187	14/07/2014	7.38	8.63		8.11				828							16.32
188	15/07/2014															

DAY #	DATE	pH				Alkalinity (mgCaCO3/L)	Alkalinity (mgCaCO3/L)	Alkalinity (mgCaCO3/L)	Alkalinity (mgCaCO3/L)	Total P (mg/L)			Soluble -PO4 (city analysis)(mgP/L)			soluble o-PO4 (mgP/L)
#	*yyyy-mm-dd*	*Pre O*	*RW*	*TK1*	*TK2*	*Pre O*	*RW*	*R1*	*TK2*	*RW*	*R1*	*R2*	*RW*	*R1*	*TK2*	*RW*
189	16/07/2014		7.34		7.44		1235		491	39.94						46.46
190	17/07/2014		7.61		7.28		1196		210	38.05			17.16			38
194	21/07/2014		7.2		7.64		1137		623	39.63		53.01	34.45		33.29	
196	23/07/2014		7.45		7.78		1155		73.5	39.87		36.49	35.83		32.44	42.42
198	25/07/2014		7.55		8.02		1314		697	53.1		43.37	38.43		30.65	59.59
199	26/07/2014		7.44		7.67		1333		634				40.14		31.66	48.48
201	28/07/2014		7.45		7.7		1220		642	47.59		40.91	37.36		33.15	52.52

DAY #	DATE	soluble o-PO4 (mgP/L)	Total TKN (mgN/L)				TSS (mg/L)				VSS (mg/L)		
#	*yyyy-mm-dd*	*RW*	*Pre O*	*RW*	*R1*	*R2*	*PreO*	*RW*	*R1*	*R2*	*RW*	*R1*	*R2*
0	08/01/2014							403			54		
1	09/01/2014												
1	09/01/2014												
1	09/01/2014												
2	10/01/2014												
2	10/01/2014												
2	10/01/2014												
3	11/01/2014												
3	11/01/2014												
4	12/01/2014												
4	12/01/2014												
5	13/01/2014	38		271.5		233.6		405			50		
5	13/01/2014												
6	14/01/2014												
6	14/01/2014												
7	15/01/2014	35											
7	15/01/2014												
8	16/01/2014												

DAY #	DATE	soluble o-PO4 (mgP/L)	Total TKN (mgN/L)				TSS (mg/L)				VSS (mg/L)		
#	*yyyy-mm-dd*	*RW*	*Pre O*	*RW*	*R1*	*R2*	*PreO*	*RW*	*R1*	*R2*	*RW*	*R1*	*R2*
9	17/01/2014	119						1090					
9	17/01/2014												
10	18/01/2014												
10	18/01/2014			175.17									
10	18/01/2014												
10	18/01/2014												
11	19/01/2014												
11	19/01/2014												
12	20/01/2014												
12	20/01/2014	38		211.39				390					
12	20/01/2014												
13	21/01/2014												
13	21/01/2014												
13	21/01/2014												
14	22/01/2014	28						750					
14	22/01/2014												
14	22/01/2014												
15	23/01/2014												

DAY #	DATE	soluble o-PO4 (mgP/L)	Total TKN (mgN/L)				TSS (mg/L)				VSS (mg/L)		
#	yyyy-mm-dd	RW	Pre O	RW	R1	R2	PreO	RW	R1	R2	RW	R1	R2
15	23/01/2014												
15	23/01/2014												
16	24/01/2014												
16	24/01/2014												
17	25/01/2014	34.5						1155					
17	25/01/2014												
17	25/01/2014												
17	25/01/2014												
20	28/01/2014	32.5		223.32				870					
22	30/01/2014	36						525					
23	31/01/2014												
24	01/02/2014							1725					
27	04/02/2014	37		243.8				850		110			
28	05/02/2014												
29	06/02/2014	36						90	140	140			
30	07/02/2014												

DAY #	DATE	soluble o-PO4 (mgP/L)	Total TKN (mgN/L)				TSS (mg/L)				VSS (mg/L)		
#	*yyyy-mm-dd*	*RW*	*Pre O*	*RW*	*R1*	*R2*	*PreO*	*RW*	*R1*	*R2*	*RW*	*R1*	*R2*
31	08/02/2014	27						400	130	30	0		
32	09/02/2014												
33	10/02/2014												
34	11/02/2014												
35	12/02/2014												
36	13/02/2014	38		271.5				1150	460	27	350		
38	15/02/2014	36.5						120					
41	18/02/2014	40		175				610	580	30			
42	19/02/2014												
44	21/02/2014	36.5						790	800	420			
46	23/02/2014												
47	24/02/2014												
48	25/02/2014	36		198				526.666667			26.66666667		
49	26/02/2014												
50	27/02/2014	38											
51	28/02/2014												

DAY #	DATE	soluble o-PO4 (mgP/L)	Total TKN (mgN/L)				TSS (mg/L)				VSS (mg/L)		
#	*yyyy-mm-dd*	*RW*	*Pre O*	*RW*	*R1*	*R2*	*PreO*	*RW*	*R1*	*R2*	*RW*	*R1*	*R2*
53	02/03/2014	40						346	373.3333333	400			86.66666667
55	04/03/2014	47		184.53				153.333333	326.6666667	46.66666667			
57	06/03/2014							286.666667		113.3333333	26.66666667		13.33333333
58	07/03/2014												
59	08/03/2014	46		185.72				400		653.3333333	60		153.3333333
62	11/03/2014	62		214.1		51.62		300	910	120			
	12/03/2014												
64	13/03/2014	47		223.84				1340	1120	660			
66	15/03/2014	46		265.75									
68	17/03/2014							445	292	413	148	30	100
69	18/03/2014												
70	19/03/2014												
71	20/03/2014												
73	22/03/2014	46		227.76				373	380	0	0	0	
76	25/03/2014	72		296.01				1160	1050	800			
78	27/03/2014							520		385			
80	29/03/2014	48		262.68	253.69	184.47		230	330	410			
81	30/03/2014												
83	01/04/2014	57		248.77	256.98	178.62		340	490	530			
85	03/04/2014			203.19				70	260	810			

