NUTRIENT AND BACTERIA DYNAMICS OF PACKAGE TREATMENT PLANTS IN COASTAL CARTERET COUNTY, NORTH CAROLINA

By:

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Nutrient and bacteria enrichment problems are well documented in the waterways along North Carolina's coast. Surface and subsurface wastewater inputs have been documented as a source of these pollutants in a variety of coastal settings. While many studies have been conducted on the effects of municipal wastewater treatment plants and septic tank systems on water quality, relatively few have focused on package treatment plants. These facilities are common in certain coastal settings where connection to sanitary sewer collection systems is not available and wastewater flows are greater than what is typically processed by septic systems. Package treatment plants discharge treated wastewater effluent onsite either at the surface or in the subsurface. The potential for the migration of wastewater constituents is high in these settings due to shallow water tables and sandy soils. This study monitored and assessed the effectiveness of seven package treatment plants located on Bogue Banks on the North Carolina coast. Influent and effluent samples were collected monthly for one year (February 2014 – January 2015) and analyzed for nitrogen, phosphorus, fecal indicator bacteria, and other water quality parameters. Annual average concentrations of total nitrogen in effluent ranged from 7.0 – 24.7 mg/l with exports of 12.6 – 47.5 kg/ha/yr. Annual average concentrations of total phosphorus in effluent ranged from 2.2 – 6.4 mg/l with exports of 4.0 – 29.0 kg/ha/yr. Six out of seven package treatment plants exceeded a state permitted maximum daily value for *E. coli* (43 CFU/100 ml) at least for 25 % of the sampling events. This variability could be the result of seasonal changes in temperature, wastewater strength, wastewater quantity, and/or microbial activity. These elevated nutrient exports suggest that additional advanced nutrient treatment should be considered to help reduce exports to the ground/surface waters.

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LIST OF SYMBOLS AND ABBREVIATIONS

ADV – Advanced Media Filtration

BOD – Biological Oxygen Demand

CCDEH – Carteret County Department of Environmental Health

CFU – Colony Forming Units

Cl^- – Chloride

CV – Coefficient of Variation

DOC – Dissolved Organic Carbon

DON – Dissolved Organic Nitrogen

EA – Extended Aeration

EC – Escherichia Coli

EN – Enterococcus

EPA – Environmental Protection Agency

GPD – Gallons per Day

LPD – Liters per Day

MBR – Membrane Bioreactor

MGD – Million Gallons per Day

MPN – Most Probable Number

N – Nitrogen

NCDEQ – North Carolina Department of Environmental Quality

NCDWR – North Carolina Division of Water Resources

NH_4 – Ammonium

NO_2 – Nitrite

NO_3 – Nitrate

NPDES – National Pollutant Discharge Elimination System

PN – Particulate Nitrogen

PO_4 – Phosphate

PP – Particulate Phosphorus

Q_{MAX} – Maximum Recorded Average Monthly Flow (GPD)

Q_{MONTH} – Average Monthly Flow Recorded (GPD)

SBR – Sequence Batch Reactor

SDWA – Safe Drinking Water Act

TC – Total Coliform

TDN – Total Dissolved Nitrogen

TDP – Total Dissolved Phosphorus

TKN – Total Kjeldahl Nitrogen

TN – Total Nitrogen

TOC – Total Organic Carbon

TP – Total Phosphorus

TSS – Total Suspended Solids

UV – Ultra Violet

CHAPTER 1: INTRODUCTION

Nutrient and pathogen enrichment problems have been well documented in many of the waterways surrounding North Carolina's coast (e.g., Lebo et al., 2012; Nearhoof and Cahoon, 2000; Paerl et al., 2004). Nonpoint source nutrient and pathogen exports are believed to be a significant factor in the impairment of water uses such as drinking water supplies, recreation, fisheries, and wildlife (Environmental Protection Agency (EPA), 2015). Excess nutrients can cause harmful algal blooms that may lead to eutrophication events (Augspurger, 1989). High bacteria concentrations are often associated with enteric viruses, and can cause the closure of shellfisheries and swimming accesses to protect human health (Nearhoof and Cahoon, 2000). Shallow water tables and sandy soils are common in coastal North Carolina, and are not conducive to nutrient and bacteria attenuation. Of particular concern is the multitude of onsite domestic wastewater treatment systems that are in close proximity to surface water bodies in many coastal areas. According to Augspurger (1989), "… the ultimate disposal of domestic wastewater has unquestionably contributed to the pollution of ground and surface waters in coastal North Carolina."

It is important to understand how wastewater treatment systems function, to ensure that they efficiently process nutrients and disinfect bacteria to minimize their impact on the environment. There are three common types of wastewater treatment systems: 1) municipal wastewater treatment plants; 2) onsite wastewater treatment systems; and 3) package treatment plants. While many studies have focused on the impacts of municipal wastewater treatment plants and onsite wastewater treatment systems (e.g., Gallego et al., 2008; Humphrey et al., 2014; Iverson et al., 2015; Oakley et al., 2010; O'Driscoll et al., 2014; Withers et al., 2014), relatively few have been conducted on package treatment plants (Guo et al., 1981; Hanna et al., 1995; Hellstrom and Jonsson, 2006). This thesis aimed to study package treatment plants in a coastal environment and determine if they were effective at reducing nutrient and bacteria concentrations to permitted levels.

1.1 Significance

Few package treatment plant studies have been conducted in coastal settings. The coastal environment can be a challenging location for wastewater treatment due to shallow water tables, sandy soils, close proximity to surface waters, and seasonal population fluctuations (Augspurger, 1989). Shallow water tables limit distances for pollutant attenuation, and wastewater pollutants can be mobilized in sandy soils. This especially becomes a problem when surface waters are within close proximity to the source of these pollutants. These treatment systems must also be able to account for the seasonal change in population. This causes a dramatic increase in the quantity of wastewater generated during the summer (peak tourist) season, and it is important that these package treatment plants can handle this increased flow and variation in wastewater inputs. They also need to function effectively during the winter (off-season) when wastewater flows are much lower.

This thesis will document the influent and effluent quality of seven coastal package treatment plants utilizing three treatment technologies (extended aeration (EA), sequence batch reactor (SBR), and advanced media filtration (ADV)). Treatment technologies and package treatment plant treatment efficiency will be evaluated with respect to nutrient and bacteria removal. Influent and effluent samples will also be analyzed for seasonal variation to determine if seasonal change influences nutrient and bacteria content in the wastewater. Ultimately, this thesis will evaluate the package treatment plants' potential influence on groundwater quality adjacent to coastal surface waters, and if there are potential risks to surface water quality in this barrier island setting.

1.2 Objectives

The goal of this thesis is to evaluate if package treatment plant performance and pollutant exports from package treatment plants have the potential to measurably affect local water quality. There are three main objectives of this study which when completed will ultimately help to address the goal stated above:

1. Analyze monthly influent and effluent water quality samples from seven package treatment plants for one year (February, 2014 – January, 2015).
2. Estimate nutrient loading exports from each system and compare to other exports from various land uses found in literature.
3. Estimate the migration potential of total nitrogen to local surface waters.

Two hypotheses were developed based on an extensive literature review on package treatment plant technologies: 1) Package treatment plant treatment efficiency, effluent quality, and nutrient loading will vary based on treatment technology and seasonality. 2) Package treatment plant nutrient exports on a unit area basis can be comparable to agricultural nutrient exports.

It is important to quantify treatment efficiency and contaminant exports from package treatment plants to assess the risk for environmental contamination. Non-point sources of nutrients and pathogens from onsite wastewater treatment systems and package treatment plants are largely unaccounted for in managing nutrients in coastal areas. This thesis will contribute to the understanding of package treatment plant treatment efficiency and quantify the water quality of effluent discharges to the subsurface to evaluate the potential for groundwater and surface water contamination associated with the various wastewater treatment and disposal approaches in sensitive coastal settings.

1.3 Background

1.3.1 Wastewater Treatment Technologies

Three common forms of wastewater treatment are municipal wastewater treatment plants, on-site wastewater treatment systems (commonly known as septic tank systems), and package treatment plants. The type of wastewater treatment implemented in different areas is based on factors such as the population needing treatment, population density, soils, and available land.

Municipal wastewater treatment plants are often used to treat wastewater for entire cities. The wastewater from these residences and commercial developments flows through a sanitary sewer collection system where it is directed via underground pipes to a wastewater treatment plant (EPA Municipal Wastewater Treatment Systems, 2004). Municipal wastewater treatment plants are capable of treating up to over one billion gallons (3.8×10^9 liters) of wastewater per day (Anderson and Meng, 2011). In the United States, these treatment plants are heavily monitored and must adhere to strict effluent quality standards for nutrients and pathogens that are determined safe by the Clean Water Act (EPA National Pollutant Discharge Elimination System, 2016).

Onsite Wastewater Treatment Systems are used to treat wastewater onsite for individual residences or businesses and are often located in rural settings (EPA Septic Systems Overview, 2015). The communities where these systems are implemented may not have the funding, means, or available land to install a municipal treatment plant. Most onsite wastewater treatment systems are much smaller than municipal wastewater treatment plants and package treatment plants, and are designed to handle far less wastewater (240 – 3,000 gallons per day (GPD) or 900 – 11,350 liters per day (LPD): North Carolina Rule 15A NCAC 18A .1949, Sewage Flow Rates for Design Units, 1999). The most common onsite wastewater treatment system is the septic tank system (Withers, 2014). These systems function by piping wastewater into a tank where the solids settle to the bottom and the liquid portion (effluent) exits the tank and flows to the distribution box. Effluent then flows to a subsurface drainage field where the wastewater will be exposed to native microbial organisms in the soil to receive further treatment. In the vadose zone aerobic bacteria will convert ammonium to nitrate via nitrification. When the nitrogen is mostly in the nitrate form, denitrification can occur when anaerobic bacteria convert the nitrate to nitrogen gas. Phosphorus is removed from the system by soil attenuation and sludge removal (Withers, 2014). The solids must be periodically removed from the tank in order to prevent system back-up or failure (Withers, 2014). In North Carolina, the effluent from these systems is not typically monitored, and there is no requirement to produce an effluent of a desired standard (North Carolina Rule 15A NCAC 18A Section 1900).

Package treatment plants are pre-assembled wastewater treatment facilities that are designed to treat onsite wastewater for small communities, commercial developments, and individual properties (EPA, 2000). These treatment systems are often found in areas where land is limited and no municipal system is available. Coastal areas often have a large seasonal population flux and can be densely populated during the summer tourist season, which may necessitate a package treatment plant if connection to municipal wastewater treatment plant is not available. In coastal settings, package treatment plants must be designed to effectively treat wastewater during both the peak season, when flows are high, and the offseason when flows are low and inconsistent. These systems are capable of treating flows ranging from 2,000 GPD to 500,000 GPD (7,500 – 1.9×10^6 LPD), but most commonly designed to treat flows ranging from 10,000 GPD to 250,000 GPD (3.8×10^4 – 9.5×10^5 LPD) (EPA, 2000). Package treatment plant effluent is discharged onsite either on the surface or through a subsurface drainfield, depending on the permit requirement (in North Carolina, the state regulates surface discharge systems while counties regulate subsurface discharge systems). Package treatment plants are monitored for effluent quality and must adhere to their permitted standards. In North Carolina, state permitted package treatment plants are usually held to more strict effluent quality standards than county permitted package treatment plants.

1.3.2 Treatment Processes

The conventional wastewater treatment process is described in three general steps: primary, secondary, and tertiary treatment. These steps aim to remove solids, organic matter, nutrients, and bacteria from wastewater. Primary treatment is responsible for removing solid constituents from wastewater, such as floatables, grit, grease, suspended solids, and some organic matter (Tchobanoglous et al., 2002). This is usually accomplished by filtering, screening, and sedimentation processes.

Secondary treatment relies on biological organisms to remove organic matter, suspended solids, and nutrients from the wastewater. This is commonly accomplished using some variation of the activated sludge process (Gerardi, 2002). This is a biological process that uses microorganisms to remove organic matter and nitrogen from wastewater. Activated sludge requires both oxygenated and anoxic environments. First, the influent which is rich in organic matter and organic nitrogen is exposed to an oxygenated environment, often in an aeration tank.

Dissolved oxygen and bacteria in activated sludge are then pumped into the mixture. Aerobic bacteria consume the organic matter which causes the bacteria to multiply and releases organic nitrogen. Mineralization (ammonification) converts the organic nitrogen into ammonium ions. The ammonium ions are then oxidized to nitrite and nitrate by aerobic bacteria in the process of nitrification. Particulate organic matter will fall to the bottom of the tank to form a sludge layer. This sludge can be reintroduced to the aeration chamber to receive further treatment and provide more bacteria and organic matter to the mixture in the form of "activated sludge". Eventually this sludge can be removed for solid waste disposal. The final step in the nitrogen removal process occurs in the secondary clarifier or anoxic tank. Here, anaerobic bacteria consume the nitrate and release nitrogen gas via denitrification. The nitrogen gas is free to move on to the atmosphere, and thus nitrogen removal has been achieved.

Phosphorus can also be removed from wastewater during the secondary treatment process via activated sludge, chemical precipitation, or enhanced biological phosphorus removal (Minnesota Pollution Control Agency, 2006). During the activated sludge process, phosphorus can flocculate and eventually be removed during the solids removal phase. Chemical precipitation involves adding metallic salts to the mixed liquor to react with soluble phosphate which will form a solid precipitate which can then be removed (Minnesota Pollution Control Agency, 2006). Enhanced biological phosphorus removal relies on microorganisms (phosphorus accumulating organisms) in the mixed liquor to store the phosphorus intracellularly (Minnesota Pollution Control Agency, 2006). These organisms take up phosphate and are eventually removed during solids removal, or are reintroduced to the system as return activated sludge.

Typically following secondary treatment there is a disinfection process (Tchobanoglous et al., 2002). This is commonly accomplished by using either chlorine, ultra violet (UV) light, or ozone to kill (or inactivate) the remaining bacteria and other pathogens in wastewater. For chlorine and ozone, disinfection relies on contact time between the pathogens and the disinfectant of sufficient concentration to inactivate the microorganisms. For UV disinfection, high energy light inactivates the pathogens. The effectiveness of this process can be compromised if there are abundant suspended solids to shadow the pathogen from the UV light.

Tertiary treatment is for advanced nutrient and bacterial removal (Tchobanoglous et al., 2002). During this stage, advanced membrane filtering can be used to remove the residual suspended solids and nutrients from the solution.

The degree to which the wastewater is treated determines which of these steps are implemented. Municipal wastewater treatment plants can treat wastewater to drinkable standards, and therefore go all the way through the tertiary treatment process to get the best quality effluent possible. Onsite wastewater treatment systems only undergo primary treatment and their effluent will not be of drinking water quality. In these systems, sedimentation separates the liquid waste from the solid waste. The liquid waste then flows into a subsurface drainfield where it will receive further treatment in the soils via potential denitrification. Package treatment plants can be designed to incorporate primary, secondary, and tertiary treatment processes depending on the desired quality of effluent.

1.3.3 Package Treatment Plant Technologies

The package treatment plants involved in this study used a variety of treatment technologies such as extended aeration, sequence batch reactors, and advanced media filtration treatment systems. Treatment processes in extended aeration plants (Figure 1) rely on an aeration chamber to allow microbes to remove biodegradable waste under aerobic conditions

(EPA, 2000). First, the influent is screened and ground to remove solid waste that may interfere with the treatment process. The fluid then enters an aeration chamber where it is held for at least eighteen hours where oxygen is pumped into the mixture (EPA, 2000). The oxygen promotes the aerobic conditions necessary for the microorganisms to metabolize the organic matter, and it provides a means of mixing to keep the organisms in contact with organic matter. This is also where the ammonification and nitrification occur. The wastewater then moves to an anoxic tank where denitrification occurs to remove nitrogen from the system. Next, the solution flows to a clarifying tank where the solids and particulates can settle to form a layer of sludge on the bottom. A portion of this sludge layer can be reintroduced into the aeration chamber for further biological treatment. This is known as return activated sludge (EPA, 2000). The liquid portion of this mixture (effluent) is directed to the disinfection system for either chlorine or UV disinfection. Once disinfected, the treated effluent is then dispersed onsite either directly on the surface or just below the surface.

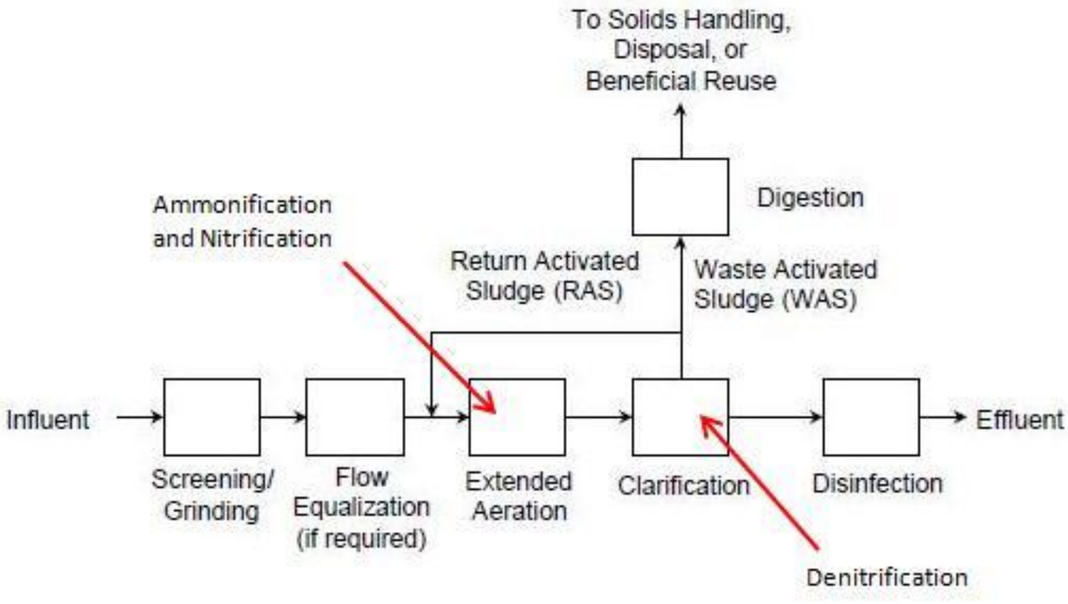

Figure 1: Processes involved in extended aeration plants (modified from EPA Fact Sheet, 2000)

Processes in sequence batch reactors (Figure 2) allow for the treatment of wastewater one batch at a time. Unlike the processes in the extended aeration plants, these systems do not require a separate tank for aeration and sedimentation (EPA, 2000). Instead, all biological treatment processes occur in a single tank. Typically sequence batch reactors function in five phases: fill, react, settle, decant, and idle. The length of each phase is controlled by a programmable logic controller which automatically runs each phase and can be controlled from a remote location. During the fill phase, screened wastewater enters the reactor where it mixes with settled sludge from the previous cycle. The react phase is next, where the solution is aerated to provide conditions necessary for the biological degradation of organic matter and ammonification and nitrification. The settling phase requires for the aeration and mixing to cease while the suspended solids and flocculates are allowed to sink and settle on the bottom of the tank. This also works as an anoxic tank, and allows for denitrification to occur. The treated wastewater is then discharged from the tank during the decant phase. From here, the wastewater can move on to disinfection and/or dispersal. In the final phase the system remains idle so that a portion of the sludge can be removed. This sludge is either discarded or recycled, where the sludge that remains in the system will receive further treatment.

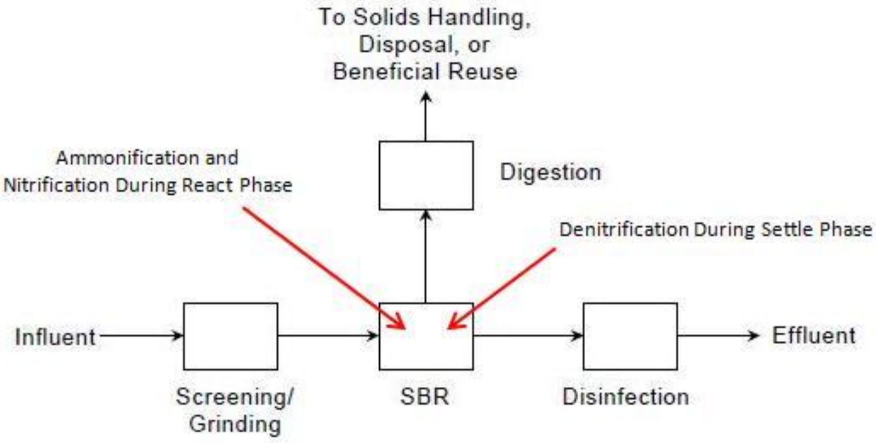

Figure 2: Processes involved in sequence batch reactor plants (modified from EPA Fact Sheet, 2000)

Processes in the advanced media filtration (Figure 3) treatment systems used in this study incorporate an engineered textile media filtration design (Orenco, 2015). The media filtration treatment process begins in a processing tank. Here, the influent separates into three layers: floatable solids, liquid wastewater, and settable solids. A pump extracts the liquid portion of this mixture and sends it to the advanced textile filter. This is a recirculating system, which circulates the wastewater through the filter multiple times. The textile medium in the filter has a large surface area, and allows for a biological film to develop on the filter surface. This film contains microorganisms which break down the organic matter under aerobic conditions so that ammonification and nitrification can occur. The wastewater then moves to an anoxic tank where denitrification can occur. Lastly, the wastewater moves on to disinfection and dispersal.

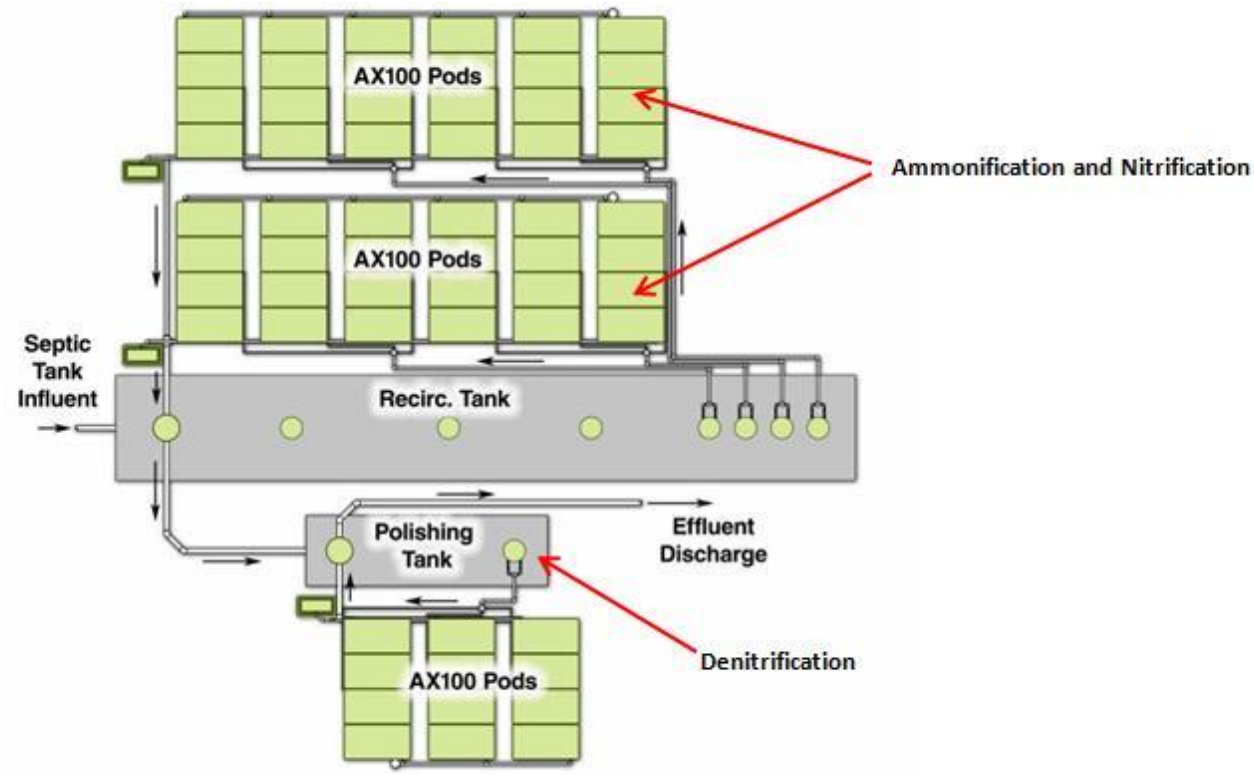

Figure 3: Processes involved in advanced media filtration plants (modified from Orenco Website – Ammonia Reduction, 2015)

1.3.4 Previous Studies

To date, there have been few published studies that analyze the performance capabilities of package treatment plants. Guo et al. (1981) showed that the effluent from 16 out of 20 extended aeration package treatment plants in Canada failed to meet water quality standards. In that study, poor effluent quality was attributed to problems associated with the facilities treatment processes, equipment failures, and operator errors. Hanna et al. (1995) determined that extended aeration package treatment plants in southwest Virginia produced “poor and inconsistent” effluent samples, and thus these facilities failed to properly treat domestic waste according to Virginia effluent quality standards (< 30 mg/l Biological Oxygen Demand (BOD), < 30 mg/l Total Suspended Solids (TSS), and < 10 mg/l Total Kjeldahl Nitrogen (TKN)). More specifically, the package treatment plants in that study failed to meet standard requirements for BOD (average = 69.4 mg/l), TSS (average = 99 mg/l), and TKN (average = 18.6 mg/l) 60-80 % of the time. Disinfection was also a problem for these systems with 16 out of 45 samples exceeding the state permit standard for fecal coliform of 200 Colony Forming Unit (CFU) per 100 ml. Oakley et al. (2010) conducted a study monitoring 20 decentralized wastewater treatment systems (many of which were package treatment plants) in Florida, Oregon, and New Zealand and compared them with the nitrogen concentration in effluent from 15 centralized wastewater treatment systems in the US and Canada. This study found that only one of the 20 decentralized plants could produce an effluent of < 10 mg/l Total Nitrogen (TN) with a 99 % probability (remaining 19 plants had less than 50 % probability to meet effluent standards). This highlights the variability and inconsistency often observed with package treatment plant performance.

