ABSTRACT

Charles Pittman Humphrey Jr. CONTROLS ON SEPTIC SYSTEM WASTEWATER TREATMENT AND SHALLOW GROUNDWATER QUALITY IN COASTAL NORTH CAROLINA. (Under the direction of Dr. Michael O'Driscoll). Ph.D. Program in Coastal Resources Management, December 2009.

Excess nitrogen and bacteria concentrations in coastal waters of North Carolina have led to eutrophic conditions, fish kills, and the closure of shellfish waters. Regulatory efforts by the state to reduce nitrogen and bacteria loading to surface waters have focused on agriculture, urban runoff, and centralized wastewater treatment plant discharges without regard to septic system derived nitrogen and bacteria. The effects of septic systems on groundwater quality (nitrogen and bacteria) were evaluated in eastern North Carolina. Sixteen sites (residential yards) with septic systems in soils ranging from sand (group I) to sandy clay loam (group III) were instrumented with groundwater monitoring wells adjacent to the systems. It was determined that the soil type and separation distance had strong influences on septic system treatment efficiency. Increasing the separation distance requirements from systems to the seasonal high water table to 60 cm (from 30-45 cm) could improve the treatment efficiency of systems (4 mg/L decrease in median NH_4^+-N concentrations and 65 cfu/100 mL decrease in geometric mean E. coli densities) and groundwater quality.

Soil profile descriptions and groundwater level data from the sites were used to evaluate the accuracy of soil color (chroma 2 or 1 colors) for determining the depth to the seasonal high water table (SHWT) for septic system design purposes. For most sites, soil

colors and the measured SHWT were within ± 18 cm of each other. Therefore water level data also suggest an increase (15+ cm) in separation distance to SHWT indicators would be beneficial.

Using groundwater quality and flow data from the sites, nitrogen loads from septic systems to groundwater were estimated. For the Newport River watershed, the septic system nitrogen loading rate to groundwater for systems in group I and II soils (28.5 to 57.5 kg/ha/yr) were similar to the nitrogen loading rate attributed to agriculture (37.5 kg/ha/yr) in the same county, and higher than estimates of atmospheric nitrogen deposition for the area (8 to 12 kg/ha/yr). Therefore, the potential pollutant contributions from septic systems to ground and surface waters should be included in watershed-scale efforts to reduce nitrogen and bacteria loading.

CONTROLS ON SEPTIC SYSTEM WASTEWATER TREATMENT AND SHALLOW GROUNDWATER QUALITY IN COASTAL NORTH CAROLINA

A Dissertation

Presented to

the Faculty of the Coastal Resources Management Ph.D. Program

East Carolina University

In Partial Fulfillment

Of the Requirements for the Degree

Doctor of Philosophy in Coastal Resources Management

By

Charles Pittman Humphrey Jr.

December 2009

CONTROLS ON SEPTIC SYSTEM WASTEWATER TREATMENT AND SHALLOW GROUNDWATER QUALITY IN COASTAL NORTH CAROLINA

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ACKNOWLEDGEMENTS

There are many people that I am indebted to for helping with the completion of this dissertation. I would like to especially thank Dr. Mike O'Driscoll for accepting me as one of his graduate students, for helping with the field and lab work, and for giving me the opportunity to learn more about water resources by working with him. I would like to thank Dr. King for encouraging me to enroll in the Coastal Resources Management program and for his continued support, Dr. Zarate for helping develop the initial grant proposal from which most of the study was funded and for his help in the field and laboratory, and Dr. Corbett and Dr. Christian for their valuable insight and direction throughout the study. I also owe gratitude to Dr. O'Brien for his help with the statistical analyses of the data.

This study required the help of many people in the field and laboratory. The efforts of Curtis Smith, Chris Armstrong, John Woods, Corey Lawson, Mike Carroll, Erik Morgan, Jacob Morgan, Gene Aston, Marcus Branch and various students in the Environmental Health Sciences Program that assisted with the project are all appreciated. I would also like to thank the North Carolina Cooperative Extension Service and my former supervisor, Dr. Tom Glasgow, for allowing me the opportunity to pursue a doctoral degree while maintaining employment and the East Carolina University Department of Health Education and Promotion for their support in completing this endeavor.

I owe my wife Kimberly Humphrey much gratitude for supporting my decision to further my education again, and for being relatively patient with me as I struggled to balance work, school, and family. I would like to thank my family including my children Charlie, Anna, and Ameilia and my parents Charles and Emogene Humphrey for inspiring me to complete this dissertation. I also am thankful for the support of my mother, father, and sister in law during this process.

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CHAPTER 1: INTRODUCTION

1.1 Overview

At the national, state, and regional scale, septic systems are utilized by 25, 50, and 60% of the population, respectively (Siegrist et al. 2005; and Pradhan et al. 2007). In North Carolina, 40,000 new systems are installed each year (Hoover 2004). These (septic) systems treat and dispose of human wastewater that contains many constituents such as viruses, bacteria, protozoa, nitrogen, phosphorus, and various metals that are potentially hazardous to public and environmental health (Canter and Knox 1985). Coastal North Carolina counties are expected to grow 20.5% by 2020 (Tillman 2004) with much of the future growth being accommodated by on-site systems. More septic systems will increase wastewater loading to the subsurface environment.

For coastal North Carolina, the potential for ground and surface water contamination by human wastewater constituents exists, due to sandy (and permeable) soils, shallow water tables, and the close proximity of on-site systems to surface waters such as rivers, estuaries, or the ocean. Ground and surface water contamination by improperly functioning septic systems may diminish the quality of drinking water, recreational waters, shellfisheries, coastal ecology, and tourism. Recent studies (Corbett et al. 2001; Buetow 2002; Borchardt et al. 2003; Reay 2004; Cahoon et al. 2006) have shown the potential for on-site systems to contribute pollutants to ground and surface waters, but there is a lack of published research that provides information on how common septic system subsurface treatment failures are in coastal areas, and the potential effect septic systems can have on shallow groundwater quality at the watershed scale. The study objectives were to: 1) assess the effects of soil type and separation distance on groundwater quality adjacent to septic systems; 2) evaluate the use of soil colors as indicators of the seasonal high water table when designing septic systems; 3) develop a watershed- scale method of estimating the nitrogen loads from septic systems to groundwater in the Newport River Basin watershed; and 4) to suggest management strategies for on-site wastewater management that can protect shallow groundwater quality in eastern North Carolina.

1.2 Organization

Chapter 2, “Effects of Soil Type and Separation Distance on Nitrogen and Bacteria Reduction from On-site Wastewater Systems in Coastal North Carolina”, presents data obtained from groundwater adjacent to 16 septic systems in soils spanning from sand to sandy clay loam. Dissolved inorganic nitrogen and E. coli densities adjacent to systems during periods of relatively shallow versus relatively deep water table periods were evaluated. Groundwater quality adjacent to septic systems in different soil groups were also compared to background conditions. This chapter provides a recommendation for vertical separation distances from septic systems to water table, based on observed water quality and water table dynamics.

Chapter 3, “Evaluation of Soil Colors as Indicators of the Seasonal High Water Table for Designing On-site Wastewater Systems in Coastal North Carolina”, evaluates the accuracy of low chroma (2 or 1) colors for predicting the depth of the 14-day seasonal high water table for 6 soil series. An analysis of the frequency and duration of water table saturation for depths 30 to 60 cm above soil color water table indicators was conducted.

The septic drainfield installation depths of the 16 systems were compared to water table indicators and the observed 14-day seasonal high water table. These data were used to assess the likelihood that septic systems designed using low chroma colors as predictors of the seasonal high water table were meeting the separation distance requirement to the actual seasonal high water table.

Chapter 4, “Septic System Nitrogen Loading to Groundwater in the Newport River Watershed, North Carolina”, details a methodology for estimating the nitrogen contributions from on-site systems to the surficial aquifer at the watershed scale. This chapter also provides a comparison of nitrogen loading rates from other sources such as row crop agriculture and atmospheric deposition.

Chapter 5 provides a synthesis of results and discusses shallow groundwater quality management implications for septic systems in coastal North Carolina and other states.

CHAPTER 2: EFFECTS OF SOIL TYPE AND SEPARATION DISTANCE ON NITROGEN AND BACTERIA REDUCTION FROM ON-SITE WASTEWATER SYSTEMS IN COASTAL NORTH CAROLINA

2.1 Abstract

The goals of this study were to evaluate the effects of soil type and vertical separation distance on shallow groundwater quality adjacent to septic systems in coastal settings. Groundwater quality and groundwater levels adjacent to 16 septic systems in three different soil groups (I-sand, II-sandy loam, and III-sandy clay loam) were monitored for the dissolved inorganic nitrogen (DIN) species (NO_3^--N, NH_4^+-N), and E. coli and compared to background groundwater concentrations for 15 months in coastal North Carolina. Systems in soil group I had the highest median concentrations of DIN (18.9 mg/L) and systems in group II had the highest geometric mean E. coli densities (127 cfu/100 mL) in groundwater adjacent to septic systems, respectively. Systems in group III soils were more efficient at reducing DIN and E. coli densities. Median groundwater NH_4^+-N and geometric mean E. coli densities for systems in soil groups I and II that maintained a 60+ cm separation to the water table were 4 mg/L and 65 cfu/100 mL lower in relation to systems that had < 60 cm separation. Increasing the North Carolina separation distance requirements to the water table for septic systems in sandy soils to 60+ cm could help in protecting shallow groundwater quality.

2.2 Introduction

Over the past 25 years, North Carolina has experienced degradation of its coastal water quality. Massive fish kills in the 1990’s and the closure of over 1150 acres of shellfish waters since 1990 have been attributed to high nutrient and bacteria concentrations in coastal waters (Whitall et al. 2003; North Carolina Division of Water Quality 2005). Regulatory efforts by the state of North Carolina to improve water quality have focused on reducing nutrient and bacterial pollution from the agriculture industry, centralized wastewater treatment plants, and stormwater runoff from new developments (North Carolina Department of Environment and Natural Resources 2003). Potential pollutant (nutrient and bacteria) loadings to ground and surface waters from septic systems were not addressed even though almost 60% of the coastal residences use septic systems (North Carolina National Estuarine Research Reserve 2003) and domestic wastewater is known to contain high concentrations of bacteria and nutrients (Canter and Knox 1985).

An analysis of North Carolina Division of Environmental Health (2006) reports indicates that nearly 1,500 coastal septic systems fail hydraulically (surfacing effluent and/or wastewater back-up in the home) each year. These failures may temporarily contribute pollutants to surface waters and/or expose people and animals to pollutants from wastewater. Hydraulic malfunctions are often visible and reported to local health departments voluntarily by users of the malfunctioning systems and/or adjacent landowners. Hydraulic malfunctions are not the only means by which septic systems can affect water quality. Groundwater transport of septic effluent to adjacent surface waters is another potential source of degraded coastal water quality. Past studies have shown that nitrogen (Robertson et al. 1991; Postma et al. 1992; Harmon et al. 1996; Ptacek 1998; Buetow 2002; Corbett et al. 2002; and Reay 2004) and/or bacteria (Carlile et al. 1981;

Cogger et al. 1988; Lipp et al. 2001; Booth et al. 2003; Ahmed et al. 2005; and Cahoon et al. 2006) loadings from septic systems to ground and/or surface waters can result in the degradation of water quality.

Nitrogen concentrations exceeding 20 mg/L in groundwater beneath and/or adjacent to septic systems have been reported for the Coastal Plain of North Carolina (Buetow 2002), a sandy aquifer in Ontario, Canada (Harman et al. 1996), a coastal barrier bar in Point Pelee, Ontario, Canada (Ptacek 1998), in Rhode Island (Postma et al. 1992) and in the Coastal Plain of Virginia (Reay 2004). Each of these sites contained sandy soils and sediments. The dissolved inorganic nitrogen concentrations (NO_3^--N + NH_4^+-N) in groundwater beneath these systems were elevated in relation to background conditions and the North Carolina Department of Environment and Natural Resources (1998) water quality standard for NO_3^- -N (10 mg/L).

Furthermore, studies by Harmon et al. (1996), Robertson (1991), and Ptacek (1998) in Canada, Buetow (2002) in North Carolina, and Corbett et al. (2002) in Florida included tracking the groundwater septic plumes for varying distances away from the systems and each study showed septic systems impacts on groundwater away from the systems. Robertson (1991) found that nitrogen derived from septic systems can migrate away from the systems and affect groundwater quality at distances as great as 130 m. However, elevated groundwater NO_3^- -N concentrations do not necessarily correspond to high loading rates of nitrogen to adjacent surface waters. Studies by Robertson (1991) and Buetow (2002) showed high concentrations of NO_3^--N in groundwater down-gradient from the septic systems, but little of the nitrogen actually made it to surface waters because the groundwater impacted plume had to flow through organic rich stream and river bed sediments that fueled denitrification.

In addition to nitrogen, bacteria from septic systems may contribute to the degradation of shallow groundwater (Carlile et al. 1981; Cogger et al. 1988; and Scandura and Sobsey 1997) and surface water quality (Lipp et al. 2001; Booth et al. 2003; Ahmed et al. 2005; and Cahoon et al. 2006). Studies in the Coastal Plain of North Carolina by Carlile et al. (1981) and Cogger et al. (1988) showed that groundwater 1.8 m and 16 m down-gradient from septic systems contained fecal coliform densities of up to 3218 and 1600 MPN/100 mL, respectively. Coliform densities in groundwater beneath septic systems were higher during periods with high water tables (up to 25,000 MPN/100 mL) than during periods of low water tables (60 MPN/100 mL). A study by Scandura and Sobsey (1997) in coastal North Carolina found that groundwater adjacent to septic systems installed in sandy soils with high water tables had extensive viral and bacterial contamination. These studies indicated that soil type and separation distance influence septic effluent treatment and shallow groundwater quality in coastal areas.

Some groundwater studies did not include monitoring adjacent surface water quality (Carlile et al. 1981; Cogger et al. 1988; and Scandura and Sobsey 1997) however, research by Lipp et al. (2001), Booth et al. (2003), Ahmed et al. (2004), and Cahoon et al. (2006) provided links between septic system derived bacteria and surface water contamination in coastal areas of Charlotte Harbor, Florida, south central Virginia, Queensland, Australia, and coastal North Carolina, respectively.

The primary controls on groundwater quality beneath septic systems include soil texture, system type, vertical separation distance, wastewater strength, and wastewater loading rate (Siegrist 1987; Karathanasis et al. 2006; and Lowe et al. 2008). Soil and system type at each site are static while vertical separation distance, wastewater strength, and loading rate are often dynamic. The soil between the septic system drainfield trenches and water table provides most of the wastewater treatment (Hoover et al. 1996). The North Carolina Division of Environmental Health, On-site Wastewater Section (1999) requires 30 cm of vertical separation distance from septic system trench bottom to the seasonal high water table for systems installed in group II-IV soils (sandy loam and finer soil types), and 45 cm of separation for group I soils (sands). Other coastal states in the southeastern US (GA, VA, FL, MD) generally require a 45 to 60 cm separation distance for systems installed in any soil type, with the exception of South Carolina (15 cm) (Stall 2008; Georgia Department of Human Resources 2007). Furthermore, North Carolina septic systems installed in group I soils are assigned the highest wastewater loading rates (Table 2.1), effectively reducing the land area required for a drainfield in group I in comparison to group II-IV soils and allowing for high septic system density. For example, in some coastal North Carolina communities, such as Atlantic Beach, densities of greater than 75 systems per square kilometer exist. If 30-45 cm of vertical separation distance from system to seasonal high water table is not sufficient in reducing pollutant concentrations in groundwater beneath systems, then shallow groundwater and potentially adjacent surface waters can be impacted by nutrients and bacteria.

The objectives of this study were to determine the effects that soil type and vertical separation distance have on shallow groundwater quality (dissolved inorganic nitrogen and E. coli) beneath septic systems in coastal settings. Groundwater quality data were analyzed in context of North Carolina's current regulations and used to assess whether the rules adequately protect groundwater quality in the coastal areas.

2.3 Methods

2.3.1 Soil Characterization and Groundwater Monitoring

Sixteen residential septic systems in coastal North Carolina (Figure 2.1) were instrumented with monitoring wells. The septic system components, including the tank and drainfield trenches, were located using a tile-drain probe rod. Wells were installed between drainfield trenches near the front of the systems (within 5 m of the start of the trench) for trench systems, and down-gradient from bed systems (Figure 2.2), to help ensure that the groundwater analyzed was within the septic plume area. At least two wells per residence or lot were installed adjacent to the septic systems. Neighboring residences and septic systems often shared a single background well. While the spatial variability of pollutant concentrations within a septic system groundwater plume may exist and not be fully captured at a site with 2 or more wells, a total of 63 monitoring wells were installed at 16 sites, and thus this approach provided a more broad comparison among groups.

The wells adjacent to the septic systems were installed such that there was a relatively shallow and deep well (Figure 2.2A). The deeper wells were installed to a depth that allowed collection of a water sample from the upper part of the water column during dry periods, while the shallow well was installed to capture the upper part of the water column during the wet season. Monitoring wells were constructed of 10 cm diameter PVC with 75 cm screen intervals and installed using hand augers. Sand was poured between the outside of the well and the borehole until the entire screen length was filled. Bentonite clay and sand slurry was then mixed and poured to seal the annular space above the well screen and prevent surface water vertical migration down the side of the pipe.

The soil profiles at each site were examined using a hand auger, the texture by feel method (Brady et al. 2004) in the field, and the hydrometer method in the lab (Day 1979) to determine the particle size distribution and NC DENR soil group status (Table 2.2). Soil samples at the trench bottom depth were collected at each site and sent to the NC Department of Agriculture and Consumer Services Agronomic Division Lab in Raleigh, NC for descriptive analysis including: pH, effective cation exchange capacity (ECEC), and % humic matter (Table 2.2).

Monthly groundwater levels adjacent to systems were determined manually using a Solinst Model 107 Temperature Level and Conductivity (TLC) meter (Solinst Canada Ltd., 2007). Automated water level loggers (Onset Computer Corporation 2007) in the deep wells adjacent to each system recorded water levels each half hour. The groundwater level data were used to determine seasonal high water table (SHWT) for each site. The SHWT is defined as the shallowest depth below soil surface that the water table continuously saturates for 14 consecutive days. The groundwater level data coupled with the depth to trench bottom measured using the tile-drain probe were used to analyze the separation distance dynamics over time for each system.

Groundwater quality adjacent to the 16 septic systems was monitored monthly and compared to background groundwater conditions and EPA standards for groundwater quality. Well water samples were collected using disposable bailers. Wells were bailed three times, allowed to recharge and then a sample was collected. Water samples were analyzed for nitrate (NO_3^--N), ammonium (NH_4^+-N) and chloride concentrations, monthly for 13 months, using a YSI Sonde 6920 multi-parameter water quality Sonde (YSI 2007). The Sonde uses ion selective reference electrodes for determining concentrations of NO_3^--N, NH_4^+-N and chloride (accuracy $\pm$ 2 mg/L or 10% whichever is higher). The Sonde was calibrated using NO_3^--N, NH_4^+-N, and chloride standards before each monthly sampling event. Sonde NO_3^--N and NH_4^+-N readings are susceptible to interference when placed in water with high chloride concentrations and specific conductance (1.2 mS/cm would cause 1.6 mg/L higher readings). However, given the mean chloride concentrations in groundwater adjacent to systems (5-254 mg/L) and the mean specific conductance (0.1 to 1.1 mS/cm for the 16 sites), potential interference from chloride would have been minimal for the sites. Sondes have been tested and performed well in relation to other analytical methods (Capelo et al. 2007) and were used in recent studies (Li et al. 2008; Li et al. 2009) for determining various water quality parameters such as nitrate and ammonium concentrations. For further quality control, twice during the study groundwater samples were collected from the sites and analyzed for the dissolved inorganic nitrogen species NO_3^--N and NH_4^+-N (DIN) at the NCSU Soil Science Department Analytical Services laboratory using procedures described in the Standard Methods for Examination of Water and Wastewater (1995) with a Quick Chem

8000 Lachet Analyzer. The groundwater (DIN) concentrations from the laboratory analysis were included with the monthly Sonde field readings for a total of 15 months of readings. Median groundwater DIN concentrations (mg/L) analyzed using the Sonde (13 months/readings) for systems in soil groups I (20.1), II (12.2) and III (3.1) were similar to median groundwater DIN concentrations for systems in soil groups I (20.0), II (8.2) and III (1.2) analyzed in the laboratory (2 months/readings).

Wastewater samples from accessible tanks (GI-A, GI-B, GI-D, GI-F, GII-A, GII-C, GII-D, GIII-A, GIII-C, GIII-D) were collected and analyzed three times (December 2007, January and February 2008) during the study period for DIN at the NCSU Soils laboratory and for E. coli at the East Carolina University Geochemistry laboratory. The E. coli densities in groundwater were analyzed seasonally for 1 year, using the membrane filtration method with m-ColiBlue 24 culture media. Samples were collected using disposable bailers (one-time), poured into sterile bottles, put on ice in coolers, transported to the laboratory and prepared for incubation the same day. Samples were incubated at 35° C for 24 hours, and the colonies counted and recorded. Because of the high bacterial densities, dilution factors ranging from 10-1000 were used for groundwater samples. Blanks were run approximately every 10 samples.

2.3.2 Data Analysis

The state and federal groundwater and surface water standard for NO_3^--N is set at 10 mg/L, for public health purposes (North Carolina Department of Environment and Natural Resources 2008). Water supplies with NO_3^--N concentrations greater than 10 mg/L may be hazardous to infants due to methemoglobinemia, or blue baby syndrome

(Brady et al. 2004). While high nitrate concentrations in drinking water are a public health risk, another environmental concern is groundwater transport of NH_4^+ and NO_3^- to surface waters. Both NH_4^+ and NO_3^- are bio-available forms of nitrogen and can cause eutrophication in surface waters, as experienced in coastal North Carolina (Whitall et al. 2003). Ammonium-N and NO_3^--N also have been shown to account for the vast majority (75-97%) of nitrogen in septic tank effluent (Buetow 2002; and Cardona 2006) and groundwater beneath the septic systems (Robertson et al. 1991; Postma et al. 1992; Harmon et al. 1996; Buetow 2002; and Reay 2004). Estuarine concentrations of available nitrogen including NH_4^+-N and NO_3^--N that are 1 mg/L or even less, can cause eutrophic conditions (Osmond et al. 2003). Therefore, inadequate nitrogen treatment was defined as an occurrence when the concentration of DIN in groundwater beneath septic systems was greater than or equal to 10 mg/L. While this chapter uses DIN as an indicator of wastewater effects on shallow groundwater quality, an analysis of septic system loading of dissolved organic nitrogen to groundwater is discussed in Chapter 4.

Inadequate bacteria treatment was defined as an occurrence when the density of E. coli in groundwater beneath septic systems was greater than or equal to the US EPA (2003) freshwater full contact standard of 126 colony forming units (cfu) per 100 milliliters. The frequency of inadequate treatment events was reported for each system and each soil group. These analyses helped to determine which soil groups were more prone to inadequate treatment. To gain a broader perspective on how common inadequate septic system treatment was in this coastal region, inadequate treatment events for all 16 sites were tallied. A Mann Whitney nonparametric test (Davis 2001; Reay 2004; Ahmed et al. 2005; and Cahoon et al. 2006) was used to determine if there was a significant ($p \leq 0.10$) difference between groundwater concentrations (DIN and bacteria) beneath septic systems installed in soils of different texture, background concentrations, and water quality standards.

There are several potential factors that can influence the water quality beneath septic systems. To control for the influence of system type, only sites with the same type of system (gravity distribution, gravel trenches or beds) were selected. To determine the influence of vertical separation distance while controlling for wastewater strength and loading rate, water quality beneath each system during periods of relatively large separation distances was compared to water quality beneath systems during relatively small vertical separations, and the data was pooled for each soil group. For nitrogen analysis, the DIN concentrations during the six months with the largest separation distances (predominantly spring and summer) were compared to the concentrations during the six months with smallest vertical separation distances (predominantly fall and winter) for each site. For E.coli analysis, seasonal sampling provided four samples per system, bacteria densities beneath septic systems during the two months with the largest separation distance were compared to the concentrations during the two months with the smallest vertical separation distance.

Typically in coastal North Carolina, the water table is highest during the winter months when there is relatively less evaporation and transpiration (ET). Groundwater tables are usually lowest during the summer months when ET is greatest, even though summer months typically have the highest seasonal rates of rainfall (Sun et al. 2002).

Coastal North Carolina has experienced flooding and elevated groundwater levels in the summer and fall seasons due to tropical storms and hurricanes. However, for the 16 month groundwater monitoring study period (December 2006-March 2008) precipitation was 10 cm below the average (172 cm) for the overall study area (Figure 2.3).

Septic system treatment efficiency (reduction in source pollutant concentration) was estimated using equation 2.1 below. The treatment efficiency for each soil group was calculated to determine the effects of soil type on wastewater treatment.

Equation 2.1 Treatment Efficiency

$$TE = \{[T - (GW - BG) / T] * 100\}$$

where: TE = Treatment Efficiency (%)

T = Median septic tank wastewater DIN or geometric mean E. coli concentrations

GW = Median groundwater DIN or geometric mean E. coli concentrations near septic system

BG = Median background groundwater DIN or geometric mean E. coli concentrations

2.4 Results

2.4.1 Effects of Soil Type on Wastewater Treatment-Dissolved Inorganic Nitrogen

Median septic tank DIN concentrations for all soil groups in this study (26-32 mg/L) were similar to the lower end of concentrations reported in a literature review by Cardona (2006) (30 – 100 mg/L) and reported in a literature review by Beutow (2002) (26-110 mg/L). Eleven of the 16 systems (69%), 7 of the 8 in soil group I and all 4 is soil group II, monitored had DIN concentrations greater than 10 mg/L in groundwater beneath the systems for more than 25% of the dates sampled (Table 2.3). Of the 226 samples analyzed for DIN, 99 (44%) were greater than 10 mg/L. Systems installed in soil group I had the highest median concentration of DIN (18.9 mg/L) in groundwater beneath the systems (Table 2.3), followed by soil group II (11.0 mg/L), and soil group III (2.6 mg/L).

Dissolved inorganic nitrogen concentrations in groundwater adjacent to systems were significantly higher ($p \leq 0.10$) than in background wells for each soil group (Figure 2.4). Only systems installed in soil group I had groundwater DIN concentrations significantly higher than 10 mg/L. Collectively, systems installed in soil group III were the most efficient (Table 2.4) at reducing DIN concentrations before discharging into shallow groundwater (93%), followed by systems in soil group II (76%), and soil group I (17%).

2.4.2 Effects of Soil Type on Wastewater Treatment-Bacteria

Eight of the 16 septic systems (50%) had E. coli densities greater than 126 cfu for more than 25% of the times sampled (Table 2.5). These include 25% of systems (2 of 8) installed in soil group I, all four systems in soil group II (100%), and two of four systems (50%) in soil group III. Of the 32 samples analyzed for E. coli beneath systems in soil group I, 9 samples (28%) exceeded the standard. Nine of the 16 groundwater samples (56%) beneath systems in group II soils exceeded 126 cfu/100 mL and 5 of the 16 (31%) samples beneath systems in soil group III exceeded the standard. The geometric mean density of E. coli (cfu/100mL) for groundwater beneath septic systems was highest for soil group II (127) followed by soil group III (47) and soil group I (23) (Table 2.5). Geometric mean densities of E. coli in groundwater were significantly higher beneath the septic systems than background groundwater for each soil group (Figure 2.5).

All septic systems reduced bacteria concentrations from the septic tanks by greater than 99.99% (Table 2.6) before discharging to shallow groundwater, but systems in soil group III were the most efficient per unit depth of vertical separation, followed by soil group II and soil group I. Geometric mean septic tank wastewater densities of E. coli reported in this study for each soil group ($6.4 \times 10^5 – 4.1 \times 10^6$ cfu/100 mL) were similar to septic system densities (1.2×10^6 cfu/100 mL) reported by Pang et al. (2003).

2.4.3 Effects of Vertical Separation Distance on Wastewater Treatment- Dissolved Inorganic Nitrogen

Group I soils, as required by North Carolina regulations (15A NCAC 18A .1955) for the design and construction of septic systems, had the largest median vertical separation between the drainfield and water table (111 cm), followed by group II soils (65 cm), and group III soils (17 cm). Dissolved inorganic nitrogen treatment efficiency was lower for systems in soil groups I that had the smallest separation distances, but DIN treatment efficiency was similar for systems in soil groups II and III with varying separation distances (Table 2.4). Median DIN concentrations in groundwater beneath systems were higher during periods of deep as compared to shallow water tables for systems in all soil groups (Figures 2.6A and 2.6B) and the hydraulic gradient was also lower during deep water table periods for most systems (Table 2.7).

Collectively, systems installed in group II soils had the highest percentage (43) of DIN in groundwater as NH_4^+-N. Systems in soil group II had median vertical separation distances of 65 cm (Table 2.3). All systems in group I soils had median vertical separation distances greater than 65 cm except system GI-A (57 cm), which also had a relative high percentage of DIN as NH_4^+-N (63%). This indicates that systems in group I and II soils may require more than 57-65 cm of median separation distance to water table for nitrification of most NH_4^+-N to occur. All systems in group II soils had less than 60 cm vertical separation to seasonal high water table (Table 2.3). Systems in soil group III with a median separation of 17 cm had NO_3^--N as the dominant species (66%) in the shallow groundwater beneath the systems, possibly due to relatively more NH_4^+-N adsorption on cation exchange sites. One system in group III soils (GIII-D) maintained a 30 cm separation distance to seasonal high water table, but the other 3 systems did not. Bacteria and DIN concentrations for all four systems in group III soils were similar.

2.4.4 Effects of Vertical Separation Distance on Wastewater Treatment - Bacteria

Geometric mean E. coli densities in the groundwater beneath systems in each soil group were higher during periods of shallow water tables and small vertical separation distances (Figures 2.7, 2.8). Relatively larger separation distances allow for more potential filtration and removal of bacteria before discharge to the groundwater system. All systems reduced bacteria densities from the tank by more than 99.99% before discharge into the shallow groundwater (Table 2.6). However, systems in group I soils had the largest mean vertical separation distance (83 cm) followed by systems in group II (53 cm) and group III (32 cm), indicating that systems in more fine textured soils can achieve relatively high bacteria density reductions with less vertical separation than coarse textured soils.

2.5 Discussion

Shallow groundwater concentrations of DIN and E. coli adjacent to septic systems in coastal North Carolina soils were significantly higher than background concentrations, and were often higher than groundwater quality standards, particularly for systems in group I and II soils with shallow water tables. While groundwater beneath systems in group I soils had higher NO_3^--N concentrations than groundwater beneath systems in group II soils, the total DIN (NH_4^+-N + NO_3^--N) concentrations were not significantly different ($p = 0.1751$) because groundwater adjacent to group II soils had relatively more NH_4^+-N. For systems installed in soil groups I and II, in particular, separation distance appears to affect the speciation of nitrogen entering the shallow groundwater system. For example, most of the DIN (87% excluding system GI-A) adjacent to systems in group I soils was NO_3^--N except for system GI-A, which had the smallest median vertical separation distance (57 cm) of the group I systems and shallowest separation distance (44 cm) during the 14-day seasonal high water table (Table 2.3). For GI-A, NH_4^+-N was the dominant species (63%) of DIN in the groundwater adjacent to the system, indicating that other conditions necessary for nitrification to occur (presence of oxygen and nitrifying bacteria) were not present.

Overall, systems installed in group I soils in comparison to group II soils had larger median separation distances, 111 and 65 cm, respectively, affecting the aeration of the soils and speciation of nitrogen. Seven of eight systems in soil group I (88%) and all four systems in group II (100%) had frequencies of groundwater DIN concentrations greater than 10 mg/L for more than 25% of the times sampled, but none of the systems in group III soil did. This indicates that the separation distance between systems and the water table in coarse-grained, sandy soils (group I and II) may affect the dominant species of nitrogen and that sandy soils are more prone to nitrogen loadings to shallow groundwater.

Systems in soil group III collectively had the highest percentages of clay, lowest hydraulic conductivities, smallest vertical separation distances, and the lowest DIN concentrations in groundwater beneath the systems (Tables 2.2, 2.3 and Figure 2.4). A possible explanation may be that relatively more of the NH_4^+-N entering the drainfield trenches in group III soils is bound to cation exchange sites on the clay minerals (Carroll et al. 2004) and/or biomat on the trench. The group I and group II soils had lower effective cation exchange capacities (mean 3.1 and 2.9 cmol/Kg, respectively) than group III soils (mean 7.4 cmol/Kg) (Table 2.2). Also, group III soils had the lowest mean hydraulic conductivities (0.19 m/day) in comparison to group II (mean 0.32 m/day) and group I soils (3.34 m/day), suggesting longer subsurface residence times (Table 2.2). Other possibilities for lower concentrations of DIN in groundwater beneath systems in group III soils are greater nitrification and denitrification rates, more immobilization of NH_4^+-N by microorganisms and/or greater plant uptake for systems installed relative to group I and II soils. These findings are consistent with the results of a recent experiment by Karathanasis et al. (2006) that found finer textured soils (group III and IV) were more efficient at reducing NH_4^+-N, total N and BOD than coarse textured soils, due to more reactive surface areas and greater nitrification/denitrification potential.

Dissolved inorganic nitrogen concentrations were higher during periods of deep relative to shallow water tables for systems in all three soil groups. Some possible reasons for the increase in DIN with an increase in separation may include less dilution and dispersion and higher nitrification and leaching rates during deeper water table periods. Darcy's law ($Q = KA*dh/dl$) relates groundwater flow rate (q) to the hydraulic gradient (dh/dl). The hydraulic gradient for most systems was smaller during deep water table conditions (Table 2.7). Lower groundwater flux and less dispersion could lead to relatively higher DIN concentrations during periods of deeper water tables and smaller hydraulic gradients due to less mixing and dilution of wastewater with rainwater that infiltrates the soil. Greater separation distances may stimulate oxidation of NH_4^+-N held on soil exchange sites (Ptacek et al. 1998) or in soil water, leading to increased nitrification and leaching.

For systems installed in all three soil groups, the geometric mean densities of bacteria during periods of shallow water tables and small vertical separation distances were higher than during periods of deep water tables and large vertical separation distances (Figures 2.7, 2.8). Even with relatively less dilution and dispersion during deep water table conditions, the larger system separation distances provided better overall treatment and bacteria reduction for each soil group. These data indicate that separation distance is an important control on bacteria treatment, particularly for coarse textured soils.

Soil type also influences shallow groundwater quality beneath systems. For example, when comparing the geometric mean E. coli densities beneath systems in soil groups II and III during periods of similar median separation distances, densities beneath group II soils were much larger. For systems in group II and III soils during periods of similar median separation distances 27 cm and 29 cm respectively, the geometric mean density of E. coli in groundwater beneath systems in soil group II were 358 compared to 28 cfu/100 mL for soil group III (Figure 2.8). These data suggest that group III soils provide better removal of bacteria per unit length of separation than group II soils. Also, the geometric mean densities of E. coli beneath group I and group III soils with median vertical separation distances of 105 cm and 29 cm, respectively, were nearly identical (32 and 28 cfu/100 mL), indicating that clay rich soils provide better treatment of bacteria per given length of separation distance (Figure 2.8).

These trends are also present when comparing the DIN treatment efficiency of systems in different soils with similar separation distances. For DIN concentration reductions, system GI-A (group I soil) with a median separation distance of 57 cm, reduced DIN by 8%, as compared to systems GII-D and GIII-D with median separation distances of 56 and 60 cm and DIN reductions of 76 and 94%, respectively (Table 2.4). While all systems were efficient at reducing E. coli densities from the tank (> 99.99%), systems in soil group III achieved the reduction percentage with the smallest mean vertical separation distance (32 cm), followed by systems in group II (53 cm) and group I (109 cm). The superior treatment efficiency of group III soils may be due to inherent properties of soils with higher clay contents such as relatively high ECEC, more reactive surface area, and lower hydraulic conductivity. These properties can increase the residence time of wastewater in soil, thus allowing more opportunity for pollutant reduction processes to occur.

While groundwater DIN and E. coli concentrations adjacent to septic systems were significantly higher than background groundwater for each soil group, there were some background groundwater samples that had elevated concentrations of DIN and E. coli. This may be due to the influence from other septic systems and row crop agriculture up-gradient from the background wells. The background wells were not installed in isolated areas; they were installed up-gradient from the monitored septic systems. Overall, the background groundwater quality for each soil group follows a similar pattern as the water quality adjacent to the septic systems in the soil groups. More specifically, the lowest median concentration of DIN was found in background groundwater in soil group III and highest geometric mean E. coli densities in soil group II. This suggests that septic systems can influence groundwater quality not only adjacent to systems, but many meters away.

2.6 Management Implications and Conclusions

Systems installed in group I and II soils that maintained a 60+ cm separation distance to the seasonal high water table (GI-B, GI-C, GI-D, GI-E, GI-F, GI-G, GI-H) had median NH_4^+-N and geometric mean E. coli densities of 0.4 mg/L and 31 cfu/100mL, respectively. Systems in group I (GI-A) and group II (GII-A, GII-B, GII-C, GII-D) soils with less than 60 cm vertical separation (Tables 2.3 and 2.5) had median NH_4^+-N and geometric mean E. coli densities of 4.4 mg/L and 96 cfu/100mL respectively. For systems in group III soils, a 30 cm separation distance to water table was effective at reducing source concentrations of bacteria and nitrogen. However, more information is needed to determine the frequency and duration of direct wastewater discharge to groundwater (periods of water table elevations greater than trench bottom elevations) for systems that meet the 30 cm standard to SHWT but experience encroachments of the separation distance requirements throughout the year.

Septic systems in coastal soils are generally more efficient at reducing bacteria in comparison to nitrogen concentrations before discharge into the shallow groundwater. Soil type and separation distance are two factors that influence water quality beneath systems. Septic systems in soil groups I and II were less effective at pollutant removal as compared to systems in soil group III per unit depth of separation.

Systems installed in soil groups II with 30 cm of required separation distance and systems in soil group I with 45 cm of required separation distance consistently contributed septic effluent with elevated NH_4^+-N and E. coli to the shallow groundwater system. The shallow groundwater in coastal North Carolina is connected to the adjacent surface waters and pollutant loading may contribute to eutrophication, closure of shellfish waters and/or beach advisories. Increasing the required vertical separation distance from system to seasonal high water table from 45 and 30 cm to 60 cm for systems in group I and II soils respectively, should increase the likelihood of effluent nitrification beneath systems and reduce bacteria concentrations in shallow groundwater. Dissolved inorganic nitrogen concentrations in groundwater adjacent to systems may increase with an increase in separation distance due to greater nitrification rates and leaching. However, DIN contributions from septic systems to adjacent surface waters may decrease if the predominant species of DIN is NO_3^-, and NO_3^- is removed via denitrification before entering surface waters. Ammonium is not removed through the denitrification process.

This study provided evidence that groundwater adjacent to septic systems can have high concentrations of nitrogen and bacteria (from the systems), but it is possible that the core of the septic system impacted groundwater plume was not sampled due to the spatial variability of the plume, and that the actual contributions were even greater. Also, we did not research the fate of the observed pollutants. Therefore, more research is needed on the spatial variability of pollutants within a wastewater impacted groundwater plume, the fate and transport of such pollutants and the environmental and public health risks of these septic system derived and groundwater transported contaminants. A long-term, shallow groundwater monitoring network is needed to help provide some of this important data.

Based on data collected in this study and other literature, increasing the separation distance requirements from systems to SHWT to 60 cm can improve the likelihood of effluent nitrification, and requiring vegetated buffers along streams may improve water quality by increasing the likelihood of denitrification and thus improve water quality (Robertson et al. 1991; and Buetow 2002).

Table 2.1 North Carolina DENR soil groups and corresponding USDA textural class designations with loading rate ranges and separation distance requirements for septic system design (NC Division of Environmental Health 1999).

