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GEOSPATIAL ANALYSIS OF DENITRIFYING SEPTIC SYSTEMS AND GROUNDWATER NITRATE CONCENTRATIONS IN JAMESTOWN SHORES, RHODE ISLAND

Amy B. Parmenter
University of Rhode Island, parmenab@gmail.com

GEOSPATIAL ANALYSIS OF DENITRIFYING SEPTIC SYSTEMS AND GROUNDWATER NITRATE CONCENTRATIONS IN JAMESTOWN SHORES, RHODE ISLAND

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AMY B. PARMENTER

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OF

AMY B. PARMENTER

APPROVED:

Thesis Committee: Dr. Tom Boving

Dr. Arthur Gold

Major Professor Dr. Anne Veeger

Nasser H. Zawia
DEAN OF THE GRADUATE SCHOOL

UNIVERSITY OF RHODE ISLAND
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ABSTRACT

High-density housing areas with onsite wastewater treatment systems (OWTS) and domestic drinking water wells are susceptible to groundwater contamination from nitrate-nitrogen (NO_3-N). One solution is to install denitrifying OWTS, which are designed to reduce the effluent nitrogen by approximately half that of conventional OWTS. Geostatistical methods were used to analyze groundwater NO_3-N data from the Jamestown Shores neighborhood of Jamestown, Rhode Island to determine if denitrifying OWTS have had an affect on water quality. Temporal trends were analyzed using NO_3-N concentrations from sample events approximately 15 years apart, 1996-1997 and 2010-2011, between which a number of denitrifying OWTS were installed. Spatial trends in the effects of housing density, percentage of denitrifying OWTS, and select confounding variables on groundwater NO_3-N concentrations were analyzed using directional buffers for groundwater flow and fracture orientation as well as circle buffers. Regionally, groundwater NO_3-N did not decrease from 1996-1997 to 2010-2011, likely because of a net increase in houses and septic systems during this time period. Although the statistical significance of each buffer-type varied, groundwater NO_3-N was generally found to increase with housing density in the immediate surrounding area and along the fracture orientation and decrease with at least one denitrifying OWTS in the area. Well depth and relative soil permeability (both normalized by housing density) did not have a statistically significant affect on NO_3-N concentrations; the sample size for the low permeability soils was too small to statistically analyze, but the NO_3-N concentrations were considerably less than for the other soils. Expected groundwater NO_3-N concentrations

were determined using estimated nitrogen loading from area OWTS, compared with measured concentrations, and a prediction model developed for the effects of increasing percentage of denitrifying OWTS. The expected vs. measured comparison model showed there are some sites with low NO_3-N concentrations that do not appear to be affected by the high density of OWTS and some with high NO_3-N concentrations above the level predicted by the density of OWTS alone. The prediction model showed that the percentage of denitrifying OWTS needed in the surrounding 400-foot radius to achieve NO_3-N concentrations below the action level (5 mg/L) is at least 75% in the highest density areas (3.1 houses/acre) and at least 25% in the average density areas (1.7 houses/acre). The town can use these two models for planning purposes to determine where denitrifying OWTS may be most effective or where confounding variables may have a more significant influence on NO_3-N concentrations.

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PREFACE

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MANUSCRIPT-I

"Geospatial Analysis of Denitrifying Septic Systems and Groundwater Nitrate Concentrations in Jamestown Shores, Rhode Island"

by

Amy B. Parmenter[1], Anne I. Veeger[1], Thomas Boving[1], Gavino Puggiono[2]

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[1] Department of Geosciences, The University of Rhode Island, Kingston, RI, USA. Corresponding Author Email: parmenab@gmail.com

[2]Department of Computer Science and Statistics, The University of Rhode Island, Kingston, RI, USA. Email: puggioni@cs.uri.edu

CHAPTER 1

INTRODUCTION

High density housing areas with onsite wastewater treatment systems (OWTS) overlying a shallow, fractured bedrock aquifer are susceptible to groundwater contamination by nitrate-nitrogen (NO_3-N) above the U.S. Environmental Protection Agency's (U.S. EPA) drinking water maximum contaminant level (MCL) of 10 mg/L NO_3-N (Tinker, 1991; U.S. EPA, 2002). A potential solution is the installation of denitrifying OWTS, which are designed to reduce the concentration of nitrogen in the effluent entering the groundwater system (Gold, et al., 1990; U.S. EPA, w/o date; U.S. EPA, 2002; URI, 2005); however, there are numerous variables contributing to the extent of the actual NO_3-N reduction in the groundwater. Concrete evidence of their impact on groundwater NO_3-N concentrations is desirable, as communities seek to justify the expense of installing denitrifying OWTS. If the denitrifying OWTS are found to be effective at reducing groundwater NO_3-N, they can be a viable community-planning tool for groundwater restoration and long-term protection.

This study used geostatistical methods to analyze the effects of denitrifying OWTS on groundwater NO_3-N concentrations in a high-density housing area of Jamestown, Rhode Island called "Jamestown Shores". Temporal analysis was conducted on groundwater NO_3-N samples taken approximately 15 years apart, between which a number of denitrifying OWTS were installed. Spatial analysis was performed to determine the relationship between groundwater NO_3-N concentrations and the following parameters: housing density, percent denitrifying OWTS, and select confounding variables. This was accomplished by creating and utilizing buffers around each sample site, including wedge-shaped buffers encompassing the dominant groundwater flow direction and fracture orientation, in addition to circle buffers.

GROUNDWATER NO_3-N CONTAMINATION FROM OWTS

Nitrate is an inorganic compound that is naturally present in groundwater at low concentrations, generally less than 1 mg/L NO_3-N (Nolan and Hitt, 2003; USGS, 1999). Groundwater concentrations greater than this relative background level are primarily from septic systems, animal waste, and/or fertilizers (Canter, 1997). These higher levels can be detrimental to human and ecological health: a potential contributor to methemoglobinemia ("blue baby syndrome") in infants (Comly, 1945; Fewtrell, 2004; Knobeloch, et al., 2000; U.S. EPA, 2002; WHO, 2008) and to eutrophication of surface water bodies (EPA, 2002). Because the presence of NO_3-N above background levels is evidence of a pathway from the surface/subsurface to the groundwater, it can also be an indicator of pathogens and other harmful chemicals such as those in pharmaceuticals and personal care products (PPCPs) and pesticides.

OWTS are often a major source of elevated NO_3-N in groundwater because conventional OWTS are not designed to remove nitrogen (Canter and Knox, 1985; URI, 2005; U.S. EPA, 2002), nitrogen can travel long distances in aquifers due to insufficient dispersion and denitrification (Canter and Knox, 1985; Robertson and Cherry, 1991), and OWTS density is often too high to allow adequate dilution before reaching wells (Bicki and Brown, 1991; Drake and Bauder, 2005; Horn and Harter, 2011; Lowe, et al., 2000; Persky, 1986; Veeger et al., 1997; Yates, 1985). A potential solution applied by many communities is the installation of denitrifying OWTS.

Denitrifying OWTS have an added treatment component that reduces effluent nitrogen concentrations. In conventional OWTS, nitrogen in the form of organic nitrogen and ammonia (NH_3) travels through the anaerobic septic tank to the drainfield, below which it infiltrates through the natural aerobic environment that converts the nitrogen to nitrate ("nitrification"). Denitrifying OWTS have an extra aerobic component that allows nitrification to occur within the OWTS so that nitrate can then be converted to harmless nitrogen gas ("denitrification") in the anaerobic septic tank (URI, 2005; U.S. EPA, 2002). These denitrifying OWTS are used in many communities with vulnerable water sources such as shallow, unconfined aquifers or nearby surface water bodies (Heufelder, et al., 2007; Town of Jamestown, 2007; U.S. EPA, w/o date). The Rhode Island Department of Environmental Management (RI DEM) requires that denitrifying OWTS reduce septic tank effluent concentrations by 50% and less than or equal to 19 mg/L nitrogen, and RI DEM has approved nine brands of denitrifying OWTS that meet this criterion (RI DEM, 2012). Studies have shown however, that denitrifying OWTS are not consistently effective at meeting the required effluent nitrogen concentration, primarily due to the operation and maintenance needs of these systems as well as variable influent concentrations (Harden et al., 2010, Heufelder, et al., 2007, Lowe, et al., 2007, Lowe et al., 2009, Oakley et al., 2010, U.S. EPA w/o date).

Heufelder, et al. (2007) and Oakley, et al. (2010) also emphasized that the effluent nitrogen standards do not take discharge volume, and therefore nitrogen mass loading, into consideration. The concentration of nitrogen in the septic tank effluent is dependent on the nitrogen loading and the amount of water use, as well as the efficiency of the OWTS. Studies have shown that influent nitrogen concentrations have likely increased due to water conservation (Lowe et al., 2007 and 2009; Harden et al. 2010) and that denitrifying OWTS test centers may not take water conservation into account (Harden et al., 2010). A study that directly compares influent or effluent nitrogen concentrations with low flow fixture use was not found in the literature.

In addition to OWTS density and the variable performance of denitrifying OWTS, there are multiple variables that can contribute to the concentration of NO_3-N in a drinking water well. Numerous studies have used geostatistical analysis to evaluate the impact of OWTS, and/or confounding variables, on NO_3-N concentrations. Pertinent findings on variables that have increased NO_3-N concentrations are listed in Table 1. These studies did not focus on the impact of denitrifying OWTS on groundwater NO_3-N. Many of them included buffers around wells to analyze the effects of land use; however, these buffers were circular and not oriented with the dominant groundwater flow (except for Tinker, 1991) or bedrock fracture orientation.

STUDY AREA

Jamestown Shores is a high-density residential area in northern Conanicut Island (the town of Jamestown) in the Narragansett Bay of Rhode Island (Fig. 1). The area is approximately 2.8 mi^2 (7.3 km^2), including approximately 0.2 mi^2 (0.5 km^2) of wetlands (RIGIS, 2013). The lots in this area are small, averaging less than 16,000 ft^2 (0.37 acres, 0.15 hectares) or 2.8 houses per acre (6.9 houses per hectare), over 20% of them 7,200 ft^2 or less (0.17 acres, 0.07 hectare) or 6 houses per acre (14.8 houses per

Table 1. Literature review of variables found to increase groundwater NO_3-N concentrations.

Variables Found to Increase Groundwater NO_3-N Concentrations			
Variable	**Source(s)**	**Variable**	**Source(s)**
Greater density of OWTS	Drake and Bauder, 2005; Gardner and Vogel, 2005; Katz, et al., 2011; Lichtenberg and Shapiro, 1997; Tinker, 1991	Greater lot density; smaller lot size	Horn and Harter, 2011; Sandorf, 1999
Greater population density	Nolan, 2001	Shallow water table	Gardner and Vogel, 2005; Yen et al., 1996
Shallow wells	Katz, et al., 2011; Lichtenberg and Shapiro, 1997; Rupert, 2008	Shallow well-screen mid-point	Yen et al., 1996
Highly permeable vadose zone	Gardner and Vogel, 2005; Katz et al., 2011	Unconfined aquifer	Lichtenberg and Shapiro, 1997
Higher aquifer hydraulic conductivity	Horn and Harter, 2011; Tinker, 1991	Parallel to groundwater flow, shorter travel time	Tinker, 1991
Greater fertilizer use	Nolan, 2001	Well-drained soils	Nolan, 2001
Oxic groundwater	Katz, et al., 2011; Rupert, 2008; Yen et al., 1996	Presence of a fracture zone	Nolan, 2001

hectare), with almost 1,000 individual OWTS and drinking water wells (Town of Jamestown, 2002 and 2013). The density of OWTS, along with increased year-round use of homes (Town of Jamestown, 2002), has contaminated the vulnerable sole source aquifer (U.S. EPA, 2008) with NO_3-N concentrations approaching and exceeding the U.S. EPA's drinking water MCL.

Groundwater NO_3-N concentrations in the northern part of Conanicut Island were analyzed by Veeger et al. (1997) and Sandorf (1999) who concluded: the highest concentrations of NO_3-N were in Jamestown Shores; the NO_3-N is derived primarily

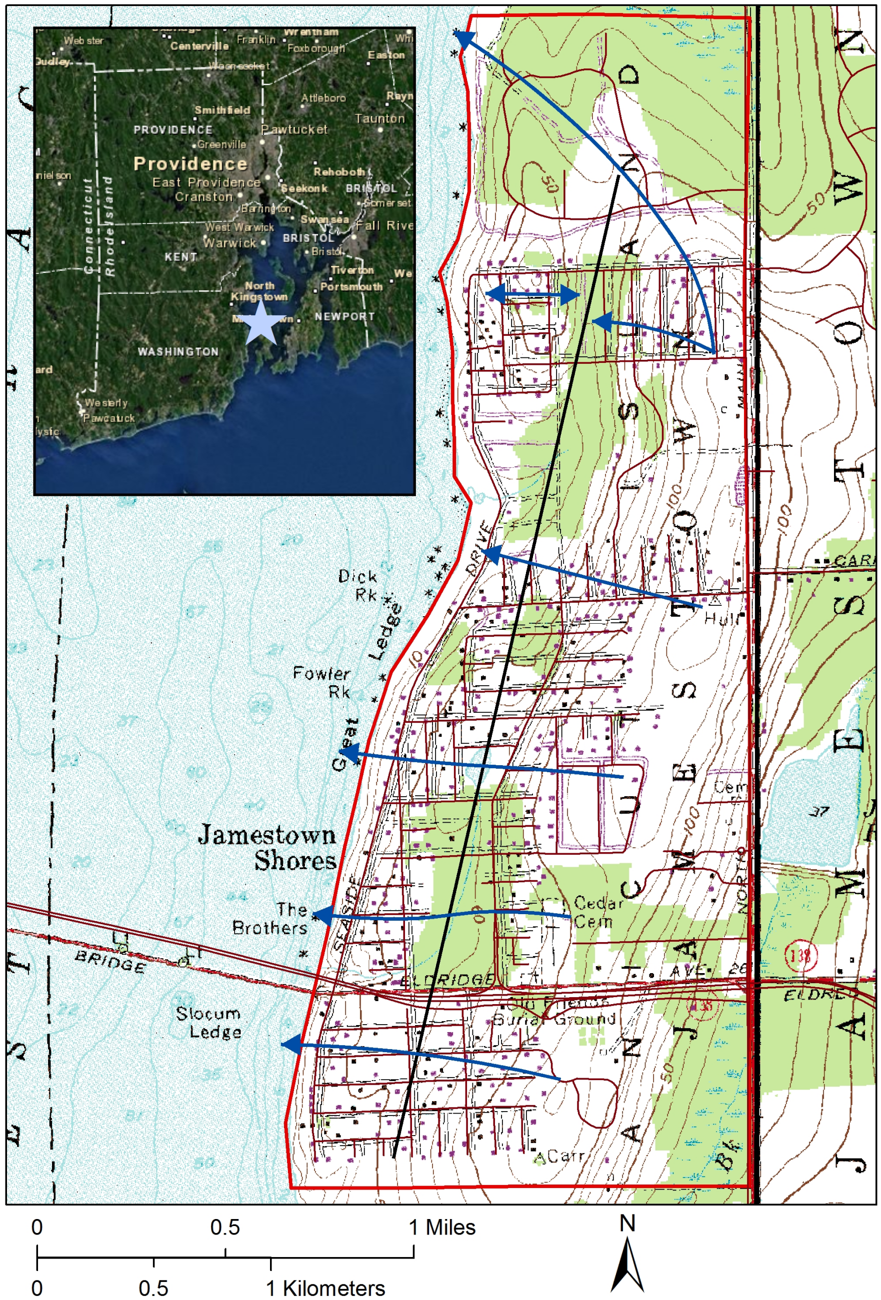


Figure 1. Location map for Jamestown Shores, Jamestown, RI with arrows depicting the approximate groundwater flow direction, and a northeast-southwest line showing the dominant fracture orientation (adapted from Veeger, 1997 and Michaud, 1998).

from OWTS (also Joubert, 2003); and there is a statistically significant increase in NO_3-N concentrations with decreasing lot size, specifically, smaller than one acre (0.4 hectare). Although the majority of the groundwater NO_3-N was determined to be from OWTS, lawn fertilizer and pet waste may also be contributors. Agriculture is not a significant land use in this area other than a few small areas of "pasture" (RIGIS, 2013); although, livestock can be a significant local source of nitrogen if present (U.K. DEFRA, 2009). The Town of Jamestown has implemented wastewater management strategies that include requiring denitrifying OWTS under certain development scenarios (Town of Jamestown, 2007). To assist with future planning, including potential increased regulations, the town would like to determine if the installed denitrifying OWTS have had an effect on the groundwater NO_3-N concentrations. Addressing the ground water contamination problem by extending the public water supply is not an option because the existing public supply system is at capacity; neither is sewering the area because the OWTS recharge the aquifer and hence help prevent salt-water intrusion (Veeger, et al., 1997). Denitrifying OWTS may therefore be the best long-term solution if they are effective at reducing the groundwater NO_3-N at a given level of implementation.

GEOLOGIC AND HYDROLOGIC SETTING

Conanicut Island is a bedrock island composed of primarily metasedimentary rocks of the Pennsylvanian-age (~300 MYA) Narragansett Bay Group and the Cambro-Ordivician (~500 MYA) Conanicut Group (Hermes et al., 1994). Jamestown Shores is located in the northwest part of the island underlain by Pennsylvanian metasedimentary rocks. This bedrock is highly fractured and overlain by 0 to 50 feet

(0 to 15 meters) of glacial till (GZA, 1986; Jim Turrene (NRCS), personal communication). Michaud (1998) determined the dominant fracture orientation in Jamestown Shores strikes north/northeast to south/southwest, with a dip to the east.

Average annual precipitation for the area was 51 inches (130 cm) in the years 1995-1997 and 60 inches (152 cm) in 2009-2011 (Kingston weather station, Carl Sawyer). Groundwater in Jamestown Shores flows primarily east to west through fractured bedrock, from the topographic high in eastern Jamestown Shores to Narragansett Bay at the western perimeter, as determined by water levels reported on OWTS applications; although, flow direction differs in a small area in the northern part and along the western boundary of Jamestown Shores (Veeger et al., 1997). Flow direction along the southwestern boundary may also be affected by the town's public water supply wells to the east (Joubert et al., 2013). Bedrock transmissivity estimates range from 40 to 2000 ft^2/day (3.7 to 186 m^2/day), with a median of 300 ft^2/day (28 m^2/day) (GZA, 1986 and Veeger et al., 1997) and hydraulic conductivity is estimated to be 1 ft/day (0.32 m/day) (GZA, 1986), indicating a relatively low water transmitting ability of the aquifer, comparable to that of silty sand (Freeze and Cherry, 1979). The water table on Conanicut Island is generally within the till layer, shallow during the wet season, from 0 to 13 feet (0 to 4 meters) below land surface, declining as low as 30 feet (8.3 meters) in late summer (GZA, 1986 and Veeger et al., 1997). Saltwater intrusion is a risk in some areas of the island because the freshwater/saltwater interface is shallow; under non-pumping conditions it is estimated to range from more than 500 feet in the center of the island to just a few tens of feet near the coast (Veeger et al., 1997).

CHAPTER 2

METHODS

WATER QUALITY DATA

Existing water quality data were used for this study. Groundwater samples were collected pre-treatment from residences in Jamestown Shores during four sample rounds: summer through fall of 1996 and 1997 (including all of Northern Jamestown), the fall of 2010, and the spring of 2011. Sample site distribution is not random; it was a result of the residents who volunteered to participate, and some were sampled in multiple years. Residents also completed a survey which provided additional data, including well depth when known. The 1996 and 1997 sample rounds were collected and analyzed for NO_3-N (minimum detection limit 0.5 mg/L) and other constituents by the University of Rhode Island Department of Geosciences and the 2010 and 2011 sample rounds were collected by the Town of Jamestown and analyzed for NO_3-N (minimum detection limit 0.05 mg/L) by the Rhode Island Department of Health Lab.

OWTS type and house built dates were provided by the Town of Jamestown (Unpublished Data: Town of Jamestown, 2013); precipitation data was provided by Carl Sawyer from the Kingston, RI weather station; and the buildings (“E911 Sites”), soils, and census Geographic Information System (GIS) shapefiles were retrieved from the Rhode Island Geographic Information System (RIGIS, 2013). Because each residence has an OWTS, the buildings (minus sheds, garages, etc.) were used as a proxy for OWTS distribution. Although the well and OWTS on each site is likely approximately 100 feet apart because of state regulations, the E-911 site points represent the location of both the OWTS and the well in this study.

GIS ANALYSIS

ESRI's ArcGIS 10.1 was used to compile and analyze data. Buffers were created around the NO_3-N sample sites to analyze the effects of housing density, percent denitrifying OWTS, and confounding variables on the groundwater NO_3-N result. The types of buffers are described in Table 2. The circle buffers were created for all of Northern Jamestown, in addition to Jamestown Shores, to compare with Sandorf's 1999 study by using housing density instead of lot size. The wedge buffers were created with the point at, and including, the sample site. The 400-foot (122-meter) radius was chosen because this is a minimum setback distance requirement for public drinking water wells (RIDEM, 2012) and is considered to cover the area of highest risk to water quality. Although the wells in the Jamestown Shores area are private, not public, the density is high which could cause interference, increasing the size of the capture zones. The 600-foot (183-meter) radius accounts for the fact that groundwater NO_3-N has been found to travel long distances (Canter and Knox, 1985; Robertson and Cherry, 1991), and that Donohue (2013) found similar results for both buffer sizes in the coastal town of Charlestown, RI. Buffer radii larger than 600 feet (183 meters) covered significantly more area outside of Jamestown Shores and were therefore not as representative of the area of interest.

Table 2. Buffers used in NO_3-N geostatistical analysis.

Buffer (radius)	**Jamestown Shores (Dates)**	**Northern Jamestown (Dates)**
Circle (400 ft/122 m)	1996-1997, 2010-2011	1996-1997
Circle (600 ft/183 m)	1996-1997, 2010-2011	1996-1997
90° Wedge Up-Groundwater Gradient (400 ft/122m)	1996-1997, 2010-2011	NA
90° Wedge Up-Fracture North to South (400 ft/122 m)	1996-1997, 2010-2011	NA
90° Wedge Up-Fracture South to North (400 ft/122 m)	1996-1997, 2010-2011	NA

The ArcGIS Overlay tool was used to identify the number of houses and denitrifying OWTS in each buffer. These values were calculated by the equations:

1) $H_d = \#houses/Area$

2) $DOWTS(\%) = \#DOWTS/TOWTS$

(where Hd is housing density, DOWTS is denitrifying OWTS and TOWTS is total OWTS)

For housing density, the 1996-1997 dataset was analyzed using only the houses with built dates prior to 1997, and the 2010-2011 dataset included all of the houses.

STATISTICAL ANALYSIS

Groundwater NO_3-N concentrations in Jamestown Shores were statistically analyzed temporally and spatially with Microsoft Excel 2008 and SAS 9.2. Groundwater NO_3-N results that were “non-detect” (ND) were changed to 0.5 mg/L for statistical analysis, as were any results less than 0.5 mg/L, because this is the highest minimum detection limit of all sample events. NO_3-N results from sites sampled in both 1996 and 1997 or both 2010 and 2011 were averaged. All statistical hypothesis tests were conducted at the 95% confidence level; therefore, the term “significant” refers to a p-value less than 0.05, except where explicitly stated. The statistical tests and analysis parameters are listed in Tables 3 and 4 below. Because the

Table 3. Statistical tests used and their parametric equivalent for reference.

Statistical Tests*	
Nonparametric Used	**Parametric Equivalent**
Kruskal-Wallis (KW)**	Analysis of Variance (ANOVA), T-Test
Spearman's Correlation Coefficient (SC)	Pearson's Correlation Coefficient (PC) (also used)
Kendall-Theil Robust Line (KT)#	Linear Regression
Normality: Shapiro-Wilk, as well as histograms and probability plots, on original and log-transformed NO_3-N data.	

*Helsel and Hirsch, 2002. ** The Kruskal-Walliis Test is the same as the Wilcoxon-Mann-Whitney Test when comparing only two groups.. #also Granato, 2006

Table 4. Statistical analysis performed on groundwater NO_3-N concentrations in Jamestown Shores. Statistical Test abbreviations are in Table 3 above.

Statistical Analysis Performed on Groundwater NO_3-N Concentrations in Jamestown Shores		
Analysis	**Statistical Test**	**Categorical Bins**
Temporal Trend		
Repeat sites from 1996 to 1997, from 2010 to 2011	PC	NA (continuous data)
Repeat sites 96-97 to 10-11	PC	NA (continuous data)
All sites 96-97 to 10-11	KW	96-97, 10-11
Spatial Trend (at the sample site or within the corresponding buffer)		
Housing density (buffer)	KW, SC, KT	0-0.9, 1-1.9, 2-2.9, 3-3.9 houses/acre (0-0.4, 0.4-0.8, 0.8-1.2, 1.2-1.6 houses/hectare)
% denit OWTS (buffer)*	KW, SC, KT	0, 1-24, 25-49, 50-100 %
Relative soil permeability (on-site)*	KW, SC, KT	Low, moderate, high
Well depth (on-site)*	KW, SC, KT	0-99, 100-199, 200+ ft (0-30, 30-61, 61+ m)
Expected NO_3-N concentration (buffer)	PC	NA (continuous data)

*NO3-N normalized by housing density. Denit = denitrifying.

data did not appear to be well described by a normal distribution, and some of the data were "censored" (below the lab minimum detection limit), nonparametric statistics were used for most analyses (Helsel and Hirsch, 2002). In all statistical analyses except for housing density, NO3-N was normalized (divided by) housing density because the amount of nitrogen loading from homes in each buffer is expected to be the largest driver of groundwater NO3-N concentration in wells.

Temporal Trend Analysis

Before evaluating trends between the two temporal datasets (1996-1997 vs. 2010-2011), a statistical test was conducted to determine seasonal or short-term variability, i.e. if there is a significant relationship between the repeat groundwater NO_3-N results in each pair of consecutive years (1996 vs. 1997 and 2010 vs. 2011). This repeatability was graphically analyzed using Bland-Altman Plots, which allowed a visual evaluation of variation against a horizontal zero-line (Bland and Altman, 1986). The temporal trends were then analyzed with the statistical tests listed in Table 3.

Spatial Trend Analysis – Housing Density and Percent Denitrifying OWTS

The groundwater NO_3-N concentration of each sample site was compared with the housing density in its corresponding buffer using the statistical tests listed in Table 3. The 1996-1997 and 2010-2011 datasets were analyzed for housing density, but only the 2010-2011 dataset was analyzed for percent denitrifying OWTS because the denitrifying OWTS did not exist in 1996-1997.

Spatial Trend Analysis – Relative Soil Permeability and Well Depth

The relative soil permeability of high, moderate, and low was designated based on the soil survey (USDA-NRCS, 2013) and communication with Rhode Island U.S.

Department of Agriculture Natural Resources Conservation Service staff and University of Rhode Island nonpoint source pollution and soil scientists (Jim Turenne, Lorraine Joubert, and Mark Stolt, personal communication). Relative soil permeability was assigned based on a combination of characteristics from the soil survey, including: Hydro Group; the material and permeability of the substratum; the presence of a "densic", "Cd", or "fragipan (Cx)" layer; hydric or not hydric designation; and water table depth. In general, the high soils are sandy with a low water table, the moderate soils are silt loams with seasonal high water table, and the low soils are hydric (Appendix A). Well depths were provided by a number of homeowners on the survey accompanying the sampling event.

Spatial Trend Analysis – Measured vs. Expected NO_3-N Concentrations

Expected groundwater NO_3-N concentration for the 2010-2011 time period was calculated from the following parameters: the number of conventional and denitrifying OWTS in each 400-foot (122-meter) circle buffer; an average population of 2.3 persons/housing unit (2010 Census); a nitrogen loading of 7 lbs (3.2 kg)/person/year N (6.3 lbs/person/year reaching groundwater) for conventional OWTS (Joubert et. al, 2003) and 2.58 lbs (1.2 kg)/person/year (a 59% reduction to drop from a 46 mg/L effluent concentration to RIDEM's required 19 mg/L) reaching groundwater for denitrifying OWTS (RIDEM, 2013); a water use of 50 gallons (6.7 ft^3)/person/day (Joubert et. al, 2003); and groundwater recharge, defined as average annual precipitation minus evapotranspiration and runoff for 2009-2011, of 18.2 inches/year (21 cm/year) (Joubert et. al, 2003, and Kingston weather station, Carl Sawyer). A more detailed explanation can be found in Appendix B. This expected concentration was compared with the measured concentration at each sample site for the 2010-2011 dataset, and the difference between the two mapped in GIS.

CHAPTER 3

RESULTS AND DISCUSSION

The descriptive statistics for groundwater NO_3-N concentrations in Jamestown Shores are shown in Table 5, including the percentage of results above the thresholds of 1 mg/L for background concentration, 5 mg/L for the U.S. EPA "action level", and 10 mg/L for the U.S. EPA MCL. Twenty-one of the samples were repeats (sampled at the same home) in both 1996 and 1997, 48 in both 2010 and 2011, and 26 in both 1996 or 1997 and 2010 or 2011. The results are shown in Figure 2.

Table 5. Groundwater NO_3-N range, mean, and median for each dataset in Jamestown Shores, RI.

Dates (M/YY)	Number of Samples	Min. NO_3-N (mg/L)	Max NO_3-N (mg/L)	Mean NO_3-N (mg/L)	Median NO_3-N (mg/L)	>1 mg/L (%)	>5 mg/L (%)	>10 mg/L (%)
6/96 – 8/96	66	<0.5	16.0	3.5	3.0	71	24	1.5
8/97 – 12/97	55	<0.5	11.0	3.8	4.0	75	27	1.8
11/10 – 12/10	81	<0.5	13.0	4.1	4.0	75	36	2.5
4/11 – 5/11	111	<0.5	12.7	4.1	3.9	79	32	0.9

TEMPORAL TRENDS

Repeatability of Consecutive-Year Datasets

The Bland-Altman Plots (Figure 3) show the 1996-1997 repeat results are generally close to the zero-line with the exception of two outliers, and many 2010-2011 repeat results are close to the zero-line but with more variability. A few of the

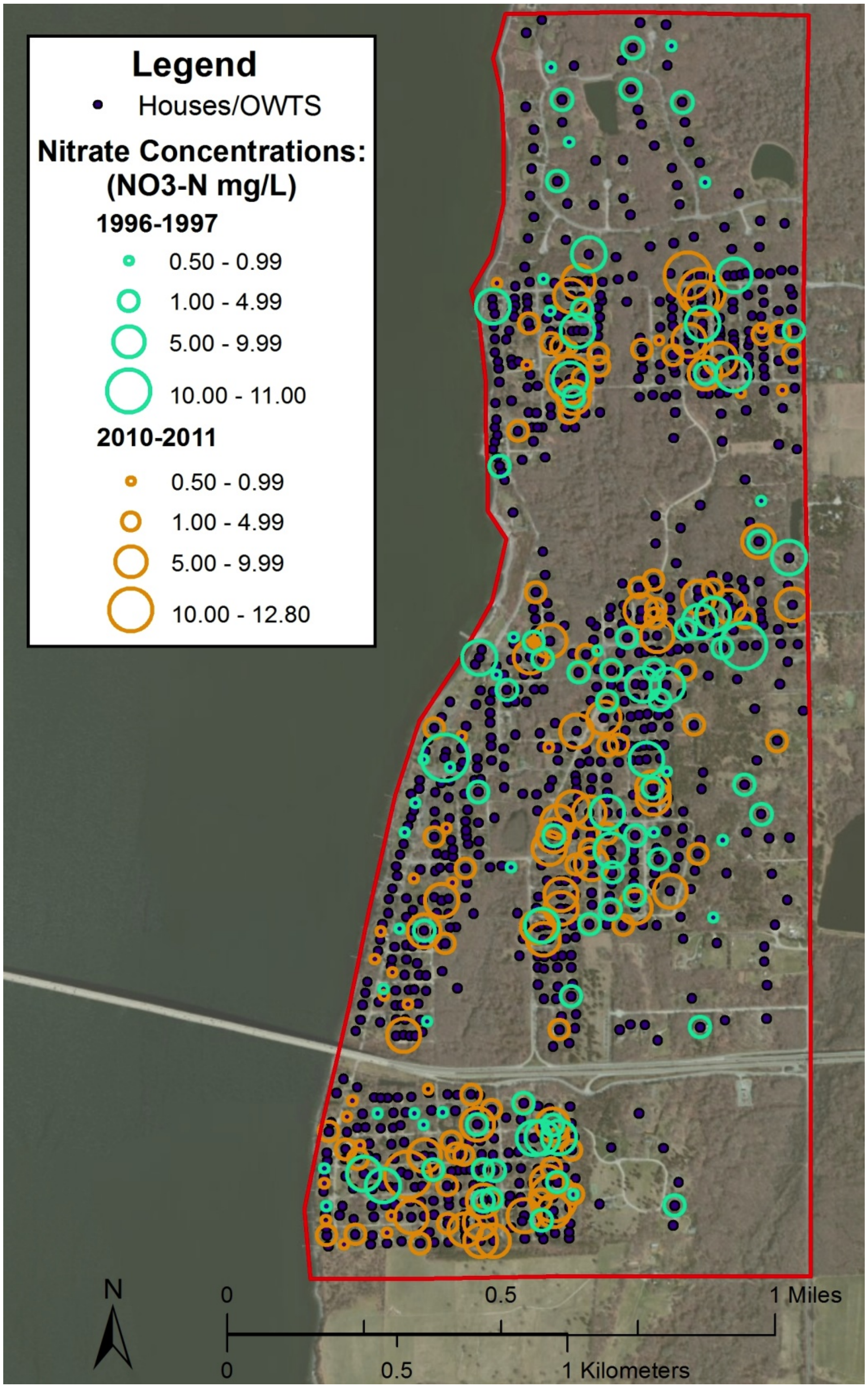
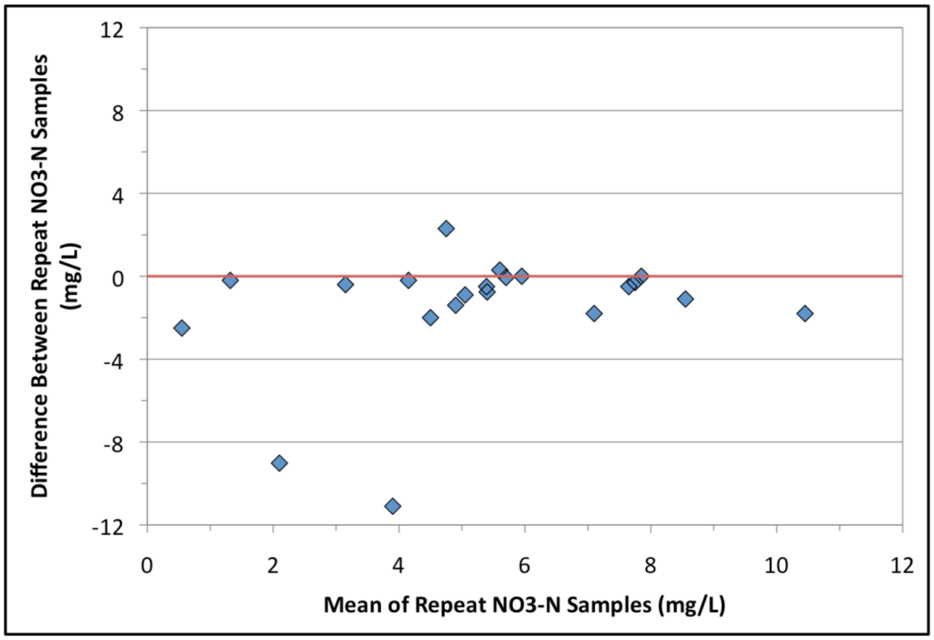


Figure 2. House/OWTS points and groundwater NO_3-N sample results for Jamestown Shores, RI in 1996-1997 and 2010-2011. Repeat samples in each consecutive-year dataset were averaged.

A) 1996-1997



B) 2010-2011

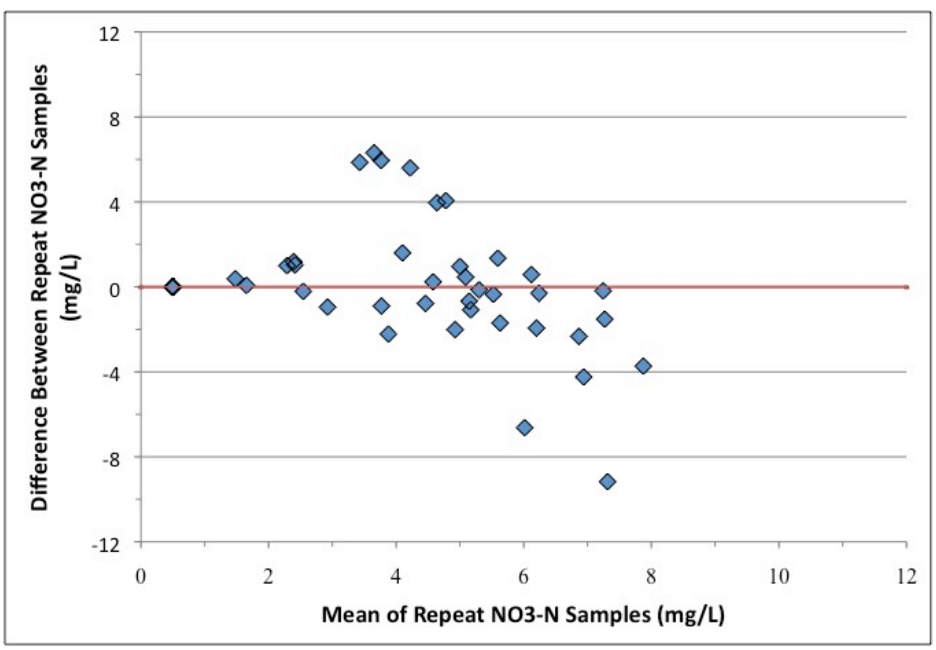


Figure 3. Bland-Altman Plots for repeatability of groundwater NO_3-N results in Jamestown Shores, RI. The difference between results from the same house in both years is plotted against the mean of those results. Points fall on the 0-line if no change occurs. Graph A is for 1996 and 1997 repeat results and Graph B is for 2010 and 2011 repeat results.

2010-2011 repeats varied significantly, some by an order of magnitude, which is possibly due to sampling/analysis error or an influx of NO_3-N due to precipitation/irrigation conditions and/or fertilizer application. The 1996 and 1997 datasets were both sampled summer through fall; however, 2010 was sampled in the fall and 2011 in the spring, which could capture seasonal changes. Despite some variability, the Pearson Correlation Coefficient was found to be significant for both consecutive-year datasets (Appendix B), which indicates seasonal or short-term variability is not statistically significant area-wide and we can have more confidence any water quality changes in results 15 years apart are due to anthropogenic modifications and not because of seasonal effects. This is consistent with a study performed in Oregon, which found considerable intra-well variability due to recharge events over the course of 15 months, but no statistically significant temporal variability area-wide, and attributed these findings to spatial heterogeneity in the subsurface as well as in land use (Mutti, 2007).

Temporal Trend Between the 15-Year Datasets

The box plot (Figure 4) shows an increase in groundwater NO_3-N from 1996-1997 to 2010-2011. This increase is not significant at the chosen 95% confidence level (Kruskal-Wallis Test $p = 0.0636$), although it would be significant at a confidence level of 90%. In addition, the scatter plot and Pearson's Correlation Coefficient ($p = 0.0001$) shows the repeat samples between the 15-year datasets are not significantly different (Figure 5). These tests indicate the groundwater NO_3-N did not significantly decrease between the 15-year datasets as hypothesized.