Hellstrom and Jonsson (2006) monitored seven sequence batch reactors in Sweden for 40 weeks and reported that systems produced a desirable quality effluent capable of removing greater than 90 % phosphorous and organic matter, and achieved greater than 50 % nitrogen removal efficiency. Hirani et al. (2013) sampled 38 membrane bioreactor package treatment plants throughout the United States to characterize the effluent water quality of the systems. This study demonstrated that 90% of the systems produced a desirable effluent water quality that contained low concentrations of ammonia-nitrogen (<0.4 mg/l-N), total organic carbon (< 8.1 mg/l TOC), and bacteria (< 100 CFU/100 ml). Engin and Demir (2006) conducted a cost analysis study comparing the practicality of municipal wastewater treatment plants, cluster treatment systems, and package treatment plants in small communities in Turkey where municipal treatment is not necessarily practical or available. This study concluded that based on economic and infrastructure considerations for their villages package treatment plants were the most economically feasible option for long term wastewater management for up to 25 years, while cluster systems were the best option for short term wastewater management (< 10 years). The results of these studies are indicative that package treatment plant performance varies across treatment technology and many factors can contribute to this variability.

The following studies have highlighted the potential for wastewater contaminant migration in the subsurface. Although most of these studies focused on the subsurface transport of effluent from municipal wastewater treatment plants and onsite wastewater treatment systems, package treatment plant contaminant migration may behave similarly in the subsurface. Mottier et al. (2000) found that high effluent loading to infiltration basins from a municipal wastewater treatment plant led to the migration of bacteria and nitrates through unconsolidated dune-sands to shallow aquifers in coastal Spain. The report concluded that reducing the loading significantly improved the oxidation potential of the subsurface soils and improved nitrogen attenuation. Humphrey et al. (2011) conducted a study monitoring the *E. coli* concentration in groundwater adjacent to onsite wastewater treatment systems with varying soil content (sandy to clay loam) in Carteret County, North Carolina. This study concluded that coastal areas with sandy soils and seasonally high water tables are most at risk for *E. coli* contamination in shallow groundwater. Humphrey et al. (2010) conducted a study in coastal Carteret County, North Carolina in which the groundwater adjacent to 16 onsite wastewater treatment systems was monitored for dissolved inorganic nitrogen (DIN) in varying soil conditions (sandy to clay loam). This study concluded that sandy soils were more prone to nitrogen loading than finer (more clay rich) soils, and vertical separation distance from the onsite wastewater treatment system to the water table influences nitrogen speciation. Humphrey et al. (2013) has shown that total nitrogen levels in the groundwater below onsite wastewater treatment systems in Beaufort County, North Carolina, were elevated (12.2 – 34.3 mg/l) compared to background levels (< 1.0 mg/l). The report also showed that elevated levels of total nitrogen could be detected up to 15 m away from the septic drainage field towards a nearby estuary. This highlights the potential for subsurface migration of nitrogen from a wastewater source. O'Driscoll et al. (2014) traced an onsite wastewater treatment system wastewater plume in the surficial aquifer of coastal Beaufort County, North Carolina, using electrical resistivity mapping. This study found total dissolved nitrogen (TDN) to be mobile in the subsurface, and detected elevated concentrations greater than 15 meters away from the source. A Water Environment Research Foundation report (2009) determined that nitrogen attenuation does not vary significantly with depth, and elevated levels of nitrogen can be detected up to 6 meters below the surface in sandy soils. Much of the soils in coastal North

Carolina are sandy and water tables in the region are often shallow, therefore the potential for both lateral and vertical nutrient migration is high.

Humphrey et al. (2014) have shown that phosphate concentrations below a Beaufort County, North Carolina onsite wastewater treatment system drainage field were not significantly different than the actual septic tank influent (3.05 mg/l and 2.97 mg/l respectively). This is likely due to sandy soils in the region having limited potential for phosphate attenuation. Also, elevated phosphate concentrations (> 0.14 mg/l) were detected up to 30 meters from the treatment system. This indicates potential for phosphate to migrate in the groundwater system. The ability of these wastewater constituents to travel laterally and vertically is a threat to any surface waters down-gradient from wastewater treatment systems. Nearhoof and Cahoon (2000) determined that the abnormally high levels of fecal coliform observed in the coastal waters surrounding South Brunswick County, North Carolina, were most likely from nearby malfunctioning package treatment plants along with failing septic tank systems. Reported onsite wastewater treatment system overflows, along with a “blowout” in a package treatment plant drainfield, were reported near many of the sample sites.

1.4 Study Area

This current study was conducted on the Bogue Banks of Carteret County, North Carolina (Figure 4). Bogue Banks is a barrier island that is aligned east-west and is bounded by the Atlantic Ocean to the south, Bogue Sound to the north, Beaufort Inlet to the East, and Bogue Inlet to the west. This island is approximately 40 km long and has an average width of 0.62 km (Szynal, 2014). Elevation on the island ranges from sea level to 19 m above mean sea level (Szynal, 2014). Bogue Banks is composed of several small townships: Atlantic Beach, Emerald

Isle, Indian Beach, Pine Knoll Shores, and Salter Path. The combined year-round population of these towns is less than 7,000 (Town of Atlantic Beach Core Land Use Plan, 2006). The island and its beaches are a popular tourist destination, and during the peak summer season, the population can grow to 50,000 (Town of Atlantic Beach Core Land Use Plan, 2006). The wastewater treatment systems on the island must be designed to account for this increased wastewater flow, while still being able to function at a reliable capacity in the offseason with minimal flows.

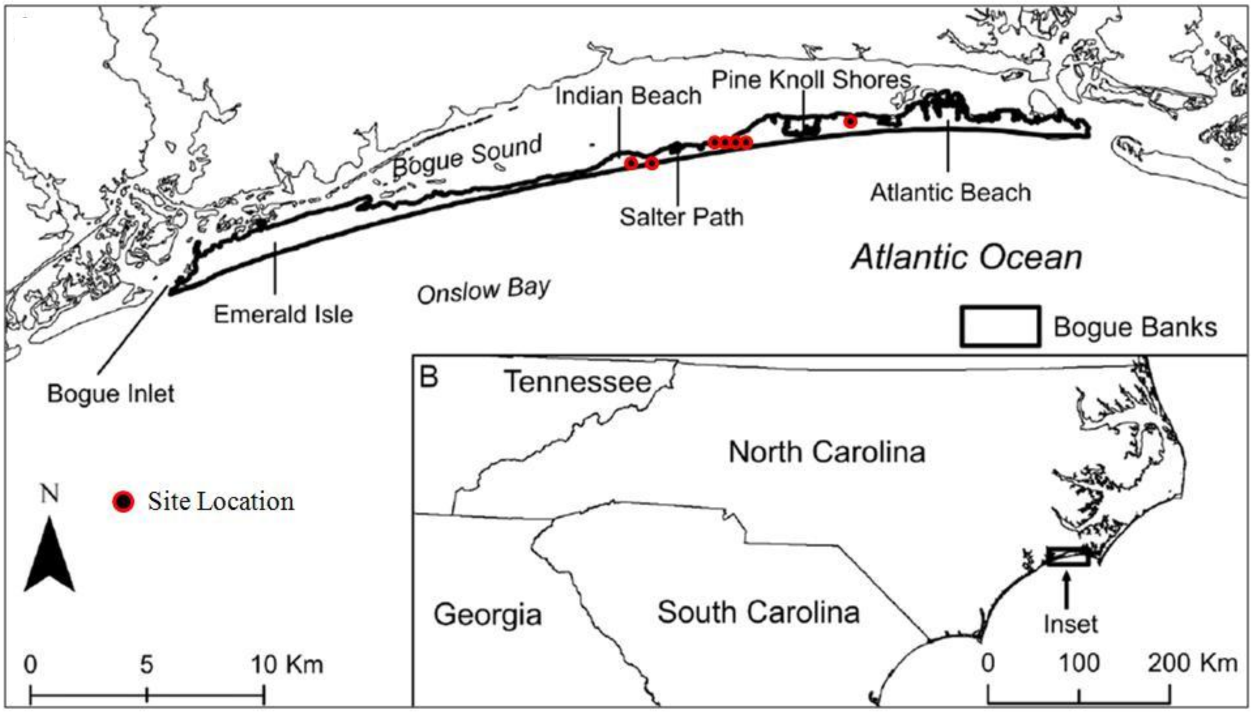

Figure 4: Map of Bogue Banks, North Carolina showing locations of package treatment plants included in this study (Modified from Szynal, 2014)

1.5 Hydrogeology

The hydrogeologic framework of eastern North Carolina consists of approximately ten aquifers separated by confining layers of non-permeable constituents (Winner & Coble, 1996). These aquifers range in age from Holocene to Cretaceous (Winner and Coble, 1996). This study, however, will be solely concerned with the surficial aquifer as it is most connected to the adjacent surface waters (estuary, wetlands, canals, and ocean) at risk for contamination. The surficial aquifer is an unconfined aquifer that underlies most of the North Carolina Coastal Plain, and is Pleistocene to Holocene in age (Winner and Coble, 1996). This aquifer is composed of fine sand, silt, clay, shell and shell fragments, soil, residuum, and peat beds (Giese et al, 1997). Coarse grained sediments can be found scattered throughout the deposit as relict beach ridges and alluvium (Giese et al, 1997). On Bogue Banks, the surficial aquifer ranges in thickness from 12 to 49 m (North Carolina Department of Environmental Quality (NCDEQ)-Division of Water Resources (DWR) 2016). The NCDWR shows multiple wells on Bogue Banks under their Hydrogeologic Framework database. The Bogue Banks Water Corporation has two cores within the approximate study area. The well on the western extent of the study area, Well Number 3a (NCDEQ, Hydrogeological Framework Database, 2010), indicates a surficial aquifer thickness of approximately 49 meters. The well near the central study area, Well Number 1 (NCDEQ, Hydrogeological Framework Database, 2010), shows a surficial aquifer thickness of approximately 12 meters. The City of Atlantic Beach has a well on the eastern extent of the study area (Well Number 2a) (NCDEQ, Hydrogeological Framework Database, 2010) that indicates a surficial aquifer thickness of approximately 12 meters. The surficial aquifer receives water from direct recharge during precipitation, and is a source of water to many of the underlying confined aquifers (Giese et al, 1997). On Bogue Banks, it is likely that the groundwater of this aquifer also discharges to nearby canals, ponds, estuaries, and the ocean as there are no streams near the study area (Sisco, 2013).

1.6 Soils

The soils in the study area were identified using the United States Department of Agriculture – Natural Resources Conservation Service's Web Soils Survey (USDA, 2013). This interactive map allows the area of interest to be defined and then provides a map of the soils found in the area. It also gives the approximate percentage of each soil unit that is found in the defined area. The soil units that were identified were Carteret Sand (CH), Carteret Sand – Low (CL), Corolla Fine Sand (Co), Corolla – Urban Land Complex (Cu), Duckston Fine Sand (DU), Fripp Fine Sand (Fr), Newhan – Corolla Complex (Nc), Newhan – Urban Land Complex (Ne), and the Newhan Fine Sand (Nh).

Soil unit properties were obtained from the United States Department of Agriculture's Soil Survey of Carteret County, North Carolina (1987). Soils in the study area ranged from very poorly draining marsh soil to excessively drained dune sands. The Carteret Sands (Ch and Cl) and the Duckston Fine Sand (Du) are poorly drained soils that encompass the low lying areas of the map such as the coastline, along marshes, and in the dune troughs. The Corolla Fine Sand (Co), Newhan Fine Sands (Nh, Nc, and Ne), and the Fripp Fine Sand (Fr) are well drained to excessively well drained sands that encompass the areas of higher elevation on the island such as the dunes and dune ridges.

One aspect that all of these soil units have in common is that they are all rated severe for use of sanitary facilities (Soil Survey of Carteret County, North Carolina). The "severe" rating is the worst possible rating for a soil to have for sanitary facility use. A severe rating implies that soil properties are unfavorable for septic effluent drainage and absorption, and may require increased construction costs or specialized design to incorporate the sanitary facility. Soil properties that would receive this rating include excessively slow or fast drainage, susceptibility to surfacing/flooding and close proximity to the water table. On this island, excessively drained soils that are often less than a meter from the water table are of particular concern. Soil units such as the Fripp and Newhan fine sands have infiltration capacities that are rated from high to very high with values ranging from 15 to 100 cm/ hr (Web Soils Survey, Carteret County, NC). Since package treatment plants discharge their effluent onsite and into the soil this could potentially be a problem. With an already established poor environment for septic effluent absorption, the chance for package treatment plant pollutants to affect water resources is increased in this area.

1.7 Site Selection

Seven package treatment plants on the Bogue Banks of Carteret County, North Carolina, were included in this study. All facilities treated wastewater for condominium complexes, although EA-1 also included a hotel. These facilities were located in the towns of Atlantic Beach, Pine Knoll Shores, and Salter Path. The sites were selected based on a willingness to participate, and to include a range of treatment technologies and sizes. These plants utilize three different wastewater treatment technologies: extended aeration, sequence batch reactor, and advanced media filtration. Each site is referred to based on the treatment technology implemented (Table 1). Chlorine and UV light were the most common disinfection methods used at these sites, however, one sight, EA-2, utilized a membrane bioreactor (MBR) to remove pathogens. Three of the sites were permitted by the state (North Carolina Division of Water Quality), while the other four sites were permitted by the county (Carteret County Department of Environmental Health). There are differences in certain aspects of the wastewater treatment permit requirements depending on whether the facility is state or county permitted (Table 1).

State permits are required for package treatment plants to discharge their treated effluent on the surface while package treatment plants that discharge their effluent in the subsurface can obtain permits through the county. State permitted systems also had stricter effluent quality standards for nitrogen (10 mg/l TN) and fecal coliform (43 CFU/ 100 ml) than the county permitted systems (20 mg/l TN and 1,000 CFU/100 ml respectively).

Table 1: Package treatment plant information for each sampling site

Site	Treatment Technology	Permit Agency	Discharge	Disinfection Method	Area (ha)	Permitted Flow Rate (GPD)	Effluent TN Limit (mg/l)	Effluent Fecal Coliform Limit (CFU/100 ml)
EA-1	Extended Aeration	State	Surface	Chlorine	5.24	101,460	10	43
EA-2	Extended Aeration	County	Subsurface	MBR	6.92	101,000	20	1,000
EA-3	Extended Aeration	State	Surface	UV	6.41	65,000	10	25
ADV-1	Advanced Media Filtration	County	Subsurface	UV	1.67	12,000	20	1,000
ADV-2	Advanced Media Filtration	County	Subsurface	UV	2.20	17,340	20	1,000
SBR-1	Sequence Batch Reactor	County	Subsurface	Chlorine	0.89	6,000	20	1,000
SBR-2	Sequence Batch Reactor	State	Surface	Chlorine	2.93	30,500	4 (NH4)	43

CHAPTER 2: METHODS

2.1 Sample Collection

Monthly samples of package treatment plant influent and effluent were collected from each site for one year from February 2014 to January 2015. Samples were typically collected between 8:00 AM and 2:00 PM on the third Monday of each month. The package treatment plant operators were usually present during collection and would grant access to the facilities. The only package treatment plant operator absent during sample collection was the operator for EA-1 (conflicting schedule). A new pair of latex gloves was worn while sampling at each location, and sampling containers were sterilized between collections.

Influent samples were gathered by lowering a sterile bucket into the primary clarification tank, and allowing the container to sink below the surface and fill with a representative sample. The container was then pulled to the surface where the sample was poured into two 250 ml bottles for chemical analyses, and one 100 ml bottle for bacterial analyses. After pouring the sample, the remaining influent in the container was measured for pH, temperature, and specific conductivity with an Oakton PC-10 Waterproof Handheld pH/Conductivity Meter. The meter was calibrated the evening before the sample collection.

Effluent samples were gathered by filling a container directly from the effluent tank or tank-access valve. The effluent was allowed to flow for a brief period in order to flush the lines before the sample was collected. The effluent samples were poured in the same manner as the influent samples and measured using the same instrument. The Oakton PC-10 Waterproof Handheld pH/Conductivity Meter was rinsed with deionized water between measurements. The only difference in sample collection for the effluent was that two 100 ml bacteria samples were collected instead of one. This was because the influent bacteria samples required dilution for analyses, and a single sample was enough, but the lower bacteria counts in the effluent required two full samples.

2.2 Sample Storage

Influent and effluent samples were placed in separate zip-lock bags and stored in a cooler filled with ice immediately after collection. Samples remained on ice until they were analyzed at the East Carolina University Environmental Health Laboratory or Environmental Research Laboratory. Half of these influent and effluent samples were filtered and frozen for particulate nutrient analysis within 24 hours of collection. The particulate nutrient analysis was performed bi-monthly. The remaining samples were left unfiltered and refrigerated until analyses for dissolved nutrients. This analysis was conducted within 72 hours of sample collection.

2.3 Sample Analysis

All analyses were conducted according to standard procedures either in the East Carolina University Environmental Research Laboratory or in the East Carolina University Environmental Health Laboratory. All samples were analyzed for the following water quality parameters: indicator bacteria, nitrogen, phosphorus, dissolved organic carbon, and chloride.

2.3.1 Indicator Bacteria

Total coliform (TC) and *Escherichia coli* (EC) were measured using the IDEXX Colilert Substrate with Quanti-Tray/2000 method (Std. Methods: 9223B). Influent TC and EC samples were diluted to a 1/10,000 concentration. *Enterococcus* (EN) was measured using the IDEXX Enterolert Substrate with Quanti-Tray/2000 method (Std. Methods: ASTM D6503-99). Influent

EN samples were diluted to a 1/1,000 concentration. These methods determine the most probable number (MPN) of bacterial colonies per 100 ml of solution. The analyses involve mixing the samples with the Colilert/Enterolert growth substrate and incubating the samples at a controlled temperature for at least 24 hours. The lower limit of detection for these methods is < 1 MPN/100 ml and the upper limit of detection is 2,419.6 MPN/100 ml.

2.3.2 Nitrogen Constituents

Ammonium (NH_4) and nitrate + nitrite (NO_3+NO_2) were measured from the filtered samples and analyzed with an Automated SmartChem (SmartChem 200 Method 375-100E-1; Solorzano, 1969; Standard Methods 4500-NH3-H). Total dissolved nitrogen (TDN) was measured from the filtered samples and analyzed with a Shimadzu TOC-TN Analyzer (Total Organic Carbon Analyzer User's Manual, 2010). Particulate nitrogen (PN) was measured from the filters collected from the filtered samples by performing a manual digestion process followed by placing the digested sample in the Automated SmartChem (SmartChem 200 Method 390-200E; Standard Methods 4500-N-ORG Nitrogen). Dissolved organic nitrogen (DON) was calculated by subtracting NH_4 and NO_3+NO_2 from TDN. Total nitrogen (TN) was calculated by adding PN and TDN.

2.3.3 Phosphorus Constituents

Phosphate (PO_4) was measured from the filtered samples and analyzed with an Automated SmartChem (EPA, 1993; SmartChem 200 Method 410-3651; Standard Methods for the Examination of Water and Wastewater. 4500). Particulate phosphorus (PP) was measured from the unfiltered samples and analyzed with an Automated SmartChem (EPA, 1993; SmartChem 200 Method 410-3651; Standard Methods for the Examination of Water and

Wastewater. 4500). Total phosphorus (TP) was measured from the unfiltered samples using the manual persulfate method (Ameel, 1993; D'Elia, 1977; Ebina, 1983; Standard Methods for the Examination of Water and Wastewater, 19th edition. 1995. Method 4500). Total dissolved phosphorus (TDP) was calculated by subtracting PP from TP. Dissolved organic phosphorus was calculated by subtracting PO_4 from TDP.

2.3.4 Other Water Quality Parameters

Dissolved organic carbon (DOC) was measured from the filtered samples and analyzed with a Shimadzu TOC-TN Analyzer (Total Organic Carbon Analyzer User's Manual, 2010). Chloride (Cl-) was measured from the filtered samples and analyzed with an Automated SmartChem (SmartChem 200 Method 231N-0406C; Standard Methods for the Examination of Water and Wastewater. 4500)**.** Temperature, pH, and specific conductivity were measured on-site using an Oakton PC-10 Waterproof Handheld pH/Conductivity Meter.

2.4 Load Calculations

Loading was evaluated as the mass of nutrients discharged onsite in the treated wastewater effluent. Monthly nutrient loads were calculated by multiplying the total monthly flow volumes for each system by the effluent concentration (mg/l) that was recorded for that month. Annual nutrient loads were calculated by summing the monthly nutrient loads for each facility. Flow information for the state permitted package treatment plants was obtained from monthly reports from the North Carolina Department of Water Quality – Division of Water Resources. Total monthly flow volume for these facilities was calculated by multiplying the average daily flow for the month by the number of days in the month. Flow information for the county permitted package treatment plants was summed from the daily records from the Carteret County Department of Environmental Health and Services.

Loads were normalized for unit area so that they could be compared to agricultural nutrient exports from the literature. Normalized nutrient loads were calculated by dividing the annual nutrient loads by the property area in which the package treatment plant was located. The property area was determined by GIS maps on the Carteret County Tax Property website (Carteret County, North Carolina, 2016).

2.5 Data Analysis

Statistical analyses were performed using the *Minitab 16* program to conduct Mann-Whitney nonparametric tests to determine if there were statistical ($P < 0.05$) differences in the data. A nonparametric test was used because the data were not normally distributed. Microsoft Excel was also used to determine descriptive statistics such as mean, median, standard deviation, and coefficient of variation.

TN migration was estimated by using the following equation (Equation 1):

$$A = 8.2095 \ln (D) + 57.751 \qquad \text{Equation 1}$$

where A is the percent attenuation and D is the distance from drainfield to surface water in meters. This equation was derived from a literature review where studies evaluated TDN decline downgradient from onsite wastewater treatment system drainfields. (O'Driscoll et al., 2014; Humphrey et al., 2013 a,b; DelRosario et al., 2014; Corbett et al., 2002; Reay, 2004; Reneau 1979; Chesapeake Bay Nutrient Attenuation Panel, 2015). These studies were conducted in coastal North Carolina, Virginia, and Florida with hydrogeologic settings similar to those in which this study was conducted. Groundwater TDN was measured in monitoring wells that were located from the edge of the system drainfield to 86 meters downgradient. A relative concentration decline curve was developed to estimate attenuation.

Residence time was estimated by using Darcy's Equation (describing fluid flow through porous media) to account for the average linear velocity of groundwater through the surficial aquifer. The following equation (Equation 2) was used:

$$v = K/n\ (dh/dl) \qquad \text{Equation 2}$$

where "v" is the average linear velocity in meters per day (m/d), "K" is the horizontal hydraulic conductivity (m/d), "n" is the effective porosity, and "dh/dl" is the hydraulic gradient from the package treatment plant drainfields to the nearest surface water. The hydraulic conductivity was obtained from Humphrey et al. (2011), porosity was obtained from Healy and Cook (2002), and the groundwater elevation was obtained from the North Carolina Division of Water Quality records of monitoring wells for state permitted package treatment plants from 2013 – 2014. The distance used for the "dl" variable was obtained from using Google Earth to measure the distance from the package treatment plant drainfields to the nearest surface water. The distance for the "dh" variable was the water table elevation at the package treatment plants above sea level. The hydraulic gradient was calculated as the difference between the groundwater elevation at the monitoring wells and the groundwater elevation at sea level (0 m) divided by the average distance from the package treatment plant drainfields to surface waters.

CHAPTER 3: RESULTS

3.1 Flow

Package treatment plant flow was recorded daily for each system by the operator. Monthly flow is represented by the average daily flow for that month, and ranged from 67 to 57,644 GPD (254 – 2.2 X 10^5 LPD) (Table 2). Extended aeration plants had the highest monthly flows ranging from 3,871 to 57,644 GPD (1.5 X 10^4 – 2.2 X 10^5 LPD). The advanced media filtration facilities had monthly flows that ranged from 422 to 10,352 GPD (1.6 X 10^3 – 3.9 X 10^4 LPD). The sequence batch reactor systems had monthly flows that ranged from 67 to11,284 GPD (254 – 4.3 X 10^4 LPD). The flow into these systems fluctuated throughout the year. All seven package treatment plants had their maximum flows during July with minimum flows occurring between December and February (Figure 5). Average monthly flows did not exceed the maximum permitted flow rates for any of the package treatment plants during the year. In fact, the maximum monthly flows reported for each system were well below (often < 50 %) their maximum permitted flow rate. The lower flow systems (permitted maximum flow rate < 50,000 GPD), advanced media filtration and sequence batch reactors, had more variable flow rates throughout the year with the coefficient of variation (CV) ranging from 0.87 to 1.04. The higher flow extended aeration facilities had less variable flows, their flow CV values ranged from 0.39 to 0.76.