NC DENR Soil Groups	USDA Textural Class	Loading Rate ($L/day/m^2$)	NC Separation Distance (cm)
Group I	Sand, Loamy Sand	0.42 – 0.28	45
Group II	Sandy Loam, Loam	0.28 – 0.21	30
Group III	Silt Loam, Clay Loam, Sandy Clay Loam, Silt, Silty Clay Loam	0.21 – 0.11	30
Group IV	Sandy Clay, Clay Silty Clay	0.14 – 0.04	30

Table 2.2 Site, soil and system information. Site elevation above mean sea level was approximated from topographic maps. Mean ground water (GW) elevation was during the December 2006-March 2008 period. Site location of NWP is Newport, AB is Atlantic Beach, and PKS is Pine Knoll Shores. Con. is a conventional system with 2 or more 90 cm wide, drainfield trenches, bed systems have one trench often 180 cm wide or greater. Effective cation exchange capacity (ECEC) is a measure of the capacity to absorb and exchange cations in reversible reactions. Humic matter percentage (HM) is the amount of complex organic material. Hydraulic conductivity (Ksat) is the measured rate (slug tests using Bower and Rice (1976) method) water moves through the soil under saturated conditions**.**

Soil Group I	Site Elevation (m)	Mean GW Elevation (m)	System Install Date	Site Location City/Town	System Type	USDA Soil Series	% Sand	% Silt	% Clay	ECEC (cmol/kg)	pH	HM%	Ksat (m/day)
GI-A	3.3	2.23	2006	NWP	Bed	Mandarin	90.3	4.6	5.1	5.6	4.7	4.8	0.98
GI-B	3.66	2.3	2005	NWP	Bed	Baymeade	94.6	2	3.4	1.2	5.3	0.2	2.47
GI-C	3.13	1.9	2006	NWP	Con.	Baymeade	90.7	3.9	5.3	3.2	6.1	0.7	1.01
GI-D	2.94	1	1991	AB	Con.	Fripp	98	0.3	1.7	2.3	4.8	0.6	1.95
GI-E	3.28	0.42	1996	PKS	Bed	Fripp	98.3	0	1.7	1.5	5.8	0	8.44
GI-F	3.15	1.05	1979	PKS	Bed	Newhan	97.2	0.3	2.5	2	6.2	0.1	1.37
GI-G	2.59	0.56	1977	PKS	Con.	Newhan	98	0.3	1.7	5.6	7.6	0.2	5.7
GI-H	2.32	0.39	1977	PKS	Con.	Newhan	97.2	1.2	1.7	3.1	6.3	0.3	4.82
Mean	3.05	1.23	1992				95.5	1.6	2.9	3.1	5.9	0.9	3.34

Soil Group II	Site Elevation (m)	Mean GW Elevation (m)	System Install Date	Site Location City/Town	System Type	USDA Soil Series	% Sand	% Silt	% Clay	ECEC (cmol/kg)	pH	HM%	Ksat (m/day)
GII-A	3.58	2.26	1987	NWP	Con.	Goldsboro	74.2	9.6	16.2	3.2	5.6	0.2	0.18
GII-B	2.74	1.96	1985	NWP	Con.	Goldsboro	80.7	10.1	9.2	3.5	6.6	1.9	0.52
GII-C	3.6	2.34	1998	NWP	Con.	Goldsboro	79	7.5	13.4	2.8	5.5	0.5	0.49
GII-D	3.44	2.37	1999	NWP	Con.	Goldsboro	75.4	11.1	13.5	2.1	5.8	0.6	0.09
Mean	3.34	2.23	1990				77.3	9.6	13.1	2.9	5.9	0.8	0.32

Soil Group III	Site Elevation (m)	Mean GW Elevation (m)	System Install Date	Site Location City/Town	System Type	USDA Soil Series	% Sand	% Silt	% Clay	ECEC (cmol/kg)	pH	HM%	Ksat (m/day)
GIII-A	2.01	1.05	1995	Smyrna	Con.	Altavista	66.8	12.3	20.9	7	6.8	0.1	0.15
GIII-B	1.68	0.85	1986	Smyrna	Con.	Altavista	71.2	5.2	23.6	7.7	7.8	0	0.18
GIII-C	1.91	0.93	1994	Smyrna	Con.	Altavista	67	8.2	24.7	7.2	7.6	0	0.09
GIII-D	2.33	1.23	1991	Smyrna	Con.	Altavista	64.9	9.7	25.4	7.5	6.9	0.1	0.34
Mean	1.98	1.02	1992				67.5	8.9	23.7	7.4	7.3	0	0.19

Table 2.3 Median and mean dissolved inorganic nitrogen concentrations (NH_4^+-N+NO_3^--N) in groundwater adjacent to septic systems in soil groups I, II and III. Frequencies of concentrations greater than 10 mg/L were reported along with the percentage of DIN as NH_4^+-N and as NO_3^--N. Mean and median separation distances from the septic system trench bottom to the water during sampling events and during the 14-day seasonal high water table* was reported.

		N-(NH_4+NO_3) mg/L					Separation (cm)		
Soil Group I	n	Mean	Med	Freq > 10	% NH4	% NO3	Mean	Med	SHWT
GI-A	14	32.3	29.7	100	63	37	58	57	44*
GI-B	15	28	28.5	67	5	95	87	88	68
GI-C	12	14	12.5	58	15	85	91	91	67
GI-D	13	24.7	24.8	85	10	90	126	130	104
GI-E	11	31.8	29	82	4	96	213	215	199
GI-F	14	15.8	13	50	15	85	135	135	116
GI-G	15	5.6	4.4	13	11	89	144	145	124
GI-H	15	14.7	4.6	33	28	72	83	83	65
Med			18.9		13	87		111	

Soil Group II	n	Mean	Med	Freq > 10	% NH4	% NO3	Mean	Med	SHWT
GII-A	14	20.6	14	50	48	52	76	77	24*
GII-B	15	14.6	12.5	73	32	68	33	38	0*
GII-C	13	8.5	6.9	31	52	48	74	73	41
GII-D	15	24.5	9.4	47	39	61	58	56	25*
Med			11		43	57		65	

Soil Group III	n	Mean	Med	Freq > 10	% NH4	% NO3	Mean	Med	SHWT
GIII-A	15	3.8	2.5	7	47	53	14	15	0*
GIII-B	15	3.3	0.9	13	43	57	16	19	0*
GIII-C	15	5.3	2.7	7	25	75	4	4	0*
GIII-D	15	3.4	3.2	7	24	76	61	60	43
Med			2.6		34	66		17	

Table 2.4 Dissolved inorganic nitrogen (NH_4^+-N+NO_3^--N) treatment efficiency for systems in soil groups I, II and III. Treatment efficiency was only calculated for systems that septic tank samples were collected from. Median and mean separation distances during sampling periods for DIN are reported. Median DIN values are listed for the tank, groundwater and background for the treatment efficiency calculations.

System	Tank (DIN) Mg/L	Groundwater (DIN) mg/L	Background (DIN) mg/L	GW-BG DIN (mg/L)	Treatment Efficiency %	Median Separation (cm)	Mean Separation (cm)
GI-A	31.2	29.7	0.9	28.8	8	57	58
GI-B	29.4	28.5	0.9	27.6	6	88	87
GI-D	32.2	24.8	0.8	24.0	25	214	213
GI-F	22.9	13	1.4	11.6	49	145	144
Median	30.3	26	0.9	25.8	17	117	116
Mean	28.9	24.0	1.0	23.0	22	126	126
GII-A	31.2	14	2.4	11.6	63	77	76
GII-C	33.9	6.9	1.9	5	85	73	74
GII-D	30.7	9.4	1.9	7.5	76	56	58
Median	31.2	9.4	1.9	7.5	76	73	74
Mean	31.9	10.1	2.0	8.0	75	69	69
GIII-A	26.4	2.5	0.8	1.7	94	15	14
GIII-C	31.0	2.7	0.5	2.2	93	19	16
GIII-D	19.9	3.2	0.5	2.7	86	60	61
Median	26.4	2.7	0.5	2.2	93	19	16
Mean	25.8	2.8	0.6	2.2	91	31	30

Table 2.5 Geometric mean and median E. coli densities in groundwater adjacent to septic systems in soil groups I, II, III. Frequencies of densities (Freq) greater than 126 cfu/100 mL of sample were reported. Mean and median vertical separation distances during times of bacteria sampling and the separation to seasonal high water table (SHWT) are reported. A "0" depth to SHWT indicates that the water table was at or higher than the septic trench bottom. Summary is for all samples in each soil group; sum of (n), geometric mean E. coli, median E. coli, mean frequency and vertical separation distance and median separation distance.

	Septic Groundwater E. coli Densities (cfu/ 100 mL)				Vertical Separation Distance		
System	n	Geo-mean	Med	Freq > 126	Mean (cm)	Med (cm)	SHWT
GI-A	4	31	57	25	68	69	44
GI-B	4	26	59	25	94	98	68
GI-C	4	20	184	50	94	91	67
GI-D	4	5	6	0	133	133	104
GI-E	4	210	385	75	223	222	199
GI-F	4	55	96	25	141	142	116
GI-G	4	40	100	25	176	176	124
GI-H	4	3	1	0	90	94	65
Summary	32	23	59	28	114	115	

System	n	Geo-mean	Med	Freq > 126	Mean Sep (cm)	Med Sep (cm)	SHWT
GII-A	4	194	117	50	37	40	24
GII-B	4	156	340	75	1	11	0
GII-C	4	52	184	50	61	54	41
GII-D	4	164	153	50	62	64	25
Summary	16	127	157	56	49	47	

System	n	Geo-mean	Med	Freq > 126	Mean Sep (cm)	Med Sep (cm)	SHWT
GIII-A	4	38	114	50	20	22	0
GIII-B	4	9	31	0	9	10	0
GIII-C	4	112	100	25	23	24	0
GIII-D	4	123	126	50	53	53	43
Summary	16	47	96	31	21	23	

Table 2.6 Septic system bacteria (E. coli) treatment efficiencies for systems in soil groups I, II, and III. Ground water adjacent to systems (GW), background groundwater (BG) and separation distance to seasonal high water table (SHWT) are shown. A "0" depth to SHWT indicates that the water table was at or higher than the septic trench bottom. Treatment efficiencies were only calculated for systems that septic tank samples were collected.

	Geometric Mean E. coli (cfu/ 100 ml)					Vertical Separation Distances (cm)		
System	Tank	GW	BG	GW - BG	Treatment Efficiency %	Median	Mean	SHWT
GI-A	433859	31	2	29	99.99	69	68	44
GI-B	4544739	26	2	24	99.99	98	94	68
GI-D	420000	5	1	4	99.99	133	133	104
GI-F	846168	55	4	51	99.99	142	141	116
Median	640013	29	2	27	99.99	116	113	86
Mean	1561191	29	2		99.99	111	109	83
GII-A	3662228	194	17	177	99.99	40	37	24
GII-C	3838294	164	2	162	99.99	64	62	41
GII-D	2363332	52	2	50	99.99	54	61	25
Median	3662228	164	2	162	99.99	61	61	25
Mean	3287951	137	7		99.99	53	53	30
GIII-A	610000	38	1	37	99.99	22	20	0
GIII-C	4100000	112	2	110	99.99	24	23	0
GIII-D	14091664	123	2	121	99.99	53	53	43
Median	4100000	112	2	110	99.99	24	23	0
Mean	5486667	91	2		99.99	33	32	14

Table 2.7 Hydraulic gradients (m/m) for systems installed in soil groups I, II and III during periods of relatively shallow water tables with small (S) separation distances and deep water tables and large (L) separation distances; (x) indicates the larger gradient. For most systems the larger gradients were during shallow water table periods.

	Shallow Water Table				Deep Water Table		
	Mean	Median			Mean	Median	
GI-A	0.0175	0.0178	x	GI-A	0.0168	0.0171	
GI-B	0.0467	0.0464	x	GI-B	0.0431	0.0433	
GI-C	0.0311	0.0304	x	GI-C	0.0267	0.0269	
GI-E	0.0349	0.0351		GI-E	0.0355	0.0357	x
GI-F	0.0272	0.0272		GI-F	0.0280	0.0272	x
GI-G	0.0006	0.0005	x	GI-G	0.0006	0.0004	
GI-H	0.0006	0.0005	x	GI-H	0.0006	0.0004	
GII-A	0.0125	0.0105		GII-A	0.0146	0.0145	x
GII-B	0.0016	0.0017	x	GII-B	0.0013	0.0006	
GII-C	0.0040	0.0039	x	GII-C	0.0034	0.0038	
GII-D	0.0056	0.0060	x	GII-D	0.0045	0.0034	
GIII-A	0.0040	0.0038	x	GIII-A	0.0032	0.0035	
GIII-B	0.0039	0.0038	x	GIII-B	0.0046	0.0028	
GIII-C	0.0063	0.0064	x	GIII-C	0.0036	0.0034	
GIII-D	0.0153	0.0147	x	GIII-D	0.0126	0.0126	

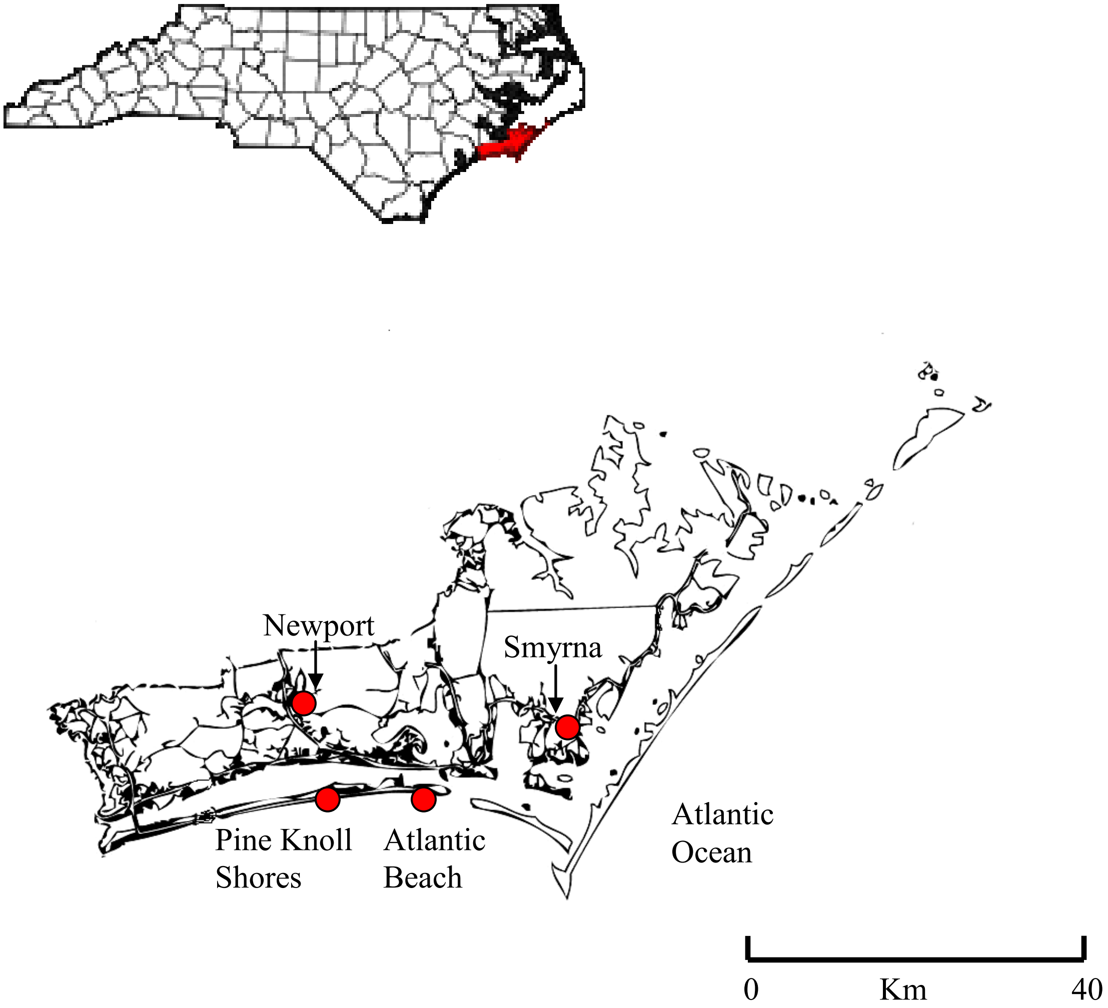


Figure 2.1 Research sites located in the towns/cities of Newport, Atlantic Beach, Pine Knoll Shores and Smyrna in coastal Carteret County, North Carolina. North Carolina state map with Carteret County in red. Scale is approximate. Maps created using base maps from Wikipedia and Carteret County GIS page.

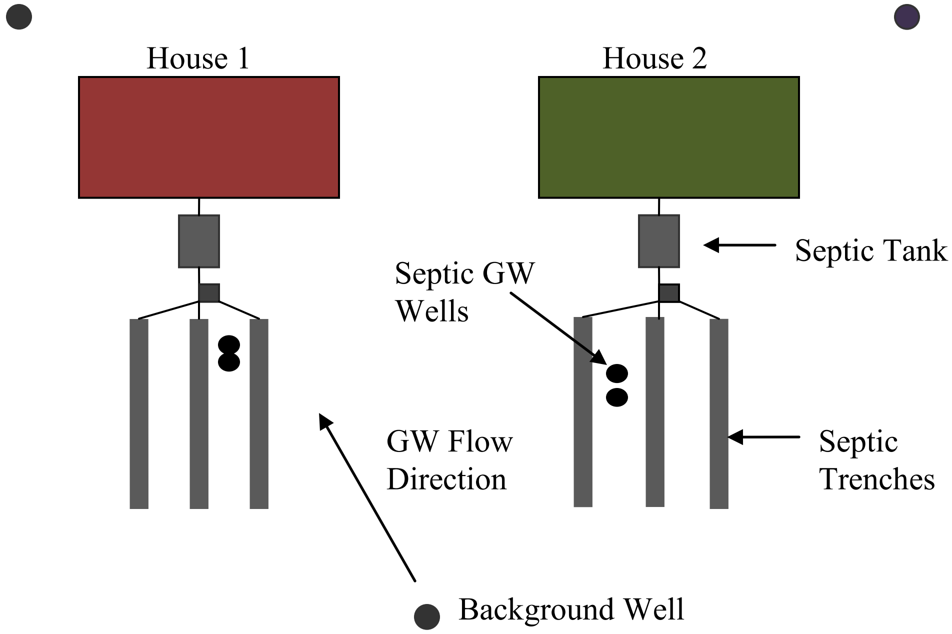


Figure 2.2A Plan-view of a groundwater monitoring design with adjacent houses, background well, nested septic groundwater monitoring wells between septic system trenches and groundwater flow direction wells at the corners of the lots. This design is similar to monitoring scheme for systems GII-C and GII-D.

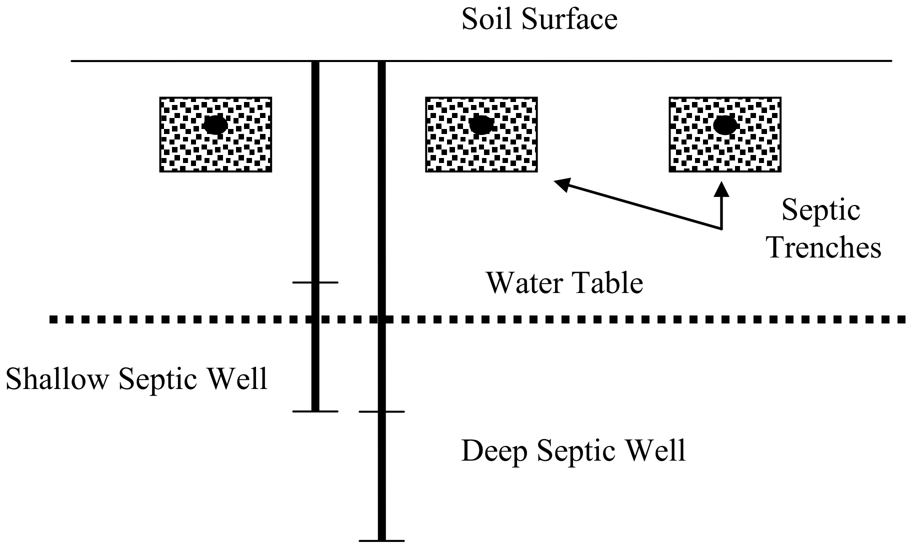


Figure 2.2B Cross-section view of septic drainfield monitoring well design with deep and shallow wells and screen intervals (75 cm each). The mean depth to trench bottom and water table for all systems was 65 cm and 145 cm, respectively.

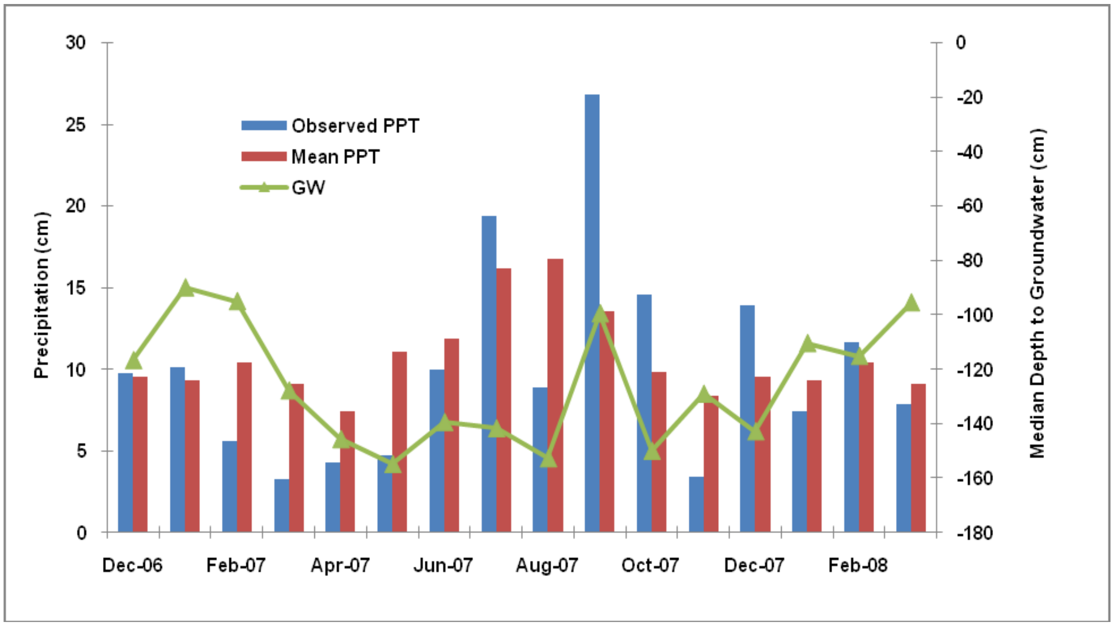


Figure 2.3 Median depths to groundwater for all 16 systems monitored and monthly average precipitation and observed precipitation for the study areas. Average and observed precipitation data was obtained from the North Carolina Climate Office (2009) for weather stations in Cherry Point, Newport, Morehead City and Atlantic Beach, North Carolina and from a research site at North River, North Carolina.

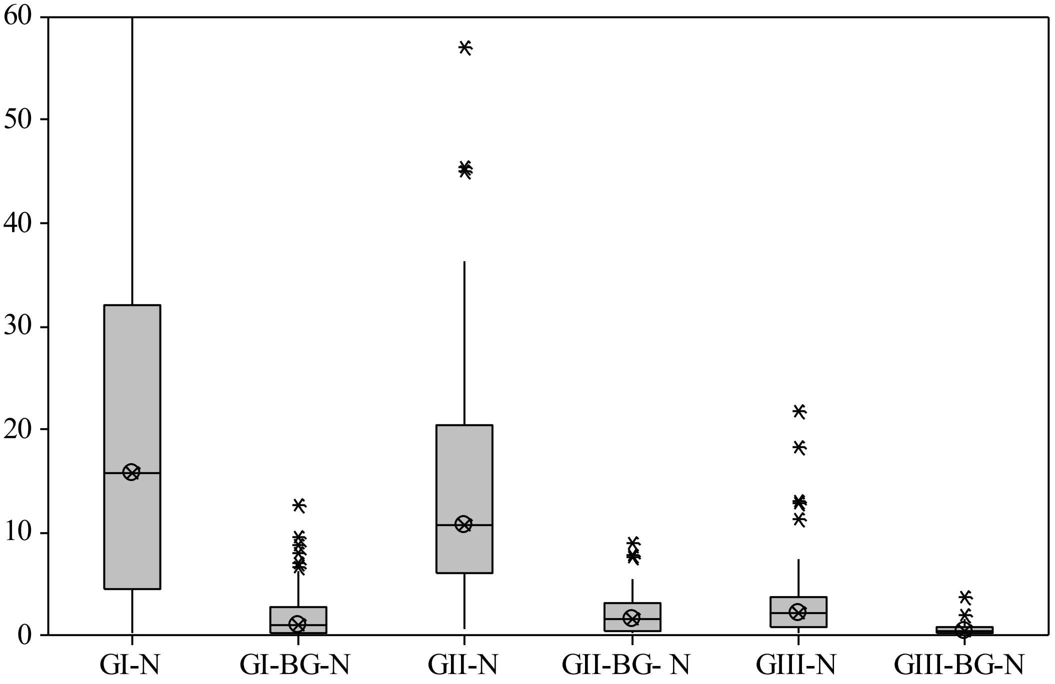


Figure 2.4 Dissolved inorganic nitrogen (DIN) concentrations (mg/L) adjacent to septic systems and in background groundwater (BG) for areas with group I (GI), group II (GII) and group III (GIII) soils. Significant ($p \leq 0.10$) differences in DIN concentrations included: GI-N > GI-BG-N, GII-N > GII-BG-N, GIII-N > GIII-BG-N, GI-N > GIII-N, and GII-N > GIII-N. No significant differences were found between GI-N and GII-N. Only GI-N was significantly greater than 10 mg/L standard.

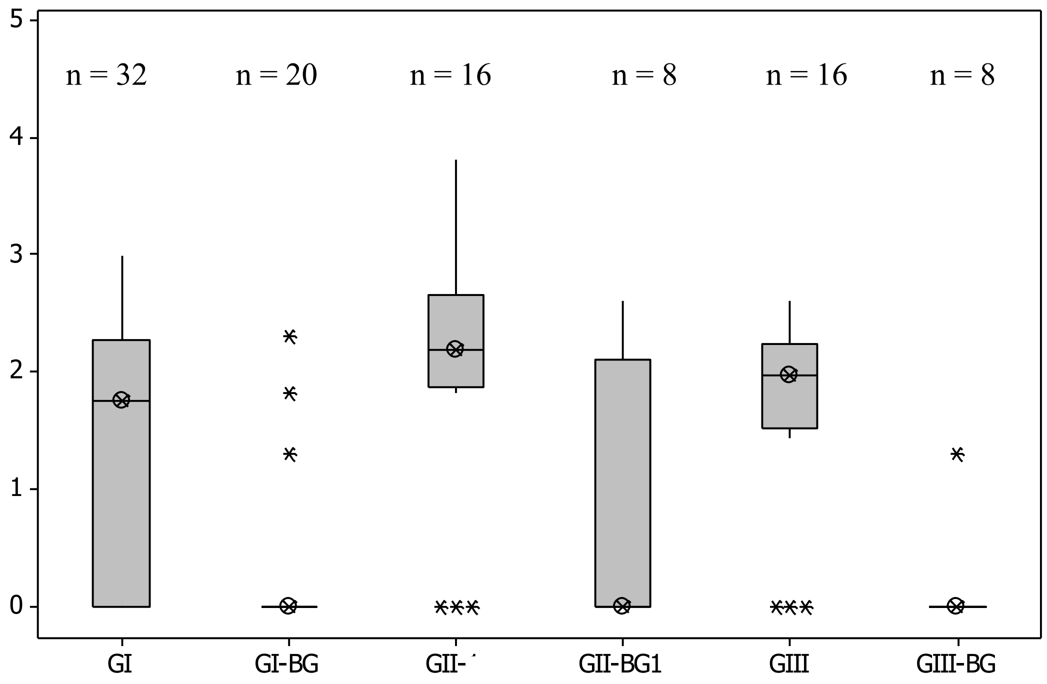


Figure 2.5 Log E. coli densities (colony forming units/ 100 mL), adjacent to septic systems in group I (GI), II (GII) and III (GIII) soils and in background groundwater (BG). Significant ($p \leq 0.10$) differences included: GI > GI-BG, GII > GII-BG, GIII > GIII-BG, GII > GI, GII > GIII. No significant differences were found between systems in GI and GIII soils.

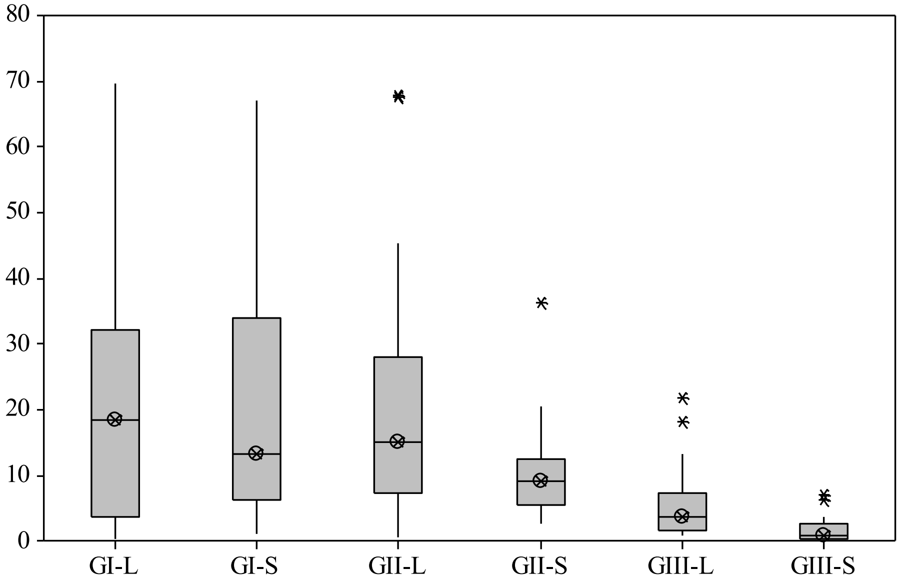


Figure 2.6A Dissolved inorganic nitrogen (DIN) concentrations (mg/L) in groundwater adjacent to systems in soil groups I, II and III during periods (6 months) of relatively large (L) and (6 months) small (S) vertical separation distances measured when sampling for DIN.

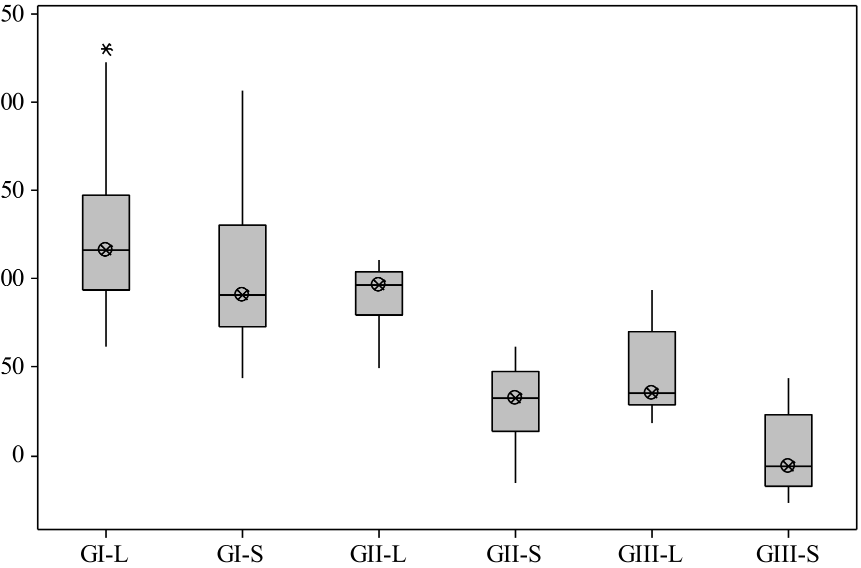


Figure 2.6B Vertical separation distances (cm) to water table measured when sampling groundwater for DIN for systems in soils groups I, II and III during the 6 months of relatively deep (L) and 6 months of shallow (S) water table periods. Deep and shallow water tables represent large and small separation distances, respectively.

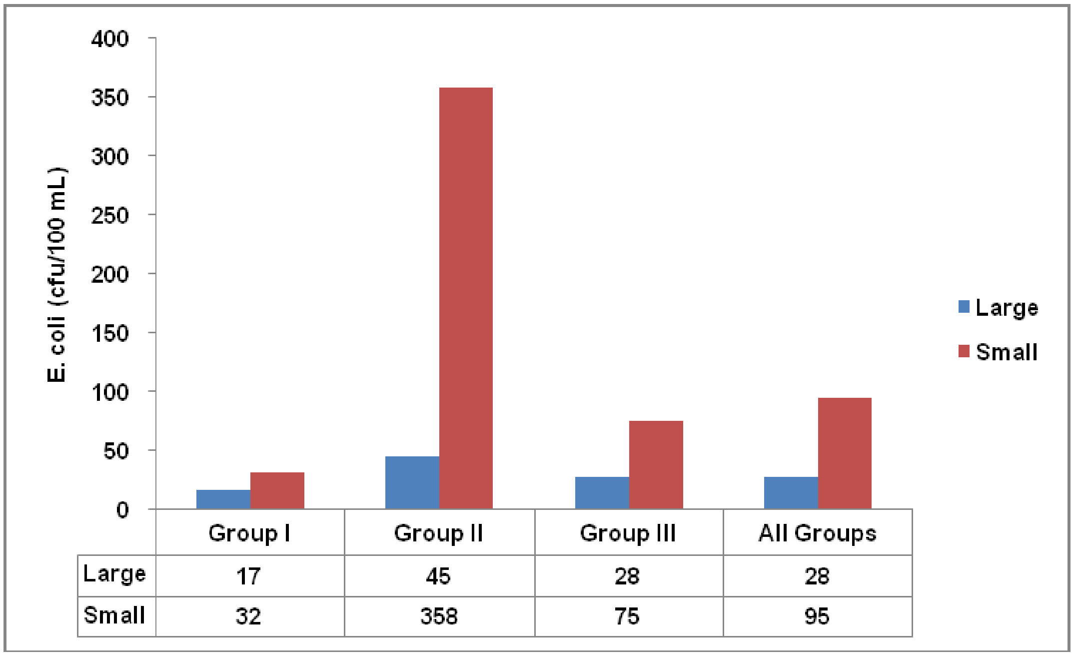


Figure 2.7A Geometric mean densities of E. coli (cfu/100mL) adjacent to septic systems in soil groups I, II and III during relatively large and small separation distances.

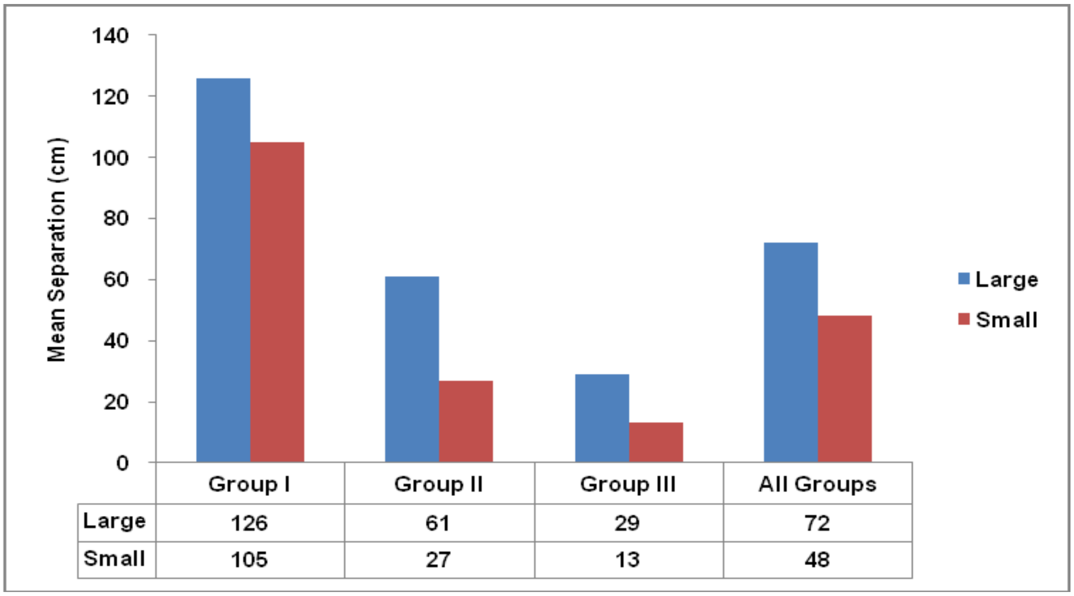


Figure 2.7B Median separation distances from septic systems to the water table in soil groups I, II, and III during periods of relatively large and small separation distances. Separation distances were measured during E. coli sampling.

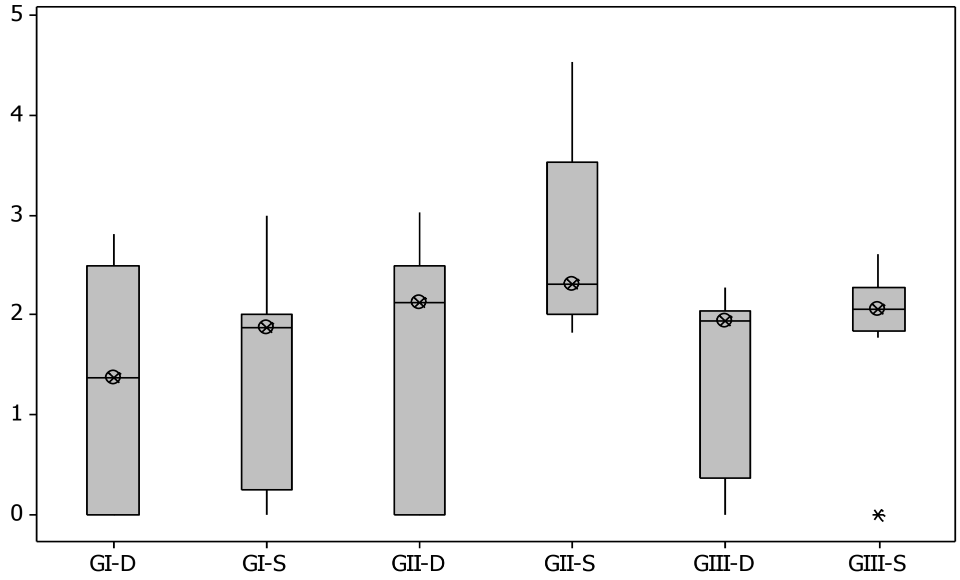


Figure 2.8A Log E. coli densities (cfu/100mL) adjacent to septic systems in soils groups I, II and III during periods of relatively deep and shallow water tables. Significant ($p \leq 0.10$) difference included: GII Shallow > GII Deep, GIII Shallow > GIII Deep. No significant difference was found between GI Shallow and GI Deep.

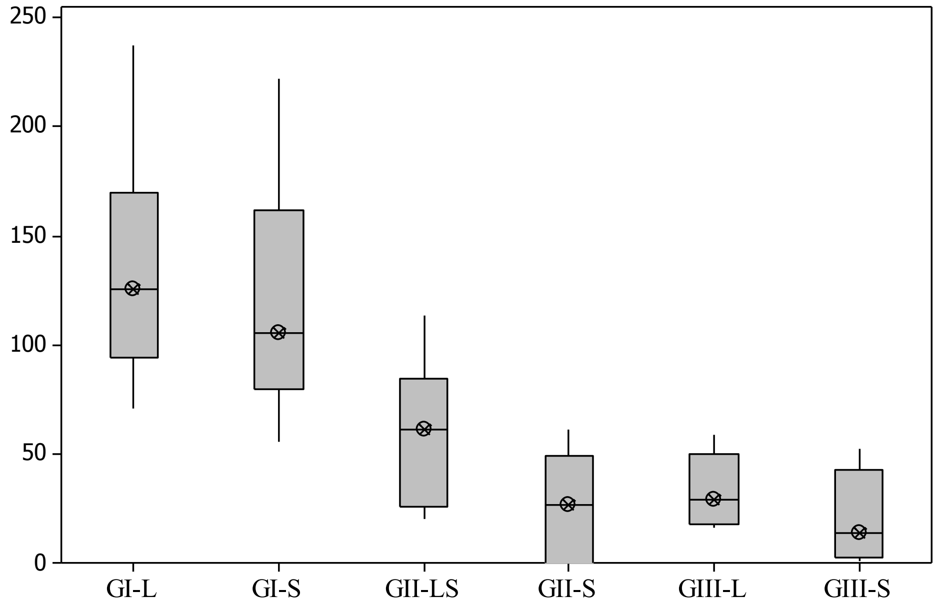


Figure 2.8B Vertical separation distances (cm) to water table in soil groups I, II and III during periods of deep (L) and shallow (S) water tables measured during E. coli sampling.

CHAPTER 3: EVALUATION OF SOIL COLORS AS INDICATORS OF THE SEASONAL HIGH WATER TABLE FOR DESIGNING ON-SITE WASTEWATER SYSTEMS IN COASTAL NORTH CAROLINA

3.1 Abstract

Low chroma (2 or less) soil colors are used as indicators of the seasonal high water table (SHWT) when land is evaluated for permitting septic systems. The separation distance from septic system to water table is important for providing aerated conditions for wastewater treatment. In North Carolina, septic systems installed in group I soils (sands) are required to have 45 cm of separation distance to the seasonal high water table, while systems in group II - IV soils (coarse loams to clay) are required to have 30 cm of separation. The objective of this study was to evaluate how closely low chroma soil colors predicted the depths to SHWT for 16 septic systems installed in 6 soil series including Goldsboro (group II), Altavista (group III), and Mandarin, Baymeade, Fripp and Newhan (all group I). For 11 of 16 systems, the depth to chroma 2 colors was within 22 cm of the observed SHWT, or both the chroma 2 depths and observed SHWT depth were greater than 122 cm, the maximum depth of evaluation for most septic system designs. Water tables frequently rose into the trenches of some systems (averages greater than 400 and 2400 hours/year for systems in Goldsboro and Altavista series, respectively) due to the installation depths and the relatively small (30 cm) separation distance requirements to SHWT. Increasing the North Carolina separation distance requirements from 30 to 45+ cm for systems in group II (sandy loam) and group III (clay loams) soils

could reduce the cumulative duration of water table levels above trenches by 75 and 67%, respectively, and thus improve groundwater quality.

3.2 Introduction

In North Carolina over 40,000 new septic systems are installed each year, 5,000 in coastal areas (North Carolina Department of Environment and Natural Resources 2007). These (septic) systems treat and dispose of human wastewater that contains many constituents such as viruses, bacteria, protozoa, nitrogen, phosphorus, and various metals that are potentially hazardous to public and/or environmental health (Canter and Knox 1985). Septic systems have three main components: a tank; drainfield trenches; and soil beneath the trenches. Liquid effluent flows from the tank to the drainfield trenches and infiltrates the soil, where most of the septic system wastewater pollutant removal occurs. The vertical separation distance from septic system to water table influences wastewater treatment efficiency, with larger separations typically providing better removal of pollutants such as nutrients (Carrol et al. 2004; Karathanasis et al. 2006), bacteria (Carlile et al. 1981; and Cogger et al. 1988), and viruses (Nicosia et al. 2001). Preventing groundwater pollution in coastal North Carolina is important because many communities rely on groundwater wells for water supply and the shallow groundwater is hydraulically connected to adjacent surface waters, many of which have experienced pollution problems such as eutrophication (Fear et al. 2004) and closure of shellfisheries due to bacterial pollution (Cahoon et al. 2006).

3.2.1 North Carolina Septic System Vertical Separation Distance Regulations

Prior to 1983, undeveloped building lots in North Carolina were evaluated for septic system suitability by performing a percolation (perk) test. The test involved digging three or more holes 45+ cm deep, within the proposed septic drainfield area, filling the holes with water and recording the depth to water after 24 hours. The perk test was a measure of the hydraulic conductivity of the soil, but did not provide definitive information on where the seasonal high water table was located within the soil profile, only an estimate of the rate at which water moves through the soil and potentially the location of the water table during the test. Research conducted in eastern North Carolina, (Daniels et al. 1971; Carlile et al. 1981) supported the use of soil colors as a relatively reliable and quick method to determine the seasonal high water table, an important design consideration for the installation of septic systems. By 1983 the North Carolina Department of Environment and Natural Resources required all counties in North Carolina to use soil morphology, more specifically, low chroma (2 or less) colors as indicators of soil wetness conditions and/or seasonal high water tables.

