Wekiva-Area Septic Tank Study

Division of Environmental Assessment and Restoration
Florida Department of Environmental Protection

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2600 Blair Stone Rd.
Tallahassee, FL 32399
www.dep.state.fl.us

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DEP staff contributing to this study include the following:

ROC staff – Sampling device installation and monitoring: Natalie Ayala, Leif Boman, Mike Drennan, Mike Eckles, Mike Linger, and Colby Marshall.

Groundwater Management Section staff – Project coordination and primary report author: Richard Hicks. Sampling device installation and monitoring, report development, and modeling: Mike Dalsis, David Huggins, Brian Katz, Celeste Lyon, Gary Maddox, and Edgar Wade.

Watershed Planning and Coordination Section – Technical editing: Linda Lord.

For More Information

This study was conducted by the DEP Water Quality Evaluation and Total Maximum Daily Load Program's Groundwater Management Section to assist stakeholders of the Wekiva River Basin. For more information, contact:

Moira Homann, Basin Coordinator

Watershed Planning and Coordination Section

moira.homann@dep.state.fl.us

850-245-8460

Executive Summary

The Florida Department of Environmental Protection (DEP) is working with stakeholders to reduce nitrogen concentrations in springs through the implementation of restoration plans to reduce nitrogen losses to groundwater. Septic systems have been identified as potential contributing sources of elevated nitrogen in Wekiwa and Rock Springs in Central Florida. In 2015 and 2016, the DEP monitored 11 conventional residential septic systems in Orange, Seminole and Lake Counties to obtain information on the input and attenuation of nitrogen in soil beneath septic system drainfields. The study included bimonthly sampling of septic tank effluent and soil pore water beneath the drainfields and from background locations. The data from some sites were then used to help evaluate the utility of a complex soil attenuation model. In addition to the study results, this report also includes summary information from recent groundwater monitoring around the study sites.

The significant findings of the study include the following:

- Septic tank effluent concentrations averaged higher than has typically been reported for most residential systems and there was not noticeable improvement in nitrogen removal by the tanks after pumping.
    - In septic tank effluent (STE) from 8 sites, average total nitrogen (TN) concentrations ranged from 57 to 140 mg/L. The average TN concentration for all sites included in the study was 85 mg/L, which is approximately 20 mg/L higher than the typical TN concentration for septic tanks in the literature. The average was skewed by several tanks that consistently had higher concentrations.
    - The study evaluated the influence of septic tank pumping on the ability of the septic tank to provide treatment for nitrogen. The results do not indicate that pumping has much of an effect. No consistent trend in TN concentrations could be determined from bi-monthly STE sampling of the four septic tanks in the study before and after they were pumped out. Nor were there significant differences between nitrogen trends from tanks that were pumped and ones that were not. Dilution from increases in water use appears to be the biggest factor influencing TN concentrations in STE.
- Nitrogen was attenuated by nitrification/denitrification processes in septic system drainfields and shallow soils, with percents attenuated ranging from 35 to 44 %.
    - Nitrogen and chloride data from representative samples collected 2 feet below the drainfields and corresponding STE samples showed that these reductions were due mainly to nitrification and denitrification and less to dilution.
    - Data from all sites could not be used to assess the reduction of nitrogen from STE. Some sites did not provide representative data due to their construction (resulting in excessive dilution) and at others STE contributions could not be measured due to nitrogen inputs from fertilizer in addition to STE.
- Fertilizer inputs of nitrogen to lawns and landscaping plants were significant at several of the study sites.