Table 2: Flows from package treatment plants on Bogue Banks

Site	Minimum Monthly Flow (GPD)	Maximum Monthly Flow (GPD)	Average Monthly Flow (GPD)	Coefficient of Variation	Maximum Permitted Flow (GPD)
EA-1	15,172	57,644	32,597	0.39	101,460
EA-2	5,747	43,175	15,790	0.76	101,000
EA-3	3,871	29,477	12,045	0.72	65,000
ADV-1	1,076	10,352	2,999	0.87	12,000
ADV-2	422	8,910	2,891	0.93	17,340
SBR-1	67	3,544	1,015	1.04	6,000
SBR-2	945	11,284	3,457	0.88	30,500

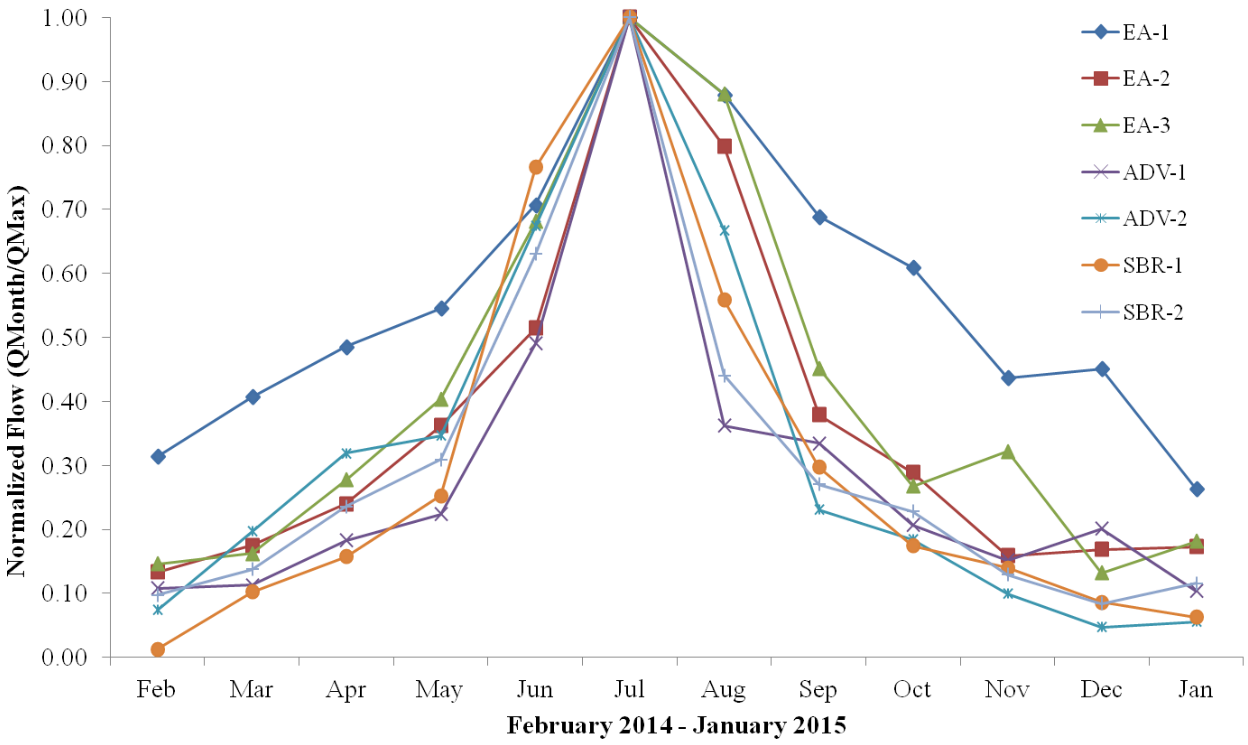

Figure 5: Normalized monthly flow of package treatment plants sampled during study period

3.2 Nitrogen

3.2.1 Influent

Average annual influent TN concentrations at individual sites had a range of 30.6 – 61.3 mg/l with an average of 48.5 mg/l (Table 3). These concentrations are comparable to influent TN concentrations found in the literature with a range of 9.0 – 240.0 mg/l (WERF, 2009). Annual influent TN loads ranged from 96 to 1,491 kg/yr (Table 3). Influent total nitrogen was evaluated as the sum of total dissolved nitrogen and particulate nitrogen. The average composition of total nitrogen was 17.8 % particulate nitrogen and 82.2 % total dissolved nitrogen (Appendix A). The total dissolved nitrogen was composed of, on average, 88.6 % NH_4, 0.4 % NO_3, and 11.0 % DON (Figure 6).

3.2.2 Effluent

Average annual effluent TN concentrations at individual sites ranged from 7.0 to 24.7 mg/l (average = 12.2 mg/l) with removal efficiencies from 55.2 to 88.5 % (average = 74.3 %) (Table 3). Annual effluent TN exports had a range of 17 – 310 kg/yr (Table 3). Seasonal average effluent TN concentration was highest during the winter (16.7 mg/l), followed by spring (14.6 mg/l), fall (10.1 mg/l), and summer (7.3 mg/l) (Table 4). Summer effluent TN concentrations were significantly lower than winter ($p = 0.009$) and spring ($p = 0.003$) concentrations, but not significantly lower than fall ($p = 0.392$) (Table 5). Seasonal average TN removal efficiencies were highest during the summer (87.6 %) followed by fall (73.3 %), spring (70.0 %), and winter (55.7 %). Seasonal effluent TN loading varied from system to system, yet summer TN loading was significantly higher than that of winter ($p = 0.027$) and fall ($p = 0.018$) (Table 5). Effluent total nitrogen was composed of, on average, 1.9 % particulate nitrogen and

98.1 % total dissolved nitrogen (Appendix A). For effluent, the average composition of the total dissolved nitrogen was 7.3 % NH_4, 77.4 % NO_3, and 15.3 % DON (Figure 7).

3.2.3 Treatment Technology

Summarizing the nitrogen removal (Table 3) by package treatment plant technology shows that EA 1 – 3 produced both the lowest and highest average effluent TN concentrations (7.0, 24.7, and 7.0 mg/l, respectively) and TN removal efficiencies (77.1, 55.2, and 88.5 %, respectively). The EA systems had higher coefficients of variation (CV) for effluent TN (0.61 – 0.91) compared to the ADV (0.38 – 0.66) and SBR (0.39 – 0.45) systems. The advanced media filtration plants (ADV-1 and ADV-2) had mixed results with average annual effluent TN concentrations of 16.1 and 7.1 mg/l, respectively, and removal efficiencies of 58.2 and 85.6 %, respectively. The sequence batch reactors produced the least variable results throughout the study with less than a 2 mg/l difference in average effluent TN concentration and less than 1 % difference in TN removal efficiency between the two systems (SBR-1 had 12.4 mg/l TN with 77.6 % TN removal and SBR-2 had 10.7 mg/l TN with 78.2 % TN removal).

With respect to effluent nitrogen loading (Table 3), the extended aeration plants had significantly ($p < 0.001$, Table 5) higher annual loads (108 – 310 kg/yr TN) than the advanced systems (27 – 56 kg/yr TN) and the sequence batch reactors (17 – 41 kg/yr TN). EA –1 and EA –2 had their highest loading occur during winter, while EA – 3 had its highest loading occur during summer (Table 4). The advanced media filtration and sequence batch reactor facilities, on the other hand, had maximum TN loads occur during the summer and minimum TN loads occur during the winter. TN loading was compared to flow to determine if loading was dependent on flow volume (Figure 8).

Extended aeration facilities had much higher loading and flow, but periods of highest loading did not correspond to periods of highest flow. This would indicate that the loadings from extended aeration plants were affected by effluent TN concentration, yet as they have a much higher permitted flow volume it is ultimately flow that gives these facilities such larger TN loads than other treatment technologies. The advanced media filtration plants exhibited loading increases with greater flows. This indicates the loadings from these facilities are more dependent on flow than effluent concentrations. The sequence batch reactor facilities had a similar pattern as the advanced media filtration systems where loading increased with flow. These facilities were influenced by flow, while effluent TN concentrations had less of an effect on monthly loads from these facilities. TN removal efficiency was also compared to flow in order to evaluate how the treatment efficiency of these facilities responded to flow rate (Figure 9). The extended aeration plants clearly demonstrated increased TN removal with increased flow rates. The treatment efficiency of advanced media filtration facilities was somewhat consistent across the flow range, although the instances of lowest treatment efficiency occurred during lower flows. Sequence batch reactor facilities did not have as strong of a response to flow as the extended aeration plants, yet their highest treatment efficiencies corresponded to their highest flow rates.

Table 3: Average influent and effluent TN concentrations with the coefficient of variation for effluent TN concentration, and average TN removal efficiencies, and annual effluent TN loading

Site	Influent TN (mg/l)	Effluent TN (mg/l)	Effluent TN CV	TN Removal (%)	Influent TN Load (kg/yr)	Effluent TN Load (kg/yr)
EA-1	30.6	7.0	0.91	77.1	1,491	249
EA-2	55.1	24.7	0.82	55.2	1,349	310
EA-3	61.3	7.0	0.61	88.5	1,174	108
ADV-1	38.6	16.1	0.66	58.2	169	56
ADV-2	49.4	7.1	0.38	85.6	213	27
SBR-1	55.3	12.4	0.39	77.6	96	17
SBR-2	49.2	10.7	0.45	78.2	239	41
Average	48.5	12.2	0.60	74.3	676	115

*Coefficient of variation is the standard deviation divided by the mean and was included to assess the variability in effluent TN concentration

Table 4: Seasonal average effluent TN concentrations and removal efficiencies with the seasonal sum of TN loads

	Spring TN			**Summer TN**			**Fall TN**			**Winter TN**		
Site	**mg/l**	**kg**	**Removal (%)**	**mg/l**	**kg**	**Removal (%)**	**mg/l**	**kg**	**Removal (%)**	**mg/l**	**kg**	**Removal (%)**
EA-1	8.0	73.3	79.1	2.5	43.8	93.6	4.9	57.3	81.3	12.6	74.7	30.7
EA-2	23.1	73.3	64.1	4.2	46.9	94.2	26.5	82.1	37.5	44.9	107.3	-9.4
EA-3	11.5	34.9	81.4	6.1	52.0	93.4	2.5	8.5	95.0	8.1	13.0	80.1
ADV-1	27.3	16.1	30.0	11.9	25.7	74.5	7.6	6.3	76.3	17.8	7.6	51.7
ADV-2	10.1	8.9	78.0	5.8	13.6	89.5	6.6	3.6	84.5	6.1	1.2	88.8
SBR-1	12.5	2.3	73.7	12.2	11.0	83.3	13.4	3.1	64.4	11.4	0.6	81.9
SBR-2	9.7	7.7	83.8	8.1	19.8	84.9	9.3	7.6	74.3	15.9	6.3	66.3
Average	14.6	30.9	70.0	7.3	30.4	87.6	10.1	24.1	73.3	16.7	30.1	55.7

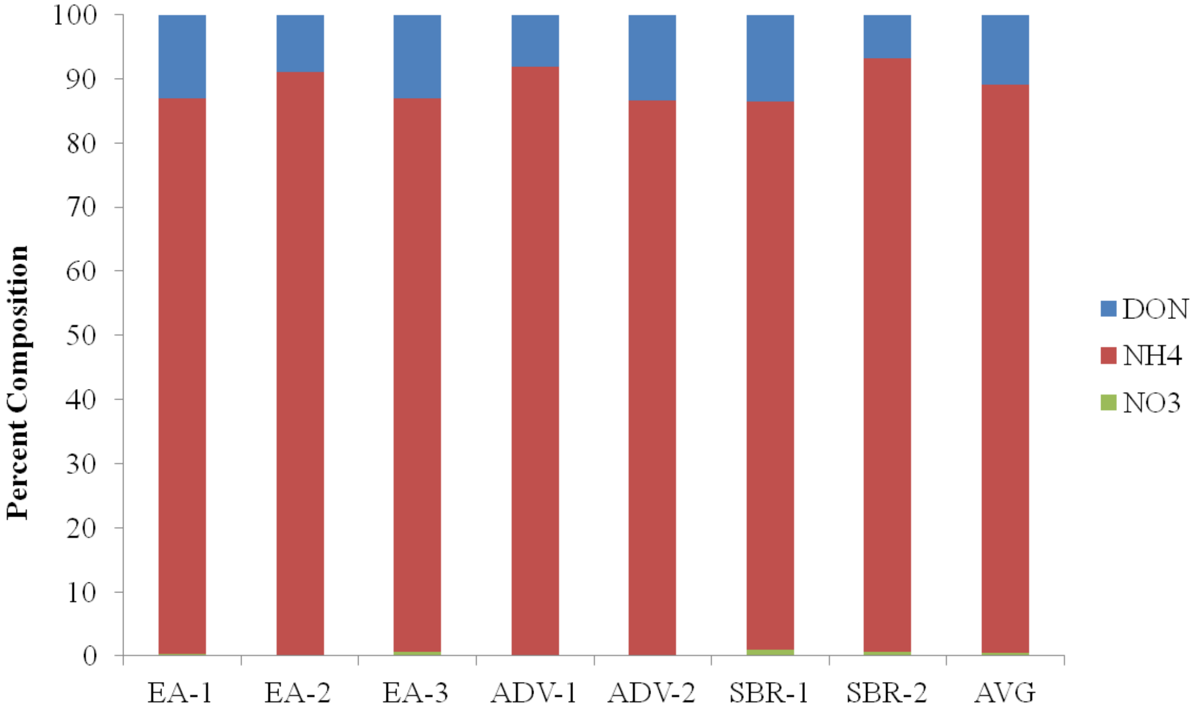

Figure 6: Composition of influent total dissolved nitrogen (annual mean, n = 12)

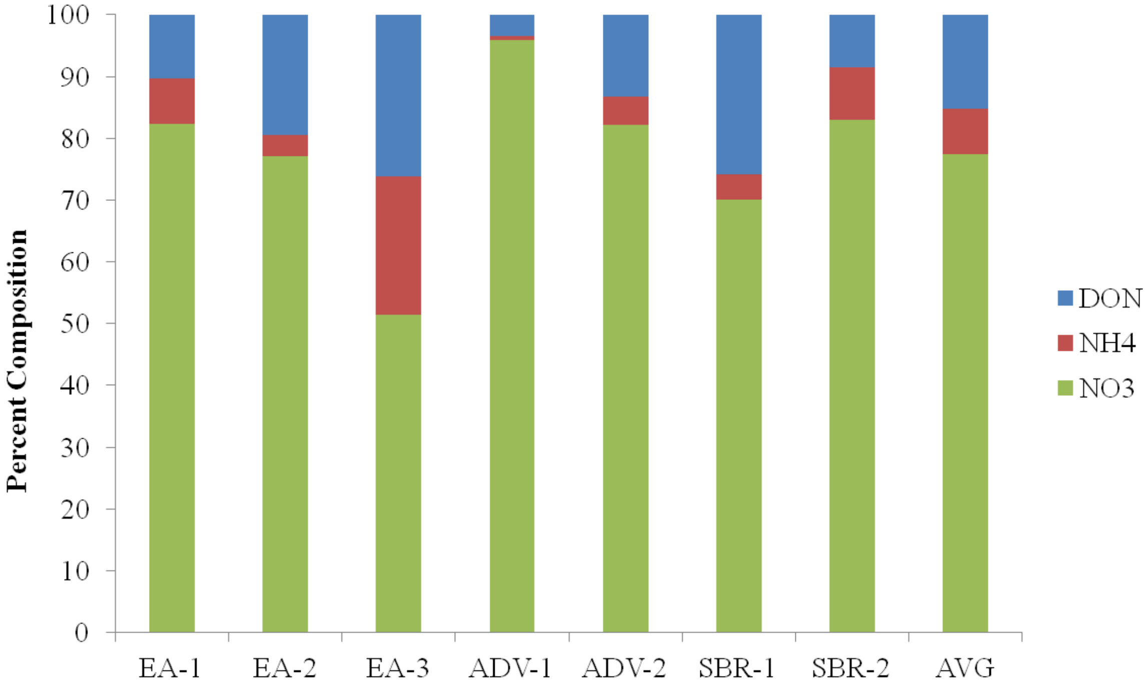

Figure 7: Composition of effluent total dissolved nitrogen (annual mean, n = 12)

Table 5: Mann-Whitney test results

Mann Whitney Test Values

Test Performed	**Effluent TN Concentration**	**Effluent TP Concentration**	
EA vs ADV	0.261	0.113	
EA vs SBR	0.068	***0.018*** (<)	
ADV vs SBR	0.230	0.871	
	Effluent TN Loading	**Effluent TP Loading**	
EA vs ADV	***0.000*** (>)	***0.000*** (>)	
EA vs SBR	***0.000*** (>)	***0.000*** (>)	
ADV vs SBR	0.164	0.244	
	Seasonal Effluent TN Concentration	**Seasonal Effluent TP Concentration**	
Summer vs Winter	***0.009*** (<)	***0.016*** (>)	
Summer vs Spring	***0.003*** (<)	0.279	
Summer vs Fall	0.392	0.466	
Fall vs Winter	0.063	***0.001*** (>)	
Fall vs Spring	***0.026*** (<)	0.062	
Winter vs Spring	0.865	0.206	
	Seasonal Effluent TN Loading	**Seasonal Effluent TP Loading**	
Summer vs Winter	***0.027*** (>)	***0.000*** (>)	
Summer vs Spring	0.191	***0.003*** (>)	
Summer vs Fall	***0.018*** (>)	***0.015*** (>)	
Fall vs Winter	0.615	***0.003*** (>)	
Fall vs Spring	0.191	0.421	
Winter vs Spring	0.174	0.066	
	Seasonal Effluent TC Concentration	**Seasonal Effluent EC Concentration**	**Seasonal Effluent EN Concentration**
Summer vs Winter	***0.000*** (>)	***0.013*** (>)	***0.029*** (>)
Summer vs Spring	0.173	0.513	0.513
Summer vs Fall	***0.000*** (>)	***0.000*** (>)	***0.031*** (>)
Fall vs Winter	0.763	0.208	0.970
Fall vs Spring	***0.020*** (<)	0.051	0.138
Winter vs Spring	0.059	0.315	0.274

Test performed at 95 % confidence level and any value less than p = 0.05 is considered significant and is bold and italicized within the table. A “greater than” (>) or “less than” (<) symbol was given to each test that had statistical significance to show if the first test component was statistically greater than or less than the second test component. Median values for each system type and season can be found in Appendix G

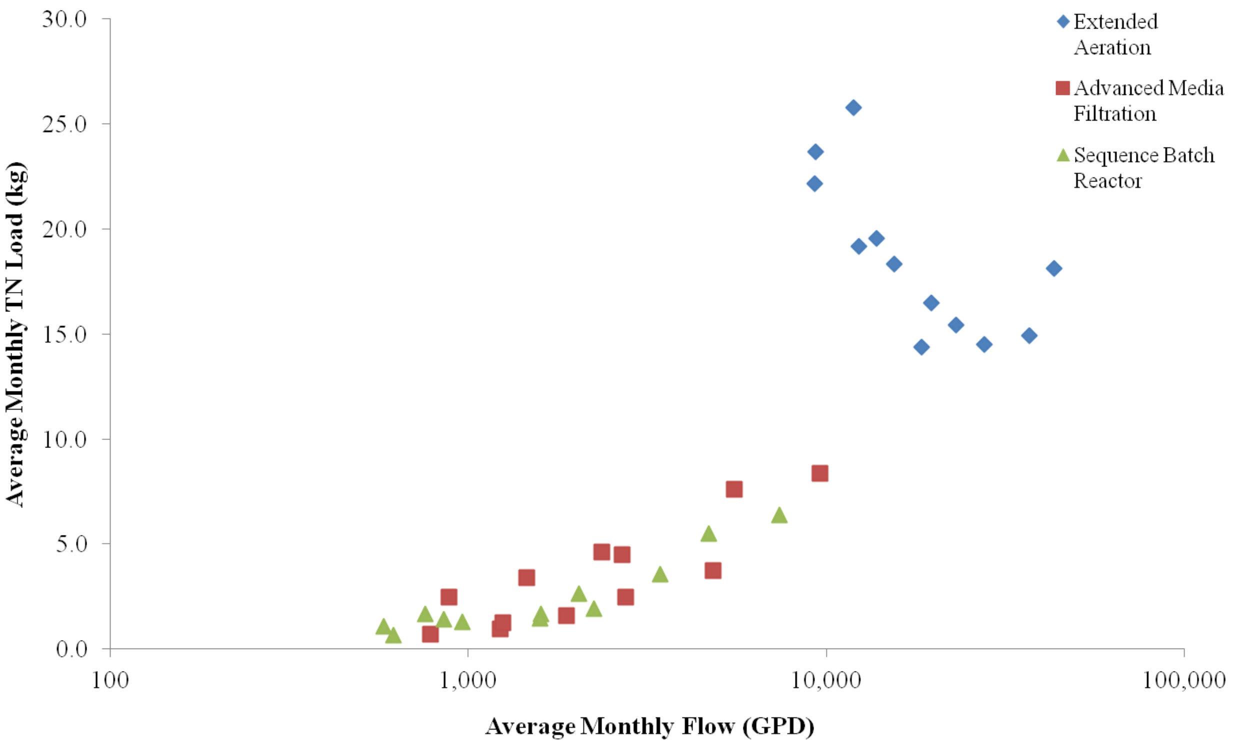

Figure 8: Average monthly flow compared to the average monthly effluent TN load by package treatment plant technology

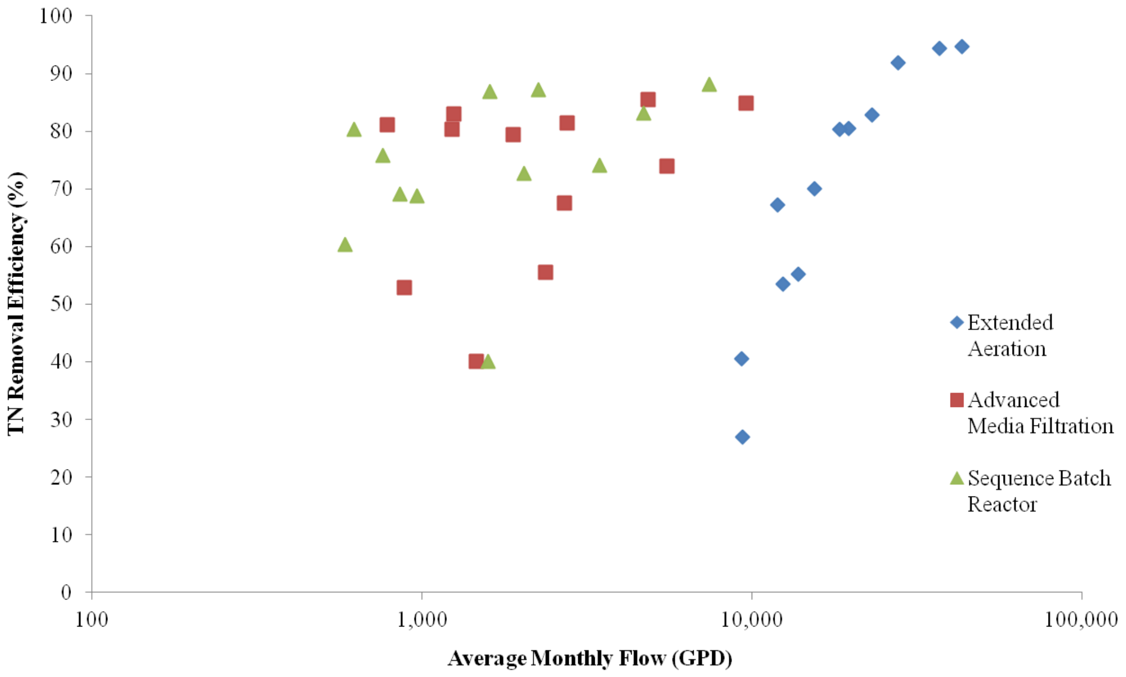

Figure 9: Average monthly flow compared to the average TN removal efficiency by package treatment plant technology

3.3 Phosphorus

3.3.1 Influent

Average annual influent TP concentrations ranged from 2.7 to 8.1 mg/l with an average of 4.8 mg/l (Table 6). This is comparable to influent TP values found in literature with a range of 0.2 – 32.0 mg/l (WERF, 2009). Annual influent TP loads ranged from 13 to 130 kg/yr (Table 6). Total phosphorus in the influent was composed of, on average, 98.4% phosphate.

3.3.2 Effluent

Average annual effluent TP concentration ranged from 2.2 to 6.4 mg/l (average = 3.5 mg/l) with a TP removal efficiency ranging from -22.3 to 52.8 % (average = 25.0 %) (Table 6). EA-1 had an average TP concentration that was higher in the effluent (3.2 mg/l) than the influent (2.7 mg/l) which explains the presence of the negative removal efficiency. This facility had the lowest average influent TP concentration (2.7 mg/l), yet that does not explain why the effluent had a higher TP concentration. There were also no recorded outliers in this data set that could account for unusually low influent concentrations (Appendix B). A potential explanation could be that the influent phosphorus was being retained in the solids and was not available in the liquid that was sampled. It is unlikely that the wastewater actually gained phosphorus as the negative removal efficiency in the analysis would indicate. Annual effluent TP loads ranged from 11 to 152 kg/yr (Table 6). Seasonal effluent TP concentration was significantly higher during the summer ($p = 0.016$) and fall ($p = 0.001$) than during winter (Table 5). All package treatment plants had significantly ($p < 0.001$) higher seasonal effluent loads occur during the summer (5 – 57 kg), and lower loads occur during the winter (0.3 – 15.0 kg) (Table 7). Effluent total phosphorus was composed of, on average, 92.9 % phosphate.

3.3.3 Treatment Technology

All treatment technologies performed similarly with respect to effluent TP concentration and removal percentage (Table 6). Extended aeration plants had significantly ($p < 0.001$, Table 5) larger effluent TP loads than the other systems with a range of 48 – 152 kg/yr, presumably due to their higher monthly flows relative to other systems. All of the remaining systems had effluent loads of less than 20 kg/yr. Seasonal effluent TP loading by treatment technology had the same trend as mentioned above: significantly ($p < 0.001$) higher loading occurred during the summer and lowest loading occurred during the winter (Table 5). TP loading was compared to flow (Figure 10) to determine the influence that flow had on loading. All package treatment plant technologies showed a positive relationship between TP loading and flow with most of the highest loading instances occurring with the highest flow periods. This indicates that TP loading is directly influenced by flow.