Current North Carolina regulations for the design and construction of septic systems require that septic system drainfield trenches maintain a 30 to 45+ cm vertical separation to seasonal high water table for systems installed in group II-IV (loam to clay textures) and group I (sand texture) soils (Figure 3.1), respectively (15A NCAC 18A .1955m). The basic field procedure for determining the depth to soil wetness conditions and/or the seasonal high water table is to evaluate soil profiles using a soil pit or soil auger, and record the depth to chroma 2 or less (Munsell's Color Chart) soil colors that occupy 2% or more of the soil volume in mottles or matrix (15A NCAC 18A .1942b). The depth to chroma 2 (or lower) colors is the reference point above which septic system trenches must maintain a 30-45 cm vertical separation distance. Soils that do not contain low chroma colors or saturation within 122 cm (4 ft) of the surface are considered suitable in relation to depth to water table (15A NCAC 18A. 1942c) and therefore, most soil evaluations do not extend below 122 cm.

3.2.2 Soil Color and Reduction – Oxidation Processes

Low chroma (2 or lower) soil colors result from the reduction and loss of iron from a soil horizon. Iron is one of the most abundant elements in most soils, and under aerobic conditions, persists predominately in the ferric (Fe^{3+}) form in various oxides, hydroxides, and coatings on mineral grains (Richardson et al. 2001). When soil organic matter becomes inundated, microorganisms deplete oxygen during the organic decomposition process. Once oxygen is depleted, microorganisms in the soil can sequentially use nitrate (NO_3^-), manganese (MnO_2), and iron ($Fe(OH)_3$) as terminal electron acceptors, thus reducing nitrate, manganese, and ferric iron while oxidizing carbon (Mitsch et al. 2000). When iron is reduced from the ferric form (Fe^3+) to the ferrous (Fe^2+) form, it becomes colorless, mobile and can be leached from the soil profile when the water table falls. The loss of ferric iron from the horizon also means a loss of the Fe colors (red, brown, yellow), leaving behind the grey (low chroma) colors of the uncoated mineral grains (Figure 3.2A) (Richardson et al. 2001). The low chroma colors are indicative of saturated soils (periods of low oxygen), available carbon supplies and microorganisms, suitable environmental conditions (temperature, pH, etc.,), and time (duration of saturation) for the iron reduction and leaching process (Vepraskas 1999).

Some coastal soils have formed from parent materials that lack iron and therefore may contain chroma 2 or lower colors throughout their profiles (Figure 3.2B) (Buol et al. 1997). Shallow soil horizons including the A and E horizons may contain chroma 2 or less colors due to the accumulation of organic matter (A horizons), or the eluviation of iron, aluminum, clay and/or organic matter (E horizon) to deeper soil horizons (B, Bt, Bh, Bs) due to podzolization processes such as chelation and translocation (Buol et al. 1997). Therefore, low chroma colors in the A and E horizons due to organic matter coated soil particles or eluviation processes are not necessarily indicative of reduction and oxidation processes (Buol et al. 1997).

Another situation in which low chroma colors may not be indicative of saturated and anaerobic conditions include soils with drainage improvements that effectively lowered the water table, but the low chroma colors persist high in the soil profile, thus reflecting past conditions. Scenarios such as these can lead to inaccurate predictions of the depth to SHWT/seasonal wetness when using soil colors and in these instances may require groundwater monitoring to determine the true level of seasonal high saturation. Inaccurate predictions of the depth to SHWT are significant to coastal wastewater management because they can result in drainfields being installed too close to the water table and increase the potential for trench flooding and direct discharge of wastewater to the shallow groundwater system.

3.2.3 Alternative Methods of Seasonal High Water Table Determination

An alternative method of determining the depth to seasonal high water table in North Carolina includes a direct monitoring procedure (15A NCAC 18A .1942). Direct monitoring requires the installation of shallow water table observation wells in the proposed system area and monitoring of the depth to groundwater (daily) and rainfall amount (hourly) for a period that extends through the typical wet season. Groundwater levels must be monitored from January through April, rainfall from December through April at a minimum. The seasonal high water table/soil wetness conditions are determined by the highest level that the water table maintains for 14 consecutive days. Therefore, the depth to low chroma soil colors should correspond to the depth to 14 days of consecutive saturation in soils as indicated by measured groundwater levels.

The designated period of 14 days of consecutive saturation as the duration required to form low chroma colors for all soils has been disputed (He 2000; He et al. 2003; Severson et al. 2008). Research in the Coastal Plain of North Carolina showed that it took an average of 21 days of continuous saturation to produce Fe-depletions of chroma 2 or less, between the soil surface and a depth of 60 cm (He 2000; He et al. 2003). Longer durations (> 21 days) of saturation were required to produce low chroma colors deeper (> 60 cm) in the soil profiles, apparently due to less soluble organic matter at deeper depths. Additional studies in the south eastern US revealed that other redoximorphic features such as Fe-depletions of chroma 3 or less and iron concentrations of chroma 6 or greater were also indicative of fluctuating water tables and reduction/oxidation processes but with shorter periods of saturation than necessary for chroma 2 or less mottling (Genthner et al. 1989; and West et al. 1998).

A recent study (Severson et al. 2008) on a toposequence of sandy loam soils including a moderately well drained soil (Foreston series), an unnamed transition soil deemed “wet Foreston”, and a somewhat poorly drained (Stallings series) soil in Coastal North Carolina found that the shallowest depth to which the soils were saturated for a 21-day or longer period was deeper in the profile than the depth of chroma 2 or less depletions with 2% or greater abundance. Therefore, less than 21 days of saturation were needed to form chroma 2 or less colors for some soils. Severson et al. (2008) showed that the 14-day continuous saturation standard related to different redoximorphic features in different soils. Average depth to redox concentrations (chroma > 6) coincided well with the average depth to 14 day saturation in the Foreston series, chroma 3 or less depletions matched with the 14 day saturation depth for the wet Foreston, and the depth of chroma 2 or less depletions related well to the 14-day continuous saturation in the Stallings series (Severson et al. 2008). Their findings have important implications for the design of septic systems in Coastal Plain soils. Since wastewater treatment is dependent upon the depth of aerated soil beneath the septic trenches (Nicosia et al. 2001; Karathanasis et al. 2006; Stall 2008), soils with high cumulative water table saturation percentages (% CS; cumulative duration of water table saturation at or above a reference point such as the chroma 2 depth) might not be as efficient at removing wastewater pollutants as systems in soils with lower % CS, even if they have similar 14-day seasonal high water table depths.

The vertical separation distance regulations aim to ensure aerated conditions beneath septic drainfield trenches and to prevent septic tank effluent from discharging directly into the groundwater. Because the seasonal high water table is defined as the shallowest depth that the soil remains saturated for 14 consecutive days, hypothetically the water table could rise to the trench bottom depth or above for several 13-day periods throughout the year and not be in violation of the regulation, but groundwater quality may be degraded because the water table encroaches on the 30-45 cm vertical separation distance to the system or rises above the trench.

With approximately 60% of coastal North Carolina residences utilizing septic systems (North Carolina Estuarine Research Reserve 2003) there is great potential for septic systems to load viruses, bacteria, nutrients and other wastewater constituents to the shallow groundwater, surface waters, and the coastal ocean if design criteria for septic systems are ineffective, not stringent enough, or not properly implemented. Regulations establishing minimum separation distances from trenches to water table have an important role in protecting water quality and public health. Equally important is the methodology for determining where the seasonal high water table is located in the soil profile. If the methodology for determining the depth to the SHWT overestimates the depth of seasonal saturation, then the intended vertical separation will not be met and water quality may be adversely affected (Figure 3.3).

The main objective of this study was to determine how accurate low chroma (2 or lower) soil colors are for predicting the depth to seasonal high water table for some common soil series in coastal North Carolina (and coastal southeastern US). Soil colors were compared to water table dynamics and the implications were evaluated in the context of vertical separation distance effects on septic system wastewater treatment and shallow groundwater quality. The % CS of different soils at the chroma 2 depth and the depth of the 14-day seasonal high water table were compared to see how closely the methods aligned. Most southeastern US states (Georgia, Florida, Maryland, Virginia and North Carolina) require a 30 to 60 cm vertical separation from septic system to water table (Stall 2008, Georgia Department of Human Resources 2007) therefore % CS at 30-60 cm above the SHWT and chroma 2 colors were evaluated.

Secondary goals were to determine the % CS for soils 30-60 cm above the chroma 2 and 14-day SHWT depths and to evaluate the frequency and duration of separation distance encroachments (when water table rises above required vertical separation distance) and trench ponding (water table rises to or above trench bottom depth) for the monitored systems (Figure 3.4).

3.3 Methods

3.3.1 Soil Colors and Seasonal High Water Table Monitoring

Sixteen sites with septic systems in 6 different soil series were evaluated in coastal Carteret County, North Carolina (Figure 3.5, Tables 3.1, 3.2). Eight sites had systems in group I soils (sand/loamy sand) including 2 in the Baymeade series (loamy, semiactive, thermic arenic hapludults), 1 in the Mandarin Series (sandy, siliceous, thermic, oxyaquic alorthod), 3 in the Newhan series (thermic, uncoated typic quartzipsamments) and 2 in the Fripp series (thermic uncoated typic quartzipsamments). Four sites had systems in the group II (sandy loam) Goldsboro series (fine-loamy, siliceous, subactive, thermic aquic paleudults) and four sites had systems in the sandy clay loam (group III), Altavista series (fine-loamy, mixed, semiactive, thermic aquic hapludults).

The soil profiles at each site were examined using a hand auger, the texture by feel method (Brady et al. 2004) in the field and the hydrometer method in the lab (Day 1979) to determine and record the particle size distribution and North Carolina Department of Environment and Natural Resources (NC DENR) soil group status (Table 3.1). The soil profiles described in the field conformed to the soil series descriptions mapped in the Carteret County, North Carolina Soil Survey (Goodwin, Jr. et al. 1984). Soil samples at the trench bottom depth were collected at each site for particle size analysis using the hydrometer method (Day 1979), and for descriptive analyses including: pH, effective cation exchange capacity, and humic matter content. The North Carolina Department of Agriculture and Consumer Services- Agronomic Division in Raleigh, North Carolina performed the descriptive analyses. Soil morphological characteristics including the depth and presence of soil mottling/matrix with chroma 2 or less colors were evaluated using a Munsell color book and tape measure (Table 3.2). The depth to chroma 2 colors represents the predicted seasonal high water table (SHWT).

3.3.2 Septic System Characterization and Groundwater Well Installation

Septic systems, including the tank and drain-field trenches at each of the 16 sites were located using a tile-drain probe rod. Adjacent to the drainfield trenches, 16 groundwater monitoring wells constructed of 10 cm diameter screened PVC were installed using hand augers. Well depths ranged from 1.3 to 3.3 m and depth of installation was generally 1 m below the water table, encountered during installation. Sand was poured between the outside of the well and the borehole until the entire screen length was filled. A bentonite clay and sand slurry was then mixed and poured to seal the annular space above the well screen and prevent surface water leaching and contamination of groundwater. The wells were encased in valve boxes and installed flush with the soil surface for easy location and accessibility.

Each month (December 2006-March 2008) groundwater depths were determined manually using the Solinst Model 107 Temperature Level and Conductivity (TLC) meter (Solinst Canada Ltd. 2007) and automated HOBO water level loggers (Onset Computer Corporation 2007) recorded one-half hourly water levels in groundwater wells adjacent to each septic system. The manual groundwater data readings were used to ground-truth the automated groundwater levels measured by loggers. Dedicated atmospheric pressure loggers and correction software were used in conjunction with the groundwater level loggers to correct for atmospheric pressure changes that would otherwise have affected the water table (pressure) measurements. Hourly precipitation data from local weather stations in Cherry Point, Newport, Atlantic Beach, Morehead City (NC Climate Office 2008) and a research site in North River, North Carolina (NC State University Biological and Agricultural Engineering Department 2008) were used for the sites in this study. Hydrographs (groundwater level over time) were produced for each site. Slug tests were performed using the Bouwer and Rice method (1976) to determine the horizontal hydraulic conductivity (Ksat) of the surficial aquifer sediments.

3.3.3 Cumulative Saturation Determination

The depth to seasonal high water table as recorded by groundwater level loggers was compared to the soil profile descriptions and depth to low chroma colors. This information was used to evaluate how closely soil colors predicted the 14 day periods of continuous saturation (Figure 3.6).

Cumulative saturation is the total amount of time the water table saturates a specific depth of soil (expressed as total hours saturated and as the ratio of total hours the water table was elevated at or above the specified depth to total hours monitored as %). The half-hour water level data were used to calculate the cumulative saturation (% CS) of the predicted SHWT (using chroma 2 soil color) depth, the observed 14-day SHWT depth, and the % CS at 30, 45, and 60 cm above the predicted and observed SHWT depths (Figure 3.7). Cumulative saturation percentages at 30, 45, and 60 cm above the predicted and observed SHWT represent the percentage of time wastewater would discharge directly to the groundwater (no vertical separation) if septic systems had been installed 30-60 cm above chroma 2 colors and the measured 14 day SHWT depths.

3.3.4 System Evaluation

The depth to trench bottom at each site was compared to the soil profile descriptions (textural class and depth to low chroma soil colors) and water table data (Figure 3.6). Systems in group I soils should by North Carolina regulations (15A NCAC 18A .1955m), be installed with the trench bottom elevated at least 45+ cm above the chroma 2 (or lower) colors (2% or greater of soil volume). Systems in group II-IV soils should be elevated at least 30+ cm above the low chroma colors. The measured vertical separation distance was recorded as the difference from the trench bottom to the top of the water table as indicated by the recorded groundwater levels adjacent to the drainfield trenches. The separation distance dynamics over time for each system were used to show the frequency and duration of encroachment of the North Carolina Division of Environmental Health (1999) vertical separation distance requirements. The amount of time each system did not meet the required 30-45 cm of separation to chroma 2 colors and the measured 14-day SHWT was tallied.

3.3.5 Compliance with Current Vertical Separation Distance Regulations

A vertical separation distance encroachment occurred when the water table was within 45 cm of the drainfield trench for systems in group I soils or less than 30 cm for systems in group II-IV soils. If the encroachments lasted for more than 14 consecutive days then the system was not in compliance with the regulations (15A NCAC 18A .1955m). The frequency and duration that each system encroached on the mandated separation distance was calculated. In addition, the number of hours that groundwater flooded the trench (trench ponding) and wastewater was seeping directly into the groundwater system was also calculated for each system.

3.4 Results

3.4.1 Predicted and Measured Seasonal High Water Tables

The predicted (depth to chroma 2 colors) and measured (water table monitoring) depths to SHWT were within 22 cm of each other for 8 of 16 sites, and for 3 sites both the predicted and measured SHWT were deeper than 122 cm (Table 3.3 and Figure 3.8). Three of 4 sites in the Goldsboro series, 3 of 4 in Altavista, the Mandarin site, and 1 of 2 sites in Baymeade soil series had chroma 2 colors within 22 cm of the measured SHWT depth (Figure 3.8). For the two sites in the Fripp series, the predicted and measured SHWT were both deeper than 122 cm. For one site in the Newhan series, the predicted and measured SHWT were both deeper than 122 cm.

In general low chroma colors were better predictors of the depth to SHWT for the group II and group III soils (75% of sites within 22 cm) in comparison to the group I soils (25% of sites within 22 cm). Also, soil series with relatively shallow mean depths to the measured SHWT (Goldsboro, Altavista and Mandarin series) had chroma 2 colors closer to the measured SHWT (mean difference of 6-14 cm) than sites with relatively deep water tables (Newhan, Fripp and Baymeade series with mean difference of 21-130+ cm) (Figure 3.9).

3.4.2 Cumulative Saturation

The cumulative saturation (CS) of the depth to chroma 2 colors (expressed as total hours saturated and as the ratio of total hours the water table was elevated above the depth to chroma 2 colors to total hours monitored as %) was highest for the Baymeade series (3908 hours, 44%), followed by the Altavista series (3120 hours, 36%), Goldsboro series (772 hours, 8.5%), and the Mandarin series (587 hours, 6.6%) (Figures 3.10 and Table 3.3). Also, the water table rose above the chroma 2 depth more frequently for the Baymeade series (33 times on average), than for the Altavista (31), Mandarin (29) or the Goldsboro series (14) (Table 3.3 and Figure 3.11).

The CS of the measured SHWT depth was highest for the Altavista series (2134 hours, 25.1%) followed by the Fripp (1610 hours, 18%), Mandarin (1497 hours, 16.8%), Baymeade (1332 hours, 14.9%), Goldsboro (1337 hours, 14.8%), and the Newhan (812 hours, 9%) (Figure 3.12 and Table 3.3). The Mandarin series had the most frequent water table spikes above the depth to measured SHWT (44 times) followed by the Fripp (29), Altavista (28), Goldsboro, and Baymeade (average of 26 times each), and the Newhan series (15) (Table 3.3 and Figure 3.13).

3.4.3 Cumulative Saturation and Frequency of Soil Saturation 30-60 cm Above Predicted SHWT Depths

The average CS (expressed in total hours) of soil 30 cm above the depth to predicted SHWT was longest for the Altavista series (642.5 hours) followed by the Baymeade series (528) and the Goldsboro series (96.8 hours) (Figure 3.10). The water table for the Mandarin series did not rise 30 cm above the predicted SHWT depth, and the depth to predicted SHWT for the Fripp series (> 165 cm) was below the soil depths typically evaluated for septic systems. For the Newhan series sites, the predicted depth to SHWT was deeper than soils were evaluated for GI-F(>122 cm); chroma 2 colors were present in the surface (0 cm) and subsurface horizons for GI-G but the measured SHWT was 198 cm deep and the water table never rose within 136 cm of the surface; chroma 2 colors were found 107 cm deep for GI-H, but the depth to measured SHWT was 172 cm and the highest the water table rose was 141 cm below the surface (Tables 3.3 and 3.4).

The frequency of saturation 30 cm above the predicted depth of SHWT was highest for the Alatavista (14 times) and Baymeade (13) series, followed by the Goldsboro (4), Mandarin (0), Fripp (0) and Newhan (0) series (Figure 3.11).

The average CS of soil 45 cm above the predicted depth to SHWT was longest for the Altavista series (211 hours) followed by the Baymeade (45) and Goldsboro (24) series (Figure 3.10). The frequency of saturation 45 cm above the predicted depth to SHWT was highest for the Altavista series (8.8 times) followed by the Goldsboro series (2.5) and Baymeade series (2) (Figure 3.11). The water table rose 60 cm above the predicted depth to SHWT only for the Altavista series (average 5 times, 65 hours of cumulative saturation) (Figure 3.11).

After log transformation of the cumulative saturation data, strong inverse relationships ($R^2 = 0.77$ to 0.98) were found between vertical separation distance requirements from chroma 2 colors and cumulative saturation durations (Figure 3.14). Therefore, increasing separation distance requirements from chroma 2 colors could reduce cumulative saturation and trench ponding durations.

3.4.4 Cumulative Saturation and Frequency of Soil Saturation 30-60 cm Above Measured Seasonal High Water Table Depths

The average CS (hours) 30 cm above the measured SHWT was longest for the Altavista series (331.3), followed by the Goldsboro (95.1), Fripp (84.3), Newhan (30.8), and Baymeade and Mandarin (0 each) series (Figure 3.12). The average frequency of saturation 30 cm above the measured SHWT was highest for Altavista series (11 times), followed by the Goldsboro (6.5), Newhan (1.7), and Fripp (0.5) series (Figure 3.13). With a 45 cm separation from the measured SHWT, the average CS was longest for the Fripp series (84.3 hours), followed by the Altavista (79.8), Goldsboro (13), and Newhan (2) series (Figure 3.12). The average frequency of saturation 45 cm above the measured

SHWT was highest for the Altavista series (6.8 times) followed by the Goldsboro (2.3), Newhan (0.7), and Fripp series (0.5) (Figure 3.13). Not all systems in the Newhan and Fripp series had water table spikes 45 cm above the measured SHWT, thus some soil series may have an average less than 1. The Fripp series also had the longest CS 60 cm above the measured SHWT (25.5 hours) followed by the Atlavista (14.8), and Goldsboro series (3.9) (Figure 3.12). The water table for the Newhan series did not rise 60 cm above the measured SHWT and the frequency of saturation 60 cm above the measured SHWT was highest for the Altavista series (3.5 times) followed by the Fripp (1.5) and Goldsboro series (0.75) (Figure 3.13)

3.4.5 Evaluation of System Installations

Ten of 16 systems monitored did not meet today's required separation distance (30 to 45 cm) from trench bottom to chroma 2 colors including systems GI-A, GI-G, GI-H, GII-A, GII-B, GII-C, GII-D, GIII-A, GIII-B and GIII-C (Table 3.4). However, two of the systems (GI-G and GI-H) were installed before 1983, the date that chroma 2 colors were first used as indicators of SHWT. It should be noted also that two of the systems that were installed with less than today's minimum separation to chroma 2 colors (GI-G and GI-H) were in the Newhan series, a soil series that formed from iron poor parent materials where field identification of the predicted SHWT using chroma 2 colors may not be useful. Systems GI-G and GI-H had chroma 2 colors at the surface and at 107 cm deep, but the water table never rose within 137 cm of the surface for either site. The use of chroma 2 colors to determine the SHWT at these sites was not effective and the two sites were evaluated correctly. Therefore, 6 systems were installed with less than 30-45 cm of separation from chroma 2 colors, indicating that the depth to chroma 2 colors was misinterpreted and/or the drainfield trenches were installed too deep. Seven systems did not meet the required (15A NCAC 18A .1955m) vertical separation distance to seasonal high water table as determined by groundwater table monitoring. The systems that did not meet their required 30-45 cm separation to the SHWT included GI-A, GII-A, GII-B, GII-D, GIII-A, GIII-B, and GIII-C (Table 3.4), six of which were also not compliant with the separation distance to chroma 2 colors.

For systems installed in the Altavista series (GIII's), the required vertical separation distance was encroached on an average of 5800 out of 8500 hours (Table 3.4 and Figure 3.15). The average cumulative encroachment time for systems in the Goldsboro series (GII's) was 2026 hours, followed by system GI-A in the Mandarin series (1838 hours) and systems in the Baymeade series averaged 57 hours of cumulative vertical separation distance encroachment (Table 3.4 and Figure 3.15).

Only systems in the Altavista and Goldsboro series experienced groundwater levels higher than the depth to trench bottoms (trench ponding of groundwater) (Table 3.4 and Figure 3.15). For systems in the Altavista series the average cumulative trench ponding was over 2400 hours and for systems in the Goldsboro series, the average cumulative trench ponding was over 410 hours (Table 3.4). During periods of trench ponding, wastewater is discharged directly to the groundwater from the septic tank.

3.5 Discussion

From a water quality perspective, the best case scenario would be for the low chroma soil color depth and the SHWT depth to be the same or a consistent distance in one direction (shallower or deeper). This (consistency) would allow regulators the ability to design septic systems that most often would meet the required standards for separation distance.

Overall, excluding the Newhan and Fripp series sites (dune sands that developed from iron poor parent materials), there were 6 sites (GI-B, GI-C, GII-B, GIII-A, GIII-B, and GIII-C) that chroma 2 colors were deeper (18 cm on average) than the SHWT depths (Table 3.4). For these sites, had the systems been installed with the minimum vertical separation distance from chroma 2 colors, they would not have met the required separation to the SHWT. Systems GI-A, GII-A, GII-C, GII-D, and GIII-D had chroma 2 colors shallower than the SHWT depths with an average difference of 17 cm (Table 3.4). Therefore excluding the Fripp and Newhan series sites in Atlantic Beach and Pine Knoll Shores (dune sands), low chroma colors on average predicted the depth to SHWT within 17-18 cm.

In general, soil series with relatively deep depths to water tables had longer periods of continuous saturation at the chroma 2 color depths than soils with relatively shallow water tables. Similar trends were also found at study sites in other coastal plain soils, possibly because available carbon for iron reduction typically decreases with depth (He 2000, 2003). Systems in the Baymeade series (GI-B and GI-C) had an average depth to SHWT of 110 cm, an average chroma 2 depth continuous saturation of 79 days and an average humic matter % of 0.5, followed by systems in the Altavista series (GIII) with average SHWT depths of 75 cm, a continuous saturation of 32 days and an average HM% of 0.05, systems in the Goldsboro series (GII) had average depths to SHWT of 71 cm an average continuous saturation of 6 days and a HM% of 0.8, and the system in the Mandarin series (GI-A) with a depth to SHWT of 92 had a similar (to Goldsboro series) chroma 2 depth continuous saturation of 6 days (Table 3.3). While the Mandarin series had a relatively deep SHWT (92 cm) with only 6 days of continuous saturation at the chroma 2 depth, the Mandarin series also had the highest humic matter percentage (4.8%) near the water table depth, possibly fueling reduction processes within a relatively short time period (Tables 3.1and 3.3).

Overall, the presence of chroma 2 colors for these soils corresponded to varying durations of saturation. Less variability was found between the mean frequency of saturation events at or above the chroma 2 depths for the Mandarin (29), Baymeade (33), Goldsboro (14) and Altavista (31) soils (standard deviation = 8.7) than for the mean periods (days) of continuous saturation durations for the Mandarin (6), Baymeade (79), Goldsboro (6), and Altavista (32) soils (standard deviation = 34.4). Therefore for these sites, during the monitored period, chroma 2 colors were more indicative of frequency of saturation events than duration of continuous saturation.

While monitoring the groundwater table is the best methodology for determining the SHWT, it is also resource and labor intensive and not practical for all site and system evaluations. If we understand that on average chroma 2 colors may overestimate the depth of the SHWT by 18 cm for many sites, then it may be more cost effective to increase the separation distance requirements from septic systems to chroma 2 colors by a similar length and continue to use chroma 2 colors as a reference point. A 15 cm increase in separation distance from the current standards would result in group I soils requiring a

60 cm separation and group II –IV soils a 45 cm separation. Many other coastal states including Georgia, Florida, Maryland and Virginia already require 45 – 60 cm of separations (Stall 2008; and Georgia Department of Health 2008).

Studies have shown that fine textured soils typically provide better removal of septic system wastewater pollutants per unit depth of aerated soil beneath the trench bottom than systems in more coarse textured soils (Karathanasis et al. 2006; and Nicosia et al. 2001) and thus some states such as North Carolina require less (than sandy soils) vertical separation distance to the SHWT for systems in clayey soils. However, with a requirement of only 30 cm of separation to the SHWT, there were some systems in this study (GII-C and GIII-D) that met the separation requirements to 14 day SHWT, but experienced periods of trench ponding (Table 3.4). Conversely, there was a system in group I soils (GI-A) that did not meet the 45 cm separation distance to SHWT requirement, but never experienced trench ponding or direct discharge of septic tank effluent to the groundwater (Table 3.4). These examples highlight the need for more than 30 cm of vertical separation distance to the SHWT for systems in group II-IV soils. Increasing the separation distance requirements for each soil group should provide longer durations of aerated soil beneath septic systems, reduce trench ponding, and thus improve water quality.

One explanation for the relatively high cumulative saturations for the Altavista series (group III soils) is the hydraulic properties of clay loam soils in relation to sandy loam and sandy soils. Darcy’s law ($Q = KA*dh/dl$) relates groundwater discharge (Q) to the hydraulic conductivity (K), the cross-sectional area (A), and the hydraulic gradient (dh/dl). The group III soils in this study had the smallest mean hydraulic conductivity (K of 0.19 m/day for group III, in comparison to 0.32 m/day for group II and 0.98 to 5.2 m/day for group I soils) (Table 3.1), indicating that to move similar volumes of water away from the septic systems, a larger hydraulic gradient would be necessary. Therefore, water tables must rise higher in fine textured soils and/or remain higher for longer durations to transmit similar volumes of water as a more coarse textured soil. The water table essentially reached the surface in three of the four systems in group III soils (within 2 cm), while systems in group I soils had the smallest water table range (85cm, in relation to 165 cm for group II and 138 cm for group III) (Table 3.4). Furthermore, because fine textured clay loam and clay soils have smaller pores and more total pore space, they retain relatively more water during periods of similar suction than do sandier soils (Hillel et al 1998) and they have thicker capillary fringes, potentially affecting the cumulative saturations. When the rainfall rate declined in February 2007 the water table remained higher in the profile of the group III in relation to group I and II soils, possibly due to the hydraulic and moisture retention properties of the clay loam soils (Table 3.1 and Figure 3.16), thus affecting the cumulative saturation.

3.6 Conclusions and Management Implications

Increasing the North Carolina separation distance requirements from septic drainfields to low chroma colors by 15+ cm could help reduce the frequency and cumulative duration of trench ponding, especially for systems in group II and III soils that currently only require a 30 cm vertical separation distance. There was an average 67% decrease in trench ponding time at a depth 45 cm above chroma 2 colors (210 hours) in comparison to 30 cm above chroma 2 colors (642 hours) for the group III Altavista series (Figure 3.10). A 45 cm separation distance requirement for the group II Goldsboro soils would have reduced trench ponding time by an average of 75% in comparison to a 30 cm separation from chroma 2 colors and increasing the separation distance requirement for group I soils to 60 cm would have eliminated all trench ponding for the Baymeade series (Figure 3.10).

Reducing or eliminating trench ponding frequency and duration should improve shallow groundwater quality by reducing the time that septic tank effluent directly discharges into the groundwater without being filtered by soil. Research (Carlile et al. 1981; Cogger et al. 1988; Nicosia et al. 2001; Carrol et al. 2004 and Karathanasis et al. 2006) has shown that wastewater pollutant treatment is related to the aerated soil beneath septic systems. Because chroma 2 colors can sometimes overestimate the depth of the SHWT, there will be cases where the vertical separation to chroma 2 colors is met but the separation to SHWT is not in compliance. Therefore, requiring an additional 15+ cm of vertical separation to chroma 2 colors (45 – 60+ cm) should increase the percentage of new systems that actually meet the current requirements for separation distances to SHWT (30-45 cm), reduce trench ponding frequencies and durations, and improve groundwater quality.

Sixteen systems were evaluated in this study, six of which were installed too deep in relation to chroma 2 colors (excluding two systems installed prior to 1983 and two systems installed in soils with iron poor parent materials, so 6/12), and seven were installed too deep in relation to the observed SHWT. While 16 septic systems represents a small percent of the total systems being used in coastal North Carolina, the results agree with a recent field survey of 163 septic systems in two counties (Craven and Carteret) in coastal North Carolina (Deal et al. 2007). Deal et al. (2007) found that 47+% of systems surveyed did not meet their North Carolina Division of Environmental Health (1999) required separation distances to the seasonal high water table as indicated by chroma 2 colors and system installation depths. On average, the surveyed systems had a 20.5 cm separation distance to chroma 2 colors, and were installed 16 cm too deep in relation to their design (Deal et al. 2007). In the current study (excluding systems installed in the iron poor Newhan and Fripp Series) the surveyed systems were installed approximately 20 cm too deep in relation to chroma 2 colors. While Deal et al. (2007) did not include actual water table and vertical separation distance monitoring, the results did highlight the need for more investigation on the links between soil morphology and water table dynamics, septic system design and installation, and system performance, as did this study. Increasing the separation distance requirements from systems to inferred SHWT (chroma 2 colors) by 15 cm+ can help improve water quality if the soils are evaluated correctly, the septic systems are designed and installed correctly, and if the systems are maintained.

In areas such as the barriers islands where the soils formed from iron poor parent materials, the use of low chroma soil colors as indicators of the seasonal high water table was not effective. Also, the effects of stream channelization, and land drainage on chroma 2 soil colors are not well known. As sea level continues to rise, coastal soils may influence changes in hydrology and potentially color. More research including groundwater monitoring and/or modeling may be necessary to accurately predict the depth of seasonal saturation for system design purposes. While monitoring and modeling requires more effort, equipment, and funds, coastal waters have already experienced excess nutrient and bacterial pollution and thus there is a need for accurate determinations of the water table to ensure that septic systems maintain the required vertical separation distance to groundwater.

Table 3.1 Site, soil and system information. Site elevation above mean sea level was approximated from topographic maps. Mean ground water (GW) elevation was during the December 2006-March 2008 period. Site location of NWP is Newport, AB is Atlantic Beach, and PKS is Pine Knoll Shores, NC. Con. is a conventional system with 2 or more 90 cm wide, drainfield trenches, bed systems have one trench often 180 cm wide or greater. Effective cation exchange capacity (ECEC) is a measure of the capacity to absorb and exchange cations in reversible reactions. Humic matter percentage (HM) is the amount of complex organic, rather than mineral composition.

Soil / Site	USDA Soil Series	Site Elevation (m)	Mean GW Elevation (m)	System Install Date	Site Location City/Town	System Type	% Sand	% Silt	% Clay	ECEC (cmol/kg)	pH	HM%	Ksat (m/day)
GI-A	Mandarin	3.3	2.23	2006	NWP	Bed	90.3	4.6	5.1	5.6	4.7	4.8	0.98
GI-B	Baymeade	3.66	2.3	2005	NWP	Bed	94.6	2	3.4	1.2	5.3	0.2	2.47
GI-C	Baymeade	3.13	1.9	2006	NWP	Con.	90.7	3.9	5.3	3.2	6.1	0.7	1.01
Avg		3.4	2.1	2006			92.7	3	4.4	2.2	5.7	0.5	1.74
GI-D	Fripp	2.94	1	1991	AB	Con.	98	0.3	1.7	2.3	4.8	0.6	1.95
GI-E	Fripp	3.28	0.42	1996	PKS	Bed	98.3	0	1.7	1.5	5.8	0	8.44
Avg		3.11	0.71	1994			98.15	0.15	1.7	1.9	5.3	0.3	5.2
GI-F	Newhan	3.15	1.05	1979	PKS	Bed	97.2	0.3	2.5	2	6.2	0.1	1.37
GI-G	Newhan	2.59	0.56	1977	PKS	Con.	98	0.3	1.7	5.6	7.6	0.2	5.7
GI-H	Newhan	2.32	0.39	1977	PKS	Con.	97.2	1.2	1.7	3.1	6.3	0.3	4.82
Avg		2.69	0.67	1978			97.5	0.6	2	3.6	6.7	0.2	3.96
GII-A	Goldsboro	3.58	2.26	1987	NWP	Con.	74.2	9.6	16.2	3.2	5.6	0.2	0.18
GII-B	Goldsboro	2.74	1.96	1985	NWP	Con.	80.7	10.1	9.2	3.5	6.6	1.9	0.52
GII-C	Goldsboro	3.44	2.37	1999	NWP	Con.	75.4	11.1	13.5	2.1	5.8	0.6	0.09
GII-D	Goldsboro	3.6	2.34	1998	NWP	Con.	79	7.5	13.4	2.8	5.5	0.5	0.49
Avg		3.34	2.23	1990			77.3	9.6	13.1	2.9	5.9	0.8	0.32
GIII-A	Altavista	2.01	1.05	1995	Smyrna	Con.	66.8	12.3	20.9	7	6.8	0.1	0.15
GIII-B	Altavista	1.68	0.85	1986	Smyrna	Con.	71.2	5.2	23.6	7.7	7.8	0	0.18
GIII-C	Altavista	1.91	0.93	1994	Smyrna	Con.	67	8.2	24.7	7.2	7.6	0	0.09
GIII-D	Altavista	2.33	1.23	1991	Smyrna	Con.	64.9	9.7	25.4	7.5	6.9	0.1	0.34
Avg		1.98	1.02	1992			67.5	8.9	23.7	7.4	7.3	0	0.19

Table 3.2 Typical soil profile descriptions for the Mandarin, Baymeade, Fripp and Newhan series in group I sandy soils, the Goldsboro series for the group II sandy loam soils and the Altavista series descriptions in the group III sandy clay loam soils. Soil groups refer to the North Carolina Department of Environment and Natural Resources classification for the soil texture beneath septic systems. Soil structure types: single grain (SG); granular (Gr); and subangular blocky (SBK).

Mandarin Series (GI-A)

Depth (cm)	Horizon	Color	Texture	Structure
0-30	Fill	10 YR 2/2	LS	Gr
30-41	A	10 YR 5/2	LS	SG
41-86	E	10 YR 6/1	LS	SG
86-94	Bh	10 YR 2/2	LS	Gr
94-130	B2	10YR 3/2 or 3/3	LS	SBK

Fripp Series (GI-D, GI-E)

Depth (cm)	Horizon	Color	Texture	Structure
0-25	A	10 YR 4/2	LS	SG
25-41	C1	10 YR 4/3	S	SG
41-84	C2	2.5 Y 6/4	S	SG
84-127+	C3	2.5Y 6/4 with 10YR 5/6 mottles	S	SG

Baymeade Series (GI-B, GI-C)

Depth (cm)	Horizon	Color	Texture	Structure
0-21	Fill	10 YR 7/1	S	Gr
37-49	A	10 YR 4/4	SL	SG
49-91	E	10YR 7/2	LS	SG
91-101	Bh	10 YR 5/3	SL	SG
101-122	Bt	10 YR 5/8	SL	SBK
122-142+	BC	2.5 YR 6/2	LS	Massive

Newhan Series (GI-F, GI-G, GI-H)

Depth (cm)	Horizon	Color	Texture	Structure
0-8	A	10 YR 2/1	LS	SG
	C1	10 YR 4/2	S	SG
25-61	C2	10 YR 3/1	S	SG
61-91+	C3	10 YR 5/2	S	SG

Goldsboro Series (GII-A to GII-D)

Depth (cm)	Horizon	Color	Texture	Structure
0-33	A	10 YR 3/2	SL	GR
33-56	B	10 YR 4/3	SL	SBK
56-64	B2	10 YR 4/3 with 10 YR 6/2 mottles	SL/SCL	SBK
64-74+	BCg	10 YR 5/2	SL	SBK
64-74+	BCg	10 YR 5/2	SL	SBK

Altavista Series (GIII-A to GIII-D)

Depth (cm)	Horizon	Color	Texture	Structure
0-18	A	10 YR 3/2	SL	Gr
18-51	E	10 YR 4/3	SL	Gr
51-61	Bt1	2.5 Y 5/6	SCL	SBK
61-69	Bt2	2.5 Y 5/3 with few 10 YR 7/2 and 10 YR 6/6 mottles	SCL	SBK
69-89	BC	2.5 Y 5/6 with common 2.5 Y 5/3 mottles	SCL	SBK
89-102+	C1	2.5 Y 5/4 with common 10 YR 7/2 mottles	SCL	Massive

Table 3.3 Predicted (depth to chroma 2 colors) and observed depths to the 14-day seasonal high water table (SHWT) for septic systems installed in group I sandy soils including Mandarin (GI-A), Baymeade (GI-B, GI-C), Fripp (GI-D, GI-E), and Newhan (GI-F, GI-G, GI-H) soil series; group II sandy loam Goldsboro series (GII-A to GII-D) and group III sandy clay loam Altavista series (GIII-A to GIII-D). Cumulative saturation is the total amount of time the water table was above a reference point such as the depth to chroma 2 colors or the depth to 14-days of continuous saturation.

Soil Group / System ID	Water Table Range (cm)	Depth (cm) to Chroma 2	Depth (cm) to 14 Day Saturation	Difference (cm) Chroma 2 and 14 day	Chroma 2 Continuous Saturation (d)	Times Above Chroma 2	Chroma 2 Cumulative Saturation (hrs)	Chroma 2 Cumulative Sat (% total)	Avg Above Chroma 2 Time (hours)	Times Above SHWT	Time Above SHWT (hrs)	Avg Time (hrs) Over SHWT	Cumulative Time % Above SHWT
GI-A	64-134	86	92	6	6	29	587	6.6	20.2	44	1497.0	34.0	16.8
GI-B	87-165	140	116	24	93	28	4776	53.5	170.6	40	1540.5	38.5	17.2
GI-C	91-182+	140	121	19	66	37	3040	34.0	82.2	11	1123.0	102.1	12.6
Avg		140	119	22	79	33	3908	44	126.4	26	1331.8	70.3	14.9
GI-D	145-213+	>122	165	N/A	N/A	N/A	N/A	N/A	N/A	29	1349.0	46.5	15.0
GI-E	204-305+	>122	272	N/A	N/A	N/A	N/A	N/A	N/A	29	1871.5	64.5	20.6
Avg			219	N/A	N/A					29	1610	56	18
GI-F	164-238+	>122	190	N/A	N/A	N/A	N/A	N/A	N/A	14	709.5	50.7	7.9
GI-G	137-270+	0	198	198	0	0	0	0	0	5	679.5	135.9	7.5
GI-H	141-207+	107	172	65	0	0	0	0	0	25	1048.0	41.9	12.0
Avg			187							15	812	76	9
GII-A	10-210	58	80	22	2	9	145.8	1.6	16.2	17	822.0	48.4	9.1
GII-B	1-154	56	40	16	17	27	2457	27.1	91.0	17	1038.0	61.1	11.5
GII-C	39-180	56	92	36	1	4	58	0.6	14.5	35	1855.5	53.0	20.5
GII-D	9-173	58	73	15	4	17	428.4	4.7	25.2	33	1633.5	49.5	18.1
Avg		57	71	22	6	14	772.3	8.5	36.7	26	1337.3	53.0	14.8
GIII-A	2-149	91	65	26	49	38	3876	43.0	102	22	1835.5	83.4	20.3
GIII-B	0-120	79	65	14	51	31	3803.7	42.0	122.7	31	2107.0	68.0	23.3
GIII-C	2-135	84	77	7	18	22	2728	33.8	124	22	2070.0	94.1	25.7
GIII-D	9-160	89	94	5	10	32	2070.4	25.5	64.7	36	2525.0	70.1	31.1
Avg		86	75	13	32	31	3119.5	36.1	103.4	28	2134.4	78.9	25.1

Table 3.4 Septic system performance including vertical separation distances to chroma 2 soil colors and 14-day seasonal high water tables, cumulative duration and frequency of vertical separation and trench/groundwater ponding for each system. Averages for each soil series were determined including the Baymeade (GI-B and GI-C), Fripp (GI-D, GI-E), Newhan (GI-F, GI-G, GI-H), Goldsboro (GII-A to GII-D) and Altavista series (GIII-A to GIII-D) and Mandarin (GI-A) series. A (--) indicates chroma 2 colors were above the trench bottom.