        - Detected TN concentrations in soil pore water at some sites on some occasions were considerably higher than the STE inputs, indicating influence by combined sources.
        - TN concentrations were also elevated in soil pore water at background locations, which were not related to the drainfields.
    - Nitrogen decreases in the soil profile were variable at the four sites with data from more than one depth interval.
        - At a depth of 10 feet below land surface (or about 8 feet below the bottom of the drainfields), TN concentrations were found to range from 3 mg/L to 122 mg/L and they fluctuated widely at individual sites. At the three sites with 15 ft- interval samples (13 ft below the drainfields) average TN concentrations ranged from 37 to 54 mg/L over the monitoring period.
        - At some sites on some dates, the differences between TN concentrations in shallower and deeper lysimeters were small, but TN concentrations in the shallower samples were significantly higher than deeper ones at others. Most of the decreases with depth were due to dilution and not denitrification or adsorption within the soil profile.
- Phosphorus in the STE was readily attenuated by drainfields and shallow soil.
    - Phosphorus concentrations in the soil pore water samples were significantly lower than the corresponding STE concentrations at most of the sites.
    - The highest total phosphorus (TP) concentrations in soil pore water were most likely related to fertilizer
    - Phosporus is attenuated by adsorption to soil particles and further attenuation would occur in the soil column and aquifer material.
- Groundwater quality data for nitrate-nitrogen in the area may reflect influence by septic systems and/or fertilizer.
    - Shallow groundwater monitoring data were collected by Orange County and DEP in this study area. Nitrate concentrations from surficial-aquifer wells ranged from 0.01 to 13 mg/L in sewered areas and from 0.1 to 3.9 mg/L in areas served by septic systems.
    - Ten wells (both monitoring wells and private supply wells) in the area provided groundwater data from the upper Floridan aquifer, the source of the springs. These well samples had nitrate-nitrogen concentrations that were lower, ranging from non-detect to 1.8 mg/L.
- DEP evaluated a model used to predict nitrogen attenuation in soil beneath septic systems and found that it shows some promise but using it with confidence requires more calibration than was available from data collected in this study.
    - Evaluation of the Soil Treatment Unit Model for Florida (STUMOD-FL) calibration using data from this study and a previous study in the area demonstrate that "one-size does not fit all" and that a consistent set of modeling parameters could not be used to produce similar results for the drainfield sites evaluated.
    - This could be due to site specific variability or issues with sample collection. Confidence in the model may increase with more opportunities for calibration.

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List of Acronyms and Abbreviations

bls	Below Land Surface
BMAP	Basin Management Action Plan
cm	Centimeter
DEP	Florida Department of Environmental Protection
EPA	U.S. Environmental Protection Agency
EPD	(Orange County) Environmental Protection Division
FDOH	Florida Department of Health
FGS	Florida Geological Survey ()
FOSNRS	Florida Onsite Nitrogen Reduction Strategies (Study)
ft	Feet
ICU	Intermediate Aquifer/Confining Unit
in/yr	Inches Per Year
lb-N/yr	Pounds of Nitrogen Per Year
mg/L	milligrams per liter
N	Nitrogen
ND	Not Detected
NO_3-NO_2	Nitrate and Nitrite
NOAA	National Oceanographic and Atmospheric Administration
NRCS	Natural Resources Conservation Service
NSILT	Nitrogen Source Inventory and Loading Tool
OFS	Outstanding Florida Spring
OSTDS	Onsite Sewage Treatment and Disposal System
PVC	Polyvinyl Chloride
ROC	Regional Operation Center
SA	Surficial Aquifer
SF_6	Sulfur Hexafluoride
SJRWMD	St. Johns River Water Management District
SSURGO	Soil Survey Geographic (Database)
STUMOD-FL	Soil Treatment Unit Model for Florida
STE	Septic Tank Effluent
TKN	Total Kjeldahl Nitrogen
TN	Total Nitrogen
TP	Total Phosphorus
UFA	Upper Floridan Aquifer
UF–IFAS	University of Florida Institute of Food and Agricultural Sciences
USDA	U. S. Department of Agriculture
USGS	U.S. Geological Survey

Section 1. Introduction

Objectives

The Florida Department of Environmental Protection (DEP) conducted this study with coordination and assistance provided by the Center for Property Rights. Formerly known as the Coalition for Property Rights, the center is an organization of concerned citizens in Orange, Seminole, and Lake Counties interested in having sound science dictate future planning related to septic systems.