Table 6: Average influent and effluent TP concentrations, removal efficiencies, and the seasonal sum of TP loads

Site	Influent TP (mg/l)	Effluent TP (mg/l)	TP Removal (%)	Influent TP Load (kg/yr)	Effluent TP Load (kg/yr)
EA-1	2.7	3.2	-22.3	130	152
EA-2	3.9	2.7	29.6	98	51
EA-3	4.4	2.2	49.1	83	48
ADV-1	4.0	2.8	30.9	18	13
ADV-2	5.0	4.3	14.0	23	19
SBR-1	8.1	6.4	21.1	13	11
SBR-2	5.8	2.7	52.8	27	12
Average	4.8	3.5	25.0	56	44

Table 7: Seasonal average effluent total phosphorus concentrations, removal efficiencies, and loadings

	Spring			Summer			Fall			Winter		
Site	**mg/l**	**kg**	**Removal (%)**	**mg/l**	**kg**	**Removal (%)**	**mg/l**	**kg**	**Removal (%)**	**mg/l**	**kg**	**Removal (%)**
EA-1	3.6	34.3	-18.0	3.2	57.0	11.7	4.0	45.9	-77.6	2.2	15.0	-30.2
EA-2	3.5	12.0	17.4	2.0	20.6	62.1	3.1	12.7	12.6	2.4	5.6	6.4
EA-3	1.8	6.1	65.5	3.2	29.4	42.8	2.7	10.2	35.1	1.1	1.9	53.3
ADV-1	3.1	1.9	29.3	3.2	7.6	38.0	2.9	2.5	25.2	2.0	1.0	28.2
ADV-2	4.4	4.1	16.8	4.9	12.1	16.0	4.8	2.6	8.8	3.2	0.5	13.8
SBR-1	3.8	0.5	41.2	9.6	8.4	-0.7	8.0	2.3	-17.7	4.1	0.3	56.6
SBR-2	1.5	1.7	71.3	2.1	5.2	57.1	4.5	3.9	49.9	2.4	0.9	39.8
Average	3.1	8.7	31.9	4.0	20.0	32.4	4.3	11.4	5.2	2.5	3.6	24.0

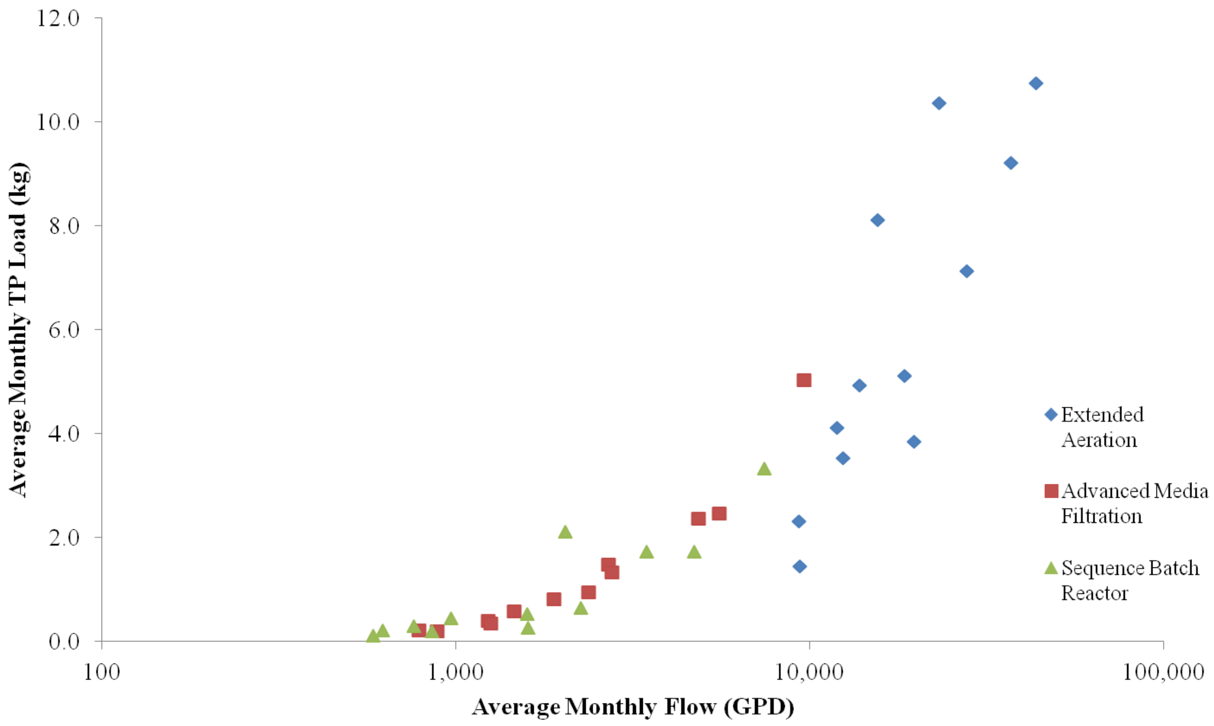

Figure 10: Average monthly flow compared to the average monthly effluent TP load by package treatment plant technology

3.4 Bacteria

3.4.1 Total Coliform

Annual median influent total coliform (TC) ranged from 2.23 x 10^6 to 8.15 x 10^6 MPN/ 100 ml (Table 8). Extended aeration systems had an influent TC range of 2.23 x 10^6 – 5.01 x 10^6 MPN/100 ml. Advanced systems had an influent TC range of 2.84 x 10^6 – 8.15 x 10^6 MPN/100 ml. Sequence batch reactors had an influent TC range of 3.01 x 10^6 – 5.01 x 10^6 MPN/100 ml.

Annual median effluent TC ranged from 1 to 534 MPN/100 ml (Table 8). Extended aeration systems had an effluent TC range of 78 – 534 MPN/100 ml. Advanced media filtration systems had an effluent TC range of 50 – 494 MPN/100 ml. Sequence batch reactors had an effluent TC range of 1 – 82 MPN/100 ml. Seasonally, effluent TC was significantly ($p < 0.001$, Table 5) higher during the summer months than the fall and winter (Table 9).

3.4.2 E. coli

Annual median influent *E. coli* (EC) ranged from 5.16 x 10^5 to 2.47 x 10^6 MPN/100 ml (Table 8). These values are comparable to those found in literature with a range of 1.0 x 10^4 – 8.16 x 10^7 MPN/100 ml (WERF, 2009). Extended aeration systems had an influent EC range of 6.45 x 10^5 – 1.55 x 10^6 MPN/100 ml. Advanced systems had an influent EC range of 1.39 x 10^6 – 2.47 x 10^6 MPN/100 ml. Sequence batch reactors had an influent EC range of 5.16 x 10^5 – 1.76 x 10^6 MPN/100 ml.

Annual median effluent *E. coli* ranged from < 1 to 37 MPN/100 ml (Table 8). Extended aeration systems had an effluent EC range of 1 – 12 MPN/100 ml. Advanced systems had an effluent EC range of 5 – 37 MPN/100 ml. Sequence batch reactors had an effluent EC range of < 1 – 32 MPN/100 ml. Seasonally, effluent EC was significantly (Table 5) higher during the summer months than the fall ($p < 0.001$) and winter ($p = 0.013$) (Table 9).

3.4.3 Enterococcus

Annual median influent *Enterococcus* (EN) had a range of 1.10 x 10^5 – 1.21 x 10^6 MPN/100 ml (Table 8). Extended aeration systems had an influent EN range of 1.56 x 10^5 – 1.21 x 10^6 MPN/100 ml. Advanced systems had an influent EN range of 7.52 x 10^5 – 9.51 x 10^5 MPN/100 ml. Sequence batch reactors had an influent EN range of 1.10 x 10^5 – 1.12 x 10^5 MPN/100 ml.

Annual median effluent *Enterococcus* ranged from < 1 to 2 MPN/100 ml (Table 8). Extended aeration systems had an effluent EN range of 1 – 2 MPN/100 ml. Advanced systems also had an effluent EN range of 1 – 2 MPN/100 ml. Both sequence batch reactors had an effluent EN concentration of < 1 MPN/100 ml. Seasonally, effluent EN was significantly (Table 5) higher during summer than the fall ($p = 0.031$) and winter ($p = 0.023$) months (Table 9).

3.4.4 Disinfection

Disinfection was evaluated by the log removal value (LRV) for each system. Annually, LRVs ranged from 3.9 – 6.7 for TC, 4.7 – 6.1 for EC, and 5.2 – 5.9 for EN (Table 8). Disinfection was also evaluated based on disinfection method: chlorine, UV light, and membrane bioreactor (Table 10). Annually, the LRV for chlorine disinfection was 5.0 for TC, 4.8 for EC and 5.0 for EN. Annual LRVs for UV disinfection averaged 4.8 for TC, 5.1 for EC, and 4.8 for EN. Annual LRVs for the membrane bioreactor were 4.7 for TC, 5.4 for EC, and 5.6 for EN. Seasonally, there were some differences in disinfection effectiveness. Chlorine disinfection of TC had an LRV of 3.2 during the spring and 3.8 during the summer while the fall and winter values were 7.0 and 5.8 respectively. For TC, all other methods had between 3.7 and 5.9 LRVs. Chlorine disinfection of EC was also low during the spring with an LRV of 2.5. All other disinfection methods for EC had LRVs of 4.6 or higher. For *Enterococcus* disinfection, all methods performed similarly throughout the year with an LRV range of 4.1 – 6.4.

Table 8: Annual median indicator bacteria concentrations and log removal values

	Total Coliform (MPN/100 ml)			E. coli (MPN/100 ml)			Enterococcus (MPN/100 ml)		
Site	**Influent**	**Effluent**	**LRV**	**Influent**	**Effluent**	**LRV**	**Influent**	**Effluent**	**LRV**
EA-1	2.23×10^6	285	3.9	6.45×10^5	1	6.1	1.56×10^5	1	5.2
EA-2	5.01×10^6	78	4.8	1.55×10^6	2	5.9	1.21×10^6	2	5.9
EA-3	4.84×10^6	534	4.0	9.54×10^5	12	5.1	3.78×10^5	2	5.4
ADV-1	2.84×10^6	50	4.8	1.39×10^6	5	5.3	9.51×10^5	1	5.3
ADV-2	8.15×10^6	494	4.2	2.47×10^6	37	4.8	7.52×10^5	2	5.7
SBR-1	5.01×10^6	1	6.7	5.16×10^5	< 1	6.0	1.12×10^5	< 1	5.4
SBR-2	3.01×10^6	82	4.6	1.76×10^6	32	4.7	1.10×10^5	< 1	5.3

Table 9: Seasonal median effluent indicator bacteria concentrations

Site	Total Coliform (MPN/100 ml)				E. coli (MPN/100 ml)				Enterococcus (MPN/100 ml)			
	Spring	Summer	Fall	Winter	Spring	Summer	Fall	Winter	Spring	Summer	Fall	Winter
EA-1	> 2,420	> 2,420	< 1	< 1	> 2,420	1	< 1	< 1	< 1	1	< 1	4
EA-2	770	33	142	45	135	2	1	2	16	< 1	2	1
EA-3	< 1	> 2,420	579	260	< 1	13	93	13	< 1	72	11	1
ADV-1	72	> 2,420	12	16	11	111	1	< 1	< 1	18	< 1	< 1
ADV-2	> 2,420	> 2,420	< 1	20	727	135	< 1	6	322	64	< 1	< 1
SBR-1	> 2,420	1,120	< 1	< 1	921	21	< 1	< 1	20	< 1	1	< 1
SBR-2	> 2,420	> 2,420	< 1	41	248	60	< 1	107	< 1	10	< 1	< 1

Table 10: Seasonal Log Removal Values for each indicator bacteria organism by disinfection method (3 chlorine, 3 UV, and 1 MBR facilities)

	TC			**EC**			**EN**		
	Cl	**UV**	**MBR**	**Cl**	**UV**	**MBR**	**Cl**	**UV**	**MBR**
Spring	3.2	5.1	3.8	2.5	5.4	4.6	4.9	5.0	4.9
Summer	3.8	3.7	5.9	4.8	4.6	6.0	5.1	4.1	6.4
Fall	7.0	5.6	4.6	6.4	5.5	5.7	5.6	5.1	5.9
Winter	5.8	4.7	4.7	5.4	5.1	5.3	4.4	5.0	5.4
Annual	5.0	4.8	4.7	4.8	5.1	5.4	5.0	4.8	5.6

3.5 Evaluating Permitted Effluent Standards

Package treatment plant performance based on permitted effluent quality standards was evaluated (Figure 11) by examining the number of times (out of 12 samples) that each package treatment plant failed to meet the permitted values for TN and fecal coliform (*E. coli* +

Enterococcus). The bar graph indicates how many times the permitted standard was violated, and how many times the permitted standard would be violated if the county permitted package treatment plants were held to state permit standards. Looking at fecal coliform, EA-1 (33 %), EA-3 (42 %), ADV-2 (17 %), and SBR-2 (50 %) all exceeded their permitted values at least once. EA-2, ADV-1, ADV-2, and SBR-1 are permitted through the county and if they were being held to the state effluent quality standard of 43 CFU/100 ml then their failure rates would have been 17 %, 25 %, 50 %, and 25 % respectively. Looking at TN, EA-1 (25%), EA-2 (50%), EA-3 (25%), ADV-1 (33%), and SBR-2 (42%) all exceeded their permitted values at least once. The county systems (EA-2, ADV-1, ADV-2, and SBR-1) would have had failure rates of 58%, 42 %, 17%, and 50% respectively if they were held to the state effluent quality standard of 10 mg/l TN. The commonly used county permitted effluent quality standard for fecal coliform was 1,000 CFU/100 ml for a single sample, and the standard for TN was 20 mg/l.

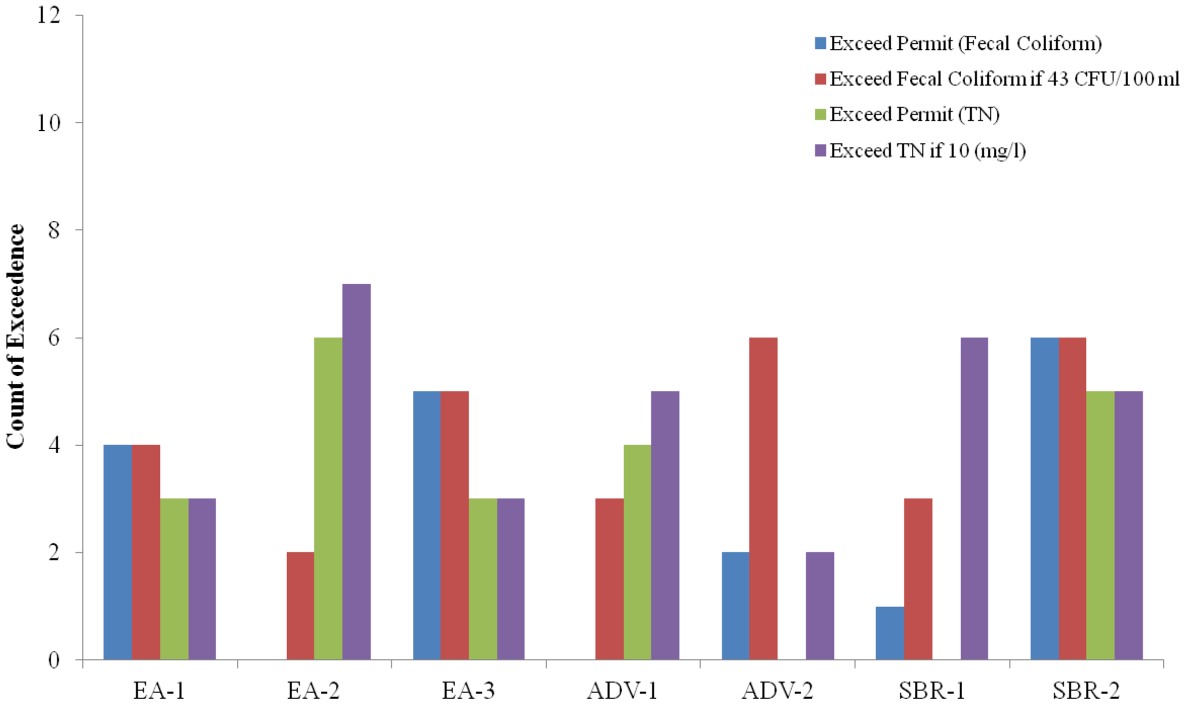

Figure 11: Permit violation count and count if all package treatment plants were held to state permit standards (n = 12)

CHAPTER 4: DISCUSSION

4.1 Nitrogen

While influent nitrogen concentrations can be attributed to the wastewater source, effluent concentrations are a result of the treatment of the wastewater. Effluent TN concentration should be within the permitted standards assigned to each system (10 mg/l TN for state permitted package treatment plants and 20 mg/l TN for county permitted package treatment plants). These standards are based on factors such as effluent discharge (surface or subsurface) and designed flow capacity. According to these standards five out of seven facilities had multiple samples exceeding their permitted limit for TN (Figure 11). However, only one system (EA-2) had an annual average TN concentration exceeding its limit of 20 mg/l with a value of 24.7 mg/l (Table 3). Looking at the effluent total nitrogen composition of the treatment systems (Figure 7), EA-2 had similar percentages of NH_4 and NO_3 + NO_2 as the other package treatment plants. This would suggest that the nitrification and denitrification processes of EA-2 are functioning similarly to the other package treatment plants. A potential reason to explain the consistently high effluent TN concentrations for this system could be that ammonification processes are not functioning as well as they should be. This is evidenced in Appendix A (EA-2) where high concentrations of total nitrogen occur with high concentrations of dissolved organic nitrogen in effluent. Ammonification is performed by aerobic bacteria, and usually is accomplished in an aeration chamber. It is possible that the wastewater in EA-2 is not being held in the aeration chamber for a long enough time for the organic nitrogen to be fully converted to ammonium therefore preventing subsequent nitrification and denitrification processes. EA-2 was also one of the largest package treatment plants involved in the study with a permitted flow rate exceeding 100,000 GPD ($3.8 X 10^5$ LPD). A system of this size producing a large quantity of high concentration effluent could potentially be a concern to local surface waters. On this barrier island setting the surrounding surface waters are in close proximity to the package treatment plants. Onsite effluent discharge from these systems has a chance to migrate to these surface waters via overland flow or through the surficial aquifer. Looking at the package treatment plants from an environmental perspective, four out of seven systems (EA-2, ADV-1, SBR-1, and SBR-2) had annual average effluent TN concentrations exceeding 10 mg/l (Table 3). Although most of those facilities are performing according to the permitted effluent standards (Figure 11), this could potentially still be a threat to water resources. The package treatment plants in this study produced an effluent composed of, on average, greater than 75 % nitrate (Figure 7). The EPA safe drinking water standard for nitrate is 10 mg/l (EPA Safe Drinking Water Act, Phase II). Although surface waters in the area are not currently used as drinking water sources, they could be at a future time, likely with reverse osmosis or membrane filtration treatment. Currently the only source of drinking water on Bogue Banks comes from the Castle Hayne Aquifer. This aquifer has a confining unit that is not completely impermeable, and direct recharge from the surficial aquifer is possible (Giese et al., 1997). There have also been studies that show a direct correlation between elevated nitrate, organic wastewater compounds, and pharmaceuticals (Schaider et al, 2015). If other package treatment plants on the island also produce an effluent with TN concentrations consistently exceeding 10 mg/l, then this could potentially be a problem.

Although all package treatment plants are currently monitored for effluent total nitrogen concentrations, sampling does not always capture the full range of nitrogen concentrations produced by these dynamic systems, or more broadly the range of pharmaceutical and personal care products that may also be mobile in the sandy surficial aquifer. Future studies that monitor these package treatment plants would be beneficial to understanding the true effluent quality that is being produced and effects on the downgradient groundwater and surface water quality. Also, broader studies using monitoring data from the DEQ and county health departments could help to increase understanding of the range of nitrogen loading in coastal counties.

Annual nitrogen loading rates were proportional to the package treatment plants designed flow capacity and average measured flows: larger systems had higher annual TN loads than the smaller systems (Figure 8). The extended aeration plants treated much more wastewater than both the advanced media filtration and sequence batch reactor facilities, and therefore had much higher annual TN loads. These data suggest that water conservation efforts could also result in decreased nutrient loadings to the surficial aquifer. In an effort to quantify the package treatment plants' loadings on an areal basis, total nitrogen loads were normalized to the developed property area where the facilities are located. This also allowed a comparison to be made to literature involving other land uses with nutrient exports. Normalized TN loads from package treatment plants ranged from 12.4 to 47.5 kg/ha/yr (Table 11) with a mean of 26.9 kg/ha/yr. The two highest normalized loads come from the two highest permitted flow systems (EA-1 and EA-2). ADV-1 had a higher normalized load (33.3 kg/ha/yr TN) than what was expected considering its smaller size (1.67 ha) and permitted flow volume (12,000 GPD or 45,000 LPD). This can be attributed to a high effluent TN concentration along with a smaller disposal area. The normalized TN loads observed in this study were comparable to, and often surpassed, TN exports recorded in literature for agricultural lands and golf courses (Table 12). EA-1 and EA-2 had normalized loads that exceeded the range of exported TN (34.9 – 43.6 kg/ha/yr) for well drained soils and agricultural land-use in the lower Coastal Plain of North Carolina (Deal, 1986). Five out of seven package treatment plants (excluding ADV-2 and SBR-2) exceeded TN exports documented for cropped soils (15 – 16 kg/ha/yr). EA-1, EA-2, and ADV-1 had normalized TN loads that exceeded those from golf-course runoff (31 kg/ha/yr) in the Upper Neuse River Basin of North Carolina (Line, 2002). All seven package treatment plants exceeded TN exports reported for pastureland (7 kg/ha/yr, Line, 2002) and atmospheric deposition (11 kg/ha/yr; Whitall, 2003) in the Neuse River Basin, North Carolina. Also, the normalized TN loads estimated in this thesis would be in addition to atmospherically deposited nitrogen over the same areas.

Table 11: Effluent TN and TP loads normalized to the land area containing package treatment plants

Site	Normalized TN load (kg/ha/yr)	Normalized TP load (kg/ha/yr)
EA-1	47.5	29.0
EA-2	44.8	7.4
EA-3	16.9	7.4
ADV-1	33.3	7.8
ADV-2	12.4	8.4
SBR-1	19.1	13.0
SBR-2	14.1	4.0

Table 12: Literature comparison of normalized TN and TP exports

Location	Source/Land Use	Total Nitrogen Load (kg/ha/yr)	Total Phosphorus Load (kg/ha/yr)	Reference
Bogue Banks, NC	Package Treatment Plant	12.4 - 47.5	4.0 - 29.0	Mahoney et al. (2016)
Greenville, NC	Septic System	1.4 - 3.9	-	Iverson et al. (2015)
Lower Coastal Plain, NC	Agricultual (well drained soils)	34.9 - 43.6	0.1 - 0.2	Deal et al. (1986)
Lower Coastal Plain, NC	Cropped Soils	15.2 - 16.0	0.5 - 7.6	Gilliam and Skaggs (1986)
Upper Neuse River Basin, NC	Golf Course	31.2	5.3	Line et al. (2002)
Upper Neuse River Basin, NC	Pasture	6.7	4.3	Line et al. (2002)
Neuse River Basin, NC	Atmospheric Deposition (wet)	11.0	-	Whitall et al. (2003)

This study only sampled seven of the thirty-seven package treatment plants (Appendix F) located on Bogue Banks (NCDEQ, Carteret County Department of Environmental Health). An estimate was made in order to assess potential island-wide nitrogen input from these facilities. The potential TN loading was estimated to be 4,250 – 6,300 kg/yr (Table 13). This estimate accounts for the potential amount of TN in treated wastewater effluent that is discharged onto the surface or in the subsurface of these facilities. This range represents two different methods for estimating island-wide TN loads. The lower value of 4,250 kg/yr was calculated by multiplying the average TN loading from package treatment plants in this study by the number of package treatment plants currently on Bogue Banks. The higher estimated TN load of 6,300 kg/yr was calculated by multiplying the average effluent TN concentration by the average annual flow from facilities in this study, and then multiplying that value by the number of package treatment plants on Bogue Banks. These loads were normalized to the land area of package treatment plant facilities on Bogue Banks for a value of 30 – 45 kg/ha/yr. The land area of the package treatment plants was calculated by taking the average area of package treatment plants in this study and multiplying the value by the total number of package treatment plants on the island. This is a substantial amount considering this loading would be in addition to septic tank nitrogen and atmospherically deposited nitrogen.

Septic tank nitrogen loading to the soils of Bogue Banks was estimated in order to give a comparison to package treatment plant nitrogen loading (Table 14). This was accomplished by extrapolating results from Pradhan et al. (2007) where septic tank nitrogen loadings were estimated for each river basin and sub-basin in North Carolina. This study used Census data from 1990 and GIS to estimate N loading to soils on a watershed scale. Bogue Banks is located in the White Oak river basin. In the Pradhan study, Bogue Banks was located within sub-watershed WOK-3 which also included the towns of Beaufort, Morehead City, and Newport (all located within Carteret County). Using the results from this sub-watershed (Table 14) for septic tank density and nitrogen loading per unit area, along with the area of Bogue Banks, an estimate for the total number of septic tanks on the island (1,086), annual nitrogen loading (6,882 kg/yr), and the N load per system (6.3 kg/yr) was derived. This estimate is based on data from 1990, and is most likely less than what the values would be today, given that the population in Carteret County has increased by over 30 % from 1990 to 2014 (North Carolina Office of State Budget and Management, 2015). With the increased population, it is likely that the amount of septic tanks has also increased. To estimate the number of septic tanks on Bogue Banks in 2014, the total from 1990 was scaled up by the same amount as the increase in population (32.3 %) to yield a value of 1,434 septic tanks. Using the N loading per system obtained from the 1990's data of 6.3 kg/yr, it was estimated that the N loading from septic tank systems in 2014 would be over 9,000 kg/yr. This value was normalized to the land area of Bogue Banks for a value of 3.1 kg/ha/yr. These estimates do not account for the increased seasonal population during the summer. However, this approximation highlights the potential N loadings from these onsite wastewater treatment systems that are largely unaccounted for in nutrient management strategies. This also allows a comparison to the loading from package treatment plants. The package treatment plant loading was estimated to be lower (4,250 – 6,300 kg/yr, Table 13) than the septic system inputs (~ 9,000 kg/yr), but package treatment plants also treat wastewater for less of the population on Bogue Banks. Future work is needed to more accurately assess the septic system inputs.