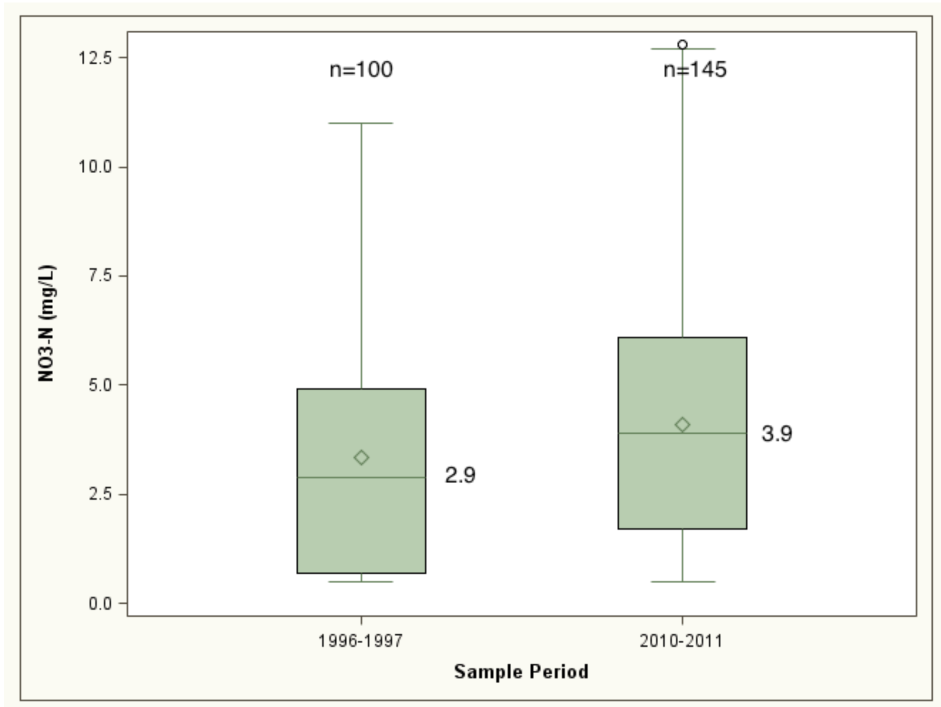


Figure 4. Groundwater NO_3-N concentration temporal trend from 1996-1997 to 2010-2011. The median value for each dataset is shown next to the median line. Repeat samples in each consecutive-year dataset were averaged. The Kruskal-Wallis Test p = 0.0636.

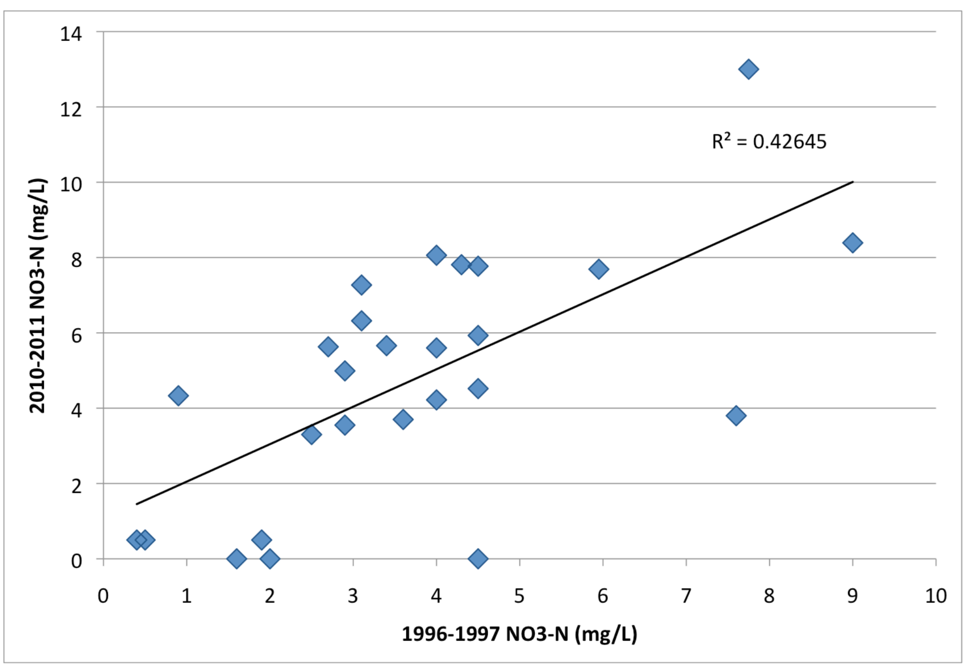


Figure 5. Repeatability of groundwater NO_3-N results sampled from the same sites in Jamestown Shores, RI in both 1996 or 1997 and 2010 or 2011. Pearson's Correlation Coefficient is 0.68760 (p=0.0001).

Travel Time

The response of well water quality to changes in land use is dependent on the age of the groundwater and the timing of the land use change (McMahon, et al., 2008; Rupert, 2008). The age of the well water in the Jamestown Shores wells is unknown, and the land use change was gradual over the 15 years. Figure 6 shows the annual percentage of the denitrifying OWTS installations between the two sampling periods. Travel time calculations are often used to determine how long it would take for a contaminant to move through the aquifer; however, the pumping of almost 1,000 wells in this area means much of the groundwater could be cycling through the domestic system instead of traveling away from the area. This, along with the fractured nature of the aquifer, and heterogeneous nature of the subsurface, makes an estimate of travel time difficult. It can be argued that a reduction in groundwater NO_3-N concentration is not seen because not enough time has passed for the denitrifying OWTS to have an effect; however, a discussion on how confounding variables can also affect this result is included later in the report.

SPATIAL TRENDS

Housing Density

The buffers used for spatial analysis are shown in Figure 7. In Jamestown Shores there is a more statistically significant increase in groundwater NO_3-N concentrations with housing density in the 400-foot (122-meter) radius circle and fracture buffers than in the 600-foot (183-meter) radius circle buffer, and no statistical significance in the up-groundwater gradient buffer (Figures 8 and 9 for a trend that is

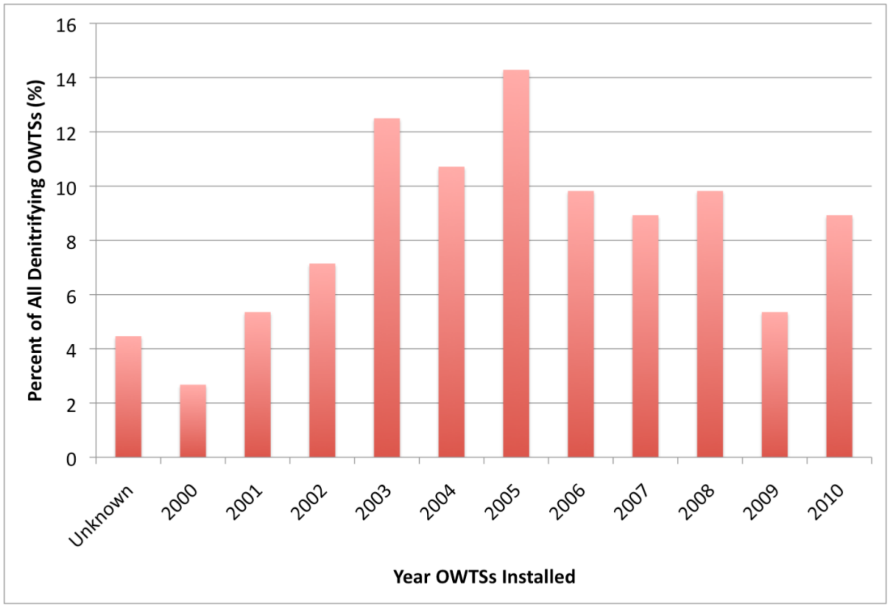


Figure 6. The percent of all denitrifying OWTS (112 total) installed per year.

statistically significant and a trend that is not statistically significant, also Table 6 and Appendix B). Also, these trends are more significant in the 1996-1997 dataset than the 2010-2011 dataset, possibly because of the variability of the data between the 2010 and 2011 datasets.

As shown on Table 6, the significance occurs both at less than vs. greater than 1 house/acre (1 house/0.4 hectares) and less than vs. greater than 2 houses/acre (2 houses/0.4 hectares) for some buffers and at one or the other for other buffers. This agrees with the groundwater NO_3-N analysis performed previously in this area (Sandorf, 1999), which determined a significant difference in NO_3-N between lot sizes less than 1 acre (0.4 hectares) and those greater than 1 acre (0.4 hectares), although Sandorf's study was more general in its analysis of lot sizes, whereas this study looked

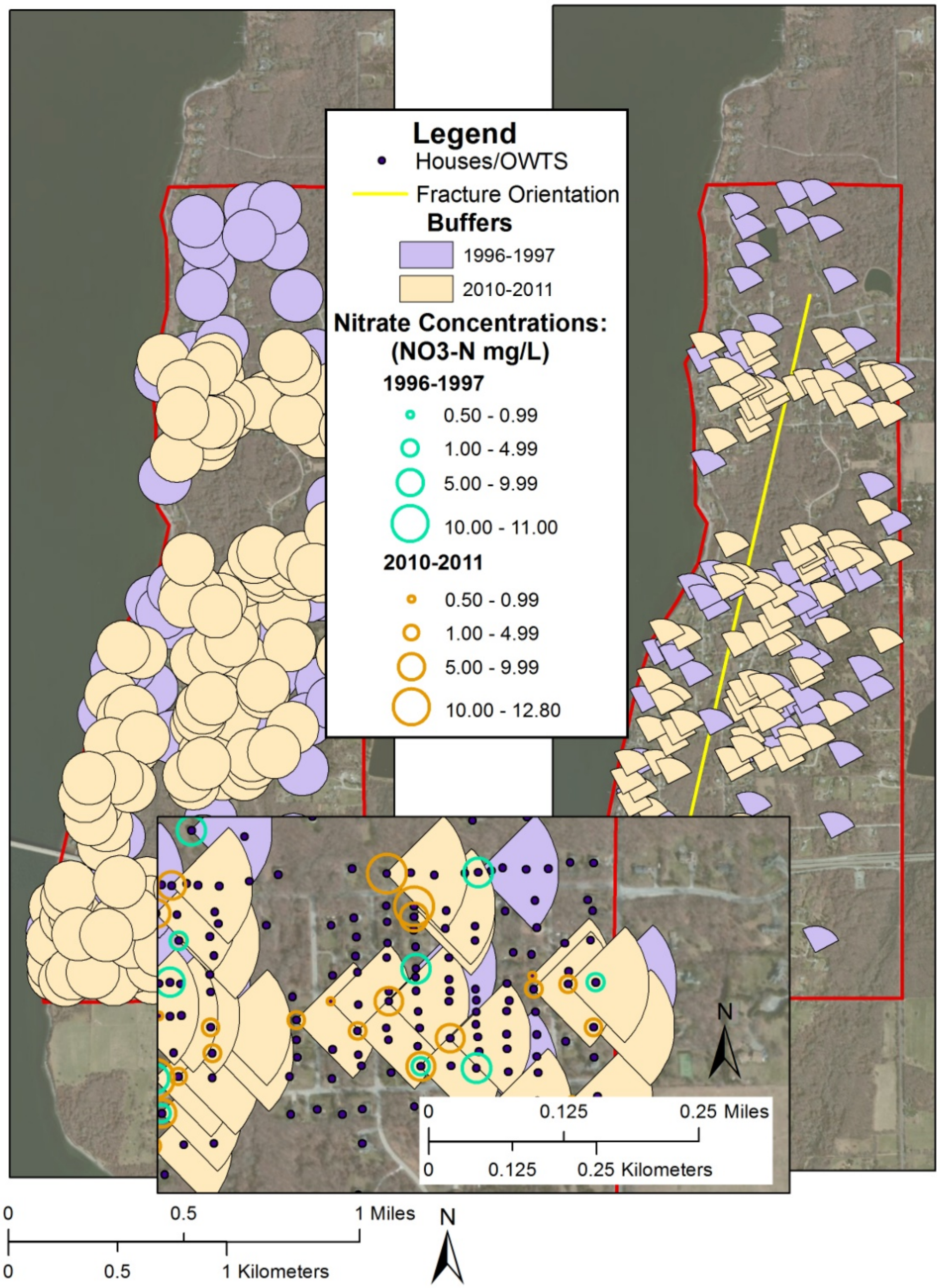
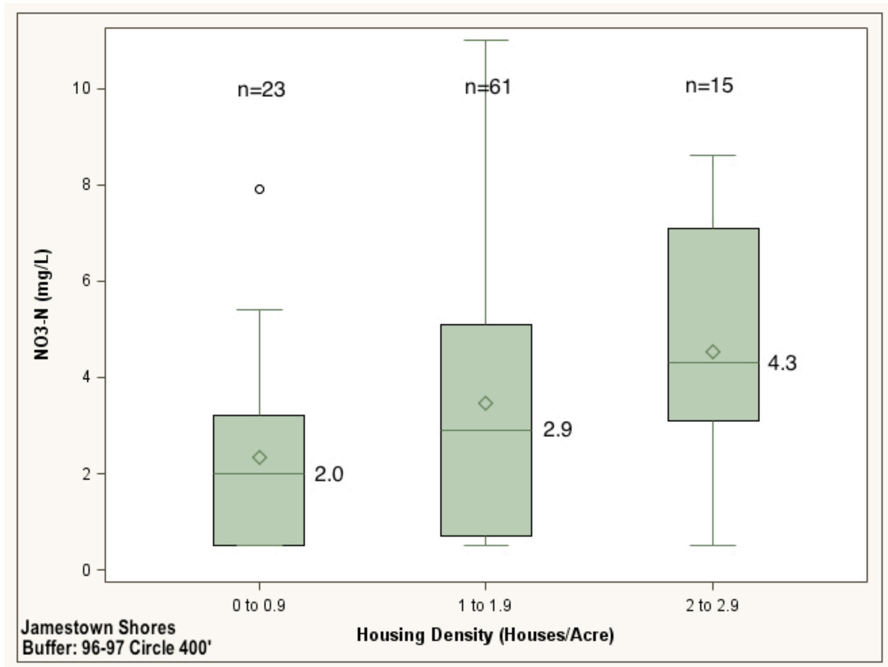


Figure 7. Maps of example buffers for each sample point in Jamestown Shores, RI, with 400-ft (122-meter) circle buffer in upper left and 400-ft (122-meter) up-fracture north to south buffer in upper right. Inset shows 400-ft (122-meter) up-groundwater gradient buffers with house/OWTS points and groundwater NO_3-N sample result symbols. Not shown are the 600-ft (183-meter) circle and up-fracture south to north buffers.

A)



B)

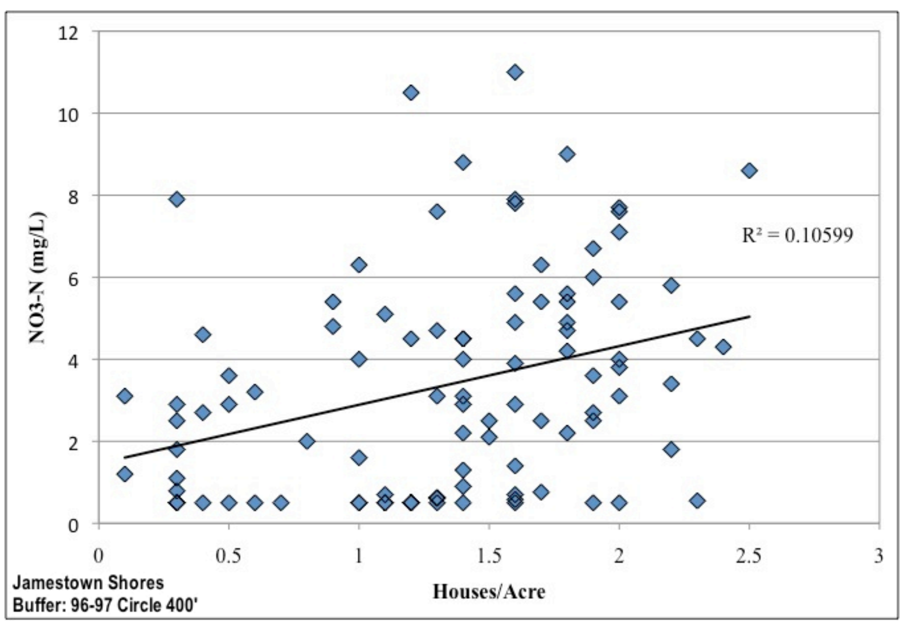
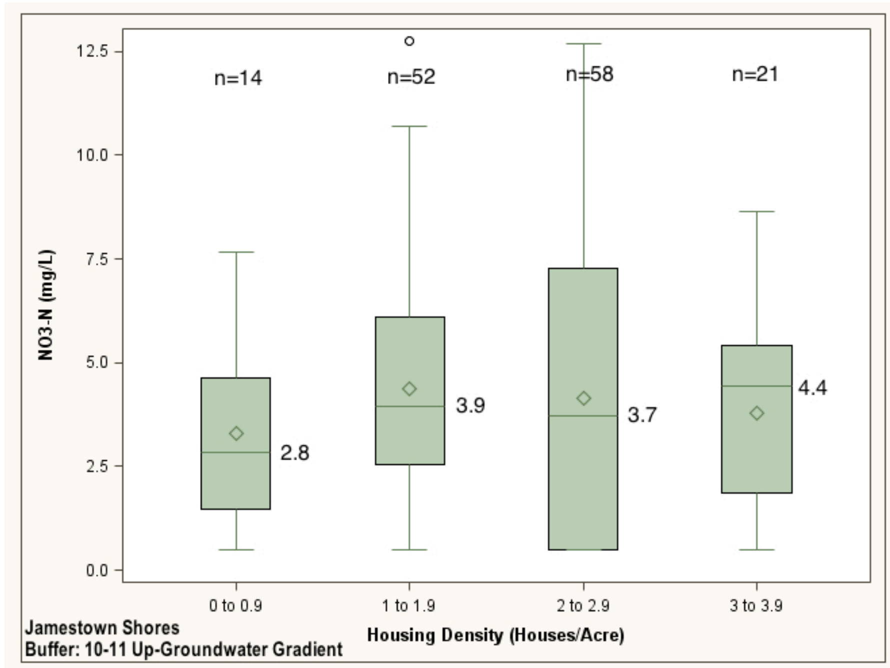


Figure 8. Groundwater NO_3-N concentrations compared with housing density bins (Graph A) and continuous housing density (Graph B) within the 400-ft (122-meter) radius circle buffers for the 1996-1997 dataset in Jamestown Shores, RI. The median value for each bin is shown next to the median line. For A, Kruskal-Wallis Test p = 0.0341. For B, Spearman's Correlation Test p=0.0002 and Kendall-Theil Robust Line confidence limits=2.25 to 0.4

A)



B)

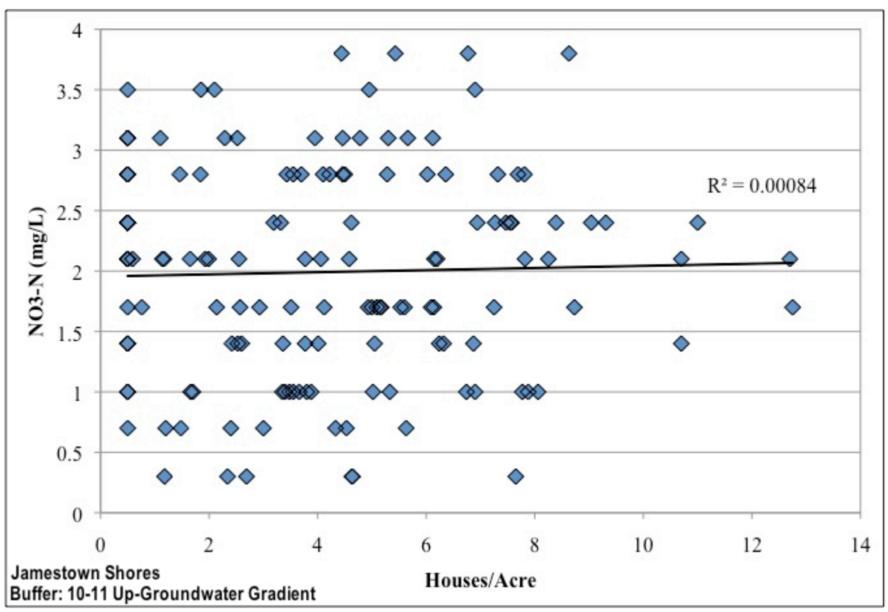


Figure 9. Groundwater NO_3-N concentrations compared with housing density bins (Graph A) and continuous housing density (Graph B) within the 400-ft (122-meter) up-groundwater gradient wedge buffers for the 2010-2011 dataset in Jamestown Shores, RI. The median value for each bin is shown next to the median line. For A, Kruskal-Wallis Test p=0.7048. For B, Spearman's Correlation Test p=0.8734 and Kendall-Theil Robust Line confidence limits=0.54 to -0.40.

Table 6. P-values for the relationship between NO_3-N and housing density in each buffer for the 1996-1997 and 2010-2011 datasets.

Buffer	**Data Set**	**Overall Significance (p at α=0.05)**	**Houses/Acre Kruskal-Wallis Significance (p at α=0.05)**				
			<1v≥1	<2v≥2	<1v≥2	<1v≥3	<2v≥3
C4NJ	96-97	**<0.0001 (KW)*** **<0.0001 (SC)*#**	**<0.0001 ***	**0.0020 ***	NA	NA	NA
C6NJ	96-97	**<0.0001 (KW)*** **<0.0001 (SC)*#**	**<0.0001 ***	NA	NA	NA	NA
C4JS	96-97	**0.0341 (KW)*** **0.0002 (SC)*#**	**0.0375 ***	**0.0456 ***	NA	NA	NA
C4JS	10-11	**0.0227 (KW)*** **0.0126 (SC)***	0.3781	**0.0066 ***	NA	NA	NA
C6JS	96-97	0.0752 (KW) **<0.0001 (SC)*#**	0.0752	NA	NA	NA	NA
C6JS	10-11	0.0704 (KW) **0.0088 (SC)***	0.3926	**0.0262 ***	NA	NA	NA
GW	96-97	0.1792 (KW) 0.2386 (SC)	0.0695	0.2554	0.0684	NA	NA
GW	10-11	0.7048 (KW) 0.8734 (SC)	0.4088	0.6270	0.7015	0.6369	NA
FrNS	96-97	**0.0044 (KW)*** **0.0005 (SC)*#**	**0.0041 ***	**0.0069 ***	NA	NA	NA
FrNS	10-11	0.1612 (KW) 0.0819 (SC)	0.2349	0.3070	0.2309	**0.0306 ***	**0.0262 ***
FrSN	96-97	**0.0034 (KW)*** **0.0037 (SC)*#**	0.0512	**0.0010 ***	NA	NA	NA
FrSN	10-11	0.3400 (KW) **0.0390 (SC)***	0.7960	0.2388	NA	0.2515	0.0725

Kruskal-Wallis (KW) p-values are for the housing density bins compared to each other all at once ("Overall") and also for pairwise comparisons , same as the Wilcoxon-Mann-Whitney Test, with different bin groupings ("Houses/Acre"). Spearman's Correlation (SC) p-values are for housing density as a continuous numerical parameter. P-values below an alpha of 0.05 are significant, in bold and noted with an asterisk (*). Slope significantly different from 0 (Kendall-Theil Robust Line) noted with a hashtag (#). C4=circle with 400-ft radius, C6=circle with 600-ft radius, NJ=Northern Jamestown, JS=Jamestown Shores, GW=wedge up-groundwater gradient, FrNS=wedge up-fracture orientation north to south.

in more detail at housing density surrounding each sample site. A recent study in Charlestown, RI found that lot sizes greater than 0.67 acres (0.27 hectares) (less than 1.5 houses/acre or 1.5 houses/0.4 hectares) were needed for NO_3-N concentrations below the 5 mg/L action level (Donohue, 2013). The geology in Charlestown is different however, with wells terminating in either unconsolidated overburden or fractured bedrock, whereas all the wells in this study terminate in fractured bedrock.

Groundwater generally flows perpendicular to water table contours; therefore, the lack of statistical significance with the up-groundwater gradient buffer was an unexpected finding. One reason for the insignificance could be that many wells and fractures in a small area could interfere and change local flow directions. The fracture orientation may be a more dominant driver of groundwater flow in this setting than the water table gradient. In addition, localized zones of contribution may be established around some wells if the pumping rate of the well is greater than the rate of groundwater flow (Ceric and Haitjema, 2005), as suggested by the significance of the 400-ft (122-meter) circle buffers.

In Jamestown Shores, the 600-ft (193-meter) circle buffers were only found to be significant for less than or greater than 2 houses/acre (2 houses/0.4 hectares) in 2010-2011 and not at all in 1996-1997, although there is significance at the 90% confidence level. Given the significance of the 400-ft (122-meter) circle buffer, this is likely because a larger buffer is more likely to cover a variety of housing density patterns, including low-density areas along the edges of Jamestown Shores. This indicates the groundwater NO_3-N at an individual well is controlled by more local conditions.

Percent Denitrifying OWTS

The distribution of the 112 denitrifying OWTS (13% of all OWTS) is shown on Fig. 10. Sixty-nine were installed for new homes, 42 replaced existing OWTS, and one is unknown. The other OWTS are conventional, sub-standard, or other types of OWTS that do not have denitrifying technology, and were not distinguished between each other because none of them are designed to remove a significant amount of nitrogen.

The percentage of denitrifying OWTS was compared with groundwater NO_3-N normalized by housing density for all buffers. Normalization was used because the effects of denitrifying OWTS are dependent on the housing density. For example, 50 percent denitrifying OWTS is expected to affect groundwater NO_3-N results differently if there is one denitrifying OWTS and one conventional OWTS than if there are 10 denitrifying OWTS and 10 conventional OWTS within the same area.

Normalized groundwater NO_3-N was found, by two out of three statistical tests, to improve (have a significant decreasing trend) with percent denitrifying OWTS in the up-groundwater gradient buffer (Figures 11 and 12 for a trend that is statistically significant and a trend that is not statistically significant, also Table 7 and Appendix B). One out of three statistical tests found significant improvement with denitrifying OWTS in the 400-ft (122-meter) circle buffer, as well as both fracture directions, although the Spearman's Correlation test would be considered significant at the 90% confidence level. This improvement was seen in the jump from zero denitrifying OWTS in the buffers to at least one denitrifying OWTS. A statistically significant improvement in normalized NO_3-N was only found with further increase of

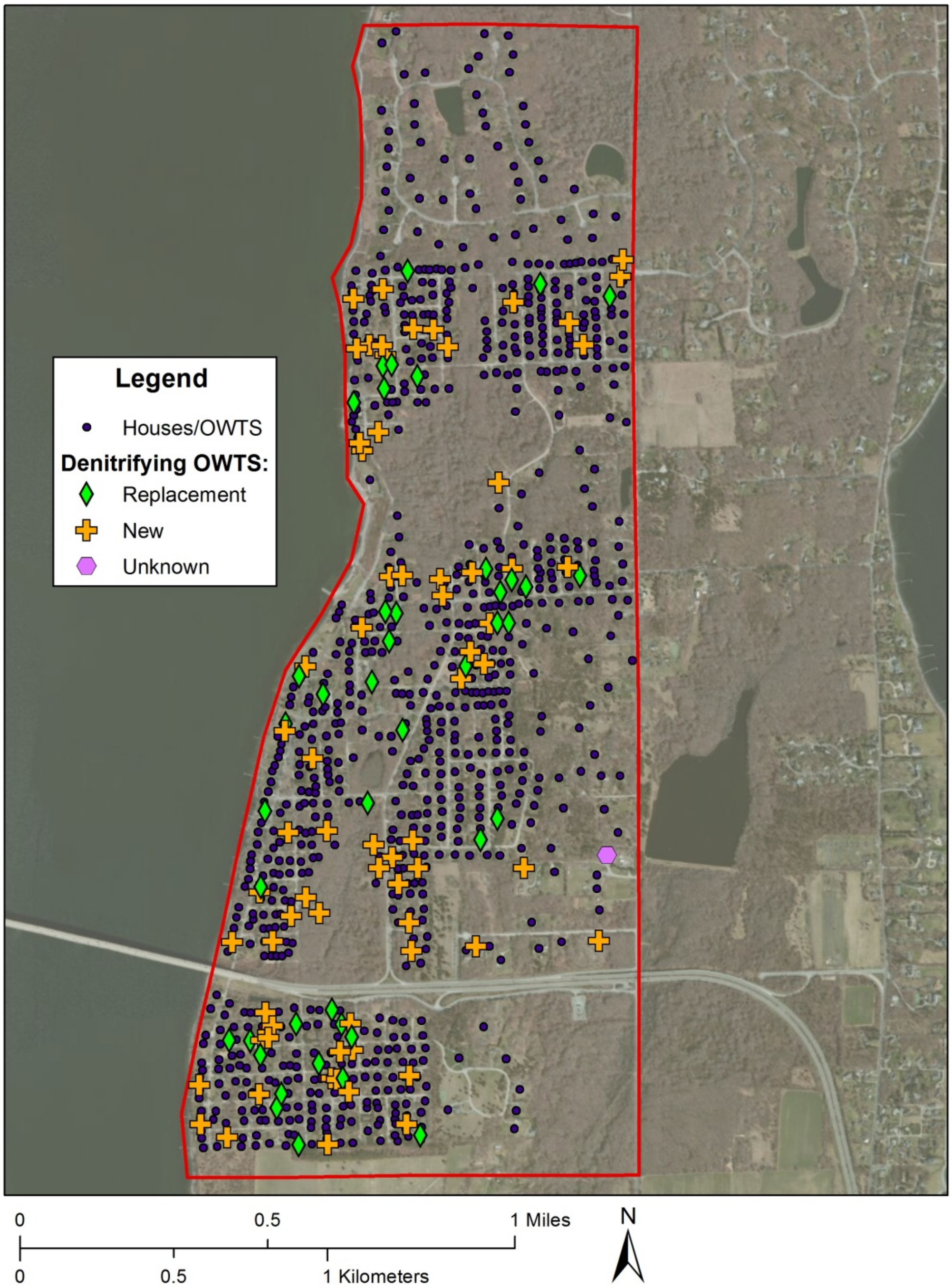
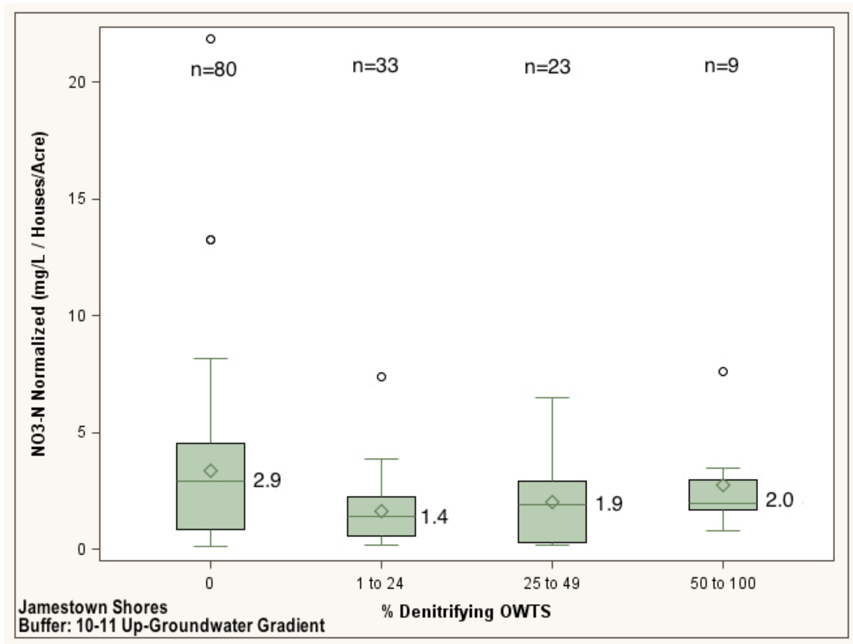


Figure 10. Distribution of OWTS in Jamestown Shores, RI, including denitrifying OWTS that have replaced existing OWTS, new construction OWTS, and other types of OWTS (conventional/sub-standard) that do not have denitrifying technology.

A)



B)

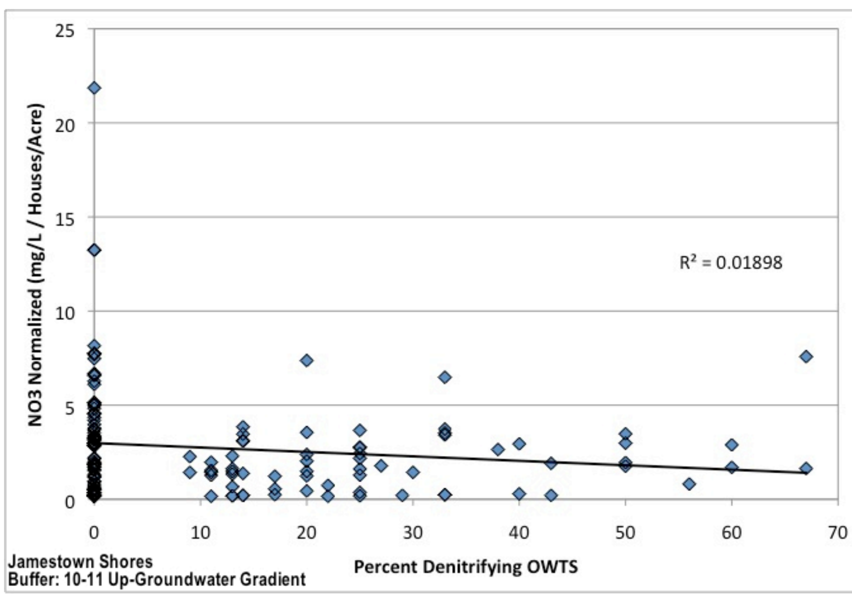
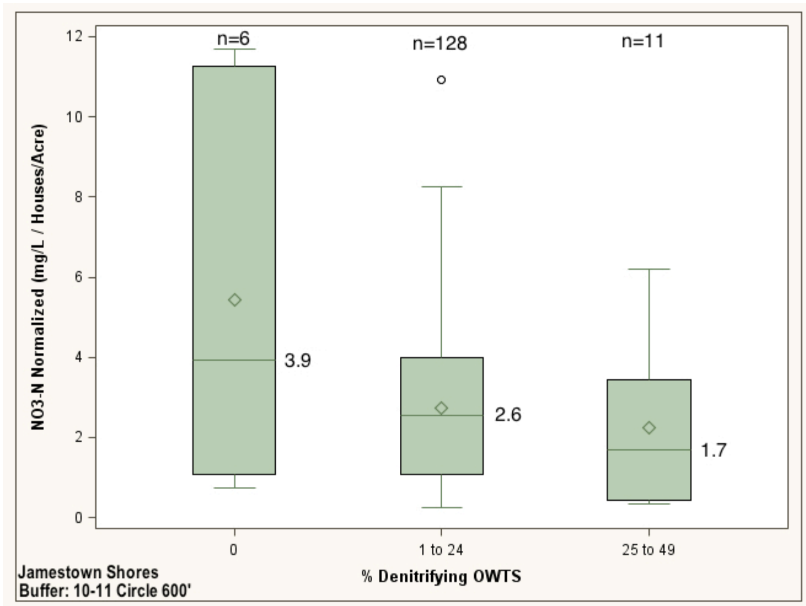


Figure 11. Groundwater NO_3-N concentrations normalized by housing density and compared with bins of the percentage of denitrifying OWTS (Graph A) and the continuous percentage of denitrifying OWTS within each 400-ft (122-meter) up-groundwater gradient buffer for the 2010-2011 dataset in Jamestown Shores, RI. The median value for each bin is shown next to the median line. For A, Kruskal-Wallis Test p=0.0127. For B, Spearman's Correlation p=0.0331 and Kendall-Theil Robust Line confidence limits=0.00120 to -0.0357.

A)



B)

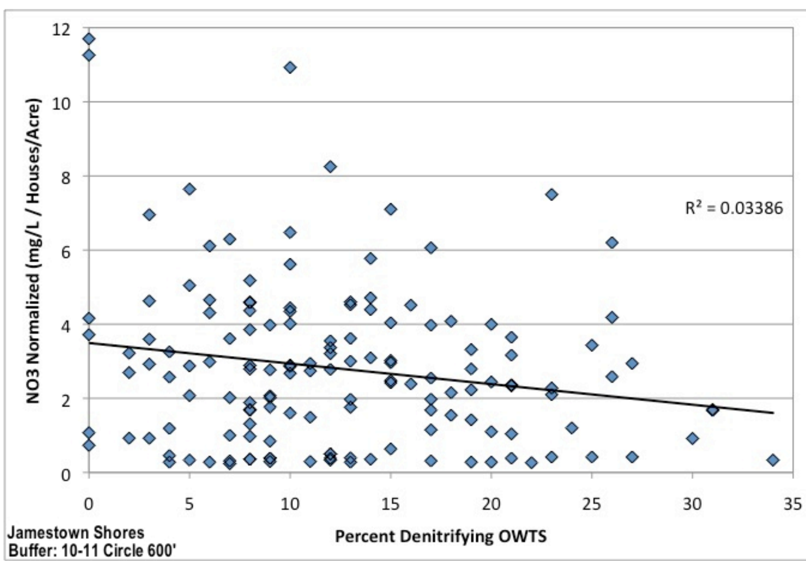


Figure 12. Groundwater NO_3-N concentrations normalized by housing density and compared with bins of the percentage of denitrifying OWTS (Graph A) and the continuous percentage of denitrifying OWTS (Graph B) within each 600-ft (183-meter) circle buffer for the 2010-2011 dataset in Jamestown Shores, RI. The median value for each bin is shown next to the median line. For A, the results look visually significant, but the plot is deceiving because of the low number of observations in the first and third bins and the non-normality of the data, and the Kruskal-Wallis Test is not statistically significant at p=0.3115. For B, Spearman's Correlation p=0.1509 and Kendall-Theil Robust Line confidence limits=0.00625 to -0.0700.

Table 7. P-values for the relationship between groundwater NO_3-N, normalized by housing density, and the percentage of denitrifying OWTS in each buffer for the 2010-2011 dataset.

Buffer	Overall **Significance (p at α=0.05)**	Percent Denitrifying OWTS Kruskal-Wallis Significance **(p at α=0.05)**		
		0 v ≥1	<25 v ≥25	<50 v ≥50
C400	**0.0382 (KW)*** 0.0873 (SC)	**0.0225***	0.3952	NA
C600	0.3115 (KW) 0.1509 (SC)	0.1676	0.4620	NA
UpGW	**0.0127 (KW)* 0.0331 (SC)***	**0.0049***	0.5867	0.5415
UpFrNS	**0.0031 (KW)*** 0.0558 (SC)	**0.0197***	0.1595	**0.0349***
UpFrSN	**0.0319 (KW)*** 0.0991 (SC)	**0.0133***	0.8549	0.5954

Kruskal-Wallis (KW) p-values are for the percent denitrifying OWTS bins compared to each other all at once ("Overall") and **also for pairwise comparisons , same as the Wilcoxon-Mann-Whitney Test,** with different bin groupings ("Percent Denitrifying OWTS"). Spearman's Correlation (SC) p-values are for percent denitrifying OWTS as a continuous numerical parameter. P-values below an alpha of 0.05 are significant, in bold and noted with an asterisk (*). Slope significantly different from 0 (Kendall-Theil Robust Line) noted with a hashtag (#). C400 = circle and radius in feet, UpGW = wedge up-groundwater gradient, UpFrNS = wedge up-fracture orientation north to south.

denitrifying systems within the buffers in the north to south fracture direction. As with housing density, normalized NO_3-N was not found to have a significant trend with percent denitrifying OWTS in 600-ft (183-meter) circle buffer. These results imply that although the trend is not as significant as housing density, having at least one denitrifying septic system in the surrounding area within 400 feet (122 meters) positively correlates with improved groundwater NO_3-N concentrations.

For both the housing density and percent denitrifying OWTS Kruskal-Wallis tests, all bins meet the minimum recommended sample size of n = 5; however in many cases there was great variability in sample sizes between the bins. For example, although a statistically significant improvement in normalized NO_3-N was found between less than and greater than 50% denitrifying OWTS within the north to south fracture buffers, there were 139 buffers with less than 50% denitrifying OWTS and only six with greater than 50%. The sample sizes are included on the box plots in the report and in Appendix B.