A main objective of this study was to assess and quantify the leaching of nitrogen from active conventional septic systems in the Wekiva River area to better understand the potential for and the conditions under which septic systems might contribute to nitrogen in area springs. Activities in the study focused on gathering data on the transport and attenuation of nitrogen from conventional drainfields within the underlying soil profile under typical conditions, mainly focusing on shallow soil profiles beneath drainfields.

In addition to collecting the soil attenuation data, the study also had several other components to help understand the performance of septic tanks in nutrient removal, the potential influence of other nitrogen sources in residential areas, and the occurrence and transport of nitrogen in groundwater. The study sites are within or close to the groundwater contributing areas for Wekiwa and Rock Springs, which are designated by the Florida Legislature as Outstanding Florida Springs (OFS). The springs' groundwater contributing area (or springshed) is included in the Wekiva River Basin Management Action Plan (BMAP) area for water quality restoration being implemented by DEP and local stakeholders. **Figure 1** shows the springshed, the BMAP area, and the study sites. **Figure 2** shows an enlarged area with emphasis on the study sites.

Technical Approach

The technical approach included the identification, instrumentation, and bimonthly monitoring of devices installed at 11 study sites with representative septic systems to obtain data on the leaching and attenuation of nitrogen from their drainfields to shallow soils over a 1-year period. At 8 of the sites, septic tank effluent (STE) samples were collected to help in evaluating nitrogen input and as part of a separate objective to evaluate the influence of septic tank pumping on subsequent water quality. In addition, soil pore water samples were collected at each site from background locations to monitor the influence of other nitrogen sources. Study sites were selected to provide a good representation of the more common drainfield designs and ages as well as the soil conditions in the area. At the completion of the study, soil pore water results from some of the sites were used to help evaluate a model that predicts nitrogen attenuation in the soil column beneath septic systems.

The project also included data from groundwater monitoring in the area to help provide information about the influence and magnitude of the groundwater quality impacts of septic systems and other potential nitrogen sources in the area. This data set was from onsite or nearby supply wells and a network of monitoring wells routinely sampled by the Orange County

Environmental Protection Division (EPD). In addition, this report includes information from groundwater tracer testing conducted by DEP in the study area to evaluate the rate of groundwater movement toward the springs.