DAY #	DATE	soluble o-PO4 (mgP/L)	Total TKN (mgN/L)				TSS (mg/L)				VSS (mg/L)		
#	*yyyy-mm-dd*	*RW*	*Pre O*	*RW*	*R1*	*R2*	*PreO*	*RW*	*R1*	*R2*	*RW*	*R1*	*R2*
87	05/04/2014	48		196.03	205.15	95.83		320	370	470			
90	08/04/2014	42.4		219.12				520	490	450	90	160	120
92	10/04/2014	46.5		230.45				520	920	290			
97	15/04/2014	45		243.94	176.08	18.33		590	260	2100			
99	17/04/2014	43		223.32				600	270	1310			
104	22/04/2014	44		227.21				650	450	840			
106	24/04/2014	46						390	390	260			
108	26/04/2014			180.11		x		260	280	730	0	70	160
110	28/04/2014	59		195.74		x		560	280	290	30	0	0
113	01/05/2014	50		323.46				980	700	440			
115	03/05/2014	47		224.2		x		420	480	600			
118	06/05/2014	46		219.01		x		510	440	570			
120	08/05/2014	49		288.91		x		520	340	320			

DAY #	DATE	soluble o-PO4 (mgP/L)	Total TKN (mgN/L)				TSS (mg/L)				VSS (mg/L)		
#	*yyyy-mm-dd*	*RW*	*Pre O*	*RW*	*R1*	*R2*	*PreO*	*RW*	*R1*	*R2*	*RW*	*R1*	*R2*
125	13/05/2014	40		243.13		x		1070	530	1060	150	400	220
127	15/05/2014	40.4		187.65				430	330	310			
129	17/05/2014	44.4		201.85				470	380	390	60	30	50
132	20/05/2014	49.5		180.18				380	240	290			
134	22/05/2014	44.44		171.44				340	320	220			
136	24/05/2014	47.5		219.53				450	210	310	0	0	0
138	26/05/2014	42.42		193.44		x		280	180				
141	29/05/2014	44.4		167.62				140	40	170			
143	31/05/2014	49.5						410	770	210	10	140	0

DAY #	DATE	soluble o-PO4 (mgP/L)	Total TKN (mgN/L)				TSS (mg/L)				VSS (mg/L)		
#	*yyyy-mm-dd*	*RW*	*Pre O*	*RW*	*R1*	*R2*	*PreO*	*RW*	*R1*	*R2*	*RW*	*R1*	*R2*
146	03/06/2014	43.4		180.39				640	1230	710			
148	05/06/2014	46.5		181.83				145	120	360			
149	06/06/2014												
150	07/06/2014	68.7		195.9				195	145	105			
151	08/06/2014												
152	09/06/2014												
153	10/06/2014	50		158.85	136.58	42.33		335	60	685			
154	11/06/2014	43											
155	12/06/2014	37		181.4	188.8	71		165	65	30			
156	13/06/2014	39											
157	14/06/2014	39		151	145.6	26.6		100	100	80			
157	15/06/2014	23											
157	16/06/2014	40											
160	17/06/2014	42		131.4	118	52.6		280	125	45			
161	18/06/2014	57											
162	19/06/2014	43		126	123.4	18.52		235	95	70			
163	20/06/2014												
164	21/06/2014	166		330	127.89	23		5980	125	80			
165	22/06/2014	60											
166	23/06/2014	58											
167	24/06/2014	58		129.87	>320	>320		250	680	560			
168	25/06/2014												
169	26/06/2014			343.9	162.4			2075	595	375			

DAY #	DATE	soluble o-PO4 (mgP/L)	Total TKN (mgN/L)				TSS (mg/L)				VSS (mg/L)		
#	*yyyy-mm-dd*	*RW*	*Pre O*	*RW*	*R1*	*R2*	*PreO*	*RW*	*R1*	*R2*	*RW*	*R1*	*R2*
170	27/06/2014												
170	28/06/2014												
172	29/06/2014												
173	30/06/2014			184.36	124	12							
174	01/07/2014												
175	02/07/2014			82.68	70.55	47.6		120	410	640			
176	03/07/2014												
177	04/07/2014												
178	05/07/2014		188.2	142.8	138.6	42	660	150	260	520			
179	06/07/2014												
180	07/07/2014												
181	08/07/2014			206		43.6	1010	2200		1500			
182	09/07/2014												
183	10/07/2014			678		82	900	15130		1070			
184	11/07/2014												
185	12/07/2014			414		84.8	460	6770		590			
186	13/07/2014												
187	14/07/2014			145		47.8	180	80		40			
188	15/07/2014												

DAY #	DATE	soluble o-PO4 (mgP/L)	Total TKN (mgN/L)				TSS (mg/L)				VSS (mg/L)		
#	*yyyy-mm-dd*	*RW*	*Pre O*	*RW*	*R1*	*R2*	*PreO*	*RW*	*R1*	*R2*	*RW*	*R1*	*R2*
189	16/07/2014	46.46		196.6		70.4		180		710	0		180
190	17/07/2014	38		140.92		58.4		270		1460			
194	21/07/2014			157.62		206.04		270		2180			
196	23/07/2014	42.42		162.67		74.59		280		290			
198	25/07/2014	59.59		239.88		82.28		1220		230			
199	26/07/2014	48.48						4190		370			
201	28/07/2014	52.52		219.27		73.22		1030		590			

DAY #	DATE	Soluble cBOD (mg/L)			Total cBOD (mg/L)			soluble COD (mg/L)				Total COD (mg/L)				Soluble ammonia (mgN/L)				% removal
#	*yyyy-mm-dd*	*RW*	*TK1*	*TK2*	*RW*	*TK1*	*TK2*	preO	*RW*	*TK1*	*TK2*	*preO*	*RW*	*TK1*	*TK2*	*Pre O*	*RW*	*TK1*	*TK2*	
0	08/01/2014	337							1041				over				115.5			#DIV/0!
1	09/01/2014									932				over				107		100
1	09/01/2014		324							970								101		100
1	09/01/2014									1014								97		100
2	10/01/2014		324							670								84		100
2	10/01/2014									748								83.8		100
2	10/01/2014									636								70.9		100
3	11/01/2014									292								42.4		100
3	11/01/2014								220				1192				110.5			#DIV/0!
4	12/01/2014																			#DIV/0!
4	12/01/2014									112								94		100
5	13/01/2014								340	120			1168				155.5	96.5		100
5	13/01/2014																			#DIV/0!
6	14/01/2014									106								8		100
6	14/01/2014																			#DIV/0!
7	15/01/2014				123				192	144			2036				164	71		100
7	15/01/2014																			#DIV/0!
8	16/01/2014									136								173		100