Table 13: Estimated effluent TN loading from all package treatment plants on Bogue Banks

Bogue Banks PTPs	37
Average Area of PTPs (ha)	3.75
Average Effluent TN Concentration (mg/l)	12.2
Average Annual TN Loading (kg/yr)	115
Average Monthly Flow (LPD)	38,000
Annual Flow All PTPs (L/yr)	5.17 X 10^8
Annual TN Load (kg)	**4,250 - 6,300**
Normalized TN Load (kg/ha/yr)	**30 - 45**

Table 14: Data used to estimate the potential N loading from septic tanks on Bogue Banks

Bogue Banks Septic Tank N Loading	
Septic Tank Density in 1990 (#/mi ^{2}) [a]	97
Septic Tanks on Bogue Banks (1990)	1,086
N loading (lb/mi ^{2}/yr) [a]	1,355
Total Septic Tank N Loading on Bogue Banks in 1990 (kg/yr)	6,882
N Loading per Septic Tank (kg)	6.3
Normalized N Loading in 1990 (kg/ha/yr)	2.4
Population Carteret County (1990) [b]	52,407
Population Carteret County (2014) [b]	69,350
Population Increase in Carteret County from 1990 to 2014 (%)	32.33
Septic Tank Increase Scaled to Population Increase	348
Total Setic Tanks on Bogue Banks (2014)	1,434
Total N Loading of Septic Tanks on Bogue Banks in 2014 (kg/yr)	9,084
Normalized N Loading in 2014 (kg/ha/yr)	3.1

[a] Values obtained from Pradhan (2007)
[b] Values obtained from North Carolina Office of State Budget and Management

One of the major aspects of this study was the seasonal evaluation of package treatment plant performance. The results indicate a clear seasonal variation in package treatment plant nitrogen concentration and loading. Average seasonal influent nitrogen concentration was highest for six out of seven package treatment plants during the summer months (SBR-2 had a slightly higher concentration in spring rather than summer). This could be attributed to flow and waste load inputs being higher during the summer season. Average seasonal effluent concentrations were lowest during the summer and fall months for six out of seven systems. The exception was SBR-2 which had its lowest seasonal effluent concentration occur during the winter (only 2 mg/l seasonal range for this system). All seven systems had their highest nitrogen removal efficiencies occur during either the summer or fall seasons. This seasonal inverse relationship between concentration and removal efficiency could be explained by factors such as microbial activity, organic carbon, temperature and flow. All of the wastewater nitrogen transformation processes are conducted by microbial organisms. Microbial organisms need a food source to populate and multiply, which in this case is the organic matter incorporated in wastewater influent. As flow increases during the summer so does the supply of organic matter into the systems. The influent DOC concentrations were not necessarily higher during summer (Appendix C), however, the mass of DOC entering the system was increased due to the seasonal increase of flow (Figure 12). This steady supply of organic matter promotes microbial growth and allows the bacteria to multiply to sufficient levels to effectively treat the wastewater (Gerardi, 2002). The organic nitrogen incorporated in the organic matter is converted to ammonium by aerobic bacteria in the ammonification process. The ammonium is then converted to nitrite and nitrate by aerobic bacteria via nitrification. These processes can benefit from the warmer temperatures that are associated with the summer season as microbial growth and activity are increased (Gerardi, 2002). Figure 13 displays the increase in total coliform concentration associated with the warmer temperatures of the summer season. Ultimately, nitrogen will be removed from the systems when the effluent reaches the anoxic tank. Here, nitrate is converted to nitrogen gas by anaerobic bacteria via denitrification. Every step in this process involves microorganisms. These microorganisms are able to multiply to large populations due to this increased organic matter supply during the summer season, and other bacteria were more abundant during seasons with increased temperatures (Appendix D), hence the nitrogen transformation processes necessary for nitrogen removal will be increased (Gerardi, 2002). On the other hand, effluent TN concentrations increased with a decreased TN removal efficiency during the winter season. This could be due to colder temperatures along with decreased flow (and organic matter supply) which can suppress the microbial activity (Gerardi, 2002). It is likely that the lower amount of bacteria in the treatment systems during this time, as indicated by the lower numbers of TC, EC, and EN (Appendix D), was not sufficient to properly treat the wastewater flowing through the system. Also, these package treatment plants were designed to treat the maximum flow during the summer season. During the winter months, these systems often operate at less than 10 % of the designed flow capacity. It is possible that this decreases a facility's treatment capabilities.

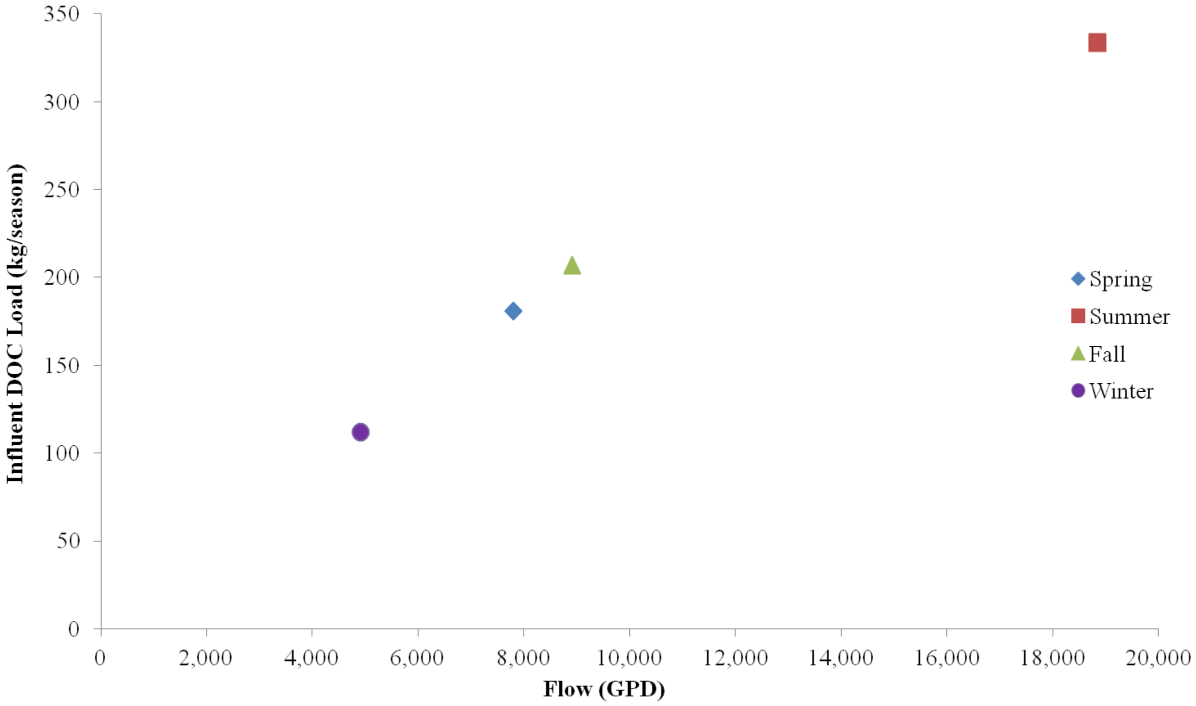

Figure 12: Average seasonal flow compared to the average seasonal influent DOC concentration

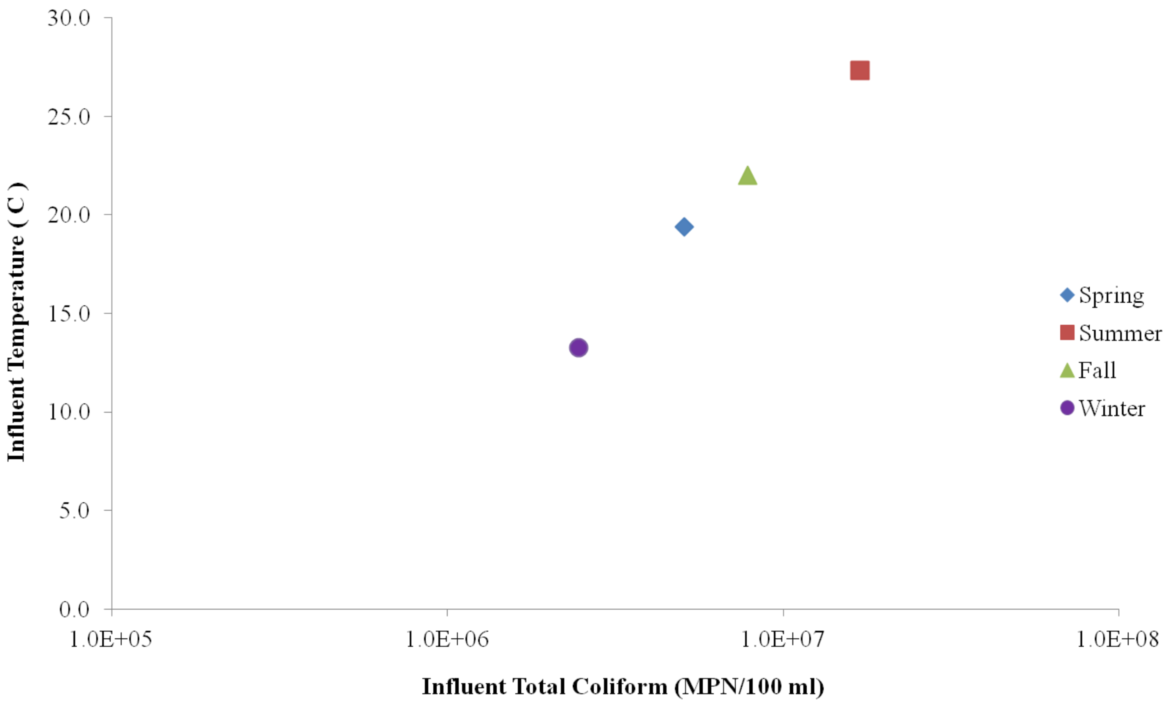

Figure 13: Average seasonal influent TC concentration compared to the average temperature of the influent

Seasonal influent TN loads were highest during the summer for all seven package treatment plants. This can be attributed to higher seasonal TN concentrations along with higher flow rates. Seasonal effluent TN loads had mixed results with different seasons having higher loads for different systems. Extended aeration facilities, for the most part, had their highest loads occur during the winter when flows were the lowest and effluent TN concentrations were the highest (Figure 8). EA-2 had an effluent concentration of nearly 45 mg/l TN during the winter, which was particularly high. This suggests that loads from these systems were affected by effluent concentrations, yet due to the higher flow rates of extended aeration facilities, loads were still higher than loads of the other treatment technologies. The advanced media filtration systems had the opposite response, where loads increased with flow. This suggests that flow had more of an influence on loads than concentrations for these facilities. The sequence batch reactor facilities had their highest loads occur during periods of higher flow when TN concentrations were lowest. This suggests that the N removal of these facilities was more influenced by flow than effluent TN concentrations.

4.2 Phosphorus

The package treatment plants involved in this study are not required to meet an effluent quality standard with respect to phosphorus, and therefore they do not have a component specifically designed for phosphorus removal. Phosphorus is removed during filtering and bacteria immobilization which is removed when sludge and solids are disposed. TP removal was low, relative to TN removal, with only one plant (SBR-2) exceeding a removal percentage of 50% (52.8 %). SBR-1 had an effluent TP concentration of 6.4 mg/l. This was higher than the average influent TP concentration for six of seven treatment plants. This package treatment plant also had the highest influent concentration (8.1 mg/l) and minimal removal (21.2 %), which would explain why the effluent concentrations were so much higher than the other facilities. With only monthly influent and effluent sampling data, the cause for elevated effluent concentrations at this particular site was not determined. The package treatment plants in this study had a lower median effluent TP concentration (2.9 mg/l, n = 84) than the median concentration of septic tank effluent (9.8 mg/l, n = 61) from a literature review evaluating decentralized wastewater treatment systems (WERF, 2009). Although neither treatment method has a specific component designed for phosphorus removal, the filtering/screening process of the package treatment plants removes at least some particulate bound phosphorus from the system.

The effluent phosphorus loads from the package treatment plants were flow dominated rather than concentration dominated. This is evidenced by the extended aeration influent and effluent TP loads. Annually these plants have influent TP loads that ranged from 80 to 130 kg/yr and effluent TP loads that ranged from 48 to 152 kg/yr. All of the other facilities with much smaller permitted flow rates had influent loads that were less than 30 kg/yr and effluent loads that were less than 20 kg/yr. The flow dominated loads can also be observed in the seasonal trends of TP loads. Seasonally, all plants had their highest TP loads occur during the summer when flows were highest (Figure 10). The TP concentrations had a lesser effect on loads than flow. SBR-1 had the highest average influent and effluent TP concentrations with the lowest influent and effluent TP loads.

TP loads were also normalized to compare the loading per unit area of each system. Normalized TP loads ranged from 4.0 to 29.0 kg/ha/yr (Table 11). Once again, an extended aeration plant had the highest normalized load (EA-1, 29 kg/ha/yr). All other normalized TP loads were less than 13 kg/ha/yr. This could be attributed to a moderately high average effluent TP concentration (3.2 mg/l) along with a smaller treatment area (5.24 ha) than the other extended aeration plants (6.41 – 6.92 ha). SBR-2 had the smallest normalized TP load (4.0 kg/ha/yr), but was also the system which had the highest permitted flow of all the non-extended aeration plants (30,500 GPD or 1.2 X 10^5 LPD). The normalized TP loads recorded in this study exceed those of many studies involving TP exports from various land uses in literature (Table 12). Deal et al. (1986) reported TP exports of 0.1 – 0.2 kg/ha/yr from well drained agricultural soils. All seven package treatment plants exceeded these values by one to two orders of magnitude. Gilliam and Skaggs (1986) reported TP exports of 0.5 – 7.6 kg/ha/yr from cropped soils. Five out of seven package treatment plants had TP exports exceeding 7 kg/ha/yr. Line et al. (2002) reported TP exports from golf courses and pasturelands of 5.3 and 4.3 kg/ha/yr respectively. All but one package treatment plant exceeded these values. Although it is generally assumed that phosphorus is sorbed by soils, studies have shown that phosphorus can be mobile in sandy coastal aquifers (Humphrey, 2014; Humphrey, 2015). With the exports recorded in this study comparable to, and often exceeding, land uses that receive much of the focus for reducing phosphorus to receiving waters, it indicates the need for further study of phosphorus exports from these systems. Overall, package treatment plants removed nitrogen more effectively than phosphorus.

4.3 Bacteria

There was not a discernible difference between the disinfection technologies (UV, chlorine, and membrane bioreactor) used in this report. While most of the package treatment plants used either UV light or chlorine for disinfection, EA-2 was permitted to function with a membrane bioreactor (MBR). According to Brepols et al. (2008), the general MBR process involves a combination of suspended growth, activated sludge, and microporous membranes for solid/liquid separation as a substitute for the secondary clarifier. Hirani et al. (2013) found that 90 % (n=38) of MBR facilities sampled had effluent with total coliform concentrations less than 100 CFU/100 ml. EA-2 had a median effluent total coliform concentration of 78 MPN/100 ml. The package treatment plants using chlorine (EA-1, SBR-1, and SBR-2) had a median effluent TC range of 1 – 285 MPN/100 ml and the facilities using UV had a median TC range of 50 – 534 MPN/100 ml.

The median bacteria concentration does not indicate the degree of variance among the indicator bacteria samples. Another way to evaluate these samples was to calculate the percentage of samples that exceeded their permit standard. Most of the state permitted systems had an effluent fecal coliform daily maximum limit of 43 CFU/100 ml while the county systems had a daily maximum limit of 1,000 CFU/100 ml. All package treatment plants were evaluated to these standards regardless of whether they were state or county permitted (Figure 11). According to the state effluent quality limit of 43 CFU/100 ml, six out of seven package treatment plants exceeded this value for at least 25 % of all samples. The one facility that did not exceed this value at least 25 % of the time was EA-2 (17 %), which did not have a component dedicated to disinfection. The package treatment plants using chlorine disinfection had exceedance rates (> 43 CFU/100 ml) of 33 % (EA-1), 25 % (SBR-1), and 50 % (SBR-2). The package treatment plants using UV disinfection had similar results with failure rates of 42 % (EA-3), 25 % (ADV-1), and 50 % (ADV-2). According to the county effluent quality limit of 1,000 CFU/100 ml, only one system (EA-1) exceeded this value at least 25 % of the time. Three facilities (EA-2, EA-3, and ADV-1) never exceeded this value. The reason why state permitted systems are held to a more strict effluent quality standard is because they discharge their effluent on the surface rather than in the subsurface. When the effluent is discharged to the surface there is a potential for human exposure and pollutant migration via runoff. With subsurface discharge the potential for migration is lower and the effluent is discharged directly to the soil system where pollutants can be attenuated.

This study took place in a coastal setting where the migration potential is increased for both surface and subsurface discharged effluents because of sandy permeable soils and a shallow water table. The EPA has recommendations for recreational water quality criteria to help states set bacteria limits to keep recreational swimmers safe from pathogens associated with fecal contaminants. For primary contact recreation, these limits are a geometric mean of 35 CFU/100 ml for *Enterococcus* (marine and fresh waters), and 126 CFU/100 ml for *E. coli* (fresh waters) over a 30 day period (EPA, 2012). They also recommend a statistical threshold value (STV) of 130 CFU/100 ml for *Enterococcus*, and 410 CFU/100 ml for *E. coli*. The STV approximates the

90th percentile of the data, and should not be exceeded by more than 10 % of the samples in the 30 day period. The data collected in this study were not for recreational waters and therefore these standards do not apply directly to wastewater effluent. Also, data from this study represents an accumulation of monthly samples which cannot be applied to the 30 day geometric mean standard. That being said, package treatment plant effluent exceeded these values multiple times (9 of 84 *Enterococcus* samples and 19 of 84 *E. coli* samples, Appendix D) during this study. If the effluent bacteria migrate to surface waters in the area, then individuals coming into contact with these waters may be at risk of becoming ill.

Seasonally, effluent bacteria concentrations were generally higher during the spring and summer months for all constituents. It is possible that the increased effluent bacteria concentrations during the summer season could be related to decreased disinfection capability caused by increased organic matter (affecting chlorine disinfection) and TSS (affecting UV disinfection) associated with higher flows (Gerardi, 2002). Package treatment plants using chlorine disinfection might not be using enough of the chemical to treat the amount of bacteria present. Package treatment plants using UV disinfection might have trouble creating direct exposure between the UV light and the increased amount of microorganisms. With effluent bacteria concentrations being higher during summer, there could potentially be a greater risk for human pathogen infection during this time. More people will be swimming and participating in recreational water activities during these warmer months when water temperatures are highest. Studies have shown that pathogens are capable of subsurface survival and migration (Sobsey, 1980; Yates, 1987; Jansons, 1989; Bitton and Harvey, 1992), although the survival times and migration potential vary from organism to organism and with soil composition. All these studies agree that sandy, porous, and loosely compacted soils have a higher potential for pathogen survival and migration. Also, saturated soils and heavy flow volumes can decrease the chances of pathogen attenuation.

Although these studies do not focus on a residence time for pathogen subsurface survival, some pathogens can persist over 100 days in a contaminated aquifer (Yates, 1987). With the higher concentrations of bacteria in wastewater effluent during the summer, a short residence time could increase the risk of human infection during recreational water activities. In this thesis, residence time of the surficial aquifer was estimated to determine how long it would take for effluent discharge to reach the nearest surface waters. This was accomplished by using Darcy's Law to account for linear groundwater velocity (Equation 2), and using surficial aquifer properties from the literature and state monitoring programs (Healy and Cook, 2002; Humphrey et al., 2011; NCDEQ Monitoring Well Records, 2013 – 2014) that involved studies conducted in similar conditions (Table 15).

The residence time in the surficial aquifer from the drainfield of the package treatment plants to the nearest surface waters was estimated to be 323 days (Estimate 1, Table 16). If the values used to calculate the residence time are altered by plus or minus one standard deviation, then the residence time could range from 85 to 1,800 days (Estimates 2 and 3, Table 16). This is assuming that the groundwater flows in a straight line from the drainfield to surface water through a surficial aquifer of homogenous composition. Although this is a rough estimation, under these conditions it could be possible for subsurface pathogen survival and eventual discharge to the surrounding surface waters. High bacterial concentrations have been recorded in the surface waters of the area, and are often attributed to wastewater treatment systems (Nearhoof and Cahoon, 2000). It is possible that package treatment plant pathogens affect local surface water quality. In addition, for surface application sites the possibility of overland flow during extreme events could also transport pathogens to nearby surface waters.

Table 15: Data used to calculate residence time (groundwater elevation, horizontal hydraulic conductivity, effective porosity, and distance from package treament plant drainfields)

Groundwater Elevation (m)						
Site	**Well ID**	**Samples**	**Mean**	**Median**	**Standard Deviation**	**Source**
EA-1	MW-1	7	3.3	2.9	1.24	NC DEQ Records for Monitoring Wells (2013 - 2014)
	MW-2	7	2.0	1.4	0.15	
	MW-3	7	2.7	2.5	0.10	
	MW-4	7	2.0	1.3	0.08	
	All	28	2.5	2.3	1.09	
EA-3	MW-1	6	2.1	2.1	0.17	
	MW-2	4	2.0	2.1	0.22	
	MW-3	5	1.8	1.9	0.30	
	All	15	2.0	2.0	0.26	
SBR-2	MW-1	6	3.0	3.0	0.09	
	MW-2	6	3.7	3.7	0.09	
	MW-3	6	2.9	2.9	0.12	
	MW-4	6	3.5	3.5	0.09	
	All	24	3.3	3.0	0.64	
Total		76	2.7	2.7	0.94	
Horizontal Hydraulic Conductivity (m/day)						
Location	**Soil ID**	**Samples**	**Mean**	**Median**	**Standard Deviation**	**Source**
Atlantic Beach & Pine Knoll Shores	Fripp	2	5.2	5.2	-	Humphrey (2011)
	Newhan	3	4.0	4.8	2.29	
Total		5	4.5	4.8	2.89	
Effective Porosity						
Soil	**Count**	**Value**	**Mean**	**Median**	**Standard Deviation**	**Source**
Fine sand	17	0.10 - 0.28	0.21	-	0.05 *	Healy and Cook (2002)
Distance from Drainfield to Surface Water (m)						
Site	**Count**	**Mean**	**Median**		**Standard Deviation**	**Source**
Package Treatment Plant Drainfields	9	138.9	125		42.28	Mahoney (2016)

*** Individual data for effective porosity samples was unavailable so the standard deviation was absent. A value of +/- 0.05 of the mean was used to calculate the "best" and "worse" case scenarios.**

Table 16: Surficial aquifer residence time estimations

Variables	Estimation Scenarios		
	1[a]	2[b]	3[c]
K (m/d)	4.5	7.4	1.6
Effective Porosity	0.21	0.26	0.16
dh (m)	2.7	3.6	1.8
dl (m)	140	100	180
Residence Time (d)	323	85	1,800

[a] Best estimate for residence time using mean values
[b] Worst case scenario using + 1 standard deviation for K, effective porosity, dh, and –1 standard deviation for dl
[c] Best case scenario using – 1 standard deviation for K, effective porosity, dh, and + 1 standard deviation for dl

4.4 Addressing Hypotheses

Hypothesis 1: Package treatment plant treatment efficiency, effluent quality, and nutrient loading will vary based on treatment technology and seasonality.

The results of this study showed variation in package treatment plant treatment efficiency, effluent quality, and nutrient loads among the differing treatment technologies and seasonally, thus supporting Hypothesis 1. Some package treatment plants had a high average nitrogen removal efficiency (EA-1, EA-3, ADV-2, SBR-1, and SBR-2 all exceeded 75 % TN removal) while others did not (EA-2 and ADV-1 had < 60 % TN removal). Seasonally, nitrogen removal efficiency was significantly higher during the summer than winter. Some package treatment plants had a low average effluent TN concentration throughout the study while others did not (EA-1, EA-3, and ADV-2 had an average effluent TN concentration of 7 mg/l while EA-2 had nearly 25 mg/l). Seasonally, effluent TN concentrations were significantly lower during the summer than winter. With respect to nutrient loads, extended aeration plants had much higher annual effluent loads of nitrogen and phosphorus (> 100 kg/yr TN; > 50 kg/yr TP) compared to the advanced media filtration and sequence batch reactor plants (< 60 kg/yr TN; < 20 kg/yr TP). Seasonally, nutrient loads were generally higher during the summer rather than winter due to increased flows associated with greater tourist populations during the summer. This was especially evident with phosphorus loads. Nitrogen loads followed this trend for most package treatment plants, however, EA-1 and EA-2 had their highest loads occur during winter.

The seasonal relationship between TN concentrations, loads, and treatment efficiencies was heavily influenced by flow. During the summer when flows were high, treatment efficiencies and loads were generally higher while effluent concentrations were generally lower. During the winter when flows were low, treatment efficiencies and loads were generally lower while effluent concentrations were higher.

Hypothesis 2: Package treatment plant nutrient exports on a unit area basis can be comparable to agricultural nutrient exports.

Chapter 4.1 discussed how normalized TN loads from the package treatment plants in this study often exceeded TN loads from various land uses that are commonly recognized as threats to surface water quality. Those estimates were for the amount of TN that is discharged onsite, but they do not account for attenuation or give a prediction to what percent of those loads actually reach the surface waters of the area. TN exports from these systems that could potentially reach the local surface waters were estimated here, thus supporting Hypothesis 2. This was accomplished by using an equation (as previously mentioned; see Equation 1, p.25) to estimate the percentage of TN potentially attenuated in the subsurface and the overall TN load that could reach nearby surface waters (Table 17). The equation used was obtained from literature where tracers were used to estimate TDN attenuation in the subsurface downgradient from onsite wastewater treatment system drainfields. These studies were performed in coastal areas where the sandy soils are similar to those in Bogue Banks. For this study, the distance from each package treatment plant drainfield to the nearest surface water was measured using Google Earth. The setback distance was then plugged into Equation 1 to estimate the percent of the TN load that would be attenuated. Estimated TN attenuation ranged from 54 – 67 %. The remaining TN was assumed to reach the nearest surface water. Based on these attenuation values, the smaller package treatment plants (advanced media filtration and sequence batch reactor facilities) could contribute 6.3 – 20.6 kg of TN annually to surface waters. The larger extended aeration systems could contribute 36.8 – 114.6 kg of TN. The difference between package treatment plant loads that were discharged onsite and the amount that could potentially reach surface waters can be observed in Figure 14. When TN exports are normalized to the package treatment plant land area, exports that could potentially reach surface waters range from 4.7 – 21.9 kg/ha/yr. The two largest package treatment plants (EA-1 and EA-2) have the highest normalized exports with 14.8 – 21.9 kg/ha/yr potentially reaching surface waters. The remaining package treatment plants had normalized exports lower than 12.3 kg/ha/yr.