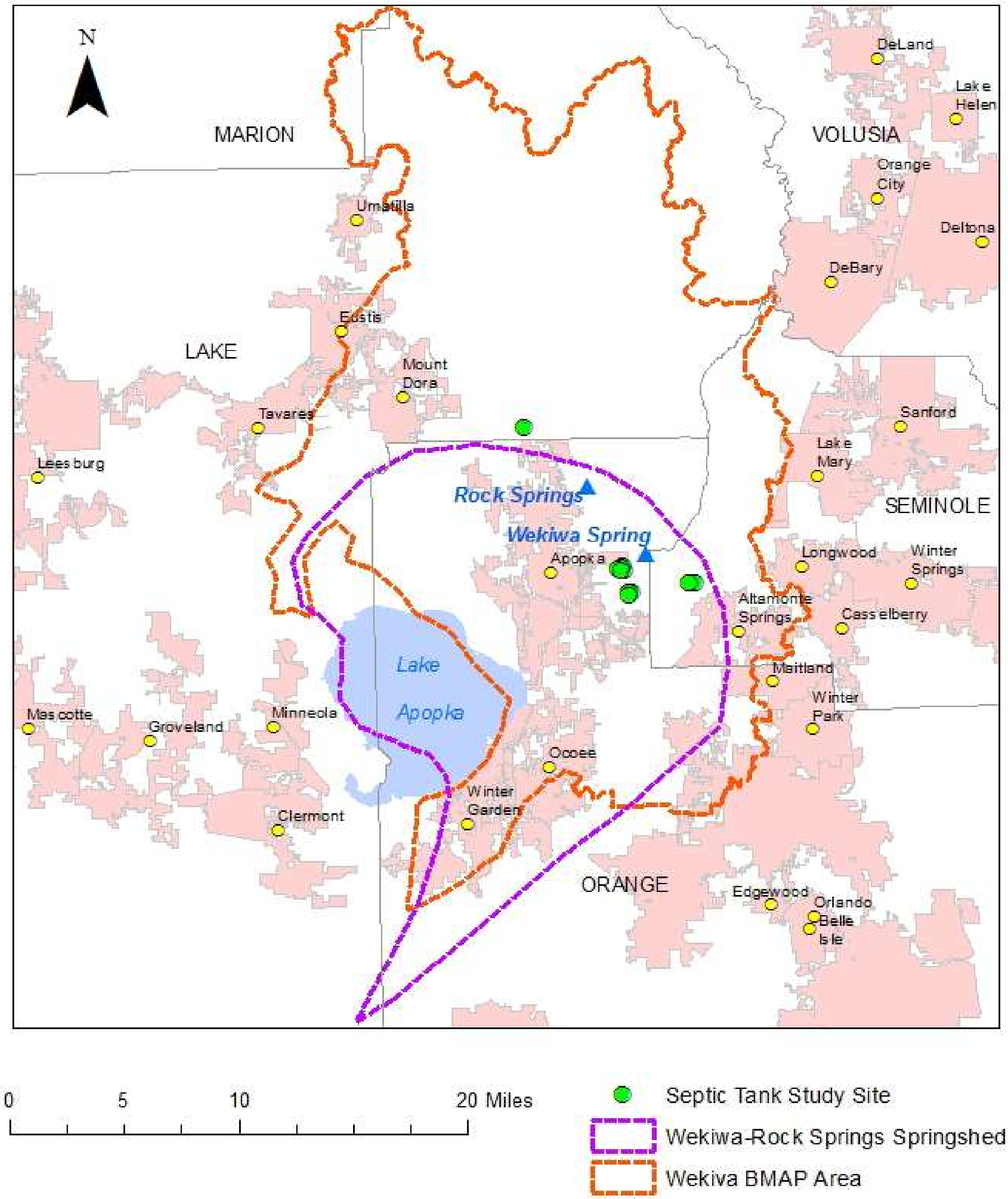

Figure 1. Wekiwa-Rock Springs Springshed, Wekiva BMAP area, and study site locations