DAY #	DATE	Soluble cBOD (mg/L)			Total cBOD (mg/L)			soluble COD (mg/L)				Total COD (mg/L)				Soluble ammonia (mgN/L)				% removal
#	*yyyy-mm-dd*	*RW*	*TK1*	*TK2*	*RW*	*TK1*	*TK2*	preO	*RW*	*TK1*	*TK2*	*preO*	*RW*	*TK1*	*TK2*	*Pre O*	*RW*	*TK1*	*TK2*	
9	17/01/2014	23	6		69				165	115			1668	844			141	143		100
9	17/01/2014																			#DIV/0!
10	18/01/2014																			
10	18/01/2014									110							141	142.5	10	93
10	18/01/2014																			
10	18/01/2014																			
11	19/01/2014																			
11	19/01/2014																			
12	20/01/2014																			
12	20/01/2014								153	108	69						175	164	18.4	89
12	20/01/2014																			
13	21/01/2014									102	74							135	32.7	76
13	21/01/2014																			
13	21/01/2014																			
14	22/01/2014	10.83	0.58	<1	103				125	98	73		1320	676	956		128	123	45.4	63
14	22/01/2014																			
14	22/01/2014																			
15	23/01/2014																			

DAY #	DATE	Soluble cBOD (mg/L)			Total cBOD (mg/L)			soluble COD (mg/L)				Total COD (mg/L)				Soluble ammonia (mgN/L)				% removal
#	*yyyy-mm-dd*	*RW*	*TK1*	*TK2*	*RW*	*TK1*	*TK2*	preO	*RW*	*TK1*	*TK2*	*preO*	*RW*	*TK1*	*TK2*	*Pre O*	*RW*	*TK1*	*TK2*	
15	23/01/2014																			
15	23/01/2014																			
16	24/01/2014																			
16	24/01/2014																			
17	25/01/2014								150	88	68						126	125	25	80
17	25/01/2014																127	125	20	84
17	25/01/2014																127	125	30	76
17	25/01/2014																127	125	30	76
20	28/01/2014								143	91	52		1268	944	176		142	142	21.4	85
22	30/01/2014	23	2	<1	54				141	83	68						130	115	29.5	74
23	31/01/2014																			
24	01/02/2014								113	102	67		2332	748	104		99	124	39.4	68
27	04/02/2014																125	121	19.4	84
28	05/02/2014																			
29	06/02/2014	46	6	<1	163				160	86	55		452	360	136		120	130	55.4	57
30	07/02/2014																			

DAY #	DATE	Soluble cBOD (mg/L)			Total cBOD (mg/L)			soluble COD (mg/L)				Total COD (mg/L)				Soluble ammonia (mgN/L)				% removal
#	*yyyy-mm-dd*	*RW*	*TK1*	*TK2*	*RW*	*TK1*	*TK2*	preO	*RW*	*TK1*	*TK2*	*preO*	*RW*	*TK1*	*TK2*	*Pre O*	*RW*	*TK1*	*TK2*	
31	08/02/2014								71	92	49		612	244	80		73	113	12	89
32	09/02/2014																			
33	10/02/2014																			
34	11/02/2014																			
35	12/02/2014																			
36	13/02/2014	24	12	<1	122				143	102	56		1168	664	624		152	145	13.9	90
38	15/02/2014								136	90	51		436	752	80		136	152	23.5	85
41	18/02/2014								154	118	52		644	167	27		117	130	15.4	88
42	19/02/2014																			
44	21/02/2014	<1	<1	<1	41				76	77	49		416	528	288		129	132	3.3	98
46	23/02/2014																			
47	24/02/2014																			
48	25/02/2014								139	86	57		908				157	167	121	28
49	26/02/2014																			
50	27/02/2014	19	4	2	43				100	60	59						140	75	99.8	
51	28/02/2014																			

DAY #	DATE	Soluble cBOD (mg/L)			Total cBOD (mg/L)			soluble COD (mg/L)				Total COD (mg/L)				Soluble ammonia (mgN/L)				% removal
#	*yyyy-mm-dd*	*RW*	*TK1*	*TK2*	*RW*	*TK1*	*TK2*	preO	*RW*	*TK1*	*TK2*	*preO*	*RW*	*TK1*	*TK2*	*Pre O*	*RW*	*TK1*	*TK2*	
53	02/03/2014								117	74	54		684	636	556		166	168	91.6	45
55	04/03/2014								110	85	55		392	252	172		157	143	88	38
57	06/03/2014								124	94	64		636	604	234		155	154	79.6	48
58	07/03/2014																			
59	08/03/2014								145	88	61		788	1036	836		168	157	66	58
62	11/03/2014								153	80	65		556	1156	144		153	161	102	37
	12/03/2014																			
64	13/03/2014	17	3	<1	48				151	86	63		1860	1540	856		158	161	107	34
66	15/03/2014								128	76	57		1284	932	1076		168	165	95	42
68	17/03/2014	10	5	<1	50				166	110	70		936	629	569		211	206	119	42
69	18/03/2014																	151	87.5	42
70	19/03/2014								166	82	68			560	702			142	65.4	54
71	20/03/2014																			#DIV/0!
73	22/03/2014								135	84	56		784	360	104		152	149	69	54
76	25/03/2014								136	84	63		1656	1488	1088		160	167	96.6	42
78	27/03/2014														572					
80	29/03/2014								124	75	55		592	544	572		171	160	109	32
81	30/03/2014																			
83	01/04/2014								115	73	51		620	744	708		162	165	109	34
85	03/04/2014								112	95	57		600	520	1072		164	159	65	59

DAY #	DATE	Soluble cBOD (mg/L)			Total cBOD (mg/L)			soluble COD (mg/L)				Total COD (mg/L)				Soluble ammonia (mgN/L)				% removal
#	*yyyy-mm-dd*	*RW*	*TK1*	*TK2*	*RW*	*TK1*	*TK2*	preO	*RW*	*TK1*	*TK2*	*preO*	*RW*	*TK1*	*TK2*	*Pre O*	*RW*	*TK1*	*TK2*	
87	05/04/2014								103	87	54		584	664	600		162	161	66.2	59
90	08/04/2014								107	85	49		818	764	576		163	169	81	52
92	10/04/2014	5	1	1	41				113	67	61		836	1394	420		177	179	117	35
97	15/04/2014								114	66	52		1336	796	2194		182	170	20.7	88
99	17/04/2014	14	1	1	71				101	67	65		926	512	1344		160	165	31.4	81
104	22/04/2014								123	84	61		1012	742	878		154	161	45.6	72
106	24/04/2014	8	0	1	35				100	68	55		592	542	314		130	129	26.5	79
108	26/04/2014								85	71	63		488	424	884		140	143	31.3	78
110	28/04/2014								77	72	58		1022	590	560		148	147	29.6	80
113	01/05/2014	53	5	2	110				114	69	53		1262	656	606		175	175	28.2	84
115	03/05/2014								111	74	68		712	626	744		188	178	46.2	74
118	06/05/2014								113	77	62		814	688	790		166	163	61	63
120	08/05/2014	13	2	0	80				102	69	62		750	400	388		195	182	67	63