Site/ System ID	Monitored (h)	Chroma 2 Depth (cm)	14-d SHWT Depth (cm)	Trench Depth (cm)	Required Sep Dis (cm)	Separation During SHWT (cm)	Trench/ Chroma 2 Sep (cm)	Vertical Sep Encroachment (h)	Vertical Sep Encroachment Freq	Avg Encroachment Time (h)	Trench Ponding (h)	Trench Ponding Freq
GI-A	8888.5	86	92	48	45	44	38	1838	60	30.6	0	0
GI-B	8933	140	116	48	45	68	92	48.5	3	17.8	0	0
GI-C	8932.5	140	121	53	45	68	87	66	5	13.8	0	0
Avg	8932.8	140	118.5	50.7		67.8	89	57.3	4	15.8	0	0
GI-D	8995.5	127	165	61	45	104	66	0	0	0	0	0
GI-E	9073	>144	272	74	45	>45	---	0	0	0	0	0
Avg	9034.3		218.5	67.4				0.0	0.0	0.0	0.0	0.0
GI-F	8961	>144	190	74	45	>45	---	0	0	0	0	0
GI-G	9083	107	198	74	45	124	33	0	0	0	0	0
GI-H	8720	0	172	107	45	65	---	0	0	0	0	0
Avg	8921		187	85				0	0	0	0	0
GII-A	9070	58	80	56	30	24	2	1216	32	38	145.5	9
GII-B	9065.5	56	40	46	30	-6	10	4114.5	11	374	1326	20
GII-C	9051	56	92	51	30	41	5	622.5	17	37	37.5	4
GII-D	9022.5	58	73	48	30	25	10	2151.5	18	120	145.5	11
Avg	9052	57	71	50		21	8	2026.1	19.5	142.0	413.6	11.0
GIII-A	9024	91	65	81	30	-16	10	7464	29	257.4	2571	14
GIII-B	9058	79	65	79	30	-14	0	8471.5	39	217.2	4259.5	26
GIII-C	8062	84	77	84	30	-7	0	6041	20	302.1	2724	24
GIII-D	8113	89	94	51	30	43	38	1432	20	71.6	130.5	7
Avg	8564	86	75	74		2	12	5852.1	27.0	212.1	2421.3	17.8

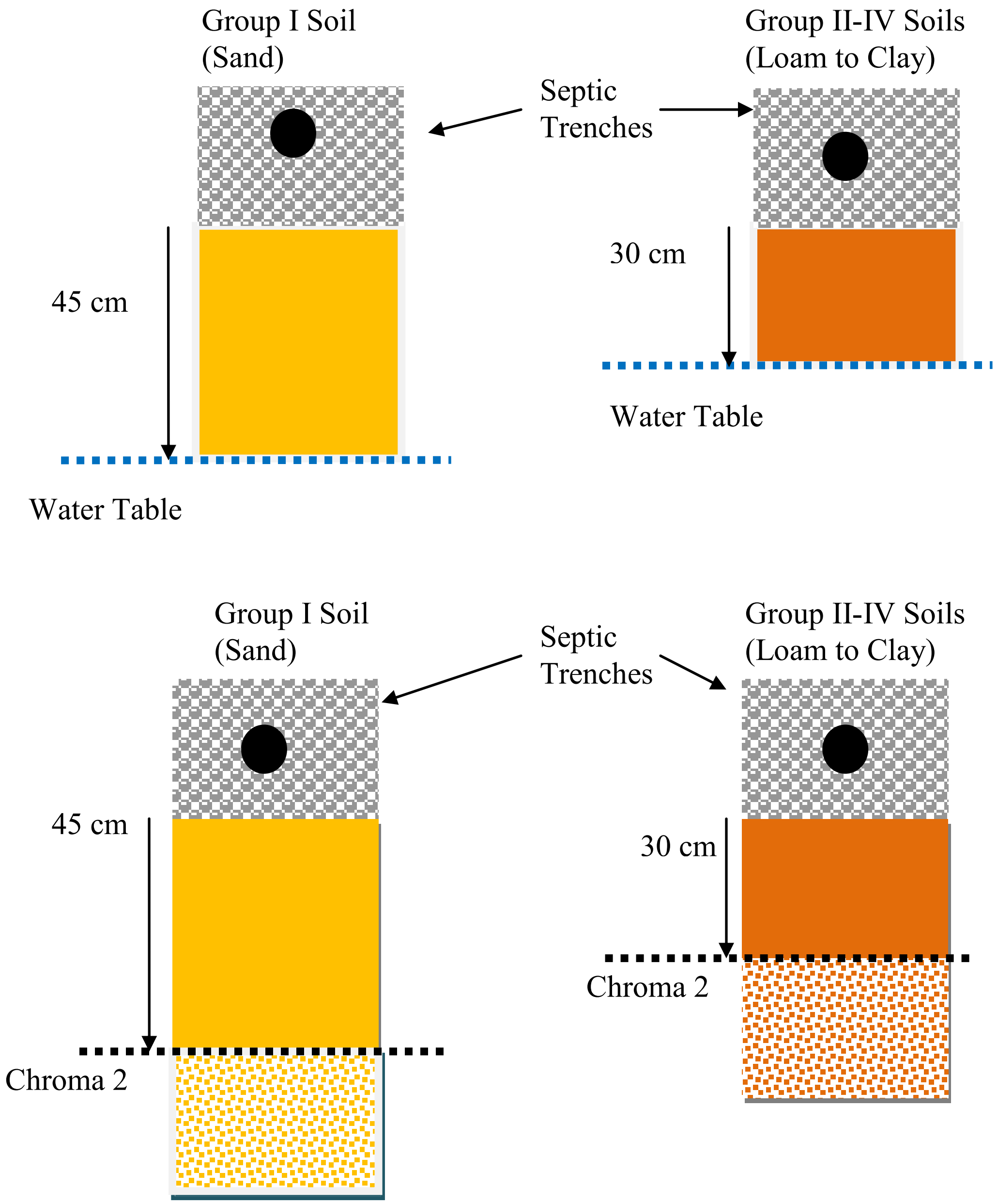


Figure 3.1 North Carolina vertical separation distance requirements from septic systems to the seasonal high water table and chroma 2 colors for systems in group I (sands) and group II-IV (sandy loam to clay) soils. Chroma 2 colors (that occupy greater than 2% of soil) are used as indicators of the depth to seasonal high water table. Systems installed in group I soils require 45 cm of vertical separation to SHWT and chroma 2 colors, while systems installed in soil groups II-IV require 30 cm of separation.

High chroma colors due to oxidized iron impart yellow, red, orange and brown colors in soil

Low chroma colors (2 or 1) due to iron reduction, leaching and loss of color (good indicator of the SHWT)

Low chroma colors (2 or 1) throughout the entire profile due to iron poor parent materials (not a good indicator of the SHWT)

Figure 3.2 Low chroma soil colors due to the reduction and leaching of iron from soil (A- Goldsboro series) and from soils formed from iron poor materials (B Newhan series). For the soil (A) the SHWT was within 15 cm of the low chroma colors. For the soil (B), the seasonal high water table was more than 2m deep, but low chroma colors were present at the surface.

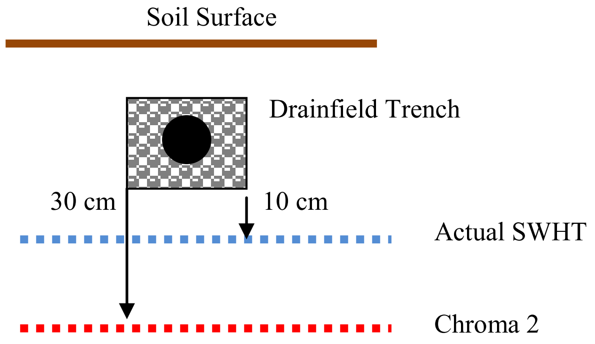


Figure 3.3A Scenario where the predicted depth of seasonal saturation based on chroma 2 colors overestimates the depth of the actual seasonal high water table (SHWT). The drainfield trench was installed 30 cm shallower than the chroma 2 colors, but would not actually maintain a 30 cm separation to the SHWT, instead a 10 cm separation would occur.

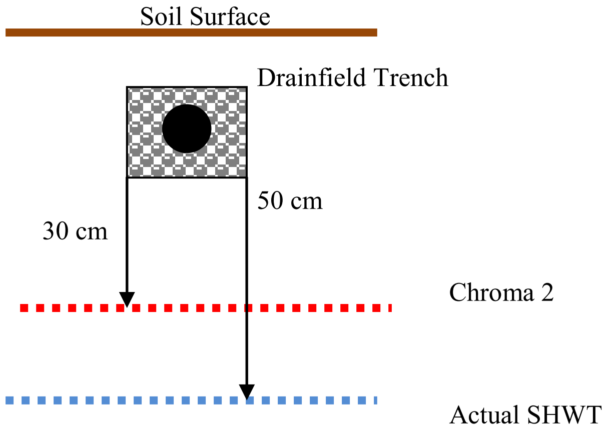


Figure 3.3B Scenario where the predicted depth of seasonal saturation based on chroma 2 colors underestimates the depth of the actual seasonal high water table (SHWT). The drainfield trench was installed with 30 cm shallower than the chroma 2 colors, and would actually maintain a 50 cm separation to the SHWT.

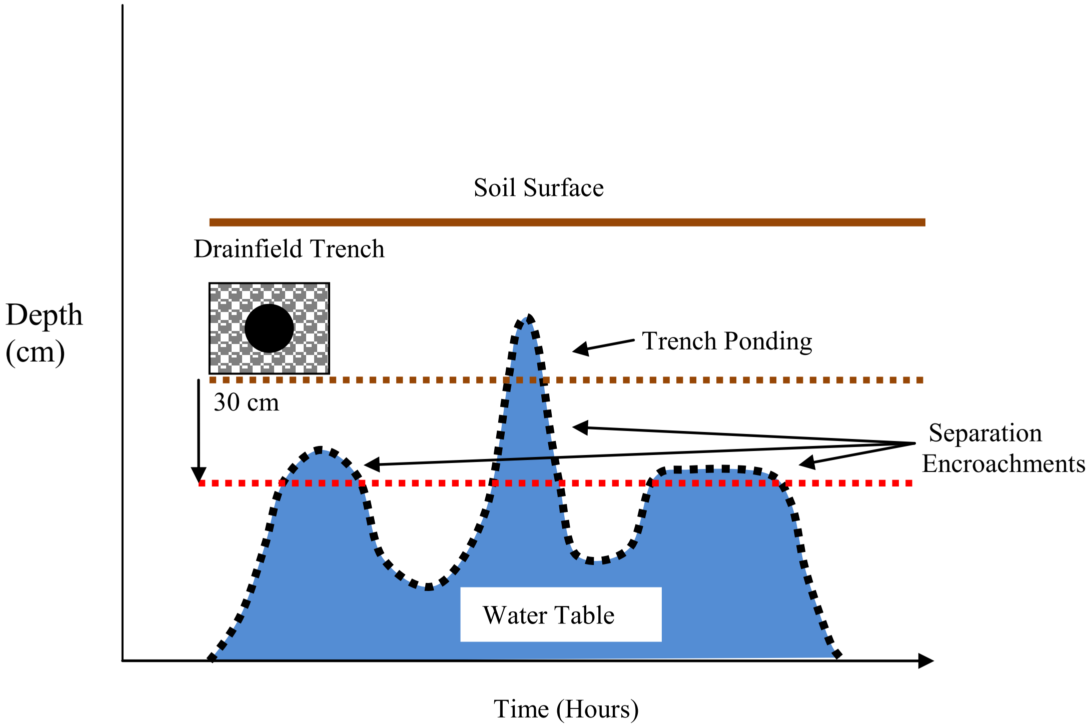


Figure 3.4 Vertical separation encroachments (VSE) occur when the water table rises to within 30 cm of the trench bottom for septic systems in soil groups II-IV (sandy loam to clay). Trench ponding (TP) occurs when the water table rises above or to the depth of the trench bottom and there is no separation. The frequency (number of encroachments) and duration (total time) of vertical separation distance encroachments and trench ponding were calculated using hydrograph data generated from automated water level loggers installed in groundwater wells near septic systems and the depth to trench bottom for each system. For septic systems in group I soils (sands), vertical separation distance encroachments would occur when the water table rises to within 45 cm of the trench bottom depth. The frequency of TP in this example is 1, and the frequency of VSE is 3. The duration of VSE is the total combined hours the water table was within 30 cm of the trench bottom for the 3 encroachments. The duration of TP is the total amount of time for water table was above the trench bottom depth.

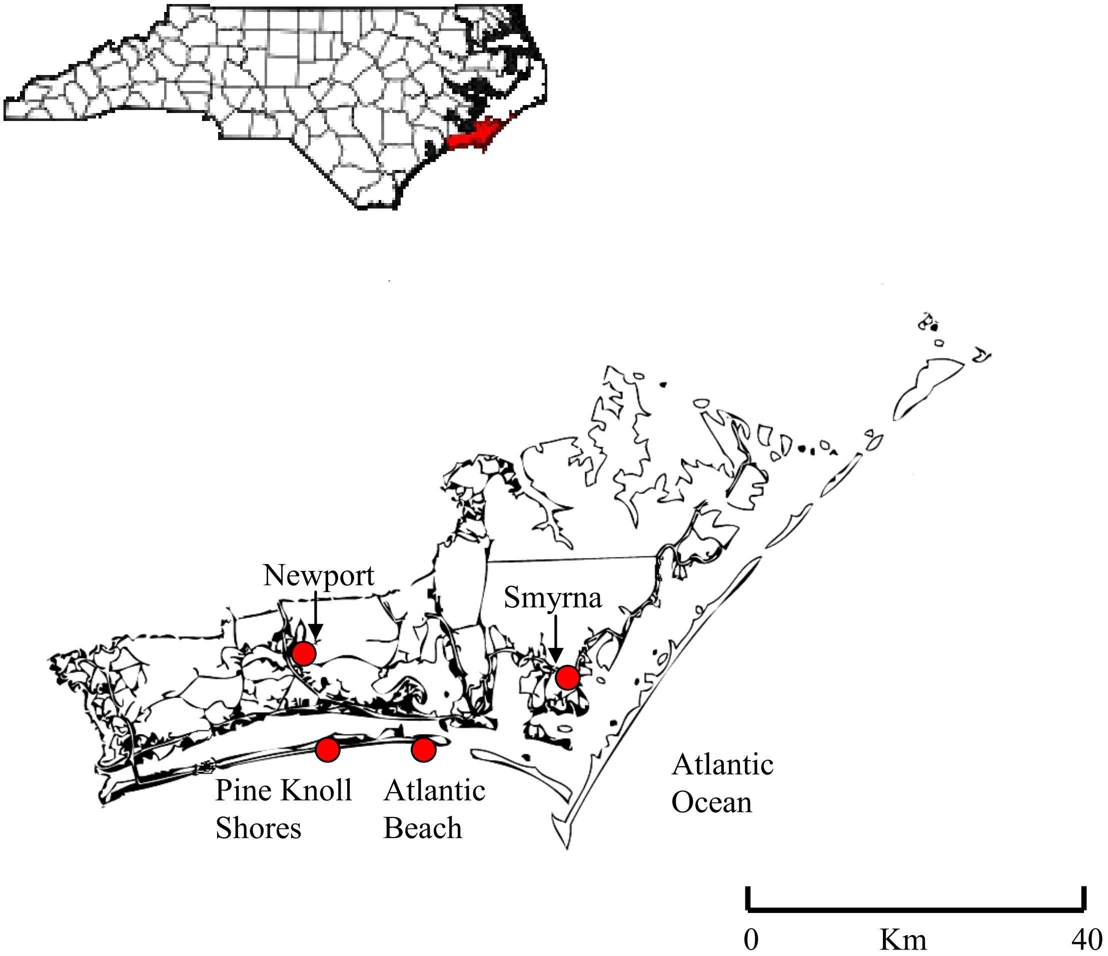


Figure 3.5 Research sites located in the towns/cities of Newport, Atlantic Beach, Pine Knoll Shores and Smyrna in Carteret County, North Carolina. Carteret County is highlighted in the state map of North Carolina. Scale is approximate. Map modified from Carteret County, NC GIS web page and Wikipedia.

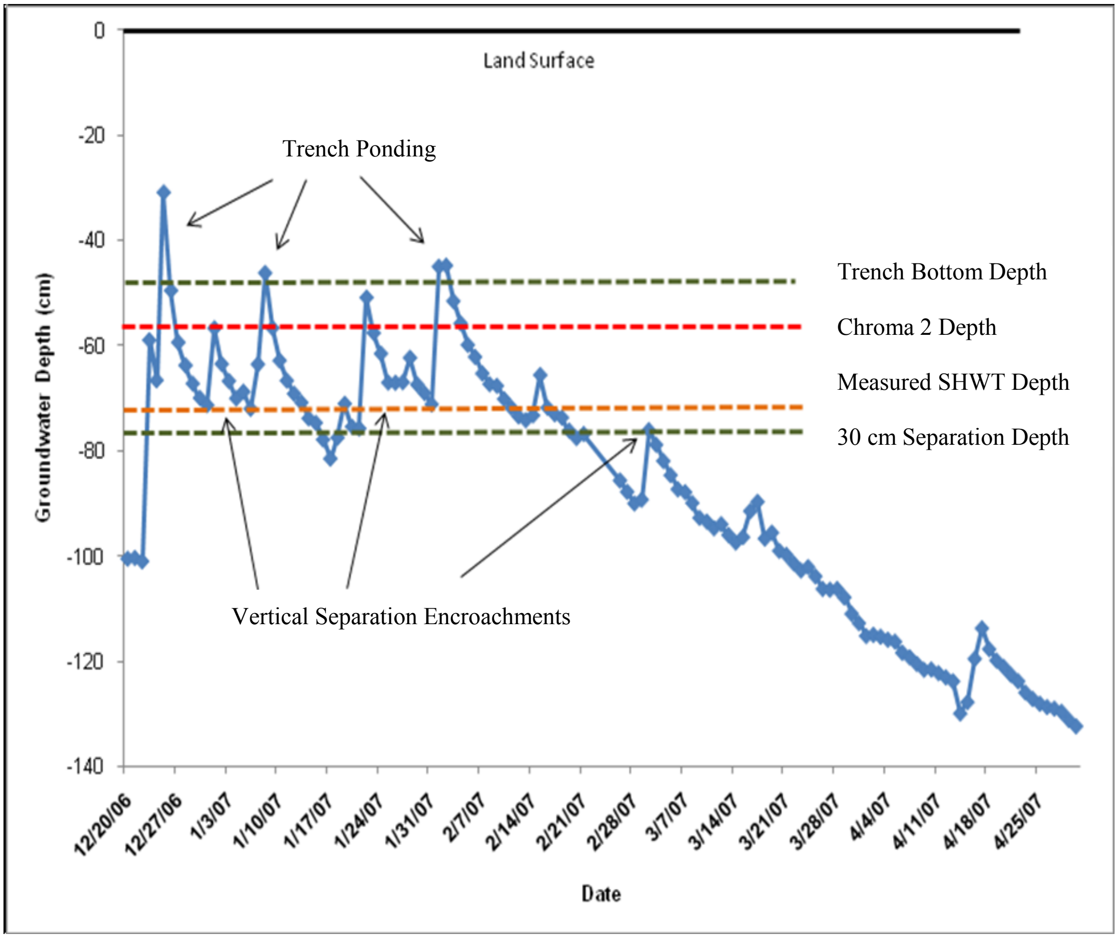


Figure 3.6 Depths to the measured seasonal high water table (SHWT), chroma 2 colors, septic system trench bottom, and 30 cm below the trench bottom (NC vertical separation requirement for group II-IV soils) for system GII-D. For this site, the chroma 2 colors underestimated the depth of seasonal saturation, the trench bottom was installed with less than 30 cm of separation from the chroma 2 colors, the water table encroached on the 30 cm vertical separation three times and there were three trench ponding events where the water table rose above the trench bottom. The measured SHWT is the shallowest depth at which the water table saturates the soil for 14 consecutive days.

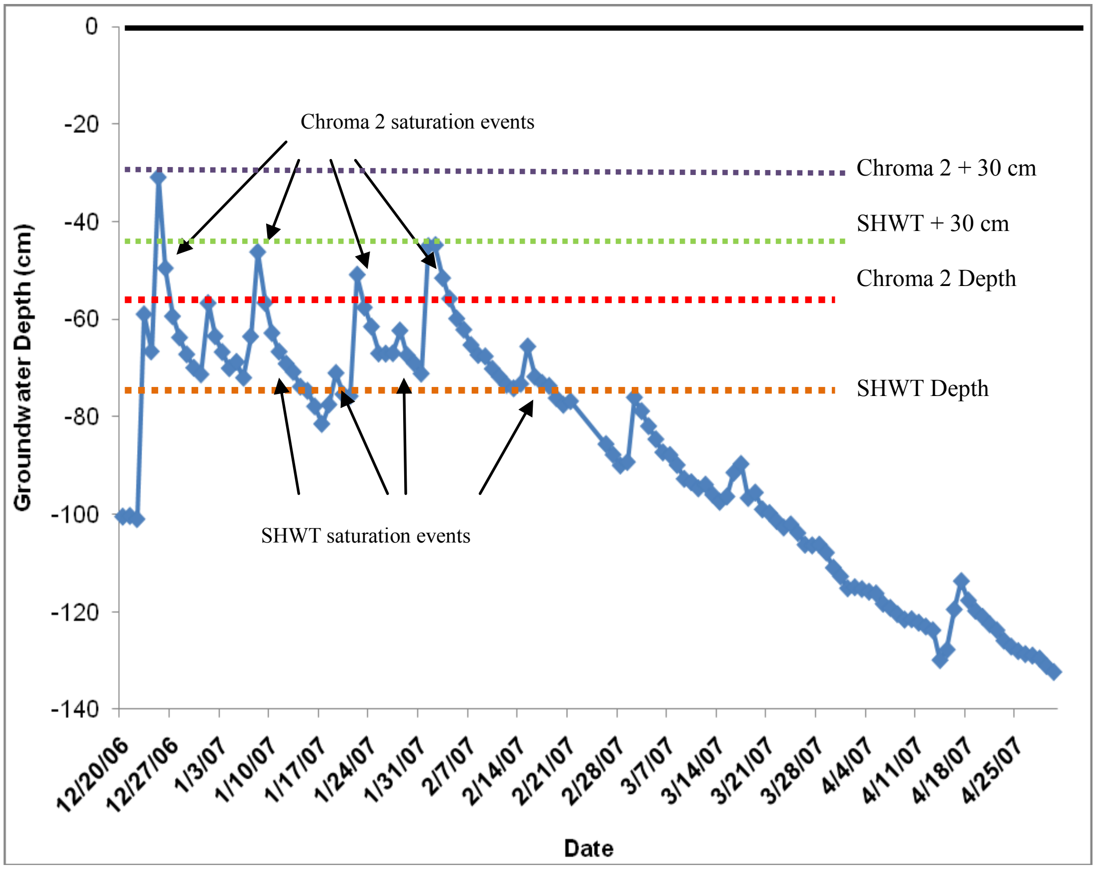
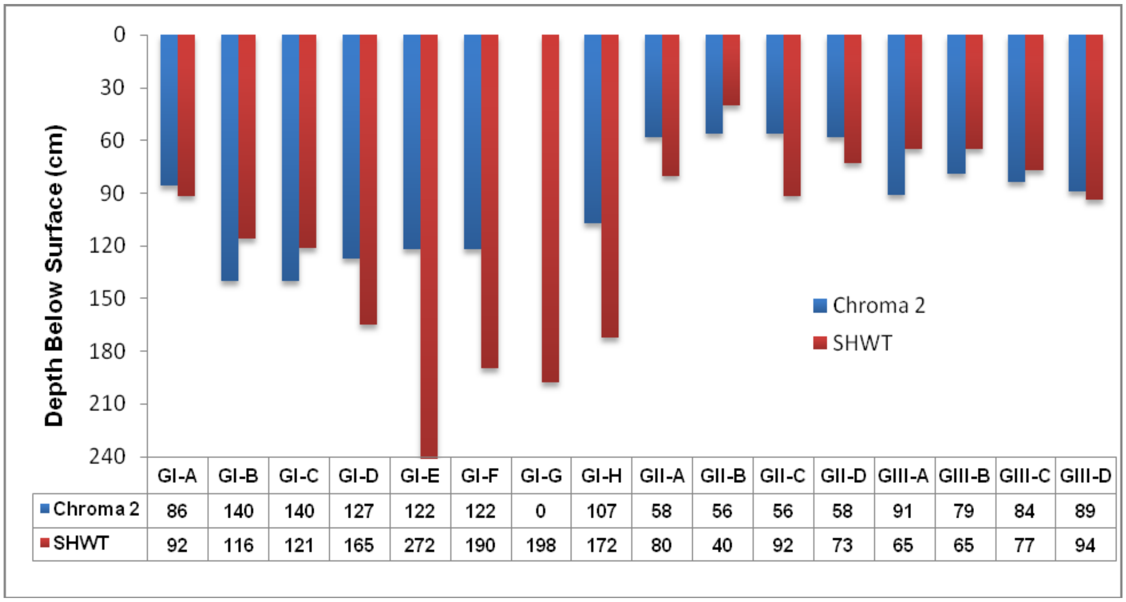
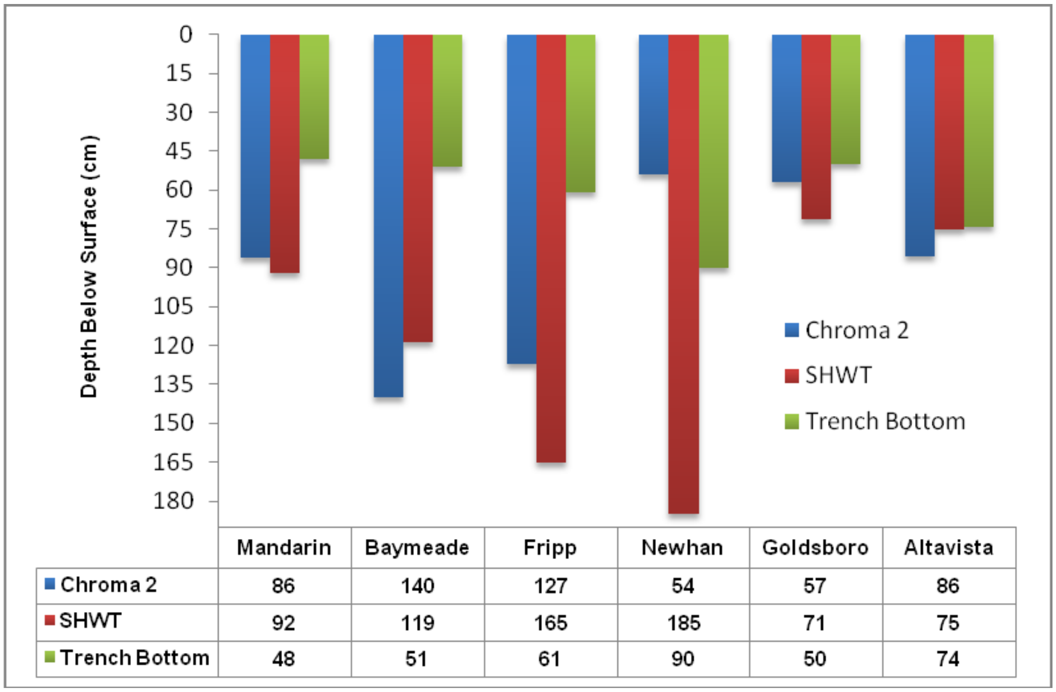


Figure 3.7 Cumulative saturation of the chroma 2 and measured SHWT depths for system GII-D. Cumulative saturation is the sum (total time) of the saturation events or periods when the water table rises to or above the chroma 2 or SHWT depths. Saturation of chroma 2 + 30 cm and SHWT + 30 cm occurs when the water table rises 30 cm or more above the chroma 2 color depth and SHWT depths, respectively. Cumulative saturation is the sum (total cumulative time) of these events.



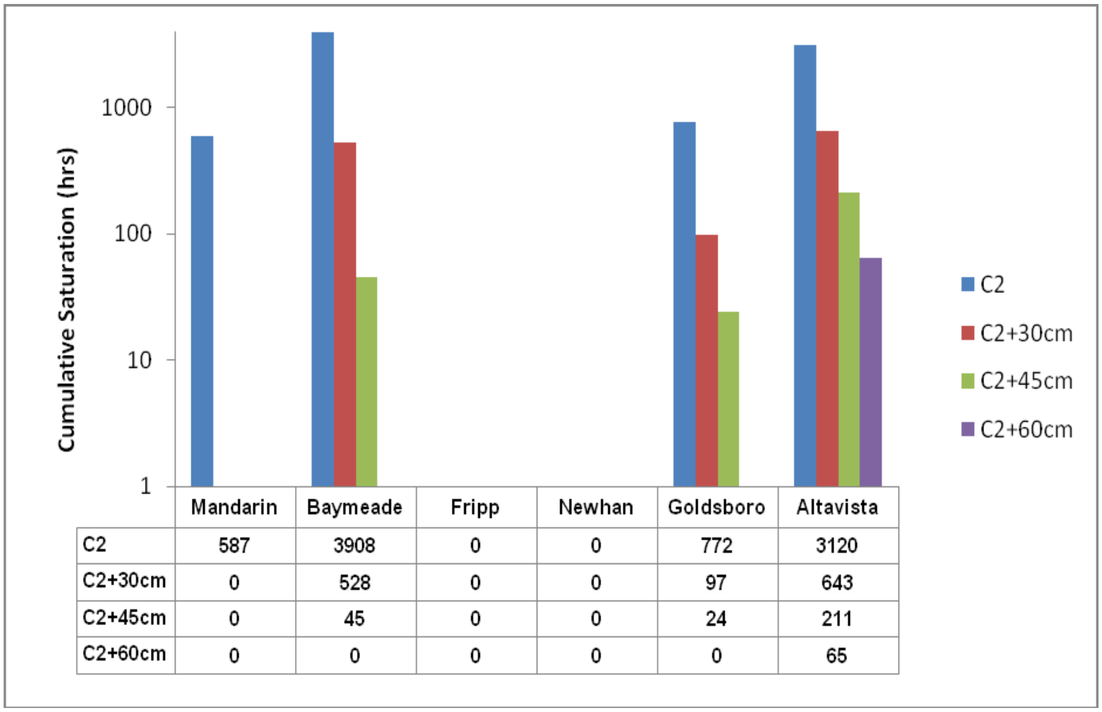
	GI-A	GI-B	GI-C	GI-D	GI-E	GI-F	GI-G	GI-H	GII-A	GII-B	GII-C	GII-D	GIII-A	GIII-B	GIII-C	GIII-D
🟦 Chroma 2	86	140	140	127	122	122	0	107	58	56	56	58	91	79	84	89
🟥 SHWT	92	116	121	165	272	190	198	172	80	40	92	73	65	65	77	94

Figure 3.8 Depths to chroma 2 colors and the 14-day seasonal high water table (SHWT) for sites GI- A in the Mandarin series, GI-B and GI-C in the Baymeade series, GI-D and GI-E in the Fripp series, GI-F, GI-G and GI-H in the Newhan series, GII-A to GII-D in the Goldsboro series and GIII-A to GIII-D in the Altavista series. Eleven of 16 sites had chroma 2 colors within 22 cm of the observed SHWT or both the chroma 2 colors and the SHWT were deeper than 122 cm. Most sites are not evaluated deeper than 122 cm beneath the surface because most septic system technologies require less soil depth than 122 cm.



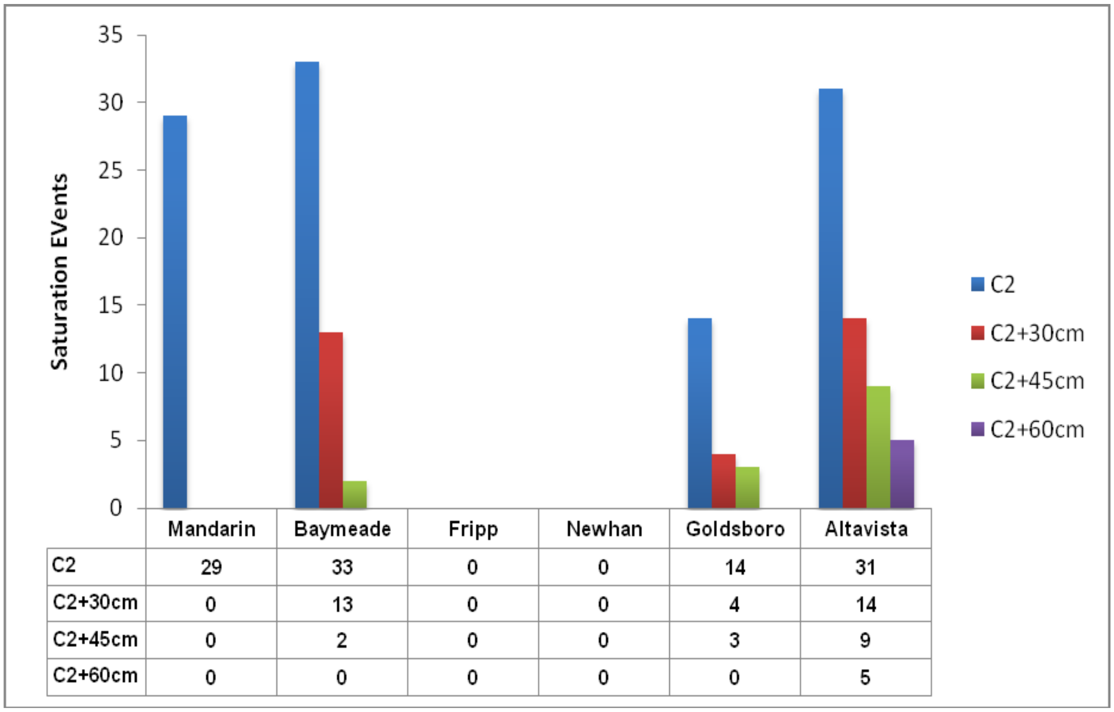
	Mandarin	Baymeade	Fripp	Newhan	Goldsboro	Altavista
🟦 Chroma 2	86	140	127	54	57	86
🟥 SHWT	92	119	165	185	71	75
🟩 Trench Bottom	48	51	61	90	50	74

Figure 3.9 Mean depths to chroma 2 colors, 14-day seasonal high water tables (SHWT), and trench bottoms for septic systems in the Mandarin, Baymeade, Fripp, Newhan, Goldsboro and Altavista series. Septic systems in the Altavista and Goldsboro series require a 30 cm separation distance from trench bottom to chroma 2 colors and the SHWT, systems in the other series require a 45 cm separation distance in North Carolina. Most systems did not meet the required separation distance.



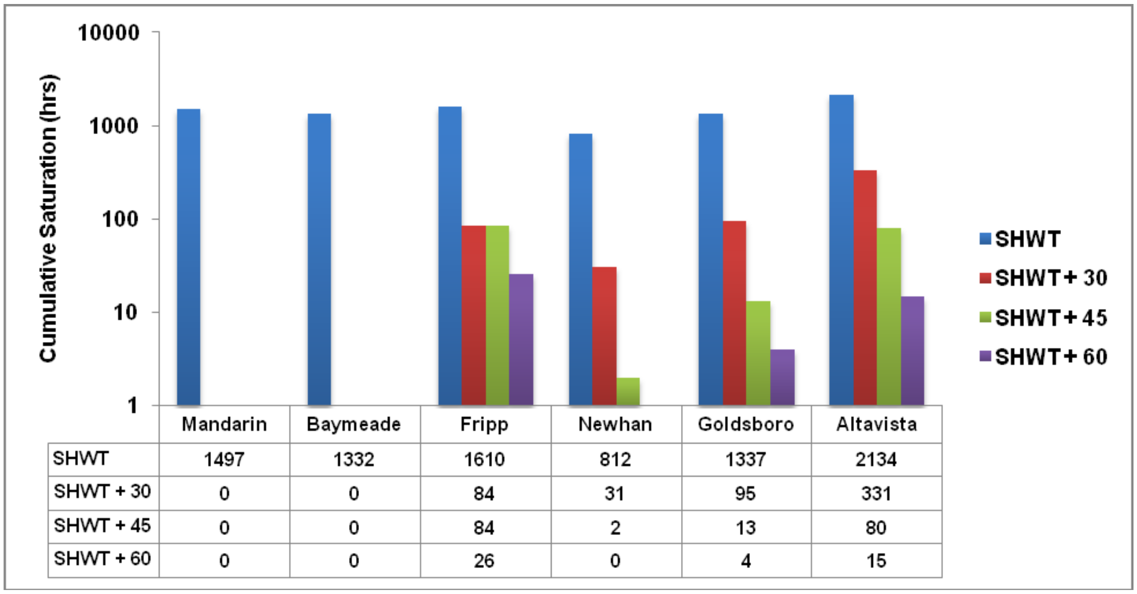
	Mandarin	Baymeade	Fripp	Newhan	Goldsboro	Altavista
C2	587	3908	0	0	772	3120
C2+30cm	0	528	0	0	97	643
C2+45cm	0	45	0	0	24	211
C2+60cm	0	0	0	0	0	65

Figure 3.10 Cumulative saturations of the depth to chroma 2 (C2) colors, or 30 to 60 cm above the depth to C2 colors for septic systems installed in the Mandarin, Baymeade, Fripp, Newhan, Goldsboro and Altavista soil series. C2 colors are used as indicators of the 14-day seasonal high water table (SHWT). Many states require septic systems to be installed at least 30 to 60 cm above indicators of the SHWT. Cumulative saturation of C2 + 30, C2 + 45 and C2 + 60 cm, refers to the time that the water table would be at or above the trench bottom of a septic systems requiring 30-60 cm of vertical separation from C2 colors. For each soil type, as the separation distance increases, the cumulative saturation decreases. Fripp and Newhan series soils had chroma 2 colors very close to the surface, but had deep water tables that never rose close to the chroma 2 colors and therefore had (0) hours of cumulative saturation.



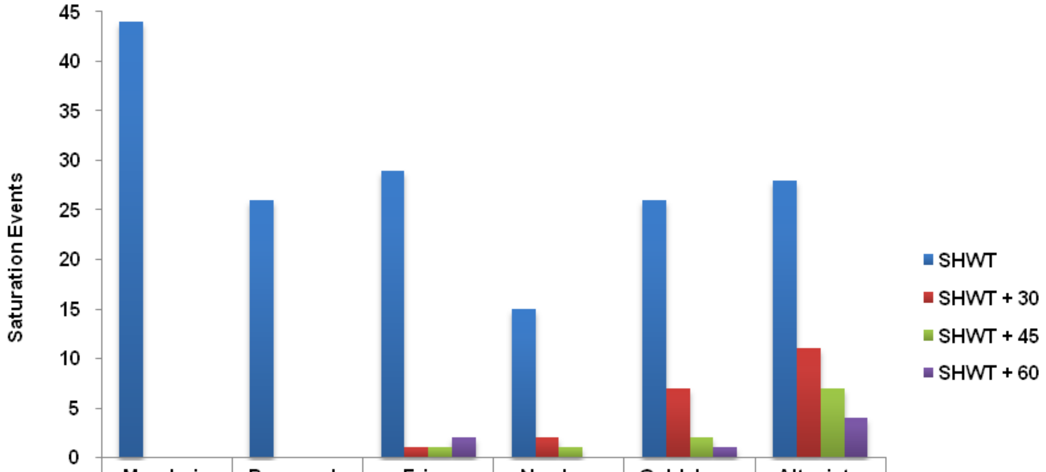
	Mandarin	Baymeade	Fripp	Newhan	Goldsboro	Altavista
C2	29	33	0	0	14	31
C2+30cm	0	13	0	0	4	14
C2+45cm	0	2	0	0	3	9
C2+60cm	0	0	0	0	0	5

Figure 3.11 Frequency of water table spikes above the depth to chroma 2 colors (C2), and 30 to 60 cm above the C2 colors. C2 colors are used as indicators of the 14-day seasonal high water table (SHWT), and many states require septic systems to be installed at least 30 to 60 cm above water table indicators. Saturation events of C2 + 30, C2 + 45 and C2 + 60 cm, refers to the number of times that the water table rose to or above the trench bottom of a septic systems requiring 30-60 cm of vertical separation from C2 colors. For each soil type, as the separation distance increased, the frequency of saturation events decreased.



	Mandarin	Baymeade	Fripp	Newhan	Goldsboro	Altavista
SHWT	1497	1332	1610	812	1337	2134
SHWT + 30	0	0	84	31	95	331
SHWT + 45	0	0	84	2	13	80
SHWT + 60	0	0	26	0	4	15

Figure 3.12 Cumulative saturations of the depths to the 14-day seasonal high water tables for group I (sandy) soils including Mandarin, Baymeade, Fripp and Newhan soil series; group II (sandy loam) soils Goldsboro, and group III (sandy clay loam) Altavista series. Values represent the total number of hours the water table was at or above the depth of 14 days of continuous saturation. The depth that soil is saturated for fourteen continuous days is considered the SHWT for permitting septic systems in North Carolina. Septic systems must be installed at least 30 to 45 cm above the SHWT. Systems in group I soils require 45+ cm of separation, systems in other soils require at least 30 cm. For each soil group, as the separation distance increased, the cumulative saturation decreased.



	Mandarin	Baymeade	Fripp	Newhan	Goldsboro	Altavista
SHWT	44	26	29	15	26	28
SHWT + 30	0	0	1	2	7	11
SHWT + 45	0	0	1	1	2	7
SHWT + 60	0	0	2	0	1	4

Figure 3.13 Frequency of water table spikes above the depth of 14 continuous days of saturation (SHWT), and 30 to 60 cm above the SHWT depth. Many states, including North Carolina, require septic systems to be installed at least 30 to 60 cm above water table indicators. Saturation events of SHWT + 30, SHWT + 45 and SHWT + 60 cm, refers to the number of times that the water table rose to or above the trench bottom of a septic systems requiring 30-60 cm of vertical separation from SHWT. For each soil type, as the separation distance increased, the frequency of saturation events decreased.