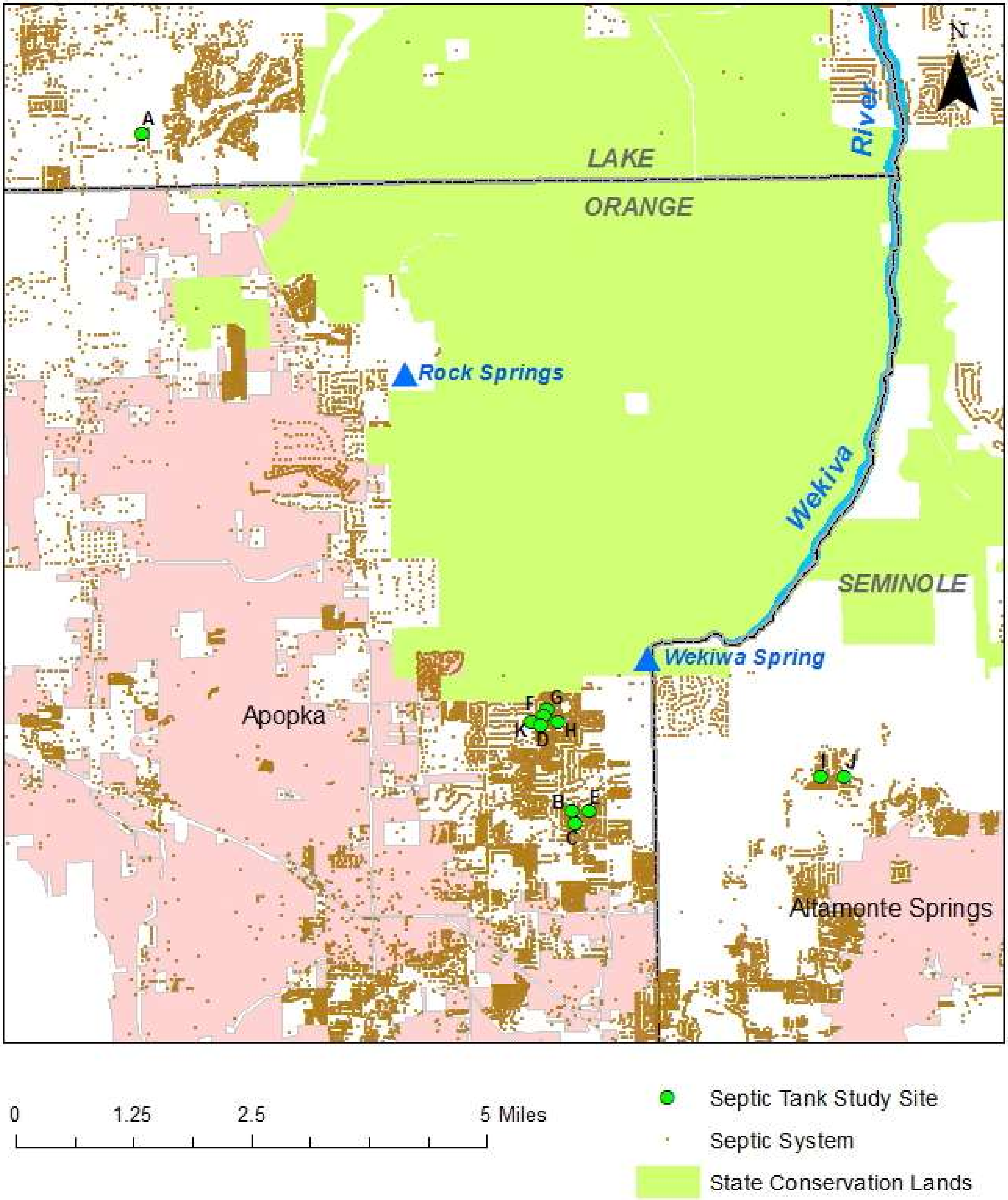

Figure 2. Study site locations

Study Site Identification and Description

Twenty homeowners volunteered to participate in the study in response to an announcement by the Center for Property Rights and later discussions with stakeholders. Information about the sites was gathered and in March 2015, DEP met with candidate homeowners to discuss the project scope and information needs. In June 2015, DEP visited 18 sites with a licensed septic tank contractor to take measurements, inspect the septic systems, and evaluate the sites for potential inclusion in the study.

Shortly afterwards, 11 sites were selected for the study. The final selection was based on the sites' geographic distribution, range in septic system age, full-time residence status, household size, drainfield construction, lawn irrigation and fertilization practices, and water source. Other factors, such as the availability and suitability of the septic systems for the installation of sampling devices, were also considered. **Table 1** summarizes some of the pertinent information about the selected sites and their septic systems obtained from homeowners and the Florida Department of Health (FDOH).

The selected study sites are in Orange County (8 sites), Seminole County (2 sites), and Lake County (1 site) and have from 1 to 5 permanent residents. The sites have drainfields that vary in age from 5 to 26 years, and all have conventional gravity-fed systems, except for one, which has a mounded drainfield and a lift pump from the septic tank. The older drainfields consist of pipe-in-gravel-beds, and the newer gravity-fed drainfields consist of rows or beds of infiltration chambers. All sites have in-ground lawn irrigation systems, and most homeowners maintain their own lawns and gardens, applying fertilizer as needed. Three sites are served by their own water wells and the others are served by public water.