DAY #	DATE	Soluble cBOD (mg/L)			Total cBOD (mg/L)			soluble COD (mg/L)				Total COD (mg/L)				Soluble ammonia (mgN/L)				% removal
#	*yyyy-mm-dd*	*RW*	*TK1*	*TK2*	*RW*	*TK1*	*TK2*	preO	*RW*	*TK1*	*TK2*	*preO*	*RW*	*TK1*	*TK2*	*Pre O*	*RW*	*TK1*	*TK2*	
125	13/05/2014								106	72	59		1398	772	1240		152	158	63	60
127	15/05/2014	37	4	3	147				118	60	60		564	428	338		153	143	52.4	63
129	17/05/2014								79	64	53		736	578	518		155	144	49	66
132	20/05/2014								80	62	58		624	462	466		149	146	102	30
134	22/05/2014								64	48	41		614	422	292		148	139	50.9	63
136	24/05/2014								92	59	58		734	572	424		166	164	53	68
138	26/05/2014								83	66	56		408	396	312		170	170	60	65
141	29/05/2014	16	12	2	79				83	87	58		402	262	392		140	122	44.8	63
143	31/05/2014								91	93	56		632	1030	1286		106	99	19.6	80

DAY #	DATE	Soluble cBOD (mg/L)			Total cBOD (mg/L)			soluble COD (mg/L)				Total COD (mg/L)				Soluble ammonia (mgN/L)				% removal
#	yyyy-mm-dd	RW	TK1	TK2	RW	TK1	TK2	preO	RW	TK1	TK2	preO	RW	TK1	TK2	Pre O	RW	TK1	TK2	
146	03/06/2014								81	78	55		922	1522	928		126	125	41.2	67
148	05/06/2014	17	0	0	13				87	79	52		258	236	344		162	155	27.6	82
149	06/06/2014																			
150	07/06/2014								83	82	49		354	276	180		162	154	31.1	80
151	08/06/2014																			
152	09/06/2014																			
153	10/06/2014								86	78	49		331	154	751		126	140	16.2	88
154	11/06/2014																			
155	12/06/2014								77	70	55		198	134	93		158	166	57.9	65
156	13/06/2014																			
157	14/06/2014								77	67	56		180	152	102		124	119	15.4	87
157	15/06/2014																			
157	16/06/2014																			
160	17/06/2014								78	81	53		121	144	94		112	92	37.4	59
161	18/06/2014																			
162	19/06/2014								76	80	52		293	156	101		111	96	5.3	94
163	20/06/2014																			
164	21/06/2014								81	97	56		5096	197	136		84	85	6.1	93
165	22/06/2014																			
166	23/06/2014																			
167	24/06/2014	<6	<6	<6	43.7				83	92	56		300	368	316		121	113	27.6	76
168	25/06/2014																			
169	26/06/2014								163	56	51		2148	1099	561		102	103	64	38

DAY #	DATE	Soluble cBOD (mg/L)			Total cBOD (mg/L)			soluble COD (mg/L)				Total COD (mg/L)				Soluble ammonia (mgN/L)				% removal
#	*yyyy-mm-dd*	*RW*	*TK1*	*TK2*	*RW*	*TK1*	*TK2*	preO	*RW*	*TK1*	*TK2*	*preO*	*RW*	*TK1*	*TK2*	*Pre O*	*RW*	*TK1*	*TK2*	
170	27/06/2014																			
170	28/06/2014																			
172	29/06/2014																			
173	30/06/2014								73	61	42		1117	197	62		106	95	4.2	96
174	01/07/2014																			
175	02/07/2014								83	103	58		234	568	731		74	43	12.2	72
176	03/07/2014																			
177	04/07/2014																			
178	05/07/2014							93	77	86	67	704	201	291	448	108	90	80	10.4	87
179	06/07/2014																			
180	07/07/2014																			
181	08/07/2014							144	80		44	1294	1997		1374	51	83		8.6	90
182	09/07/2014																			
183	10/07/2014	8		1	178			127	60		44	1386	5594		570	69	51		24.3	52
184	11/07/2014																			
185	12/07/2014							81	106		61	629	2839		689	140	116		32.6	72
186	13/07/2014																			
187	14/07/2014							66	54		33		123		101	147	116		34.5	70
188	15/07/2014																			

DAY #	DATE	Soluble cBOD (mg/L)			Total cBOD (mg/L)			soluble COD (mg/L)				Total COD (mg/L)				Soluble ammonia (mgN/L)				% removal
#	*yyyy-mm-dd*	*RW*	*TK1*	*TK2*	*RW*	*TK1*	*TK2*	preO	*RW*	*TK1*	*TK2*	*preO*	*RW*	*TK1*	*TK2*	*Pre O*	*RW*	*TK1*	*TK2*	
189	16/07/2014								88		52		279		1076		142		10.7	92
190	17/07/2014	1		1					77		50		274		944		118		9	92
194	21/07/2014								479		300	1831			12414		119		51.8	56
196	23/07/2014	4		2	49				58		35		413		184		107		48.5	54.6728972
198	25/07/2014								60		37		1525		264		149		47.1	68.38926174
199	26/07/2014								89		52		4768		244		122		34.2	71.96721311
201	28/07/2014								86		56		1268		2242		143		41.1	71.25874126

DAY #	DATE	Soluble nitrates (mgN/L)			Soluble nitrates (method 10020) (mgN/L)			Soluble nitrites (mgN/L)			Soluble TKN (mgN/L)			NO3-N Produced/ NH4-N Removed (%)	Calculated NH3 fraction (mgN/L)	Ratio NH4 to NO3 formed	SALR (NH3) (g soluble NH3/m2 media/day)
#	*yyyy-mm-dd*	*RW*	*TK1*	*TK2*	*RW*	*TK1*	*TK2*	*RW*	*TK1*	*TK2*	*RW*	*TK1*	*TK2*	*TK2*	*TK2*	*Tk2*	*R2*
0	08/01/2014	1.5						8							0.00		#DIV/0!
1	09/01/2014		0.9						5						0.00		#DIV/0!
1	09/01/2014		0												0.00		#DIV/0!
1	09/01/2014		0.4												0.00		#DIV/0!
2	10/01/2014		0												0.00		#DIV/0!
2	10/01/2014		1.9						8						0.00		#DIV/0!
2	10/01/2014		3						3						0.00		#DIV/0!
3	11/01/2014		12						2						0.00		#DIV/0!
3	11/01/2014	7.9						5							0.00		#DIV/0!
4	12/01/2014														0.00		#DIV/0!
4	12/01/2014		13.5						15						0.00		#DIV/0!
5	13/01/2014	12.5	38					40	30		181.82				0.00		#DIV/0!
5	13/01/2014														0.00		#DIV/0!
6	14/01/2014		117						72						0.00		#DIV/0!
6	14/01/2014														0.00		#DIV/0!
7	15/01/2014	8.5	102.5					3.5	103						0.00		#DIV/0!
7	15/01/2014														0.00		#DIV/0!
8	16/01/2014		3.3												0.00		#DIV/0!