Measured vs. Expected NO_3-N Concentrations

To compare the 2010-2011 measured groundwater NO_3-N concentrations with what would be expected from nitrogen input from OWTS, expected nitrogen loading was calculated for the entire Jamestown Shores area as well as for each buffer using 7 lbs (3.2 kg)/person/year N (6.3 lbs/person/year reaching groundwater) and 50 gal (6.7 ft^3)/person/day water use (Appendix B). Although nitrogen loading and water use rates can vary, these values were used to complement the MANAGE model performed for Jamestown in 2003 (Joubert et. al, 2003). The loading for the denitrifying OWTS was calculated with a 59% reduction in N input to reduce the effluent concentration from 46 mg/L to the regulatory requirement of 19 mg/L. The resulting expected average groundwater NO_3-N concentration for Jamestown Shores if all houses were occupied is 3.9 mg/L, which is slightly less than the observed mean for the 2010-2011 dataset of 4.1 mg/L and closer to the observed median of 4.0 mg/L. The difference between expected and measured is shown in Figure 13. The Pearson's Correlation was found to be statistically significant (Figure 14A), although the Bland-Altman Plot (Figure 14B) shows a trend wherein the expected values over-estimate concentrations in low housing-density areas and underestimate concentrations in high housing-density areas.

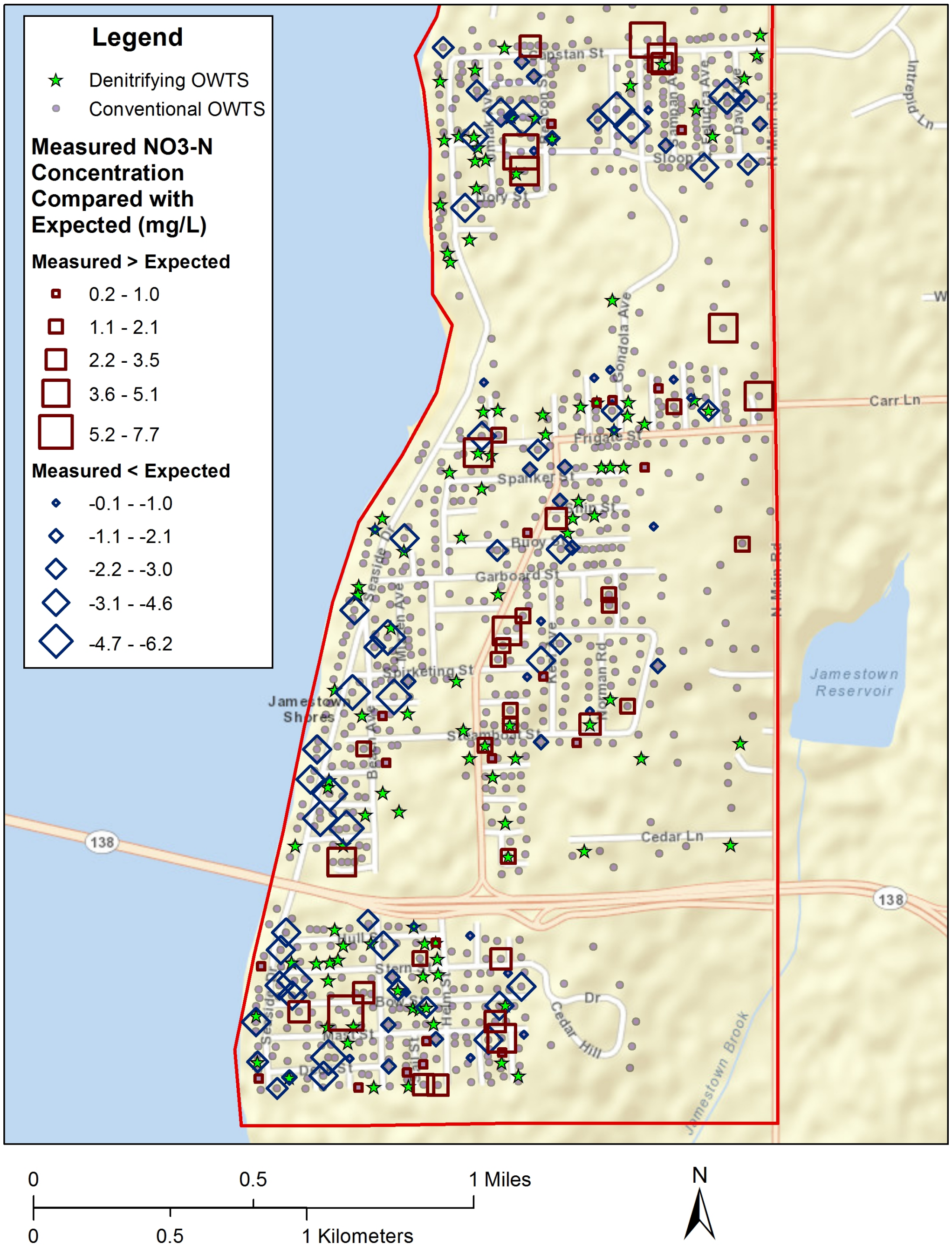
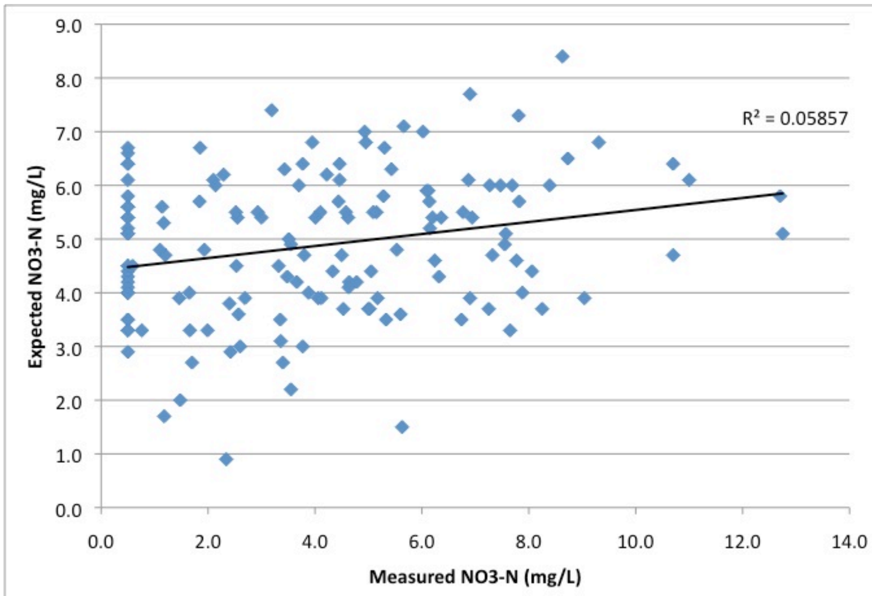


Figure 13. The difference between the measured NO_3-N concentration in the 2010-2011 dataset and the expected concentration given nitrogen loading from the number of conventional and denitrifying OWTS in each 400-ft (122-meter) circle buffer in Jamestown Shores, RI.

A)



B)

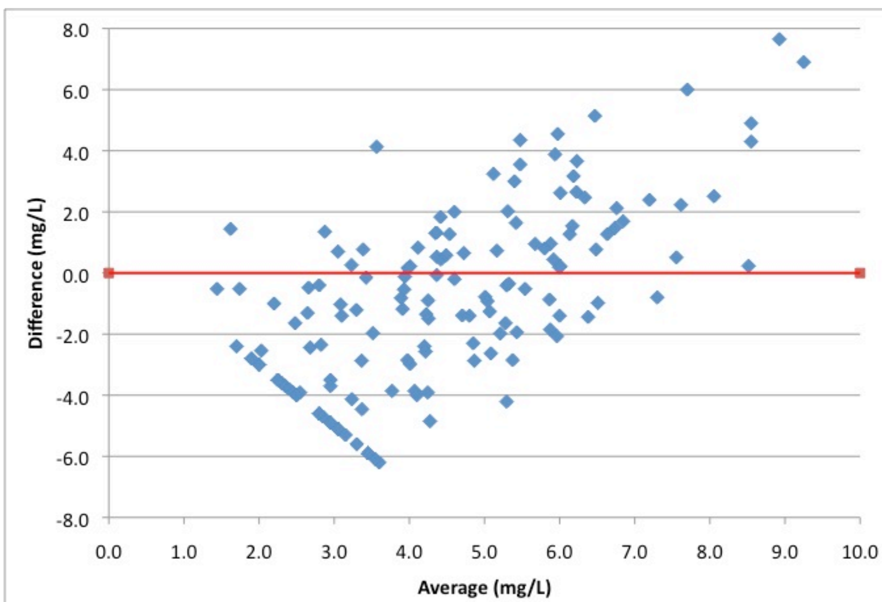


Figure 14. Comparison of measured NO_3-N concentrations from the 2010-2011 dataset with concentrations expected from the number of conventional and denitrifying OWTS in each 400-ft (122-meter) circle buffer in Jamestown Shores, RI. For Graph A, Pearson's Correlation p=0.0034. Graph B is the difference between the measured and expected NO_3-N concentrations is plotted against the mean of those concentrations. Points fall on the 0-line if there is no difference.

Despite the significant correlation overall, there are many sites with large differences which implies confounding variables play a greater role in these areas or, in the case of a low measured concentration compared to expected concentration, the groundwater is not strongly influenced by anthropogenic activity.

The town can use this finding for planning purposes to determine where more denitrifying OWTS, or other measures such as increased fertilizer education, may be needed. For example, three wells with high NO_3-N were chosen to compare expected NO_3-N concentration given present OWTS conditions with the concentration if all OWTS were denitrifying (Table 8). Two of these wells have higher surrounding housing densities but one with a measured concentration much higher than expected given present conditions, and one with only 0.2 mg/L difference between measured and expected presently. The third well has a moderately-low surrounding housing density. At the Mast Street well, if all conventional OWTS were converted to denitrifying OWTS, the measured NO_3-N concentration would be just under the MCL, but at 75% denitrifying OWTS it would still be over. At the Sail Street well, the housing density is less and the measured concentration starts between the action level and MCL; installing all denitrifying OWTS will reduce it to just under the action level, but at 75% denitrifying OWTS it would still be over. In both of these cases, the measured concentration is much higher than expected from present OWTS nitrogen contribution alone. The Sampan Avenue well has very high housing density, but there is only a 0.2 mg/L difference between the concentration measured and the concentration expected presently, and if 75% to 100% of conventional OWTS were

Table 8. Examples of expected NO_3-N concentration if all conventional OWTS were replaced with denitrifying OWTS.

Measured Parameter	**Mast Street**	**Sail Street**	**Sampan Ave**
# of conventional OWTS	21	14	34
# of denitrifying OWTS	4 (16%)	1 (7%)	2 (8%)
Housing density (houses/acre)	2.2	1.3	3.1
Measured concentration	12.7 mg/L	6.9 mg/L	8.6 mg/L
Expected conc (presently)	5.8 mg/L	3.9 mg/L	8.4 mg/L
Expected conc (if 25% denitrifying OWTS)	5.5 mg/L	3.5 mg/L	7.4 mg/L
Expected conc (50%)	4.5 mg/L	2.9 mg/L	6.1 mg/L
Expected conc (75%)	3.6 mg/L	2.3 mg/L	4.8 mg/L
Expected conc (if 100% denitrifying OWTS)	2.6 mg/L	1.7 mg/L	3.5 mg/L
Difference btw expected presently and expected if 100% denitrifying OWTS	3.2 mg/L	2.2 mg/L	5.0 mg/L
Expected reduction in measured conc if 100% denitrifying OWTS	12.7 - 3.2 = 9.5 mg/L	6.9 – 2.2 = 4.7 mg/L	8.6 – 5.0 = 3.6 mg/L

replaced with denitrifying OWTS, the measured concentration would drop from above the action level to below, but at 25% to 50% it would still be over. Figure 15 shows what should be expected at the highest, median, and lowest density areas: at the most dense buffer area, the expected NO_3-N concentration will only decrease less than the action level if 75% of houses had denitrifying OWTS. The median density areas can achieve this with 25% denitrifying OWTS and the lowest density should be below background concentrations at all times. The distribution of density and the percentage of denitrifying OWTS required to achieve groundwater NO_3-N concentrations below the action level is shown in Figure 16.

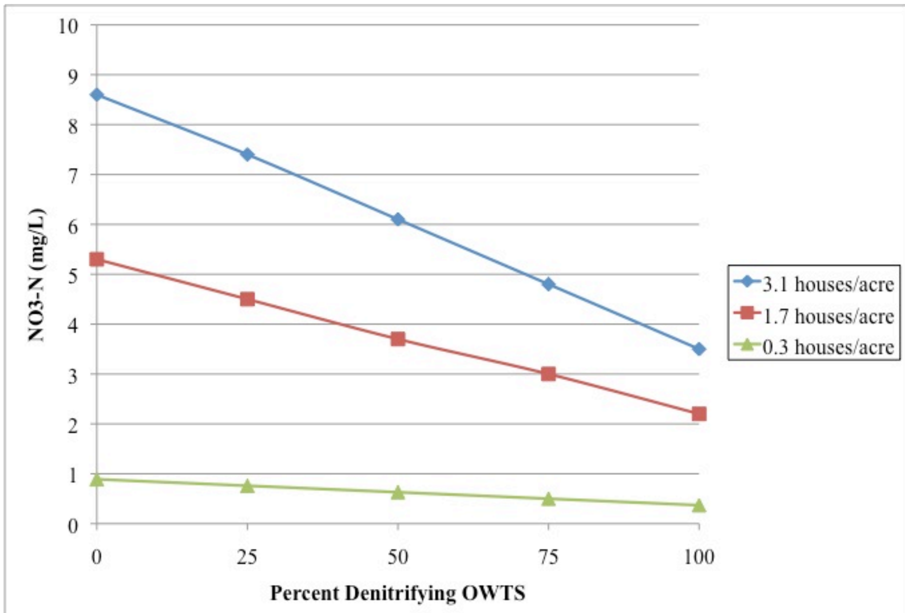


Figure 15. Change in expected NO_3-N concentration with percent denitrifying OWTS for the maximum, median, and minimum housing densities within the 400-ft radius circle buffers in Jamestown Shores, Jamestown, RI. Given a buffer area of 11.54 acres, 3.1 houses/acre is 36 houses, 1.7 houses/acre is 20 houses, and 0.3 houses/acre is 3 houses. No other sources of NO_3-N are considered.

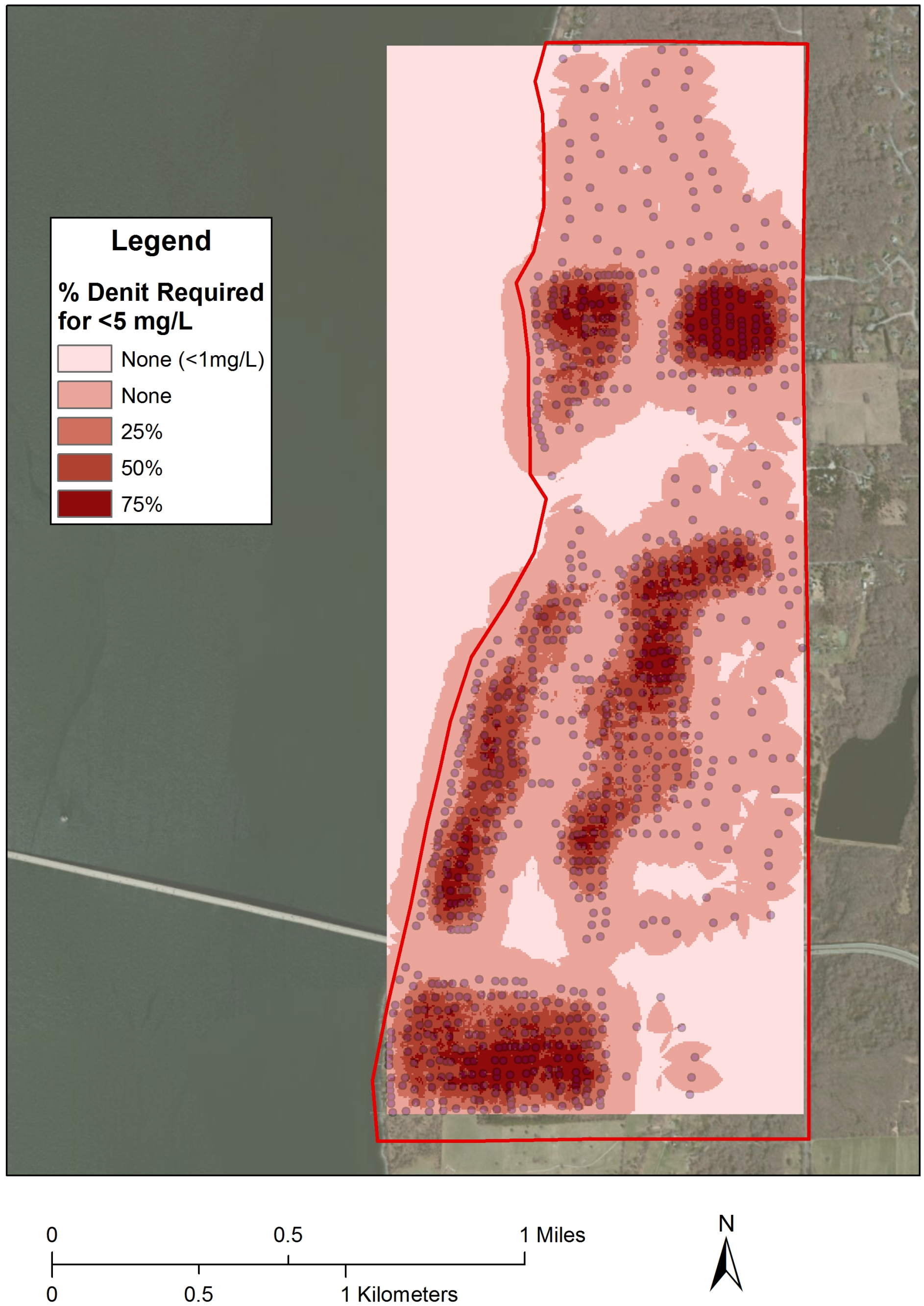


Figure 16. Percentage of denitrifying OWTS required within a 400-foot radius to achieve groundwater NO_3-N concentrations less than the action level of 5 mg/L. Zero to 1.4 houses/acre require no denitrifying OWTS, 1.5 to 1.9 require 25%, 2.0 to 2.3 require 50%, and 2.4 to 3.1 require 75%. Also, the lightest areas, <0.3 houses/acre, are those where groundwater NO_3-N should be less than the background concentration (1 mg/L) even without denitrifying OWTS.

SELECT CONFOUNDING VARIABLE ANALYSIS

Soil Permeability

Soil is the first line of defense for nitrogen degradation once it leaves the OWTS. Lower soil permeability increases the residence time and improves the potential for denitrifying conditions under anoxic conditions; therefore groundwater NO_3-N concentrations in relatively low permeability soils are expected to be lower than in relatively high permeability soils (Nolan, 2001). In addition, the presence of a restrictive (low permeability) layer near the surface could prevent recharge to groundwater, instead creating runoff to other areas or surface water bodies (Art Gold, personal communication). The assignment of relative soil permeability in Jamestown Shores is categorized in Appendix A and the distribution is shown in Fig. 17. Few residences are located in the hydric (low permeability) soils because a shallow water table can cause OWTS failure (Gold and Sims, 2000) and RI DEM permits are normally not granted in these areas. At first glance, groundwater NO_3-N was found to have a significant increasing trend from low to high permeability in both datasets (Figure 18). Although the Low bin is too small to statistically analyze (n=4), there is still a statistically significant trend when combining the Low and Moderate bins and comparing them with the High bin. After normalizing groundwater NO_3-N by housing density, however, a significant relationship was not found (Figure 19). Although not considered statistically significant because of the small sample size of the Low bin, it is worth noting that the NO_3-N concentrations in the wells underlying the Low soils were considerably lower than for the other soils; however, the difference between the original and normalized analysis implies that housing density is a stronger driver of NO_3-N concentration than relative soil permeability. These results are similar to the findings of the 1999 USGS study of public-supply wells in Rhode Island (USGS, 1999), which found that, within the wellhead protection areas, soils with high permeability or high leaching potential do not significantly correlate with elevated nitrate concentrations.

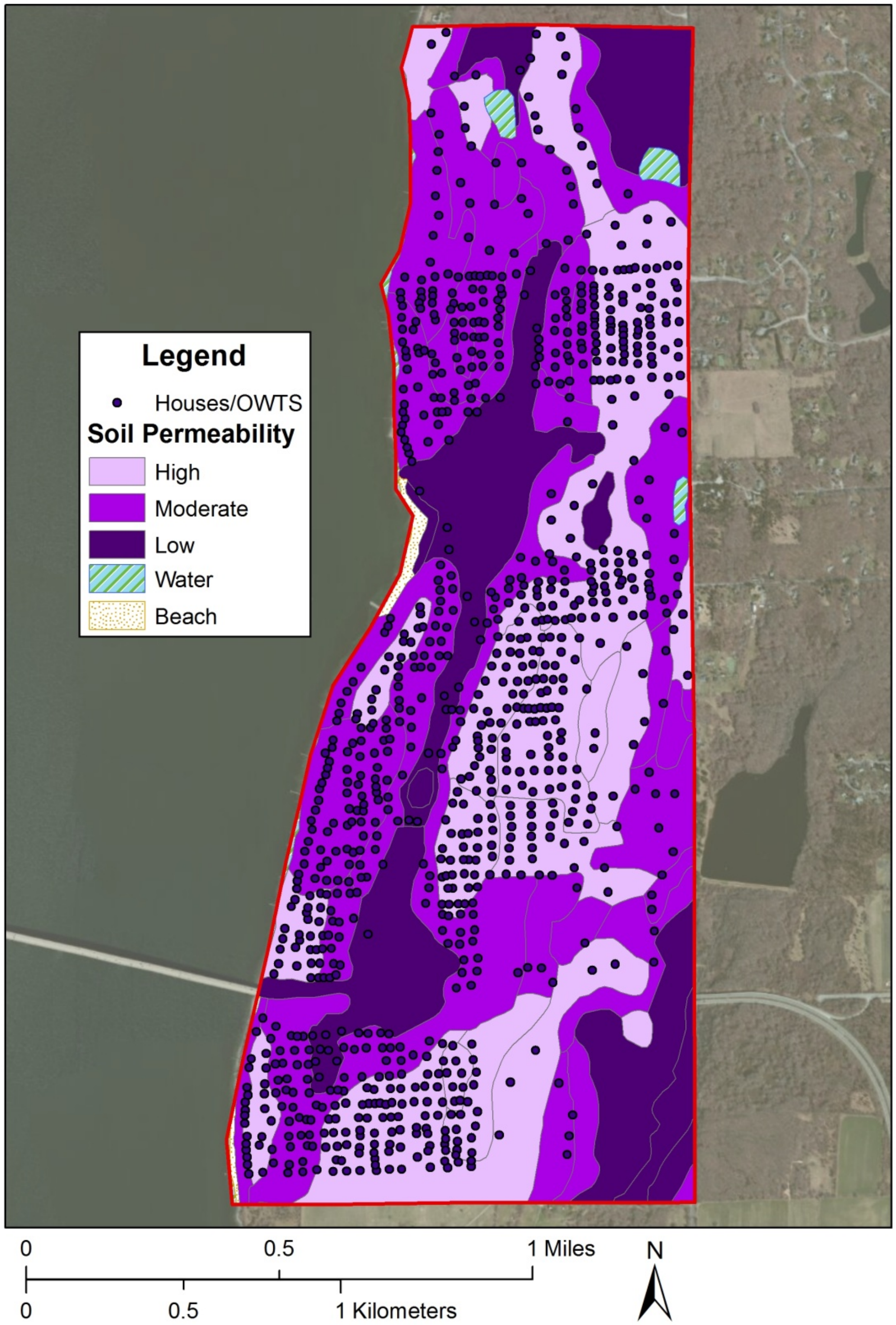
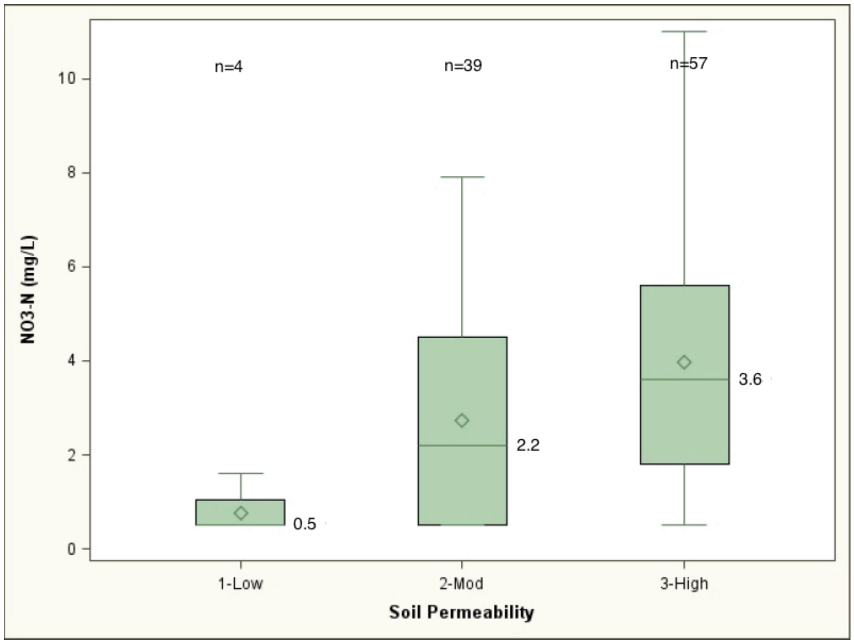


Figure 17. Relative soil permeability in Jamestown Shores, RI, categorized into high, moderate, and low permeability.

A) 1996-1997



B) 2010-2011

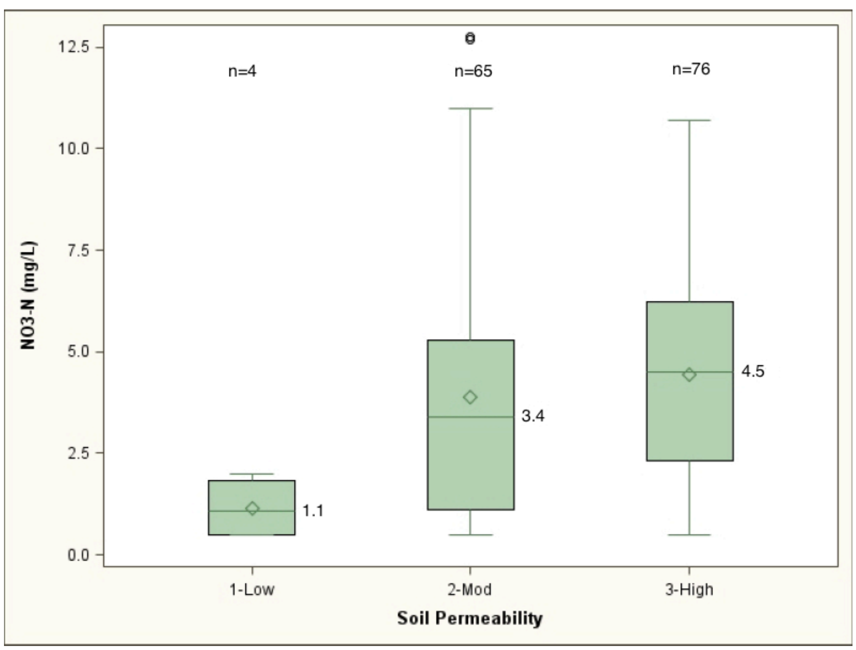
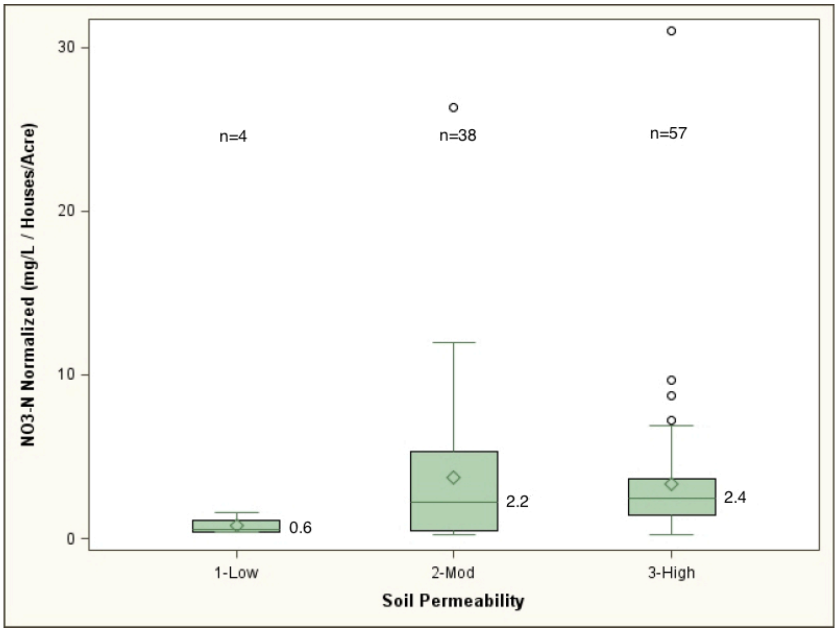


Figure 18. Groundwater NO_3-N concentrations compared with relative soil permeability at the sample locations for the 1996-1997 (Graph A) and 2010-2011 (Graph B) datasets in Jamestown Shores, RI. The median value for each bin is shown next to the median line. Kruskal-Wallis Tests: p=0.0042 (A) and p=0.0170 (B).

A) 1996-1997



B) 2010-2011

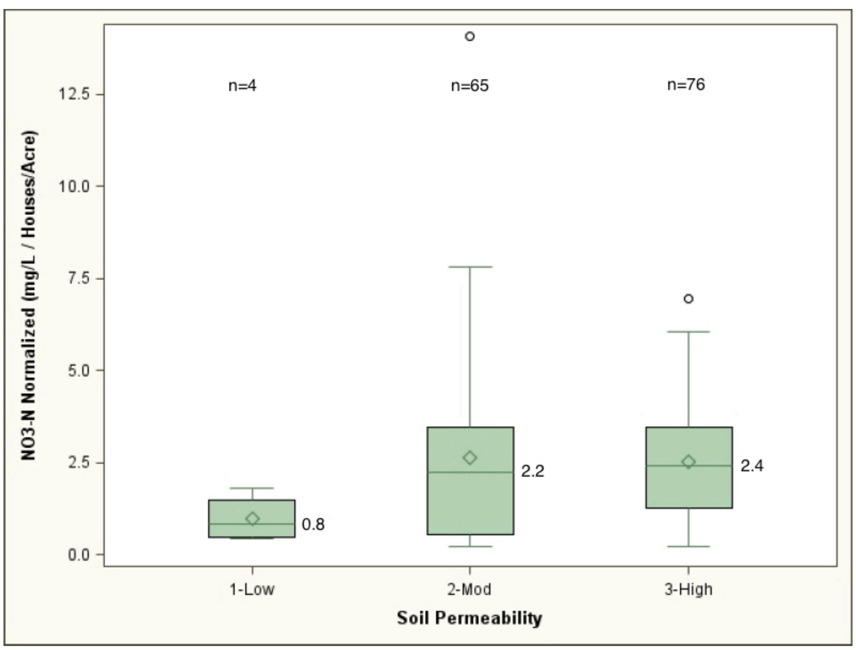
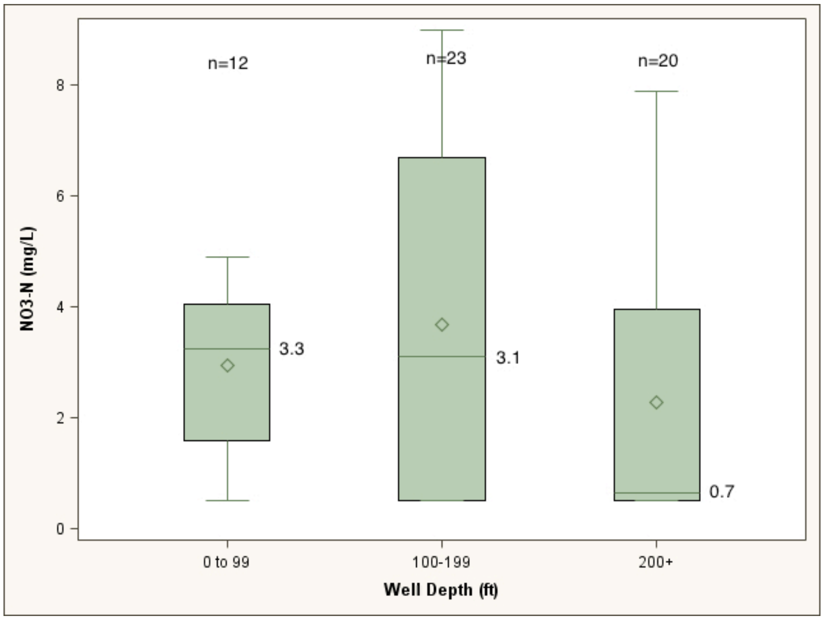


Figure 19. Groundwater NO_3-N concentrations normalized by housing density and compared with relative soil permeability at the sample locations for the 1996-1997 (Graph A) and 2010-2011 (Graph B) datasets in Jamestown Shores, RI. The median value for each bin is shown next to the median line. Kruskal-Wallis Tests: p=0.0865 (A) and p=0.1640 (B).

Well Depth

A relatively deep well is expected to have lower groundwater NO_3-N concentrations than a shallower well because the longer travel time could provide more opportunity for dilution and degradation (Katz et al., 2011; Lichtenberg and Shapiro, 1997; Rupert, 2008). Estimated well depths were provided by homeowners for 55% of the sample sites in 1996-1997 and 51% of the sample sites in 2010-2011. The distribution of these depths can be seen in Appendix C. As shown in Figure 20 and 21, groundwater NO_3-N appears to have a decreasing trend with well depth, but it is not significant for total or normalized NO_3-N concentrations. This lack of significance is also seen when comparing groundwater NO_3-N with a continuous well depth variable; the p-values for the Spearman's Correlations are greater than 0.05 and the confidence limits for the Kendall-Theil Robust Lines include a slope of zero (Appendix B). This is reasonable given the amount of variability in the results, which can be seen in the long error bars and the difference between the mean and median symbols. An explanation may be that well depth in uncased, fractured bedrock wells is often not a strong proxy for the depth of the actual water-bearing zone. Well drillers generally drill significantly beyond the water-bearing fractures to provide storage capacity in the well bore, particularly for low-yield wells. In addition, well depths were provided by homeowners, without source (e.g. well log) documentation. These findings are also similar to the 1999 USGS study of public-supply wells in Rhode Island (USGS, 1999), which found that well depth does not significantly correlate with elevated NO_3-N concentrations.

A) 1996-1997



B) 2010-2011

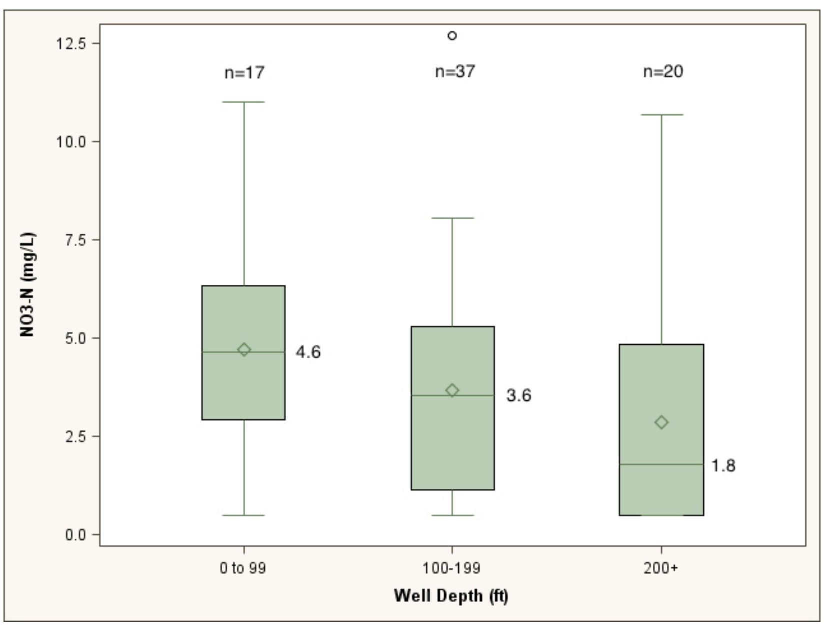
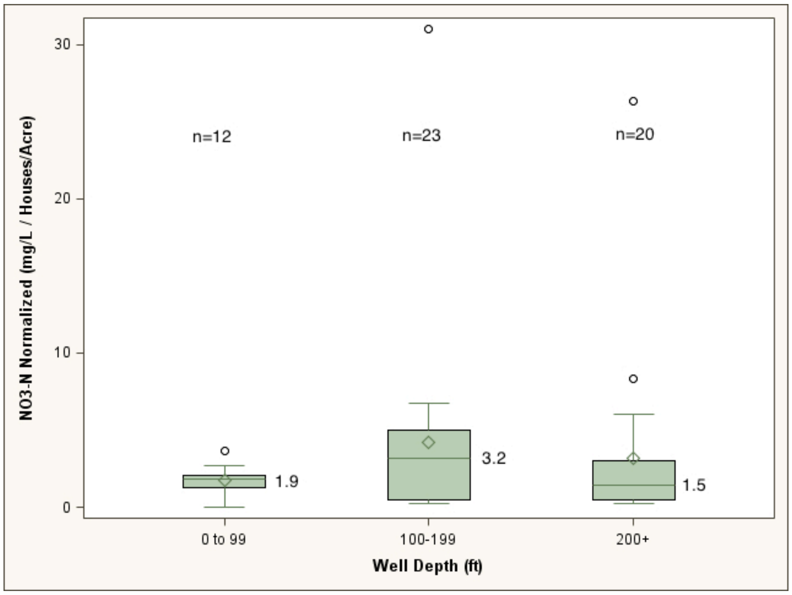


Figure 20. Groundwater NO_3-N concentrations compared with well depth at the sample locations for the 1996-1997 (Graph A) and 2010-2011 (Graph B) datasets in Jamestown Shores, RI. The median value for each bin is shown next to the median line. Kruskal-Wallis Tests: p=0.1622 (A) and p=0.1191 (B).

A) 1996-1997



B) 2010-2011

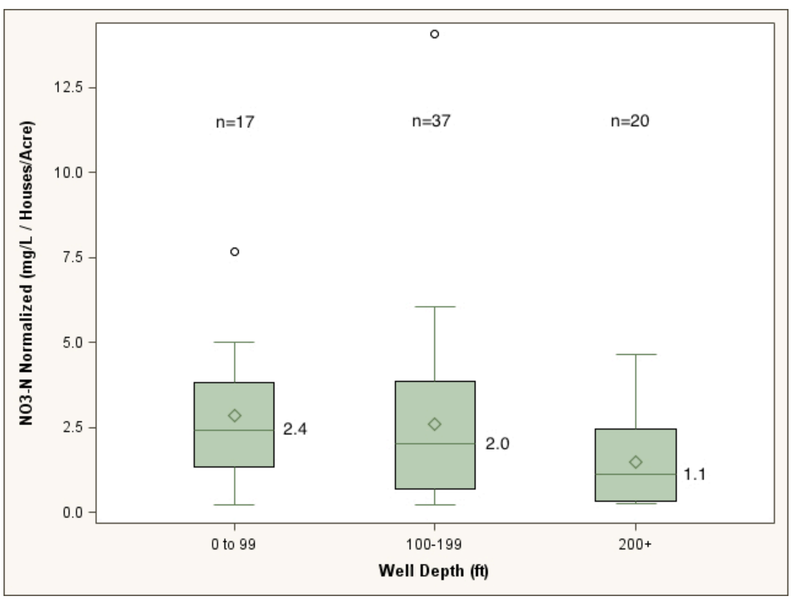


Figure 21. Groundwater NO_3-N concentrations normalized by housing density and compared with well depth at the sample locations for the 1996-1997 (Graph A) and 2010-2011 (Graph B) datasets in Jamestown Shores, RI. The median value for each bin is shown next to the median line. Kruskal-Wallis Tests: $p=0.3187$ (A) and $p=0.1020$ (B).