Site Instrumentation and Sampling Methodology

Septic Tank Effluent

STE samples were collected at eight of the sites (A, B, C, E, F, G, I, and J) to help evaluate the variation in effluent concentration and to use in calculating constituent reductions in the drainfields and soil. The effluent samples were collected through tubing inserted into risers at the outlet side of the septic tanks. These risers were installed on top of inspection ports used to gain access for pumping and filter replacement. DEP contracted with a licensed septic tank contractor to install risers on the septic tanks at six sites but was able to use preexisting risers on septic tanks at the two other sites.

STE samples were collected each time the sites were visited. Effluent samples were collected using a peristaltic pump and tubing. The tubing was inserted next to the effluent outlet of the tank so that the water collected was representative of the water quality received by the drainfield. During the study, septic tanks were pumped out at four of the study sites to collect effluent samples representative of conditions before and after pumping. These findings are discussed in a subsequent section of the report.

Table 1. Study site information

Note: All sites have in-ground irrigation systems.

Site ID	Location	Number of Residents	Year of Septic Tank	Year Drainfield Installed	Drainfield Construction/ Repair History	Lawn Fertilizer Use	Water Source
A	Lake (Sorrento)	2	2004	2004	Infiltration chamber rows/original	Applied by homeowner	Water well
B	Orange (Apopka)	3	1984	2009	Infiltration chamber bed/installed as repair	Applied by homeowner	Public water
C	Orange (Apopka)	3	1986	2010	Infiltration chamber bed/installed as repair	Applied by homeowner	Public water
D	Orange (Apopka)	2	1990	1990	Pipe-in-gravel-bed/ original	Applied by commercial service	Public water
E	Orange (Apopka)	2	197	1989	Pipe-in-gravel-bed/ installed as a repair	Applied by homeowner	Public water
F	Orange (Apopka)	5	1990	2010	Infiltration chamber rows/installed as repair and later increased as modification	Applied by homeowner	Public water
G	Orange (Apopka)	3	1996	1996	Pipe-in-gravel-bed/ original	Applied by homeowner	Public water
H	Orange (Apopka)	2	1997	1997	Pipe-in-gravel-bed/ original	Applied by homeowner	Public water
I	Seminole (Longwood)	1–2	1970	1999	Infiltration chamber rows/installed as repair	Applied by commercial service	Public water
J	Seminole (Longwood)	2	2000	2000	Mounded drainfield, pipe-in-gravel-bed/ original	None used in drainfield area	Water well
K	Orange (Apopka)	2	1990	1990	Pipe-in-gravel-bed/ original	Applied by homeowner	Water well

Soil Pore Water from Lysimeters

Suction lysimeters were the main monitoring devices deployed at the study sites to collect shallow soil pore water samples beneath drainfields. A suction lysimeter is a device used to collect pore water samples from unsaturated soil. Each of the lysimeters used in the study consisted of a one and a half-inch diameter polyvinyl chloride (PVC) pipe with a porous ceramic cup attached to the bottom. To collect a pore-water sample, a pump attached to the lysimeter with a tube is used to apply a vacuum. A valve is closed after the vacuum is applied, and this vacuum slowly pulls pore water through the ceramic cup, where it accumulates inside the lysimeter. The following day, the water sample is pumped out into sample containers and sent for laboratory analysis.

Depending on drainfield construction, shallow lysimeters were installed at the edge of drainfield beds or between drainfield rows at depths of approximately 2 feet (ft) below the bottom of the drainfields. Between 2 and 4 shallow drainfield lysimeters were installed at each site, and most were installed to depths of about 5 ft below the land surface. At several sites, deeper lysimeters were also installed. Deeper lysimeters were clustered with shallow ones to provide information on changes in nutrient concentrations with depth as soil moisture moved downward. At 4 sites, deep lysimeters were installed 5 ft deeper than the shallow lysimeters (10 ft deep or 7 ft below the drainfields). At 2 sites, even deeper lysimeters were installed to a depth of 5 ft below the corresponding deep lysimeters (10 ft below the shallow lysimeters and 15 ft below the land surface). Shallow lysimeters were also installed at background locations to monitor for the effects of atmospheric deposition, irrigation, and fertilizer application on pore water quality. These were installed to the same depths as the shallow drainfield lysimeters. **Table 2** contains summary information on the lysimeters.