DAY #	DATE	Soluble nitrates (mgN/L)			Soluble nitrates (method 10020) (mgN/L)			Soluble nitrites (mgN/L)			Soluble TKN (mgN/L)			NO3-N Produced/ NH4-N Removed (%)	Calculated NH3 fraction (mgN/L)	Ratio NH4 to NO3 formed	SALR (NH3) (g soluble NH3/m2 media/day)
#	*yyyy-mm-dd*	*RW*	*TK1*	*TK2*	*RW*	*TK1*	*TK2*	*RW*	*TK1*	*TK2*	*RW*	*TK1*	*TK2*	*TK2*	*TK2*	*Tk2*	*R2*
9	17/01/2014	2.3	2.2					12	12						0.00		#DIV/0!
9	17/01/2014														0.00	#DIV/0!	
10	18/01/2014														0.00	#DIV/0!	
10	18/01/2014														0.00	0.0	
10	18/01/2014														0.00	#DIV/0!	
10	18/01/2014														0.00	#DIV/0!	
11	19/01/2014														0.00	#DIV/0!	
11	19/01/2014														0.00	#DIV/0!	
12	20/01/2014														0.00	#DIV/0!	
12	20/01/2014	4.1	3.1	14.5				2.13	3.65	3.04	172.18		19.1	7.8	0.78	10.0	0.738
12	20/01/2014														0.00	#DIV/0!	
13	21/01/2014		1.8	15.5					4	2				13.4	0.00	15.2	0.6075
13	21/01/2014														0.00	#DIV/0!	
13	21/01/2014														0.00	#DIV/0!	
14	22/01/2014	4.8	1	11				2	2	3				12.9	3.05	14.2	0.5535
14	22/01/2014														0.00	#DIV/0!	
14	22/01/2014														0.00	#DIV/0!	
15	23/01/2014														0.00	#DIV/0!	

DAY #	DATE	Soluble nitrates (mgN/L)			Soluble nitrates (method 10020) (mgN/L)			Soluble nitrites (mgN/L)			Soluble TKN (mgN/L)			NO3-N Produced/ NH4-N Removed (%)	Calculated NH3 fraction (mgN/L)	Ratio NH4 to NO3 formed	SALR (NH3) (g soluble NH3/m2 media/day)
#	*yyyy-mm-dd*	*RW*	*TK1*	*TK2*	*RW*	*TK1*	*TK2*	*RW*	*TK1*	*TK2*	*RW*	*TK1*	*TK2*	*TK2*	*TK2*	*Tk2*	*R2*
15	23/01/2014														0.00	#DIV/0!	
15	23/01/2014														0.00	#DIV/0!	
16	24/01/2014														0.00	#DIV/0!	
16	24/01/2014														0.00	#DIV/0!	
17	25/01/2014	3.6	0.9	20				1	2	3				19.1	1.15	20.0	0.5625
17	25/01/2014														0.00	0.0	0.5625
17	25/01/2014														0.00	0.0	
17	25/01/2014														0.00	0.0	0.50625
20	28/01/2014	3.7	1.4	32.5				1	2	3	151.46		18.5	25.8	1.18	26.9	0.5751
22	30/01/2014	3.4	0.9	27				1	1	4				30.5	1.28	31.6	0.46575
23	31/01/2014														0.00	#DIV/0!	
24	01/02/2014	1.1	1.4	24				0.14	0.1	2.3				26.7	1.96	28.4	0.5022
27	04/02/2014	16.2	2.7	6.2				0.08	0.1	2.05	156.2	150.3	19	3.4	1.03	6.1	0.363
28	05/02/2014																
29	06/02/2014	6	0.7	23.5				0.08	0.3	2.75				30.6	3.03	31.5	0.39
30	07/02/2014															#DIV/0!	

DAY #	DATE	Soluble nitrates (mgN/L)			Soluble nitrates (method 10020) (mgN/L)			Soluble nitrites (mgN/L)			Soluble TKN (mgN/L)			NO3-N Produced/ NH4-N Removed (%)	Calculated NH3 fraction (mgN/L)	Ratio NH4 to NO3 formed	SALR (NH3) (g soluble NH3/m2 media/day)
#	*yyyy-mm-dd*	*RW*	*TK1*	*TK2*	*RW*	*TK1*	*TK2*	*RW*	*TK1*	*TK2*	*RW*	*TK1*	*TK2*	*TK2*	*TK2*	*Tk2*	*R2*
31	08/02/2014	0.8	1.1	23.5				0.12	1.78	1.85				22.2	0.42	23.3	0.339
32	09/02/2014														0.00	#DIV/0!	
33	10/02/2014														0.00	#DIV/0!	
34	11/02/2014														0.00	#DIV/0!	
35	12/02/2014														0.00	#DIV/0!	
36	13/02/2014	5.5	4	20				0	0	1.91	173		12.6	12.2	0.69	15.3	0.4785
38	15/02/2014	15.2	1.7	23.5				0.06	0.1	1.85				17.0	1.07	18.3	0.5016
41	18/02/2014	13.4	1.4	22				0.1	0.06	1.5	X		14	18.0	0.92	19.2	0.429
42	19/02/2014														0.00	#DIV/0!	
44	21/02/2014	0.7	2.2	19.5				1	10	1.1	146	144	59.7	13.4	0.16	15.2	0.5346
46	23/02/2014														0.00	#DIV/0!	
47	24/02/2014														0.00	#DIV/0!	
48	25/02/2014	12.8	3.7	15				0.04	0.06	0.95	158	177	89.1	24.6	8.68	32.6	0.87675
49	26/02/2014														0.00	#DIV/0!	
50	27/02/2014	4.2	1.4	7.5				0.06	2.36	0.8			76.6		9.21		0.39375
51	28/02/2014														0.00	#DIV/0!	