THE EFFECT OF CONFOUNDING VARIABLES

Well depth and relative soil permeability are two spatial confounding variables that were statistically analyzed. Many other confounding variables were not analyzed because of insufficient data. Some examples are: nitrogen input from non-OWTS sources such as fertilizer and pet or livestock waste; nitrogen input from homes controlled by number of residents, whether the home is occupied year-round or seasonally, and equipped with low-flow fixtures and appliances; failure/ponding of OWTS; effectiveness of denitrifying OWTS; depth to water table; and distance between the well and OWTS. For example, the timing of fertilizer application, irrigation/precipitation events, and groundwater sampling may be a significant driver of NO_3-N concentration (Landon, 2000; Mutti, 2007; Petrovic, 1990), but the distribution of fertilizer use is unknown. Tinker (1991) found that 48 to 91 percent of lawns in select unsewered subdivisions in Wisconsin were fertilized and that 18 to 68 percent of nitrogen leached to groundwater was from fertilizer. Joubert, et al. (2003) estimated high fertilizer use in Jamestown Shores could cancel out the nitrogen-reducing benefits of denitrifying OWTS. In addition, a single horse on a large lot could produce 46 lbs N/year (21 kg/yr) (DEFRA, 2009), the equivalent of seven people or 3 OWTS. As another example, water consumption from fixtures and appliances has reduced significantly since the 1990s (Meyer et al., 1999; U.S. EPA, 2002; Energystar.gov, 2013). A reduction in water use means an increase in influent nitrogen concentration to the OWTS, which can result in an increase in nitrogen concentration in the effluent as well if the OWTS reduces nitrogen by 50% but not necessarily below 19 mg/L as required.

Two temporal confounding variables that were considered are precipitation and population. Average annual available precipitation (precipitation minus evapotranspiration and runoff) was determined to increase slightly from 14 inches/year (36 cm/yr) in 1995-1997 to 18 inches/year (46 cm/yr) in 2009-2011 (Kingston weather station, Carl Sawyer). Precipitation can increase or decrease NO_3-N concentrations in groundwater depending on the pattern of precipitation, irrigation, and sampling as well as the heterogeneity of the subsurface (Landon, 2000; Mutti, 2007). A more detailed analysis would be required to determine the effect on the temporal groundwater NO_3-N trend. Housing density was used as a proxy for population, and according to the house built dates approximately 130 homes were constructed since 1996 in Jamestown Shores. Census data on the change in population and housing units over this time period is displayed in Appendix A. Approximately 13% of the housing units are for seasonal use only but the summer population is unknown because the census is conducted in April (U.S. Census Bureau, 2010 and Jamestown Comprehensive Community Plan, 2002).

Although 112 denitrifying OWTS were installed during the study period, this is a small percentage (13%) of all the OWTS in Jamestown Shores. Forty-two of the denitrifying OWTS were for existing homes, assumed to be replacing conventional OWTS, and 69 were for new homes assumed to be on lots without a previous OWTS. The amount of nitrogen loading would be expected to increase temporally with a greater number of new-construction denitrifying OWTS than replacement denitrifying OWTS, although this is also dependent on population changes. Although there was a small April population decrease between 2000 and 2010, the summer population is unknown and given the increase in vacant housing units between 2000 and 2010 it is possible the summer population increased. The overall trend between 1990 and 2010 is one of increasing housing and population, with somewhat of a population plateau between 2000 and 2010. This census data is for the census blocks that include Jamestown Shores. Although the blocks extend beyond Jamestown Shores to the north and south, this extended area only had approximately 20 homes in the 1990s and 30 homes in 2010 (RIGIS, 2013). This number is only a small proportion of the data as a whole; therefore, the data are still considered representative of Jamestown Shores.

Another important confounding variable is the actual nitrogen removal efficiency of the denitrifying OWTS. Although RIDEM approves denitrifying OWTS that can reduce the effluent nitrogen concentration to 19 mg/L, the actual nitrogen removal of individual OWTS is unknown. The town enforces bi-annual maintenance requirements but there is no state or town reporting requirement for effluent nitrogen concentration (Town of Jamestown, personal communication, and RI DEM, 2013). Studies have shown denitrifying OWTS are not consistently effective at meeting the required nitrogen concentration, primarily due to the operation and maintenance needs of these systems as well as variable influent concentrations (Harden et al., 2010; Heufelder, et al., 2007; Lowe, et al., 2007; Lowe et al., 2009; Oakley et al., 2010; U.S. EPA w/o date).

CHAPTER 4

CONCLUSIONS AND RECOMMENDATIONS

The groundwater NO_3-N concentrations in Jamestown Shores, Jamestown, RI have not decreased area-wide between 1997 and 2011 despite the installation of 112 denitrifying OWTS. The temporal trend shows a small increase, which is statistically significant at the 90% confident level. This is likely because there was a net increase in OWTS during this time period.

Spatially, the groundwater NO_3-N positively correlates with housing density within a 400-foot radius as well as along the dominant fracture orientation within 400 feet; but not along the dominant groundwater flow direction (400 feet up-gradient) or within a 600-foot radius. NO_3-N concentrations increased significantly from a housing density of less than 1 house/acre (1-acre lot) to 1 houses/acre or greater and again from less than 2 houses/acre (0.5-acre lots) to 2 houses/acre or greater. In addition, having at least one denitrifying OTWS within a 400-foot radius decreases the groundwater NO_3-N concentration when normalized by housing density. Relative soil permeability showed no statistical significance with NO_3-N normalized by housing density; the sample size for the low permeability soils was too small to statistically analyze, but the NO_3-N concentrations were considerably less than for the other soils. Well depth showed no statistical significance with NO_3-N normalized by housing density. Other confounding variables could contribute to elevated or lower NO_3-N concentrations, but were not analyzed due to insufficient data.

Based on OWTS nitrogen loading calculations, the expected NO_3-N concentration for Jamestown Shores area-wide is 3.9 mg/L, which is close to the observed median concentration of 4.0 mg/L. The expected concentration at each well did not differ significantly from the measured concentration on a regional level, but there were several local differences. These differences can indicate a stronger effect from confounding variables, such as fertilizer or OWTS influent concentrations, or a well that is not affected by anthropogenic inputs. Replacing conventional or substandard OWTS with denitrifying OWTS (meeting the 19 mg/L regulatory limit) in the surrounding area could have a substantial impact on the local ground water NO_3-N concentration, potentially reducing it by several milligrams/liter. This effect is dependent on the housing density, the percent of denitrifying OWTS installed, and the influence of other sources of NO_3-N. In the least dense areas (0.3 houses/acre), the expected groundwater NO_3-N concentration due to OWTS is expected to be below background concentrations at all times. In the densest areas (3.1 houses/acre), the expected NO_3-N concentration approaches the MCL at close to 9 mg/L but would be expected to decrease less than the action level if at least 75% of houses had denitrifying OWTS. The median density areas (1.7 houses/acre) should be able to achieve this with at least 25% denitrifying OWTS.

The limitations of this study must be considered when making planning decisions based on the results. Regionally the seasonal difference in NO_3-N concentrations was not significant, but in several repeat sites there were substantial differences from fall to spring that were averaged to analyze the 2010-2011 dataset. Spatially, high and low NO_3-N concentrations occurred next to each other throughout Jamestown Shores, implying nitrogen sources and confounding variables can have very localized effects on the groundwater quality.

Given the variability in NO_3-N concentrations, and the numerous potential confounding variables, the results of this study should be used as part of a holistic management approach that takes multiple variables into consideration. Although it is known that denitrifying OWTS reduce effluent nitrogen concentrations, their presence alone may not achieve the desired level of groundwater quality in all areas. Additional studies could be conducted to further define the effects of the confounding variables. For example, groundwater could be sampled for constituents that help identify the source of the NO_3-N (e.g. OWTS or fertilizer) in different areas, or the methods used in this study could be used to compare smaller sub-areas of Jamestown Shores with similar environmental conditions in the same season. Additionally, OWTS effluent concentrations could be monitored so that the actual nitrogen loading is known. The methods and recommendations in this study could also be applied to communities other than Jamestown Shores and potentially to other septic contaminants such as phosphate.

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APPENDICES

APPENDIX A: DATA

SAMPLE SITE DATA

Table 9. NO_3-N, OWTS, well depth, and soil data for 1996 and 1997 sample sites in Jamestown Shores, Jamestown, RI. Continued on four pages. Conv (NP) = Conventional (Non-Pressurized), Conv (P) = Conventional (Pressurized), Denit = Denitrifying.

PLAT-LOT	NO_3-N (MG/L)	SAMPLE DATE	WELL DEPTH (FT)	SOIL PERM	OWTS TYPE (SPECIFIC)	OWTS TYPE (GENERAL)	YEAR HOUSE BUILT	DENITRIFYING OWTS INSTALL DATE
15-54	8.80	12/4/97	Unk	High	Conv (NP)	Conv	1972	NA
14-366	1.80	8/22/96	Unk	High	Conv (NP)	Conv	1985	NA
14-274	4.90	10/16/97	93	High	Conv (NP)	Conv	1973	NA
14-210	9.00	8/22/97	150	High	Pending	Pending	1976	NA
3-508	0.50	11/5/97	300	Moderate	Conv (NP)	Conv	1987	NA
3-511	3.60	8/9/96	Unk	High	Conv (NP)	Conv	1984	NA
14-167	7.60	10/24/97	120	High	Conv (NP)	Conv	1972	NA
15-298	4.00	7/12/96	Unk	High	Conv (NP)	Conv	1971	NA
16-223	2.20	8/8/96	129	Moderate	Textile Filter	Denit	1972	2009
16-142	7.20	8/12/96	Unk	High	Conv (NP)	Conv	1982	NA
16-142	4.70	8/8/97	Unk	High	Conv (NP)	Conv	1982	NA
16-28	1.90	8/14/96	75	Moderate	Textile Filter	Denit	2011	2010
3-519	0.50	7/15/96	Unk	High	Conv (NP)	Conv	1986	NA
6-32	1.20	12/4/97	Unk	Moderate	Conv (NP)	Conv	1993	NA
15-171	0.50	7/9/96	125	Moderate	Conv (NP)	Conv	1983	NA
5-213	0.76	8/12/96	250	High	Conv (NP)	Conv	1984	NA
14-129	4.50	10/1/97	Unk	High	Conv (NP)	Conv	1984	NA
3-514	0.50	8/26/96	280	High	Conv (NP)	Conv	1989	NA
15-50	8.30	8/21/96	Unk	High	Conv (NP)	Conv	1971	NA
15-50	7.00	8/8/97	Unk	High	Conv (NP)	Conv	1971	NA
5-106	3.10	6/25/96	Unk	Moderate	Conv (NP)	Conv	1981	NA
5-102	0.50	8/2/96	250	Moderate	Conv (NP)	Conv	1983	NA
14-165	5.60	10/14/97	300	High	Conv (NP)	Conv	1973	NA

PLAT-LOT	NO_3-N (MG/L)	SAMPLE DATE	WELL DEPTH (FT)	SOIL PERM	OWTS TYPE (SPECIFIC)	OWTS TYPE (GENERAL)	YEAR HOUSE BUILT	DENITRIFYING OWTS INSTALL DATE
15-71	2.90	7/2/96	98	High	Conv (NP)	Conv	1956	NA
15-331	3.10	7/12/96	90	High	Conv (NP)	Conv	1963	NA
5-242	5.20	8/22/96	Unk	Moderate	Conv (NP)	Conv	1991	NA
5-242	4.30	8/8/97	Unk	Moderate	Conv (NP)	Conv	1991	NA
5-458	4.00	6/21/96	Unk	High	Conv (NP)	Conv	1976	NA
5-458	3.80	8/14/97	Unk	High	Conv (NP)	Conv	1976	NA
15-19	2.50	12/10/97	Unk	High	Conv (NP)	Conv	1972	NA
16-214	0.61	12/10/97	Unk	Moderate	Conv (NP)	Conv	1950	NA
15-210	0.70	7/9/96	Unk	Moderate	Conv (NP)	Conv	1971	NA
3-565	2.50	7/2/96	260	Moderate	Conv (NP)	Conv	1994	NA
3-71	4.00	8/26/96	125	Moderate	Conv (NP)	Conv	1987	NA
14-332	0.90	10/1/97	305	High	Conv (NP)	Conv	1988	NA
3-191	8.30	8/26/96	124	Moderate	Conv (NP)	Conv	1969	NA
3-191	7.20	8/2/97	Unk	Moderate	Conv (NP)	Conv	1969	NA
15-206	0.50	7/2/96	225	Moderate	Conv (NP)	Conv	1988	NA
14-16	0.50	10/8/97	Unk	High	Conv (NP)	Conv	1950	NA
14-163	5.40	8/27/97	Unk	High	Conv (NP)	Conv	1973	NA
5-469	2.50	8/9/96	330	High	Conv (NP)	Conv	1978	NA
3-87	0.63	8/14/96	Unk	Moderate	Conv (NP)	Conv	1969	NA
15-201	0.50	7/12/96	140	Moderate	Conv (NP)	Conv	1977	NA
15-163	11.00	10/8/97	Unk	High	Conv (NP)	Conv	1958	NA
3-533	2.90	8/8/96	Unk	High	Conv (NP)	Conv	1987	NA
16-192	16.00	7/12/96	Unk	High	Conv (NP)	Conv	1968	NA
16-192	4.90	10/29/97	Unk	High	Conv (NP)	Conv	1968	NA
5-448	0.50	8/9/96	300	Moderate	Conv (NP)	Conv	1985	NA
5-448	0.50	8/9/96	300	Moderate	Conv (NP)	Conv	1985	NA
5-456	6.30	12/4/97	Unk	High	Conv (NP)	Conv	1975	NA
5-461	2.10	6/21/96	Unk	High	Conv (NP)	Conv	1975	NA

PLAT-LOT	NO_3-N (MG/L)	SAMPLE DATE	WELL DEPTH (FT)	SOIL PERM	OWTS TYPE (SPECIFIC)	OWTS TYPE (GENERAL)	YEAR HOUSE BUILT	DENITRIFYING OWTS INSTALL DATE
5-461	2.10	8/5/97	Unk	High	Conv (NP)	Conv	1975	NA
16-10	6.30	10/14/97	108	Moderate	Conv (NP)	Conv	1994	NA
15-256	1.40	7/12/96	Unk	Moderate	Conv (NP)	Conv	1975	NA
16-19	0.50	8/22/96	105	High	Conv (NP)	Conv	1975	NA
15-334	0.70	10/14/97	150	High	Conv (NP)	Conv	1975	NA
5-444	5.80	8/12/96	Unk	High	Conv (NP)	Conv	1985	NA
5-444	4.00	8/2/97	Unk	High	Conv (NP)	Conv	1985	NA
3-532	1.80	8/27/97	Unk	High	Conv (NP)	Conv	1985	NA
14-82	0.50	10/24/97	200	Low	Conv (NP)	Conv	1995	NA
15-195	8.10	8/21/96	145	High	Conv (NP)	Conv	1979	NA
15-195	6.10	8/2/97	Unk	High	Conv (NP)	Conv	1979	NA
5-443	0.58	6/18/96	Unk	High	Conv (NP)	Conv	1981	NA
5-493	0.50	7/12/96	250	High	Conv (NP)	Conv	1994	NA
15-31	2.20	10/8/97	Unk	Moderate	Conv (NP)	Conv	1971	NA
16-195	1.70	7/15/96	85	High	Conv (NP)	Conv	1957	NA
16-195	0.94	8/8/97	Unk	High	Conv (NP)	Conv	1957	NA
14-12	0.50	10/3/97	100	High	Conv (NP)	Conv	1970	NA
3-354	3.40	8/2/96	85	High	Conv (NP)	Conv	1973	NA
15-78	4.70	8/9/96	Unk	High	Conv (NP)	Conv	1986	NA
3-130	3.40	8/21/96	110	Moderate	Conv (NP)	Conv	1980	NA
3-130	2.90	10/29/97	Unk	Moderate	Conv (NP)	Conv	1980	NA
3-530	0.50	7/30/97	175	Moderate	Conv (NP)	Conv	1987	NA
14-230	2.70	10/14/97	Unk	High	Conv (NP)	Conv	1991	NA
5-455	4.70	7/15/96	100	Moderate	Conv (NP)	Conv	1976	NA
5-455	4.30	8/8/97	Unk	Moderate	Conv (NP)	Conv	1976	NA
14-327	4.00	7/17/96	Unk	High	Conv (NP)	Conv	1982	NA
3-346	7.40	8/21/96	Unk	High	Conv (NP)	Conv	1981	NA
3-346	9.70	8/14/97	Unk	High	Conv (NP)	Conv	1981	NA
15-14	1.60	12/19/97	150	Low	Conv (NP)	Conv	1988	NA

PLAT-LOT	NO_3-N (MG/L)	SAMPLE DATE	WELL DEPTH (FT)	SOIL PERM	OWTS TYPE (SPECIFIC)	OWTS TYPE (GENERAL)	YEAR HOUSE BUILT	DENITRIFYING OWTS INSTALL DATE
3-528	2.90	8/22/97	Unk	Moderate	Conv (NP)	Conv	1987	NA
3-200	4.50	11/5/97	75	Moderate	Conv (NP)	Conv	1963	NA
14-228	3.60	8/27/97	30	High	Textile Filter	Denit	1954	2005
14-335	4.30	7/31/96	51	High	Conv (NP)	Conv	1986	NA
16-124	2.50	7/12/96	145	High	Textile Filter	Denit	1984	2006
5-398	0.50	8/9/96	275	Low	Textile Filter	Denit	1984	2010
5-427	9.90	6/25/96	300	High	Conv (P)	Conv	1970	NA
5-427	0.88	8/14/97	Unk	High	Conv (P)	Conv	1970	NA
14-113	4.50	8/27/97	Unk	Moderate	Conv (NP)	Conv	1973	NA
5-420	3.10	7/9/96	130	High	Conv (NP)	Conv	1990	NA
14-76	0.50	8/9/96	280	Moderate	Conv (NP)	Conv	1985	NA
3-498	5.40	7/30/96	200	Moderate	Conv (NP)	Conv	1985	NA
3-119	4.90	7/15/96	160	Moderate	Conv (NP)	Conv	1984	NA
3-119	5.20	8/8/97	Unk	Moderate	Conv (NP)	Conv	1984	NA
5-123	8.10	7/31/96	150	High	Conv (NP)	Conv	1945	NA
5-123	7.60	8/5/97	Unk	High	Conv (NP)	Conv	1945	NA
3-226	6.50	8/14/96	Unk	High	Conv (NP)	Conv	1967	NA
3-226	4.70	8/5/97	Unk	High	Conv (NP)	Conv	1967	NA
14-87	0.50	8/8/96	33	Moderate	Conv (NP)	Conv	1946	NA
3-381	5.80	6/18/96	Unk	High	Conv (NP)	Conv	1979	NA
5-463	2.90	8/26/96	Unk	High	Conv (NP)	Conv	1977	NA
14-67	2.00	8/27/97	260	Moderate	Conv (NP)	Conv	1940	NA
5-489	4.60	7/15/96	Unk	Moderate	Conv (NP)	Conv	1979	NA
14-221	3.80	10/3/97	75	High	Conv (NP)	Conv	1950	NA
15-351	1.10	7/2/96	95	High	Conv (NP)	Conv	1980	NA
14-105	0.50	8/22/97	Unk	Low	Conv (NP)	Conv	1988	NA
5-281	0.50	8/24/96	Unk	Moderate	Conv (NP)	Conv	1972	NA
16-133	6.70	10/24/97	185	High	Conv (NP)	Conv	1972	NA

PLAT-LOT	NO_3-N (MG/L)	SAMPLE DATE	WELL DEPTH (FT)	SOIL PERM	OWTS TYPE (SPECIFIC)	OWTS TYPE (GENERAL)	YEAR HOUSE BUILT	DENITRIFYING OWTS INSTALL DATE
15-26	4.70	12/4/97	Unk	High	Textile Filter	Denit	1973	2005
16-343	7.90	8/2/96	350	Moderate	Conv (NP)	Conv	1980	NA
16-346	2.70	7/9/96	150	Moderate	Conv (NP)	Conv	1980	NA
16-85	4.30	6/14/96	Unk	High	Conv (NP)	Conv	1970	NA
16-85	4.00	8/5/97	Unk	High	Conv (NP)	Conv	1970	NA
15-1	0.50	10/8/97	103	High	Conv (NP)	Conv	1994	NA
16-342	0.79	10/1/97	Unk	Moderate	Conv (NP)	Conv	1980	NA
3-91	7.60	8/16/96	270	Moderate	Conv (NP)	Conv	1994	NA
14-248	6.10	7/15/96	Unk	Moderate	Conv (NP)	Conv	1984	NA
14-248	4.70	8/14/97	Unk	Moderate	Conv (NP)	Conv	1984	NA
3-429	3.10	8/26/96	Unk	High	Conv (NP)	Conv	1973	NA
3-52	0.58	7/12/96	260	Moderate	Conv (NP)	Conv	1980	NA
3-52	0.52	8/2/97	Unk	Moderate	Conv (NP)	Conv	1980	NA

Table 10. NO_3-N, OWTS, well depth, and soil data for 2010 and 2011 sample sites in Jamestown Shores, Jamestown, RI. Continued on seven pages. Conv (NP) = Conventional (Non-Pressurized), Conv (P) = Conventional (Pressurized), Denit = Denitrifying.

PLAT-LOT	NO_3-N (MG/L)	SAMPLE DATE	WELL DEPTH (FT)	SOIL PERM	OWTS TYPE (SPECIFIC)	OWTS TYPE (GENERAL)	YEAR HOUSE BUILT	DENITRIFYING OWTS INSTALL DATE
14-381	7.34	11/10/10	180	High	Conv (NP)	Conv	1988	NA
14-381	7.15	4/18/11	180	High	Conv (NP)	Conv	1988	NA
5-462	6.74	4/18/11	Unk	High	Textile Filter	Denit	1976	2008
15-339	1.18	4/11/11	140	High	Conv (NP)	Conv	2003	NA
5-407	4.46	11/17/10	Unk	High	Conv (NP)	Conv	1972	NA
5-407	4.70	4/11/11	Unk	High	Conv (NP)	Conv	1972	NA
14-360	4.46	5/11/11	100	High	Conv (NP)	Conv	1969	NA
3-18	0.50	4/19/11	300	Moderate	Textile Filter	Denit	2008	2004
14-362	6.09	5/2/11	Unk	High	Conv (NP)	Conv	1988	NA
14-210	8.39	5/9/11	50	High	Pending	Pending	1976	NA
16-216	1.65	5/23/11	Unk	Low	Conv (NP)	Conv	1971	NA
14-171	1.14	5/17/11	150	Moderate	Conv (NP)	Conv	1972	NA
16-102	3.40	12/2/10	85	High	Conv (NP)	Conv	1970	NA
16-102	2.45	4/4/11	85	High	Conv (NP)	Conv	1970	NA
14-331	10.70	4/19/11	355	High	Conv (NP)	Conv	1998	NA
15-333	6.39	11/8/10	Unk	High	Conv (NP)	Conv	1948	NA
15-333	6.09	4/4/11	Unk	High	Conv (NP)	Conv	1948	NA
14-167	3.80	4/20/11	93	High	Conv (NP)	Conv	1972	NA
16-82	7.17	12/13/10	Unk	High	Conv (P)	Conv	1999	NA
16-82	5.23	4/20/11	Unk	High	Conv (P)	Conv	1999	NA
3-218	10.70	5/9/11	Unk	Moderate	Conv (NP)	Conv	1998	NA
14-133	0.50	11/29/10	400	Moderate	Conv (NP)	Conv	1998	NA
14-133	0.50	4/20/11	400	Moderate	Conv (NP)	Conv	1998	NA
15-298	4.92	11/8/10	155	High	Conv (NP)	Conv	1971	NA
15-298	6.27	5/17/11	155	High	Conv (NP)	Conv	1971	NA
14-62	1.70	12/1/10	Unk	Moderate	Aerobic(Fast)	Denit	1980	NA

PLAT-LOT	NO_3-N (MG/L)	SAMPLE DATE	WELL DEPTH (FT)	SOIL PERM	OWTS TYPE (SPECIFIC)	OWTS TYPE (GENERAL)	YEAR HOUSE BUILT	DENITRIFYING OWTS INSTALL DATE
5-305	3.55	5/17/11	150	Moderate	Textile Filter	Denit	2003	2003
16-44	5.02	5/23/11	Unk	Moderate	Conv (NP)	Conv	1972	NA
15-294	9.04	12/13/10	Unk	High	Conv (NP)	Conv	1987	NA
14-356	5.43	5/2/11	225	High	Conv (NP)	Conv	1970	NA
14-238	2.14	5/23/11	155	High	Conv (NP)	Conv	1995	NA
15-236	0.50	11/15/10	100	Moderate	Conv (NP)	Conv	1977	NA
15-236	0.50	5/17/11	100	Moderate	Conv (NP)	Conv	1977	NA
16-142	7.69	11/18/10	Unk	High	Conv (NP)	Conv	1982	NA
16-28	0.50	11/10/10	75	Moderate	Textile Filter	Denit	2011	2010
16-28	0.50	4/5/11	75	Moderate	Textile Filter	Denit	2011	2010
5-214	0.50	11/17/10	250	High	Conv (NP)	Conv	1991	NA
16-225	9.74	12/20/10	60	Moderate	Textile Filter	Denit	1962	2005
16-225	6.01	4/19/11	60	Moderate	Textile Filter	Denit	1962	2005
14-305	5.28	5/9/11	60	High	Conv (NP)	Conv	1997	NA
14-272	8.73	5/2/11	Unk	High	Conv (NP)	Conv	1995	NA
16-151	9.33	11/8/10	Unk	High	Textile Filter	Denit	2004	2004
16-151	2.70	4/18/11	Unk	High	Textile Filter	Denit	2004	2004
15-304	5.71	12/8/10	150	High	Conv (NP)	Conv	2003	NA
15-304	4.63	4/20/11	150	High	Conv (NP)	Conv	2003	NA
14-129	7.77	12/2/10	155	High	Conv (NP)	Conv	1984	NA
5-212	0.50	11/17/10	40	High	Conv (NP)	Conv	1972	NA
5-12	0.50	4/4/11	270	High	Conv (NP)	Conv	1992	NA
14-349	8.03	11/8/10	140	High	Conv (NP)	Conv	1986	NA
14-349	5.70	4/5/11	140	High	Conv (NP)	Conv	1986	NA
14-18	0.50	5/9/11	Unk	High	Textile Filter	Denit	2001	2001
5-472	5.33	12/2/10	175	High	Conv (NP)	Conv	1989	NA
5-106	8.03	11/17/10	Unk	Moderate	Conv (NP)	Conv	1981	NA
5-106	6.51	4/19/11	Unk	Moderate	Conv (NP)	Conv	1981	NA
5-8	0.50	11/29/10	125	Moderate	Conv (NP)	Conv	1989	NA

PLAT-LOT	NO_3-N (MG/L)	SAMPLE DATE	WELL DEPTH (FT)	SOIL PERM	OWTS TYPE (SPECIFIC)	OWTS TYPE (GENERAL)	YEAR HOUSE BUILT	DENIT OWTS INSTALL DATE
5-8	0.50	4/20/11	125	Moderate	Conv (NP)	Conv	1989	NA
16-100	4.06	5/23/11	Unk	Moderate	Conv (NP)	Conv	1975	NA
15-121	5.05	4/18/11	160	High	Conv (NP)	Conv	1975	NA
3-63	0.50	5/23/11	Unk	Moderate	Conv (NP)	Conv	1980	NA
5-134	5.83	11/15/10	Unk	High	Conv (NP)	Conv	1949	NA
5-134	6.41	5/2/11	Unk	High	Conv (NP)	Conv	1949	NA
15-71	3.55	12/2/10	Unk	High	Conv (NP)	Conv	1956	NA
15-331	6.32	4/19/11	90	High	Conv (NP)	Conv	1963	NA
3-474	0.50	5/11/11	Unk	High	Conv (NP)	Conv	1979	NA
5-25	0.50	11/18/10	200	Moderate	Conv (NP)	Conv	1972	NA
5-25	0.50	4/19/11	200	Moderate	Conv (NP)	Conv	1972	NA
15-224	0.50	11/8/10	Unk	Moderate	Conv (NP)	Conv	1950	NA
15-224	6.36	5/17/11	Unk	Moderate	Conv (NP)	Conv	1950	NA
15-383	4.53	4/11/11	Unk	High	Conv (NP)	Conv	2001	NA
14-391	4.12	12/8/10	Unk	High	Conv (NP)	Conv	1979	NA
14-395	6.90	11/18/10	Unk	High	Conv (NP)	Conv	1962	NA
14-387	0.76	11/18/10	175	High	Conv (NP)	Conv	1972	NA
3-187	3.48	11/17/10	Unk	Moderate	Conv (NP)	Conv	1964	NA
3-82	4.85	12/2/10	100	Moderate	Sand-Recirc	Denit	2000	2001
3-82	4.07	4/19/11	100	Moderate	Sand-Recirc	Denit	2000	2001
16-129	6.36	5/17/11	Unk	Moderate	Conv (NP)	Conv	1970	NA
16-87	2.57	5/9/11	Unk	Moderate	Conv (NP)	Conv	1995	NA
15-19	3.30	11/17/10	Unk	High	Conv (NP)	Conv	1972	NA
15-19	4.90	4/19/11	Unk	High	Conv (NP)	Conv	1972	NA
3-203	7.57	11/15/10	Unk	Moderate	Conv (NP)	Conv	1976	NA
3-193	6.81	4/5/11	Unk	Moderate	Conv (NP)	Conv	1969	NA
3-193	0.50	11/17/11	Unk	Moderate	Conv (NP)	Conv	1969	NA
3-71	8.06	12/1/10	100	Moderate	Conv (NP)	Conv	1987	NA
14-330	3.19	5/17/11	Unk	High	Conv (NP)	Conv	1989	NA

PLAT-LOT	NO_3-N (MG/L)	SAMPLE DATE	WELL DEPTH (FT)	SOIL PERM	OWTS TYPE (SPECIFIC)	OWTS TYPE (GENERAL)	YEAR HOUSE BUILT	DENIT OWTS INSTALL DATE
14-302	0.50	5/2/11	100	Moderate	Conv (NP)	Conv	1975	NA
14-332	4.33	12/1/10	305	High	Conv (NP)	Conv	1988	NA
3-191	13.00	11/18/10	Unk	Moderate	Conv (NP)	Conv	1969	NA
3-191	12.50	4/20/11	Unk	Moderate	Conv (NP)	Conv	1969	NA
3-476	5.37	12/2/10	125	Moderate	Conv (NP)	Conv	1963	NA
3-476	5.23	5/2/11	125	Moderate	Conv (NP)	Conv	1963	NA
15-206	0.50	11/10/10	Unk	Moderate	Conv (NP)	Conv	1988	NA
5-451	5.70	11/8/10	Unk	High	Conv (NP)	Conv	1974	NA
5-451	5.35	4/5/11	Unk	High	Conv (NP)	Conv	1974	NA
16-137	4.50	11/18/10	Unk	High	Conv (NP)	Conv	1991	NA
5-475	3.40	11/10/10	85	Moderate	Conv (NP)	Conv	1976	NA
15-353	0.50	11/15/10	120	High	Conv (NP)	Conv	2006	NA
15-353	0.50	4/18/11	120	High	Conv (NP)	Conv	2006	NA
15-356	1.90	11/10/10	Unk	Moderate	Textile Filter	Denit	1971	2006
15-356	2.93	4/11/11	Unk	Moderate	Textile Filter	Denit	1971	2006
15-123	11.90	11/17/10	Unk	High	Conv (NP)	Conv	1926	NA
15-123	2.73	5/11/11	Unk	High	Conv (NP)	Conv	1926	NA
5-436	1.62	11/15/10	400	High	Conv (NP)	Conv	1996	NA
5-436	1.69	4/5/11	400	High	Conv (NP)	Conv	1996	NA
15-153	4.44	12/8/10	Unk	High	Conv (NP)	Conv	1972	NA
16-96	3.35	5/23/11	Unk	Moderate	Conv (NP)	Conv	1956	NA
5-450	1.17	4/18/11	300	High	Conv (NP)	Conv	1975	NA
14-257	4.95	5/9/11	360	High	Conv (NP)	Conv	1950	NA
14-14	0.50	5/23/11	280	High	Pending	Pending	1972	NA
16-12	1.29	11/8/10	Unk	Moderate	Unk	Unk	Unk	NA
16-12	1.67	5/2/11	Unk	Moderate	Unk	Unk	Unk	NA
15-151	2.10	11/15/10	75	High	Conv (NP)	Conv	1954	NA
5-446	1.93	11/15/10	400	High	Conv (NP)	Conv	1970	NA
3-354	5.66	12/13/10	85	High	Conv (NP)	Conv	1973	NA

PLAT-LOT	NO_3-N (MG/L)	SAMPLE DATE	WELL DEPTH (FT)	SOIL PERM	OWTS TYPE (SPECIFIC)	OWTS TYPE (GENERAL)	YEAR HOUSE BUILT	DENIT OWTS INSTALL DATE
14-203	1.20	5/9/11	400	High	Conv (NP)	Conv	1972	NA
14-316	0.59	5/11/11	100	Moderate	Conv (NP)	Conv	1997	NA
15-293	9.06	12/13/10	110	High	Conv (NP)	Conv	1971	NA
15-293	4.82	5/17/11	110	High	Conv (NP)	Conv	1971	NA
3-247	1.80	12/2/10	Unk	Moderate	Textile Filter	Denit	2005	2005
3-247	2.99	4/5/11	Unk	Moderate	Textile Filter	Denit	2005	2005
3-96	8.63	4/18/11	Unk	High	Conv (NP)	Conv	1986	NA
3-320	1.85	5/11/11	155	Moderate	Conv (NP)	Conv	1992	NA
14-312	3.32	5/2/11	160	Moderate	Aerobic(Sing.)	Denit	2002	2003
5-455	2.53	4/18/11	100	Moderate	Conv (NP)	Conv	1976	NA
3-275	1.46	4/11/11	Unk	Moderate	Conv (NP)	Conv	1989	NA
3-245	4.63	5/17/11	125	Moderate	Conv (NP)	Conv	1967	NA
3-334	6.90	4/18/11	200	Moderate	Conv (NP)	Conv	1981	NA
3-404	4.22	11/18/10	Unk	High	Conv (NP)	Conv	1968	NA
3-404	3.32	4/11/11	Unk	High	Conv (NP)	Conv	1968	NA
3-304	0.50	5/17/11	Unk	Moderate	Conv (NP)	Conv	1985	NA
3-418	3.00	11/15/10	110	High	Conv (NP)	Conv	1973	NA
14-327	1.42	12/2/10	100	High	Conv (NP)	Conv	1982	NA
14-327	7.02	4/20/11	100	High	Conv (NP)	Conv	1982	NA
3-403	0.50	5/17/11	Unk	High	Conv (NP)	Conv	1987	NA
15-14	1.99	5/17/11	Unk	Low	Conv (NP)	Conv	1988	NA
3-143	1.10	12/1/10	250	Moderate	Conv (NP)	Conv	1981	NA
3-200	5.93	11/17/10	325	Moderate	Conv (NP)	Conv	1963	NA
3-200	3.92	5/11/11	325	Moderate	Conv (NP)	Conv	1963	NA
3-342	9.31	4/5/11	Unk	Moderate	Textile Filter	Denit	1988	NA
14-228	3.70	12/13/10	Unk	High	Textile Filter	Denit	1954	2005
14-335	7.81	5/11/11	Unk	High	Conv (NP)	Conv	1986	NA
14-134	1.84	11/29/10	Unk	High	Sub-Standard	Sub-Standard	1960	NA
14-113	4.52	11/18/10	Unk	Moderate	Conv (NP)	Conv	1973	NA

PLAT-LOT	NO_3-N (MG/L)	SAMPLE DATE	WELL DEPTH (FT)	SOIL PERM	OWTS TYPE (SPECIFIC)	OWTS TYPE (GENERAL)	YEAR HOUSE BUILT	DENIT OWTS INSTALL DATE
14-113	5.48	5/9/11	Unk	Moderate	Conv (NP)	Conv	1973	NA
5-426	5.48	12/8/10	90	High	Conv (NP)	Conv	1965	NA
5-426	4.81	4/4/11	90	High	Conv (NP)	Conv	1965	NA
5-79	7.47	12/8/10	Unk	High	Textile Filter	Denit	2009	2010
3-468	0.50	5/17/11	Unk	High	Conv (NP)	Conv	1979	NA
14-187	4.62	5/9/11	90	High	Conv (NP)	Conv	1949	NA
5-390	4.01	12/1/10	100	Moderate	Conv (NP)	Conv	1986	NA
14-186	2.52	5/23/11	Unk	High	Textile Filter	Denit	1950	2010
3-116	0.50	12/1/10	100	Moderate	Conv (NP)	Conv	1992	NA
15-145	0.50	12/8/10	75	Low	Conv (P)	Conv	1962	NA
15-145	0.50	4/18/11	75	Low	Conv (P)	Conv	1962	NA
14-7	2.75	11/18/10	200	Moderate	Conv (NP)	Conv	1971	NA
14-7	6.81	4/4/11	200	Moderate	Conv (NP)	Conv	1971	NA
5-31	0.50	11/29/10	100	Moderate	Conv (NP)	Conv	1976	NA
5-31	0.50	4/18/11	100	Moderate	Conv (NP)	Conv	1976	NA
14-151	3.51	5/2/11	Unk	Moderate	Conv (NP)	Conv	1948	NA
14-94	3.36	5/11/11	Unk	Moderate	Aerobic(Sing.)	Denit	2000	2000
5-122	6.77	12/8/10	Unk	High	Textile Filter	Denit	2002	2003
14-87	0.50	11/10/10	Unk	Moderate	Conv (NP)	Conv	1946	NA
14-87	0.50	4/5/11	Unk	Moderate	Conv (NP)	Conv	1946	NA
5-149	2.66	12/8/10	60	Moderate	Conv (NP)	Conv	1984	NA
5-149	6.62	4/19/11	60	Moderate	Conv (NP)	Conv	1984	NA
14-70	0.50	12/13/10	Unk	High	Conv (P)	Conv	1971	NA
14-70	0.50	4/20/11	Unk	High	Conv (P)	Conv	1971	NA
5-55	6.14	5/23/11	Unk	Moderate	Conv (NP)	Conv	1979	NA
16-163	2.65	12/2/10	125	High	Textile Filter	Denit	1959	2005
16-163	2.44	4/11/11	125	High	Textile Filter	Denit	1959	2005
5-463	4.99	11/29/10	Unk	High	Conv (NP)	Conv	1977	NA
5-463	2.77	4/20/11	Unk	High	Conv (NP)	Conv	1977	NA

PLAT-LOT	NO_3-N (MG/L)	SAMPLE DATE	WELL DEPTH (FT)	SOIL PERM	OWTS TYPE (SPECIFIC)	OWTS TYPE (GENERAL)	YEAR HOUSE BUILT	DENIT OWTS INSTALL DATE
14-370	6.15	5/23/11	Unk	High	Conv (NP)	Conv	1972	NA
14-20	0.79	11/15/10	Unk	High	Conv (NP)	Conv	1980	NA
14-20	6.74	5/2/11	Unk	High	Conv (NP)	Conv	1980	NA
14-67	2.60	5/2/11	255	Moderate	Conv (NP)	Conv	1940	NA
16-105	4.86	12/20/10	Unk	High	Textile Filter	Denit	1967	2007
16-105	5.32	4/19/11	Unk	High	Textile Filter	Denit	1967	2007
14-182	7.55	5/9/11	Unk	Moderate	Conv (NP)	Conv	1986	NA
14-27	0.50	5/23/11	Unk	Moderate	Sub-Standard	Sub-Standard	1962	NA
15-350	2.34	4/20/11	Unk	Moderate	Conv (NP)	Conv	1963	NA
3-68	1.79	11/17/10	275	Moderate	Conv (NP)	Conv	1988	NA
3-68	2.79	4/4/11	275	Moderate	Conv (NP)	Conv	1988	NA
16-229	7.65	5/17/11	85	Moderate	Sub-Standard	Sub-Standard	1876	NA
14-36	0.50	5/17/11	Unk	Low	Conv (NP)	Conv	1987	NA
14-217	12.70	5/17/11	120	Moderate	Conv (NP)	Conv	1984	NA
5-328	8.25	12/13/10	Unk	Moderate	Conv (NP)	Conv	1948	NA
16-346	6.48	11/15/10	150	Moderate	Conv (NP)	Conv	1980	NA
16-346	4.78	4/4/11	150	Moderate	Conv (NP)	Conv	1980	NA
5-266	0.50	11/29/10	170	Moderate	Conv (NP)	Conv	1972	NA
5-73	7.82	12/2/10	Unk	High	Conv (NP)	Conv	1985	NA
3-101	3.95	5/17/11	125	Moderate	Conv (NP)	Conv	1963	NA
3-53	2.69	5/2/11	155	High	Conv (NP)	Conv	1994	NA
3-341	11.00	5/17/11	60	Moderate	Conv (NP)	Conv	1968	NA

Table 11. An example density and nitrogen loading analysis within the 400-ft circle buffers for the 2010-2011 data set in Jamestown Shores, Jamestown, RI. The same analysis was performed for the other buffers and for the 1996-1997 data set. Continued on six pages. Meas = Measured, Conv = Conventional, Denit = Denitrifying, HD = Housing Density (Houses/Acre), DD = Denitrifying OWTS Density (Houses/Acre), Exptd = Expected.