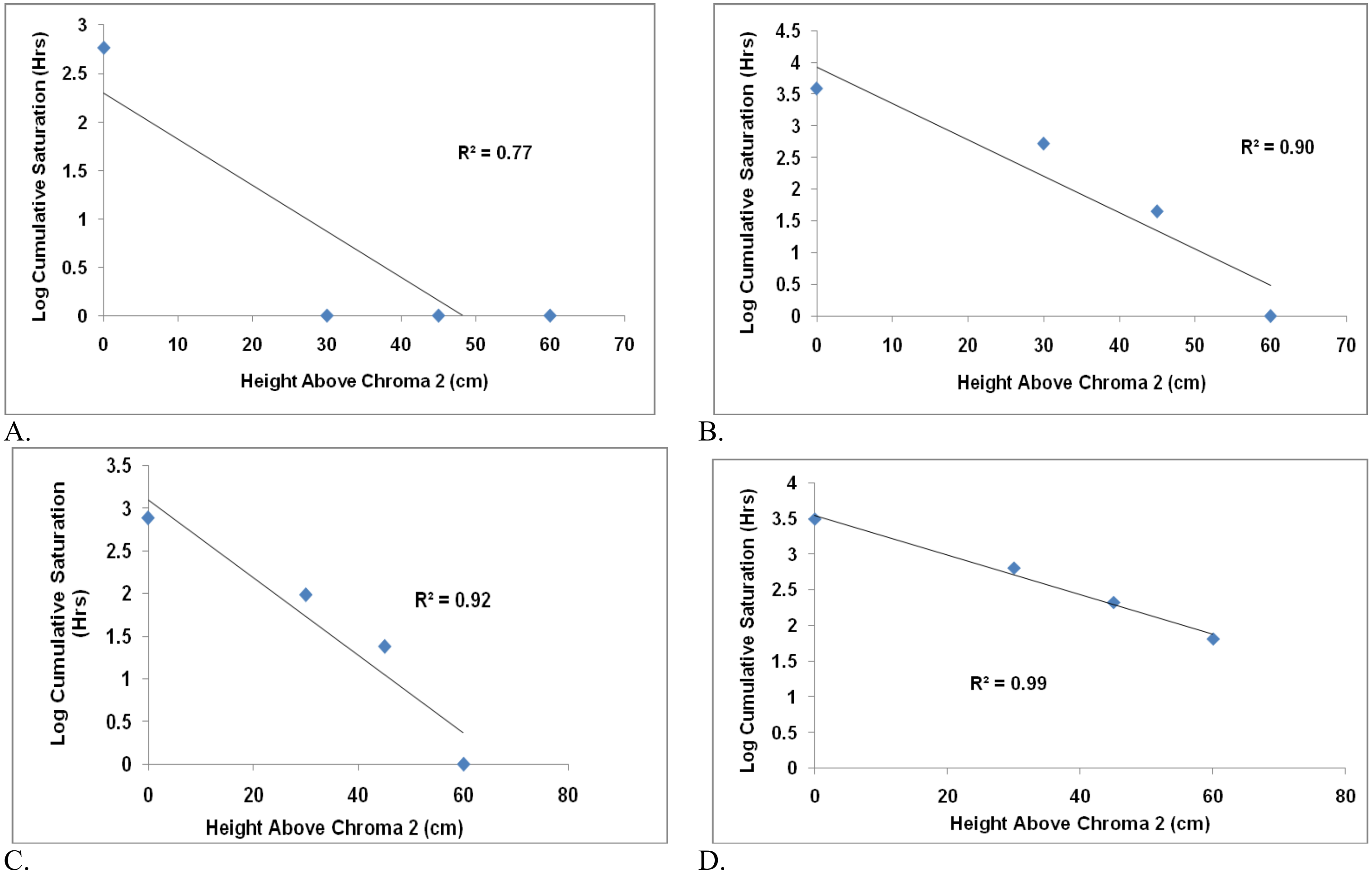
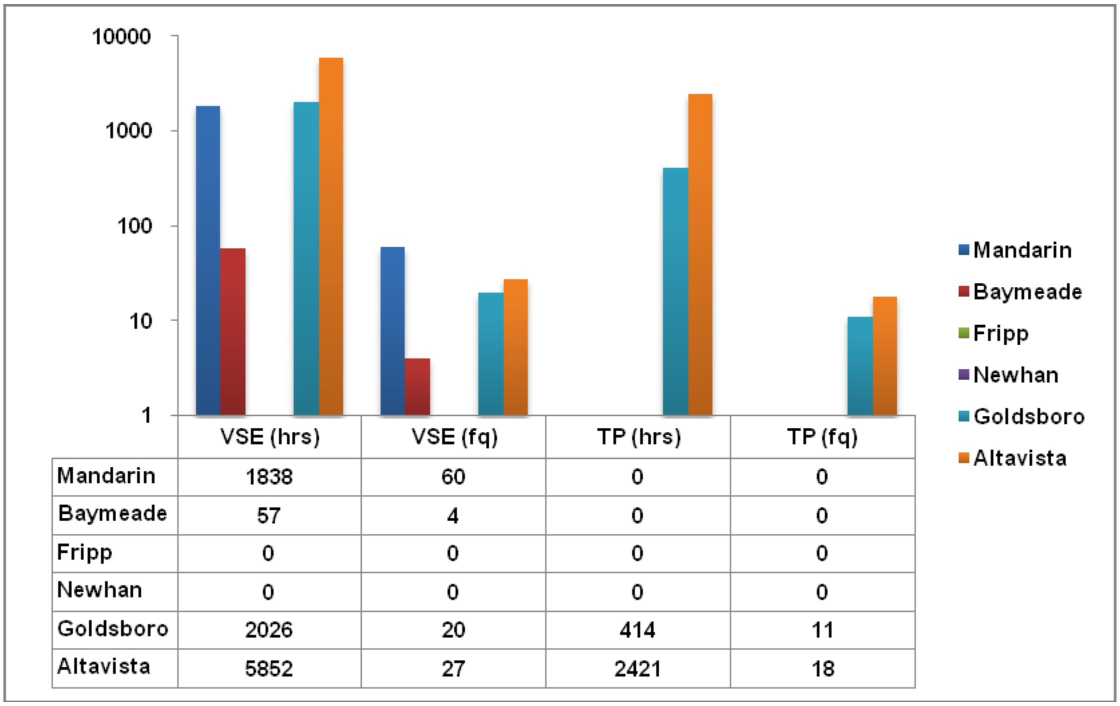


Figure 3.14 Log of the cumulative saturation duration (hours) at the chroma 2 depth and 30, 45 and 60 cm above the chroma 2 depths. Cumulative saturation 30-60 cm above the chroma 2 depths represents the duration of groundwater levels above the trench bottoms of septic systems (trench ponding) and duration of direct discharge of wastewater into the groundwater. A) group I Mandarin series; B) group I Baymeade series; C) group II Goldsboro series; and D) group III Altavista series.



	VSE (hrs)	VSE (fq)	TP (hrs)	TP (fq)
Mandarin	1838	60	0	0
Baymeade	57	4	0	0
Fripp	0	0	0	0
Newhan	0	0	0	0
Goldsboro	2026	20	414	11
Altavista	5852	27	2421	18

Figure 3.15 Mean vertical separation distance encroachment (VSE) times and frequencies and mean total trench ponding times and frequencies (TP) for septic systems in the Mandarin, Baymeade, Fripp, Newhan, Goldsboro and Altavista series. VSE's and Tp's were more common for systems in the Goldsboro and Altavista soils, which require a 30 cm separation distance to SHWT, while systems in the Mandarin, Baymeade, Fripp and Newhan soil series require a 45 cm separation distance. Frequencies indicate the number of VSEs or TPs.

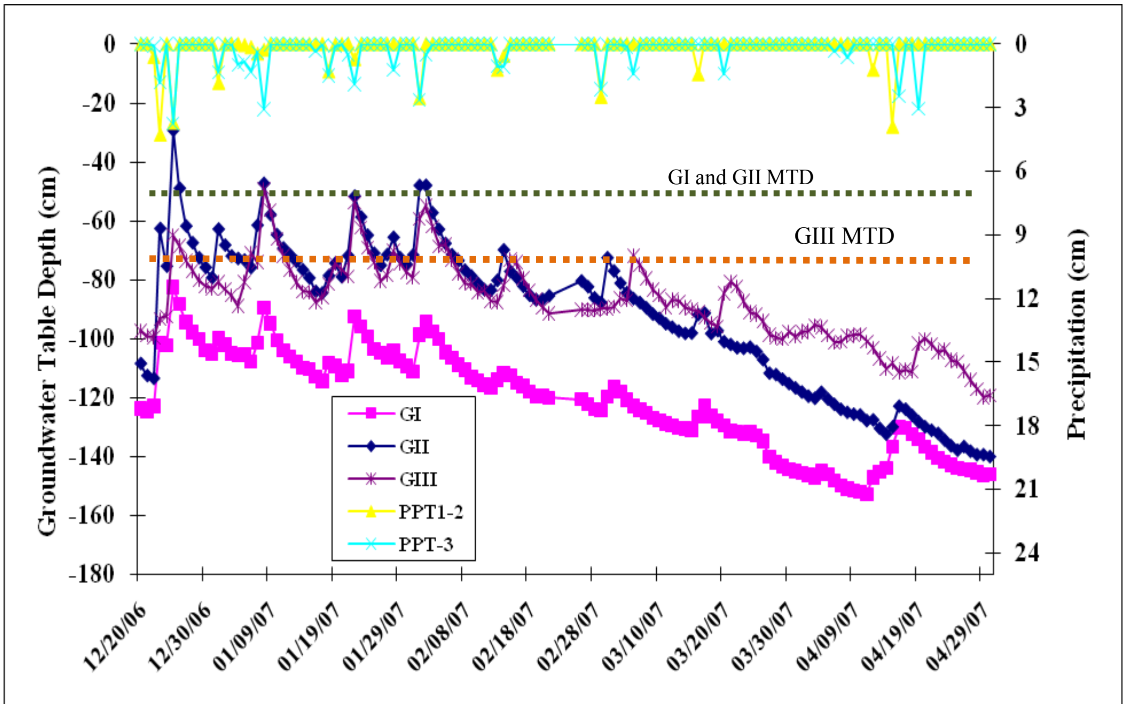


Figure 3.16 Average daily depths to the water table and daily precipitation for systems in group I (Baymeade and Mandarin series), group II (Goldsboro series) and group III (Altavista series) soils during the typical wet season (December – May). Mean trench bottom depths (MTD) were 50 cm for systems in GI and GII soils, and 74 for systems in GIII soils. When precipitation amounts began to decline in February 2007, the Group II and III soils still experienced vertical separation encroachments due to the installation depths of the systems and the relatively shallow water tables.

CHAPTER 4: SEPTIC SYSTEM NITROGEN LOADING TO GROUNDWATER IN THE NEWPORT RIVER WATERSHED, NORTH CAROLINA

4.1 Abstract

Excess nutrient loading to surface waters in North Carolina have been linked with eutrophic conditions, designation of entire river basins as nutrient sensitive waters, and massive fish kills. To address these issues, regulations (15A NCAC 2B .0232-.0240 and 15A NCAC 2B .0255-.0259) were implemented to reduce nitrogen loads from various sources of pollution. However, nitrogen loads from septic systems to the shallow aquifer were not addressed in the regulations. Nitrogen loading to septic tanks and groundwater in the Newport River watershed in coastal North Carolina were calculated using hydrological and water quality data from 16 septic systems installed in three different soil groups and the groundwater adjacent to these systems. Demographic and soil survey data indicate that over 30,000 people use septic systems in the watershed with 76% of the systems installed in group I soils (sands), 11% in group II soils (sandy loams), and 13% in group III soils (sandy clay loams). Systems in group III soils had lower dissolved inorganic nitrogen (0.2 kg/person/yr) and total dissolved nitrogen loading rates (0.3 kg/person/yr) to groundwater than systems in group I (2.0 and 4.0 kg/person/yr) and II soils (0.7 and 1.9 kg/person/yr), respectively. Mean annual watershed dissolved inorganic nitrogen (DIN) and total dissolved nitrogen (TDN) loading from septic systems to the groundwater were 47,226 kg and 95,973 kg, respectively. Septic systems reduced TDN loading by over 180,000 kg/yr (65%) before discharge to the groundwater. Overall, the TDN annual loading rates from septic systems to groundwater, assuming 5 systems/ha in

group I and II soils (28.5 to 57.5 kg/ha), were similar to potential agricultural contributions to groundwater (37.5 kg/ ha) for the Carteret County area (Neuse Basin Oversight Committee 2009) and higher than estimated atmospheric deposition rates of nitrogen (8.0-12.0 kg/ ha) in eastern North Carolina (Whitall et al. 2003). The results suggest that coastal watersheds with sandy soils are particularly vulnerable to shallow nitrogen loading from septic systems and septic systems should be considered in future regulatory efforts to reduce nitrogen loading to shallow groundwater and surface waters.

4.2 Introduction

4.2.1 Septic Systems and Water Quality

Approximately 60% of residences in coastal, North Carolina currently rely on on-site systems for wastewater treatment and disposal (North Carolina National Estuarine Research Reserve 2003) and the population of Coastal counties is expected to grow 20.5% from 2000 to 2010 (Tillman 2004). Much of the future growth of coastal North Carolina will likely be accommodated by on-site systems, meaning greater discharges of wastewater to the subsurface environment. An analysis of North Carolina Division of Environmental Health (2006) reports shows that nearly 1,500 coastal septic systems fail hydraulically (surfacing effluent and/or wastewater back-up in the home) each year, temporarily contributing pollutants to surface waters and/or exposing people and animals to wastewater pollutants. Septic system hydraulic failures can affect the quality of drinking water, recreational waters, shellfisheries, coastal ecology and tourism by discharging wastewater pollutants such as nutrients, bacteria and viruses directly into surface waters without any treatment by the soil. Another potential pathway of pollutant transport from septic systems to surface waters is through the shallow groundwater system (non-point source pollution).

Past studies have shown that nitrogen (Robertson et al. 1991; Postma et al. 1992; Harmon et al. 1996; Ptacek 1998; Buetow 2002; Corbett et al. 2002; and Reay 2004), bacteria (Carlile et al. 1981; Cogger et al. 1988; Lipp et al. 2001; Booth et al. 2003; Borchardt et al. 2003; Ahmed et al. 2005; and Cahoon et al. 2006;) and viruses (Scandura and Sobsey 1997) can be transmitted from septic systems to ground and/or surface waters, resulting in the degradation of water quality.

Nitrogen concentrations exceeding 20 mg/L in groundwater beneath and/or adjacent to septic systems have been reported for the Coastal Plain of North Carolina (Buetow 2002), a sandy aquifer in Ontario, Canada (Harman et al. 1996), a coastal barrier bar in Point Pelee, Ontario, Canada (Ptacek 1998), in Rhode Island (Postma et al. 1992) and in the Coastal Plain of Virginia (Reay 2004). Each of these sites contained sandy soils and sediments.

Furthermore, studies by Harmon et al. (1996), Robertson (1991), and Ptacek (1998) in Canada, Buetow (2002) in North Carolina, and Corbett et al. (2002) in Florida included tracking the groundwater septic plumes for varying distances away from the systems and each study showed septic systems impacts on groundwater away from the systems. Robertson (1991) found that nitrogen derived from septic systems can migrate away from the systems and affect groundwater quality at distances as great as 130 m. However, elevated groundwater NO_3^- -N concentrations do not necessarily correspond to high loading rates of nitrogen to adjacent surface waters. Studies by Robertson (1991) and Buetow (2002) showed high concentrations of NO_3^--N in groundwater down-gradient from the septic systems, but less than 25% of the nitrogen load actually made it to surface waters because the groundwater impacted plume had to flow through organic rich stream and river bed sediments that fueled denitrification.

In addition to nitrogen, bacteria from septic systems may contribute to the degradation of shallow groundwater (Carlile et al. 1981; Cogger et al. 1988; and Scandura and Sobsey 1997) and surface water quality (Lipp et al. 2001; Booth et al. 2003; Ahmed et al. 2005; and Cahoon et al. 2006;). Studies in the Coastal Plain of North Carolina by Carlile et al. (1981) and Cogger et al. (1988) showed that groundwater 1.8 m and 16 m down-gradient from septic systems contained fecal coliform densities of up to 3218 and 1600 MPN/100 mL, respectively. Coliform densities in groundwater beneath septic systems were higher during periods with high water tables (up to 25,000 MPN/100 mL) than during periods of low water tables (60 MPN/100 mL). A study by Scandura and Sobsey (1997) in coastal North Carolina found that groundwater adjacent to septic systems installed in sandy soils with high water tables had extensive viral and bacterial contamination. These studies indicated that soil type and separation distance influence septic effluent treatment and shallow groundwater quality in coastal areas.

Some groundwater studies did not include monitoring adjacent surface water quality (Carlile et al. 1981; Cogger et al. 1988; and Scandura and Sobsey, 1997) however, research by Lipp et al. (2001), Booth et al. (2003), Ahmed et al. (2004), and Cahoon et al. (2006) provided links between septic system derived bacteria and surface water contamination in coastal areas of Charlotte Harbor, Florida, south central Virginia, Queensland, Australia, and coastal North Carolina, respectively.

4.2.2 North Carolina Watershed Water Quality Issues

Coastal and inland waters of North Carolina have witnessed the effects of poor water quality resulting from excess nutrient and bacteria loadings. In the 1990's, there were a series of massive fish kills near the mouths of the Neuse and Tar-Pamlico Rivers within the Albemarle-Pamlico Estuary system (APES). The primary causative agent of the fish kills in the 1990's was determined to be excess nutrient loadings (Fear et al 2004). Since the massive fish kills in the 1990's, many point and non-point source polluters operating within the watersheds of two of the larger river basins (Neuse and Tar-Pamlico) feeding the APES, have been more stringently regulated under the umbrella of Nutrient Sensitive Waters (NSW) Strategies (North Carolina Department of Environment and Natural Resources, 2003) (Figure 4.1).

Included in the strategies were goals focused on reducing nutrient loadings to the estuary by 30% from 1991-1995 baseline periods. Regulations targeted point and non-point sources of nutrient loadings to the rivers including agricultural producers, industrial and municipal wastewater treatment plants, and developments that generate significant stormwater runoff in both the Neuse and Tar-Pamlico river systems. There was also a moratorium on new hog farms enacted in 1997 (NC House Bill 515), and several Bills since to continue the moratorium. Not addressed were the nitrogen loads from septic systems, even though almost 40 and 48% of the population in the Neuse and Tar-Pamlico River Basins rely on septic systems, respectively (Pradhan et al. 2007). A similar watershed scale nutrient reduction strategy was recently implemented for the Jordan Lake Watershed (North Carolina Department of Environment and Natural Resources 2009) due to excess algae growth and eutrophic conditions. Similarly, the Jordan Lake rules targeted agriculture, urban stormwater runoff, and centralized wastewater treatment plants, but again, did not address nitrogen contributions from septic systems.

Under the various NSW strategies, when agricultural lands are converted to residential or commercial developments, the agricultural industry receives a nitrogen reduction credit due to the land use conversion. While stormwater runoff (and stormwater delivered nitrogen load) from the newly developed property may be mitigated by the use of engineered runoff controls, the nitrogen loads from the septic systems serving these developments are not accounted for. Also there is the possibility of nitrogen loadings to shallow groundwater via lawn fertilization (Sharma et al. 1996) and pet waste (Flipse et al. 1984). Reay (2004) estimated that nitrogen loading from septic systems to shallow groundwater was significant (5.7 to 10.7 kg/household/yr) and with 0.2 to 0.4 ha lot sizes, comparable to loadings from predominant row crop agriculture in the mid-Atlantic Coastal Plain. Therefore, when land use changes from agricultural to residential/urban development, actual nitrogen loading reduction to the groundwater and eventually the estuary may not be realized, although reduction credit (for the basin) is received.

The White Oak River Basin Watershed, located just south of the Tar-Pamlico and Neuse River Basins (Figure 4.1) has also experienced water quality problems. The basin has four river systems including the New River, White Oak River, Newport River, and North River and 3 sounds: Core, Bogue, and Back. Of the estimated 47,348 ha of shellfish growing waters in the watershed, 15,032 ha or 32% were listed as impaired in 2007 (North Carolina Division of Water Quality 2007). This area represents a 3,800 ha increase in use impairment since 2001. The primary stressor for shellfishing waters in the watershed is fecal coliform, but nutrients have also contributed to use impairment in the White Oak (North Carolina Division of Water Quality 2007). There are over 4,320 ha of nutrient sensitive waters in the basin. Thus, nutrient and bacteria loadings to surface water in the watershed are of increasing concern. The increase in acreage of nutrient sensitive and impaired waters has corresponded with an increase in population and land use conversion from forestry and agriculture to urban landscapes. From 1982 to 1997, there was an estimated 7.7% decline or loss of nearly 12,000 ha of forest lands, a 13.6 % decline or loss of over 3,600 ha of cultivated cropland and a population increase of over 63,000 in the watershed (North Carolina Division of Water Quality 2007). Urban areas grew by 65.6% from 1982 to 1997 and expanded by over 14,000 ha of land (NC DWQ, 2007). North Carolina Division of Environmental Health (2007) reports indicate that from 1995 to 2006, over 13,800 new septic systems were installed in Carteret and Onslow counties. Furthermore, the counties (Carteret and Onslow) that contain most of the watershed acreage and have the largest populations are expected to see 13.9% - 15.8% increases in population from 2000 to 2020 (NC DWQ 2007). Future growth is likely to be accommodated by an increase in the number of septic systems.

As more land is converted from agriculture and forestry to residential and commercial developments, septic system nitrogen loading to ground and surface waters will increase. In North Carolina, sandy soils (group I soils common in coastal settings) are assigned relatively high wastewater loading rates (0.42 to 0.28 L/d/m^2) (15A NCAC 18A .1955) that allow for lot sizes smaller than 0.2 ha. Shallow groundwater quality and groundwater contribution of dissolved nitrogen to adjacent surface waters may not improve as land is converted from agricultural to residential development in coastal areas. This research aims to calculate the nitrogen loads contributed from septic systems to soils and shallow groundwater in the Newport River watershed (Figure 4.2), a coastal watershed that has experienced excess nutrient loadings.

4.3 Methods

4.3.1 Septic System and Groundwater Monitoring

Sixteen residential septic systems in coastal North Carolina were instrumented with 10 cm diameter PVC monitoring wells. A minimum of two wells per residence/lot were installed adjacent to the septic systems. The wells were nested such that one well was relatively deep and the other relatively shallow (Figure 4.3). At each site, the septic system components including the tank and drainfield trenches were located using a tile-drain probe rod and the soil properties were evaluated. The soil profiles at each site were examined using a hand auger, the texture by feel method (Brady et al. 2004) in the field, and the hydrometer method in the lab (Day 1979) to determine the particle size distribution and NC DENR soil group status (Table 4.1). Wells were installed between drainfield trenches for trench systems and down gradient from bed systems (Figure 4.3).

Groundwater quality adjacent to the septic systems was monitored monthly for the most common species of nitrogen associated with septic tank effluent and non-point source pollution (NH_4^+ and NO_3^-) (Robertson et al. 1991; Postma et al. 1992; Harmon et al. 1996; Buetow 2002; and Reay 2004). Well water samples were collected using disposable bailers. Wells were bailed three times, allowed to recharge and then a sample was collected. Water samples were analyzed for NO_3^--N and NH_4^+-N monthly for 13 months, using a YSI Sonde 6920 multi-parameter water quality Sonde (YSI 2007). The Sonde uses ion selective reference electrodes for determining concentrations of NO_3-N and NH_4-N (accuracy 2 mg/L or 10% whichever is greater). The Sonde was calibrated using NO_3^--N and NH_4^+-N standards before each monthly sampling event. Twice during the study (December 2007 and February 2008) groundwater samples were collected from the sites and analyzed for NO_3^--N, NH_4^+-N and Total Kjeldahl nitrogen (TKN) at the NCSU Soil Science Department Analytical Services laboratory using procedures described in Methods for Examination of Water and Wastewater (1995) with a Quick Chem 8000 Lachet Analyzer.

Wastewater from 10 accessible tanks (GI-A, GI-B, GI-D, GI-F, GII-A, GII-C, GII-D, GIII-A, GIII-C, GIII-D) was collected and analyzed three times (December 2007, January and February 2008) during the study period for the dissolved inorganic species NO_3-N and NH_4-N and TKN at the NCSU Soils laboratory. Total dissolved nitrogen (TDN) was calculated by adding NO_3-N and TKN, while dissolved inorganic nitrogen (DIN) was calculated by adding the concentrations of NH_4^+-N and NO_3^--N. Mean tank and groundwater and TDN concentrations were determined for each system and each soil group.

4.3.2 Nitrogen Loadings to Septic Tanks and Shallow Groundwater

Estimates of mean daily water use (EPA 2002) with the measured mean septic tank nitrogen concentrations from the study sites were used to calculate nitrogen loadings processed by septic tanks. The EPA estimated monthly water use was multiplied by the mean tank DIN and TDN concentrations to determine the monthly loading to the septic tank for each home. Monthly nitrogen loading was divided by the number of people in the home, thus providing the per-person loading of pollutants to the septic tank. Mean nitrogen loading to tanks was calculated and compared to other published estimates (Buetow 2002; and US EPA 2002). The watershed scale loading of nitrogen (N) to tanks was calculated for the Newport River watershed (within the White Oak River Basin) by multiplying the number of people using septic systems by the mean nitrogen loading per person.

Nitrogen loading to the septic tank should be higher than loading to the shallow groundwater system, because of pollutant removal mechanisms in the tank and unsaturated zone between the trench bottom and water table. Potential N reduction and transformation mechanisms such as adsorption, cation exchange, plant and microbial uptake, ammonification, nitrification, and denitrification processes can result in load reductions to shallow groundwater in comparison to soil loading. To calculate N loadings to shallow groundwater, the additional information required includes mean groundwater N concentrations adjacent to systems, soil types and groundwater hydrological properties including the soil hydraulic conductivity, hydraulic gradient, and groundwater flow direction.

Mean groundwater DIN and TDN concentrations for each site was calculated from monthly water quality sampling and by taking the average DIN and TDN concentrations of the shallow and deep wells. To determine the various hydraulic properties, the monitoring wells at the 16 sites were located and plotted on maps using Global Positioning Systems (GPS) and their relative elevations were surveyed using laser levels. The relative elevation data was coupled with the water level depth information to calculate the relative elevation of the water table at each well. With the elevation and GPS spatial data, three-point contouring (Heath 1998) was used to determine groundwater flow direction and to determine the hydraulic gradient. Slug tests (Bouwer and Rice 1976) were performed to calculate hydraulic conductivity at each site.

Darcy's law ($Q = KA*dh/dl$) relates groundwater discharge (Q) to the hydraulic conductivity (K), the aquifer cross-sectional area (A) and the hydraulic gradient (dh/dl) and was used to calculate the septic system plume discharge. Groundwater hydraulic gradients, hydraulic conductivity measurements, plume width and depth information, and mean nitrogen concentrations were used to estimate loading rates of nitrogen to shallow groundwater at each site. For each site, plume width was calculated based on the configuration of septic system drainfield and the groundwater flow direction (Figure 4.3). Plume depth was based on the water level and water quality data obtained from the deep and shallow monitoring wells (150 cm total screen interval) adjacent to the system (Figure 4.3). The groundwater discharge multiplied by the mean DIN and TDN concentrations (in the groundwater) was used to determine loading to the groundwater for each system. System loading to the groundwater was divided by the number of people using each system, thus providing a per-person nitrogen loading rate to groundwater. The mean nitrogen loading to shallow groundwater was calculated for each soil group by averaging the DIN and TDN loadings for each system in soil groups I, II and III.

4.3.3 Septic System Nitrogen Loading to Shallow Groundwater in the Newport River Watershed

For the Newport River watershed (Figure 4.2) the N loading to shallow groundwater was estimated using mean nitrogen loading per soil group for the total population using septic systems installed in soil groups I, II, and III. The population within the Newport River watershed was determined using demographic information from the North Carolina Office of State Budget and Management (2009) and Carteret County Economic Development Council (2009) for the Towns and Cities of Morehead, Beaufort, Newport, Pine Knoll Shores, Indian Beach, Emerald Isle, Bogue, Atlantic Beach, Cape Carteret and Cedar Point and the unincorporated areas. Centralized wastewater treatment plants serve most of the municipal populations of Newport, Beaufort and Morehead City (personal communication with Newport Planning Office, Carteret County Health Department, Town of Beaufort and Morehead City Administration, 2009), while an estimated 26% of the population in Atlantic Beach, Pine Knoll Shores, and Indian Beach have centralized sewer service via package plants (Dickinson 2007). The remaining watershed residents use septic systems. In 1990, the last year septic system data was collected during the US Census, 68% of Carteret County residences used septic systems for wastewater treatment and disposal (North Carolina National Estuarine Research Reserve 2001).

The geographic boundaries of the sewer/package plant service areas were delineated using maps and information provided by town officials (personal communication, Newport Planning Office, Carteret County Health Department, Town of Beaufort and Morehead City Town Manager 2009) and engineering reports (Dickson 2007). The number of people serviced by these centralized systems was subtracted from the total population of the watershed to yield the number of people using septic systems. By grouping adjacent towns using zip code population data and subtracting out the municipal populations of each using sewer services, an estimate of septic system use for the group of towns was calculated. Soil and demographic data from Newport, Bogue, Morehead City and Beaufort were pooled into one association, data for Atlantic Beach, Indian Beach, Pine Knoll Shores and Emerald Isle comprised another association and Cape Carteret and Cedar Point made the last association. Once the population statistics and geographic boundaries of the sewer service areas were established, aerial photographs and web soil surveys were used to determine the location of developments using septic systems (outside sewer service areas).

4.3.4 Delineation of Areas Served by Septic Systems

Soil surveys are land use planning tools published and digitized by the United States Department of Agriculture (USDA). Soil surveys include aerial photographs of counties and soil series maps. Soil series and soil boundaries are provided in the web soil survey as a data layer that is overlain on aerial photographs (USDA 2009).The web soil survey was used to create “areas of interest” for developments that used septic systems. Areas of interest (AOI) were produced for each town. The boundaries of municipal areas serviced by sewer, agricultural, and forestry land uses, and sparse residential developments were excluded from the (AOI) procedure. A spreadsheet was produced with the creation of each AOI that included the acreage and percentage of each soil series within the AOI and the total area per AOI.

Each soil series was catalogued as a group I, II, or III depending on the soil texture characteristics of the series at the 45 to 120 cm depth range (soil group depends on the textural group beneath the trench bottom and most systems are installed between 45-90 cm deep). Therefore for each town and association, the percentage of land area used for septic systems in the group I, II, and III soils was determined. The total population of the town/area using septic systems was then multiplied by the ratio of land in soil group I, II, and III for each area to estimate the number of people using septic systems in the three soil groups. With an estimate of the population using septic systems in soil groups I, II, and III and the mean nitrogen loading rate to the groundwater for each soil group, an estimate of the loading of nitrogen to the groundwater in the Newport River watershed was calculated. A comparison of loading to the soils (from tank samples) and to the groundwater system (from groundwater samples and estimates) for each soil group (I, II, and III) was used to determine the effectiveness of different soil types at treating wastewater.

4.4 Results and Discussion

4.4.1 Tank and Groundwater Nitrogen Loading

Mean DIN tank loading was similar for systems in group I, II, and III soils ranging from 2.1 kg/person/yr for systems in group III soils to 2.7 kg/person/yr for systems in group II soils. Mean TDN loading to tanks in soil groups I-III was higher and more variable (than DIN loading), but followed the same trends as DIN loading, with systems in group III soils having the lowest loading rate at 6.9 kg/person/yr and systems in group II soils having the highest loading rate of 12.6 kg/person/yr (Table 4.2). The TDN loading was higher than DIN loading due to the presence of organic nitrogen in the septic tanks. While mean tank DIN concentrations ranged from 25.8 to 32.3 mg/L, mean tank TDN ranged from 83.3 to 151.8 mg/L (Table 4.2). The mean tank TDN concentrations for this study were similar to those measured by Ptacek (1998) (98 mg/L) but were higher than those reported by Buetow (2002) (18.9-54 mg/L) and the US EPA (2002) (26-75 mg/L). Mean tank DIN concentrations for the study sites (25.8 -32.2 mg/L) were similar to those reported previously by Buetow (2002), Cogger et al. (1988) and Waller et al. (1987), with ranges and means of (16-48.3 mg/L), 28 mg/L, and 26.2 mg/L, respectively.

Septic system DIN and TDN loading to groundwater was less than nitrogen loading to the tanks due to septic system treatment processes. The mean groundwater DIN loading for septic systems in group I soils were the highest (2 kg/person/yr), followed by group II soils (0.7 kg/person/yr), and group III soils (0.2 kg/person/yr) (Table 4.3). The TDN loading from septic systems to the groundwater were also highest for group I soils (4.0 kg/person/yr), followed by group II soils (1.9 kg/person/yr), and group III soils (0.3 kg/person/yr) (Table 4.3). The TDN loading to the groundwater in group III soils were lower than in group I and II soils due to lower mean groundwater TDN concentrations (3.4 mg/L for group III, 34.3 and 32 mg/L for group I and II, respectively) (Table 4.3). The TDN loading was much higher than DIN loading due to the predominance of organic nitrogen in groundwater adjacent to many systems. Prior studies (Robertson et al. 1991; Ptacek 1998; and Buetow 2002) showed the potential for dissolved inorganic nitrogen species (NO_3^--N and NH_4^+-N) to migrate at high concentrations away from septic systems, but research is needed on the fate of dissolved organic nitrogen discharged by septic systems.

Research has shown that soils with relatively larger percentages of silt and clay provide better treatment of wastewater pollutants due to higher cation exchange capacities and more potential for denitrification (Carrol et al. 2004; Karathanasis et al. 2006). The group III soils had the largest mean effective cation exchange capacity (group III-7.4, group II- 2.9, and group I-3.1 cmol/kg) and lowest mean hydraulic conductivity (group III- 0.19, group II-0.34, and group I-3.34 m/day) of the soil groups, indicating longer residence times for wastewater in the subsoil and more cation exchange sites for ammonium adsorption. Group III soils were the most efficient at reducing DIN and TDN loads to the groundwater (91 and 96%), followed by group II soils (74 and 85%) and group I soils (17 and 56%) (Table 4.4). These data suggest that watersheds using septic systems with more clayey soils may have better shallow groundwater quality than watersheds with sandier soils.

4.4.2 Demographic and Soil Group Data for the Newport Watershed

Using web soil surveys and sewer service boundary information provided by local government officials, developed areas using septic systems within the Newport watershed were delineated and the acreage and percentage of land in group I, II and III soils was calculated (Figures 4.4-4.15 and Tables 4.5-4.16). The towns/cities of Morehead City, Newport, Bogue and Beaufort were evaluated as an association (MH) by combining the demographic data using septic systems with the percent population using septic systems in soil groups I, II and III and the mean DIN and TDN per person loading to tank and groundwater. The other associations include Atlantic Beach, Indian Beach, Pine Knoll Shores and Emerald Isle on the barrier island (BI), and the Cape Carteret and Cedar Point association (CC). The MH association contained most of the watershed's septic systems using population (22,169 of 30,277 people) and the predominate soil group was group I (61.8%) followed by group III (20.5%) and group II (17.7%) (Tables 4.15, 4.16, and Figure 4.15). For the BI association the total estimated population using septic systems was 6958, with 100% of the systems installed in group I soils (Tables 4.15, 4.16, and Figure 4.15). The CC association had 1150 people with 97.1% of the population using septic systems in group I soils, 2.4% in group II soils and 0.5% in group III soils (Tables 4.15, 4.16, and Figure 4.15). For each association the DIN and TDN loading was highest for systems in group I soils and lowest for systems in group III soils (Tables 4.15, 4.16). For the entire watershed, the annual DIN and TDN loadings to septic tanks were 72,766 kg and 277,155 kg, respectively (Table 4.16). The annual DIN loading to groundwater was an estimated 47,226 kg, and the annual TDN loading was 95,973 kg (Table 4.15). Therefore septic systems did reduce watershed DIN and TDN loadings by 35 and 65% respectively from the source.

Regions with sandy soils such as the Outer Banks and Sand Hills are most likely to experience high nitrogen loading rates to groundwater from septic systems.

Communities developed on soils with higher percentages of silt and clay (group III and IV) are less likely to have high groundwater nitrogen concentrations and loadings from septic systems. In North Carolina, the percentage of areas with sandy soils decreases as you travel from the coast to the mountains (Daniels et al. 1999), with some of the barrier islands having essentially 100% of the buildable land in soil group I (>88% sand fraction). Piedmont and Mountain soils typically have relatively higher percentages of silt and clay (group III and IV soils) and therefore are less likely to experience high nitrogen loadings from septic systems to the groundwater, but more research is needed for confirmation.

Also of note, Carteret County is a tourist attraction and while the year round population of the County is just over 63,000 (NC Office of State Budget and Management 2008), during the summer the population can more than double as people visit the beach communities (Carteret County Economic Development 2008). Therefore, it is possible in coastal areas that wastewater loads processed by septic systems and entering groundwater also more than double during the tourism months, if the ratio of housing units served by septic systems used by tourists is equivalent to the year round population septic/sewer ratio.

Currently, nitrogen contributions to ground and surface waters from septic systems are not considered in watershed-scale nutrient management strategies in North Carolina. Regulatory emphasis for non-point sources of pollution has focused on agriculture and stormwater runoff, with growing concern that atmospheric deposition (Whitall et al. 2003) can be significant as well. However, the TDN loading rates from septic systems to groundwater for group I and II soils were 11.5 and 5.7 kg/household/yr. With five homes per ha (1/2 acre lots), the total septic system loadings rates would be 28.5 to 57.5 kg/ha, comparable to the annual loading rates used by regulatory agencies for cropland (37.5 kg/ha) in the same County (Neuse Basin Oversight Committee 2009). Therefore, if land use changes from row crop agriculture to residential development with lots less than 0.4 ha (1 acre), total nitrogen loadings to water resources may not be reduced. Atmospheric deposition rates for Eastern North Carolina typically range from 8 to 12 kg/ ha/yr (Whitall et al. 2003) comparable to the septic system loading of TDN to groundwater in sandy soils from 1 person. As more land is developed, the contributions from septic systems will increase.

4.6 Conclusions

Soil type is an important controlling factor for septic system nitrogen loading to groundwater, with finer textured soils providing better treatment efficiency. There was an order of magnitude difference in nitrogen loading when comparing systems in group I and II soils to the finer textured group III soils. Watersheds with greater percentages of group III soils should have lower risks for shallow groundwater N contamination. Currently septic systems in North Carolina are designed based on the hydraulic conductivity of the soil, with sandy soils assigned higher loading rates and smaller drainfield areas. This methodology allows for relatively high density development in soil groups (I and II) that are the least effective at reducing nitrogen loading to groundwater. Also, many of the sandier soils are adjacent to estuaries and rivers that have experienced problems with excess nutrient loadings and eutrophication. At the watershed scale the potential for substantial groundwater transport of septic system wastewater nitrogen to nearby surface waters is significant and comparable to the loading rates of agriculture and greater than rates from atmospheric deposition on a unit area basis. Vegetated and riparian buffers can help reduce the contribution of groundwater transported nitrogen to surface waters in geomorphic settings where the water table is within the root zone of buffer vegetation. However, vegetated buffers are not required in all coastal river basins, and drainage ditches and canals may short circuit the groundwater transport of septic system impacted groundwater through existing buffers. Also, if nitrogen in the groundwater flowing through the root zones of buffer vegetation is in the organic or NH_4^+-N form, then nitrogen removal via denitrification will be limited, because the denitrification process requires nitrogen in the NO_3^- species (Sylvia et al. 1999). While most previous work involving groundwater nitrogen transport has focused on DIN, a recent study by Kroeger et al. (2006) suggests that a substantial portion of anthropogenic nitrogen introduced to watersheds is exported as DON. Therefore, septic system contributions of DON and NH_4^+-N could be significant.

The potential nitrogen loading from septic systems to surface waters should be accounted for in future water quality improvement initiatives and regulations. It should also be noted that human wastewater treatment via centralized sewer and package plants also can contribute significant nitrogen loads to surface and groundwater waters, but these technologies are monitored more closely than septic systems. More work is needed in comparing the nitrogen loads and species, from different wastewater treatment systems to ground and surface water.

Table 4.1 Soil and site information including soil series name, particle size distribution, NC Department of Environment and Natural Resources soil group information, effective cation exchange capacity, pH, humic matter percentage, septic system type, installation date and location. Site location of NWP is Newport, AB is Atlantic Beach, and PKS is Pine Knoll Shores, NC. Con. is a conventional system with 2 or more 90 cm wide, drainfield trenches, bed systems have one trench often 180 cm wide or greater. Effective cation exchange capacity (ECEC) is a measure of the capacity to absorb and exchange cations in reversible reactions. Humic matter percentage (HM) is the amount of complex organic, rather than mineral composition.