DAY #	DATE	Soluble nitrates (mgN/L)			Soluble nitrates (method 10020) (mgN/L)			Soluble nitrites (mgN/L)			Soluble TKN (mgN/L)			NO3-N Produced/ NH4-N Removed (%)	Calculated NH3 fraction (mgN/L)	Ratio NH4 to NO3 formed	SALR (NH3) (g soluble NH3/m2 media/day)
#	*yyyy-mm-dd*	*RW*	*TK1*	*TK2*	*RW*	*TK1*	*TK2*	*RW*	*TK1*	*TK2*	*RW*	*TK1*	*TK2*	*TK2*	*TK2*	*Tk2*	*R2*
53	02/03/2014	9.5	1.7	1.1	0.5	0.4	3.8	0.04	0.14	0.7				4.5	5.63	2.7	0.882
55	04/03/2014	4	3.6	1.3			3.3	0.16	4	1.85		157.7	51.4		7.22	0.0	0.75075
57	06/03/2014	9.6	2	1.5			4.4	0.08	0.12	2				3.2	0.00	3.2	0.8085
58	07/03/2014																
59	08/03/2014	16.9	2.5	2.8			7.1	0.10	0.62	0.65	X	x	51.43	5.1	3.73	5.1	0.82425
62	11/03/2014	16.8	1.5	1			3.5	0.06	0.12	1.9	184.52	182.01	51.43	3.4	1.12	3.4	0.966
	12/03/2014															#DIV/0!	
64	13/03/2014				0.9	0.7	3.4	0.1	0.04	1.55	184.05	184.18	51.22	5.0	10.95	6.3	0.966
66	15/03/2014	9	0.4	3.2			4.5	0.04	0.12	1.45	198.54	184.12	50.9	5.9	9.12	5.9	0.99
68	17/03/2014	3.6	1	3.2				0	0	1.4				2.5	10.28	-1.1	1.236
69	18/03/2014		0.3	5.2										7.7	3.24	-0.5	0.906
70	19/03/2014		1.6	9.6					0.14	1.15				10.4	4.76	-2.1	0.852
71	20/03/2014													#DIV/0!			0
73	22/03/2014	13.2	0.6	4.8			7.2	0.14	0.12	1.35	177.99	180.4	48.67	8.3	5.15	8.3	0.9834
76	25/03/2014	12.9	1.5	1.9			5.1	0.06	0.12	1.2	210.03	215.55	114.88	5.1	7.22	5.1	1.07715
78	27/03/2014														0.00	#DIV/0!	
80	29/03/2014	8.2	4	1.2			4.9	0.1	0.48	0.85	215.73	218.53	133.88	1.8	7.15	1.8	1.032
81	30/03/2014														0.00	#DIV/0!	
83	01/04/2014	5.9	1	6.3			4.8	0.04	0.01	1.45	204.98	206.6	121.39	6.8	10.27	6.8	1.06425
85	03/04/2014	11.6	1.6	7.1			6.4			1.6				5.1	5.51	5.1	1.02555

DAY #	DATE	Soluble nitrates (mgN/L)			Soluble nitrates (method 10020) (mgN/L)			Soluble nitrites (mgN/L)			Soluble TKN (mgN/L)			NO3-N Produced/ NH4-N Removed (%)	Calculated NH3 fraction (mgN/L)	Ratio NH4 to NO3 formed	SALR (NH3) (g soluble NH3/m2 media/day)
#	*yyyy-mm-dd*	*RW*	*TK1*	*TK2*	*RW*	*TK1*	*TK2*	*RW*	*TK1*	*TK2*	*RW*	*TK1*	*TK2*	*TK2*	*TK2*	*Tk2*	*R2*
87	05/04/2014	5.9	0.6	8.1			7.2	0.084	0.063	1.887	167.25	166.36	56.3	7.0	2.99	7.0	1.03845
90	08/04/2014	22	2.6	4.8			4.9	0.084	0.084	1.785	174.93	166.58	79.84	2.6	6.38	2.6	1.09005
92	10/04/2014	11.7	1.1	4.3			2.1	0	1	3	173.88	174.7	118.5	1.6	9.59	1.612903226	1.15455
97	15/04/2014	16.0	1.8	20.7			22.6	0	1	4	181.2		18.33	13.9	0.60	13.93168118	1.1475
99	17/04/2014	4.5	0.6	21.4			17.8	1	1	5	165.23	171.06	11.74	12.9	1.12	12.8742515	1.2375
104	22/04/2014	4.4	0.3	28			22.8	0	1	4	177.08	173.51	31.78	19.5	0.91	19.49740035	1.2075
106	24/04/2014	2.5	1.1	18.9			14.2	0.672	0.315	2.4	141.09		25.7	12.8	1.56	12.7804878	0.9675
108	26/04/2014						10.8	1	3	4	137.48	148.67	30.51	9.7	1.22	9.668755595	1.17975
110	28/04/2014	1.1	1.1				12.2	0.273	1.806	2.016	142.31	155.76	27.93	9.5	1.50	9.454855196	1.21275
113	01/05/2014	1.6	3.4	26			12.1	0.063	2.9	4.3	169.75	172.37	22.09	5.9	1.09	5.926430518	1.3125
115	03/05/2014	2	0.8	30			10.5	0.128	0.063	4.386	189.46	184.1	39.05	7.4	1.71	7.359635812	1.335
118	06/05/2014	3	4	29			8.7	0.042	0.063	4.284	181.37		46.55	4.6	2.95	4.607843137	1.34475
120	08/05/2014	2	1.6	20.4				0.042	0.105	4.641	177.99	187.45	46.09		3.17	-1.39130435	1.5015

DAY #	DATE	Soluble nitrates (mgN/L)			Soluble nitrates (method 10020) (mgN/L)			Soluble nitrites (mgN/L)			Soluble TKN (mgN/L)			NO3-N Produced/ NH4-N Removed (%)	Calculated NH3 fraction (mgN/L)	Ratio NH4 to NO3 formed	SALR (NH3) (g soluble NH3/m2 media/day)
#	*yyyy-mm-dd*	*RW*	*TK1*	*TK2*	*RW*	*TK1*	*TK2*	*RW*	*TK1*	*TK2*	*RW*	*TK1*	*TK2*	*TK2*	*TK2*	*Tk2*	*R2*
125	13/05/2014	1.6	0.2	22			7.7	0.063	0.063	3.315	168.21		42.89	7.9	1.81	7.894736842	1.3035
127	15/05/2014	2	4	32			6.7	0.02	0.2	4.9	150.56		41.56	3.0	1.34	2.98013245	1.17975
129	17/05/2014	13	18	27			6.5	0.084	5.9	4.4	151.09		41.59		1.12	-12.1052632	1.188
132	20/05/2014	4	12	12.4			2.9	1.47	5.4	2.8	144.21		46.45		2.01	-20.6818182	1.095
134	22/05/2014	4.4	8.8				7.7	1.72	3.34	3.98	143.14		42.34		0.91	-1.24858116	1.0425
136	24/05/2014	2	8	23.2			6.1	0.105	2.709	3.264	171.08		41.26		1.07	-1.71171171	1.23
138	26/05/2014	2.4	2.4	24			6.6	0.021	0.126	3.519	175.27		43.31	3.8	1.44	3.818181818	1.4025
141	29/05/2014				1.5	0.8	7.4	6.7	0.084	3.77	135.93		40.3	8.5	0.20	9.585492228	
143	31/05/2014				1.9	2.3	10.6	16	25	3.32				10.5	0.00	13.35012594	1.0395