PLAT-LOT	MEAS NO_3-N (MG/L)	AREA (AC)	CONV OWTS (#)	DENIT OWTS (#)	HD	DD	N LOADING CONV (LBS/YR)	N LOADING DENIT (LBS/YR)	RECHARGE (GAL/YR)	EXPTD NO_3-N (MG/L)	DIFFERENCE (MEAS-EXPTD) (MG/L)
3-18	0.50	11.54	14	7	1.8	0.6	202.9	41.6	6598835	4.40	-3.90
3-53	2.69	11.54	14	0	1.2	0.0	202.9	0.0	6305010	3.90	-1.20
3-63	0.50	11.54	24	3	2.3	0.3	347.8	17.8	6850685	6.40	-5.90
3-68	2.29	11.54	23	4	2.3	0.3	333.3	23.8	6850685	6.20	-3.90
3-71	8.06	11.54	15	3	1.6	0.3	217.4	17.8	6472910	4.40	3.70
3-82	4.46	11.54	24	3	2.3	0.3	347.8	17.8	6850685	6.40	-1.90
3-96	8.63	11.54	34	2	3.1	0.2	492.7	11.9	7228460	8.40	0.20
3-101	3.95	11.54	26	3	2.5	0.3	376.7	17.8	6934635	6.80	-2.90
3-116	0.50	11.54	12	2	1.2	0.2	173.9	11.9	6305010	3.50	-3.00
3-143	1.10	11.54	17	3	1.7	0.3	246.3	17.8	6556860	4.80	-3.70
3-187	3.48	11.54	15	2	1.5	0.2	217.4	11.9	6430935	4.30	-0.80
3-191	12.75	11.54	17	6	2.0	0.5	246.3	35.6	6682785	5.10	7.70
3-193	3.66	11.54	14	4	1.6	0.3	202.9	23.8	6472910	4.20	-0.50
3-200	4.93	11.54	27	2	2.5	0.2	391.2	11.9	6934635	7.00	-2.10
3-203	7.57	11.54	19	1	1.7	0.1	275.3	5.9	6556860	5.10	2.50
3-218	10.70	11.54	17	1	1.6	0.1	246.3	5.9	6472910	4.70	6.00
3-245	4.63	11.54	14	3	1.5	0.3	202.9	17.8	6430935	4.10	0.50
3-247	2.40	11.54	13	2	1.3	0.2	188.4	11.9	6346985	3.80	-1.40
3-275	1.46	11.54	14	0	1.2	0.0	202.9	0.0	6305010	3.90	-2.40
3-304	0.50	11.54	21	1	1.9	0.1	304.3	5.9	6640810	5.60	-5.10

PLAT-LOT	MEAS NO_3-N (MG/L)	AREA (AC)	CONV OWTS (#)	DENIT OWTS (#)	HD	DD	N LOADING CONV (LBS/YR)	N LOADING DENIT (LBS/YR)	RECHARGE (GAL/YR)	EXPTD NO_3-N (MG/L)	DIFFERENCE (MEAS-EXPTD) (MG/L)
3-320	1.85	11.54	26	1	2.3	0.1	376.7	5.9	6850685	6.70	-4.80
3-334	6.90	11.54	31	1	2.8	0.1	449.2	5.9	7060560	7.70	-0.80
3-341	11.00	11.54	23	2	2.2	0.2	333.3	11.9	6766735	6.10	4.90
3-342	9.31	11.54	26	2	2.4	0.2	376.7	11.9	6892660	6.80	2.50
3-354	5.66	11.54	28	0	2.4	0.0	405.7	0.0	6892660	7.10	-1.40
3-403	0.50	11.54	25	3	2.4	0.3	362.3	17.8	6892660	6.60	-6.10
3-404	3.77	11.54	24	3	2.3	0.3	347.8	17.8	6850685	6.40	-2.60
3-418	3.00	11.54	20	1	1.8	0.1	289.8	5.9	6598835	5.40	-2.40
3-468	0.50	11.54	19	1	1.7	0.1	275.3	5.9	6556860	5.10	-4.60
3-474	0.50	11.54	12	0	1.0	0.0	173.9	0.0	6221060	3.30	-2.80
3-476	5.30	11.54	26	1	2.3	0.1	376.7	5.9	6850685	6.70	-1.40
5-8	0.50	11.54	15	2	1.5	0.2	217.4	11.9	6430935	4.30	-3.80
5-12	0.50	11.54	16	2	1.6	0.2	231.8	11.9	6472910	4.50	-4.00
5-25	0.50	11.54	19	2	1.8	0.2	275.3	11.9	6598835	5.20	-4.70
5-31	0.50	11.54	20	2	1.9	0.2	289.8	11.9	6640810	5.40	-4.90
5-55	6.14	11.54	21	2	2.0	0.2	304.3	11.9	6682785	5.70	0.40
5-73	7.82	11.54	21	2	2.0	0.2	304.3	11.9	6682785	5.70	2.10
5-79	7.47	11.54	22	3	2.2	0.3	318.8	17.8	6766735	6.00	1.50
5-106	7.27	11.54	23	1	2.1	0.1	333.3	5.9	6724760	6.00	1.30
5-122	6.77	11.54	19	6	2.2	0.5	275.3	35.6	6766735	5.50	1.30
5-134	6.12	11.54	21	6	2.3	0.5	304.3	35.6	6850685	5.90	0.20
5-149	4.64	11.54	15	1	1.4	0.1	217.4	5.9	6388960	4.20	0.40
5-212	0.50	11.54	24	3	2.3	0.3	347.8	17.8	6850685	6.40	-5.90
5-214	0.50	11.54	19	4	2.0	0.3	275.3	23.8	6682785	5.40	-4.90
5-266	0.50	11.54	23	2	2.2	0.2	333.3	11.9	6766735	6.10	-5.60
5-305	3.55	11.54	7	2	0.8	0.2	101.4	11.9	6095135	2.20	1.30
5-328	8.25	11.54	13	1	1.2	0.1	188.4	5.9	6305010	3.70	4.60
5-390	4.01	11.54	20	1	1.8	0.1	289.8	5.9	6598835	5.40	-1.40
5-407	4.58	11.54	21	0	1.8	0.0	304.3	0.0	6598835	5.50	-0.90

PLAT-LOT	MEAS NO_3-N (MG/L)	AREA (AC)	CONV OWTS (#)	DENIT OWTS (#)	HD	DD	N LOADING CONV (LBS/YR)	N LOADING DENIT (LBS/YR)	RECHARGE (GAL/YR)	EXPTD NO_3-N (MG/L)	DIFFERENCE (MEAS-EXPTD) (MG/L)
5-426	5.15	11.54	21	0	1.8	0.0	304.3	0.0	6598835	5.50	-0.30
5-436	1.66	11.54	12	0	1.0	0.0	173.9	0.0	6221060	3.30	-1.60
5-446	1.93	11.54	18	0	1.6	0.0	260.8	0.0	6472910	4.80	-2.90
5-450	1.17	11.54	20	0	1.7	0.0	289.8	0.0	6556860	5.30	-4.10
5-451	5.53	11.54	18	0	1.6	0.0	260.8	0.0	6472910	4.80	0.70
5-455	2.53	11.54	16	2	1.6	0.2	231.8	11.9	6472910	4.50	-2.00
5-462	6.74	11.54	12	2	1.2	0.2	173.9	11.9	6305010	3.50	3.20
5-463	3.88	11.54	14	2	1.4	0.2	202.9	11.9	6388960	4.00	-0.10
5-472	5.33	11.54	12	2	1.2	0.2	173.9	11.9	6305010	3.50	1.80
5-475	3.40	11.54	9	1	0.9	0.1	130.4	5.9	6137110	2.70	0.70
14-113	5.00	11.54	11	7	1.6	0.6	159.4	41.6	6472910	3.70	1.30
14-129	7.77	11.54	17	0	1.5	0.0	246.3	0.0	6430935	4.60	3.20
14-133	0.50	11.54	20	4	2.1	0.3	289.8	23.8	6724760	5.60	-5.10
14-134	1.84	11.54	21	3	2.1	0.3	304.3	17.8	6724760	5.70	-3.90
14-14	0.50	11.54	14	2	1.4	0.2	202.9	11.9	6388960	4.00	-3.50
14-151	3.51	11.54	17	5	1.9	0.4	246.3	29.7	6640810	5.00	-1.50
14-167	3.80	11.54	17	1	1.6	0.1	246.3	5.9	6472910	4.70	-0.90
14-171	1.14	11.54	20	4	2.1	0.3	289.8	23.8	6724760	5.60	-4.50
14-18	0.50	11.54	11	2	1.1	0.2	159.4	11.9	6263035	3.30	-2.80
14-182	7.55	11.54	17	4	1.8	0.3	246.3	23.8	6598835	4.90	2.70
14-186	2.52	11.54	19	6	2.2	0.5	275.3	35.6	6766735	5.50	-3.00
14-187	4.62	11.54	18	7	2.2	0.6	260.8	41.6	6766735	5.40	-0.80
14-20	3.77	11.54	10	2	1.0	0.2	144.9	11.9	6221060	3.00	0.80
14-203	1.20	11.54	17	1	1.6	0.1	246.3	5.9	6472910	4.70	-3.50
14-210	8.39	11.54	22	3	2.2	0.3	318.8	17.8	6766735	6.00	2.40
14-217	12.70	11.54	21	4	2.2	0.3	304.3	23.8	6766735	5.80	6.90
14-228	3.70	11.54	21	7	2.4	0.6	304.3	41.6	6892660	6.00	-2.30
14-238	2.14	11.54	23	1	2.1	0.1	333.3	5.9	6724760	6.00	-3.90
14-257	4.95	11.54	25	6	2.7	0.5	362.3	35.6	7018585	6.80	-1.90

PLAT-LOT	MEAS NO_3-N (MG/L)	AREA (AC)	CONV OWTS (#)	DENIT OWTS (#)	HD	DD	N LOADING CONV (LBS/YR)	N LOADING DENIT (LBS/YR)	RECHARGE (GAL/YR)	EXPTD NO_3-N (MG/L)	DIFFERENCE (MEAS-EXPTD) (MG/L)
14-27	0.50	11.54	14	2	1.4	0.2	202.9	11.9	6388960	4.00	-3.50
14-272	8.73	11.54	25	2	2.3	0.2	362.3	11.9	6850685	6.50	2.20
14-302	0.50	11.54	21	4	2.2	0.3	304.3	23.8	6766735	5.80	-5.30
14-305	5.28	11.54	21	4	2.2	0.3	304.3	23.8	6766735	5.80	-0.50
14-312	3.32	11.54	16	2	1.6	0.2	231.8	11.9	6472910	4.50	-1.20
14-316	0.59	11.54	16	2	1.6	0.2	231.8	11.9	6472910	4.50	-3.90
14-327	4.22	11.54	23	4	2.3	0.3	333.3	23.8	6850685	6.20	-2.00
14-330	3.19	11.54	29	2	2.7	0.2	420.2	11.9	7018585	7.40	-4.20
14-331	10.70	11.54	24	3	2.3	0.3	347.8	17.8	6850685	6.40	4.30
14-332	4.33	11.54	15	3	1.6	0.3	217.4	17.8	6472910	4.40	-0.10
14-335	7.81	11.54	28	4	2.8	0.3	405.7	23.8	7060560	7.30	0.50
14-349	6.87	11.54	23	2	2.2	0.2	333.3	11.9	6766735	6.10	0.80
14-356	5.43	11.54	24	1	2.2	0.1	347.8	5.9	6766735	6.30	-0.90
14-36	0.50	11.54	9	3	1.0	0.3	130.4	17.8	6221060	2.90	-2.40
14-360	4.46	11.54	23	2	2.2	0.2	333.3	11.9	6766735	6.10	-1.60
14-362	6.09	11.54	22	2	2.1	0.2	318.8	11.9	6724760	5.90	0.20
14-370	6.15	11.54	19	2	1.8	0.2	275.3	11.9	6598835	5.20	1.00
14-381	7.25	11.54	13	1	1.2	0.1	188.4	5.9	6305010	3.70	3.50
14-387	0.76	11.54	11	2	1.1	0.2	159.4	11.9	6263035	3.30	-2.50
14-391	4.12	11.54	14	1	1.3	0.1	202.9	5.9	6346985	3.90	0.20
14-395	6.90	11.54	14	1	1.3	0.1	202.9	5.9	6346985	3.90	3.00
14-62	1.70	11.54	8	4	1.0	0.3	115.9	23.8	6221060	2.70	-1.00
14-67	2.60	11.54	10	2	1.0	0.2	144.9	11.9	6221060	3.00	-0.40
14-7	4.78	11.54	15	1	1.4	0.1	217.4	5.9	6388960	4.20	0.60
14-70	0.50	11.54	16	2	1.6	0.2	231.8	11.9	6472910	4.50	-4.00
14-87	0.50	11.54	14	4	1.6	0.3	202.9	23.8	6472910	4.20	-3.70
14-94	3.36	11.54	9	6	1.3	0.5	130.4	35.6	6346985	3.10	0.30
15-121	5.05	11.54	16	1	1.5	0.1	231.8	5.9	6430935	4.40	0.70
15-123	7.32	11.54	16	4	1.7	0.3	231.8	23.8	6556860	4.70	2.60

PLAT-LOT	MEAS NO_3-N (MG/L)	AREA (AC)	CONV OWTS (#)	DENIT OWTS (#)	HD	DD	N LOADING CONV (LBS/YR)	N LOADING DENIT (LBS/YR)	RECHARGE (GAL/YR)	EXPTD NO_3-N (MG/L)	DIFFERENCE (MEAS-EXPTD) (MG/L)
15-14	1.99	11.54	11	2	1.1	0.2	159.4	11.9	6263035	3.30	-1.30
15-145	0.50	11.54	12	2	1.2	0.2	173.9	11.9	6305010	3.50	-3.00
15-151	2.10	11.54	23	2	2.2	0.2	333.3	11.9	6766735	6.10	-4.00
15-153	4.44	11.54	21	3	2.1	0.3	304.3	17.8	6724760	5.70	-1.30
15-19	4.10	11.54	20	3	2.0	0.3	289.8	17.8	6682785	5.50	-1.40
15-206	0.50	11.54	14	3	1.5	0.3	202.9	17.8	6430935	4.10	-3.60
15-224	3.43	11.54	24	1	2.2	0.1	347.8	5.9	6766735	6.30	-2.90
15-236	0.50	11.54	26	1	2.3	0.1	376.7	5.9	6850685	6.70	-6.20
15-293	6.94	11.54	20	1	1.8	0.1	289.8	5.9	6598835	5.40	1.50
15-294	9.04	11.54	14	1	1.3	0.1	202.9	5.9	6346985	3.90	5.10
15-298	5.60	11.54	13	0	1.1	0.0	188.4	0.0	6263035	3.60	2.00
15-304	5.17	11.54	14	0	1.2	0.0	202.9	0.0	6305010	3.90	1.30
15-331	6.32	11.54	16	0	1.4	0.0	231.8	0.0	6388960	4.30	2.00
15-333	6.24	11.54	17	0	1.5	0.0	246.3	0.0	6430935	4.60	1.60
15-339	1.18	11.54	6	0	0.5	0.0	86.9	0.0	5969210	1.70	-0.50
15-350	2.34	11.54	3	0	0.3	0.0	43.5	0.0	5843285	0.90	1.40
15-353	0.50	11.54	18	3	1.8	0.3	260.8	17.8	6598835	5.10	-4.60
15-356	2.42	11.54	9	3	1.0	0.3	130.4	17.8	6221060	2.90	-0.50
15-383	4.53	11.54	12	4	1.4	0.3	173.9	23.8	6388960	3.70	0.80
15-71	3.55	11.54	17	4	1.8	0.3	246.3	23.8	6598835	4.90	-1.40
16-100	4.06	11.54	12	6	1.6	0.5	173.9	35.6	6472910	3.90	0.20
16-102	2.93	11.54	19	6	2.2	0.5	275.3	35.6	6766735	5.50	-2.60
16-105	5.09	11.54	18	9	2.3	0.8	260.8	53.5	6850685	5.50	-0.40
16-12	1.48	11.54	6	2	0.7	0.2	86.9	11.9	6053160	2.00	-0.50
16-129	6.36	11.54	19	4	2.0	0.3	275.3	23.8	6682785	5.40	1.00
16-137	4.50	11.54	17	1	1.6	0.1	246.3	5.9	6472910	4.70	-0.20
16-142	7.69	11.54	22	3	2.2	0.3	318.8	17.8	6766735	6.00	1.70
16-151	6.02	11.54	27	2	2.5	0.2	391.2	11.9	6934635	7.00	-1.00
16-163	2.55	11.54	20	2	1.9	0.2	289.8	11.9	6640810	5.40	-2.90

PLAT-LOT	MEAS NO_3-N (MG/L)	AREA (ACRES)	CONV OWTS (#)	DENIT OWTS (#)	HD	DD	N LOADING CONV (LBS/YR)	N LOADING DENIT (LBS/YR)	RECHARGE (GAL/YR)	EXPTD NO_3-N (MG/L)	DIFFERENCE (MEAS-EXPTD) (MG/L)
16-216	1.65	11.54	14	2	1.4	0.2	202.9	11.9	6388960	4.00	-2.30
16-225	7.88	11.54	13	5	1.6	0.4	188.4	29.7	6472910	4.00	3.90
16-229	7.65	11.54	12	0	1.0	0.0	173.9	0.0	6221060	3.30	4.40
16-28	0.50	11.54	13	4	1.5	0.3	188.4	23.8	6430935	4.00	-3.50
16-346	5.63	11.54	5	0	0.4	0.0	72.4	0.0	5927235	1.50	4.10
16-44	5.02	11.54	12	4	1.4	0.3	173.9	23.8	6388960	3.70	1.30
16-82	6.20	11.54	19	5	2.1	0.4	275.3	29.7	6724760	5.40	0.80
16-87	2.57	11.54	12	3	1.3	0.3	173.9	17.8	6346985	3.60	-1.00
16-96	3.35	11.54	12	2	1.2	0.2	173.9	11.9	6305010	3.50	-0.20

NO$_3$-N NORMALIZATION

Table 12. An example NO$_3$-N normalization within the 400-ft circle buffers for the 2010-2011 data set in Jamestown Shores, Jamestown, RI. The same calculation was performed for the other buffers and for the 1996-1997 data set. Continued on four pages. Denit = Denitrifying.

PLAT-LOT	NO$_3$-N (MG/L)	HOUSING DENSITY (HOUSES/AC)	NO$_3$-N / HOUSING DENSITY (MG/L)	DENIT OWTS IN BUFFER (%)
3-18	0.50	1.8	0.28	33
3-53	2.69	1.2	2.24	0
3-63	0.50	2.3	0.22	12
3-68	2.29	2.3	1.00	15
3-71	8.06	1.6	5.04	16
3-82	4.46	2.3	1.94	12
3-96	8.63	3.1	2.78	6
3-101	3.95	2.5	1.58	10
3-116	0.50	1.2	0.42	14
3-143	1.10	1.7	0.65	15
3-187	3.48	1.5	2.32	12
3-191	12.75	2.0	6.38	26
3-193	3.66	1.6	2.29	22
3-200	4.93	2.5	1.97	7
3-203	7.57	1.7	4.45	5
3-218	10.70	1.6	6.69	5
3-245	4.63	1.5	3.09	18
3-247	2.40	1.3	1.85	13
3-275	1.46	1.2	1.22	0
3-304	0.50	1.9	0.26	4
3-320	1.85	2.3	0.80	4
3-334	6.90	2.8	2.46	3
3-341	11.00	2.2	5.00	8
3-342	9.31	2.4	3.88	7
3-354	5.66	2.4	2.36	0
3-403	0.50	2.4	0.21	11
3-404	3.77	2.3	1.64	12
3-418	3.00	1.8	1.67	5
3-468	0.50	1.7	0.29	5
3-474	0.50	1.0	0.50	0
3-476	5.30	2.3	2.30	4
5-8	0.50	1.5	0.33	12
5-12	0.50	1.6	0.31	10

PLAT-LOT	NO_3-N (MG/L)	HOUSING DENSITY (HOUSES/AC)	NO_3-N / HOUSING DENSITY (MG/L)	DENIT OWTS IN BUFFER (%)
5-25	0.50	1.8	0.28	10
5-31	0.50	1.9	0.26	9
5-55	6.14	2.0	3.07	9
5-73	7.82	2.0	3.91	9
5-79	7.47	2.2	3.40	12
5-106	7.27	2.1	3.46	4
5-122	6.77	2.2	3.08	24
5-134	6.12	2.3	2.66	23
5-149	4.64	1.4	3.31	6
5-212	0.50	2.3	0.22	11
5-214	0.50	2.0	0.25	17
5-266	0.50	2.2	0.23	8
5-305	3.55	0.8	4.44	22
5-328	8.25	1.2	6.88	7
5-390	4.01	1.8	2.23	5
5-407	4.58	1.8	2.54	0
5-426	5.15	1.8	2.86	0
5-436	1.66	1.0	1.66	0
5-446	1.93	1.6	1.21	0
5-450	1.17	1.7	0.69	0
5-451	5.53	1.6	3.46	0
5-455	2.53	1.6	1.58	11
5-462	6.74	1.2	5.62	14
5-463	3.88	1.4	2.77	12
5-472	5.33	1.2	4.44	14
5-475	3.40	0.9	3.78	10
14-113	5.00	1.6	3.13	37
14-129	7.77	1.5	5.18	0
14-133	0.50	2.1	0.24	17
14-134	1.84	2.1	0.88	12
14-14	0.50	1.4	0.36	12
14-151	3.51	1.9	1.85	23
14-167	3.80	1.6	2.38	5
14-171	1.14	2.1	0.54	17
14-18	0.50	1.1	0.45	15
14-182	7.55	1.8	4.19	19
14-186	2.52	2.2	1.15	24
14-187	4.62	2.2	2.10	28
14-20	3.77	1.0	3.77	18
14-203	1.20	1.6	0.75	6
14-210	8.39	2.2	3.81	12

PLAT-LOT	NO_3-N (MG/L)	HOUSING DENSITY (HOUSES/AC)	NO_3-N / HOUSING DENSITY (MG/L)	DENIT OWTS IN BUFFER (%)
14-217	12.70	2.2	5.77	16
14-228	3.70	2.4	1.54	25
14-238	2.14	2.1	1.02	4
14-257	4.95	2.7	1.83	19
14-27	0.50	1.4	0.36	12
14-272	8.73	2.3	3.80	7
14-302	0.50	2.2	0.23	16
14-305	5.28	2.2	2.40	16
14-312	3.32	1.6	2.07	11
14-316	0.59	1.6	0.37	11
14-327	4.22	2.3	1.83	15
14-330	3.19	2.7	1.18	6
14-331	10.70	2.3	4.65	11
14-332	4.33	1.6	2.71	16
14-335	7.81	2.8	2.79	12
14-349	6.87	2.2	3.12	8
14-356	5.43	2.2	2.47	4
14-36	0.50	1.0	0.50	25
14-360	4.46	2.2	2.03	8
14-362	6.09	2.1	2.90	8
14-370	6.15	1.8	3.42	10
14-381	7.25	1.2	6.04	7
14-387	0.76	1.1	0.69	15
14-391	4.12	1.3	3.17	7
14-395	6.90	1.3	5.31	7
14-62	1.70	1.0	1.70	36
14-67	2.60	1.0	2.60	17
14-7	4.78	1.4	3.41	6
14-70	0.50	1.6	0.31	11
14-87	0.50	1.6	0.31	22
14-94	3.36	1.3	2.58	40
15-121	5.05	1.5	3.37	6
15-123	7.32	1.7	4.31	20
15-14	1.99	1.1	1.81	15
15-145	0.50	1.2	0.42	14
15-151	2.10	2.2	0.95	8
15-153	4.44	2.1	2.11	12
15-19	4.10	2.0	2.05	13
15-206	0.50	1.5	0.33	18
15-224	3.43	2.2	1.56	4
15-236	0.50	2.3	0.22	4

PLAT-LOT	NO_3-N (MG/L)	HOUSING DENSITY (HOUSES/AC)	NO_3-N / HOUSING DENSITY (MG/L)	DENIT OWTS IN BUFFER (%)
15-293	6.94	1.8	3.86	5
15-294	9.04	1.3	6.95	7
15-298	5.60	1.1	5.09	0
15-304	5.17	1.2	4.31	0
15-331	6.32	1.4	4.51	0
15-333	6.24	1.5	4.16	0
15-339	1.18	0.5	2.36	0
15-350	2.34	0.3	7.80	0
15-353	0.50	1.8	0.28	14
15-356	2.42	1.0	2.42	27
15-383	4.53	1.4	3.24	25
15-71	3.55	1.8	1.97	19
16-100	4.06	1.6	2.54	32
16-102	2.93	2.2	1.33	24
16-105	5.09	2.3	2.21	35
16-12	1.48	0.7	2.11	25
16-129	6.36	2.0	3.18	17
16-137	4.50	1.6	2.81	5
16-142	7.69	2.2	3.50	12
16-151	6.02	2.5	2.41	7
16-163	2.55	1.9	1.34	9
16-216	1.65	1.4	1.18	12
16-225	7.88	1.6	4.93	26
16-229	7.65	1.0	7.65	0
16-28	0.50	1.5	0.33	24
16-346	5.63	0.4	14.08	0
16-44	5.02	1.4	3.59	25
16-82	6.20	2.1	2.95	21
16-87	2.57	1.3	1.98	20
16-96	3.35	1.2	2.79	14

RELATIVE SOIL PERMEABILITY

Table 13. Relative soil permeability in Jamestown Shores, Jamestown, RI.

Soil Name	Soil Symbol	Relative Permeability
Agawam fine sandy loam, 0 to 3 % slopes	AfA	High
Beaches, Undifferentiated	Be	Beach
Birchwood sandy loam	Bc	Mod
Canton And Charlton fine sandy loams, very rocky, 3 to 15 % slopes	CeC	Mod
Mansfield mucky silt loam	Ma	Low
Newport silt loam, 0 to 3 % slopes	NeA	Mod
Newport silt loam, 3 to 8 % slopes	NeB	Mod
Newport silt loam, 8 to 15 % slopes	NeC	Mod
Pittstown silt loam, 0 to 3 % slopes	PmA	Mod
Pittstown silt loam, 3 to 8 % slopes	PmB	Mod
Poquonock loamy fine Sand, 0 to 3 % slopes	PsA	High
Poquonock loamy fine Sand, 3 to 8 % slopes	PsB	High
Ridgebury, Whitman, And Leicester extremely stony fine sandy loams	Rf	Low
Sandyhook mucky peat, 0 to 3 percent slopes	Sa	Low
Scarboro mucky sandy loam	Sb	Low
Stissing silt loam	Se	Low
Swansea mucky peat, 0 to 2 percent slopes	SwA	Low
Udorthents-Urban land complex	UD	High
Water	W	Water
Water, saline	Ws	Water
Windsor loamy sand, 0 to 3 % slopes	WgA	High
Windsor loamy sand, 3 to 8 % slopes	WgB	High

CENSUS DATA FOR POPULATION AND HOUSING UNITS

Table 14. Change in census data in population and housing units (HUs) between the years 1990 and 2010 in Jamestown Shores, RI. Included is the percent change of the actual number; and for occupied, vacant, and seasonal housing units the change in the percent of total housing units is also included. Seasonal HU data is missing from the 2000 census.

Measured Parameter	Change from 1990-2000 (%)	Change from 2000-2010 (%)	Total Change from 1990-2010 (%)
April Population (#)	+13.0	-2.6	+10.0
Total Housing Units (HUs) (#)	+14.0	+9.3	+24.5
Occupied Housing Units (# / % of total HUs)	+22.9 / +7.8	+2.4 / -6.2	+25.9 / +1.1
Housing Units Vacant in April, Including Seasonal (# / % of total HUs)	-27.0 / -35.8	+62.1/ +47.8	+18.4/ -5.0
Seasonal Housing Units (# / % of total HUs)	2000 Unknown. For 1990, #: 108; % of total HUs: 13.7	Unknown	+13.0 / -9.5
Average Household Size	-7.7	-4.2	-11.5

APPENDIX B: STATISTICAL DATA

NORMALITY DETERMINATION – NO_3-N DATA

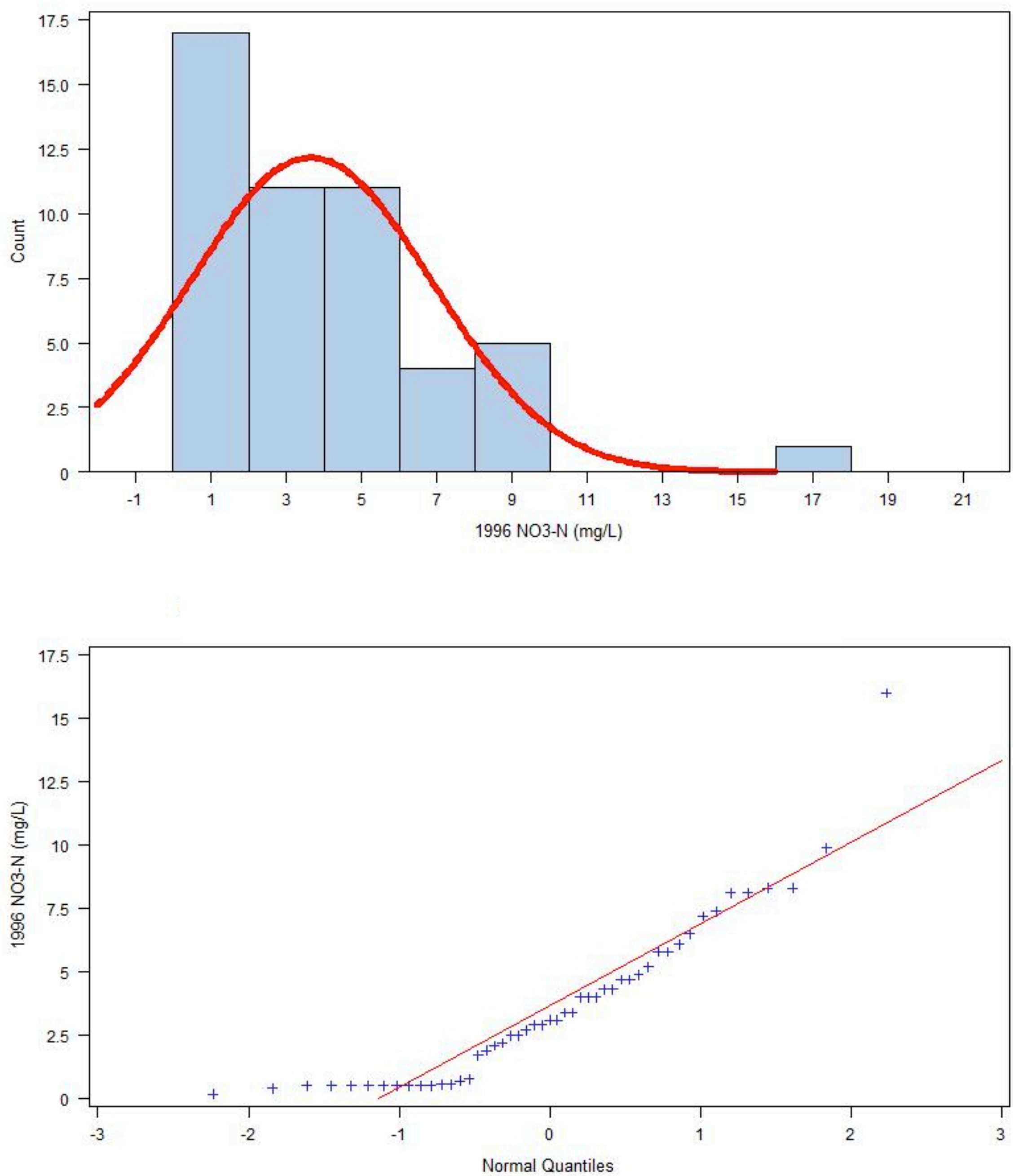
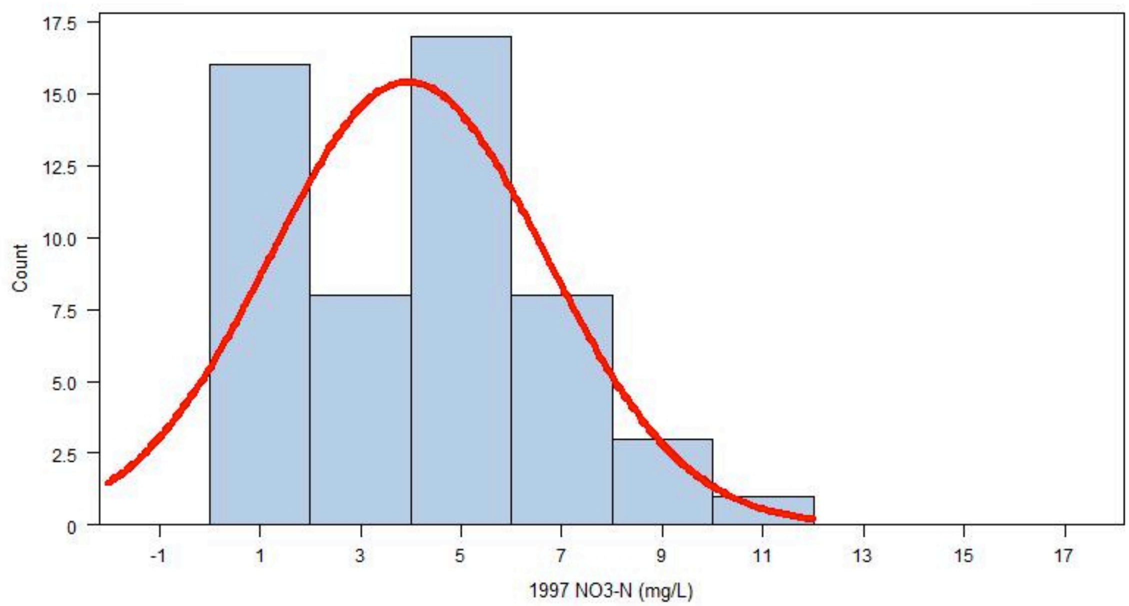


Figure 22. Histogram (with a normal curve for comparison) and Q-Q Plot for 1996 NO_3-N results in Jamestown Shores, Jamestown, RI. Shapiro-Wilk Test p=<0.0001, indicating a rejection of normality.



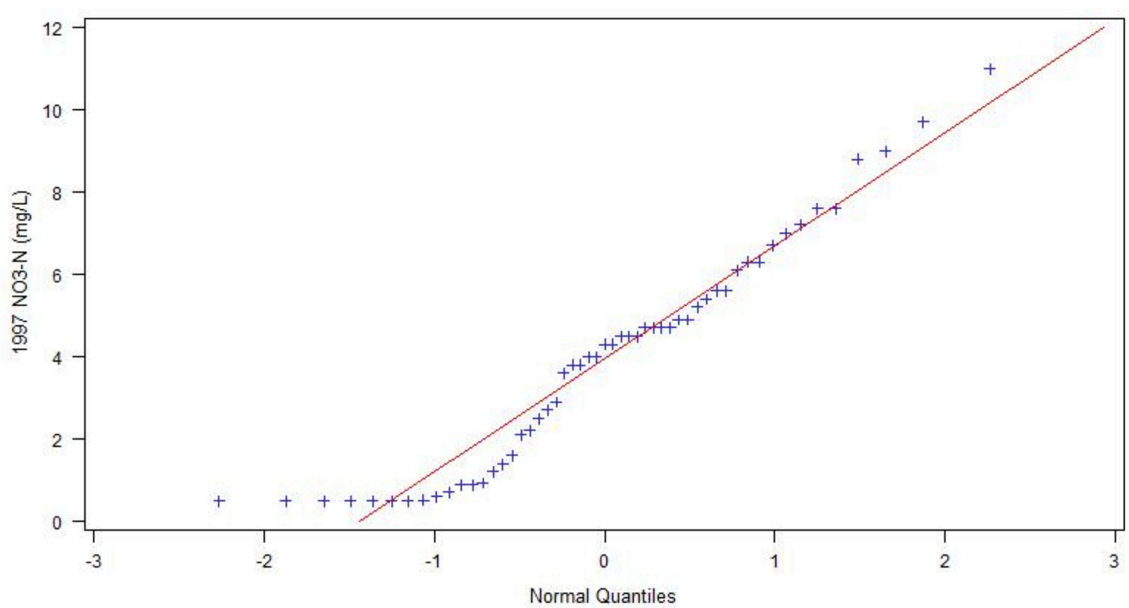
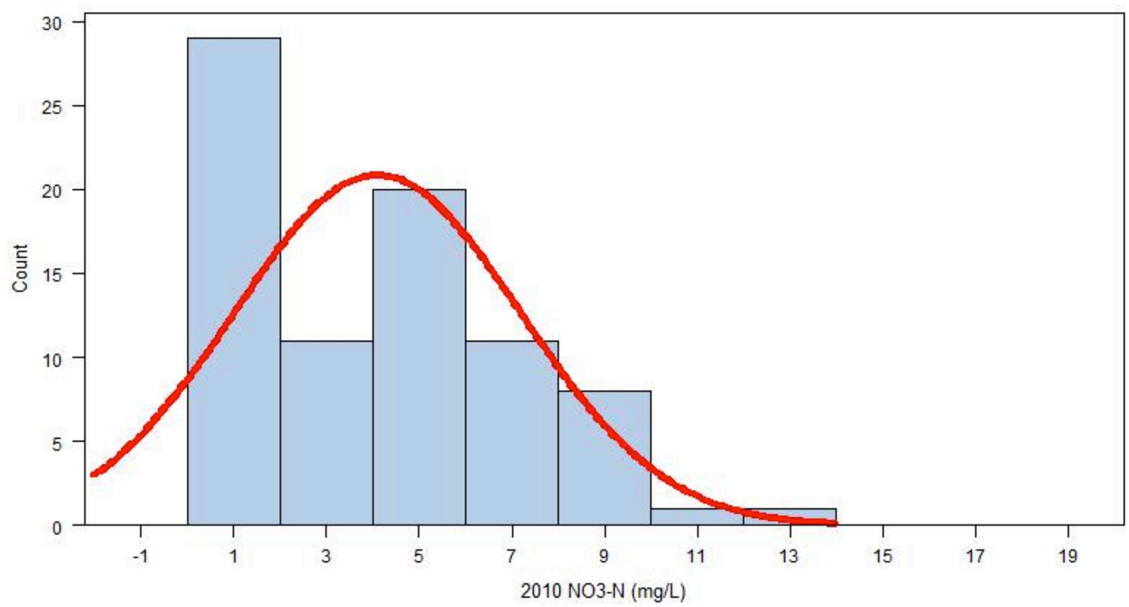


Figure 23. Histogram (with a normal curve for comparison) and Q-Q Plot for 1997 NO_3-N results in Jamestown Shores, Jamestown, RI. Shapiro-Wilk Test p=0.0066, indicating a rejection of normality.