Soil / Site	USDA Soil Series	System Install Date	Site Location City/Town	System Type	% Sand	% Silt	% Clay	ECEC (cmol/kg)	pH	HM%
GI-A	Mandarin	2006	NWP	Bed	90.3	4.6	5.1	5.6	4.7	4.8
GI-B	Baymeade	2005	NWP	Bed	94.6	2	3.4	1.2	5.3	0.2
GI-C	Baymeade	2006	NWP	Con.	90.7	3.9	5.3	3.2	6.1	0.7
GI-D	Fripp	1991	AB	Con.	98	0.3	1.7	2.3	4.8	0.6
GI-E	Fripp	1996	PKS	Bed	98.3	0	1.7	1.5	5.8	0
GI-F	Newhan	1979	PKS	Bed	97.2	0.3	2.5	2	6.2	0.1
GI-G	Newhan	1977	PKS	Con.	98	0.3	1.7	5.6	7.6	0.2
GI-H	Newhan	1977	PKS	Con.	97.2	1.2	1.7	3.1	6.3	0.3
GI-Avg		1992			95.5	1.6	2.9	3.1	5.9	0.9
GII-A	Goldsboro	1987	NWP	Con.	74.2	9.6	16.2	3.2	5.6	0.2
GII-B	Goldsboro	1985	NWP	Con.	80.7	10.1	9.2	3.5	6.6	1.9
GII-C	Goldsboro	1999	NWP	Con.	75.4	11.1	13.5	2.1	5.8	0.6
GII-D	Goldsboro	1998	NWP	Con.	79	7.5	13.4	2.8	5.5	0.5
Avg		1990			77.3	9.6	13.1	2.9	5.9	0.8
GIII-A	Altavista	1995	Smyrna	Con.	66.8	12.3	20.9	7	6.8	0.1
GIII-B	Altavista	1986	Smyrna	Con.	71.2	5.2	23.6	7.7	7.8	0
GIII-C	Altavista	1994	Smyrna	Con.	67	8.2	24.7	7.2	7.6	0
GIII-D	Altavista	1991	Smyrna	Con.	64.9	9.7	25.4	7.5	6.9	0.1
Avg		1992			67.5	8.9	23.7	7.4	7.3	0

Table 4.2 Total dissolved nitrogen (TDN= TKN + NO_3-N) and dissolved inorganic nitrogen (DIN = NH_4-N + NO_3-N) loading to the septic tank for systems in soil groups I, II and III. Loadings calculated using mean nitrogen concentrations and mean estimated water use (EPA 2002).

System	Tank DIN (mg/L)	Tank TN (mg/L)	Water Use (L/day)	DIN Loading Kg / yr	DIN Loading Kg/person/Yr	TDN Loading Kg / yr	TDN Loading Kg/person/Yr
GI-A	31.7	134.1	454	5.3	2.6	22.2	11.1
GI-B	29.5	91.9	907	9.8	2.4	30.4	7.6
GI-D	32.2	141.2	680	8	2.7	35.1	11.7
GI-F	22.9	67	454	3.8	1.9	11.1	5.6
GI-Avg	29.1	108.6	624	6.7	2.4	24.7	9.0
STDEV	4.3	35.2		2.7	0.4	10.5	2.9
GII-A	31.6	121.2	907	10.5	2.6	40.1	10.0
GII-C	33.9	182.3	454	5.6	2.8	30.2	15.1
GII-D	31.4		680	7.8	2.6		
GII-Avg	32.3	151.8	680	8.0	2.7	35.2	12.6
STDEV	1.4	43.2		2.4	0.1	7.0	3.6
GIII-A	26.4	78.5	454	4.4	2.2	13.0	6.5
GIII-C	31	127.6	454	5.1	2.6	21.1	10.6
GIII-D	20	43.7	454	3.3	1.7	7.2	3.6
GIII-Avg	25.8	83.3	454	4.3	2.1	13.8	6.9
STDEV	5.5	42.2		0.9	0.5	7.0	3.5

Table 4.3 Dissolved inorganic nitrogen (DIN) and total dissolved nitrogen (TDN = TKN + NO_3-N) loading to the groundwater for septic systems installed in group I, II and III soils. Loadings calculated using Darcy's law and mean nitrogen concentrations adjacent to monitored systems. Plume area is the cross sectional area of surficial aquifer impacted by the septic system.

System	DIN (mg/L)	TDN (mg/L)	DH/DL	K(m/day)	n_e	Plume Area (m^2)	Plume Q L/day	DIN GW Loading Kg/yr	TDN GW Loading Kg/yr	DIN GW Loading Kg/person/yr	TDN GW Loading Kg/person/yr
GI-A	16.7	26.4	0.027	0.98	0.3	9.3	820	5	7.9	2.5	4
GI-B	27.9	82.3	0.027	2.47	0.3	5.6	1245	12.7	37.4	3.2	9.3
GI-C	10.3	22.2	0.035	1.01	0.3	8.4	990	3.7	8	1.9	4
GI-D	18.2	19.7	0.012	1.95	0.25	20.4	1909	12.7	13.7	4.2	4.6
GI-E	20	48.1	0.004	8.44	0.25	3.7	500	3.7	8.8	0.9	2.2
GI-F	14.8	24.5	0.034	1.37	0.25	5.6	1043	5.6	9.3	2.8	4.7
GI-G	2.8	42.1	0.002	5.7	0.25	7.8	356	0.4	5.6	0.2	2.8
GI-H	10.5	8.9	0.002	4.82	0.25	7.4	285	1.1	0.9	0.5	0.5
Avg	15.2	34.3	0.018	3.34	0.27	8.5	894	5.6	11.5	2	4
STDEV	7.5	23.0	0.014	2.71		5.1	535	4.7	11.1	1.4	2.6
GII-A	12.2	29.4	0.017	0.37	0.2	19	1055	3.5	8.5	0.9	2.1
GII-B	10.6	19.6	0.017	0.37	0.2	19	1160	3.1	5.6	0.8	1.4
GII-C	6.9	70.4	0.008	0.3	0.2	25.2	1058	0.8	7.9	0.4	3.9
GII-D	18.1	8.6	0.008	0.3	0.2	23.2	1740	1.8	0.9	0.6	0.3
Avg	12	32	0.013	0.34	0.2	21.6	1275	2.3	5.7	0.7	1.9
STDEV	4.7	27.0	0.005	0.04		3.1	328	1.2	3.5	0.2	1.5
GIII-A	3.1	2.6	0.006	0.15	0.1	27.9	209	0.3	0.2	0.1	0.1
GIII-B	2.4	2.1	0.006	0.18	0.1	40.9	221	0.4	0.3	0.2	0.2
GIII-C	4	3.4	0.007	0.09	0.1	23.2	104	0.2	0.2	0.1	0.1
GIII-D	2	5.6	0.015	0.34	0.1	19.5	1193	0.7	2	0.4	1
Avg	2.9	3.4	0.009	0.19	0.1	27.9	432	0.4	0.7	0.2	0.3
STDEV	0.9	1.5	0.004	0.11		9.3	510	0.2	0.9	0.1	0.4

Table. 4.4 Mean tank and groundwater dissolved inorganic (DIN) and total dissolved nitrogen (TDN) loading calculations and reductions for systems in soil groups from tank and groundwater samples were collected. Percent reduction based on the difference in nitrogen loading from the tank to the groundwater.

Soil Group	Tank DIN (Kg/person/yr)	Tank TDN (Kg/person/yr)	GW DIN (Kg/person/yr)	GW TDN (Kg/person/yr)	% DIN Reduction	% TDN Reduction
GI	2.4	9.0	2.0	4.0	17	56
GII	2.7	12.6	0.7	1.9	74	85
GIII	2.1	6.9	0.2	0.3	91	96

Table 4.5 Soil series, soil group and acreage information for areas of Morehead City, NC that use septic systems for wastewater treatment and disposal.

Morehead City Soil Series	Total (ha)	Total (acres)	Group
Altavista Loamy Fine Sand, 0-2% slopes (AaA)	29.8	74.6	3
Augusta Loamy Fine Sand (Ag)	33.9	84.8	3
Autryville Loamy Fine Sand, 0-6% slopes (AuB)	149.4	373.5	2
Arapahoe Fine Sandy Loam (Ap)	66.3	165.7	2
Baymeade Fine Sand, 1-6% slopes (ByB)	71.7	179.3	1
Carteret Sand, freq. flooded (CH)	9.4	23.5	1
Conetoe Loamy Fine Sand, 0-5% slopes (CnB)	33.1	82.8	1
Corolla-Urban Land Complex (Cu)	2.0	5	1
Goldsboro Loamy Fine Sand, 0-2% slopes (GoA)	0.8	2.1	2
Hobucken Mucky Fine Sandy Loam, freq. flooded (HB)	0.4	1.1	2
Kureb Sand, 0-6% slopes (KuB)	418.5	1046.3	1
Leon Sand (Ln)	584.1	1460.2	1
Lynchburg Fine Sandy Loam (Ly)	13.6	33.9	3
Masontown Mucky Loam, freq. flooded (MA)	18.0	45	2
Mandarin Sand (Mn)	22.6	56.6	1
Murville Mucky Sand (Mu)	235.7	589.3	1
Onslow Loamy Sand (On)	59.7	149.2	3
Pantego Fine Sandy Loam (Pa)	0.3	0.8	3
Rains Fine Sandy Loam (Ra)	44.3	110.8	3
Seabrook Fine Sand (Se)	130.0	324.9	1
State Loamy Fine Sand, 0-2% slopes (StA)	9.6	24	2
Tomotley Fine Sandy Loam (Tm)	43.4	108.4	3
Torhunta Mucky Fine Sandy Loam (To)	70.0	175.1	2
Wando Fine Sand, 0-6% slopes (WaB)	173.1	432.7	1
Total	2219.8	5549.6	

Table 4.6 Soil series, soil group and acreage information for areas of Newport, NC that use septic systems for wastewater treatment and disposal.

Newport Soil Series	Total (ha)	Total (acres)	Group
Autryville Loamy Fine Sand, 0-6% slopes (AuB)	11.3	28.3	2
Altavista Loamy Fine Sand, 0-2% slopes (AaA)	1.2	2.9	3
Augusta Loamy Fine Sand (Ag)	4.5	11.2	3
Arapahoe Fine Sandy Loam (Ap)	2.9	7.2	2
Baymeade Fine Sand, 1-6% slopes (ByB)	80.6	201.6	1
Conetoe Loamy Fine Sand, 0-5% slopes (CnB)	2.0	5.1	1
Goldsboro Loamy Fine Sand, 0-2% slopes (GoA)	101.8	254.6	2
Hobucken Mucky Fine Sandy Loam, freq. flooded (HB)	0.4	1	2
Kureb Sand, 0-6% slopes (KuB)	50.4	126.1	1
Leon Sand (Ln)	46.6	116.6	1
Lynchburg Fine Sandy Loam (Ly)	56.1	140.3	3
Masontown Mucky Loam, freq. flooded (MA)	15.2	38.1	2
Mandarin Sand (Mn)	20.2	50.6	1
Murville Mucky Sand (Mu)	11.9	29.8	1
Norfolk Loamy Fine Sand, 0-2% slopes (NoA)	13.8	34.5	3
Norfolk Loamy Fine Sand, 2-6% slopes (NoB)	20.2	50.6	3
Onslow Loamy Sand (On)	22.5	56.3	1
Pantego Fine Sandy Loam (Pa)	33.4	83.6	3
Rains Fine Sandy Loam (Ra)	103.9	259.8	3
Seabrook Fine Sand (Se)	3.9	9.8	1
Tomotley Fine Sandy Loam (Tm)	6.5	16.3	2
Torhunta Mucky Fine Sandy Loam (To)	62.2	155.5	2
Total	671.9	1679.8	

Table 4.7 Soil series, soil group and acreage information for areas of Beaufort, NC that use septic systems for wastewater treatment and disposal.

Beaufort Soil Series	Total (ha)	Total (acres)	Group
Altavista Loamy Fine Sand, 0-2% slopes (AaA)	103.8	259.4	3
Augusta Loamy Fine Sand (Ag)	81.3	203.2	3
Arapahoe Fine Sandy Loam (Ap)	87.6	219	2
Baymeade Fine Sand, 1-6% slopes (ByB)	8.1	20.3	1
Carteret Sand, freq. flooded (CH)	3.4	8.4	1
Conetoe Loamy Fine Sand, 0-5% slopes (CnB)	4.6	11.5	2
Corolla_Urban Land Complex (Cu)	1.9	4.8	3
State Loamy Fine Sand, 0-2% slopes (StA)	49.3	123.2	2
Deloss Fine Sandy Loam (De)	16.5	41.2	3
Hobucken Mucky Fine Sandy Loam, freq. flooded (HB)	3.2	8.1	2
Leon Sand (Ln)	42.3	105.7	1
Wando Fine Sand, 0-6% slopes (WaB)	6.8	16.9	1
Tomotley Fine Sandy Loam (Tm)	56.6	141.5	3
Totals	465.3	1163.2	

Table 4.8 Soil series, soil group and acreage information for areas of Bogue, NC that use septic systems for wastewater treatment and disposal.

Bogue Soil Series	Total (ha)	Total (acres)	Group
Autryville Loamy Fine Sand, 0-6% slopes (AuB)	1.8	4.6	2
Kureb Sand, 0-6% slopes (KuB)	129.4	323.6	1
Arapahoe Fine Sandy Loam (Ap)	22.6	56.5	2
Carteret Sand, freq. flooded (CH)	0.6	1.4	1
Leon Sand (Ln)	68.1	170.3	1
Mandarin Sand (Mn)	0.2	0.4	1
Masontown Mucky Loam, freq. flooded (MA)	4.5	11.2	2
Murville Mucky Sand (Mu)	10.0	25	1
Seabrook Fine Sand (Se)	63.5	158.7	1
Wando Fine Sand, 0-6% slopes (WaB)	177.6	444	1
Total	478.3	1195.7	

Table 4.9 Soil series, soil group and acreage information for areas of Atlantic Beach, NC that use septic systems for wastewater treatment and disposal.

Atlantic Beach Soil Series	Total (ha)	Total (acres)	Soil Group
Corolla Fine Sand (Co)	9.5	23.8	1
Fripp Fine Sand, 2-30% slopes (Fr)	31.2	77.9	1
Newhan-Corolla Complex, 0-30% slopes (Nc)	17.1	42.8	1
Duckston Fine Sand, freq. flooded (Du)	6.5	16.2	1
Newhan-Urban Land Complex, 0-8% slopes (Ne)	46.6	116.5	1
Newhan Fine Sand, 2-30% slopes (Nh)	28.7	71.7	1
Corolla-Urban Land Complex (Cu)	44.0	110.1	1
Carteret Sand, low, freq. flooded (CL)	0.0	0.1	1
Total	183.6	459.1	

Table 4.10 Soil series, soil group and acreage information for areas of Emerald Isle, NC that use septic systems for wastewater treatment and disposal.

Emerald Isle Soil Series	Total (ha)	Total (acres)	Soil Group
Corolla Fine Sand (Co)	45.2	113.1	1
Fripp Fine Sand, 2-30% slopes (Fr)	195.0	487.6	1
Newhan-Corolla Complex, 0-30% slopes (Nc)	163.1	407.7	1
Duckston Fine Sand, freq. flooded (Du)	41.4	103.6	1
Newhan-Urban Land Complex, 0-8% slopes (Ne)	9.9	24.8	1
Newhan Fine Sand, 2-30% slopes (Nh)	223.8	559.5	1
Corolla-Urban Land Complex (Cu)	1.4	3.5	1
Beaches, coastal (Be)*	0.1	0.3	1
Carteret Sand, freq. flooded (CH)	1.4	3.6	1
Carteret Sand, low, freq. flooded (CL)	0.2	0.4	1
Total	681.6	1704.1	

Table 4.11 Soil series, soil group and acreage information for areas of Indian Beach, NC that use septic systems for wastewater treatment and disposal.

Indian Beach Soil Series	Total (ha)	Total (acres)	Soil Group
Corolla Fine Sand (Co)	5.6	14	1
Fripp Fine Sand, 2-30% slopes (Fr)	2.4	6	1
Newhan-Corolla Complex, 0-30% slopes (Nc)	54.9	137.2	1
Duckston Fine Sand, freq. flooded (Du)	3.7	9.2	1
Newhan-Urban Land Complex, 0-8% slopes (Ne)	23.3	58.2	1
Newhan Fine Sand, 2-30% slopes (Nh)	42.6	106.6	1
Corolla-Urban Land Complex (Cu)	6.6	16.4	1
Carteret Sand, freq. flooded (CH)	0.9	2.3	1
Carteret Sand, low, freq. flooded (CL)	0.4	0.9	1
Total	140.3	350.8	

Table 4.12 Soil series, soil group and acreage information for areas of Pine Knoll Shores, NC that use septic systems for wastewater treatment and disposal.

Pine Knoll Shore Soil Series	Total (ha)	Total (acres)	Soil Group
Corolla Fine Sand (Co)	10.2	25.5	1
Beaches, coastal (Be)	1.5	3.8	1
Fripp Fine Sand, 2-30% slopes (Fr)	27.2	67.9	1
Newhan-Corolla Complex, 0-30% slopes (Nc)	268.4	670.9	1
Duckston Fine Sand, freq. flooded (Du)	2.5	6.3	1
Newhan-Urban Land Complex, 0-8% slopes (Ne)	5.4	13.4	1
Newhan Fine Sand, 2-30% slopes (Nh)	3.3	8.3	1
Carteret Sand, low, freq. flooded (CL)	0.6	1.5	1
Total	319.0	797.6	

Table 4.13 Soil series, soil group and acreage information for areas of Cape Carteret, NC that use septic systems for wastewater treatment and disposal.

Cape Carteret Soil Series	Total (ha)	Acres	Soil Group
Arapahoe Fine Sandy Loam (Ap)	1.8	4.4	1
Baymeade Fine Sand, 1-6% slopes (ByB)	54.7	136.7	1
Hobucken Mucky Fine Sandy Loam, freq. flooded (HB)	0.0	0.1	2
Kureb Sand, 0-6% slopes (KuB)	133.0	332.4	1
Leon Sand (Ln)	42.3	105.8	1
Murville Mucky Sand (Mu)	2.4	5.9	1
Seabrook Fine Sand (Se)	27.4	68.4	1
Wando Fine Sand, 0-6% slopes (WaB)	177.3	443.3	1
Total	438.8	1097	

Table 4.14 Soil series, soil group and acreage information for areas of Cedar Point, NC that use septic systems for wastewater treatment and disposal.

Cedar Point Soil Series	Total (ha)	Total (acres)	Group
Arapahoe Fine Sandy Loam (Ap)	14.7	36.7	2
Baymeade Fine Sand, 1-6% slopes (ByB)	56.9	142.3	1
Carteret Sand, freq. flooded (CH)	0.5	1.2	1
Corolla-Urban Land Complex (Cu)	8.4	21	1
Hobucken Mucky Fine Sandy Loam, freq. flooded (HB)	2.9	7.2	2
Kureb Sand, 0-6% slopes (KuB)	21.8	54.6	1
Leon Sand (Ln)	15.5	38.7	1
Newhan Fine Sand, dredged, 2-30% slopes (Nd)	0.8	2.1	1
Norfolk Loamy Fine Sand, 2-6% slopes (NoB)	3.2	8	3
Seabrook Fine Sand (Se)	41.6	104	1
Wando Fine Sand, 0-6% slopes (WaB)	124.3	310.8	1
Total	290.6	726.6	

Table 4.15 Estimated dissolved inorganic nitrogen (DIN) and total dissolved nitrogen (TDN) loading from septic systems to the groundwater in the Newport River watershed, North Carolina. Septic systems in group I and II soils had the highest loading rates, nearly an order of magnitude higher than systems in group III soils. The majority (76%) of the population in the Newport River watershed lives on group I soils.

Association	Population w/ Septic	Fraction Group I	Fraction Group II	Fraction Group III	DIN Loading to Groundwater Kg/yr				Kg/person
					Group I	Group II	Group III	Total Loading	
MH/NP/B/B	22169	0.618	0.177	0.205	27401	2747	909	31057	GI-2.0
AB/PKS/IB/EI	6958	1.000	0.000	0.000	13916	0	0	13916	GII-0.7
CC/CP	1150	0.971	0.024	0.004	2233	19	1	2254	GIII-0.2
Total	30277	0.76	0.11	0.13	43550	2766	910	47226	

Association	Population w/ Septic	Fraction Group I	Fraction Group II	Fraction Group III	TDN Loading to Groundwater Kg/yr				Kg/person
					Group I	Group II	Group III	Total Loading	
MH/NP/B/B	22169	0.618	0.177	0.205	54802	7455	1363	63621	GI- 4.0
AB/PKS/IB/EI	6958	1.000	0.000	0.000	27832	0	0	27832	GII-1.9
CC/CP	1150	0.971	0.024	0.004	4467	52	1	4520	GIII-0.3
Total	30277	0.76	0.11	0.13	87100	7508	1365	95973	

Table 4.16 Estimated dissolved inorganic nitrogen (DIN) and total dissolved nitrogen (TDN) loading to septic tanks in the Newport River watershed, North Carolina.

					DIN Loading to Tank Kg/yr				
	Population w/ Septic	Fraction Group I	Fraction Group II	Fraction Group III	Group I	Group II	Group III	Total Loading	Kg/person
MH/NP/B/B	22169	0.618	0.177	0.205	33033	10467	9720	53220	2.4
AB/PKS/IB/EI	6958	1.000	0.000	0.000	16769	0	0	16769	2.7
CC/CP	1150	0.971	0.024	0.004	2692	74	11	2777	2.1
Total	30277	0.76	0.11	0.13	52495	10541	9730	72766	

					TDN Loading to Tank Kg/yr				
	Population w/ Septic	Fraction Group I	Fraction Group II	Fraction Group III	Group I	Group II	Group III	Total Loading	Kg/person
MH/NP/B/B	22169	0.618	0.177	0.205	123304	49441	31358	203757	9.0
AB/PKS/IB/EI	6958	1.000	0.000	0.000	62622	0	0	62552	12.6
CC/CP	1150	0.971	0.024	0.004	10050	348	32	10427	6.9
Total	30277	0.76	0.11	0.13	195976	49789	31390	277155	

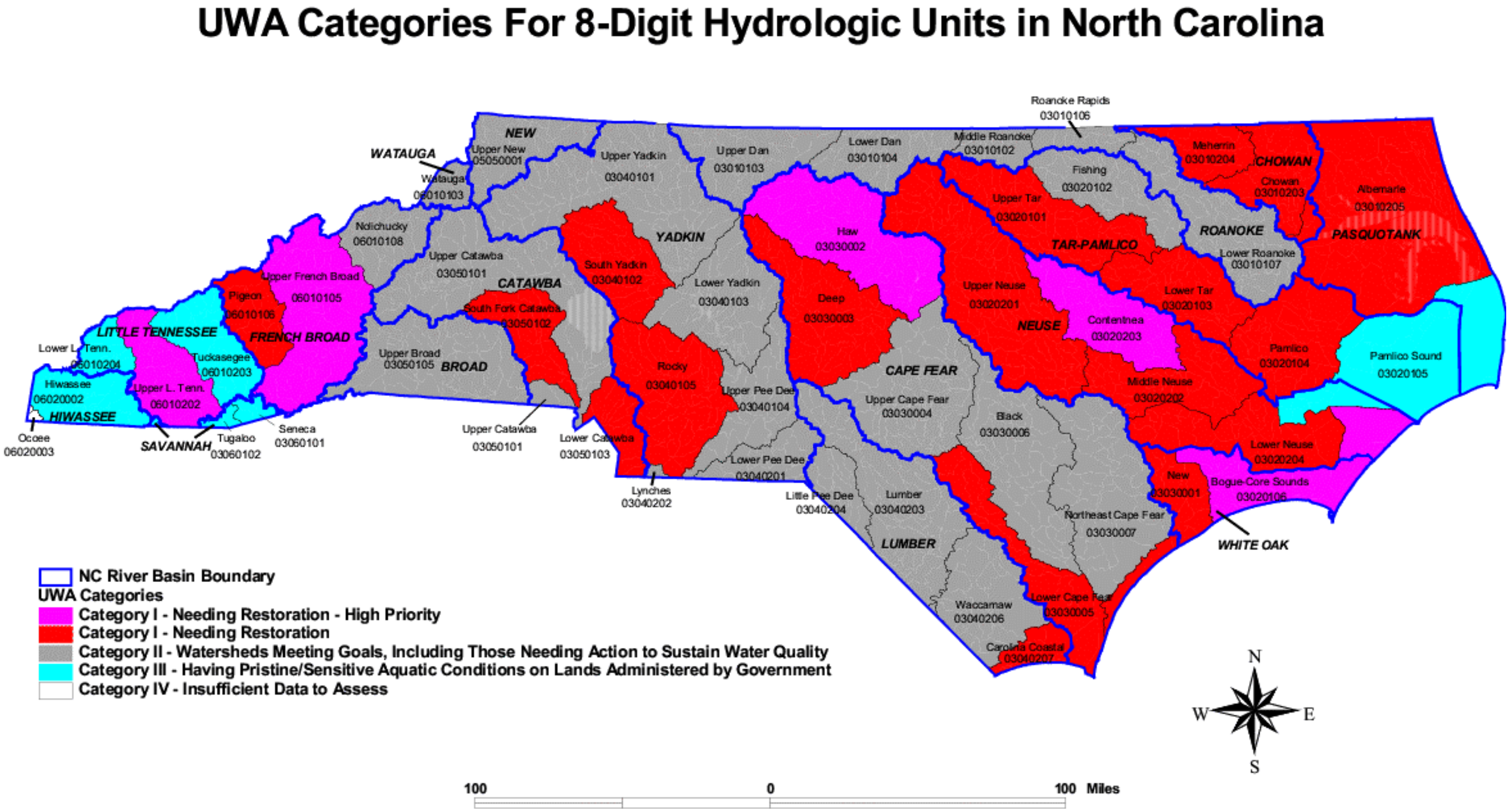


Figure 4.1 Unified Watershed Assessment categories (UWA) and major river basins in North Carolina, including the Neuse, Tar-Pamlico and White Oak River Basins located in eastern and coastal North Carolina. The Newport River watershed is a sub-unit of the White Oak River Basin. Map courtesy of the North Carolina Division of Water Quality Basinwide Planning Program (2007).

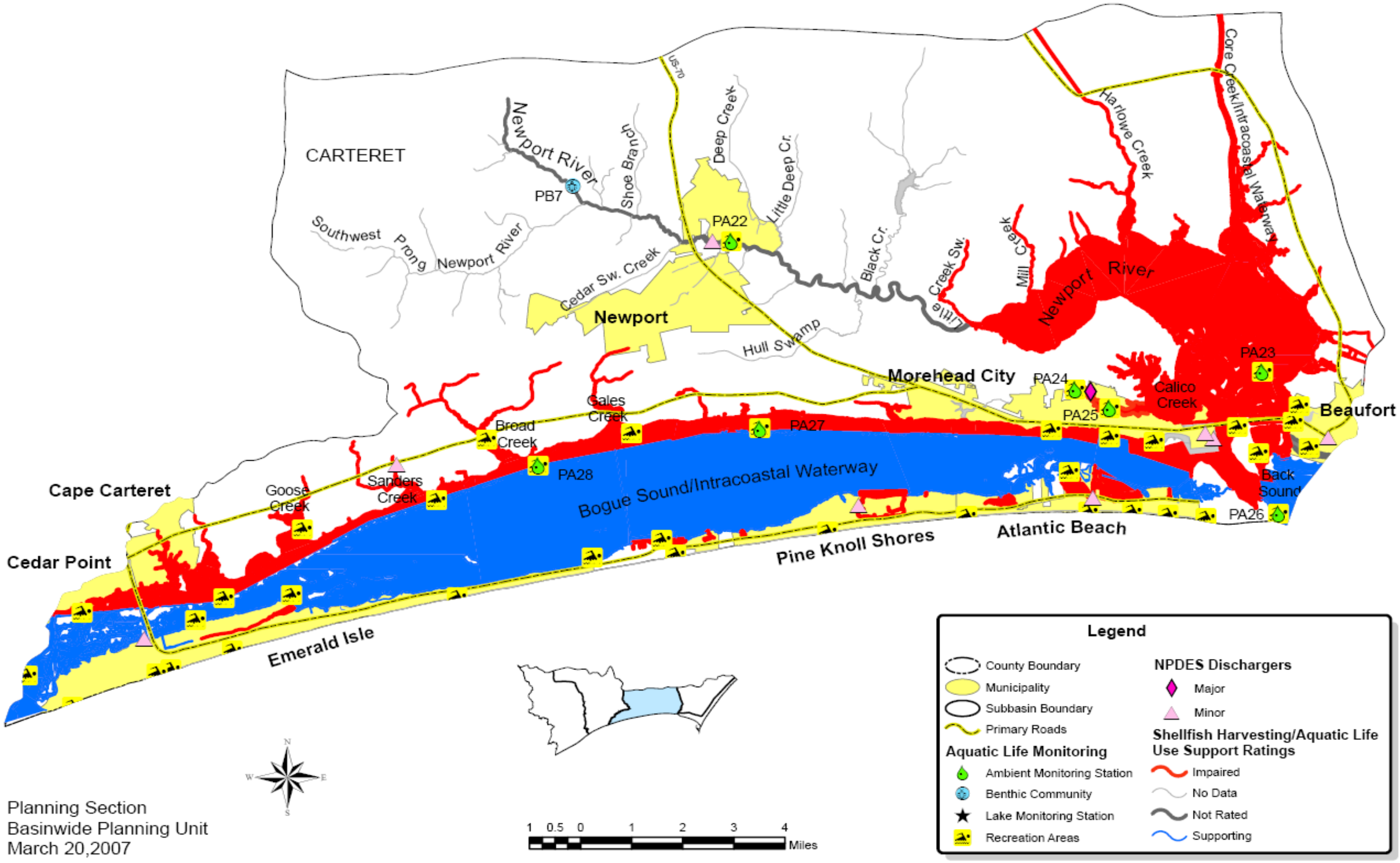


Figure 4.2 Newport River watershed located within the White Oak River Basin unified watershed assessment category in coastal North Carolina. Map courtesy of the North Carolina Division of Water Quality Basinwide Planning Program (2007).

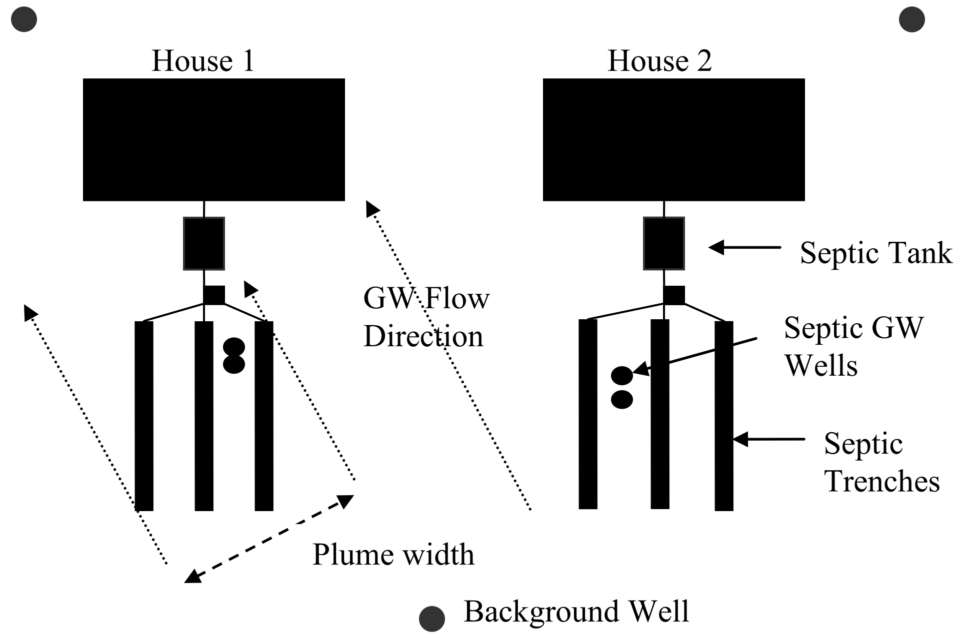


Figure 4.3A Plan-view of a groundwater monitoring design with a background well, nested septic groundwater monitoring wells between septic system trenches and groundwater flow direction wells at the corners of the lots. The plume width as indicated by the dashed arrows adjacent to the septic system of house 1, is determined by the configuration of the septic system and the direction of groundwater flow as indicated by the monitoring well data.

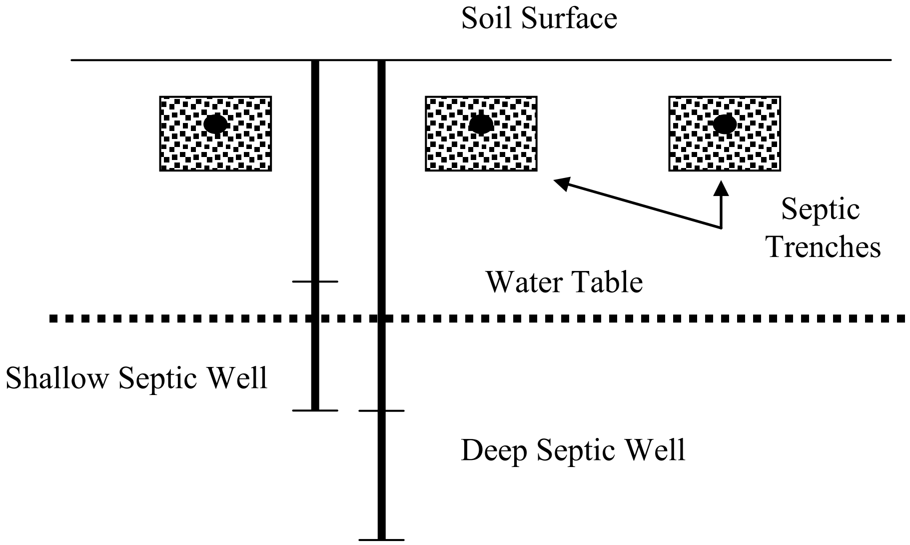


Figure 4.3B Cross-section view of septic system drainfield monitoring well design with deep and shallow wells and screen intervals. Each well had a 75 cm screen interval, so each monitoring nest covered approximately 150 cm.

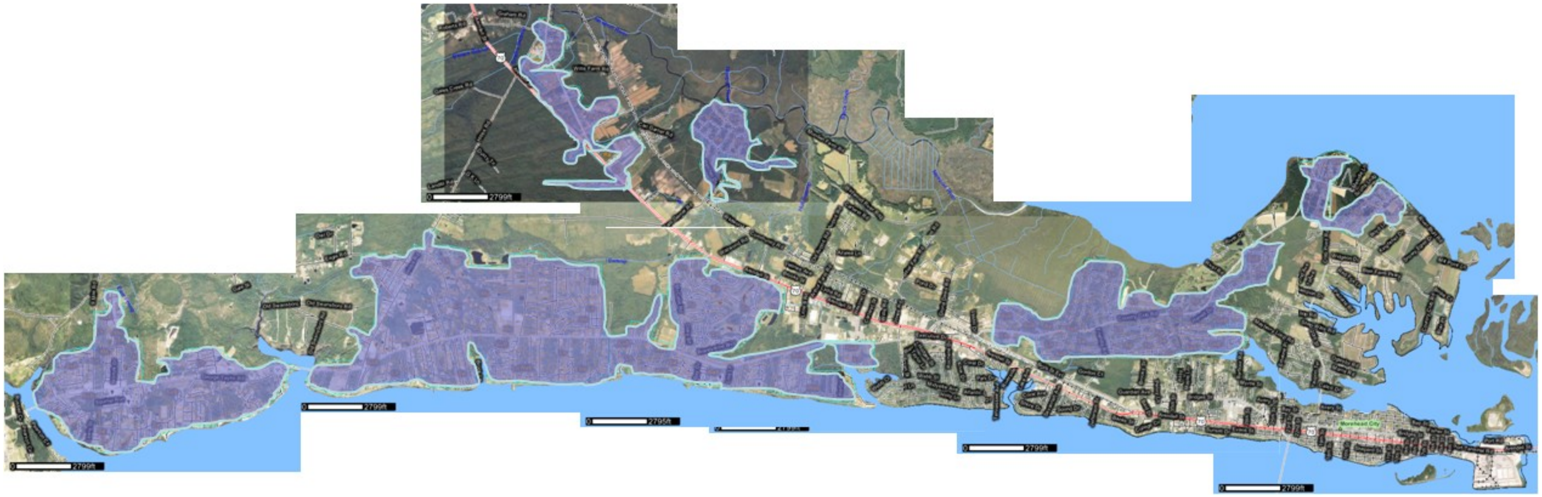


Figure 4.4 Soil survey map of Morehead City, NC with the shaded portions representing areas that use septic systems.

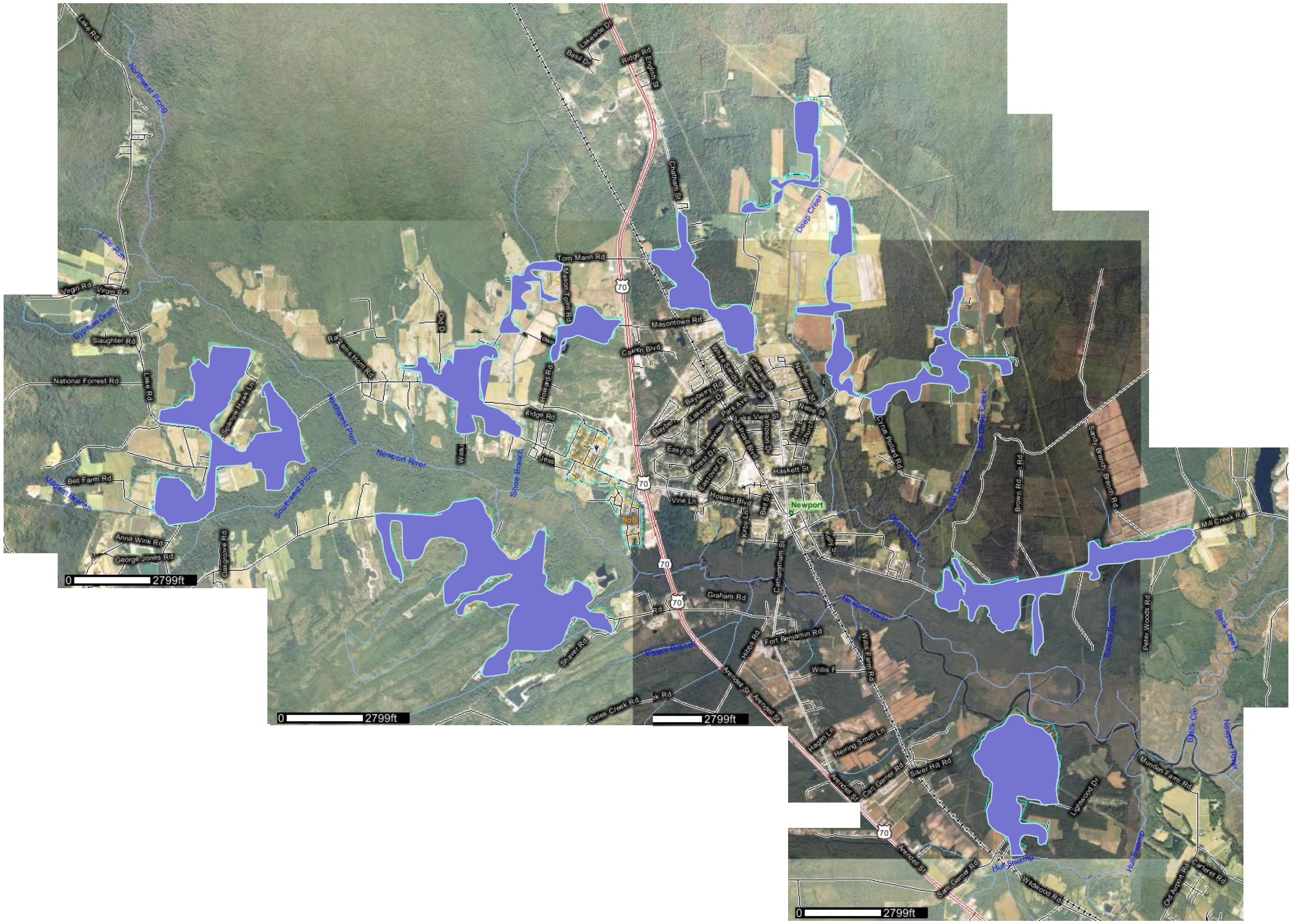


Figure 4.5 Soil survey map of Newport, NC with the shaded portions representing areas that use septic systems.

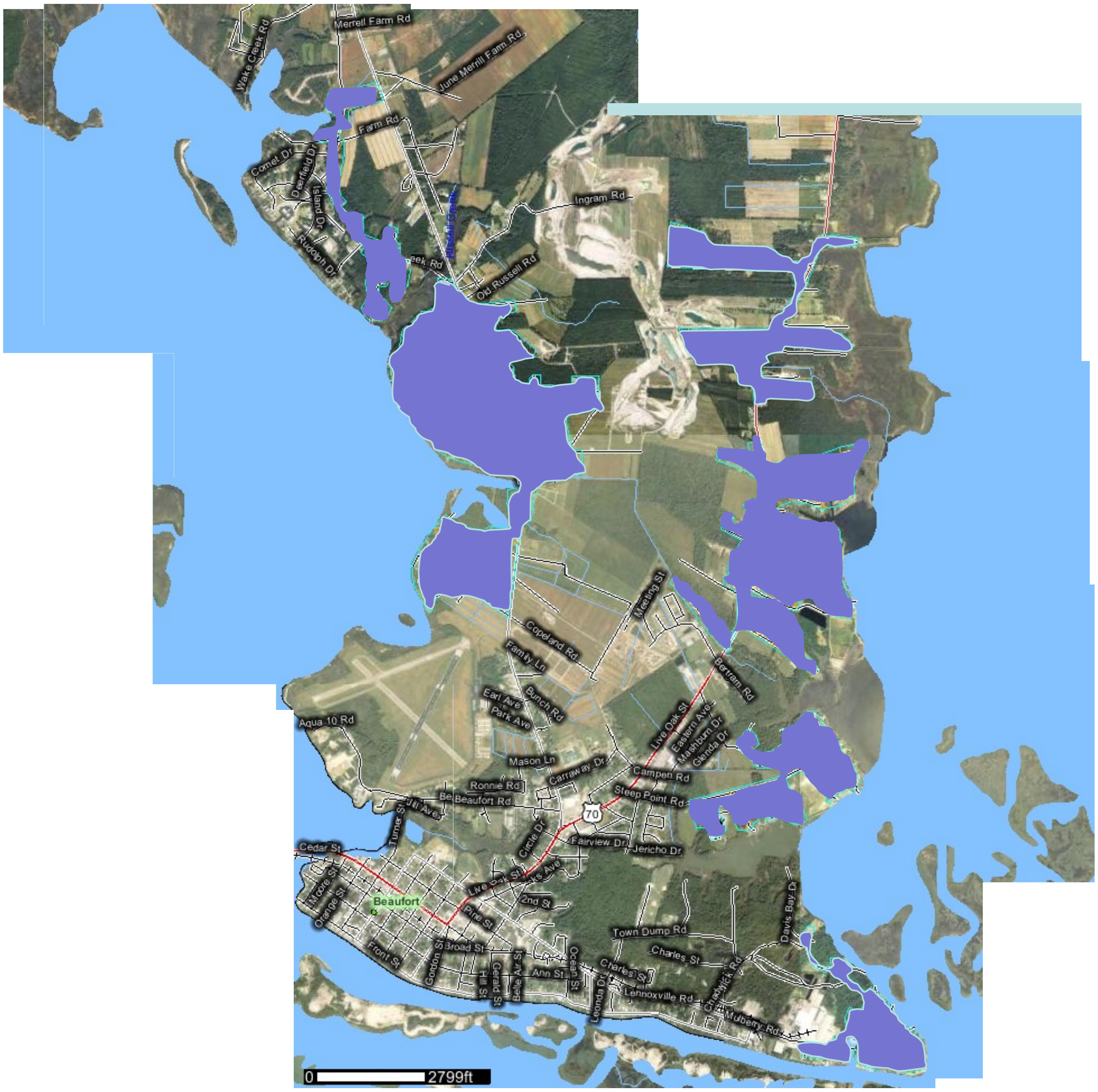


Figure 4.6 Soil survey map of Beaufort, NC with the shaded portions representing areas that use septic systems.