DAY #	DATE	Soluble nitrates (mgN/L)			Soluble nitrates (method 10020) (mgN/L)			Soluble nitrites (mgN/L)			Soluble TKN (mgN/L)			NO3-N Produced/ NH4-N Removed (%)	Calculated NH3 fraction (mgN/L)	Ratio NH4 to NO3 formed	SALR (NH3) (g soluble NH3/m2 media/day)
#	*yyyy-mm-dd*	*RW*	*TK1*	*TK2*	*RW*	*TK1*	*TK2*	*RW*	*TK1*	*TK2*	*RW*	*TK1*	*TK2*	*TK2*	*TK2*	*Tk2*	*R2*
146	03/06/2014	26.8	46.4	24			12.4	10	15	4			37.55		0.81	-40.5727924	0.84375
148	05/06/2014				2.2	1.3	13.3	4.9	6	3.3	167.51		26.37	9.4	0.38	10.43956044	1.27875
149	06/06/2014																
150	07/06/2014	6	16.8				14.3	1.62	7.35	2.5	173.58		25.79	6.8	1.18	-2.03417413	1.386
151	08/06/2014																
152	09/06/2014																
153	10/06/2014	10.2	10.1				17.4	6.3	14.535	22.44		127.97	12.47	5.8	0.59	5.896607431	1.365
154	11/06/2014																
155	12/06/2014	8	4	34			9.3	0.105	0.147	2.244	164.47		39.68	4.9	3.64	4.902867715	1.6185
156	13/06/2014																
157	14/06/2014				1.1	1.5	10.1	6	8.9	4.75				8.3	0.98	9.749034749	1.16025
157	15/06/2014																
157	16/06/2014																
160	17/06/2014				2.4	2.6	8	13	20	5				9.9	2.01	14.65201465	0.897
161	18/06/2014																
162	19/06/2014					2.4	9.3	11	20	6				7.6	0.25	10.25358324	0.936
163	20/06/2014																
164	21/06/2014						10	8	30	4	99.6		9.8		0.31	12.67427123	0.82875
165	22/06/2014																
166	23/06/2014																
167	24/06/2014				1.8	2.8	5.4	8	17	5	>320		>320	3.0	1.93	6.323185012	1.27125
168	25/06/2014																
169	26/06/2014				1.2	2.8	3.9	4	14	4	117.2		6.8	2.8	0.00	10	1.236

DAY #	DATE	Soluble nitrates (mgN/L)			Soluble nitrates (method 10020) (mgN/L)			Soluble nitrites (mgN/L)			Soluble TKN (mgN/L)			NO3-N Produced/ NH4-N Removed (%)	Calculated NH3 fraction (mgN/L)	Ratio NH4 to NO3 formed	SALR (NH3) (g soluble NH3/m2 media/day)
#	*yyyy-mm-dd*	*RW*	*TK1*	*TK2*	*RW*	*TK1*	*TK2*	*RW*	*TK1*	*TK2*	*RW*	*TK1*	*TK2*	*TK2*	*TK2*	*Tk2*	*R2*
170	27/06/2014																
170	28/06/2014																
172	29/06/2014																
173	30/06/2014				1.5	5.7	6.9	1	10	5	119.2		8	1.3	0.00	7.599118943	1.14
174	01/07/2014																
175	02/07/2014				2.5	3.9	6.4	20	39	8				8.1	0.50	20.77922078	0.5805
176	03/07/2014																
177	04/07/2014																
178	05/07/2014				2.2	2.5	3.1	14	25	5	102.38			0.9	0.67	4.454022989	1.08
179	06/07/2014																
180	07/07/2014																
181	08/07/2014				2		10.2	13		4	95.8		12.8	11.0	0.32	13.70967742	1.245
182	09/07/2014																
183	10/07/2014				1		4	1		5	59		31.5	11.2	0.83	11.23595506	0.918
184	11/07/2014																
185	12/07/2014				1.3		11.3	1		5	136.4		45.1	12.0	2.00	11.99040767	2.349
186	13/07/2014																
187	14/07/2014				1.1		7.9	6		5	131.6		43.4	8.3	1.69	8.343558282	1.305
188	15/07/2014																

DAY #	DATE	Soluble nitrates (mgN/L)			Soluble nitrates (method 10020) (mgN/L)			Soluble nitrites (mgN/L)			Soluble TKN (mgN/L)			NO3-N Produced/ NH4-N Removed (%)	Calculated NH3 fraction (mgN/L)	Ratio NH4 to NO3 formed	SALR (NH3) (g soluble NH3/m2 media/day)
#	*yyyy-mm-dd*	*RW*	*TK1*	*TK2*	*RW*	*TK1*	*TK2*	*RW*	*TK1*	*TK2*	*RW*	*TK1*	*TK2*	*TK2*	*TK2*	*Tk2*	*R2*
189	16/07/2014						15.3	1.76		2.34	186		17.6		0.22	11.65270373	2.13
190	17/07/2014				1.2		19.8	7		4	127.02		19.8	17.1	0.12	17.06422018	1.416
194	21/07/2014				1.9		22.3	9		2	123.8		46.93	30.4	1.76	30.35714286	2.142
196	23/07/2014				2.5		24.3	7		2	135		43.84	37.3	1.97	37.26495726	1.605
198	25/07/2014				1.2		27	0.925		2.5	156.66		41.43	25.3	3.44	25.31894014	1.89975
199	26/07/2014				1.6		30.2	0.25		1.4	153.8		30.94	32.6	1.26	32.57403189	1.5555
201	28/07/2014				2.4		32	6.1		1.25	151.17		35.28	29.0	1.50	29.04808636	2.145
															0.00		

DAY #	DATE	SALR (kg N-fed/ m3 reactor volume)	SARR (NH3) (g soluble NH3/m2 media/day)
#	*yyyy-mm-dd*	*R2*	*R2*
0	08/01/2014		#DIV/0!
1	09/01/2014		#DIV/0!
1	09/01/2014		#DIV/0!
1	09/01/2014		#DIV/0!
2	10/01/2014		#DIV/0!
2	10/01/2014		#DIV/0!
2	10/01/2014		#DIV/0!
3	11/01/2014		#DIV/0!
3	11/01/2014		#DIV/0!
4	12/01/2014		#DIV/0!
4	12/01/2014		#DIV/0!
5	13/01/2014		#DIV/0!
5	13/01/2014		#DIV/0!
6	14/01/2014		#DIV/0!
6	14/01/2014		#DIV/0!
7	15/01/2014		#DIV/0!
7	15/01/2014		#DIV/0!
8	16/01/2014		#DIV/0!