Table 17: Estimates of TN load attenuation and potential TN migration to surface waters

Site	Distance to Surface Water (m)	Buffer Description	Annual Load (kg)	Normalized Load (kg/ha/yr)	Estimated Attenuation (%)	Annual Load to Surface Water (kg)	Normalized Load to Surface Water (kg/ha/yr)
EA-1`	60 - 120	trees and marsh (50 - 100 m)	249.0	47.5	54 - 62	94.6 - 114.6	18.1 - 21.9
EA-2	200	none (impervious and sand dunes)	309.7	44.8	67	102.2	14.8
EA-3	140 - 180	Mix of trees and impervious	108.4	16.9	64 - 66	36.8 - 39.0	5.7 - 6.1
ADV-1	125	none (impervious and sand dunes)	55.7	33.3	63	20.6	12.3
ADV-2	120	none (dune shrubs)	27.3	12.4	62	10.4	4.7
SBR-1	125	minor trees and impervious	17.0	19.1	63	6.3	7.1
SBR-2	180	trees and impervious	41.4	14.1	66	14.1	4.8

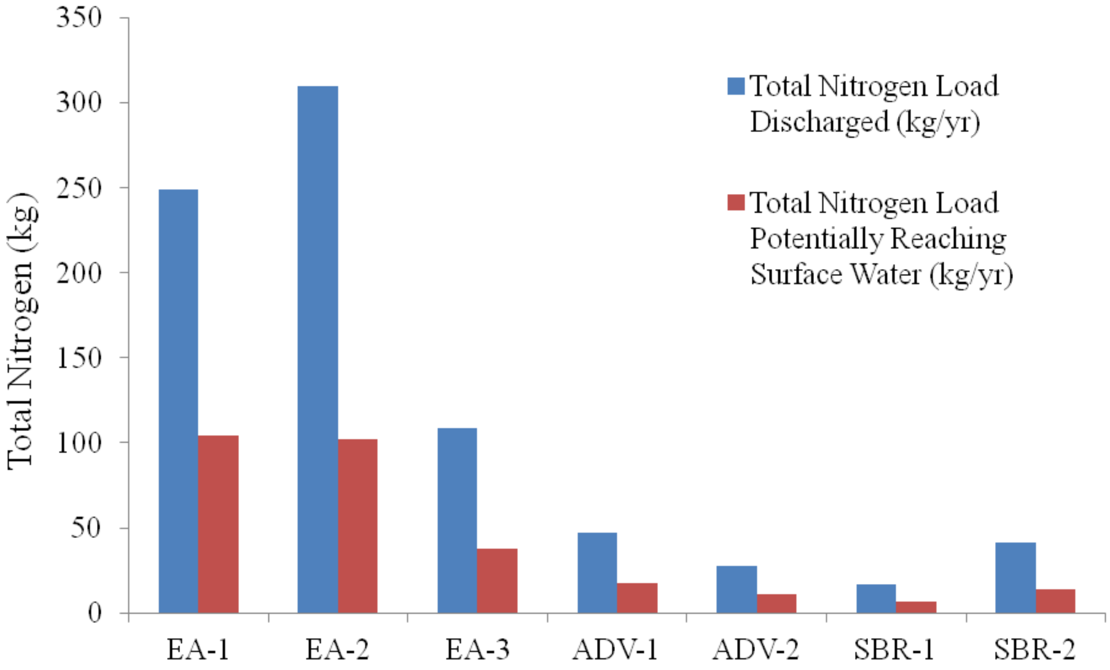

Figure 14: Total nitrogen discharged from each package treatment plant vs. the amount that could potentially reach surface waters

This analysis is a rough estimation and there are factors that could contribute to higher or lower attenuation values such as soil type and buffer presence. The soils on Bogue Banks are all rated severe for sanitary facilities. A severe rating is used for soils that are extremely unfavorable, difficult to manage, and may require special construction or maintenance to accommodate a sanitary facility (USDA, 1987). The soils on the sound side of Bogue Banks are commonly poorly draining and the water table is often at or near the surface. These soils are susceptible to overland flow and flooding, and the nitrogen in package treatment plant effluent could be minimally attenuated in these conditions. The sound side of the island also has abundant marshland which can have soils with high organic matter content and shallow groundwater with low dissolved oxygen. These settings would promote denitrification of the effluent. The ocean side of Bogue Banks has soils that are very permeable and have rapid drainage. These conditions promote the migration of nitrogen through the subsurface and little attenuation is to be expected. Another factor that can affect nitrogen attenuation is the presence of a buffer. If there is a buffer with abundant vegetation then nitrogen may be attenuated by the plants. Most of the package treatment plants in this study have a poor buffer with impervious surfaces and/or sparse vegetation.

Barrier islands are dynamic systems that are constantly being altered by environmental conditions, and migrate over time (Anderson, 2000). Surficial aquifer modeling of these islands is often oversimplified and hydrogeologic conditions are commonly assumed to be homogenous and isotropic, which is not always accurate (Anderson, 2000). Nitrogen attenuation estimations presented in this thesis assume that the groundwater flow path is in a straight line from the package treatment plant drainfield to surface water, and that the surficial aquifer is homogenously composed of fine to coarse grained sands. It is possible, however, that the groundwater of the surficial aquifer flows through beds of buried organic matter along some of these flow paths. On the barrier islands of the Outer Banks of North Carolina, areas where organic matter is often present as relict wetlands that have been buried by the aeolian transport of sediment (Anderson, 2000). This could increase the nitrogen attenuation and denitrification potential of the sediments, and the estimates presented in this report could be reduced.

CHAPTER 5: CONCLUSIONS

This study quantified package treatment plant nutrient and bacteria exports in a barrier island setting. However, there were some limitations to the study. There were only seven package treatment plants included in this study and three different treatment technologies evaluated. With thirty-seven package treatment plants on Bogue Banks, this is a relatively small sample size to accomplish this objective. Future work should use a larger number of systems and could synthesize monitoring data collected by the counties and state to achieve a better understanding of package treatment plant water quality and potential nutrient exports. Another limitation to the project was the time constraint. There was enough funding to collect samples monthly, which only provides a snapshot estimate of the package treatment plants performance at one moment in time each month. If the package treatment plant was performing unusually poorly for the day of sample collection, then that performance was represented for the entire month. Daily or sub-daily sampling of these package treatment plants would yield more representative results which may differ from those represented by this report. Frequent sampling was, however, unfeasible for this project. Gathering continuous data with water quality sondes could provide better information about the processes that take place within the various stages of the package treatment plants over time, rather than having data from just the inlet and outlet of the system. Flow was an important factor in package treatment plant loading and it would be helpful to have more samples collected during high-flow periods. A continuous logging flow meter would also be beneficial to understanding how wastewater is cycled through these facilities.

Wastewater pollutants pose a significant risk to ground and surface water quality. This risk is heightened in a coastal environment due to conditions that are not always suitable for nutrient and pathogen attenuation. Additionally, the coastal population and sea level are both predicted to rise in the near future. In 2010, nearly thirty-nine percent of the United States population lived in counties that border the ocean (National Oceanic and Atmospheric Administration, 2015). By 2020, this population is expected to increase by eight percent which would put nearly half the population of the country living in coastal counties (National Oceanic and Atmospheric Administration, 2015). This almost assuredly will increase the population density on barrier islands like the Bogue Banks of North Carolina. Being that package treatment plants are commonly used in these settings, it is likely that more of these systems will be implemented to treat the increased amount of wastewater being generated by this influx of people. According to the International Panel on Climate Change (IPCC), the global mean sea level will continue to rise through the end of the 21st century at an increasing rate (Wong et al, 2014). This will "very likely" affect the coastal United States, including its barrier islands and coastal aquifers (Wong et al, 2014). If sea level rises, the depth to the water table in barrier island settings could decrease significantly leading to inundation or a decrease in the vadose zone (Masterson, 2014; Walter, 2016). This could be problematic for the wastewater treatment systems on Bogue Banks. A decreased vadose zone would leave less room for nutrient and bacteria attenuation and could ultimately increase nutrient and bacteria exports to local surface waters and increase the likelihood of effluent surfacing during storm events.

Future research is needed to validate estimates of nutrient loadings to surface waters relative to loadings from surface and subsurface discharge of package treatment plant effluent. There are several studies that would help to quantify and assess the environmental impact that package treatment plants have in coastal settings. Installing piezometers around and downgradient of these treatment systems would allow a more precise estimation of the fate and transport of package treatment plant nutrients and other pollutants in the subsurface. Wastewater nitrate has been correlated with the presence of organic wastewater compounds such as pharmaceuticals, antibiotics, birth control, etc. (Schaider et al. (2015). The installation of piezometers would allow one to test for the presence and concentration of these pollutants in groundwater of the surficial aquifer and to refine hydraulic conductivity and gradient data. Another area of study to explore with these treatment systems is how they are affected by storms, and if treatment efficiency is compromised during these conditions. This could be determined by collecting influent and effluent samples before, during, and after storm events. With so little data available concerning the efficiency of wastewater treatment by package treatment plants in sensitive coastal settings, there is an abundance of other studies that could be conducted to further benefit the understanding of the treatment capability of these systems.

Package treatment plants are capable of treating wastewater to an acceptable level, yet results vary across treatment technologies and over time. The seasonal fluctuation in treatment efficiency and effluent quality is also a concern to the reliability of these systems. Future monitoring of package treatment plants should be considered to fully understand the response these systems have to seasonal changes in temperature and wastewater generation. Package treatment plants might perform better in areas where the wastewater inputs are consistent, and the environment is conducive to pollutant attenuation, yet they may not be appropriate for certain coastal settings. The North Carolina Division of Water Resources and the Carteret County Department of Environmental Health and Services should consider implementing a phosphorus removal component to package treatment plants to help reduce phosphorus loading to the environment.

There is very little synthesis of data on package treatment plant performance and influent and effluent constituents. Much of the data that is currently available is dated, and has been conducted in a small variety of settings. It would be beneficial to the understanding of these systems if future studies were conducted. County, state, and federal agencies should take package treatment plant nutrient exports into consideration when developing nutrient management strategies.

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APPENDIX A: INFLUENT AND EFFLUENT NITROGEN CONSTITUENTS

*Data marked with asterisk was either above or below the limit of detection for that particular analysis. The lower limit of detection for NH4 was 0.04 mg/l therefore any sample recorded with this value was assumed to be equal to 0.02 mg/l. The lower limit of detection for NO3 was 0.007 mg/l therefore any sample recorded with this value was assumed to be equal to 0.0035 mg/l. The upper limit of detection for NO3 was 35.0 mg/l, but there was no value substituted for samples reaching this limit. Data labeled as “No Sample” was corrupted during analysis, unobtained due to equipment failure, or lost prior to analysis.

EA-1 Nitrogen Constituents (mg/l)

	NH4		**NO3 + NO2**		**DON**		**TDN**		**PN**		**TN**	
Date	**Influent**	**Effluent**	**Influent**	**Effluent**	**Influent**	**Effluent**	**Influent**	**Effluent**	**Influent**	**Effluent**	**Influent**	**Effluent**
2/19/14	11.72	0.10	0.08	23.13	7.23	0.00	19.04	23.23	6.13	0.35	25.16	23.58
3/12/14	33.59	0.32	0.09	10.41	0.00	3.59	33.67	14.32	5.18	0.20	38.85	14.52
4/21/14	25.25	0.90	0.00*	2.22	5.49	0.10	30.74	3.21	10.12	0.18	40.86	3.39
5/27/14	22.73	No Sample	0.00*	No Sample	3.10	No Sample	25.84	No Sample	9.52	0.11	35.36	No Sample
6/23/14	26.65	0.03	0.02	2.53	0.00	0.35	26.67	2.91	7.11	0.08	33.78	2.99
7/21/14	40.40	0.19	0.00*	2.78	0.00	0.00	40.40	2.97	9.39	0.19	49.78	3.16
8/18/14	29.53	0.18	0.00*	1.15	0.00	0.00	29.54	1.33	5.39	0.10	34.93	1.43
9/22/14	16.92	0.11	0.00*	5.70	0.00	0.00	16.92	5.80	8.86	0.16	25.78	5.96
10/20/14	21.25	0.11	0.00*	2.71	4.13	1.21	25.38	4.03	7.21	0.19	32.59	4.22
11/17/14	11.35	1.08	0.01	2.30	0.85	0.93	12.22	4.31	8.42	0.24	20.64	4.56
12/8/14	4.54	0.03	0.13	2.88	2.43	0.21	7.11	3.12	2.75	0.12	9.86	3.24
1/20/15	10.60	0.04	0.07	9.26	5.07	1.55	15.74	10.85	3.87	0.18	19.61	11.03
Average	21.21	0.28	0.03	5.92	2.36	0.72	23.61	6.92	7.00	0.18	30.60	7.10
Median	21.99	0.11	0.01	2.78	1.64	0.21	25.61	4.03	7.16	0.18	33.18	4.22
Std. Dev.	10.59	0.36	0.04	6.46	2.61	1.10	9.61	6.66	2.37	0.07	10.87	6.72

EA-2 Nitrogen Constituents (mg/l)

	NH4		**NO3 + NO2**		**DON**		**TDN**		**PN**		**TN**	
Date	**Influent**	**Effluent**	**Influent**	**Effluent**	**Influent**	**Effluent**	**Influent**	**Effluent**	**Influent**	**Effluent**	**Influent**	**Effluent**
2/19/14	24.34	0.85	0.07	34.14	3.39	0.00	27.80	34.98	4.92	0.06	32.72	35.04
3/12/14	67.18	0.04	0.20	35.00 *	0.00	0.00	67.38	35.04	6.60	0.02	73.98	35.06
4/21/14	39.32	0.05	0.00 *	30.93	9.47	0.00	48.80	30.98	11.19	0.02	59.99	31.00
5/27/14	38.38	0.03	0.00 *	2.50	5.57	0.67	43.96	3.20	15.31	0.02	59.27	3.22
6/23/14	63.37	0.01	0.00 *	4.15	0.00	0.17	63.38	4.32	11.20	0.01	74.58	4.33
7/21/14	65.78	0.78	0.00 *	0.64	0.04	0.71	65.82	2.14	10.35	0.02	76.17	2.15
8/18/14	57.00	0.04	0.02	6.12	0.00	0.00	57.01	6.16	9.52	0.03	66.54	6.19
9/22/14	29.41	0.05	0.00 *	8.98	0.00	0.00	29.41	9.03	5.14	0.02	34.55	9.05
10/20/14	26.15	0.03	0.03	14.58	4.04	0.96	30.21	15.56	8.82	0.02	39.03	15.58
11/17/14	41.73	0.03	0.33	20.57	1.44	34.27	43.50	54.86	10.21	0.03	53.71	54.89
12/8/14	26.82	0.03	0.40	24.96	7.97	29.14	35.19	54.13	6.92	0.04	42.11	54.17
1/20/15	31.77	0.01	0.06	21.17	9.99	24.17	41.82	45.36	6.39	0.03	48.21	45.39
Average	42.60	0.16	0.09	16.98	3.49	7.51	46.19	24.65	8.88	0.03	55.07	24.67
Median	38.85	0.03	0.02	17.57	2.42	0.42	43.73	23.27	9.17	0.02	56.49	23.29
Std. Dev.	16.39	0.31	0.14	12.57	3.90	13.26	14.40	20.26	3.03	0.01	15.81	20.26

EA-3 Nitrogen Constituents (mg/l)

	NH4		NO3 + NO2		DON		TDN		PN		TN	
Date	**Influent**	**Effluent**	**Influent**	**Effluent**	**Influent**	**Effluent**	**Influent**	**Effluent**	**Influent**	**Effluent**	**Influent**	**Effluent**
2/19/14	13.11	0.30	0.40	2.05	7.83	7.13	21.34	9.48	17.14	0.30	38.48	9.79
3/12/14	37.87	0.01	1.75	9.28	0.00	1.85	39.62	11.13	42.24	0.02 *	81.86	11.15
4/21/14	17.20	1.17	1.05	7.12	No Sample	0.00	No Sample	8.29	121.89	0.06	No Sample	8.36
5/27/14	20.94	14.14	0.27	0.44	14.41	0.20	35.62	14.78	6.06	0.21	41.68	14.98
6/23/14	44.30	7.02	0.01	0.43	0.00	0.64	44.32	8.09	38.33	0.12	82.65	8.20
7/21/14	85.29	0.11	0.07	6.21	0.00	0.00	85.36	6.33	7.31	0.05	92.67	6.38
8/18/14	89.72	0.05	0.00 *	3.61	0.00	0.00	89.73	3.65	11.52	0.03	101.25	3.68
9/22/14	26.06	0.07	0.00 *	1.55	0.00	0.00	26.07	1.62	52.20	0.09	78.27	1.71
10/20/14	28.68	0.08	0.00 *	1.24	0.80	1.78	29.48	3.10	22.58	0.05	52.06	3.16
11/17/14	11.77	0.05	0.01	0.46	1.77	2.15	13.55	2.66	8.81	0.12	22.36	2.78
12/8/14	25.60	0.84	0.01	0.25	7.32	1.43	32.94	2.52	8.99	0.32	41.93	2.84
1/20/15	24.45	2.76	0.00 *	6.72	9.76	1.95	34.22	11.42	6.86	0.11	41.08	11.53
Average	35.42	2.22	0.30	3.28	3.81	1.43	41.11	6.92	28.66	0.12	61.30	7.05
Median	25.83	0.21	0.01	1.80	0.80	1.03	34.22	7.21	14.33	0.10	52.06	7.29
Std. Dev.	26.06	4.26	0.63	3.21	5.12	2.00	24.48	4.27	33.32	0.10	26.53	4.28

ADV-1 Nitrogen Constituents (mg/l)

	NH4		NO3 + NO2		DON		TDN		PN		TN	
Date	**Influent**	**Effluent**	**Influent**	**Effluent**	**Influent**	**Effluent**	**Influent**	**Effluent**	**Influent**	**Effluent**	**Influent**	**Effluent**
2/19/14	40.37	0.02	0.05	35.00 *	0.00	0.00	40.42	35.02	8.91	0.14	49.34	35.17
3/12/14	23.01	0.06	0.00 *	33.74	0.00	0.00	23.02	33.80	3.49	0.04	26.51	33.84
4/21/14	39.32	0.06	0.03	28.03	1.33	0.00	40.68	28.09	5.17	0.02 *	45.85	28.11
5/27/14	35.72	0.39	0.00 *	19.64	3.28	0.00	39.00	20.03	5.90	0.05	44.90	20.08
6/23/14	36.91	0.07	0.00 *	17.47	3.63	0.00	40.54	17.54	6.60	0.07	47.14	17.62
7/21/14	32.41	0.08	0.00 *	9.58	1.40	0.00	33.82	9.66	6.52	0.07	40.34	9.73
8/18/14	42.31	0.05	0.00 *	8.22	0.00	0.00	42.31	8.27	10.22	0.10	52.54	8.38
9/22/14	28.19	0.05	0.05	8.26	0.00	0.00	28.24	8.30	7.70	0.07	35.94	8.37
10/20/14	23.53	0.05	0.05	6.16	2.66	0.43	26.24	6.63	3.47	0.06	29.71	6.70
11/17/14	25.41	0.03	0.24	6.37	1.74	1.24	27.39	7.64	2.87	0.06	30.26	7.70
12/8/14	20.68	0.07	0.15	8.37	9.04	0.97	29.87	9.40	2.69	0.04	32.56	9.44
1/20/15	18.52	0.03	0.06	7.84	6.63	0.73	25.22	8.61	3.24	0.06	28.46	8.67
Average	30.53	0.08	0.05	15.72	2.48	0.28	33.06	16.08	5.57	0.07	38.63	16.15
Median	30.30	0.05	0.04	8.97	1.57	0.00	31.85	9.53	5.54	0.06	38.14	9.59
Std. Dev.	8.33	0.10	0.07	10.92	2.86	0.45	7.16	10.70	2.51	0.03	9.14	10.70

ADV-2 Nitrogen Constituents (mg/l)

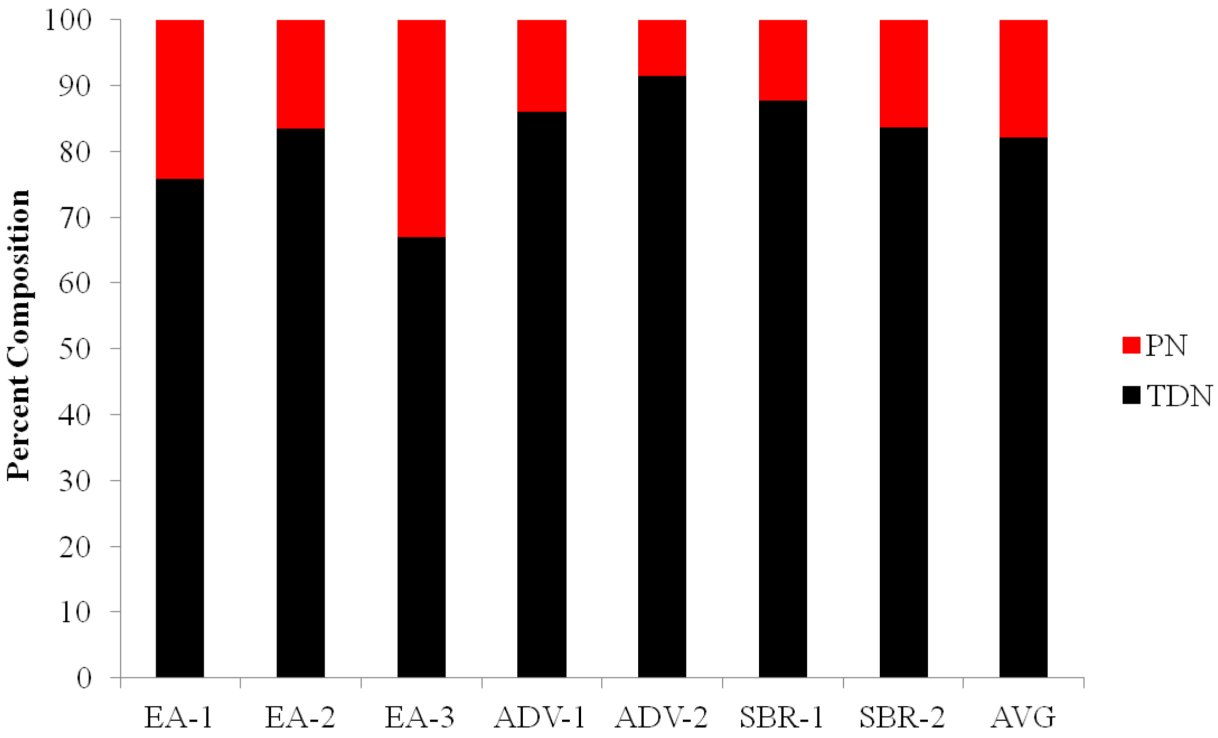
	NH4		NO3 + NO2		DON		TDN		PN		TN	
Date	**Influent**	**Effluent**	**Influent**	**Effluent**	**Influent**	**Effluent**	**Influent**	**Effluent**	**Influent**	**Effluent**	**Influent**	**Effluent**
2/19/14	37.69	0.02	0.14	4.07	7.25	6.79	45.08	10.88	2.33	0.04	47.41	10.93
3/12/14	48.92	0.00 *	0.01	5.61	0.00	4.89	48.93	10.51	4.30	0.02	53.24	10.53
4/21/14	26.88	0.03	0.04	9.91	5.84	0.00	32.76	9.94	3.35	0.02	36.11	9.96
5/27/14	31.74	0.61	0.00 *	9.13	10.64	0.00	42.38	9.74	5.77	0.02	48.15	9.76
6/23/14	35.12	0.36	0.19	7.00	8.89	0.00	44.20	7.35	6.04	0.03	50.24	7.38
7/21/14	50.79	1.58	0.11	2.68	16.40	0.33	67.30	4.60	7.05	0.04	74.35	4.63
8/18/14	35.89	0.32	0.00 *	5.04	0.00	0.00	35.89	5.35	5.49	0.04	41.39	5.39
9/22/14	45.02	0.03	0.00 *	6.87	0.00	0.00	45.02	6.91	4.41	0.04	49.43	6.94
10/20/14	37.56	0.02	0.00 *	6.90	0.13	0.50	37.70	7.42	2.21	0.04	39.91	7.46
11/17/14	34.21	0.04	0.00 *	4.15	0.00	1.07	34.21	5.26	3.53	0.04	37.74	5.30
12/8/14	35.95	0.02	0.02	2.47	14.17	0.24	50.14	2.74	3.51	0.04	53.65	2.78
1/20/15	42.83	0.03	0.00 *	4.18	16.53	0.30	59.36	4.51	2.33	0.03	61.69	4.54
Average	38.55	0.25	0.04	5.67	6.65	1.18	45.25	7.10	4.19	0.03	49.44	7.13
Median	36.76	0.03	0.01	5.33	6.55	0.27	44.61	7.13	3.92	0.04	48.79	7.16
Std. Dev.	7.05	0.46	0.07	2.36	6.68	2.24	10.25	2.69	1.61	0.01	10.79	2.68

SBR-1 Nitrogen Constituents (mg/l)

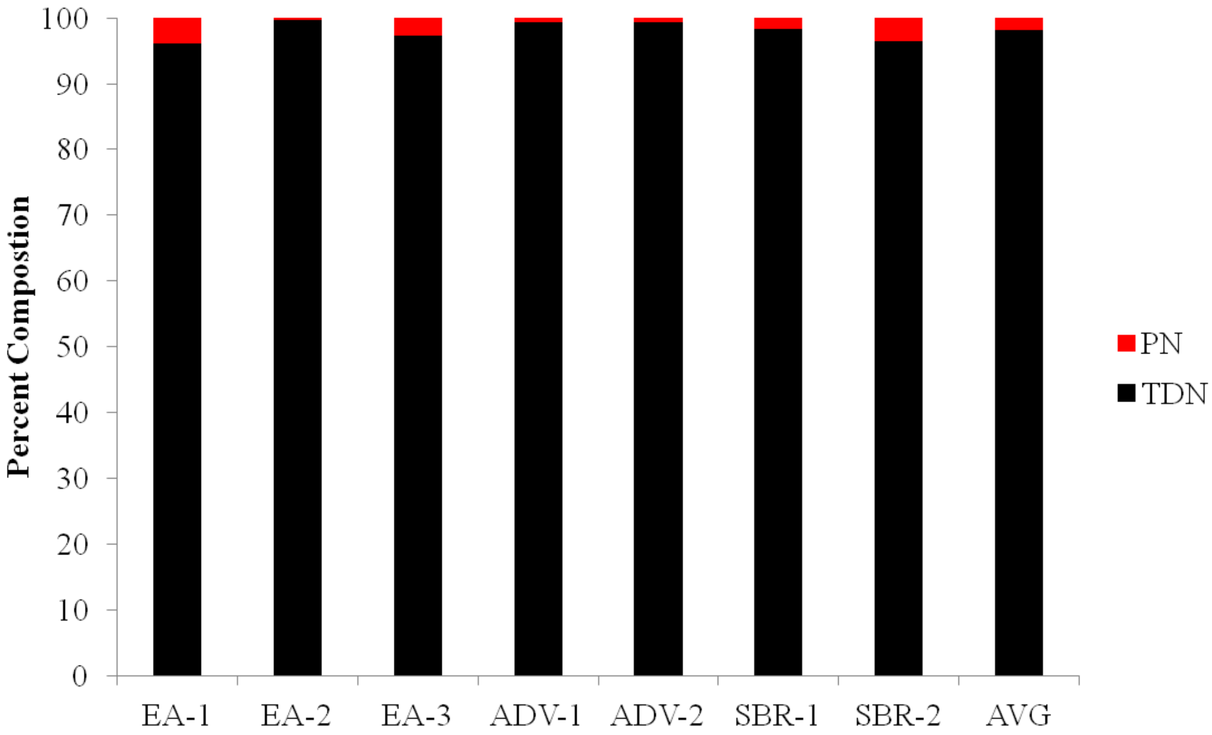
	NH4		NO3 + NO2		DON		TDN		PN		TN	
Date	**Influent**	**Effluent**	**Influent**	**Effluent**	**Influent**	**Effluent**	**Influent**	**Effluent**	**Influent**	**Effluent**	**Influent**	**Effluent**
2/19/14	27.68	0.80	0.02	8.97	4.49	5.31	32.20	15.08	1.13	0.08	33.33	15.17
3/12/14	22.68	5.19	0.13	5.56	16.79	4.51	39.60	15.26	2.55	0.40	42.15	15.67
4/21/14	47.02	0.09	0.00 *	7.69	3.23	1.34	50.26	9.13	13.06	0.19	63.32	9.32
5/27/14	25.11	No Sample	3.30	No Sample	4.31	No Sample	32.72	No Sample	4.32	0.11	37.04	No Sample
6/23/14	47.04	0.04	0.00 *	8.17	4.98	1.24	52.02	9.45	6.44	0.06	58.46	9.52
7/21/14	127.26	0.18	0.00 *	18.40	0.00	0.00	127.26	18.58	10.30	0.35	137.56	18.93
8/18/14	19.89	0.05	0.00 *	7.87	0.00	0.00	19.89	7.92	2.98	0.17	22.87	8.09
9/22/14	34.22	0.07	0.00 *	10.82	0.00	0.00	34.22	10.89	18.86	0.27	53.08	11.16
10/20/14	5.15	0.06	0.06	7.95	2.73	1.69	7.94	9.70	0.77	0.10	8.71	9.79
11/17/14	43.05	0.00 *	0.01	8.74	0.00	10.36	43.06	19.11	7.85	0.08	50.90	19.19
12/8/14	66.06	0.18	0.02	8.90	18.61	5.62	84.68	14.70	4.06	0.37	88.74	15.07
1/20/15	48.29	0.05	0.01	0.70	13.21	3.22	61.50	3.98	6.38	0.11	67.88	4.08
Average	42.79	0.61	0.30	8.53	5.70	3.03	48.78	12.16	6.56	0.19	55.34	12.36
Median	38.63	0.07	0.01	8.17	3.77	1.69	41.33	10.89	5.35	0.14	51.99	11.16
Std. Dev.	31.19	1.54	0.95	4.18	6.71	3.21	31.60	4.73	5.33	0.13	33.51	4.78