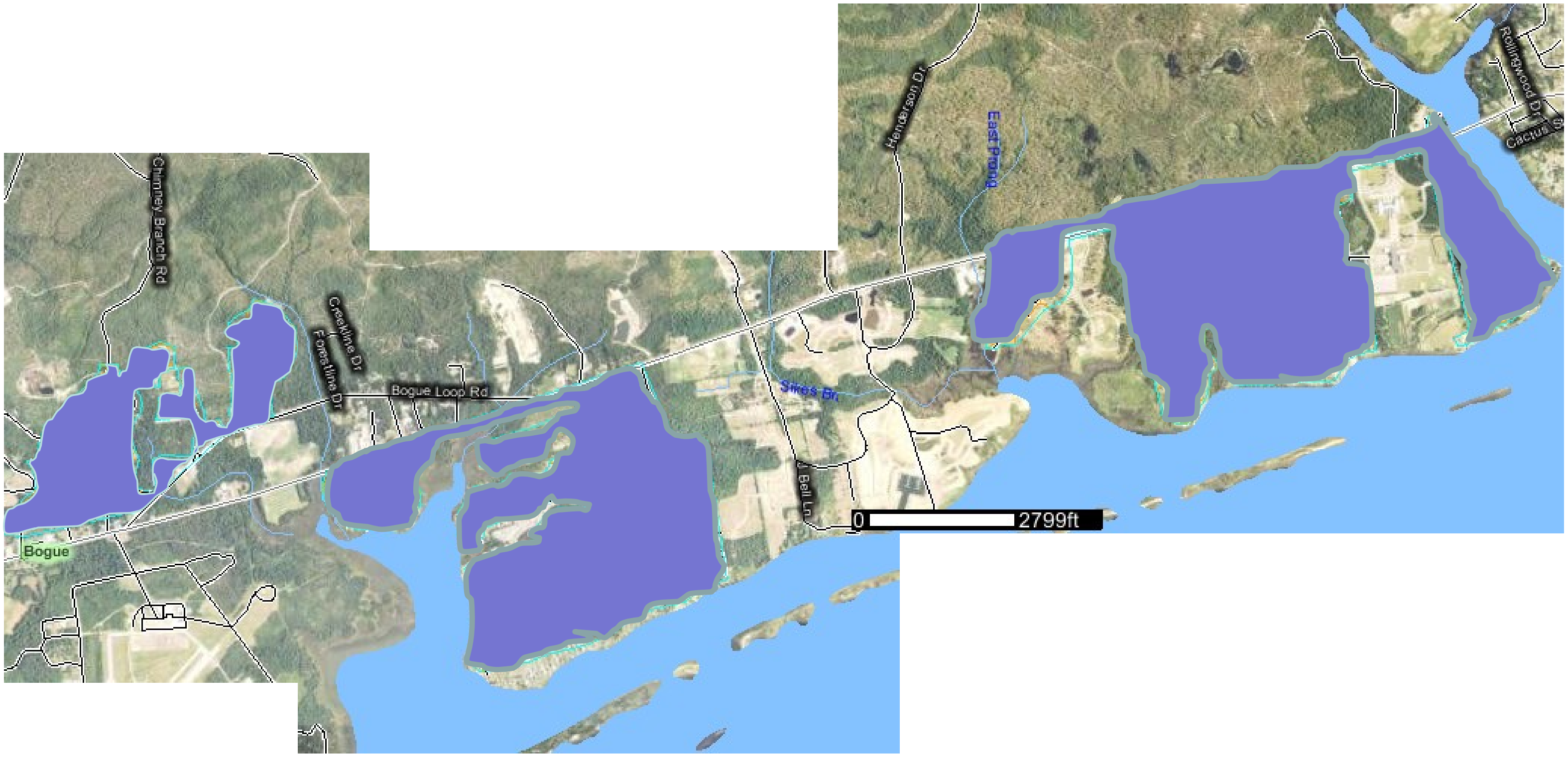


Figure 4.7 Soil survey map of Bogue, NC with the shaded portions representing areas that use septic systems.

Figure 4.8 Soil survey map of Atlantic Beach, NC with the shaded portions representing areas that use septic systems.

Figure 4.9 Soil survey map of Emerald Isle, NC with the shaded portions representing areas that use septic systems.

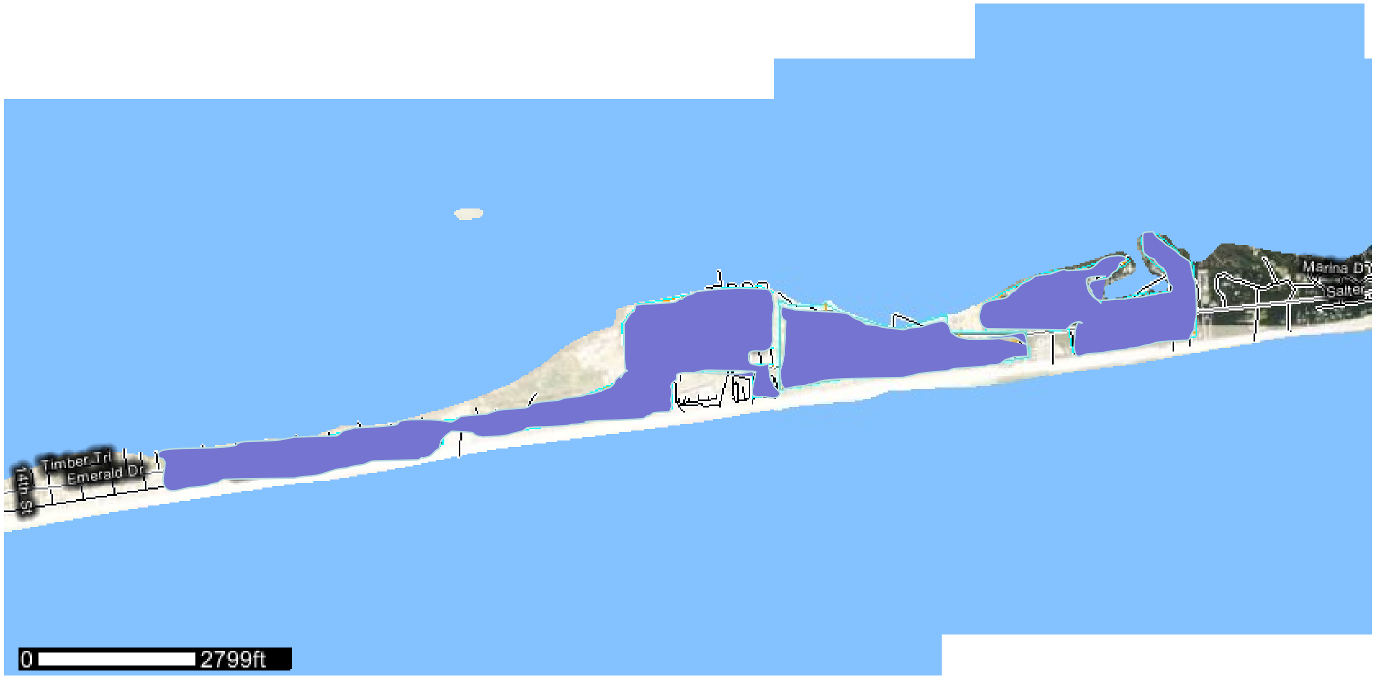


Figure 4.10 Soil survey map of Indian Beach, NC with the shaded portions representing areas that use septic systems.

Figure 4.11 Soil survey map of Pine Knoll Shores, NC with the shaded portions representing areas that use septic systems.

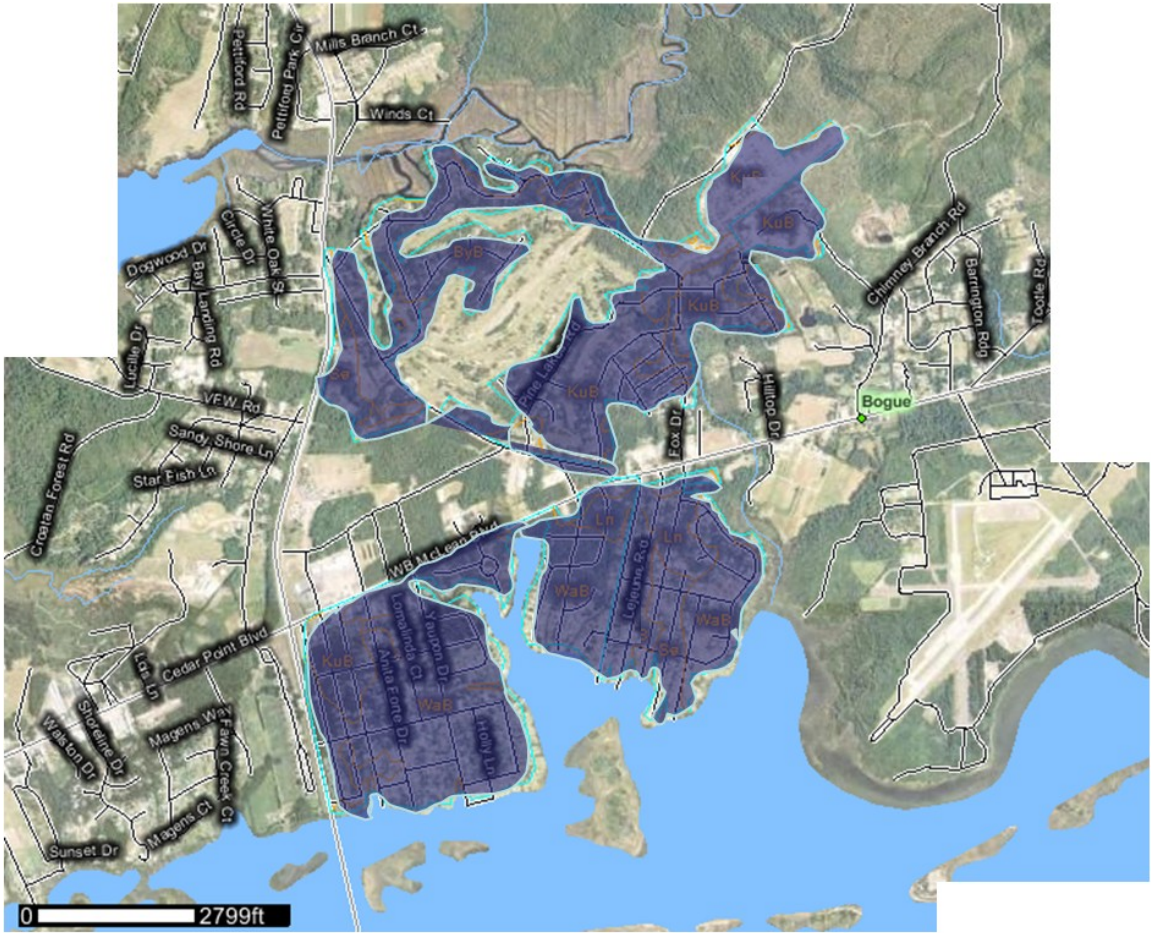


Figure 4.12 Web soil survey map of Cape Carteret, NC including areas that were developed and use septic systems for wastewater treatment and disposal (shaded). The symbols behind the polygons refer to the soil series.

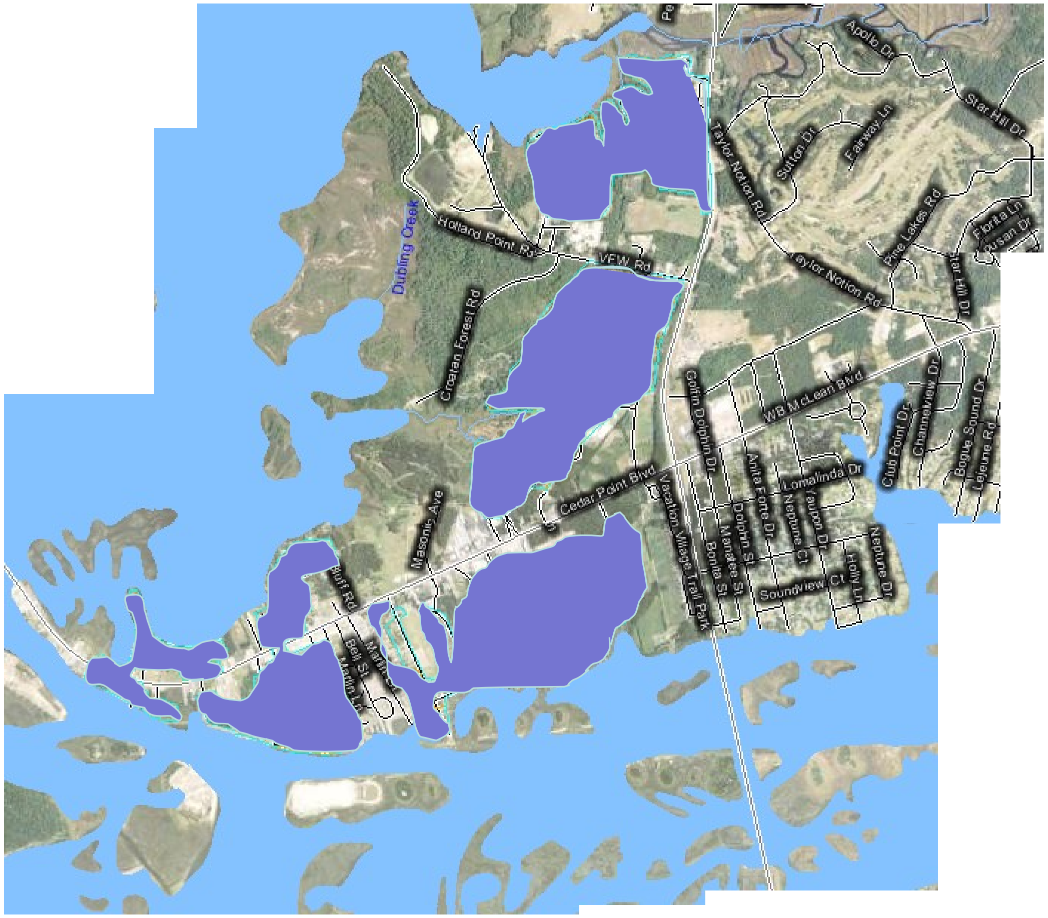


Figure 4.13 Soil survey map of Cedar Point, NC with the shaded portions representing areas that use septic systems.

CHAPTER 5: MANAGEMENT IMPLICATIONS

Nitrogen and bacteria in septic system wastewater are transformed and/or reduced in aerated soil beneath the septic system trench bottom. North Carolina regulations require 30-45 cm of separation distance from the trench bottom to seasonal high water table for systems installed in group II-IV and group I soils, respectively. Results showed that increasing the separation distance requirements from 30 and 45 cm to 60 cm, could improve water quality by increasing the likelihood of effluent nitrification and reduction of bacteria contributions to groundwater. Nitrification requires a source of NH_4^+-N, oxygen, and nitrifying microorganisms. Nitrification of wastewater is important for subsequent removal of nitrogen via denitrification in groundwater. Denitrification requires a source of nitrate, denitrifying microorganisms, an available carbon source and anaerobic conditions. If septic systems are installed with insufficient aerobic soil beneath the drainfield trenches, NH_4^+-N in septic effluent may not be converted to NO_3^--N, thus resulting in high NH_4^+-N concentrations in shallow groundwater and limiting denitrification because of relatively low NO_3^--N.

Increasing the separation distance to the seasonal high water table helps to increase the residence time of wastewater in aerated soil by providing longer flow paths for the wastewater. Many bacteria in wastewater are anaerobic or facultative bacteria that are at a competitive disadvantage when introduced to aerated soils. They (anaerobic bacteria) cannot compete well with microorganisms suited for aerobic conditions and thus may die due to lack of nutrients or food due to competition, or they can become prey to other microorganisms in the soil (Arnold et al 1996). Bacteria can also be filtered out of the wastewater as they pass through small soil pores during unsaturated flow conditions. Hence, aerobic soil is very important for wastewater bacteria reduction. Results showed that systems with 60 cm or more vertical separation distance to the seasonal high water table had significantly lower ($p \leq 0.10$) median and geometric mean groundwater NH_4^+-N and E. coli densities, 4 mg/L and 65 cfu/100 mL lower respectively, than systems with less than 60 cm of vertical separation. Data indicated that by increasing the required vertical separation distance to 60 cm, the groundwater quality would improve. Many southeastern US states including Florida, Georgia, and Virginia already require a 60 cm separation distance from septic system to seasonal high water table.

The current methodology in North Carolina for determining the depth to the seasonal high water table is finding the depth to low chroma (2 or 1) soil colors that occupy 2% or more of the soil. The current study has shown that, excluding soils formed from iron poor parent materials, over half the soils tested had seasonal high water tables closer to the surface (mean of 18 cm closer) than the soil color indicators predicted. Therefore, many systems (even if correctly designed and installed according to the current regulations) may not have 30-45 cm of vertical separation to the seasonal high water table. Increasing the separation distance requirements from chroma 2 or 1 colors by 15+ cm from the current standard could help ensure aerated conditions beneath septic systems for longer periods. For group II and III soils, a 15 cm increase in separation distance to chroma 2 colors would have reduced periods of water table flooding of the trench bottom by 67 and 75%, respectively and a 15 cm increase in separation distance for group I soils would have eliminated water table ponding of the trench completely, thus improving water quality. Therefore, water quality and water level data indicate that an increase in the vertical separation distance requirement from septic systems to seasonal high water table is warranted.

In addition to increasing the separation distance from drainfield to chroma 2 soil colors, requiring vegetated buffers along streams may increase the carbon supply in stream bank and bed sediments, thus increasing the likelihood of denitrification before septic influenced groundwater discharges into the buffered streams (Robertson et al. 1991; and Buetow 2002) or estuaries. Fifty foot (16 m) riparian buffers are currently required on intermittent and perennial streams in the Neuse and Tar Pamlico River Basins but not other river systems that empty into estuarine waters in North Carolina or along the estuarine coastline. These regulatory measures could improve septic system wastewater treatment efficiency and water quality and should be considered for implementation in future watershed scale nutrient reduction strategies.

Septic systems are non-point sources of nutrient and bacterial pollution and their pollutant contributions to ground and surface water resources in North Carolina should be accounted for when watershed-scale strategies of pollutant mitigation are developed. Major North Carolina river basins such as the Neuse and Tar-Pamlico and watersheds such as Jordan Lake have regulations in place that require the use of agricultural and stormwater best management practices (BMPs) on agricultural and urban areas to reduce the nutrient loads leaving these lands. Wastewater treatment plants were required to reduce nutrient loadings and have to monitor and report nutrient and bacteria concentrations and loadings discharged from their plants. Nutrient loads from septic systems were not addressed in any of the watershed-scale strategies to improve water quality. Because septic systems are used by nearly half of North Carolina residents and septic system loading rates of nitrogen to groundwater (28.5 to 57.5 kg/ha/yr) are comparable to rates from row crop agriculture (37.5 kg/ha/yr) and exceed estimated rates of atmospheric nitrogen deposition (8 to 12 kg/ha/yr) in eastern North Carolina, septic systems should be included in watershed scale regulations and initiatives to improve water quality.

Methods used in this research to calculate the nitrogen loads from septic systems to groundwater can be used in other watersheds by gathering specific data. The required data include the predominant soil types, population and soil distribution characteristics within the watershed of interest, and groundwater level and groundwater quality data adjacent to septic systems in the common soil types. The septic systems evaluated in this study were installed in 6 soil series including Goldsboro, Altavista, Mandarin, Baymeade, Newhan, and Fripp. While the study was conducted solely in Coastal North Carolina, the 6 soil series researched are also found in 8 other states including Alabama, Arkansas, Florida, Georgia, Mississippi, South Carolina, Tennessee, and Virginia and encompass over 674,000 ha of land (Figures 5.1A, 5.1B) (USDA 2009). Furthermore, the groundwater nitrogen concentrations near septic systems in sandy soils (median 11 -19+ mg/L) and annual total nitrogen loading from septic systems to groundwater (1.9 to 4.0 kg/person) observed in this study were similar to the nitrogen concentrations and loadings observed in different coarse textured soil series in NC, other states, and other countries.

For example, Buetow (2002) reported mean groundwater nitrogen concentrations of approximately 20 mg/L and annual nitrogen loadings of 4.5 kg/person beneath septic systems in an Autryville loamy sand soil series in New Bern, North Carolina; Reay (2004) reported groundwater nitrogen concentrations (greater than 20 mg/L) and annual nitrogen loadings of 2.4 to 2.9 kg/person in groundwater adjacent to systems in sandy soils on the Coastal Plain of Virginia; Gold et al. (1990) reported nitrogen concentrations greater than 10 mg/L and annual nitrogen loadings of approximately 3.2 kg/person from septic systems to groundwater near Kingston, Rhode Island; and Ptacek (1998) reported nitrogen concentrations ranging from 10 to 80 mg/L in groundwater adjacent to septic systems in beach and dune sands in Point Pelee, Ontario, Canada. Thus, this work should be applicable to areas beyond Coastal North Carolina, especially for settings with coarse textured soils.

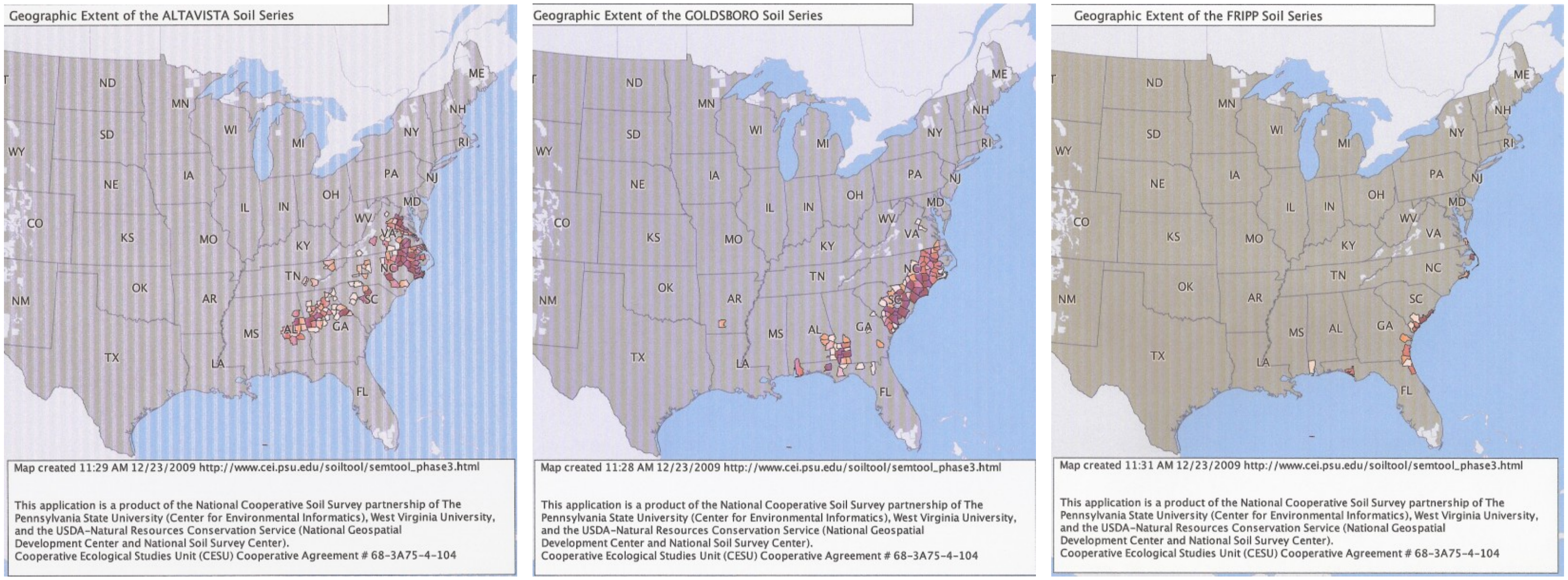
During this study, many other potential research needs were discovered. Some suggestions for future work include:

1) Transport and fate on TKN and total phosphorus in groundwater beneath septic systems in soil textures ranging from sands to clays
2) Transport and fate of indicator bacteria in groundwater beneath septic systems in soil texture ranging from sands to clays
3) Investigation of the links between groundwater quality adjacent to septic systems and drinking water and/or irrigation wells

4) Comparison of wastewater treatment technologies, treatment efficiencies and long term costs, including package plants, centralized sewer systems, conventional septic systems and advanced technology septic systems
5) Investigation of the seasonal loading of wastewater pollutants to ground and surface waters in coastal, tourism based communities
6) Transport and fate of pharmaceuticals and other personal care products from septic systems to water resources in retirement communities
7) Establishment of a permanent shallow groundwater monitoring network for long term trend analyses
8) Sea level rise impacts on septic system treatment efficiencies
9) Land use changes and impacts on groundwater and surface water quality

The findings of this research in conjunction with literature cited in this study can help guide strategies for reducing the impacts of septic systems on ground and surface waters. Potential mitigation strategies such as increasing the required separation distance to seasonal high water table to 60+cm, requiring vegetated buffers adjacent to waterways, drainage canals and ditches, limiting septic system density to 3-4 systems/ha in coarse textured soils (from 5+ systems/ha), requiring pre-treatment technologies such as peat filters and sand filters in areas adjacent to sensitive waters (shellfish growing areas, nutrient sensitive waters, etc.) could all help reduce impact of septic systems on ground and surface water quality. Another potential septic system water quality mitigation strategy would be to assess a recurring septic system environmental impact fee on households that use septic systems. For example, with over 1.4 million active septic systems in North Carolina (Arnold et al. 1996), a nominal $50 annual impact fee would generate $70,000,000/yr. The annual $50 fee would be an order of magnitude lower than what many people pay per year for centralized sewer service. The impact fee funds could be used for developing a statewide on-site wastewater management trust fund (OSWWTF). The OSWWTF, lead by a board of commissioners and field representatives could send out requests for proposals for projects that facilitate on-site wastewater related research, implementation and monitoring of various on-site wastewater best management practices and mitigation strategies (such as planting vegetated buffers), and enhancement of county-level on-site wastewater management programs (continuing education training, technical expertise, equipment, etc.).

It is evident from this work that on-site wastewater systems, like other methods of wastewater treatment and disposal, are impacting water resources and should not be overlooked when developing and implementing water quality management strategies.



Geographic Extent of the ALTAVISTA Soil Series

Map created 11:29 AM 12/23/2009 http://www.cei.psu.edu/soiltool/semtool_phase3.html

This application is a product of the National Cooperative Soil Survey partnership of The Pennsylvania State University (Center for Environmental Informatics), West Virginia University, and the USDA-Natural Resources Conservation Service (National Geospatial Development Center and National Soil Survey Center).
Cooperative Ecological Studies Unit (CESU) Cooperative Agreement # 68-3A75-4-104

Geographic Extent of the GOLDSBORO Soil Series

Map created 11:28 AM 12/23/2009 http://www.cei.psu.edu/soiltool/semtool_phase3.html

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Cooperative Ecological Studies Unit (CESU) Cooperative Agreement # 68-3A75-4-104

Geographic Extent of the FRIPP Soil Series

Map created 11:31 AM 12/23/2009 http://www.cei.psu.edu/soiltool/semtool_phase3.html

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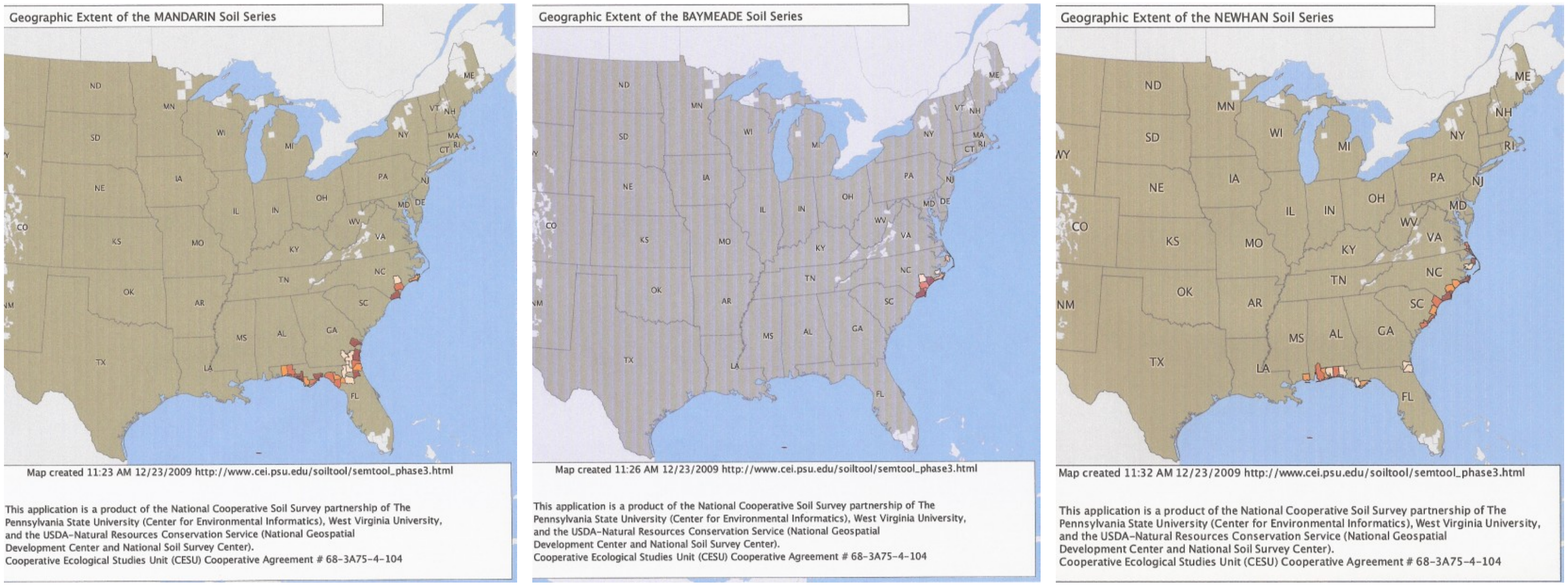
Cooperative Ecological Studies Unit (CESU) Cooperative Agreement # 68-3A75-4-104

Total area (ha): Altavista- 11,793 Goldsboro- 505,730 Fripp- 11,646

Figure 5.1A Soil series distribution maps for the Altavista, Goldsboro, and Fripp series and estimated area (ha) of coverage from the USDA web soil survey (2009). Orange, brown, and yellow shaded areas indicate locations where the soil series were mapped.



Map created 11:23 AM 12/23/2009 http://www.cei.psu.edu/soiltool/semtool_phase3.html

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Cooperative Ecological Studies Unit (CESU) Cooperative Agreement # 68-3A75-4-104

Map created 11:26 AM 12/23/2009 http://www.cei.psu.edu/soiltool/semtool_phase3.html

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Cooperative Ecological Studies Unit (CESU) Cooperative Agreement # 68-3A75-4-104

Map created 11:32 AM 12/23/2009 http://www.cei.psu.edu/soiltool/semtool_phase3.html

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Cooperative Ecological Studies Unit (CESU) Cooperative Agreement # 68-3A75-4-104

Total area (ha): Mandarin- 77,633 Baymeade-46,693 Newhan- 20,645

Total area (ha) for all 6 soil series: 674,140

Figure 5.1B Soil series distribution maps for the Mandarin, Baymeade, and Newhan series and estimated area (ha) of coverage from the USDA web soil survey (2009). Orange, brown, and yellow shaded areas indicate locations where the soil series were mapped.

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APPENDIX: WATER QUALITY, SOIL AND WATER LEVEL DATA.

Table A.1 Highest monthly NH_4^+-N concentrations mg/L (deep or shallow well) adjacent to systems.

Group I	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Median	Mean
A	23.8	40.8	22.5	32.3	36	28.5	24.7	24.4	15.2	14.3	11.3	12.5	0.1	14.5	22.9	21.6
B	0.6	0.5	0.3	1.5	2	0.6	2.7	1.1	0.9	0.4	0.1	0.6	0.1	0.3	0.6	0.8
C	0.2	0.3	0.1	2.1	1.9	1.3		0.4		0.1		4	0.1	0.3	0.3	0.9
D	0.2	0.1	0.3	1.1	1.2	0.7	7.7	4	0.4	0.5	0.1	0.2	0.1	0.5	0.5	1.2
E	0.5	0.3	0.2	0.9	3	0.5	0.4	0.8	0.2	0.3	0.1	0.1	0.1		0.3	0.6
F	0.2	0.3	0.1	0.7	0.5	0.5	0.4	0.8	0.2	0.3	0.1	0.1	0.1	0.4	0.3	0.3
G	0.3	0.2	0.4	0.5	6.8	3.9	9.2	1.8	0.5	0.4	0.1	0.1	0.1	0.3	0.4	1.7
H	0.9		0.5	2.5	1.7		0.7	1.3	0.3	0.5	5.2	0.1	0.2	0.2	0.7	1.1
Summary	3.7	6.1	3.4	5.6	7.3	5.1	7.5	4.8	2.9	2.3	2.0	2.5	0.1	2.7	0.5	3.5

Group II	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Median	Mean
A	3.2	12.8	9.6	15		31	101	35.7	14.8	4.5	8.1	1	0.1	4.1	9.6	18.5
B	2	2.7	1.6	4.9	9.6	5.8	6.4	2.6	0.3	0.4	0.2	0.1	0.1	0.2	1.8	2.6
C	0.3	0.5	0.9	7.7	8.8	6.5		7.5	1.1	3.8	1.1	13.4	0.1		2.5	4.3
D	0.4	3.8	11.5	29.9	29.4	11.7	14.9	5	12.3	1.5	0.2	0.1	0.1	0.1	4.4	8.6
Summary	1.5	5.0	5.9	14.4	15.9	13.8	40.8	12.7	7.1	2.6	2.4	3.7	0.1	1.5	3.4	8.5

Group III	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Median	Mean
A	0.4	6.8	6	8.1	0.7	4.6	0.9	0.6	2	0.1	1.3	0.1	0.1	0.2	0.8	2.3
B	0.1	0.1	0.2	1.2	4.2	2.9	1.3	0.6	0.2	0.2	0.1	0.1	0.1	0.1	0.2	0.8
C	0.2	0.2	0.3	0.4	1.2	0.5	0.4	0.3	0.1	0.8	0.1	0.1	0.1	0.1	0.3	0.3
D	0.2	0.1	0.1	0.5	0.4	0.4	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.2
Summary	0.2	1.8	1.7	2.6	1.6	2.1	0.7	0.4	0.6	0.3	0.4	0.1	0.1	0.1	0.2	0.9

Table A.2 Highest monthly NO_3^--N concentrations mg/L (deep or shallow well) adjacent to systems.

Group I	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Median	Mean
A		22	9.7	39	16.5	15.7	5.3	7.3	0.7	1	15.4	13.6	6	21.6	8.6	11.7	13.0
B	30.3	36.6	27.2	28.1	9.1	36.2	10.9	7.6	6.7	1.7	38.9	0.9	60.6	43.8	40.4	28.1	25.3
C	13.2	11.6	19	7.7	1.8	22.8	0.7		4		1.8		11.9	21.8	41.6	11.8	13.2
D	51	36.3		35	34.5	36		31.8	11.5	3.3	10.2	1.1	17.2	16.5	24.6	24.6	23.8
E				30	25.2	62.3	2.7	62	11.4	7	66	27.5		31.9	39.8	30.0	33.3
F	19.7	15.5	27	29	9	6.8	0.3	1.8	0.4	6.1	6.7	18.2	55	17.9		12.3	15.2
G	3.2	3.5	2	13	2.5	7.6	1.3	1.4	4.8	5.3	11.9	3.1	3.3	1.1	8	3.3	4.8
H	1.6	3	7.5	45	22.1	59.5	0.7	3.2	12.6	3.8	1.3	0.3	1.4	0.1	2.6	3.0	11.0
Summary	19.8	18.4	15.4	28.4	15.1	30.9	3.1	16.4	6.5	4.0	19.0	9.2	22.2	19.3	23.7	12.0	17.4

Group II	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Median	Mean
A	2.8	7	9.3	8.1	9		14	31	0.6	0.2	2.5	5.2	3.2	6.3	5.2	5.8	7.5
B	9.2	10.5	2.4	8.9	14.5	6.5	17.6	6.1	0.3	0.3	33.3	12.6	12.4	17.4	13.7	10.5	11.0
C	2.5	8.2	5.6	8.8	15.5	38.5	45.4	14.4	1.3	0.5	4.7	0.5	5.1	3.9	11.7	5.6	11.1
D	6.9	8.4	2.1	2.9	9.1	13.2	0.1		0.5	0.1	2.2	1.5	7.1	10.5		2.9	5.0
Summary	5.4	8.5	4.9	7.2	12.0	19.4	19.3	17.2	0.7	0.3	10.7	5.0	7.0	9.5	10.2	5.7	8.6

Group III	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Median	Mean
A	2.1	0.8	0.8	0.8	10.1	8.9	0.1	1.9	0.1	0.1	0.4	1.2	3.5	2.2	0.1	0.8	2.2
B	0.9	0.4	0.5	0.6	3.2	21	3	1.2	0.1	0.1	0.4	0.3	3.4	0.3	0.1	0.5	2.4
C	6.3	3.5	6.8	4.9	5	12.5	0.7	2.3	0.1	0.1	0.4	1.1	6.8	2.6	1.1	2.6	3.6
D	3.7	3.3	3.8	3.3	6.8	17.6	3	1.1	0.2	0.1	0.6	0.1	1.6	0.5	0.1	1.6	3.1
Summary	3.3	2.0	3.0	2.4	6.3	15.0	1.7	1.6	0.1	0.1	0.5	0.7	3.8	1.4	0.4	1.2	2.8

Table A.3 Highest DIN concentrations (NH_4^+-N + NO_3^--N) mg/L in groundwater adjacent to septic systems in soil groups I, II and III from January 2007 to March 2008.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Avg	Med
GI-A	0.9	45.8	50.5	61.5	48.8	51.7	33.8	32.0	25.1	16.2	29.7	24.9	18.5	21.7	23.1	32.3	29.7
GI-B	30.3	44.4	28.5	28.1	9.1	43.0	10.9	7.6	6.7	1.7	38.9	0.9	60.6	43.8	65.3	28.0	28.5
GI-C	13.2	11.8	19.1	7.8	3.9	24.7	1.6		4.3		1.9		15.9	21.9	41.9	14.0	12.5
GI-D	51.0	37.0		35.5	37.0	37.7		32.5	12.8	3.6	10.7	5.2	17.3	16.6	24.8	24.7	24.8
GI-E		4.2	1.8	30.3	26.3	63.5	3.4	62.6	12.4	7.4	66.5	27.6	67.2	32.0	40.3	31.8	29.0
GI-F	19.7	16.0	27.3	29.2	9.9	9.7	0.8	2.2	1.2	6.3	7.0	18.3	55.1	17.9		15.8	13.0
GI-G	3.0	3.7	2.3	13.1	5.0	7.8	1.3	1.3	5.0	5.5	15.1	3.2	3.4		8.4	5.6	4.4
GI-H	1.6	3.3	7.7	76.2	22.6	66.3	4.6	11.3	14.4	6.4	1.7	0.4	1.5	0.2	2.9	14.7	4.6

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Avg	Med
GII-A	3.0	9.6	14.7	15.3	22.5		33	31	36.3	15	7	13.3	4.2	6.4	8.9	15.7	14.0
GII-B	9.2	11.6	5.1	10.5	24.4	16.1	23.4	12.5	2.9	0.6	33.4	12.7	12.5	17.5	27.2	14.6	12.5
GII-C	6.9	8.6	2.6	3.8	16.8	22	6.6		8.0	1.2	5.7	2.6	14.9	10.6		8.5	6.9
GII-D	2.5	8.5	9.4	20.3	45.4	67.7	57.1	109.4	6.3	12.8	6.2	0.7	5.2	4.0	11.8	24.5	9.4

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Avg	Med
GIII-A	2.1	1.2	7.6	6.8	10.8	9.6	4.7	2.7	0.7	2.1	0.5	2.5	3.6	2.3	0.2	3.8	2.5
GIII-B	1.5	1.2	0.9	0.8	4.4	25.2	5.9	3.4	0.7	0.3	0.6	0.4	3.5	0.4	0.3	3.3	0.9
GIII-C	6.3	3.7	7.0	5.0	5.4	34.0	1.1	2.5	0.5	0.2	1.2	1.2	6.9	2.7	1.2	5.3	2.7
GIII-D	3.7	3.5	3.9	3.4	7.3	18.0	3.2	3.7	0.4	0.2	0.7	0.2	1.7	0.6	0.2	3.4	3.2

Table A.4 Dissolved inorganic nitrogen concentrations (mg/L) in shallow (A), deep (B) and background (BG) groundwater wells adjacent to septic systems in soil groups I, II and III from January 2007 to March 2008.