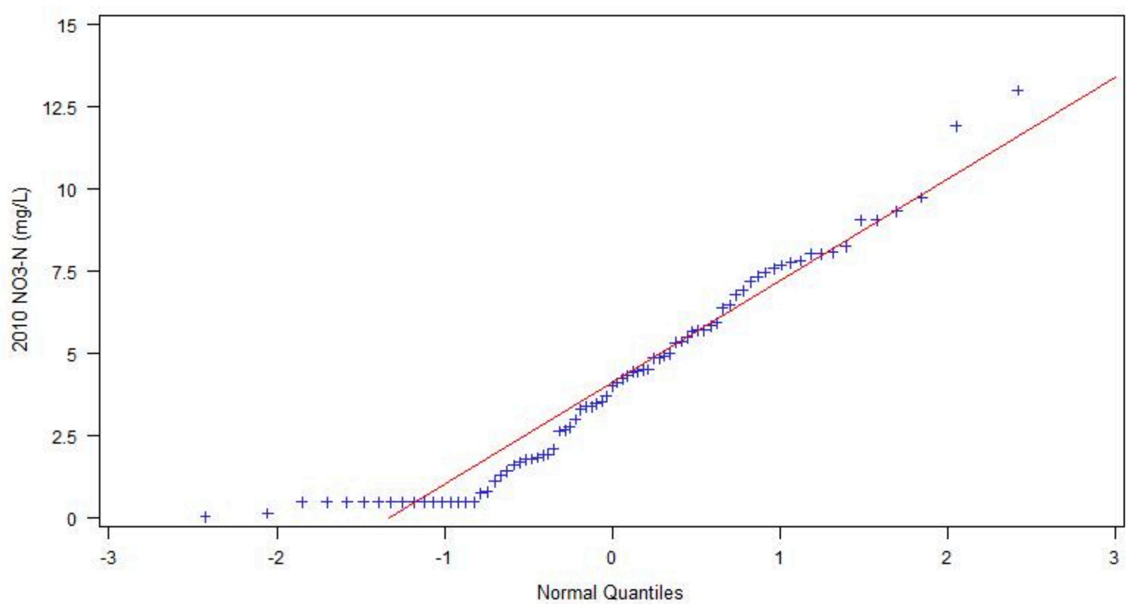
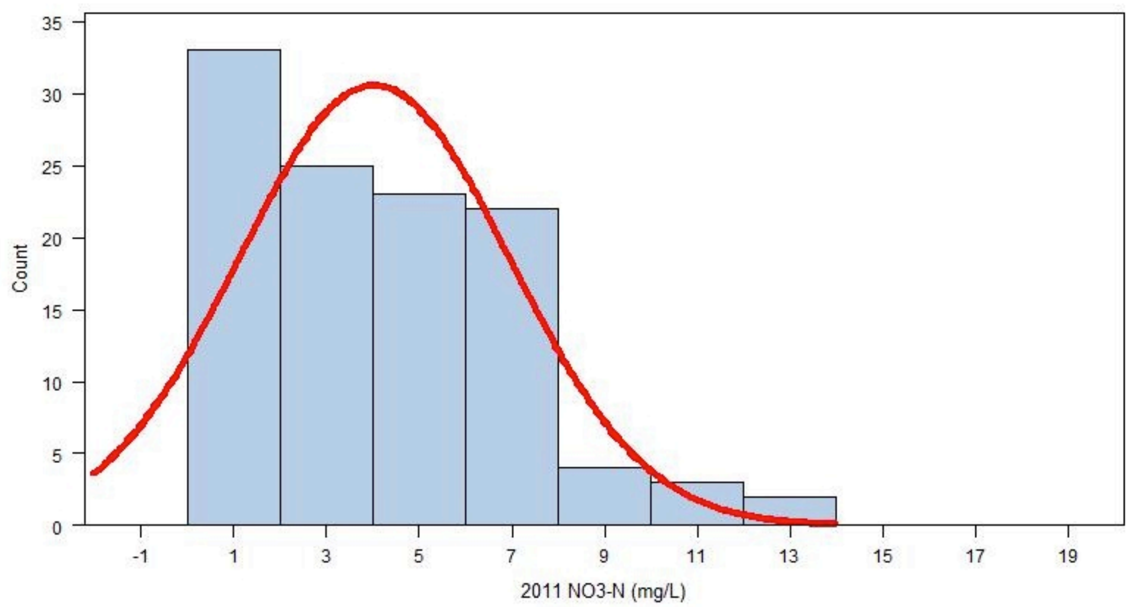


Figure 24. Histogram (with a normal curve for comparison) and Q-Q Plot for 2010 NO_3-N results in Jamestown Shores, Jamestown, RI. Shapiro-Wilk Test p=<0.0004, indicating a rejection of normality.



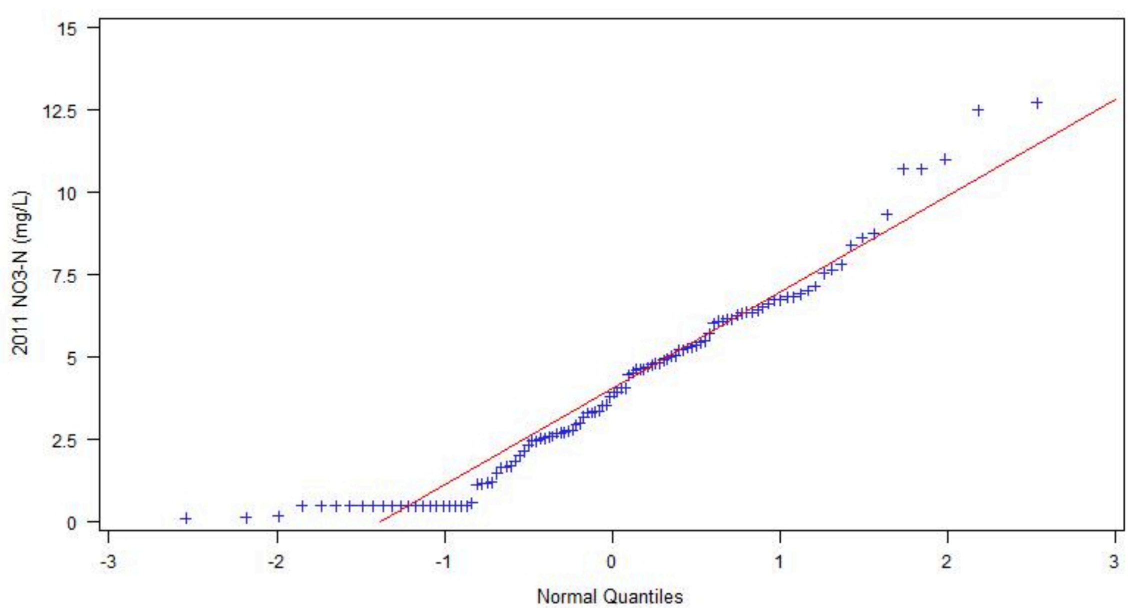
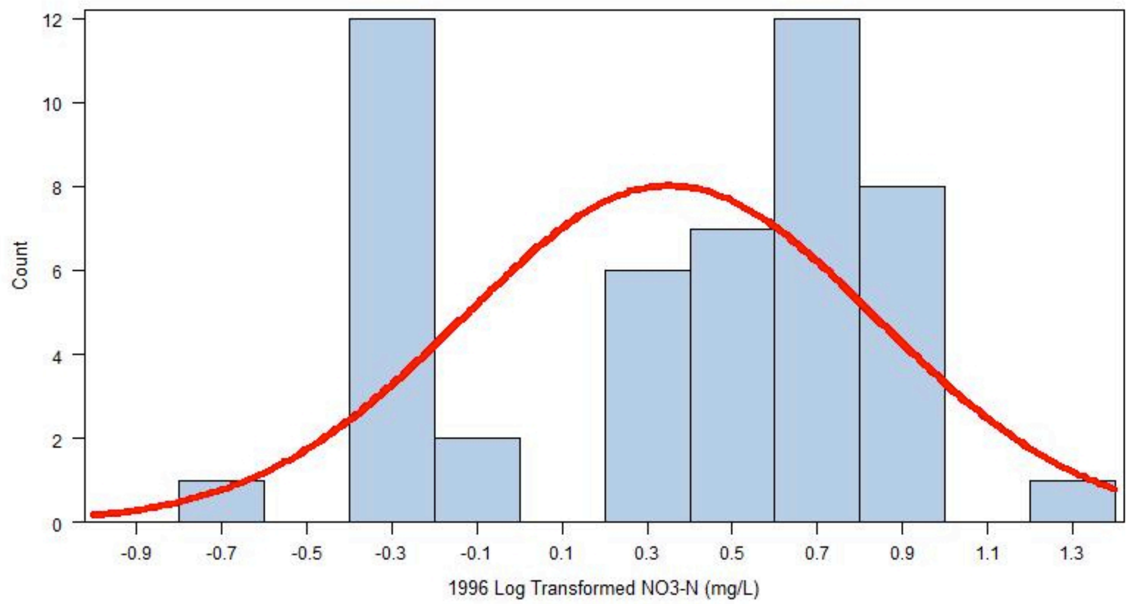


Figure 25. Histogram (with a normal curve for comparison) and Q-Q Plot for 2011 NO_3-N results in Jamestown Shores, Jamestown, RI. Shapiro-Wilk Test p=<0.0001, indicating a rejection of normality.

NORMALITY DETERMINATION – LOG-TRANSFORMED NO_3-N DATA



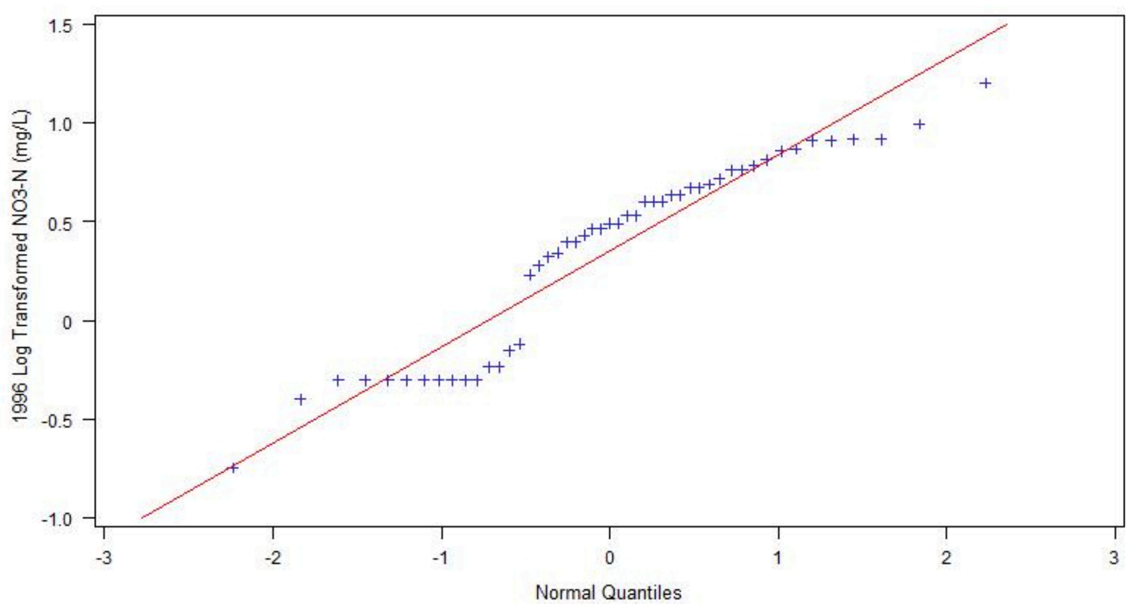
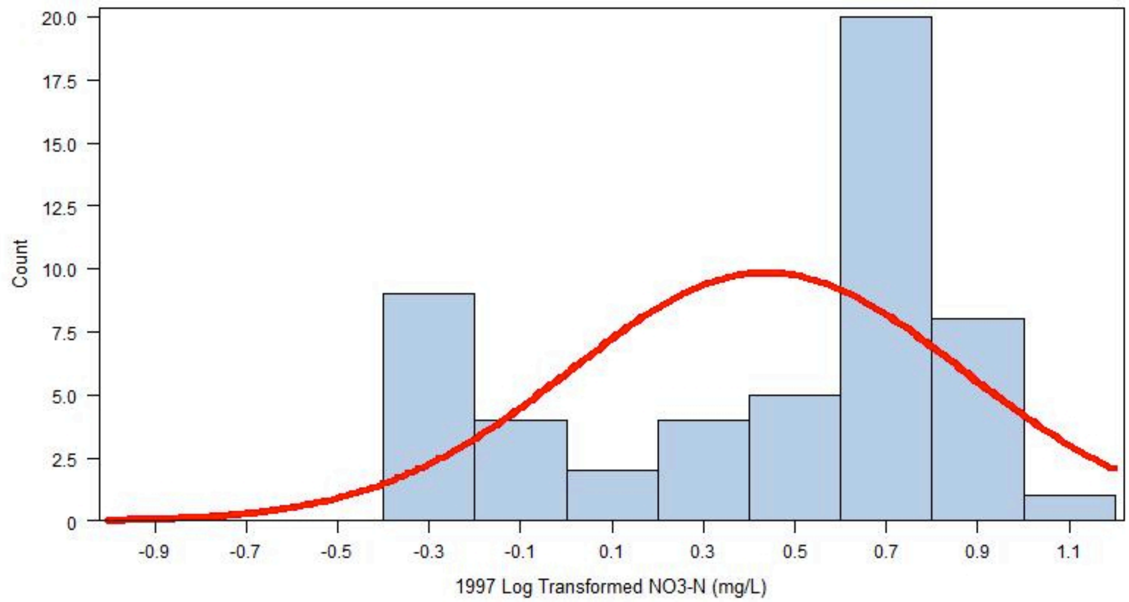


Figure 26. Histogram (with a normal curve for comparison) and Q-Q Plot for log-transformed 1996 NO_3-N results in Jamestown Shores, Jamestown, RI. Shapiro-Wilk Test $p=0.0010$, indicating a rejection of normality.



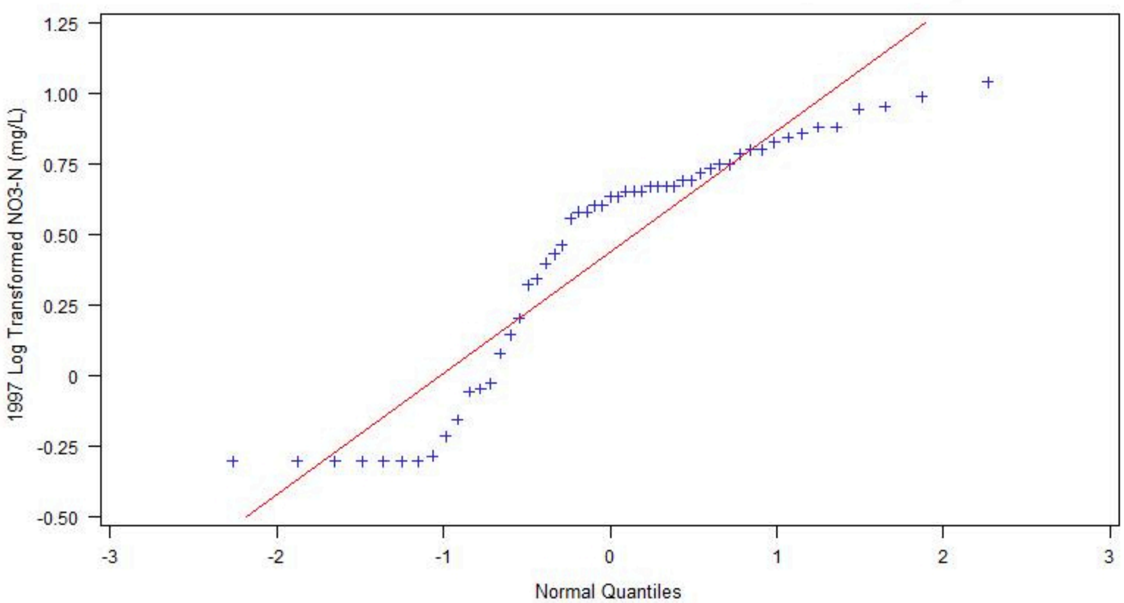
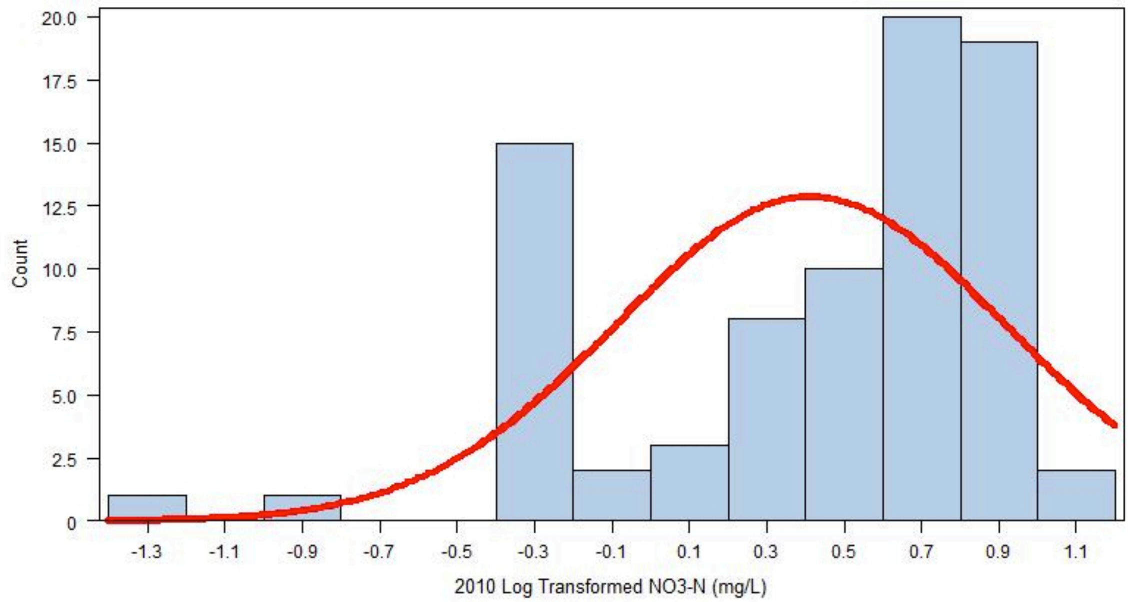


Figure 27. Histogram (with a normal curve for comparison) and Q-Q Plot for log-transformed 1997 NO_3-N results in Jamestown Shores, Jamestown, RI. Shapiro-Wilk Test p=<0.0001, indicating a rejection of normality.



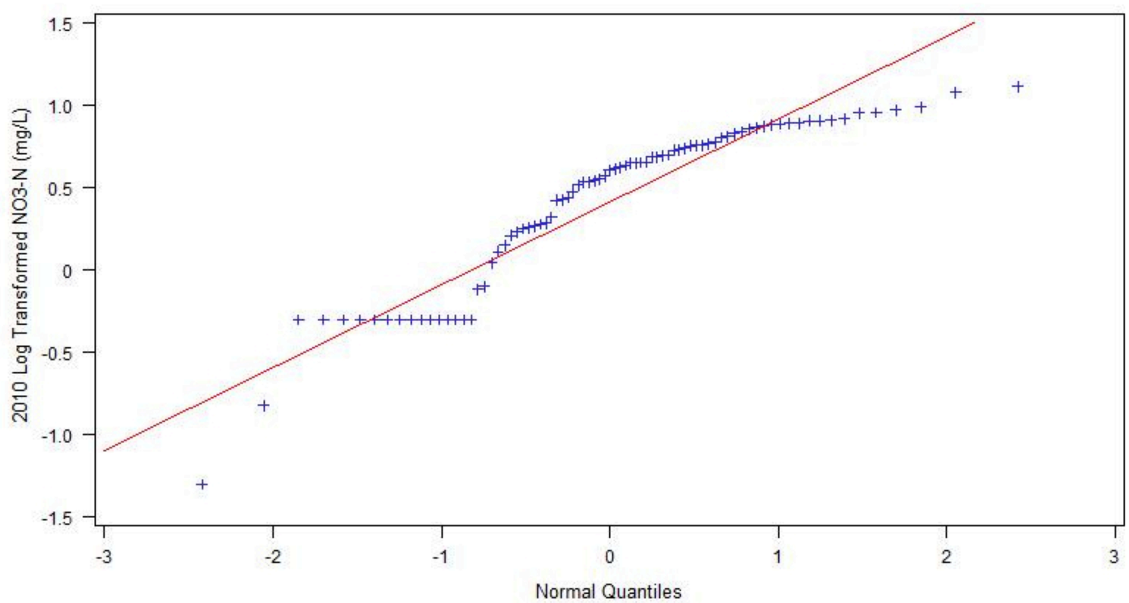
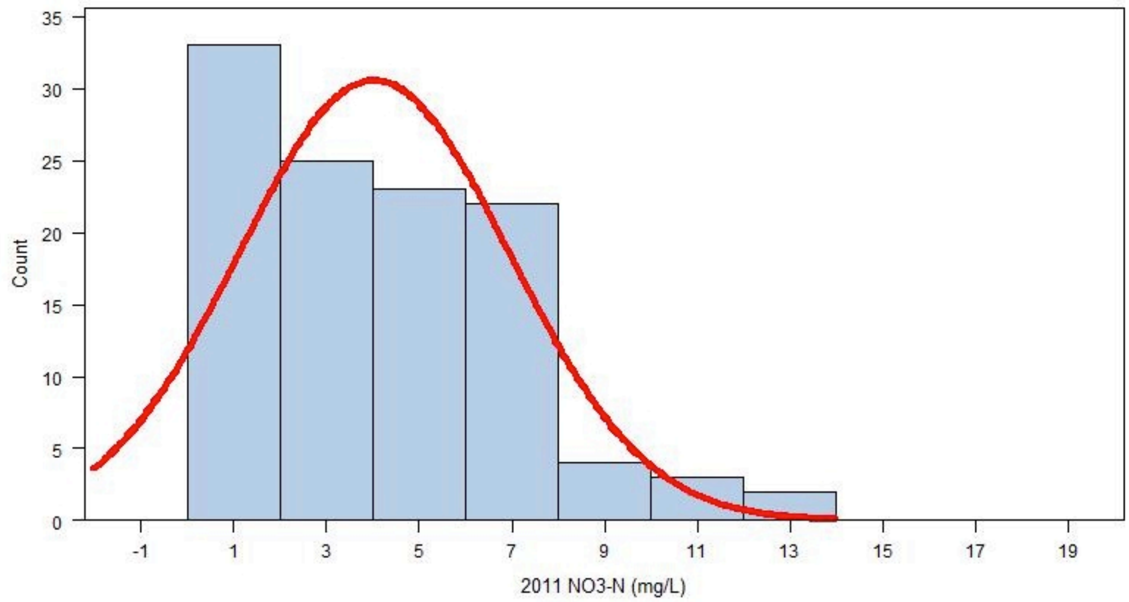


Figure 28. Histogram (with a normal curve for comparison) and Q-Q Plot for log-transformed 2010 NO_3-N results in Jamestown Shores, Jamestown, RI. Shapiro-Wilk Test p=<0.0001, indicating a rejection of normality.



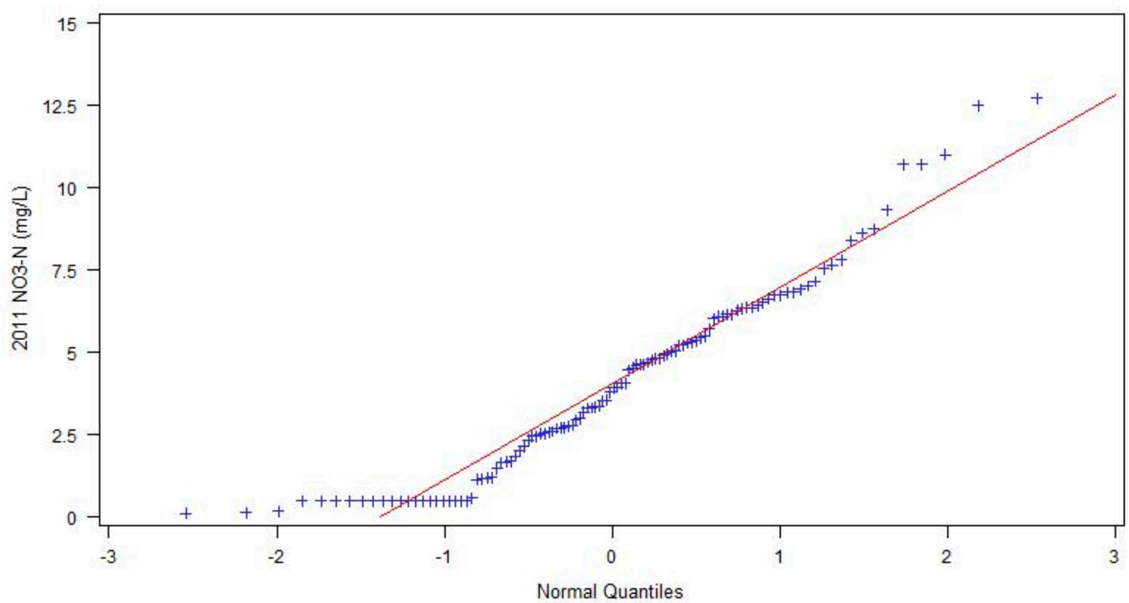


Figure 29. Histogram (with a normal curve for comparison) and Q-Q Plot for log-transformed 2011 NO_3-N results in Jamestown Shores, Jamestown, RI. Shapiro-Wilk Test p=<0.0001, indicating a rejection of normality.

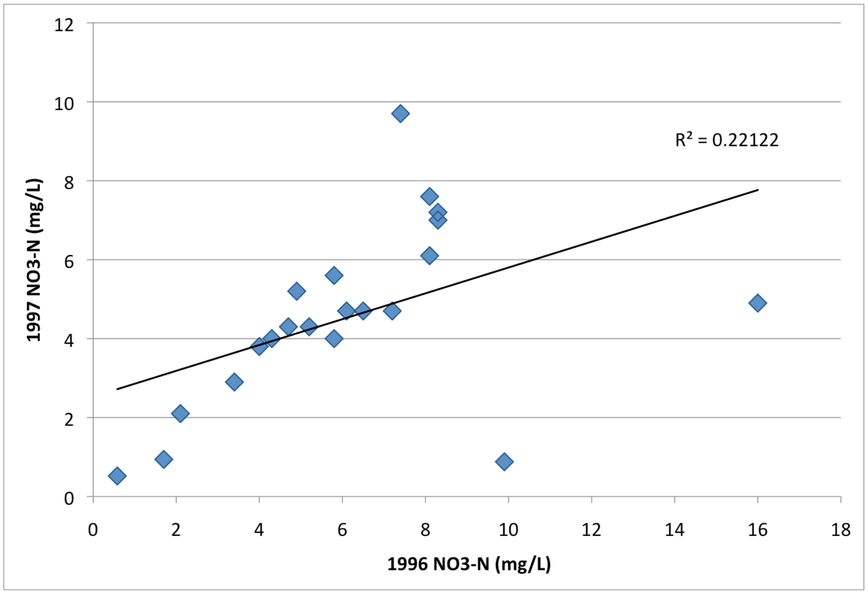


Figure 30. Repeatability of groundwater NO_3-N results sampled from the same sites in Jamestown Shores, RI in both 1996 and 1997. Pearson's Correlation Coefficient is 0.47034 (p=0.0314).

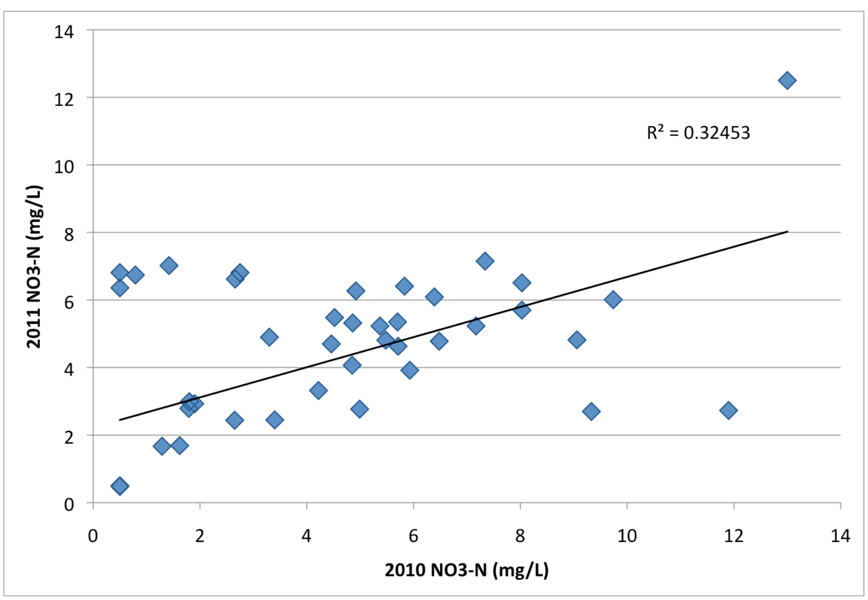
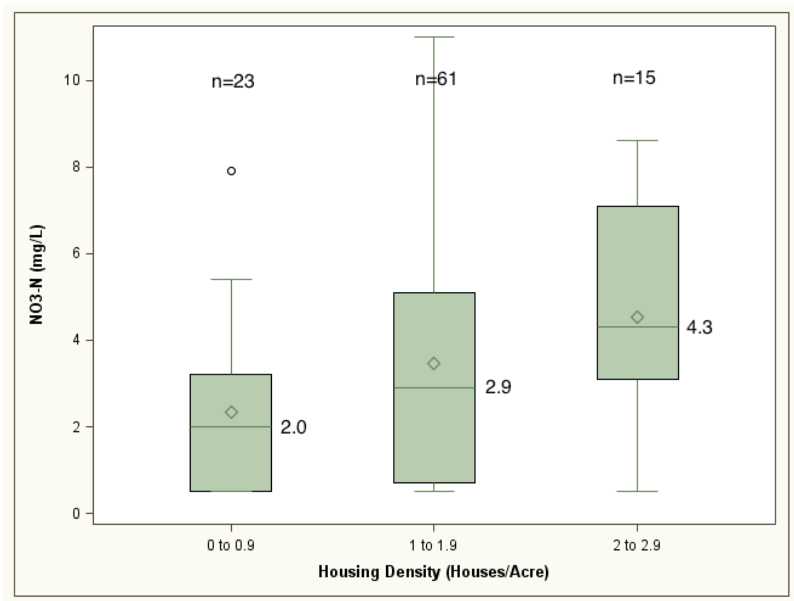


Figure 31. Repeatability of groundwater NO_3-N results sampled from the same sites in Jamestown Shores, RI in both 2010 and 2011. Pearson's Correlation Coefficient is 0.56968 (p=<0.0001).

HOUSING DENSITY

A) Dataset: 1996-1997; Buffer: Circle, 400-ft Radius



B) Dataset: 1996-1997; Buffer: Circle, 400-ft Radius

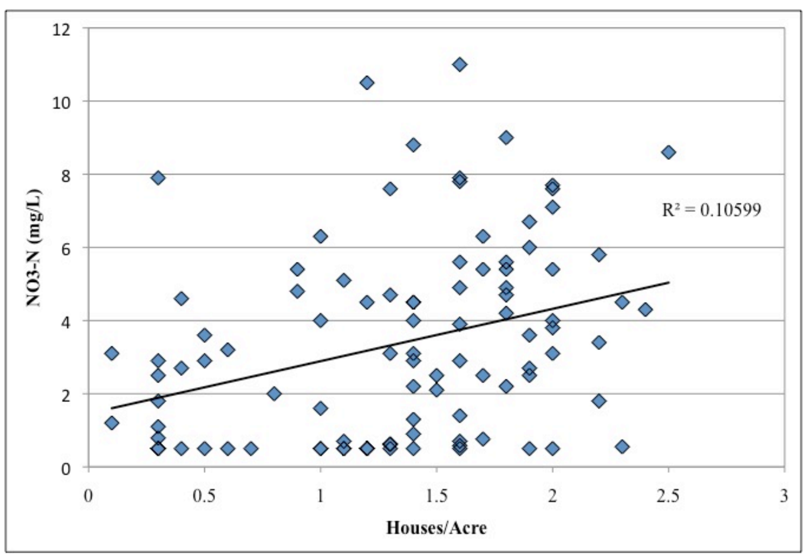
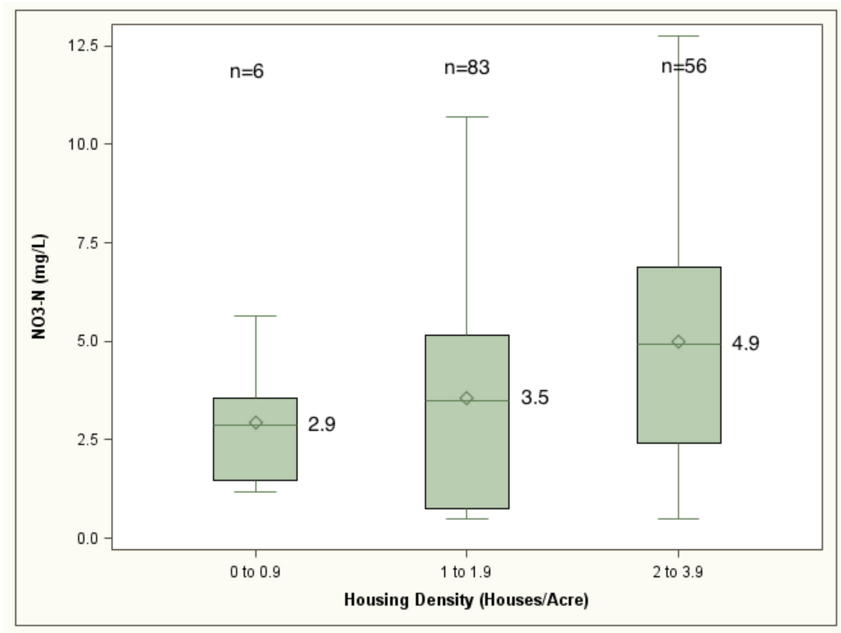


Figure 32. Groundwater NO_3-N concentrations compared with housing density bins (Graph A) and continuous housing density (Graph B) within the 400-ft (122-meter) radius circle buffers for the 1996-1997 dataset in Jamestown Shores, RI. The median value for each bin is shown next to the median line. For A, Kruskal-Wallis Test p = 0.0341. For B, Spearman's Correlation Test p=0.0002 and Kendall-Theil Robust Line confidence limits=2.25 to 0.4.

A) Dataset: 2010-2011; Buffer: Circle, 400-ft Radius



B) Dataset: 2010-2011; Buffer: Circle, 400-ft Radius

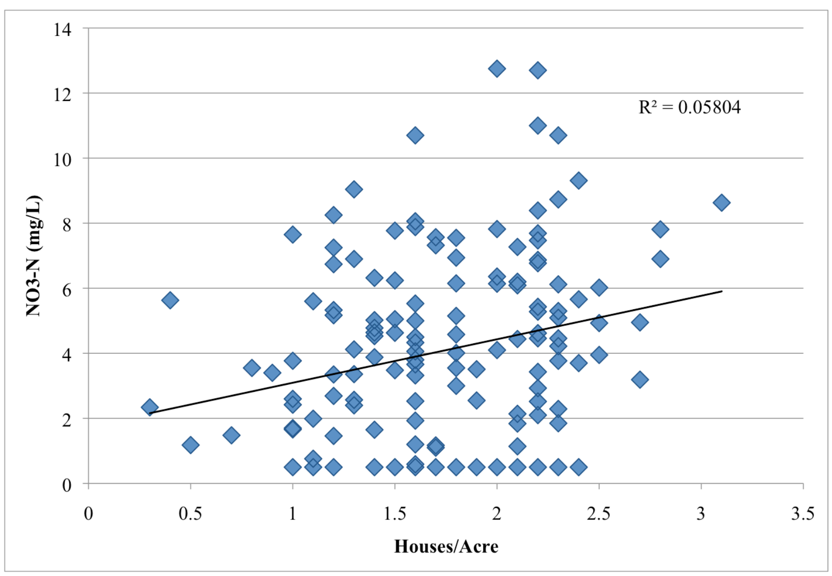
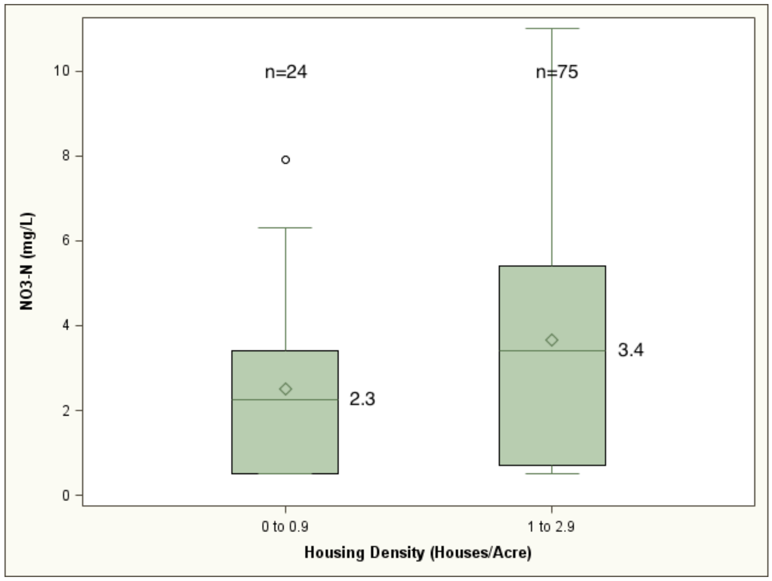


Figure 33. Groundwater NO_3-N concentrations compared with housing density bins (Graph A) and continuous housing density (Graph B) within the 400-ft (122-meter) radius circle buffers for the 2010-2011 dataset in Jamestown Shores, RI. The median value for each bin is shown next to the median line. For A, Kruskal-Wallis Test p = 0.0227. For B, Spearman's Correlation Test p=0.0126 and Kendall-Theil Robust Line confidence limits=2.07 to 0.