SBR-2 Nitrogen Constituents (mg/l)

	NH4		NO3 + NO2		DON		TDN		PN		TN	
Date	**Influent**	**Effluent**	**Influent**	**Effluent**	**Influent**	**Effluent**	**Influent**	**Effluent**	**Influent**	**Effluent**	**Influent**	**Effluent**
2/19/14	49.02	0.01	0.02	17.65	0.00	0.00	49.04	17.66	4.01	0.30	53.06	17.97
3/12/14	56.00	0.21	0.24	9.54	0.00	4.14	56.24	13.89	2.15	0.52	58.39	14.41
4/21/14	45.31	0.09	0.00 *	7.63	0.15	0.28	45.46	8.00	27.12	0.38	72.58	8.38
5/27/14	37.97	0.20	0.00 *	5.54	6.94	0.00	44.92	5.74	3.74	0.48	48.66	6.22
6/23/14	6.85	0.61	0.54	9.77	1.39	0.00	8.78	10.39	53.80	0.49	62.59	10.87
7/21/14	39.04	0.04	0.01	4.15	0.00	0.00	39.06	4.19	3.58	0.05	42.64	4.24
8/18/14	49.30	0.21	0.00 *	9.00	0.00	0.00	49.30	9.21	6.70	0.09	56.00	9.30
9/22/14	28.55	0.07	0.01	10.33	0.00	0.00	28.56	10.40	3.35	0.37	31.91	10.77
10/20/14	33.90	0.35	0.00 *	5.87	1.72	1.16	35.63	7.38	2.66	0.20	38.29	7.58
11/17/14	34.11	0.70	0.03	6.66	1.34	1.81	35.48	9.17	2.96	0.38	38.44	9.55
12/8/14	28.95	1.09	0.01	6.13	7.59	0.99	36.55	8.21	2.33	0.49	38.88	8.70
1/20/15	37.90	12.06	0.01	3.84	9.66	4.42	47.56	20.33	1.72	0.64	49.28	20.97
Average	37.24	1.30	0.07	8.01	2.40	1.07	39.71	10.38	9.51	0.37	49.23	10.75
Median	37.93	0.21	0.01	7.14	0.75	0.14	41.99	9.19	3.46	0.38	48.97	9.43
Std. Dev.	12.77	3.40	0.16	3.73	3.52	1.62	12.43	4.73	15.59	0.18	11.89	4.83



Composition of influent total nitrogen (annual mean, n = 12)



Composition of effluent total nitrogen (annual mean, n = 12)

APPENDIX B: INFLUENT AND EFFLUENT PHOSPHORUS CONSTITUENTS

*During laboratory sample analysis, some DP and PP samples generated negative values, which isn’t realistic. These negative values were assumed to equal zero. Some PO4 samples exceeded TP samples, which also isn’t possible as PO4 is included in TP. When this occurred, PO4 was considered to be equal to TP.

EA-1 Phosphorus Constituents (mg/l)										
	PO4		**DP**		**TDP**		**PP**		**TP**	
Date	**Influent**	**Effluent**	**Influent**	**Effluent**	**Influent**	**Effluent**	**Influent**	**Effluent**	**Influent**	**Effluent**
2/19/14	1.29	1.43	0.00	0.00	1.3	1.4	0.4	0.0	1.69	1.43
3/12/14	3.47	2.64	0.00	0.00	3.5	2.6	0.0	0.0	3.47	2.64
4/21/14	3.07	6.43	0.00	0.00	3.1	6.4	0.0	0.0	3.07	6.43
5/27/14	2.66	0.00	0.00	1.76	2.7	1.8	0.0	0.0	2.66	1.79
6/23/14	3.38	2.72	0.00	0.00	3.4	2.7	0.0	0.0	3.38	2.72
7/21/14	3.98	3.84	0.00	0.00	4.0	3.8	0.0	0.0	3.98	3.84
8/18/14	3.58	2.51	0.00	0.54	3.6	3.1	0.0	0.0	3.58	3.09
9/22/14	1.95	4.97	0.00	0.00	2.0	5.0	0.4	0.0	2.31	4.97
10/20/14	2.83	2.85	0.00	0.00	2.8	2.9	0.0	0.0	2.83	2.85
11/17/14	1.58	4.10	0.00	0.00	1.6	4.1	0.0	0.0	1.58	4.10
12/8/14	0.72	2.51	0.00	0.00	0.7	2.5	0.6	0.0	1.35	2.51
1/20/15	1.96	2.57	0.00	0.00	2.0	2.6	0.0	0.0	1.96	2.57
Average	2.54	3.05	0.00	0.19	2.54	3.24	0.11	0.01	2.65	3.25
Median	2.74	2.68	0.00	0.00	2.74	2.78	0.00	0.00	2.74	2.78
Std. Dev.	1.03	1.65	0.00	0.52	1.03	1.40	0.22	0.01	0.87	1.40

EA-2 Phosphorus Constituents (mg/l)										
	PO4		**DP**		**TDP**		**PP**		**TP**	
Date	**Influent**	**Effluent**	**Influent**	**Effluent**	**Influent**	**Effluent**	**Influent**	**Effluent**	**Influent**	**Effluent**
2/19/14	2.72	2.02	0.00	0.00	2.72	2.02	0.00	0.00	2.72	2.02
3/12/14	4.71	5.40	0.00	0.00	4.71	5.40	0.00	0.00	4.71	5.40
4/21/14	4.44	2.86	0.00	0.00	4.44	2.86	0.00	0.00	4.44	2.86
5/27/14	3.41	2.11	0.00	0.00	3.41	2.11	0.00	0.00	3.41	2.11
6/23/14	4.49	2.96	0.00	0.00	4.49	2.96	0.00	0.00	4.49	2.96
7/21/14	5.20	0.75	0.00	0.19	5.20	0.93	0.00	0.01	5.20	0.94
8/18/14	6.09	1.97	0.00	0.09	6.09	2.06	0.00	0.01	6.09	2.07
9/22/14	3.43	3.79	0.00	0.00	3.43	3.79	0.00	0.00	3.43	3.79
10/20/14	3.19	1.76	0.00	0.27	3.19	2.02	0.00	0.01	3.19	2.03
11/17/14	4.07	3.52	0.00	0.00	4.07	3.52	0.00	0.00	4.07	3.52
12/8/14	2.33	3.05	0.00	0.00	2.33	3.05	0.00	0.00	2.33	3.05
1/20/15	2.57	1.61	0.00	0.44	2.57	2.04	0.00	0.01	2.57	2.05
Average	3.89	2.65	0.00	0.08	3.89	2.73	0.00	0.00	3.89	2.73
Median	3.75	2.49	0.00	0.00	3.75	2.49	0.00	0.00	3.75	2.49
Std. Dev.	1.14	1.23	0.00	0.14	1.14	1.15	0.00	0.00	1.14	1.15

EA-3 Phosphorus Constituents (mg/l)

	PO4		DP		TDP		PP		TP	
Date	**Influent**	**Effluent**	**Influent**	**Effluent**	**Influent**	**Effluent**	**Influent**	**Effluent**	**Influent**	**Effluent**
2/19/14	1.92	0.10	0.00	0.33	1.92	0.43	0.05	0.07	1.97	0.50
3/12/14	6.29	0.18	0.00	0.05	6.29	0.23	0.00	0.03	6.29	0.26
4/21/14	6.22	2.39	0.00	0.00	6.22	2.39	0.00	0.00	6.22	2.39
5/27/14	2.95	2.68	0.00	0.00	2.95	2.68	0.00	0.00	2.95	2.68
6/23/14	6.29	3.05	0.00	0.00	6.29	3.05	0.00	0.00	6.29	3.05
7/21/14	4.34	5.03	0.00	0.00	4.34	5.03	0.00	0.00	4.34	5.03
8/18/14	6.38	1.49	0.00	0.16	6.38	1.64	0.00	0.01	6.38	1.66
9/22/14	7.78	2.63	0.00	1.04	7.78	3.68	0.00	0.03	7.78	3.70
10/20/14	2.96	1.76	0.00	0.00	2.96	1.76	0.00	0.00	2.96	1.76
11/17/14	1.43	2.78	0.00	0.00	1.43	2.78	0.54	0.00	1.97	2.78
12/8/14	2.88	0.72	0.00	0.32	2.88	1.04	0.00	0.08	2.88	1.12
1/20/15	2.48	0.77	0.00	1.02	2.48	1.78	0.00	0.02	2.48	1.81
Average	4.33	1.96	0.00	0.24	4.33	2.21	0.05	0.02	4.38	2.23
Median	3.65	2.07	0.00	0.03	3.65	2.09	0.00	0.01	3.65	2.10
Std. Dev.	2.15	1.42	0.00	0.39	2.15	1.37	0.15	0.03	2.08	1.35

ADV-1 Phosphorus Constituents (mg/l)

	PO4		DP		TDP		PP		TP	
Date	**Influent**	**Effluent**	**Influent**	**Effluent**	**Influent**	**Effluent**	**Influent**	**Effluent**	**Influent**	**Effluent**
2/19/14	3.02	1.29	0.00	0.58	3.02	1.87	0.00	0.08	3.02	1.95
3/12/14	3.77	3.13	0.00	0.00	3.77	3.13	0.00	0.00	3.77	3.13
4/21/14	4.36	2.69	0.00	0.00	4.36	2.69	0.00	0.00	4.36	2.69
5/27/14	4.96	3.43	0.00	0.00	4.96	3.43	0.00	0.00	4.96	3.43
6/23/14	5.53	3.57	0.00	0.00	5.53	3.57	0.00	0.00	5.53	3.57
7/21/14	4.37	3.77	0.00	0.00	4.37	3.77	0.00	0.00	4.37	3.77
8/18/14	5.52	2.22	0.00	0.00	5.52	2.22	0.00	0.00	5.52	2.22
9/22/14	4.32	3.65	0.00	0.00	4.32	3.65	0.00	0.00	4.32	3.65
10/20/14	2.74	2.85	0.00	0.00	2.74	2.85	0.00	0.00	2.74	2.85
11/17/14	4.41	2.08	0.00	0.00	4.41	2.08	0.00	0.00	4.41	2.08
12/8/14	3.29	1.97	0.00	0.00	3.29	1.97	0.00	0.00	3.29	1.97
1/20/15	1.89	1.98	0.00	0.00	1.89	1.98	0.00	0.00	1.89	1.98
Average	4.02	2.72	0.00	0.05	4.02	2.77	0.00	0.01	4.02	2.77
Median	4.34	2.77	0.00	0.00	4.34	2.77	0.00	0.00	4.34	2.77
Std. Dev.	1.11	0.81	0.00	0.17	1.11	0.73	0.00	0.02	1.11	0.72

ADV-2 Phosphorus Constituents (mg/l)

	PO4		DP		TDP		PP		TP	
Date	Influent	Effluent	Influent	Effluent	Influent	Effluent	Influent	Effluent	Influent	Effluent
2/19/14	2.22	2.08	0.00	0.00	2.22	2.08	0.00	0.00	2.22	2.08
3/12/14	5.65	3.51	0.00	0.00	5.65	3.51	0.00	0.00	5.65	3.51
4/21/14	4.71	4.11	0.00	0.00	4.71	4.11	0.00	0.00	4.71	4.11
5/27/14	5.57	5.62	0.00	0.00	5.57	5.62	0.00	0.00	5.57	5.62
6/23/14	6.19	4.19	0.00	0.00	6.19	4.19	0.00	0.00	6.19	4.19
7/21/14	6.34	5.26	0.00	0.00	6.34	5.26	0.00	0.00	6.34	5.26
8/18/14	5.15	5.40	0.00	0.00	5.15	5.40	0.00	0.00	5.15	5.40
9/22/14	6.46	5.28	0.00	0.00	6.46	5.28	0.00	0.00	6.46	5.28
10/20/14	4.08	4.79	0.00	0.00	4.08	4.79	0.00	0.00	4.08	4.79
11/17/14	5.16	4.24	0.00	0.00	5.16	4.24	0.00	0.00	5.16	4.24
12/8/14	3.64	4.39	0.00	0.00	3.64	4.39	0.00	0.00	3.64	4.39
1/20/15	5.37	3.21	0.00	0.00	5.37	3.21	0.00	0.00	5.37	3.21
Average	5.04	4.34	0.00	0.00	5.04	4.34	0.00	0.00	5.04	4.34
Median	5.27	4.31	0.00	0.00	5.27	4.31	0.00	0.00	5.27	4.31
Std. Dev.	1.23	1.04	0.00	0.00	1.23	1.04	0.00	0.00	1.23	1.04

SBR-1 Phosphorus Constituents (mg/l)

	PO4		DP		TDP		PP		TP	
Date	Influent	Effluent	Influent	Effluent	Influent	Effluent	Influent	Effluent	Influent	Effluent
2/19/14	9.00	2.18	0.00	0.00	9.00	2.18	0.00	0.00	9.00	2.18
3/12/14	4.91	8.48	0.00	0.00	4.91	8.48	0.00	0.00	4.91	8.48
4/21/14	8.69	0.51	0.00	0.25	8.69	0.75	0.00	0.03	8.69	0.79
5/27/14	5.94	0.00	0.00	2.20	5.94	2.20	0.00	0.02	5.94	2.23
6/23/14	8.24	6.33	0.00	0.00	8.24	6.33	0.00	0.00	8.24	6.33
7/21/14	16.32	13.48	0.00	0.00	16.32	13.48	0.00	0.00	16.32	13.48
8/18/14	4.04	8.97	0.00	0.00	4.04	8.97	0.00	0.00	4.04	8.97
9/22/14	11.72	12.21	0.00	0.00	11.72	12.21	0.00	0.00	11.72	12.21
10/20/14	1.27	6.10	0.00	0.00	1.27	6.10	0.02	0.00	1.29	6.10
11/17/14	7.31	5.61	0.00	0.00	7.31	5.61	0.00	0.00	7.31	5.61
12/8/14	9.46	6.77	0.00	0.00	9.46	6.77	0.00	0.00	9.46	6.77
1/20/15	10.12	0.83	0.00	2.54	10.12	3.37	0.00	0.08	10.12	3.45
Average	8.08	5.96	0.00	0.42	8.08	6.37	0.00	0.01	8.09	6.38
Median	8.46	6.22	0.00	0.00	8.46	6.22	0.00	0.00	8.46	6.22
Std. Dev.	3.89	4.45	0.00	0.92	3.89	3.96	0.01	0.02	3.88	3.94

SBR-2 Phosphorus Constituents (mg/l)										
	PO4		**DP**		**TDP**		**PP**		**TP**	
Date	**Influent**	**Effluent**	**Influent**	**Effluent**	**Influent**	**Effluent**	**Influent**	**Effluent**	**Influent**	**Effluent**
2/19/14	3.33	1.85	0.00	0.00	3.33	1.85	0.00	0.00	3.33	1.85
3/12/14	5.72	1.48	0.00	0.00	5.72	1.48	0.00	0.00	5.72	1.48
4/21/14	5.52	1.54	0.00	0.00	5.52	1.54	0.00	0.00	5.52	1.54
5/27/14	4.54	0.29	0.00	0.00	4.54	No Sample	0.00	0.00	4.54	No Sample
6/23/14	4.18	2.47	0.00	0.00	4.18	2.47	0.93	0.00	5.12	2.47
7/21/14	4.67	1.21	0.00	0.00	4.67	1.21	0.00	0.00	4.67	1.21
8/18/14	5.25	2.77	0.00	0.00	5.25	2.77	0.00	0.00	5.25	2.77
9/22/14	10.05	7.41	0.00	0.00	10.05	7.41	0.00	0.00	10.05	7.41
10/20/14	7.75	2.19	0.00	0.00	7.75	2.19	0.00	0.06	7.75	2.25
11/17/14	8.86	3.70	0.00	0.00	8.86	3.70	0.00	0.00	8.86	3.70
12/8/14	3.98	2.39	0.00	0.00	3.98	2.39	0.00	0.00	3.98	2.39
1/20/15	4.70	2.51	0.00	0.24	4.70	2.76	0.00	0.23	4.70	2.98
Average	5.71	2.48	0.00	0.02	5.71	2.71	0.08	0.02	5.79	2.73
Median	4.97	2.29	0.00	0.00	4.97	2.39	0.00	0.00	5.18	2.39
Std. Dev.	2.08	1.78	0.00	0.07	2.08	1.71	0.27	0.07	2.04	1.71

APPENDIX C: OTHER INFLUENT AND EFFLUENT WATER QUALITY PARAMETERS

EA-1 Other Water Quality Parameters

	pH		Temperature (C)		Specific Conductivity (µs/cm)		DOC (mg/l)		Cl^- (mg/l)	
Date	**Influent**	**Effluent**	**Influent**	**Effluent**	**Influent**	**Effluent**	**Influent**	**Effluent**	**Influent**	**Effluent**
2/19/14	8.01	7.62	14.8	13.2	907	913	23.68	13.25	49.95	98.74
3/12/14	8.23	8.13	16.1	14.6	933	833	22.52	13.51	105.40	76.80
4/21/14	8.06	7.52	20.4	16.4	352	342	141.54	73.28	80.88	83.56
5/27/14	7.75	7.88	26.3	26.5	973	849	42.80	No Sample	68.69	No Sample
6/23/14	7.99	8.12	29.0	29.2	1153	875	32.08	10.02	210.79	114.56
7/21/14	8.05	8.03	29.1	28.8	1043	784	48.84	9.55	125.81	106.15
8/18/14	8.15	8.17	30.3	31.5	1064	853	28.60	9.74	96.86	78.22
9/22/14	7.95	8.06	27.8	25.7	854	792	27.36	10.39	50.91	73.10
10/20/14	8.10	7.88	23.4	20.9	874	783	97.39	69.29	59.67	64.60
11/17/14	7.87	7.60	21.2	16.6	918	895	83.40	72.83	85.24	86.63
12/8/14	7.82	7.66	No Sample	No Sample	234	246	73.25	65.68	50.53	73.42
1/20/15	7.04	7.68	16.3	12.0	914	864	98.55	66.93	84.25	91.09
Average	7.92	7.86	23.2	21.4	852	752	60.00	37.68	89.08	86.08
Median	8.00	7.88	23.4	20.9	916	841	45.82	13.51	82.56	83.56
Std. Dev.	0.31	0.24	5.7	7.2	276	219	38.41	30.67	45.08	15.31

EA-2 Other Water Quality Parameters

	pH		Temperature (C)		Specific Conductivity (µs/cm)		DOC (mg/l)		Cl^- (mg/l)	
Date	**Influent**	**Effluent**	**Influent**	**Effluent**	**Influent**	**Effluent**	**Influent**	**Effluent**	**Influent**	**Effluent**
2/19/14	7.61	7.75	12.2	11.5	2510	1506	42.04	14.07	636.52	482.26
3/12/14	8.21	7.33	14.0	15.5	1254	1378	29.86	10.88	458.89	621.90
4/21/14	8.05	7.60	18.6	18.0	312	337	133.26	9.67	224.45	332.42
5/27/14	8.12	7.81	25.0	25.8	1077	982	59.84	10.77	101.08	143.67
6/23/14	8.23	7.73	26.2	28.2	2670	1365	48.92	10.43	688.46	317.84
7/21/14	8.31	7.57	27.1	29.1	1100	861	51.72	11.42	146.56	159.25
8/18/14	8.34	7.75	27.6	30.0	1388	1530	43.30	10.84	165.36	340.32
9/22/14	7.93	7.86	25.2	26.5	3070	1415	18.71	9.67	655.23	331.10
10/20/14	8.11	7.86	21.9	22.4	1191	1265	89.96	40.52	163.50	235.84
11/17/14	8.13	7.72	18.3	18.3	1634	1660	103.30	22.79	256.16	349.53
12/8/14	7.75	7.55	No Sample	No Sample	1783	1230	45.68	15.07	560.87	331.16
1/20/15	7.75	7.55	13.4	13.8	1543	1634	86.23	25.67	299.13	388.91
Average	8.05	7.67	20.9	21.7	1628	1264	62.73	15.98	363.02	336.18
Median	8.12	7.73	21.9	22.4	1466	1372	50.32	11.15	277.64	331.79
Std. Dev.	0.24	0.16	5.8	6.6	779	378	33.51	9.33	222.28	129.61

EA-3 Other Water Quality Parameters

	pH		Temperature (C)		Specific Conductivity (µs/cm)		DOC (mg/l)		Cl$^-$ (mg/l)	
Date	Influent	Effluent	Influent	Effluent	Influent	Effluent	Influent	Effluent	Influent	Effluent
2/19/14	7.35	7.51	10.5	10.2	1066	890	29.20	14.34	108.41	212.54
3/12/14	7.45	8.22	13.3	13.2	1079	1405	31.92	11.34	336.53	635.58
4/21/14	7.48	7.58	16.8	15.4	1296	1197	No Sample	10.97	235.56	221.24
5/27/14	8.11	7.73	24.4	25.8	945	1186	63.78	12.92	116.91	199.53
6/23/14	7.71	7.76	27.2	28.4	1527	1225	56.92	12.10	314.96	235.46
7/21/14	8.44	7.77	28.0	29.1	1220	1056	93.74	11.46	237.67	315.01
8/18/14	8.62	7.95	27.1	29.7	1849	1130	88.70	11.85	305.47	192.82
9/22/14	7.39	7.70	25.2	25.8	1306	1062	23.34	11.44	229.82	211.62
10/20/14	7.51	7.74	20.4	25.8	1273	1008	86.82	48.80	184.49	174.36
11/17/14	7.67	7.50	15.2	17.6	678	696	50.96	38.81	92.08	105.37
12/8/14	7.28	7.40	15.0	15.0	320	296	79.75	41.98	161.90	159.09
1/20/15	7.53	7.61	12.5	11.1	1028	928	80.79	43.13	176.61	153.10
Average	7.71	7.71	19.6	20.6	1132	1007	62.36	22.43	208.37	234.64
Median	7.52	7.72	18.6	21.7	1150	1059	63.78	12.51	207.15	205.57
Std. Dev.	0.44	0.22	6.5	7.5	390	289	25.75	15.51	82.51	136.21

ADV-1 Other Water Quality Parameters

	pH		Temperature (C)		Specific Conductivity (µs/cm)		DOC (mg/l)		Cl$^-$ (mg/l)	
Date	Influent	Effluent	Influent	Effluent	Influent	Effluent	Influent	Effluent	Influent	Effluent
2/19/14	7.05	7.92	15.2	14.8	1003	2350	64.58	12.12	60.47	961.24
3/12/14	7.82	8.13	14.8	13.7	852	1935	29.20	12.84	101.14	432.30
4/21/14	7.11	7.78	18.3	33.0	458	335	92.78	6.62	743.73	419.95
5/27/14	6.95	7.73	24.3	24.0	1780	1975	105.88	8.94	330.69	455.27
6/23/14	7.51	7.90	25.8	27.2	1079	2390	75.16	8.40	112.83	648.36
7/21/14	7.29	7.80	26.3	29.2	2620	1804	62.54	8.74	596.32	639.75
8/18/14	7.22	7.94	28.0	29.6	1232	1930	49.28	8.75	126.50	489.44
9/22/14	7.08	8.27	26.0	26.9	993	1750	41.00	9.47	106.94	462.97
10/20/14	6.98	8.28	23.2	24.7	5850	1634	89.77	39.11	1630.17	392.91
11/17/14	7.16	8.35	20.4	31.6	938	1562	116.40	39.08	56.51	292.23
12/8/14	7.22	8.09	No Sample	No Sample	553	1039	141.30	43.81	59.95	394.81
1/20/15	7.25	7.69	14.9	14.5	2044	1436	78.14	47.00	498.50	333.20
Average	7.22	7.99	21.6	24.5	1617	1678	78.84	20.41	368.65	493.54
Median	7.19	7.93	23.2	26.9	1041	1777	76.65	10.79	119.67	443.78
Std. Dev.	0.24	0.23	5.0	7.0	1473	563	32.49	16.34	462.61	181.35