	Jan-07	Feb-07	Mar-07	Apr-07	May-07	June-07	July-07	Aug-07	Sep-07	Oct-07	Nov-07	Dec-07	Jan-08	Feb-08	Mar-08	Avg
GI-A																
Deep		3.1	1.9	2.1	2.2	2.0	0.7	0.9	0.6	0.2	0.5	0.8	0.2	0.3	0.6	1.1
Shallow		45.8	50.5	61.5	48.8	51.7	33.8	32.0	25.1	16.2	29.7	24.9	18.5	21.7	22.9	32.3
BG	0.9	3.6	2.0	2.2	0.0	4.5	0.8	0.0	0.8	0.0	1.1	0.7	0.2	0.2	0.7	1.2
GI-B																
Deep	17.2	36.6	27.2	28.1	9.1	36.2	10.9	7.6	6.7	1.7	38.9	0.9	33.3	9.3	65.3	21.9
Shallow	30.3	44.4	28.5			43.0	7.3		6.4				60.6	43.8	40.4	33.9
GI-C																
Deep	13.2	11.8	19.1	7.8	3.9	24.7	1.1		4.3		1.9	0.1	8.7	21.9	41.8	12.3
Shallow	2.6	6.3	9.6	1.6		8.8	1.6		0.7				15.9	9.1	26.6	8.3
BG	0.5	2.2	2.9	0.0	0.0	0.0	0.5	0.0	0.0	0.0	0.5	0.0	3.7	6.2	8.8	1.7
GI-D																
Deep	51.0	36.6		35.5					4.4		10.7	1.1	17.3			22.4
Shallow	33.6	37.0											3.3	0.0	0.0	14.8
Background	0.8	3.0							0.7		0.8		0.3	1.4	2.1	1.3
Deep-b					37.0	37.7		32.5	12.8	3.6	2.5	5.2	2.9	16.6	24.8	17.6

Table A.4 Continued

GI-E	Jan-07	Feb-07	Mar-07	Apr-07	May-07	June-07	July-07	Aug-07	Sep-07	Oct-07	Nov-07	Dec-07	Jan-08	Feb-08	Mar-08	Avg
Deep		4.2	1.8	6.0	2.4	8.8	0.7	10.7	4.2	0.6	1.0	2.8	4.6	0.1	0.5	3.5
Shallow				30.3	26.3	63.5	3.4	62.6	12.4	7.4	66.5	27.6	67.2	32.0	39.9	36.6
BG		3.0	4.3	2.3	3.2	6.3	1.6	1.0	0.3	0.2	0.4	0.1	1.1	0.5	6.9	2.2
GI-F																
Deep	19.7	16.0	27.3	29.2	9.9	7.7	0.8	2.2	1.2	3.3	7.0	18.3	36.5	17.9		14.1
Shallow	17.0					9.7			1.0	6.3	4.1		55.1			15.5
BG	1.5	3.1	4.9	9.6	6.3	8.0	2.1	1.9	1.1	0.9	0.6	1.8	0.5	1.0		3.1
GI-G																
Deep	3.0	3.7			3.1	7.8	0.9	1.5	1.5	0.8	2.1		3.4	0.2	8.4	3.0
Shallow									0.8		1.8		0.7	0.1		0.9
Up					5.0	7.6	1.3	1.4	0.8	5.5	12.0	3.2	1.8	1.2	4.3	4.0
Down				13.1	2.4	5.7	0.6	1.5	5.0	0.9	3.0	0.4	1.2	0.1	3.2	3.1
Other	3.2		2.3	3.5	0.4	0.5	0.2	0.1			0.1				0.1	1.2
GI-H																
Deep	1.5	3.2	3.9	30.8	22.6	35.8	0.8	3.8	3.7	2.1	0.8	0.4	1.5	0.2	2.9	7.6
Shallow	1.6	3.3	7.7	45.4		66.3	4.6	11.3	14.4	4.3	1.7		1.0	0.1		13.5
BG	0.9	1.4	2.2	4.1	4.3	12.6	0.7	1.1	0.8	1.4	0.4	0.2	0.9	0.8	2.6	2.3

Table A.4 Continued

GII-A	Jan-07	Feb-07	Mar-07	Apr-07	May-07	June-07	July-07	Aug-07	Sep-07	Oct-07	Nov-07	Dec-07	Jan-08	Feb-08	Mar-08	Avg
Deep	3.0	9.6	11.3	15.3	22.5		33.0	31.0	6.8	15.0	7.0	13.3	4.2	6.4	8.9	13.4
Shallow	2.4	7.4	14.7	9.7	22.3		14.0	11.1	36.3		5.9		2.1	0.3	6.5	11.1
BG	7.8	9.1	3.1	3.7	8.6		6.7	4.5	1.1	1.3	1.1	1.6	0.7	0.2	1.1	3.4
GII-B																
Deep	9.2	11.6	5.1	10.5	14.9	16.1	23.4	12.5	2.9	0.6	5.8	2.0	6.0	6.5	13.4	9.4
Shallow	8.8	10.7	2.8	8.6	24.4			5.4	2.8	0.4	33.4	12.7	12.5	17.5	13.8	11.8
GII-C																
Deep	2.2	6.2	2.5	3.8	16.8	22.0	6.6		2.7	1.2	5.7	2.6	14.9	10.6		7.5
Shallow	6.9	8.6	2.6						8.0		4.5		7.4	6.0		6.3
Background	2.0	5.7	1.9	1.8	6.3		3.7	7.2	0.9	0.9	1.8	0.4	1.0	2.3		2.8
GII-D																
Deep	2.4	8.0	9.4	20.3	45.4	67.7	57.1	18.7	1.2	12.8	0.8	0.7	4.5	1.1	6.0	17.1
Shallow	2.5	8.5	3.0			65.9	6.5	109.4	6.3	0.6	6.2		5.2	4.0	11.8	19.2

Table A.4 Continued

GIII-A	Jan-07	Feb-07	Mar-07	Apr-07	May-07	June-07	July-07	Aug-07	Sep-07	Oct-07	Nov-07	Dec-07	Jan-08	Feb-08	Mar-08	Avg
Deep	2.1	1.2	7.5	4.7	10.4	9.6	0.8	2.7	0.7	0.4	0.5	1.5	3.6	1.3	0.2	3.1
Shallow	0.9	0.6	7.6	6.8	10.8	3.3	4.7	2.2	0.5	2.1	0.3	2.5	1.6	2.3	0.2	3.1
GIII-B																
Deep	0.9	0.5	0.6	0.8	4.4	25.2	5.9	2.1	0.7	0.2	0.4	0.3	1.9	0.4	0.2	3.0
Shallow	1.5	1.2	0.9	0.5	3.8	7.9	3.3	3.4	0.5	0.3	0.6	0.4	3.5	0.2	0.2	1.9
BG	1.3	1.1	0.9	0.6	2.6	4.4	0.8	0.8	0.4	0.2	0.5	0.3	3.3	0.1	0.2	1.2
GIII-C																
Deep	6.3	3.7	7.0	5.0	5.4	13.1	1.0	2.5	0.3	0.2	0.4	1.2	5.9	2.7	1.2	3.7
Shallow	1.8	1.3	3.0	2.9		34.0	1.1	2.5	0.5	0.2	1.2	1.2	6.9	2.4	1.2	4.3
GIII-D																
Deep	3.7	3.5	3.9	3.4	7.3	18.0	3.2	1.3	0.4	0.2	0.7	0.2	1.7	0.6	0.2	3.2
Shallow	1.2	1.0	1.5				0.5	3.7	0.3	0.2	0.4	0.2	0.9	0.2	0.2	0.9
BG	0.9	1.1	0.6	0.4	1.3	0.0	0.0	1.2	0.0	0.2	0.4	0.3	0.7	0.1	0.2	0.5

Table A.5 Hydraulic gradients used in the Darcy's law equation for determining groundwater flux.

							Hydraulic Gradients									
	Jan	Feb	March	April	May	June	July	August	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Avg
GIA	0.029		0.025	0.025	0.025	0.027	0.028	0.026	0.027		0.027		0.026	0.026		0.027
GIB	0.029		0.025	0.025	0.025	0.027	0.028	0.026	0.027		0.027		0.026	0.026		0.027
GIC	0.035	0.037	0.032	0.033	0.028	0.032	0.038	0.026	0.044		0.037	0.033	0.031	0.039	0.043	0.035
GID	0.001	0.001	0.002		0.049	0.047				0.001		0.001		0.002	0.002	0.012
GIE	0.004	0.005	0.005		0.005	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.006	0.003		0.004
GIF	0.034	0.034	0.034		0.041	0.033	0.034	0.035	0.035	0.034	0.033	0.034	0.035	0.032		0.034
GIG	0.002	0.002	0.006	0.007					0.001		0.001	0.001	0.001		0.001	0.002
GIH	0.002	0.002	0.006	0.007					0.001		0.001	0.001	0.001		0.001	0.002
GIIA	0.013	0.023	0.017	0.018	0.018	0.018		0.020	0.017		0.014		0.012			0.017
GIIB	0.003	0.005	0.006	0.006	0.005	0.005		0.008	0.008		0.006		0.005			0.006
GIIC		0.004	0.003	0.004		0.004			0.005		0.002		0.004	0.003		0.004
GIID	0.005	0.005	0.005	0.007		0.010	0.012	0.008	0.009			0.007	0.008			0.008
GIIIA	0.005	0.004	0.005	0.004	0.004		0.007	0.004	0.006	0.004	0.004	0.004	0.006	0.004	0.018	0.006
GIIIB	0.004	0.006	0.013	0.002	0.010	0.002	0.003	0.004	0.005	0.006	0.004	0.004	0.005	0.005	0.018	0.006
GIIIC	0.007	0.007	0.005	0.003	0.002	0.006	0.002	0.003	0.006	0.017	0.004	0.004	0.008	0.006	0.021	0.007
GIIID	0.020	0.013	0.012	0.011	0.013	0.012	0.013	0.015	0.015	0.016	0.014	0.013	0.013	0.016	0.031	0.015

Table A.6 E. coli densities (cfu/100 ml) in groundwater adjacent to septic systems in soil groups I, II and III. M is March 2007, S is September 2007, N is November 2007 and F is February 2008.

Soil Group	M	S	N	F	Median	Freq viol	Geomean
GI-A	1	33	333	80	57	25	31
GI-B	250	17	1	100	59	25	26
GI-C	1	1	367	400	184	50	20
GI-D	1	1	50	10	6	0	5
GI-E	636	33	133	700	385	75	210
GI-F	91	1	100	1000	96	25	55
GI-G	1	100	100	250	100	25	40
GI-H	1	1	67	1	1	0	3

Soil Group	M	S	N	F	Median	Freq viol	Geomean
GII-A	1067	100	133	100	117	50	194
GII-B	1	6533	500	180	340	75	156
GII-C	364	300	67	1	184	50	52
GII-D	1	35000	100	205	153	50	164

Soil Group	M	S	N	F	Median	Freq viol	Geomean
GIII-A	1	27	200	400	114	50	38
GIII-B	91	1	1	60	31	0	9
GIII-C	83	191	100	100	100	25	112
GIII-D	91	118	133	160	126	50	123

Table A.7 E. coli densities (cfu/100 ml) in back ground groundwater near septic systems in soil groups I, II and III. Some sites shared a common background well. M is March 2007, S is September 2007, N is November 2007 and F is February 2008.

Soil Group	M	S	N	F	Median	Freq viol	Geomean
GI-A,B	1	1	1	20	1	0	2
GI-C	1			1	1	0	1
GI-D	1	1	1	1	1	0	1
GI-E	1		1	1	1	0	1
GI-F	1	1	200	1	1	25	4
GI-G,H	1		67	1	1	0	4

Soil Group	M	S	N	F	Median	Freq viol	Geomean
GII-A,B	400	1	200	1	101	50	17
GII-C,D	1	1	33	1	1	0	2

Soil Group	M	S	N	F	Median	Freq viol	Geomean
GIII-A,B	1	1	1	1	1	0	1
GIII-C,D	1	1	1	20	1	0	2

Table A.8 Depth to groundwater (m) adjacent to each septic system from December 2006 to March 2008.

	Depth to GW (m)															
	Dec	Jan	Feb	March	April	May	June	July	August	Sept	Oct	Nov	Dec	Jan	Feb	Mar
GI-A	1.02	0.91	0.94	1.09	1.19	1.22	0.96	0.98	1.11	0.91	1.19	1.10	1.31	1.04	1.06	0.98
GI-B	1.31	1.08	1.21	1.43	1.53	1.51	1.26	1.25	1.53	1.16	1.50	1.45	1.54	1.34	1.40	1.22
GI-C	1.37	1.15	1.27	1.53	1.63	1.70	1.46	1.43	1.75	1.28		1.60	1.34	1.44	1.46	1.29
GI-D	1.60	1.61	1.69		2.07	2.11	1.98	2.13	2.01	1.75	1.98	1.76	1.98	1.71	1.91	1.76
GI-E		2.79	2.87	3.04	2.91	2.95	2.73	2.86	2.81	2.67	2.77	2.77	2.97	2.93	2.94	
GI-F	1.98	2.01	2.09	2.21	2.20	2.20	2.04	2.13	2.13	1.94	2.05	1.94	2.19	2.06	2.16	
GI-G	2.23	2.16	2.26			2.28	2.08	2.21	2.20	1.97	2.14	2.04	2.27	2.16	2.26	2.18
GI-H	1.87	1.80	1.89	2.04	2.01	1.98	1.80	1.91	1.90	1.73	1.85	1.79	2.01	1.90	1.97	1.97
GII-A	1.25	0.84	0.83	1.31	1.46	1.66	1.77	1.61	1.60	1.00	1.60	1.34	1.63	1.17	1.17	0.89
GII-B	0.71	0.49	0.45	0.79	0.97	1.10	1.20	1.40	0.92	0.30	0.94	0.88	0.96	0.46	0.58	0.41
GII-C	1.17	0.86	0.90	1.28	1.48	1.59	1.55	1.51		0.99	1.52	1.24	1.51	1.03	1.13	0.98
GII-D	1.00	0.67	0.71	1.06	1.24	1.40	1.31	1.09	1.38	0.80	1.26	1.03	1.33	0.94	1.02	0.78
GIII-A	0.94	0.76	0.89	1.09	1.12	1.19	1.25	1.12	0.98	0.58	0.84	0.94	1.10	0.63	1.04	0.81
GIII-B	0.84	0.61	0.72	0.98	1.09	1.16	0.99	0.96	0.84	0.52	0.69	0.81	0.97	0.58	0.82	0.72
GIII-C	1.04	0.76	0.96	1.20	1.43	1.30	1.13	1.18	1.06	0.60	0.76	0.95	1.11	0.68	1.01	0.87
GIII-D	1.11	0.89	0.94	1.27	1.43	1.44	1.33	1.40	1.25	0.78	0.94	1.10	1.24	0.77	1.11	0.94

Table A.9 Relative water table elevations used to calculate the hydraulic gradients and groundwater flow directions.

	Relative Elevation of Water (m)																
	Dec-06	Jan-07	Feb-07	Mar-07	Apr-07	May-07	June-07	July-07	Aug-07	Sep-07	Oct-07	Nov-07	Dec-07	Jan-08	Feb-08	Mar-08	Avg
GI-A	2.28	2.39	2.36	2.22	2.11	2.08	2.34	2.33	2.19	2.39	2.11	2.20	1.99	2.26	2.24	2.33	2.24
GI-B	2.35	2.58	2.45	2.23	2.13	2.15	2.39	2.40	2.13	2.50	2.16	2.21	2.12	2.32	2.26	2.44	2.30
GI-B 3pt		0.95	1.00	0.86	0.89	0.73	0.92	0.91	0.78	0.96	0.66	0.83	0.72	0.93	0.90		0.86
GI-B BG	2.32	2.55	0.00	2.25	2.28	2.09	2.42	2.44	2.23	2.46		2.30	0.00	2.35	2.31		2.33
GI-C	1.56	1.79	1.66	1.41	1.30	1.23	1.47	1.50	1.18	1.66		1.33	1.59	1.50	1.47	1.65	1.49
GI-C 3ptr	1.66	1.57	1.39	1.35	1.19	1.41	1.44	1.18	1.51		1.35		1.50	1.45			1.42
GI-C 3ptl	0.58	0.54	0.35	0.29	0.16	0.34	0.36	0.08	0.42		0.30		0.45	0.42			0.36
GI-C BG	2.00	2.24	2.13	1.86	1.76	1.69	1.91	1.95	1.68	2.13		1.79	2.04	1.95	1.91	2.10	1.94
GI-E		0.32	0.23	0.06	0.19	0.16	0.37	0.25	0.30	0.43	0.33	0.33	0.13	0.18	0.16		0.24
GI-E BG		1.34	1.27	1.10		1.19	1.37	1.24	1.30	1.45	1.34	1.35	1.15	1.24	1.15	1.18	1.26
GI-E 3 pt		0.81	0.71			0.64	0.83	0.73	0.73	0.88	0.77	0.77					0.76
GI-F	1.16	1.14	1.05	0.93	0.94	0.94	1.10	1.01	1.01	1.20	1.09	1.20	0.95	1.09	0.98		1.05
GI-F BG	2.05	2.03	1.95	1.82		2.05	1.98	1.90	1.94	2.12	2.00	2.09	1.86	2.01	1.83		1.97
GI-F 3Pt		1.27	1.16				1.21		1.09	1.37	1.18	1.32		1.20			1.22
GI-G	0.37	0.43	0.34			0.31	0.51	0.38	0.39	0.62	0.45	0.55	0.32	0.43	0.34	0.41	0.42
GI-H	0.45	0.51	0.42	0.26	0.30	0.32	0.51	0.42	0.41	0.55	0.46	0.52	0.28				0.41
GI-H BG	0.44	0.51	0.42	0.26	0.30	0.30	0.49	0.40	0.39	0.59	0.44	0.52	0.29	0.41	0.32	0.37	0.40

Table A. 9 Relative water table elevations continued.

	Dec-06	Jan-07	Feb-07	Mar-07	Apr-07	May-07	June-07	July-07	Aug-07	Sep-07	Oct-07	Nov-07	Dec-07	Jan-08	Feb-08	Mar-08	Avg
GII-A	2.33	2.93	3.08	2.37	2.30	2.30	2.26	2.52	2.40	2.62		2.30		2.45	2.45	2.69	2.50
GII- BG	2.21	2.61	2.50	2.14	2.01	1.91	1.88	2.12	2.19	2.55	1.98	2.18	1.97	2.32	2.28	2.44	2.21
GII-3pt	1.74	2.32	1.99	1.58	1.45	1.45	1.43		1.46	1.82		1.65		1.89			1.71
GII-B	1.83	2.43	2.28	1.97	1.96	1.85	1.70	1.71	1.97	2.43	2.01	2.08	1.93	2.29	2.11	2.28	2.05
GII-C	2.43	2.72	2.71	2.40	2.34		2.33			2.63		2.40		2.56	2.49	2.61	2.51
GII-C BG	2.44	2.75	2.75	2.37	2.20	2.09	1.98	2.27	2.31	2.66	2.16	2.40	2.14	2.55	2.46	2.63	2.39
GII-C 3 pt			2.54	2.23	2.13	1.99	2.12	2.06	1.86	2.37	2.24	2.30	2.03	2.35	2.33		2.20
GII-D	2.47	2.79	2.76	2.40	2.26	2.21	2.23	2.38	2.37	2.76	2.38	2.60		2.70	2.69	2.82	2.52
GII-D 3pt			2.55	2.20	2.05	1.92		1.96	1.85	2.42	1.99		2.01	2.39	2.35		2.15
GIII-A	1.06	1.25	1.12	0.91	0.89	0.81	0.76	0.89	1.03	1.42	1.17	1.06	0.90	1.37	0.97	1.19	1.05
GIII-A 3ptf		1.08	1.08	0.72	0.65	0.60	0.78	0.79	1.15	1.17	1.03	0.92	0.79	1.16	0.87		0.91
GIII-A 3ptb		0.90	0.84	0.60	0.60	0.52	0.78	0.41	0.76	1.05	0.88	0.78	0.64	0.98	0.69		0.74
GIII-B	0.89	1.11	1.00	0.69	0.58	0.55	0.69	0.71	0.82	1.19	1.01	0.87	0.74	1.17	0.83	0.95	0.86
GIII-BG	0.81	1.05	0.98	0.64	0.56	0.51	0.72	0.66	0.79	1.15	1.01	0.84	0.67	1.11	0.76	0.93	0.82
GIII-3pt		0.88	0.70		0.49		0.58	0.54	0.61	0.94	0.71	0.67	0.53	0.92	0.59		0.68
GIII-C	1.09	1.31	1.17	0.89	0.85	0.73	0.85	0.90	0.88	1.43	1.01	1.12	1.00	1.43	1.09	1.23	1.06
GIII-C 3Pt		0.90	0.77	0.60	0.70	0.61	0.50	0.81	0.73	1.10		0.90	0.76	0.95	0.76		0.78
GIII-D	1.26	1.51	1.45	1.11	1.03	1.01	1.09	1.02	1.18	1.66	1.51	1.33	1.18	1.67	1.29	1.49	1.30
GIII-D 3pt		0.54	0.82	0.51	0.51	0.39	0.51	0.41	0.48	0.92	0.75	0.65	0.55	1.02	0.54		0.61

Table A.10 Demographic and septic system use data for the Newport River watershed.

	Sewer	Septic
NP,Bo, Be, MH	16497	22169
AB, IB, PKS, EI	1039	6958
CC, CP		1150
Total	17536	30277
% Service	36.7	63.3

	Septic	Sewer
Newport	16195	3806
Bogue	653	
AB, IB, PKS	3055	1039
Morehead	5321	8691
Emerald Isle	3903	
Cape Carteret	700	
Cedar Point	450	
Beaufort	0	4000
Totals	30277	17536
Total Population	47813	
Ratio Septic	0.633	

Table A.11 Soil profile descriptions and photographs.

GI-A (Mandarin Series)

Depth (cm)	Horizon	Color	Texture
0-30	Fill	10 YR 2/2	LS
30-41	A	10 YR 5/2	LS
41-86	E	10 YR 6/1	LS
86-94	Bh	10 YR 2/2	LS
94-130	B2	10YR 3/2	LS

Table A.11 Continued

Baymeade Series (GI-B)

Depth (cm)	Color	Texture
0-10	10 YR 6/2	S
10-56	10 YR 7/1	S
56-137	10 YR 4/4	SL
137-152	10 YR 5/3	SL
152+	2.5 YR 6/2	LS

Table A.11 Continued

GI-C (Baymead Series)

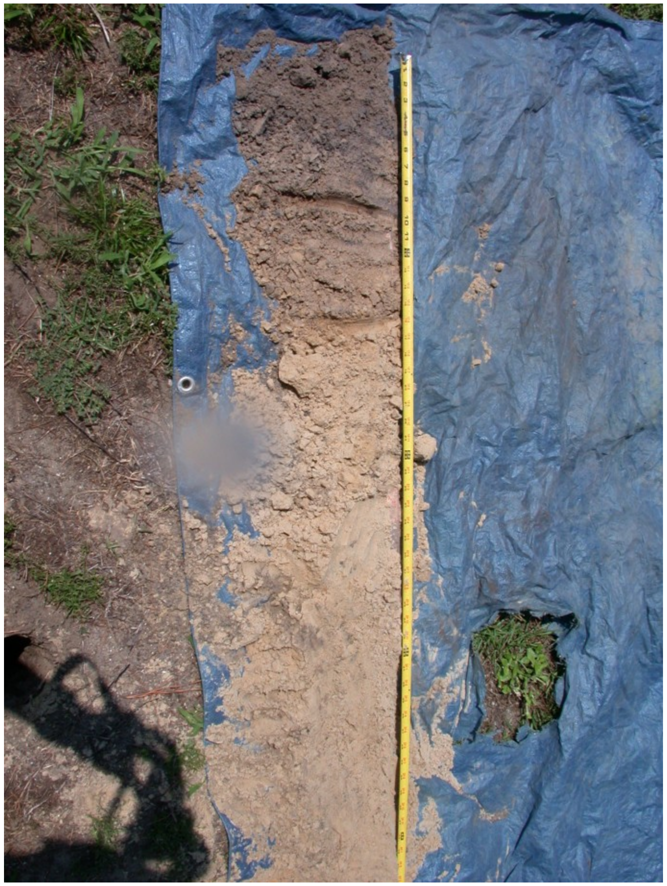
Depth (cm)	Horizon	Color	Texture
0-21	Fill	10 YR 7/1	S
37-49	A	10 YR 4/4	SL
49-91	E		LS
91-101	Bh	10 YR 5/3	SL
101-122	Bt		SL
122-142+		2.5 YR 6/2	LS

Table A.11 Continued

Fripp Series (GI-D)

Depth(cm)	Color	Texture
0-28	10 YR 5/3	S
28-45	10 YR 6/2	S
45-61	2.5 Y 6/4	LS
61-127	10 YR 5/6	LS
127+	10 YR 6/2 10 YR 5/6 mottles	S

Table A.11 Continued



GI-E (Fripp Series)

Depth (cm)	Horizon	Color	Texture
0-25	A1	10 YR 4/2	LS
25-41	A2	10 YR 4/3	LS
41-84	B	2.5 Y 6/4	LS
84-127+	C	2.5Y 6/4 with 10 YR 5/6 mottles	

Table A.11 Continued

Newhan Series (GI-F)

Depth (cm)	Color	Texture
0-8	10 YR 3/2	LS
8-56	10 YR 4/3	LS
56-66	10 YR 5/1	S
66-91	10 YR 4/4	LS
91+	10 YR 5/6	S

Table A.11 Continued

Newhan Series (GI-G)

Depth (cm)	Color	Texture
0-8	10 YR 2/1	SL
8-107	2.5 Y 7/3	LS
107-132	2.5 Y 5/1	LS
132+	2.5 Y 4/2	LS

Table A.11 Continued

GI-H (Newhan Series)

Depth (cm)	Horizon	Color	Texture
0-20	A	10 YR 2/1	SL
20-64	E	10 YR 4/2	S
64-155	B	10 YR 3/1	S
155-230+	C	10 YR 5/2	S

Table A.11 Continued

Goldsboro Series (GII-A)

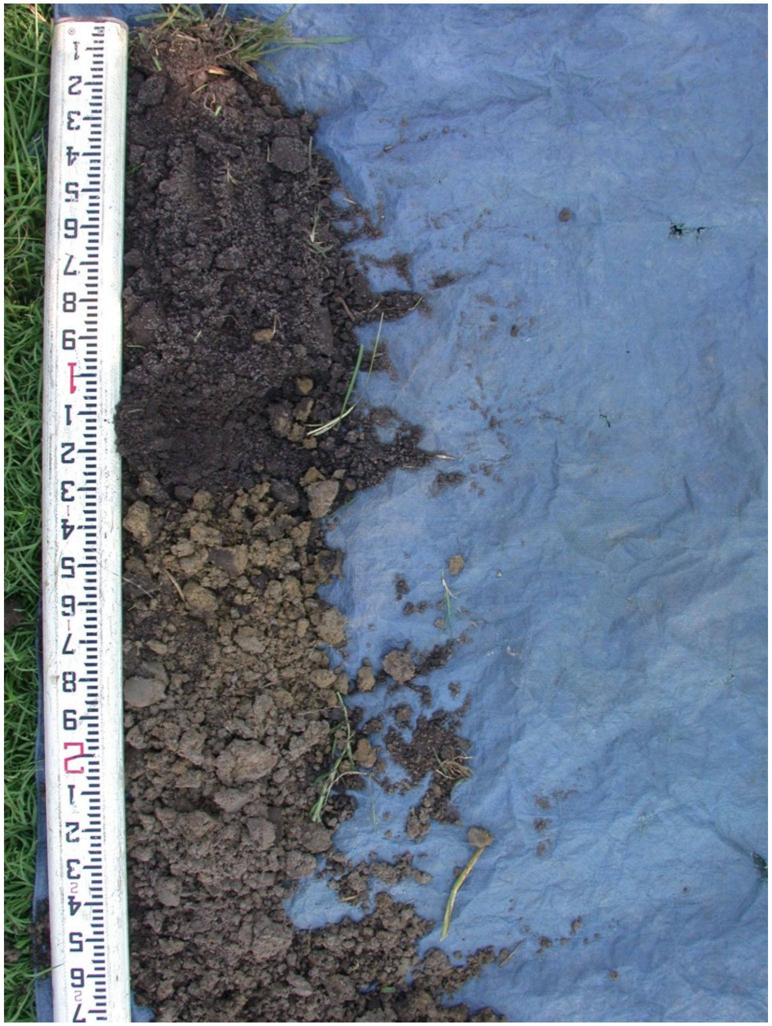
Depth (cm)	Color	Texture
0-41	10 YR 3/2	SL
41-51	10 YR 4/3 with few 10 YR 5/2 and 10 YR 4/6 mottles	SL
51-64	10 YR 4/3 with 10 YR 5/2 mottles common	SL
64 +	10 YR 6/2 with	SL

Table A.11 Continued

GII-B (Goldsboro Series)

Depth (cm)	Horizon	Color	Texture
0-33	A	10 YR 3/2	SL
33-56	B	10 YR 4/3	SL
56-64	B2	10 YR 4/3 with 10 YR 6/2 mottles	SL/SCL
64-74+	C	10 YR 5/2	SL

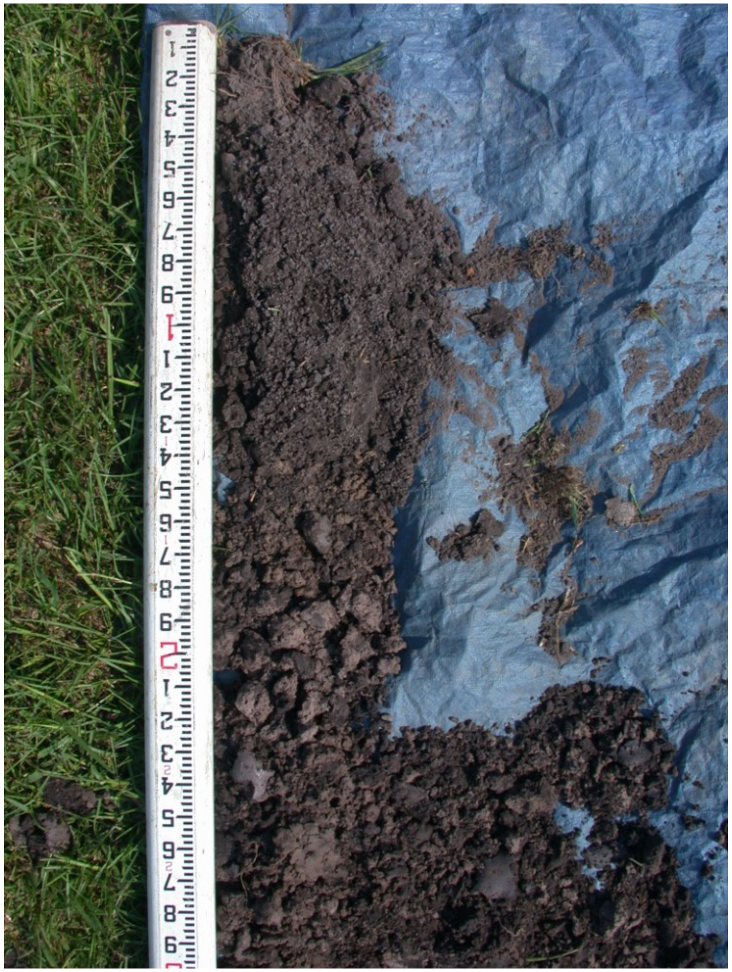
Table A.11 Continued



Goldsboro Series (GII-C)

Depth (cm)	Color	Texture
0-41	10 YR 3/2	SL
41-53	10 YR 5/6	SL
53-64	10 YR 5/4 10 YR 5/2 & 5/6 mottles common	SL
64-76	10 YR 5/2 with 5/4 and 5/6 mottles	

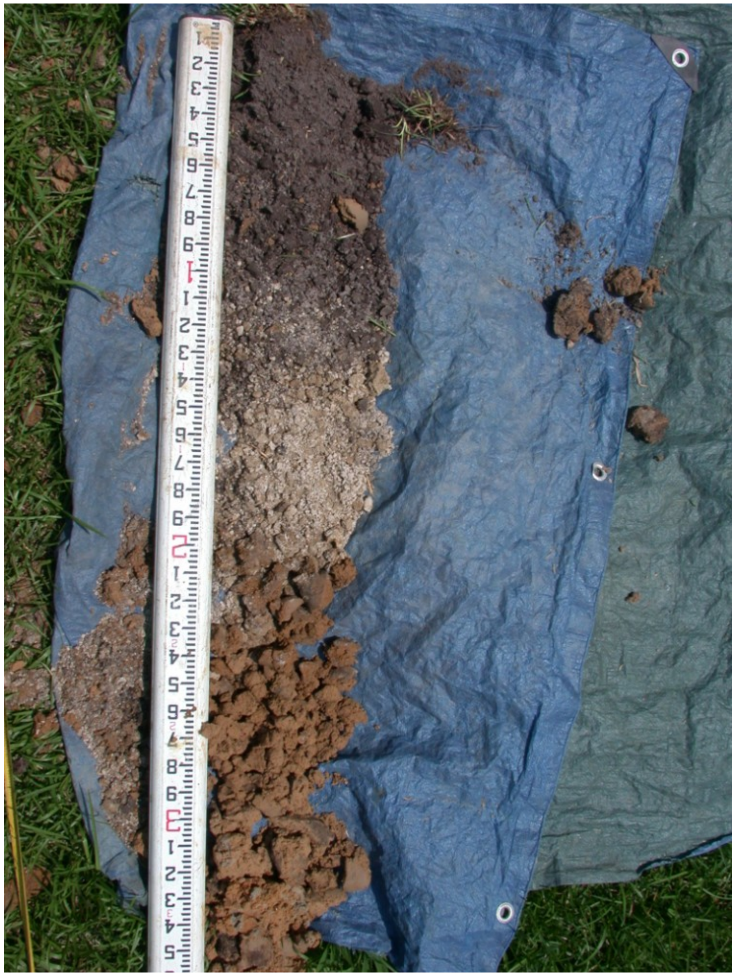
Table A.11 Continued



Goldsboro Series (GII-D)

Depth (cm)	Color	Texture
0-41	2.5 Y 3/2	SL
41-58	10 YR 4/3	SL
58- 84	10 YR 5/2 with 10 YR 4/6 mottles at 64 cm	SL
84+	10 YR 3/2	SL

Table A.11 Continued



Altavista Series (GIII-A)

Depth (cm)	Color	Texture
0-33	10 YR 2/1	SL
33-43	10 YR 3/2	SL
43-58	2.5 Y 6/3 2.5 Y 6/5 mottles	SL
58-91	2.5 Y 4/3 with 5 Y 5/6 mottles few 10YR 6/3 mottles common	SCL
91-112	10YR 5/4 10 YR 7/2 mottles	SCL

Table A.11 Continued

Altavista Series (GIII-B)

Depth (cm)	Color	Texture
0-30	10 YR 3/2	SL
30-43	10 YR 4/6 2.5 Y 6/3 mottles	SL
43-48	2.5 Y 7/3	LS
48-64	10 YR 4/4 2.5 Y 6/3 mottles common	SCL
64-91	10 YR 4/4 2.5 Y 6/2 mottles at 78 cm	

Table A.11 Continued

Altavista Series (GIII-C)

Depth (cm)	Color	Texture
0-38	10 YR 4/3	SL
38-48	10 YR 5/4	SL
48-58	2.5 Y 6/3	SL
58-84+	10 YR 4/6 with 10 YR 6/3 mottles 10 YR 6/2 mottles few at 69	SCL
84+	10 YR 4/6 with 10 YR 6/2 & 5/8 mottles common 10 YR 6/1 mottles	

Table A.11 Continued

GIII-D (Altavista Series)

Depth (cm)	Horizon	Color	Texture
0-18	A	10 YR 3/2	SL
18-51	A2	10 YR 4/3	SL
51-61	B1	2.5 Y 5/6	
61-69	B2	2.5 Y 5/3 with few 10 YR 7/2 and 10 YR 6/6 mottles	SCL
69-89	B3	2.5 Y 5/6 with 2.5 Y 5/3 mottles common	SCL
89-102+	C	2.5 Y 5/4 with 10 YR 7/2 mottles common	SCL

Table A.12 Mann Whitney statistical test results for groundwater and tank E. coli and nitrogen data.

Mann Whitney Test Results (P values)

E. coli Tests

Groundwater

GI > GI BG = 0.0026

GII > GII BG = 0.0526

GIII > GIII BG = 0.0526

GII > GI = 0.0373

GII > GIII = 0.0562

GIII > GI = 0.2223

GII BG > GI BG = 0.1497

GII BG > GIII BG = 0.428

GI BG > GIII BG = 0.207

GI S > GI D = 0.3359

GII S > GII D = 0.0628

GIII S > GIII D = 0.077

GI and GII E. coli

< 60 cm Sep > 60+ cm Sep = 0.0794

Septic Tanks

GII > GI = 0.1844

GII > GIII = 0.0404

GI > GIII = 0.1080

Dissolved Inorganic Nitrogen

Groundwater

GI > GI BG = 0.0012

GII > GII BG = 0.0526

GIII > GIII BG = 0.0526

GI > GII = 0.1975

GI > GIII = 0.0042

GII > GIII = 0.0152

Lab Results (TKN + NO3)

GI > GII = 0.3995

GII > GIII = 0.0152

GI > GIII = 0.0042

Septic Tanks

GI < GII = 0.1080

GII > GIII = 0.0404

GI > GIII = 0.1080

GI and GII -NH4

< 60 cm Sep > 60 cm + Sep = 0.0027

GI = Group I soils (sands)

GII = Group II soils (coarse loams)

GIII = Group III soils (fine loams)

BG = Back ground groundwater

Sep = Separation distance to seasonal high water table

Dissolved Inorganic Nitrogen = NH_4-N + NO_3-N

S = Shallow water table periods

D = Deep water table periods

Lab Results = Samples analyzed for TKN, NH_4 and NO_3 in laboratory, others in the field

Table A.13 Chloride concentrations (mg/L) in groundwater.

GI-A	Jan	Feb	March	April	May	June	July	Aug	Sep	Oct	Nov	Dec	Jan	Feb	AVG
Deep		12	9	7	12	7	14	5	1	12	3	11	3	11	8
Shallow		102	89	92	98	58	57	33	5	20	16	82	10	68	56
Background		16		42		16	161		44		86	218	21		76

GI-B	Jan	Feb	March	April	May	June	July	Aug	Sep	Oct	Nov	Dec	Jan	Feb	AVG
Deep		40	42	38	3	39	41	18	5	22	16	44	7	49	28
Shallow		46	33			44	44		4				6	41	31

GI-C	Jan	Feb	March	April	May	June	July	Aug	Sep	Oct	Nov	Dec	Jan	Feb	AVG
Deep		21	12	9		17	11		2		3		5	71	17
Shallow		4	9	5		6	11		1				5	14	7
Background		10	9				18				6		14	51	18

GI-D	Jan	Feb	March	April	May	June	July	Aug	Sep	Oct	Nov	Dec	Jan	Feb	AVG
Deep	3	53		52	54	40			68	35	34	68		60	52
Shallow	4	40													
Background	1	27							31		195			113	92

GI-E	Jan	Feb	March	April	May	June	July	Aug	Sep	Oct	Nov	Dec	Jan	Feb	AVG
Deep		14	16	11	19	20	12	7	5	12	11	26		20	14
Shallow				70	72	75	70	60	16	25	47	87		58	58
Background		24	25	22	27	38	40	11	5	43	41	45		29	29

GI-F	Jan	Feb	March	April	May	June	July	Aug	Sep	Oct	Nov	Dec	Jan	Feb	AVG
Deep	2	43	44	33	38	67	81	26	12	30	19	63		52	42
Shallow						63			19	34	23				35
Background		62	79	51	69	29	78	42	14	46	30	94		103	58

GI-G	Jan	Feb	March	April	May	June	July	Aug	Sep	Oct	Nov	Dec	Jan	Feb	AVG
Deep	3	64	480	46	355	148	88	27	118	90	54			249	156
Shallow									11						
newup	1				312	84	30	11	5	520	540	169		202	208
newdown				700	50	55	43	16	628	360	181	172		116	232

GI-H	Jan	Feb	March	April	May	June	July	Aug	Sep	Oct	Nov	Dec	Jan	Feb	AVG
Deep		131	139	116	102	102	70	38	23	57	49	96		103	86
Shallow	9	126	138	102		122	80	42	72	93	60	109			94
Background	19	214	121	32	75	69	85	65	82	62	260	107		122	108

Table A.13 Continued. Chloride concentrations (mg/L) in groundwater.

Sites	Jan	Feb	March	April	May	June	July	Aug	Sep	Oct	Nov	Dec	Jan	Feb	AVG
GII-A															
Deep	1	27		27	43		85	75	6	31	20	58	8	44	39
Shallow	0	6	9	8	35		266	24	56		109		28	115	66
Background	0		20	4	20			3	5	13	4	7	1	5	8
GII-B															
Deep	2	42	26	26	42	36	82	8	160	185	208	202	38	124	91
Shallow	1	9	9	19	47			8	66	270	48	93	7	36	56
GII-C															
Deep		22	9		62	47	38		24	104	80	131	18	40	52
Shallow		18	11						44		62		8	40	31
Background	0	3	3	2	16		15	22	2	7	6	7		4	8
GII-D															
Deep	2	35	42	61	92	110	80	18	12	1660	24	57	10	34	172
Shallow	0	13	23			80	150	16	360	60	50		19	37	81
GIII-A	Jan	Feb	March	April	May	June	July	Aug	Sep	Oct	Nov	Dec	Jan	Feb	AVG
Deep	1	20	26	12	35	19	15		1	3	2	7	2	14	13
Shallow	1	17	34	24	20	36	25		1	7	5	27	2	18	18
GIII-B															
Deep	3	51	58	29	45	94	73		2	13	6	20	4	23	35
Shallow	4	37	43	34	36	43	43		1	11	5	23	2	13	24
Background	2	24	23	13	19	27	21		1	5	3	7	1	9	13
GIII-C															
Deep	10	130	101	77		104	58		2	27	17	100	20	107	68
Shallow	6	126	81	24		54	37		4	14	19	88	3	81	48
GIII-D															
Deep		60	57	47	52	63	22		1	7	12	48	3	44	35
Shallow		23	24			38	143		1	4	4	11	1	11	26
Background	10	175	160	161	180	262				13		79	6	62	122