DAY #	DATE	SALR (kg N-fed/ m3 reactor volume)	SARR (NH3) (g soluble NH3/m2 media/day)
#	yyyy-mm-dd	R2	R2
9	17/01/2014		#DIV/0!
9	17/01/2014		
10	18/01/2014		
10	18/01/2014		
10	18/01/2014		
10	18/01/2014		
11	19/01/2014		
11	19/01/2014		
12	20/01/2014		
12	20/01/2014		0.6552
12	20/01/2014		
13	21/01/2014		0.46035
13	21/01/2014		
13	21/01/2014		
14	22/01/2014		0.3492
14	22/01/2014		
14	22/01/2014		
15	23/01/2014		

DAY #	DATE	SALR (kg N-fed/ m3 reactor volume)	SARR (NH3) (g soluble NH3/m2 media/day)
#	*yyyy-mm-dd*	*R2*	*R2*
15	23/01/2014		
15	23/01/2014		
16	24/01/2014		
16	24/01/2014		
17	25/01/2014		0.45
17	25/01/2014		0.4725
17	25/01/2014		
17	25/01/2014		0.38475
20	28/01/2014		0.48843
22	30/01/2014		0.346275
23	31/01/2014		
24	01/02/2014		0.34263
27	04/02/2014		0.3048
28	05/02/2014		
29	06/02/2014		0.2238
30	07/02/2014		

DAY #	DATE	SALR (kg N-fed/ m3 reactor volume)	SARR (NH3) (g soluble NH3/m2 media/day)
#	*yyyy-mm-dd*	*R2*	*R2*
31	08/02/2014		0.303
32	09/02/2014		
33	10/02/2014		
34	11/02/2014		
35	12/02/2014		
36	13/02/2014		0.43263
38	15/02/2014		0.42405
41	18/02/2014		0.37818
42	19/02/2014		
44	21/02/2014		0.521235
46	23/02/2014		
47	24/02/2014		
48	25/02/2014		0.2415
49	26/02/2014		
50	27/02/2014		
51	28/02/2014		

DAY #	DATE	SALR (kg N-fed/ m3 reactor volume)	SARR (NH3) (g soluble NH3/m2 media/day)
#	*yyyy-mm-dd*	*R2*	*R2*
53	02/03/2014		0.4011
55	04/03/2014		0.28875
57	06/03/2014		0.3906
58	07/03/2014		
59	08/03/2014		0.47775
62	11/03/2014		0.354
	12/03/2014		
64	13/03/2014		0.324
66	15/03/2014		0.42
68	17/03/2014		0.522
69	18/03/2014		0.381
70	19/03/2014		0.4596
71	20/03/2014		0
73	22/03/2014		0.528
76	25/03/2014		0.45408
78	27/03/2014		
80	29/03/2014		0.32895
81	30/03/2014		
83	01/04/2014		0.3612
85	03/04/2014		0.6063

DAY #	DATE	SALR (kg N-fed/ m3 reactor volume)	SARR (NH3) (g soluble NH3/m2 media/day)
#	*yyyy-mm-dd*	*R2*	*R2*
87	05/04/2014		0.61146
90	08/04/2014		0.5676
92	10/04/2014		0.3999
97	15/04/2014		1.007775
99	17/04/2014		1.002
104	22/04/2014		0.8655
106	24/04/2014		0.76875
108	26/04/2014		0.921525
110	28/04/2014		0.96855
113	01/05/2014		1.101
115	03/05/2014		0.9885
118	06/05/2014		0.8415
120	08/05/2014		0.94875

DAY #	DATE	SALR (kg N-fed/ m3 reactor volume)	SARR (NH3) (g soluble NH3/m2 media/day)
#	*yyyy-mm-dd*	*R2*	*R2*
125	13/05/2014		0.78375
127	15/05/2014		0.74745
129	17/05/2014		0.78375
132	20/05/2014		0.33
134	22/05/2014		0.66075
136	24/05/2014		0.8325
138	26/05/2014		0.9075
141	29/05/2014		
143	31/05/2014		0.8337

DAY #	DATE	SALR (kg N-fed/ m3 reactor volume)	SARR (NH3) (g soluble NH3/m2 media/day)
#	*yyyy-mm-dd*	*R2*	*R2*
146	03/06/2014		0.56565
148	05/06/2014	0.512781955	1.05105
149	06/06/2014		
150	07/06/2014	0.555789474	1.1061
151	08/06/2014		
152	09/06/2014		
153	10/06/2014	0.547368421	1.20705
154	11/06/2014		
155	12/06/2014	0.649022556	1.053975
156	13/06/2014		
157	14/06/2014	0.465263158	1.0101
157	15/06/2014		
157	16/06/2014		
160	17/06/2014	0.359699248	0.53235
161	18/06/2014		
162	19/06/2014	0.375338346	0.884325
163	20/06/2014		
164	21/06/2014	0.332330827	0.769275
165	22/06/2014		
166	23/06/2014		
167	24/06/2014	0.509774436	0.96075
168	25/06/2014		
169	26/06/2014	0.495639098	0.468

DAY #	DATE	SALR (kg N-fed/ m3 reactor volume)	SARR (NH3) (g soluble NH3/m2 media/day)
#	*yyyy-mm-dd*	*R2*	*R2*
170	27/06/2014		
170	28/06/2014		
172	29/06/2014		
173	30/06/2014	0.457142857	1.0896
174	01/07/2014		
175	02/07/2014	0.232781955	0.4158
176	03/07/2014		
177	04/07/2014		
178	05/07/2014	0.433082707	0.9396
179	06/07/2014		
180	07/07/2014		
181	08/07/2014	0.49924812	1.116
182	09/07/2014		
183	10/07/2014	0.368120301	0.4806
184	11/07/2014		
185	12/07/2014	0.941954887	1.68885
186	13/07/2014		
187	14/07/2014	0.523308271	0.916875
188	15/07/2014		

DAY #	DATE	SALR (kg N-fed/ m3 reactor volume)	SARR (NH3) (g soluble NH3/m2 media/day)
#	*yyyy-mm-dd*	*R2*	*R2*
189	16/07/2014		1.9695
190	17/07/2014		1.308
194	21/07/2014		1.2096
196	23/07/2014		0.8775
198	25/07/2014		1.299225
199	26/07/2014		1.11945
201	28/07/2014		1.5285