ADV-2

	pH		Temperature (C)		Specific Conductivity (µs/cm)		DOC (mg/l)		Cl^- (mg/l)	
Date	**Influent**	**Effluent**	**Influent**	**Effluent**	**Influent**	**Effluent**	**Influent**	**Effluent**	**Influent**	**Effluent**
2/19/14	7.84	8.23	14.1	14.4	3120	823	78.30	11.85	700.54	59.64
3/12/14	8.50	8.78	14.8	16.0	1066	921	58.46	11.77	87.97	152.14
4/21/14	7.97	8.10	18.6	19.5	330	322	67.32	9.06	50.25	72.34
5/27/14	8.28	7.74	24.5	25.6	896	806	80.38	10.42	52.86	59.60
6/23/14	8.15	7.73	26.5	28.0	859	792	71.30	8.97	84.06	96.50
7/21/14	8.12	7.60	26.3	28.7	1271	778	79.66	10.93	240.21	70.67
8/18/14	8.18	7.64	28.2	29.6	927	832	55.88	11.13	75.59	71.44
9/22/14	8.54	8.27	25.5	28.3	1012	771	34.60	10.52	62.45	75.77
10/20/14	8.50	8.33	22.5	25.5	989	743	96.18	57.40	72.19	63.80
11/17/14	7.66	8.41	20.1	25.0	999	751	123.40	60.75	55.27	56.41
12/8/14	7.29	8.23	No Sample	No Sample	444	306	148.30	70.79	59.32	75.63
1/20/15	7.83	8.35	14.6	19.3	1072	791	168.10	71.03	70.67	66.06
Average	8.07	8.12	21.4	23.6	1082	720	88.49	28.72	134.28	76.67
Median	8.14	8.23	22.5	25.5	994	785	78.98	11.45	71.43	71.06
Std. Dev.	0.38	0.36	5.3	5.4	694	195	39.37	27.05	185.52	26.01

SBR-1 Other Water Quality Parameters

	pH		Temperature (C)		Specific Conductivity (µs/cm)		DOC (mg/l)		Cl^- (mg/l)	
Date	**Influent**	**Effluent**	**Influent**	**Effluent**	**Influent**	**Effluent**	**Influent**	**Effluent**	**Influent**	**Effluent**
2/19/14	7.64	7.76	9.2	9.6	1437	1230	25.10	16.39	140.55	278.54
3/12/14	7.92	7.65	15.5	11.3	845	1368	78.94	18.99	81.27	269.68
4/21/14	7.29	7.86	17.2	17.4	353	314	96.02	15.53	74.04	76.64
5/27/14	7.89	7.78	25.4	25.5	969	816	40.16	No Sample	69.24	No Sample
6/23/14	7.42	7.95	26.7	29.1	1130	834	105.60	14.52	63.20	88.99
7/21/14	8.10	7.74	26.4	28.8	1383	851	138.70	20.48	140.20	95.22
8/18/14	7.72	7.90	27.2	30.5	796	892	35.38	16.44	54.80	99.64
9/22/14	7.42	7.78	25.0	26.5	1036	847	28.52	18.48	71.20	90.32
10/20/14	8.11	7.89	20.6	22.6	634	808	71.81	65.45	32.96	70.37
11/17/14	7.17	7.56	15.6	17.6	1150	818	161.10	69.03	65.98	85.48
12/8/14	7.22	7.62	No Sample	No Sample	851	531	218.30	83.41	89.12	86.63
1/20/15	7.34	7.35	12.5	12.9	1190	618	165.00	52.40	86.05	45.87
Average	7.60	7.74	20.1	21.1	981	827	97.05	35.56	80.72	117.03
Median	7.53	7.77	20.6	22.6	1003	826	87.48	18.99	72.62	88.99
Std. Dev.	0.34	0.17	6.4	7.6	309	279	62.60	26.38	31.57	79.03

SBR-2 Other Water Quality Parameters										
	pH		**Temperature (C)**		**Specific Conductivity (µs/cm)**		**DOC (mg/l)**		**Cl$^-$ (mg/l)**	
Date	**Influent**	**Effluent**	**Influent**	**Effluent**	**Influent**	**Effluent**	**Influent**	**Effluent**	**Influent**	**Effluent**
2/19/14	7.28	7.87	12.3	10.8	2310	1396	51.58	17.53	543.33	567.15
3/12/14	8.55	7.96	14.5	12.6	150	1484	73.90	16.36	189.87	411.69
4/21/14	6.97	7.91	19.0	18.5	387	359	102.74	12.63	294.63	256.81
5/27/14	6.98	7.79	25.0	25.4	5040	1665	93.38	11.95	1157.64	374.04
6/23/14	8.18	7.87	26.4	26.8	1336	1150	16.30	9.75	264.67	279.28
7/21/14	7.41	7.96	26.3	27.5	1303	1011	59.86	10.16	238.25	209.48
8/18/14	7.13	8.00	27.9	29.8	1627	1515	48.54	10.78	253.51	331.10
9/22/14	7.14	7.90	24.9	25.6	1204	1283	26.32	10.65	170.86	262.82
10/20/14	7.22	7.70	21.7	21.3	1384	1195	96.45	44.82	188.72	218.85
11/17/14	7.35	7.53	17.7	17.5	1527	1175	94.05	52.78	244.01	208.55
12/8/14	6.86	7.51	No Sample	No Sample	1229	492	115.00	58.47	584.51	168.83
1/20/15	6.77	7.40	13.2	12.4	1443	1297	122.00	62.20	185.90	239.04
Average	7.32	7.78	20.8	20.7	1578	1169	75.01	26.51	359.66	293.97
Median	7.18	7.87	21.7	21.3	1360	1239	83.64	14.49	248.76	259.81
Std. Dev.	0.53	0.20	5.7	6.8	1222	392	34.42	21.23	285.66	111.84

APPENDIX D: INFLUENT AND EFFLUENT INDICATOR BACTERIA

*Samples highlighted in green and labeled with a “>” symbol indicate a value that exceeded the limit of detection for that analysis which was 2,419.6 MPN/100 ml. Samples labeled as “< 1” indicate that no bacteria was recorded during the analysis, yet the lower limit of detection for the analysis was equal to 1 MPN/100 ml. Therefore, there is a possibility that there are some bacteria in the sample that was undetected. An “error” value indicates that the recorded analysis was an unrealistic value. For example, if there was an influent sample that recorded a value of zero, then that was considered unrealistic as there should always be TC, EC, or EN bacteria in a raw domestic wastewater sample. The recorded value will be listed in parentheses next to the “error” label.

EA-1 Indicator Bacteria (MPN/100 ml) (Chlorine Disinfection)

	TC		EC		EN	
Date	**Influent**	**Effluent**	**Influent**	**Effluent**	**Influent**	**Effluent**
2/19/14	> 2.42 X 10^6	> 2,420	> 2.42 X 10^6	613	> 2.42 X 10^5	16
3/12/14	> 4.84 X 10^6	> 2,420	2.41 X 10^6	1	> 4.84 X 10^5	1
4/21/14	> 4.84 X 10^6	> 2,420	> 4.84 X 10^6	> 2,420	> 4.84 X 10^5	31
5/27/14	8.60 X 10^5	< 1	8.60 X 10^4	< 1	7.06 X 10^4	< 1
6/23/14	> 2.42 X 10^7	19	7.27 X 10^6	1	1.58 X 10^4	1
7/21/14	1.55 X 10^7	> 2,420	1.94 X 10^6	1,230	6.13 X 10^5	37
8/18/14	2.05 X 10^6	> 2,420	3.27 X 10^5	< 1	4.16 X 10^5	1
9/22/14	> 2.42 X 10^7	550	5.79 X 10^6	2	6.87 X 10^5	< 1
10/20/14	5.56 X 10^5	< 1	1.08 X 10^5	< 1	5.17 X 10^5	< 1
11/17/14	2.01 X 10^6	< 1	9.33 X 10^5	< 1	6.13 X 10^4	1
12/8/14	2.46 X 10^5	< 1	1.21 X 10^5	< 1	7.30 X 10^3	< 1
1/20/15	2.00 X 10^4	< 1	Error (0)	< 1	1.21 X 10^4	4
Median	2.23 X 10^6	285	1.94 X 10^6	1	3.29 X 10^5	1

EA-2 Indicator Bacteria (MPN/100 ml) (Membrane Bioreactor Disinfection)

	TC		EC		EN	
Date	**Influent**	**Effluent**	**Influent**	**Effluent**	**Influent**	**Effluent**
2/19/14	> 2.42 X 10^6	45	> 2.42 X 10^6	4	> 4.84 X 10^5	< 1
3/12/14	> 4.84 X 10^6	1	> 4.84 X 10^6	< 1	5.85 X 10^4	1
4/21/14	> 1.21 X 10^7	1,986	> 1.21 X 10^7	135	> 1.21 X 10^6	27
5/27/14	2.43 X 10^5	770	6.30 X 10^4	194	1.99 X 10^6	16
6/23/14	> 2.42 X 10^7	10	1.84 X 10^6	1	3.61 X 10^5	< 1
7/21/14	> 2.42 X 10^7	222	9.21 X 10^6	16	> 2.42 X 10^6	< 1
8/18/14	5.17 X 10^6	33	1.26 X 10^6	2	1.20 X 10^6	< 1
9/22/14	> 2.42 X 10^7	238	5.17 X 10^6	1	1.73 X 10^6	4
10/20/14	2.26 X 10^5	142	3.18 X 10^5	< 1	1.73 X 10^6	2
11/17/14	6.13 X 10^6	107	5.56 X 10^5	3	5.91 X 10^4	< 1
12/8/14	2.10 X 10^6	35	3.84 X 10^5	2	1.40 X 10^5	1
1/20/15	1.48 X 10^5	48	4.10 X 10^4	2	1.55 X 10^6	7
Median	5.01 X 10^6	78	1.55 X 10^6	2	1.21 X 10^6	2

EA-3 Indicator Bacteria (MPN/100 ml) (UV Disinfection)

	TC		EC		EN	
Date	**Influent**	**Effluent**	**Influent**	**Effluent**	**Influent**	**Effluent**
2/19/14	> 2.42 X 10^{6}	> 2,420	9.21 X 10^{5}	13	6.13 X 10^{4}	1
3/12/14	> 4.84 X 10^{6}	> 2,420	2.41 X 10^{6}	< 1	> 4.84 X 10^{5}	< 1
4/21/14	> 4.84 X 10^{6}	< 1	> 4.84 X 10^{6}	< 1	1.21 X 10^{6}	< 1
5/27/14	2.25 X 10^{6}	727	9.88 X 10^{5}	10	1.05 X 10^{6}	2
6/23/14	> 2.42 X 10^{7}	31	6.13 X 10^{6}	< 1	4.11 X 10^{5}	1
7/21/14	1.12 X 10^{7}	> 2,420	4.61 X 10^{6}	411	9.80 X 10^{5}	72
8/18/14	> 2.42 X 10^{7}	> 2,420	1.73 X 10^{7}	13	3.45 X 10^{5}	613
9/22/14	> 2.42 X 10^{7}	> 2,420	7.98 X 10^{5}	< 1	1.73 X 10^{5}	1
10/20/14	4.88 X 10^{6}	579	9.09 X 10^{5}	96	1.20 X 10^{6}	17
11/17/14	4.48 X 10^{5}	488	4.10 X 10^{4}	93	1.37 X 10^{5}	11
12/8/14	4.61X 10^{6}	260	2.75 X 10^{5}	9	3.84 X 10^{4}	2
1/20/15	1.45 X 10^{6}	112	2.11 X 10^{5}	81	1.94 X 10^{5}	1
Median	4.84 X 10^{6}	534	9.54 X 10^{5}	12	3.78 X 10^{5}	2

ADV-1 Indicator Bacteria (MPN/100 ml) (UV Disinfection)

	TC		EC		EN	
Date	**Influent**	**Effluent**	**Influent**	**Effluent**	**Influent**	**Effluent**
2/19/14	> 2.42 X 10^{6}	88	> 2.42 X 10^{6}	< 1	9.21 X 10^{4}	< 1
3/12/14	> 2.42 X 10^{6}	1	1.55 X 10^{6}	< 1	1.73 X 10^{5}	< 1
4/21/14	> 1.21 X 10^{7}	72	> 1.21 X 10^{7}	11	9.81 X 10^{5}	< 1
5/27/14	1.12 X 10^{6}	921	8.60 X 10^{4}	80	8.23 X 10^{4}	15
6/23/14	> 2.42 X 10^{7}	517	5.48 X 10^{6}	111	3.87 X 10^{5}	20
7/21/14	8.13 X 10^{5}	> 2,420	7.50 X 10^{4}	166	3.87 X 10^{5}	18
8/18/14	3.08 X 10^{6}	> 2,420	2.79 X 10^{5}	24	1.47 X 10^{5}	1
9/22/14	> 2.42 X 10^{7}	< 1	1.73 X 10^{7}	1	2.31 X 10^{4}	1
10/20/14	1.42 X 10^{6}	12	1.85 X 10^{5}	< 1	8.05 X 10^{3}	< 1
11/17/14	4.88 X 10^{6}	27	2.22 X 10^{6}	8	1.15 X 10^{5}	< 1
12/8/14	2.61 X 10^{6}	16	5.65 X 10^{5}	2	1.55 X 10^{5}	< 1
1/20/15	6.77 X 10^{5}	1	3.41 X 10^{5}	< 1	8.05 X 10^{3}	1
Median	2.52 X 10^{6}	50	1.06 X 10^{6}	5	1.31 X 10^{5}	1

ADV-2 Indicator Bacteria (MPN/100 ml) (UV Disinfection)

	TC		EC		EN	
Date	Influent	Effluent	Influent	Effluent	Influent	Effluent
2/19/14	> 2.42 X 10^{6}	20	2.42 X 10^{6}	6	9.21 X 10^{4}	< 1
3/12/14	> 4.84 X 10^{6}	< 1	> 4.84 X 10^{6}	< 1	4.84 X 10^{5}	< 1
4/21/14	> 1.21 X 10^{7}	> 2,420	> 1.21 X 10^{7}	1,046	> 1.21 X 10^{6}	322
5/27/14	6.49 X 10^{6}	> 2,420	Error (0)	727	1.99 X 10^{6}	326
6/23/14	> 2.42 X 10^{7}	1,553	6.49 X 10^{6}	135	6.49 X 10^{5}	153
7/21/14	> 2.42 X 10^{7}	> 2,420	> 2.42 X 10^{7}	128	> 2.42 X 10^{6}	2
8/18/14	> 2.42 X 10^{7}	> 2,420	2.51 X 10^{6}	238	8.16 X 10^{5}	64
9/22/14	> 2.42 X 10^{7}	< 1	1.20 X 10^{7}	< 1	6.87X 10^{5}	< 1
10/20/14	2.48 X 10^{6}	770	7.38 X 10^{5}	18	> 2.42 X 106	1
11/17/14	9.80 X 10^{6}	< 1	8.55 X 10^{5}	< 1	> 2.42 X 106	< 1
12/8/14	4.35 X 10^{6}	< 1	5.28 X 10^{5}	< 1	3.45 X 10^{4}	< 1
1/20/15	5.94 X 10^{5}	219	1.48 X 10^{5}	56	1.32 X 10^{4}	4
Median	8.15 X 10^{6}	495	2.51 X 10^{6}	37	7.52 X 10^{5}	2

SBR-1 Indicator Bacteria (MPN/100 ml) (Chlorine Disinfection)

	TC		EC		EN	
Date	Influent	Effluent	Influent	Effluent	Influent	Effluent
2/19/14	> 2.42 X 10^{6}	1	> 2.42 X 10^{6}	< 1	1.10 X 10^{3}	< 1
3/12/14	2.67 X 10^{5}	< 1	8.20 X 10^{3}	< 1	Error (0)	< 1
4/21/14	> 4.84 X 10^{6}	> 2,420	> 4.84 X 10^{6}	980	> 4.84 X 10^{5}	88
5/27/14	2.25 X 10^{6}	> 2,420	7.40 X 10^{4}	921	3.97 X 10^{5}	20
6/23/14	> 2.42 X 10^{7}	1,120	> 2.42 X 10^{7}	21	7.73 X 10^{4}	< 1
7/21/14	2.36 X 10^{6}	1,553	1.71 X 10^{5}	173	> 2.42 X 10^{6}	2
8/18/14	> 2.42 X 10^{7}	17	9.10 X 10^{5}	< 1	1.85 X 10^{5}	< 1
9/22/14	> 2.42 X 10^{7}	1	2.60 X 10^{6}	< 1	5.17 X 10^{5}	1
10/20/14	1.02 X 10^{6}	< 1	7.30 X 10^{4}	< 1	1.47 X 10^{5}	7
11/17/14	> 2.42 X 10^{7}	< 1	8.60 X 10^{5}	< 1	3.36 X 10^{4}	< 1
12/8/14	5.17 X 10^{6}	< 1	2.00 X 10^{4}	< 1	1.73 X 10^{4}	< 1
1/20/15	7.27 X 10^{6}	< 1	1.22 X 10^{5}	< 1	3.05 X 10^{4}	< 1
Median	5.01 X 10^{6}	1	5.16 X 10^{5}	< 1	1.47 X 10^{5}	< 1

SBR-2 Indicator Bacteria (MPN/100 ml) (Chlorine Disinfection)						
	TC		EC		EN	
Date	**Influent**	**Effluent**	**Influent**	**Effluent**	**Influent**	**Effluent**
2/19/14	> 2.42 X 10^{6}	< 1	1.72 X 10^{6}	< 1	> 2.42 X 10^{5}	< 1
3/12/14	> 2.42 X 10^{3}	> 2,420	> 2.42 X 10^{6}	1,553	1.73 X 10^{3}	< 1
4/21/14	> 1.21 X 10^{7}	4	1.55 X 10^{3}	< 1	> 1.21 X 10^{6}	< 1
5/27/14	9.21 X 10^{6}	> 2,420	> 1.21 X 10^{7}	248	7.23 X 10^{4}	18
6/23/14	1.02 X 10^{6}	> 2,420	8.84 X 10^{5}	60	No Sample	10
7/21/14	1.55 X 10^{7}	> 2,420	4.10 X 10^{4}	291	No Sample	921
8/18/14	3.26 X 10^{6}	214	6.13 X 10^{6}	4	1.66 X 10^{5}	< 1
9/22/14	3.23 X 10^{5}	1	1.31 X 10^{5}	< 1	1.48 X 10^{5}	< 1
10/20/14	1.30 X 10^{7}	< 1	6.30 X 10^{4}	< 1	1.73 X 10^{6}	< 1
11/17/14	2.76 X 10^{6}	< 1	3.26 X 10^{6}	< 1	5.65 X 10^{4}	< 1
12/8/14	9.21 X 10^{6}	41	1.79 X 10^{6}	107	5.04 X 10^{4}	< 1
1/20/15	1.86 X 10^{6}	124	2.60 X 10^{6}	> 2,420	6.24 X 10^{4}	1
Median	3.01 X 10^{6}	83	1.76 X 10^{6}	32	1.10 X 10^{5}	< 1

APPENDIX E: MONTHLY FLOW DATA

*Data represents the flow rate in gallons per day during each month.

Average Daily Flow per Month (GPD) February 2014 – January 2015

Average Daily Flow per Month (GPD) February 2014 - January 2015							
Date	**EA-1**	**EA-2**	**EA-3**	**ADV-1**	**ADV-2**	**SBR-1**	**SBR-2**
February	18,083	5,747	4,304	1,117	655	67	1,099
March	23,460	7,540	4,779	1,166	1,756	157	1,552
April	27,977	10,349	8,183	1,892	2,839	545	2,658
May	31,447	15,624	11,897	2,311	3,085	1,018	3,487
June	40,748	22,225	20,070	5,079	6,004	2,287	7,108
July	57,644	43,175	29,477	10,352	8,910	3,544	11,284
August	50,689	34,464	25,955	3,747	5,945	1,932	4,970
September	39,698	16,349	13,310	3,459	2,053	1,029	3,050
October	35,101	12,451	7,890	2,135	1,639	604	2,573
November	25,151	6,829	9,477	1,573	888	483	1,453
December	26,000	7,290	3,871	2,080	422	298	945
January	15,172	7,440	5,332	1,076	494	215	1,306

APPENDIX F: BOGUE BANKS PACKAGE TREATMENT PLANT FACILITIES

Facility	**Location**	**Permit Agency**
8 1/2 Marina Village	Atlantic Beach	County
A Place at the Beach	Atlantic Beach	DWQ
Beachwalk Villas	Pine Knoll Shores	County
Beacons Reach	Pine Knoll Shores	DWQ
Bogue Shore Club	Pine Knoll Shores	County
Cape Royal Dolphin/ Cape Emerald	Emerald Isle	DWQ
Colony By The Sea	Indian Beach	County
Coral Bay West	Pine Knoll Shores	County
Dunescape	Atlantic Beach	DWQ
Emerald Plantation	Emerald Isle	County
Genesis	Pine Knoll Shores	DWQ
Grande Villas at the Preserve	Salter Path	County
Hampton Inn	Pine Knoll Shores	County
Island Beach & Racquet Club / Sheraton Hotel	Atlantic Beach	DWQ
Mariner's Point	Salter Path	County
McGinnis Point	Pine Knoll Shores	County
Ocean Club	Salter Path	DWQ
Ocean Terrace	Pine Knoll Shores	County
Oceans	Pine Knoll Shores	County
Pebble Beach	Emerald Isle	DWQ
Peppertree Resort	Atlantic Beach	DWQ
Pine Knoll Townes II	Pine Knoll Shores	County
Point Emerald Villas	Emerald Isle	DWQ
Queens Court	Emerald Isle	DWQ
Sands Villas	Atlantic Beach	DWQ
Sea Isle Plantation/North	Indian Beach	DWQ
Sea Spray	Atlantic Beach	County
Shutters on the Shore	Pine Knoll Shores	County
Sound of the Sea	Emerald Isle	DWQ
Southwinds	Atlantic Beach	DWQ
Sugarloaf-Atlantic Station/Days Inn	Atlantic Beach	DWQ
Summerwinds	Salter Path	County
Sunbay	Pine Knoll Shores	County
Tar Landing	Atlantic Beach	County
US Coast Guard	Atlantic Beach	County
Whaler Inn	Pine Knoll Shores	County
Windward Dunes	Indian Beach	DWQ

APPENDIX G: MEDIAN VALUES THAT CORRESPOND TO MANN-WHITNEY TEST RESULTS

MEDIAN VALUES CORRESPONDING TO MANN-WHITNEY TESTS

	Effluent TN Concentration	Effluent TP Concentration
	(mg/l)	
EA	6.3	2.7
ADV	8.5	3.5
SBR	9.8	3.0

	Effluent TN Loading	Effluent TP Loading
	(kg/month)	
EA	17.1	4.8
ADV	3.2	0.8
SBR	1.9	0.5

	Seasonal effluent TN Concentration	Seasonal effluent TP Concentration
	(mg/l)	
Spring	10.8	2.7
Summer	6.4	3.1
Fall	7.6	3.7
Winter	11.0	2.1

	Seasonal Effluent TN Loading	Seasonal Effluent TP Loading
	(kg/month/season)	
Spring	5.4	1.0
Summer	8.8	4.8
Fall	2.6	1.6
Winter	2.3	0.3

	Seasonal effluent TC Concentration	Seasonal effluent EC Concentration	Seasonal effluent EN Concentration
		(MPN/100 ml)	
Spring	770.1	9.8	1.0
Summer	1553.1	24.1	2.0
Fall	1.0	0.0	0.0
Winter	34.5	2.0	0.0

***Mann – Whitney test results can be found on page 34**

APPENDIX H: GROUNDWATER ELEVATION DATA FOR MONITORING WELLS AT STATE PERMITTED PACKAGED TREATMENT PLANTS

EA-1

Well ID	Month	Year	Value (m)
MW1	2	2013	4.08
MW1	10	2013	4.30
MW1	6	2013	4.38
MW2	2	2013	2.63
MW2	10	2013	2.82
MW2	6	2013	2.91
MW3	2	2013	2.11
MW3	10	2013	2.32
MW3	6	2013	2.38
MW4	2	2013	1.26
MW4	10	2013	1.30
MW4	6	2013	1.38
MW1	10	2014	0.96
MW1	6	2014	4.12
MW1	2	2014	4.36
MW2	10	2014	2.54
MW2	6	2014	2.65
MW2	2	2014	2.91
MW3	10	2014	2.11
MW3	2	2014	2.16
MW3	6	2014	2.26
MW4	10	2014	1.12
MW4	2	2014	1.31
MW4	6	2014	1.32
MW1	2	2015	4.19
MW2	2	2015	2.71
MW3	2	2015	2.24
MW4	2	2015	1.32

EA-1

Well ID	MW-1	MW-2	MW-3	MW-4	All Wells
Number of Samples	N =7	N =7	N =7	N =7	N = 28
Mean	3.3	2.0	2.7	2.0	2.5
Median	2.9	1.4	2.5	1.3	2.3
Standard Deviation	1.24	0.15	0.10	0.08	1.09

EA-3			
Well ID	**Month**	**Year**	**Value (m)**
MW-1	4	2013	1.98
MW-1	7	2013	2.35
MW-1	11	2013	2.01
MW-2	4	2013	2.38
MW-2	7	2013	2.23
MW-3	4	2013	1.86
MW-3	7	2013	2.13
MW-3	11	2013	1.83
MW-1	3	2014	2.04
MW-1	7	2014	2.07
MW-1	11	2014	1.83
MW-2	7	2014	2.07
MW-2	11	2014	1.86
MW-3	3	2014	1.92
MW-3	7	2014	1.31

EA-3				
Well ID	MW-1	MW-2	MW-3	All Wells
Number of Samples	N = 6	N = 4	N = 5	N = 15
Mean	2.1	2.0	1.8	2.0
Median	2.1	2.1	1.9	2.0
Standard Deviation	0.17	0.22	0.30	0.26

SBR-2			
Well ID	**Month**	**Year**	**Value (m)**
MW1	3	2013	2.99
MW1	7	2013	3.04
MW1	11	2013	3.11
MW2	3	2013	2.97
MW2	7	2013	3.05
MW2	11	2013	3.11
MW3	3	2013	2.99
MW3	7	2013	2.87
MW3	11	2013	2.87
MW4	3	2013	4.32
MW4	7	2013	4.41
MW4	11	2013	4.48
MW1	3	2014	2.87
MW1	7	2014	2.92
MW1	11	2014	2.91
MW2	3	2014	2.88
MW2	7	2014	2.92
MW2	11	2014	2.93
MW3	3	2014	2.69
MW3	7	2014	2.73
MW3	11	2014	2.68
MW4	3	2014	4.25
MW4	7	2014	4.27
MW4	11	2014	4.27

SBR-2					
Well ID	MW-1	MW-2	MW-3	MW-4	All Wells
Number of Samples	N = 6	N = 6	N = 6	N = 6	N = 24
Mean	3.0	3.7	2.9	3.5	3.3
Median	3.0	3.7	2.9	3.5	3.0
Standard Deviation	0.09	0.09	0.12	0.09	0.64