A) Dataset: 1996-1997; Buffer: Circle, 600-ft Radius



B) Dataset: 1996-1997; Buffer: Circle, 600-ft Radius

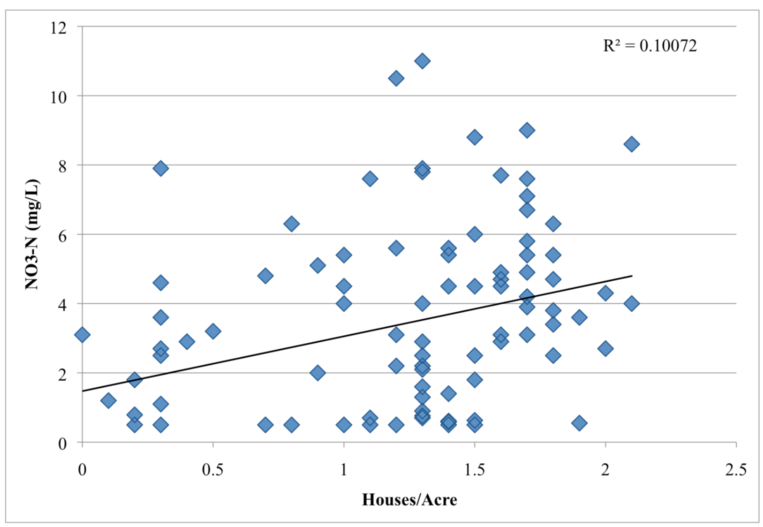
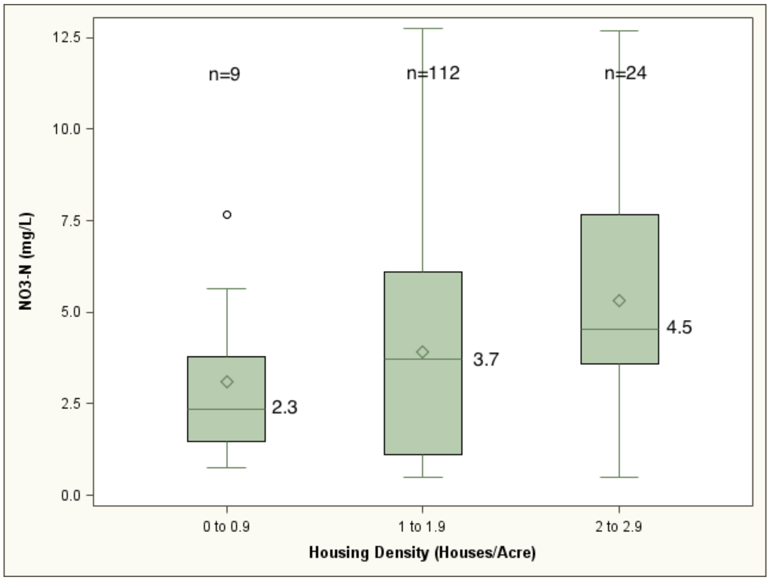


Figure 34. Groundwater NO_3-N concentrations compared with housing density bins (Graph A) and continuous housing density (Graph B) within the 600-ft (183-meter) radius circle buffers for the 1996-1997 dataset in Jamestown Shores, RI. The median value for each bin is shown next to the median line. For A, Kruskal-Wallis Test p = 0.0752. For B, Spearman's Correlation Test p=<0.0001 and Kendall-Theil Robust Line confidence limits=2.67 to 0.50.

A) Dataset: 2010-2011; Buffer: Circle, 600-ft Radius



B) Dataset: 2010-2011; Buffer: Circle, 600-ft Radius

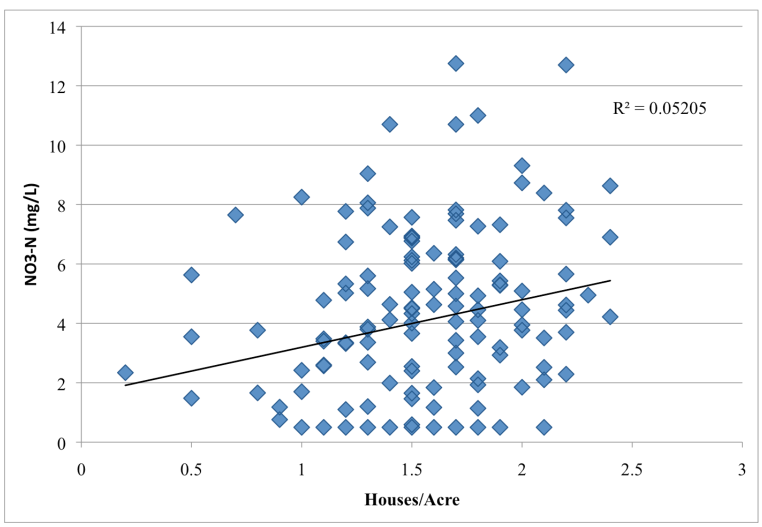
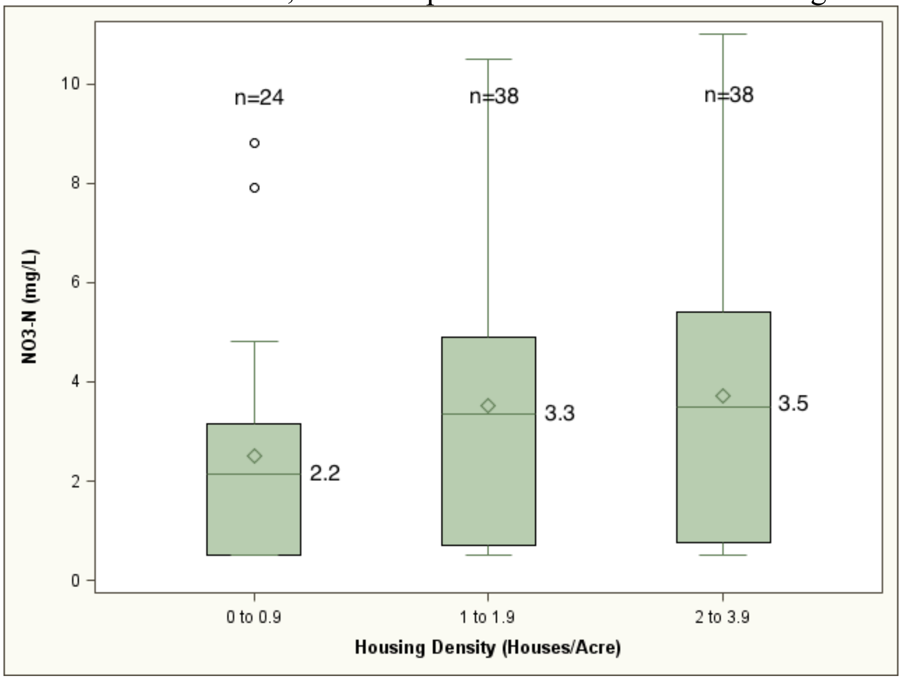


Figure 35. Groundwater NO_3-N concentrations compared with housing density bins (Graph A) and continuous housing density (Graph B) within the 600-ft (183-meter) radius circle buffers for the 2010-2011 dataset in Jamestown Shores, RI. The median value for each bin is shown next to the median line. For A, Kruskal-Wallis Test p = 0.0704. For B, Spearman's Correlation Test p=0.0088 and Kendall-Theil Robust Line confidence limits=2.70 to 0.

A) Dataset: 1996-1997; Buffer: Up-Groundwater Gradient Wedge



B) Dataset: 1996-1997; Buffer: Up-Groundwater Gradient Wedge

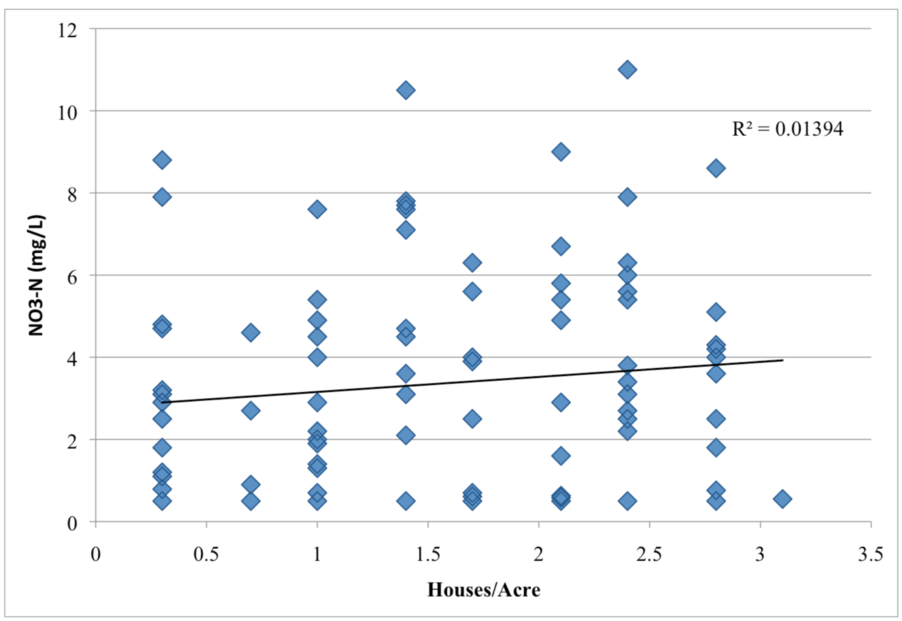
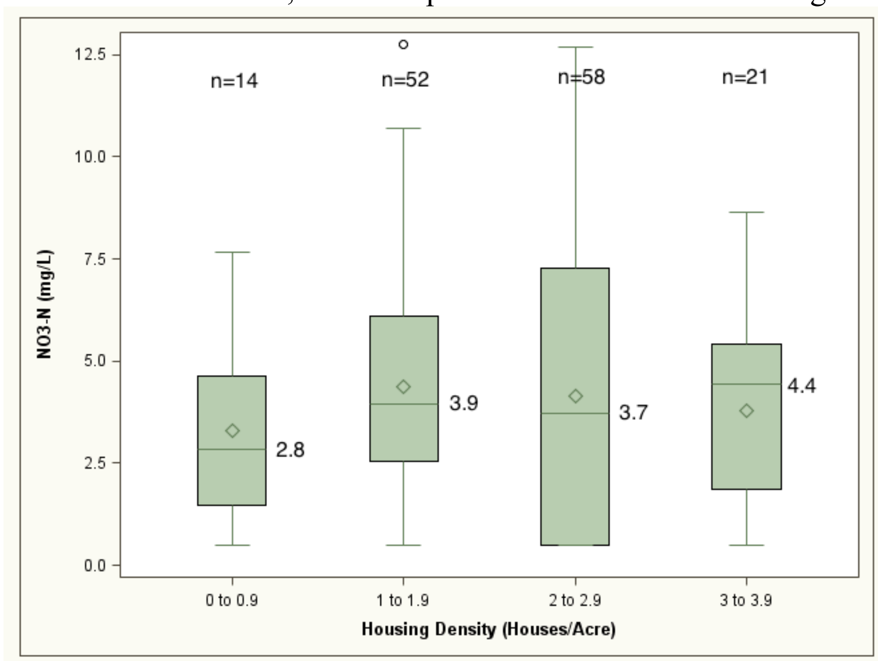


Figure 36. Groundwater NO_3-N concentrations compared with housing density bins (Graph A) and continuous housing density (Graph B) within the 400-ft (122-meter) up-groundwater gradient wedge buffers for the 1996-1997 dataset in Jamestown Shores, RI. The median value for each bin is shown next to the median line. For A, Kruskal-Wallis Test p=0.1792. For B, Spearman's Correlation Test p=0.2386 and Kendall-Theil Robust Line confidence limits=0.93 to -0.11.

A) Dataset: 2010-2011; Buffer: Up-Groundwater Gradient Wedge



B) Dataset: 2010-2011; Buffer: Up-Groundwater Gradient Wedge

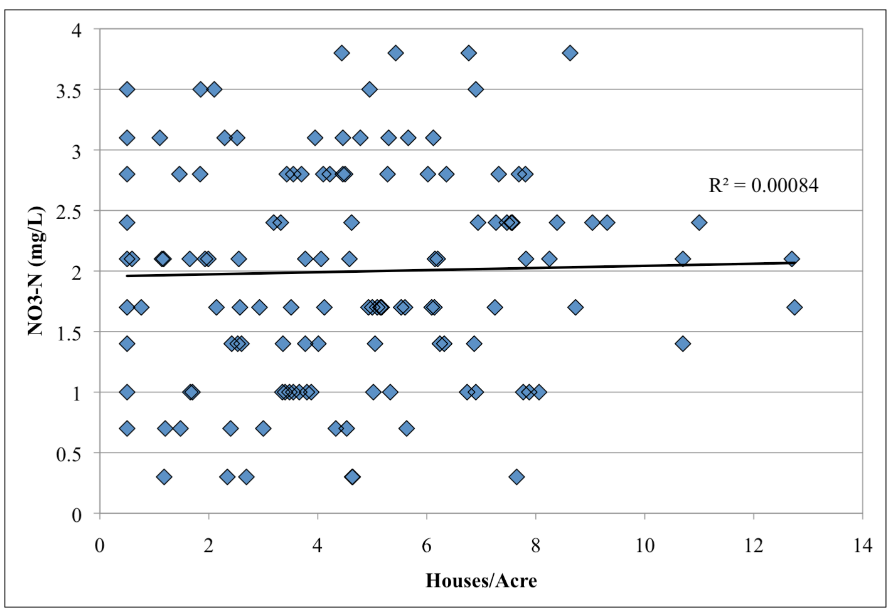
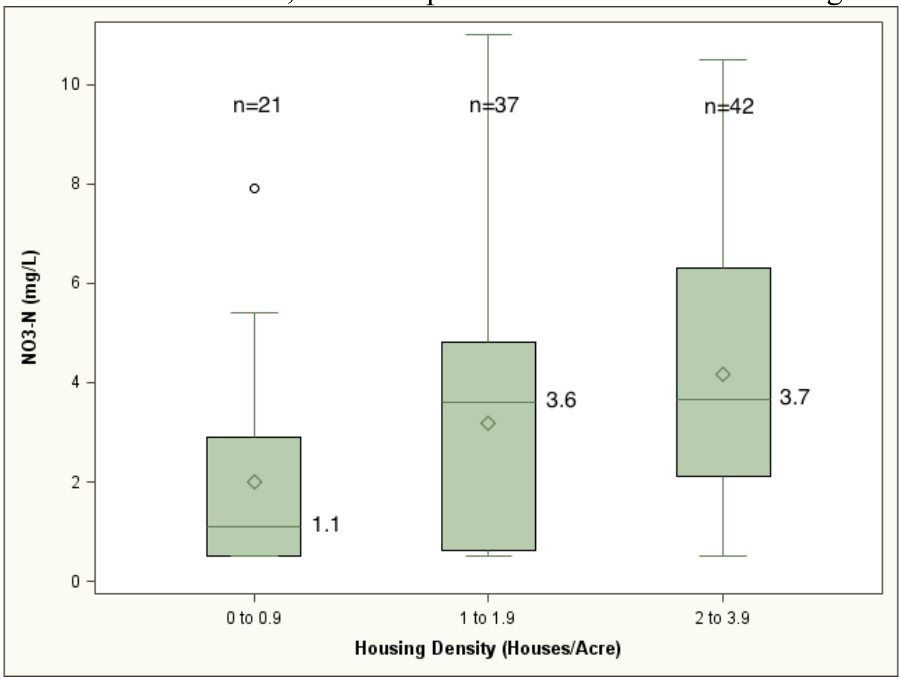


Figure 37. Groundwater NO_3-N concentrations compared with housing density bins (Graph A) and continuous housing density (Graph B) within the 400-ft (122-meter) up-groundwater gradient wedge buffers for the 2010-2011 dataset in Jamestown Shores, RI. The median value for each bin is shown next to the median line. For A, Kruskal-Wallis Test p=0.7048. For B, Spearman's Correlation Test p=0.8734 and Kendall-Theil Robust Line confidence limits=0.54 to -0.40.

A) Dataset: 1996-1997; Buffer: Up-Fracture North to South Wedge



B) Dataset: 1996-1997; Buffer: Up-Fracture North to South Wedge

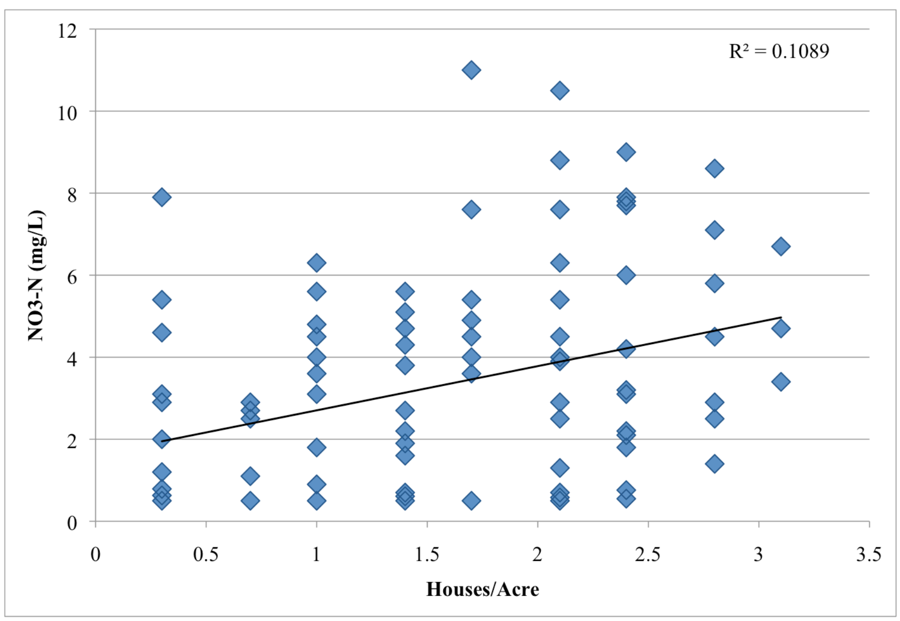
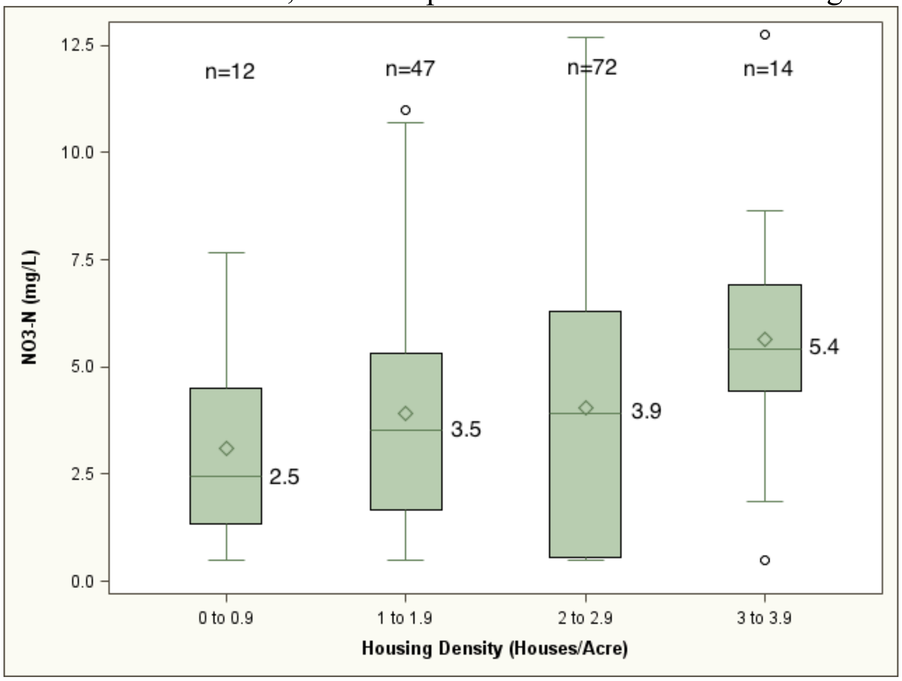


Figure 38. Groundwater NO_3-N concentrations compared with housing density bins (Graph A) and continuous housing density (Graph B) within the 400-ft (122-meter) up-fracture north to south wedge buffers for the 1996-1997 dataset in Jamestown Shores, RI. The median value for each bin is shown next to the median line. For A, Kruskal-Wallis Test p=0.0044. For B, Spearman's Correlation Test p=0.0005 and Kendall-Theil Robust Line confidence limits=1.6 to 0.26.

A) Dataset: 2010-2011; Buffer: Up-Fracture North to South Wedge



B) Dataset: 2010-2011; Buffer: Up-Fracture North to South Wedge

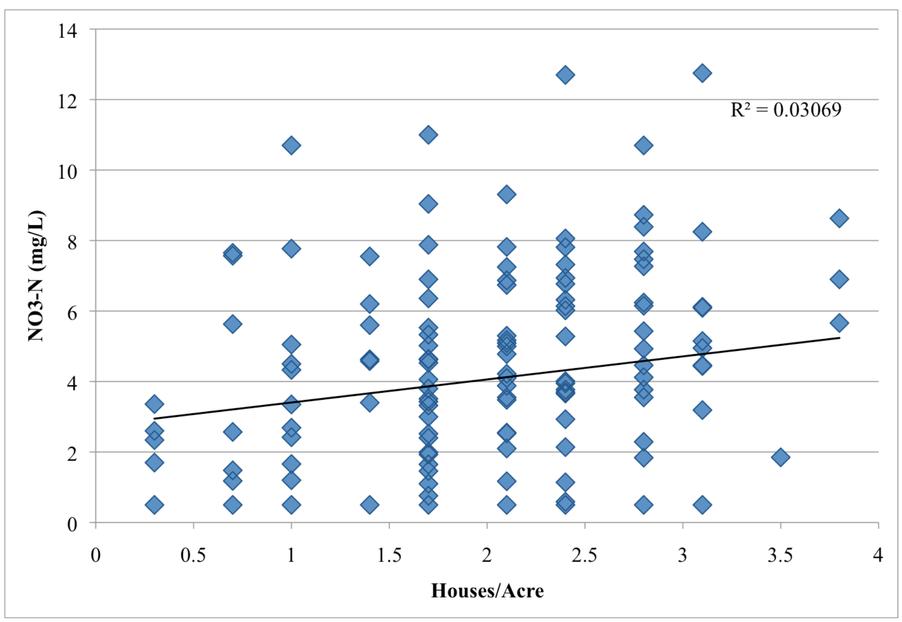
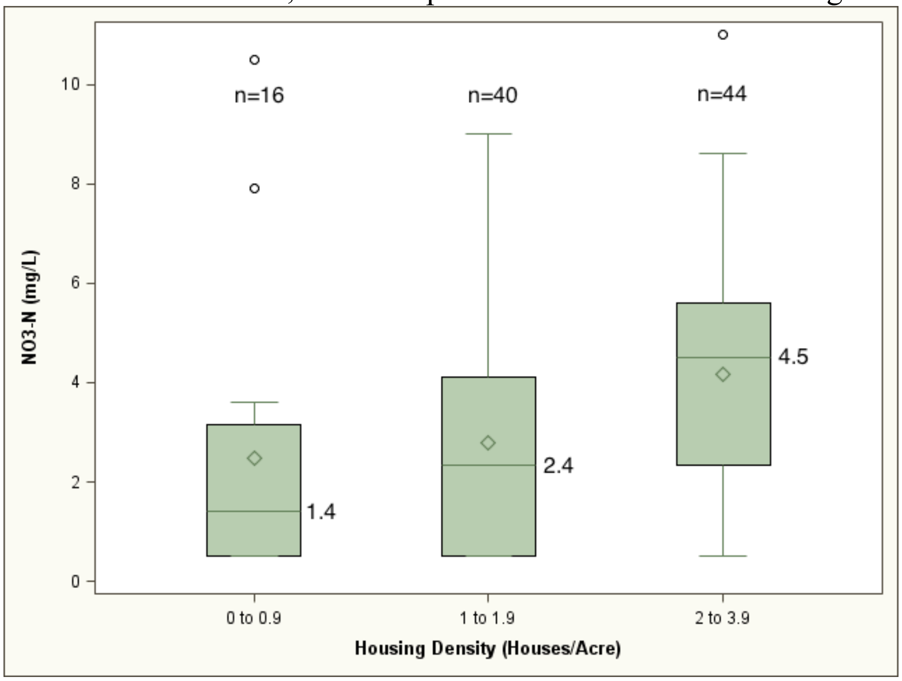


Figure 39. Groundwater NO_3-N concentrations compared with housing density bins (Graph A) and continuous housing density (Graph B) within the 400-ft (122-meter) up-fracture north to south wedge buffers for the 2010-2011 dataset in Jamestown Shores, RI. The median value for each bin is shown next to the median line. For A, Kruskal-Wallis Test p=0.1612. For B, Spearman's Correlation Test p=0.0819 and Kendall-Theil Robust Line confidence limits=1.17 to 0.

A) Dataset: 1996-1997; Buffer: Up-Fracture South to North Wedge



B) Dataset: 1996-1997; Buffer: Up-Fracture South to North Wedge

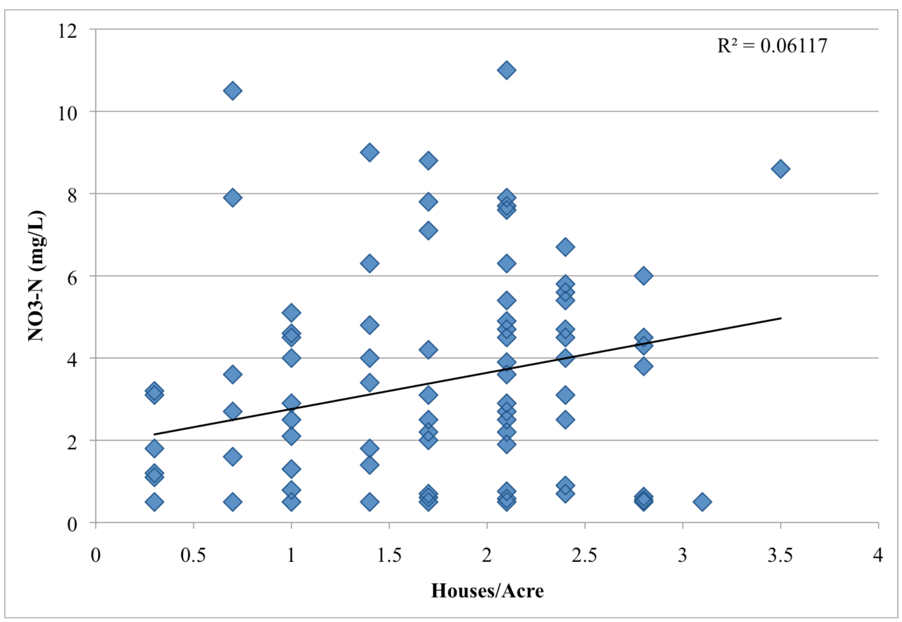
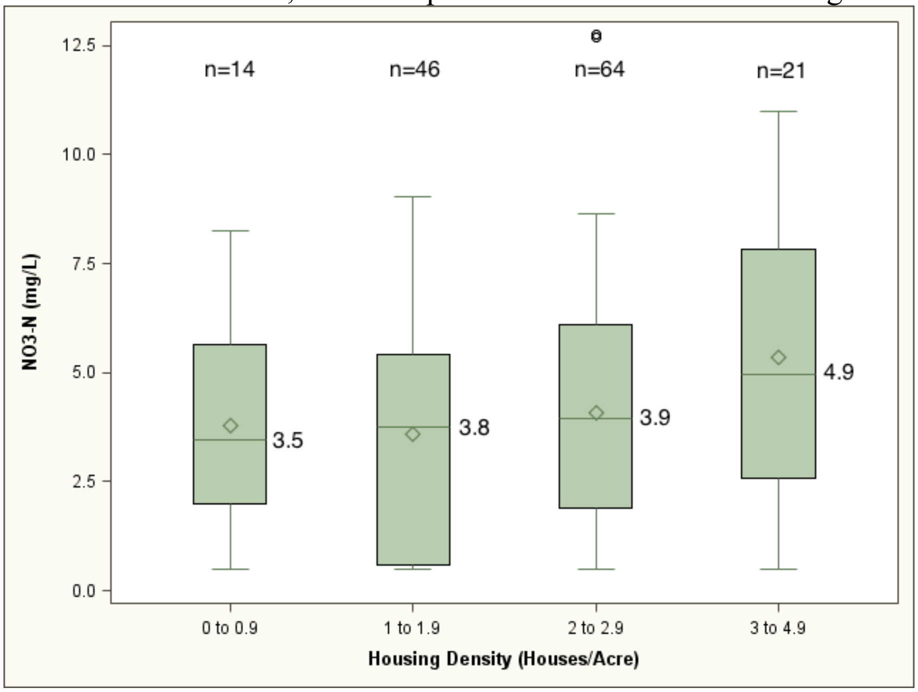


Figure 40. Groundwater NO_3-N concentrations compared with housing density bins (Graph A) and continuous housing density (Graph B) within the 400-ft (122-meter) up-fracture south to north wedge buffers for the 1996-1997 dataset in Jamestown Shores, RI. The median value for each bin is shown next to the median line. For A, Kruskal-Wallis Test p=0.0034. For B, Spearman's Correlation Test p=0.0037 and Kendall-Theil Robust Line confidence limits=1.7 to 0.07.

A) Dataset: 2010-2011; Buffer: Up-Fracture South to North Wedge



B) Dataset: 2010-2011; Buffer: Up-Fracture South to North Wedge

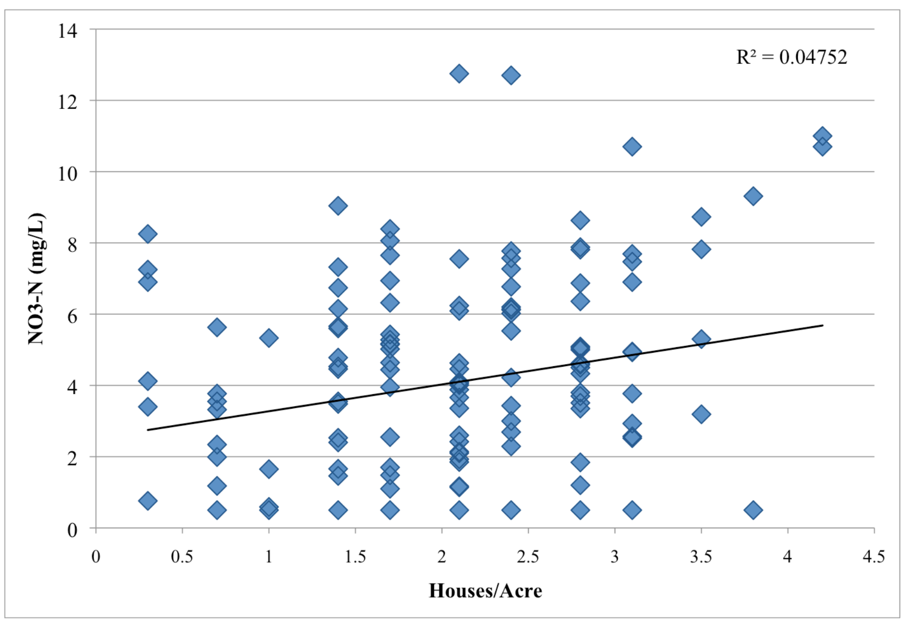
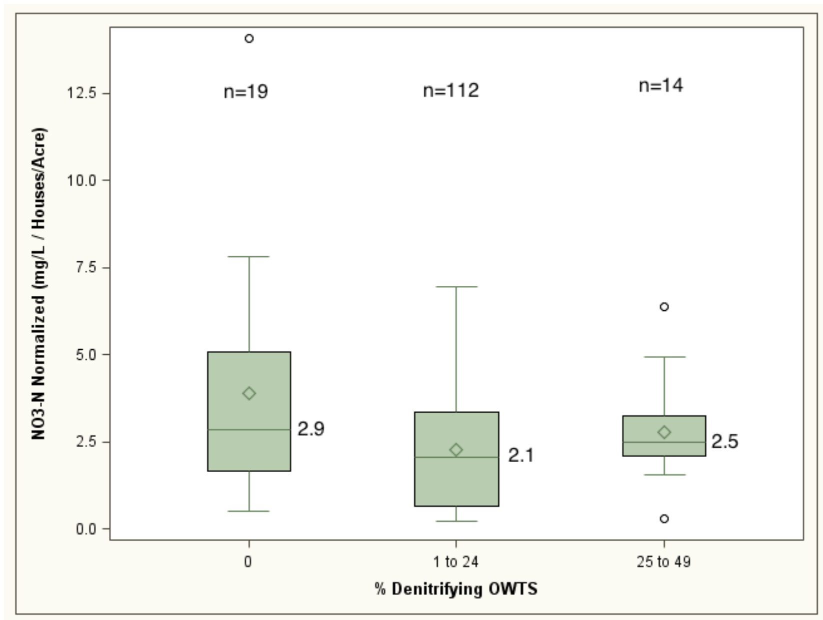


Figure 41. Groundwater NO_3-N concentrations compared with housing density bins (Graph A) and continuous housing density (Graph B) within the 400-ft (122-meter) up-fracture south to north wedge buffers for the 2010-2011 dataset in Jamestown Shores, RI. The median value for each bin is shown next to the median line. For A, Kruskal-Wallis Test p=0.3400. For B, Spearman's Correlation Test p=0.0390 and Kendall-Theil Robust Line confidence limits=1.3 to 0.

PERCENT DENITRIFYING OWTS IN JAMESTOWN SHORES

A) Dataset: 2010-2011; Buffer: Circle, 400-ft Radius



B) Dataset: 2010-2011; Buffer: Circle, 400-ft Radius

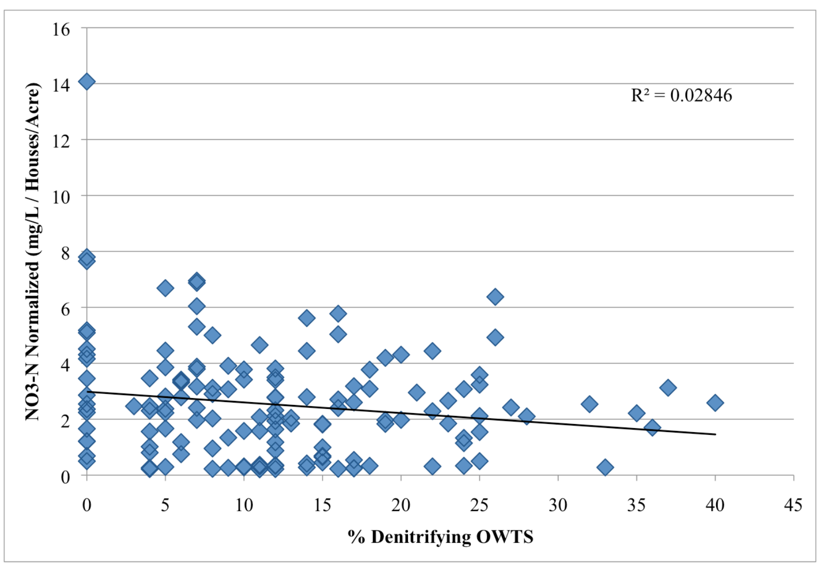
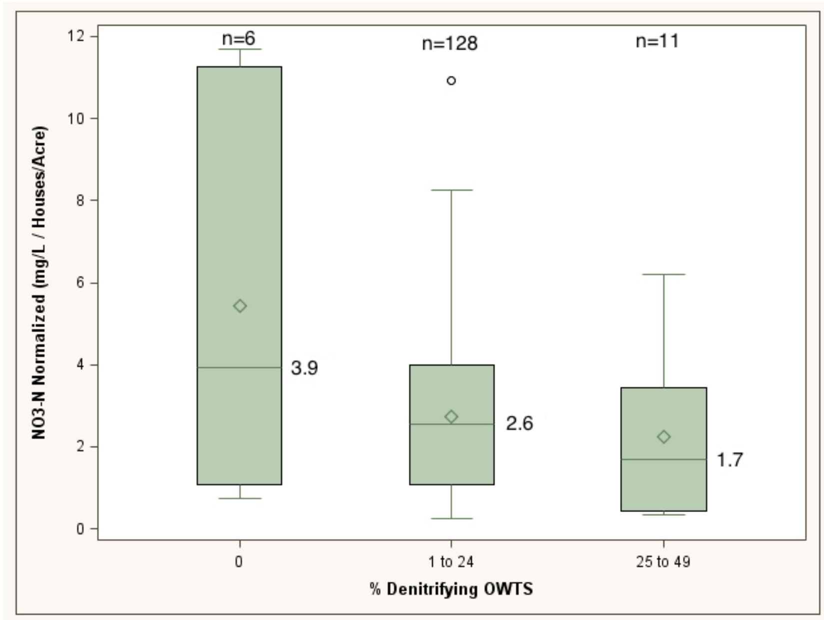


Figure 42. Groundwater NO_3-N concentrations normalized by housing density and compared with bins of the percentage of denitrifying OWTS (Graph A) and the continuous percentage of denitrifying OWTS (Graph B) within each 400-ft (122-meter) circle buffer for the 2010-2011 dataset in Jamestown Shores, RI. The median value for each bin is shown next to the median line. For A, Kruskal-Wallis Test p=0.0382. For B, Spearman's Correlation p=0.0873 and Kendall-Theil Robust Line confidence limits=0.0047 to -0.058.

A) Dataset: 2010-2011; Buffer: Circle, 600-ft Radius



B) Dataset: 2010-2011; Buffer: Circle, 600-ft Radius

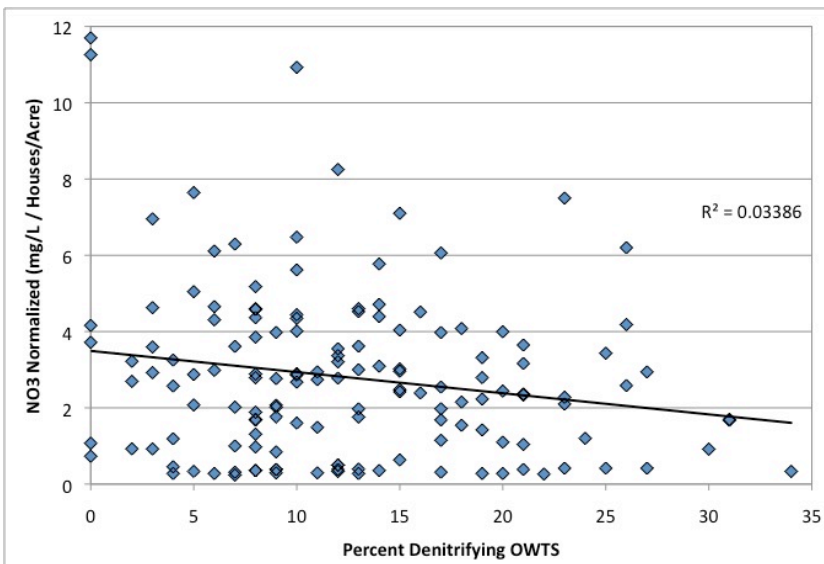
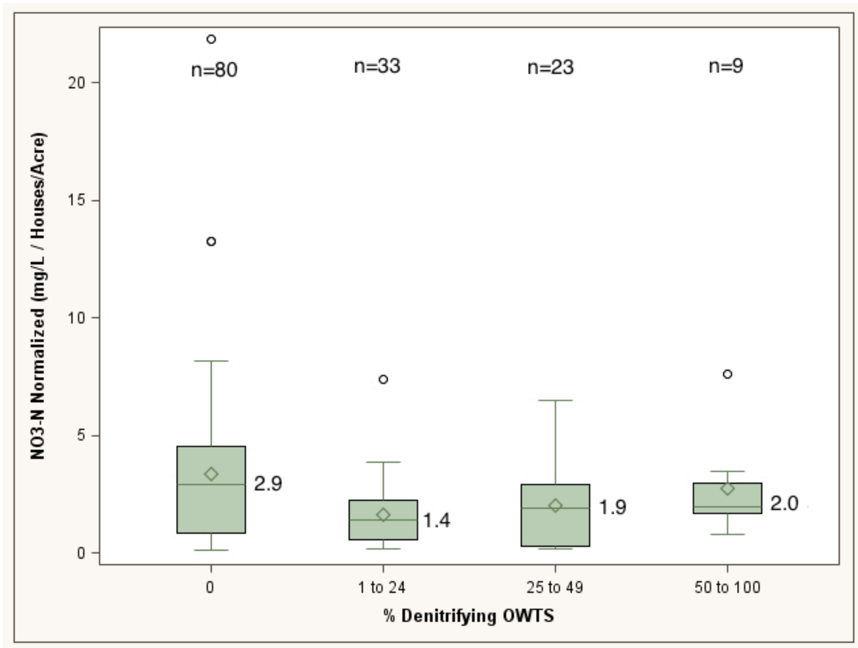


Figure 43. Groundwater NO_3-N concentrations normalized by housing density and compared with bins of the percentage of denitrifying OWTS (Graph A) and the continuous percentage of denitrifying OWTS (Graph B) within each 600-ft (183-meter) circle buffer for the 2010-2011 dataset in Jamestown Shores, RI. The median value for each bin is shown next to the median line. For A, the Kruskal-Wallis Test is not statistically significant at p=0.3115. For B, Spearman's Correlation p=0.1509 and Kendall-Theil Robust Line confidence limits=0.00625 to -0.0700.

A) Dataset: 2010-2011; Buffer: Up-Groundwater Gradient Wedge



B) Dataset: 2010-2011; Buffer: Up-Groundwater Gradient Wedge

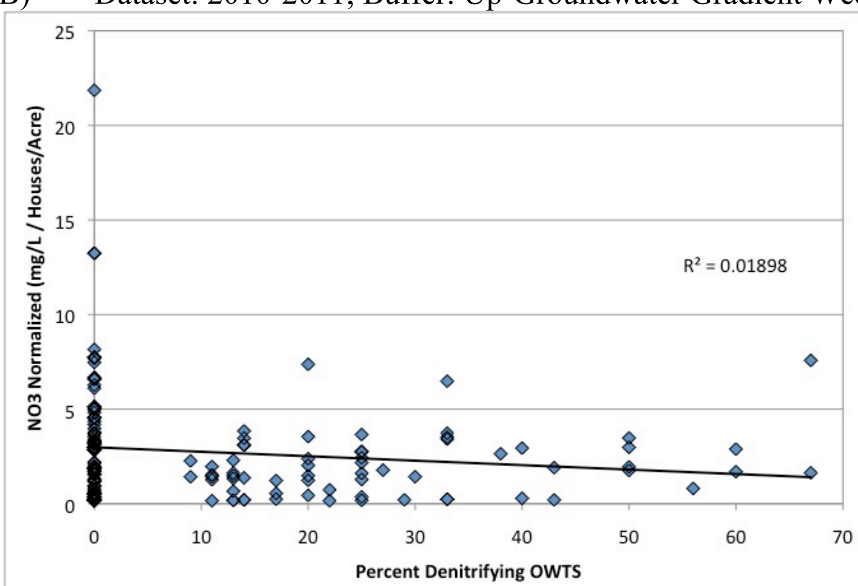
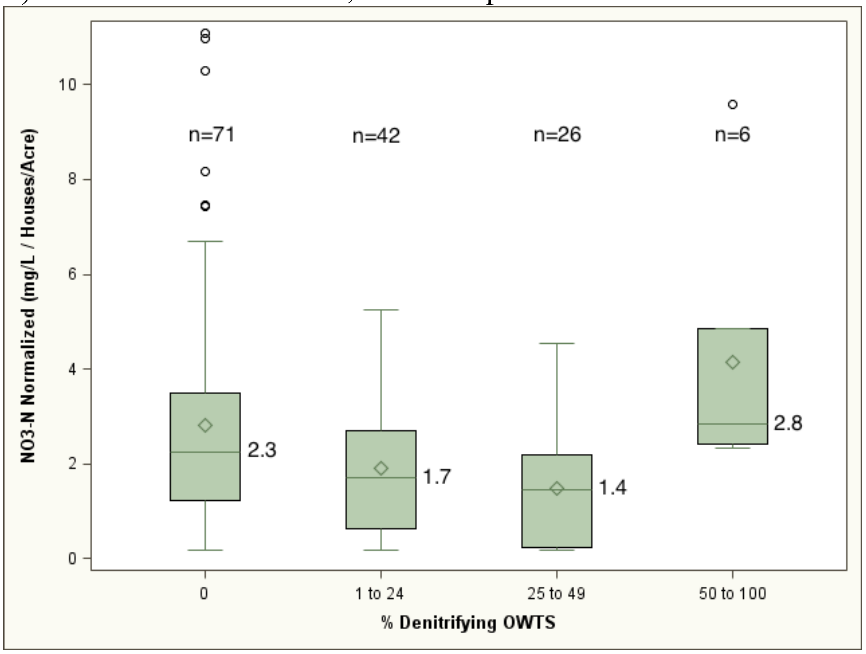


Figure 44. Groundwater NO_3-N concentrations normalized by housing density and compared with bins of the percentage of denitrifying OWTS (Graph A) and the continuous percentage of denitrifying OWTS within each 400-ft (122-meter) up-groundwater gradient buffer for the 2010-2011 dataset in Jamestown Shores, RI. The median value for each bin is shown next to the median line. For A, Kruskal-Wallis Test p=0.0127. For B, Spearman's Correlation p=0.0331 and Kendall-Theil Robust Line confidence limits=0.00045 to -0.042.

A) Dataset: 2010-2011; Buffer: Up-Fracture North to South Wedge



B) Dataset: 2010-2011; Buffer: Up-Fracture North to South Wedge

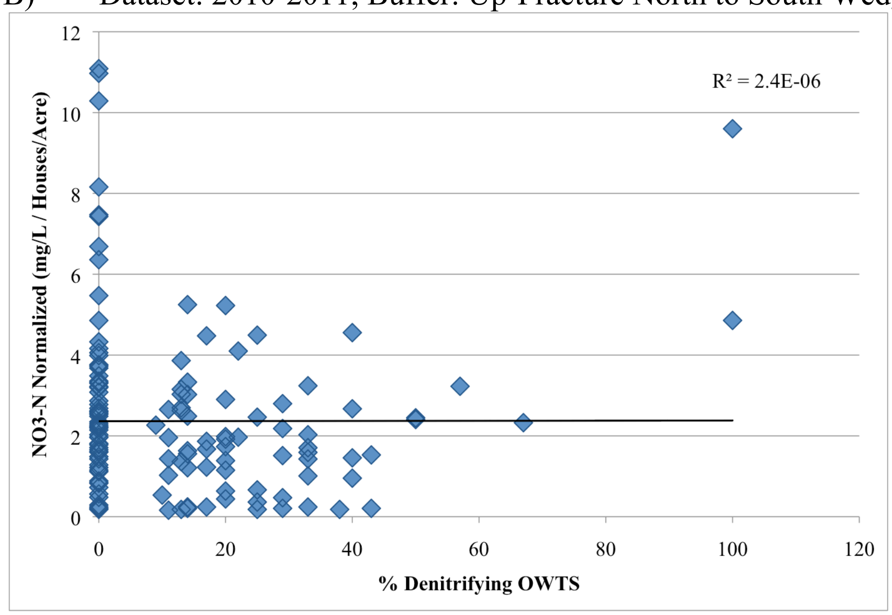
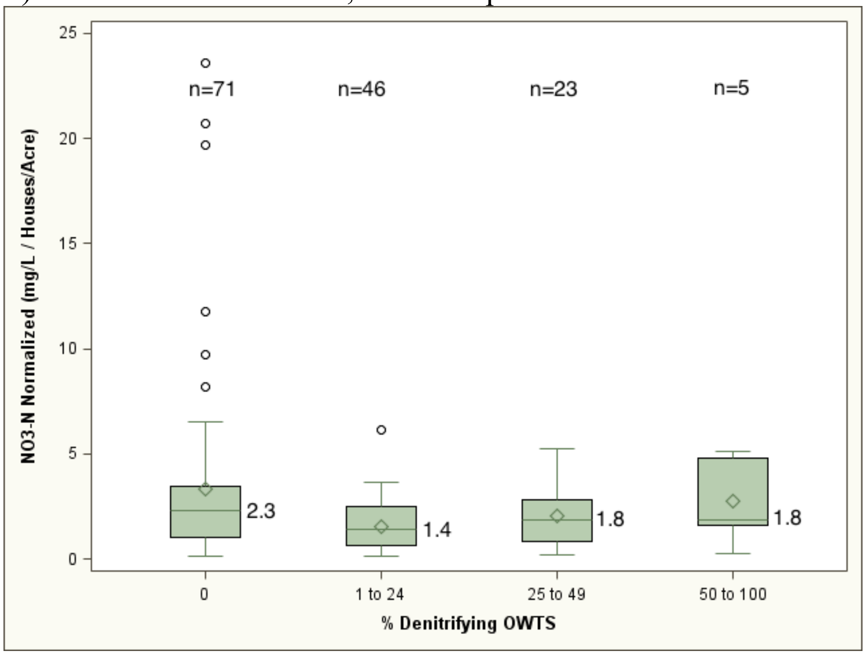


Figure 45. Groundwater NO_3-N concentrations normalized by housing density and compared with bins of the percentage of denitrifying OWTS (Graph A) and the continuous percentage of denitrifying OWTS within each 400-ft (122-meter) up-fracture north to south buffer for the 2010-2011 dataset in Jamestown Shores, RI. The median value for each bin is shown next to the median line. For A, Kruskal-Wallis Test p=0.0031. For B, Spearman's Correlation p=0.0558 and Kendall-Theil Robust Line confidence limits=0.00120 to -0.0357.

A) Dataset: 2010-2011; Buffer: Up-Fracture South to North Wedge



B) Dataset: 2010-2011; Buffer: Up-Fracture South to North Wedge

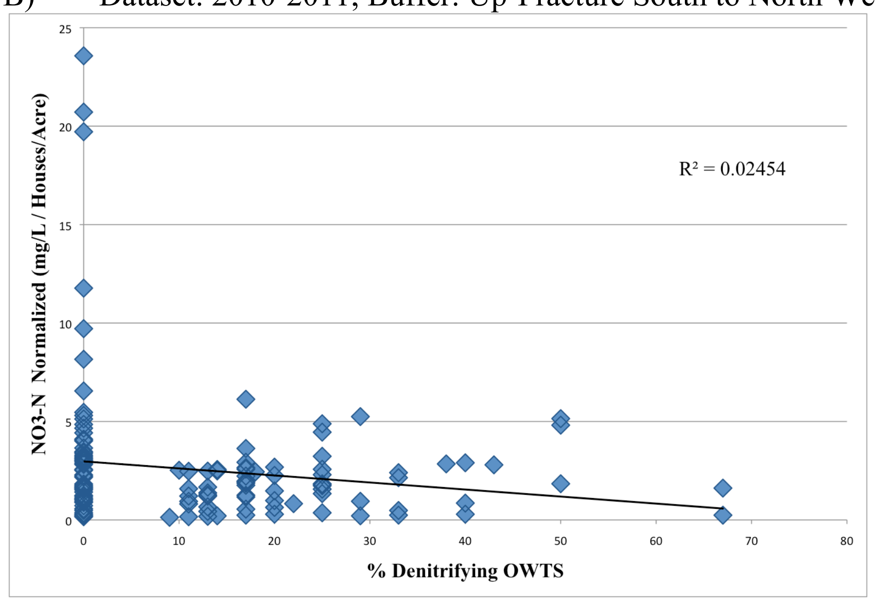
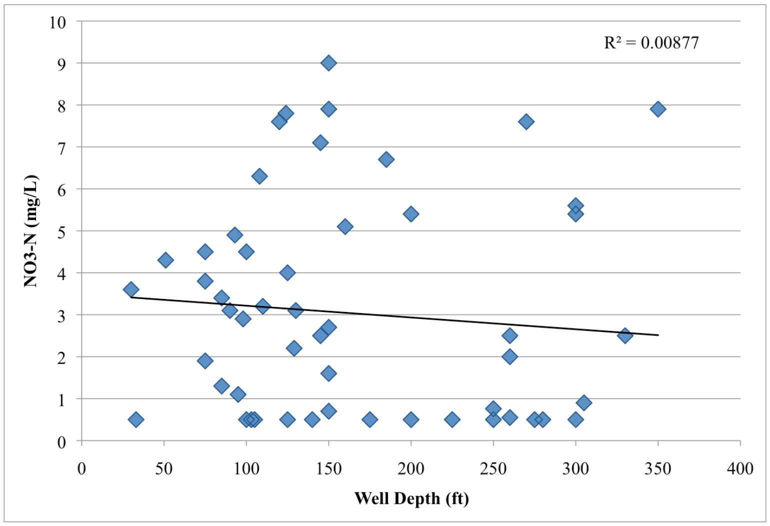


Figure 46. Groundwater NO_3-N concentrations normalized by housing density and compared with bins of the percentage of denitrifying OWTS (Graph A) and the continuous percentage of denitrifying OWTS within each 400-ft (122-meter) up-fracture south to north buffer for the 2010-2011 dataset in Jamestown Shores, RI. The median value for each bin is shown next to the median line. For A, Kruskal-Wallis Test p=0.0319. For B, Spearman's Correlation p=0.0991 and Kendall-Theil Robust Line confidence limits=0.0037 to -0.036.

WELL DEPTH

A) 1996-1997



B) 2010-2011

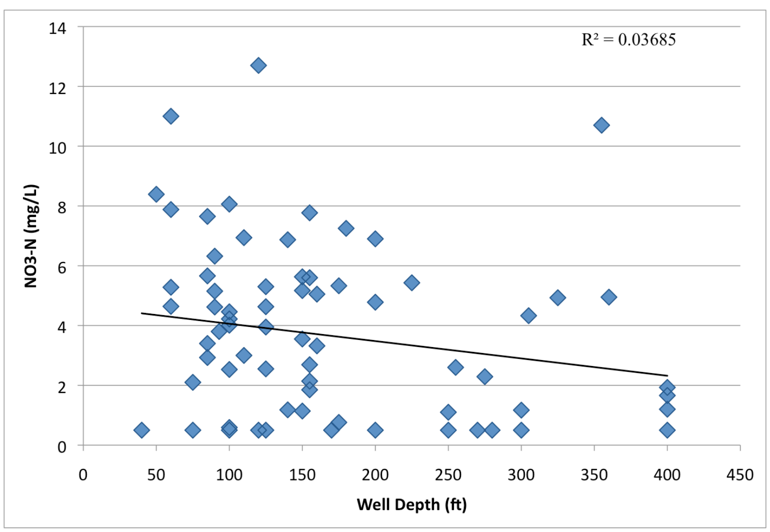
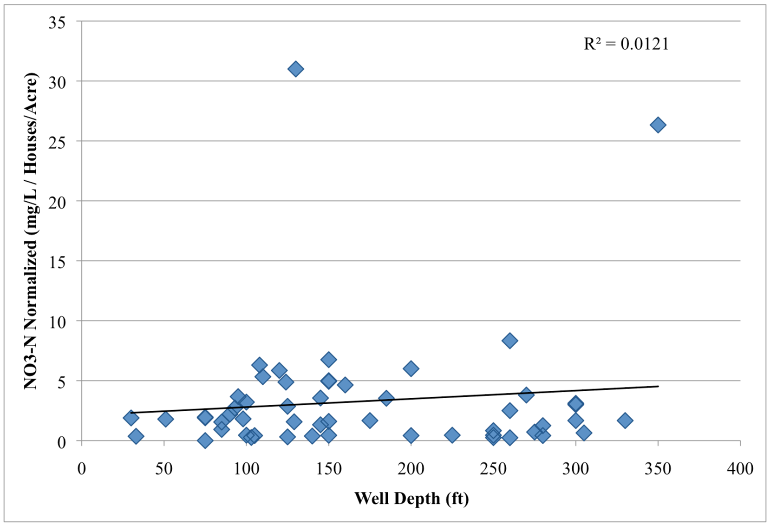


Figure 47. Groundwater NO_3-N concentrations compared with well depth at the sample locations for the 1996-1997 (Graph A) and 2010-2011 (Graph B) datasets in Jamestown Shores, RI. Spearman's Correlation p=0.3278 (A) and p=0.1327 (B) and Kendall-Theil Robust Line confidence limits = 0.00044 to -0.011 (A) and 0 to -0.013 (B).

A) 1996-1997 Normalized



B) 2010-2011 Normalized

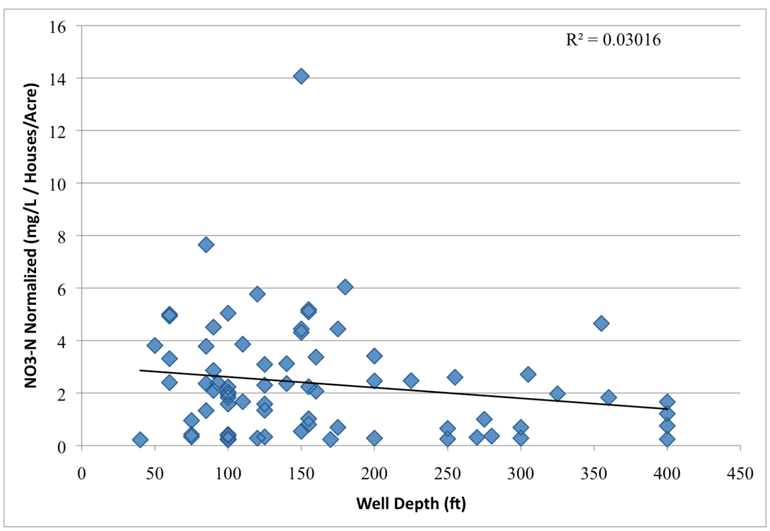


Figure 48. Groundwater NO_3-N concentrations normalized by housing density and compared with well depth at the sample locations for the 1996-1997 (Graph A) and 2010-2011 (Graph B) datasets in Jamestown Shores, RI. Spearman's Correlation p=0.8211 (A) and p=0.2265 (B) and Kendall-Theil Robust Line confidence limits = 0.0071 to -0.0045 (A) and 0.0011 to -0.0076 (B).

N LOADING – EXPECTED NO_3-N CONCENTRATIONS

Table 15. Average NO_3-N concentration available to infiltrate groundwater (annual N loading ÷ annual recharge). See Table 16 for data and source footnotes. This spreadsheet can be used for Jamestown Shores as a whole (shown) or for individual sample sites.

Annual N Loading (from OWTS only)						
Total OWTS (HUs)[1]	959					
% Denitrifying[2]	11.7					
		Pop/HU (census)[3]	**# People (2.3*HU)**	**N(lbs)/person/yr[4]**	**N (lbs)/person/yr leaching to GW (90%)[5]**	**Annual Loading (lbs), Conventional**
# Conventional[2]	847	2.30	1948	**7**	6.3	12270.1
						Denitrifying
# Denitrifying[2]	112	2.30	258	**7**	2.583	666.6
						Annual Loading (lbs) - Total
						12936.7
Annual Recharge	Annual Precip (in/yr)[7]	Annual ET (in/yr)[8]	Annual Runoff (in/yr)[9]	Natural Infiltration (in/yr) (B22-C22-D22)	**Water Use (gal)/person/day)[10]**	**OWTS Recharge (gal/yr)**
	59.8	23.3	18.2	18.2	50	40254025.0
	An. Precip (ft/yr)	An. ET (ft/yr)	An. Runoff (ft/yr)	Nat. Infiltration (ft/yr)		**Annual Recharge (gal)**
	5.0	1.9	1.5	1.5		
Area of concern (ft^2)[6]	An. Precip (ft3/yr)	An. ET (ft3/yr)	An. Runoff (f3/yr)	Nat. Infiltration (ft3/yr)	Effluent Conc (mg/L): One Conventional[11]	392858160.3
31000000	154423055.6	60143875.0	47139590.3	47139590.3	46.0	
	An. Precip (gal/yr)	**An. ET (gal/yr)**	**An. Runoff (gal/yr)**	**Nat. Infiltration (gal/yr)**	Effluent Conc (mg/L): One Denitrifying[11,12]	**Annual Recharge (Mgal)**
	1155084455.6	**449876185.0**	**352604135.3**	352604135.3		392.9
					19.0	
Equations						
Avg NO_3-N Conc = Annual loading / Annual Recharge				**Avg NO_3-N Conc, Conven (lbs/gal/yr)**	**Avg NO_3-N Conc, Denit (lbs/gal/yr)**	**Avg NO_3-N Conc, Total (lbs/gal/yr)**
Annual Loading = # of people x 7 lb N/person/yr x 0.90				0.0000312	0.0000017	0.0000329
Ann Recharge = Avg Ann Natural Infiltration + Recharge from OWTS				**Avg NO_3-N Conc, Conven (mg/L)[11]**	**Avg NO_3-N Conc, Denit (mg/L)[11]**	**Avg NO_3-N Conc, Total (mg/L)**
Avg Ann Nat Infilt. = Annual Precip - Annual ET – Annual Runoff						
Recharge from OWTS = # of People x 50 gal/person/day x 365 days/year				3.7	0.2	**3.9**

Table 16. Data for determination of average NO_3-N concentration available to infiltrate groundwater in Table 15.

Area Data							
[6] Jamestown Shores (ft^2)	31000000						
One House (1/4 Acre)(ft^2)	10,890						
One 400-ft radius circle (ft^2)	502655						
Precipitation Data[7]							
Year	**Precip**	**Pan Evap**	**ET (pan evap * 0.85)[8]**	**Precip-ET**	**Avail Precip (Precip-ET-Runoff)**		
1995	43.7	28.39	24.13	19.57	9.78		
1996	60.77	24.66	20.96	39.81	19.90		
1997	49.02	27.24	23.15	25.87	12.93		
Average	***51.16***	***26.76***	**22.75**	**28.41**	**14.21**		
2009	59.62	24.81	21.09	38.53	19.27		
2010	59.96	29.49	25.07	34.89	17.45		
2011	59.75	27.87	23.69	36.06	18.03		
Average	***59.78***	***27.39***	**23.28**	**36.50**	**18.25**		
Sources of Data:	**Value**	**Source**					
[1] # of Housing Units (HUs)	959	RIGIS' E911 Structures GIS Shapefile					
[2] % Denitrifying	11.7	Town of Jamestown (112 denitrifying OWTS)					
[3] Pop/HU (Census)	2.3	"Average Household Size" in Census 2010					
[4] N(lbs)/person/yr	7	SWA/MANAGE					
[5] Actual N leaching to GW	90%	SWA/MANAGE					
[6] Area of concern (ft^2)	31000000	Approximate Jamestown Shores area calculated in GIS					
[7] Annual Precip	59.8	Average annual for 2009-2011 from Carl Sawyer's Kingston Weather Station data					
[8] ET (pan evap*correct factor)	23.3	Average annual * correction factor (0.85) from American Society of Civil Engineer's Hydrology Handbook 1996					
[9] Runoff	50% of (Precip-ET)	SWA/MANAGE					
[10] Water Use (gal/person/day)	50	SWA/MANAGE					
[11] Conversion lbs/gal to mg/L	1 lb = 453592 mg and 1 gal = 3.78541 L; so lbs/gal * 453592 mg/lb * 1 gal/3.78541 L = lbs/gal * 119,826.4 = mg/L						
[12] Denitrifying- 59% removed	46 mg/L effluent for 7 lbs/person/yr (MANAGE), 19 mg/L required by RIDEM.						
	So ((46-19)/46)*100 = 58.7% removal, (19/46)*100 = 41.3% of 7 lbs/person/yr loading.						

EXPECTED VS. MEASURED NO_3-N CONCENTRATION CALCULATIONS IN GIS LAYER

Expected NO_3-N concentration available to infiltrate groundwater for 2010-2011 data given the number of conventional and denitrifying OWTS in a 400-foot radius circle (502654.8 ft^2 area) surrounding the sampling sites. See notes in Table 13 for sources of data. To determine the difference between the two, subtract the expected NO_3-N concentration from the measured concentration.

Equation for Annual Nitrogen Loading, Conventional OWTS (lbs/yr):

annual nitrogen loading =

# of people x 7 lbs/person/yr x 0.90 =

# of houses x 2.3 people/house x 7 lbs/person/yr x 0.90

Equation for Annual Nitrogen Loading, Denitrifying OWTS (lbs/yr):

annual nitrogen loading =

# of people x 7 lbs/person/yr x 0.41 x 0.90 =

# of houses x 2.3 people/house x 7 lbs/person/yr x 0.41 x 0.90

Equation for Expected NO_3-N Concentration (mg/L):

(*annual nitrogen loading ÷ annual recharge) x conversion factor =*

[(annual nitrogen loading, conventional OWTS + annual nitrogen loading, denitrifying OWTS) ÷ (avg annual natural infiltration + OWTS recharge)] x conversion factor =

{(annual nitrogen loading, conventional OWTS + annual nitrogen loading, denitrifying OWTS)÷ [5,717,360 gal/yr + (# of people x 50 gal/person/day x 365)]} x 119,826.4

APPENDIX C: ADDITIONAL MAPS

CHANGE IN NO_3-N AT REPEAT SITES

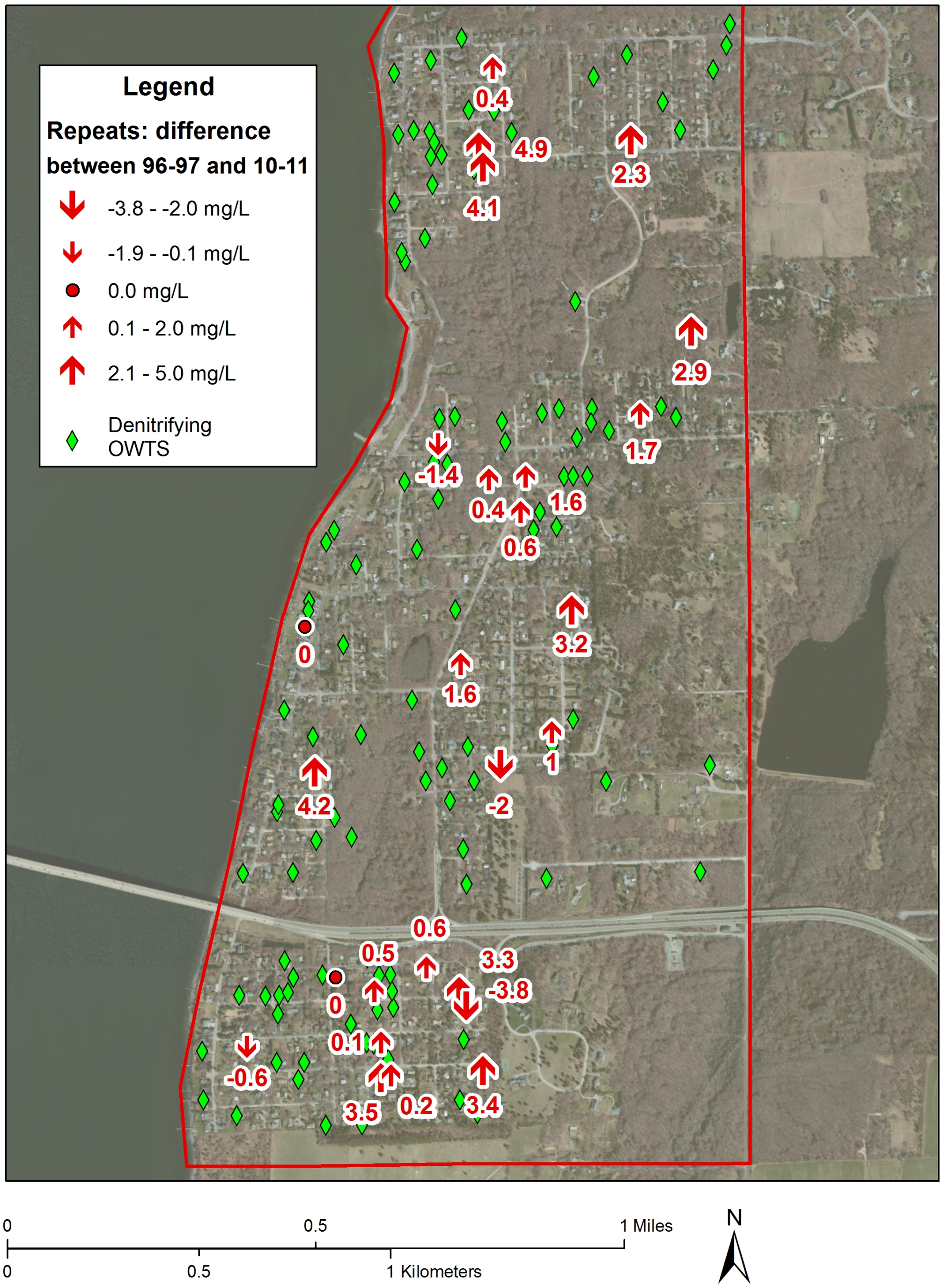


Figure 49. . Change in NO_3-N at repeat sites between 1996-1997 and 2010-2011 in Jamestown Shores, Jamestown, RI.

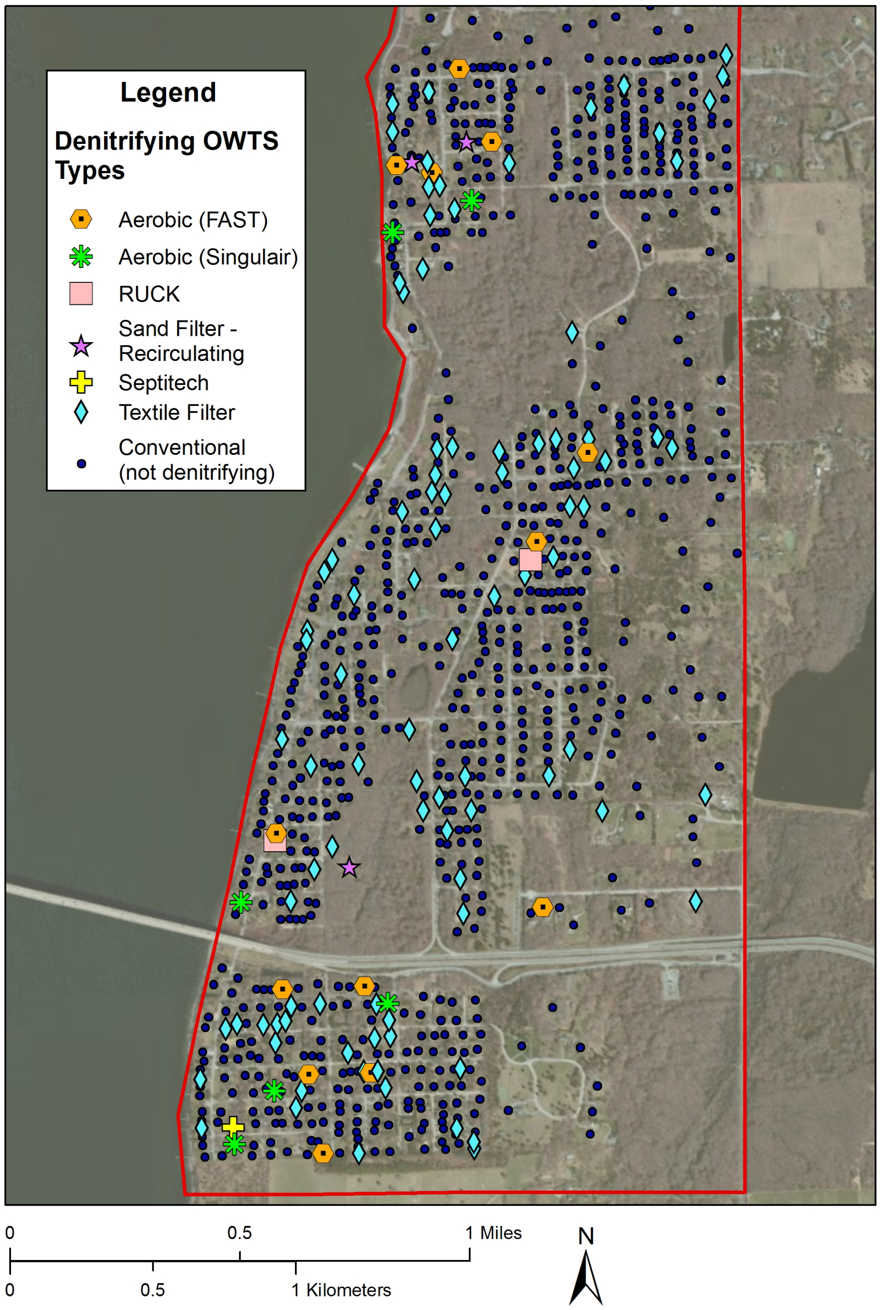


Figure 50. Types of denitrifying OWTS in Jamestown Shores, Jamestown, RI.

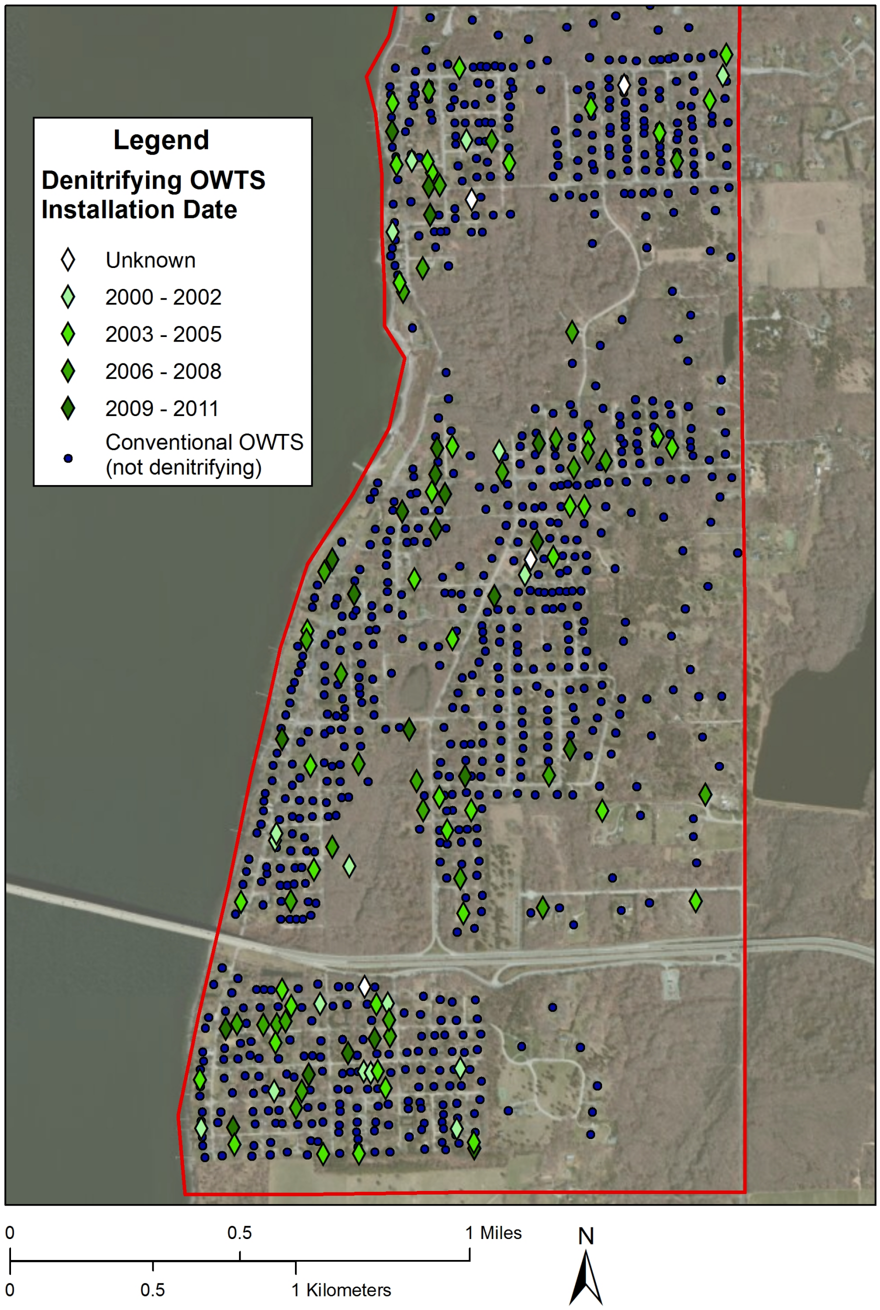


Figure 51. Installation dates of the denitrifying OWTS in Jamestown Shores, Jamestown, RI.

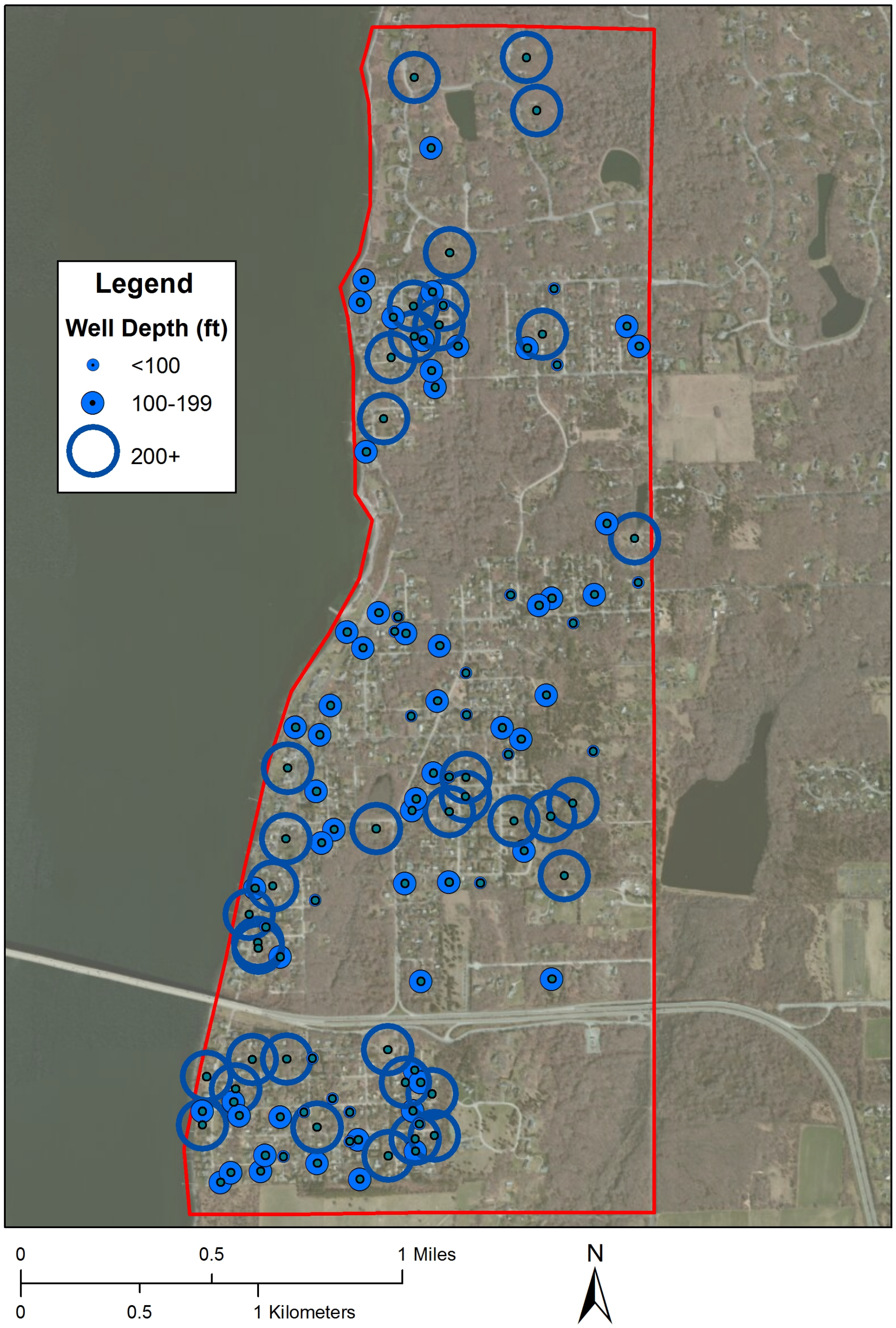


Figure 52. Well depths reported by homeowners on the NO_3-N sampling survey forms in Jamestown Shores, Jamestown, RI.