DEP staff installed each of the lysimeters using a hand auger to bore a hole to the desired depth and location. A silica flour slurry was then placed at the bottom of the hole and the lysimeter, with vacuum and sampling tubes, was inserted. Clean sand was then slowly added with water through a tremie pipe to ensure contact between the ceramic cup and the surrounding soil and to prevent the seepage of effluent along the annular space surrounding the lysimeter that might bias sampling results. The vacuum and sample tubes for each lysimeter were contained in a 6-inch-diameter plastic irrigation vault.

Groundwater Monitoring

Groundwater sampling data collected by the Orange County EPD from its network of 29 monitoring wells were used in the study to help evaluate the influence of land uses on water quality in the surficial and Floridan aquifers. These data included results from two monitoring wells (Fortune Lane [U] and Palm Beach [S/U]) installed by a DEP contractor for use in the groundwater tracer study. DEP also installed shallow monitoring wells at two of the study sites (J and K) to evaluate shallow groundwater quality near the drainfields. In addition, data were also included from DEP-collected samples from residential water wells that serve three of the study sites (A, I, and J). Also included are data from a private supply well and monitoring well at a nearby alternative drainfield study site (Peeler, PMW1). Subsequent sections of this report provide information about the wells used in the study and maps showing their locations.

Section 2. Study Area Information

Demographics and Land Use

The monitoring sites were selected to reflect typical occupancy patterns, household sizes, and lot sizes for residential areas in the BMAP area. Most of the septic systems in this area serve homes on medium-density residential lots (2 to 5 dwellings per acre). Average households for Orange, Seminole, and Lake Counties contain 2.75, 2.85, and 2.57 full-time residents, respectively, per household (according to the most recent Census). Most of the sites selected for the study were in medium-density residential areas and had septic systems serving 2 or more full-time residents.

Table 2. Lysimeter installation details

Site	Lysimeters Installed	Total Depth (ft below land surface)	Location
A	AL1S-AL4S	5	Drainfield
A	AL5S	5	Background
A	AL2D	10	Drainfield adjacent to AL2S
B	BL1S-BL4S	5	Drainfield
B	BL5S	5	Background
B	BL3D	10	Drainfield, adjacent to BL3S
B	BL3E	15	Drainfield, adjacent to BL3S
C	CL1S-CL3S	5	Drainfield
C	CL4S	5	Background
D	DL1S-DL2S	5	Drainfield
D	DL3S	5	Background
E	EL1S-EL3S	5	Drainfield
E	EL4S	5	Background
F	FL1S-FL3S	5	Drainfield
F	FL4S	5	Background
F	FL2D	10	Drainfield, adjacent to FL2S
G	GL1S-GL2S	5	Drainfield
G	GL3S	5	Background
G	GL1D	10	Drainfield, adjacent to GL1S
G	GL1E	15	Drainfield, adjacent to GL1S
H	HL1S-HL2S	5	Drainfield
H	HL3S	5	Background
I	IL1S-IL3S	5	Drainfield
I	IL4S	5	Background
J	JL1S-JL3S	5	Drainfield
J	JL4S	5	Background
K	KL1S-KL4S	5	Drainfield
K	KL5S	5	Background

Soil Conditions

In Florida, 30 % to 40 % of nitrogen in septic systems is removed by the septic tank, drainfield, and soil immediately beneath the drainfield.[1] Additional removal can occur in the soil profile, depending on soil properties. The attenuation of nitrogen in the soil beneath conventional septic tank drainfields depends on the soil's texture and drainage as well as its organic carbon content.

Soil order is the most general taxonomic classification of soils. There are seven soil orders in Florida, and 2 of these orders (Spodosols and Entisols) are important to this study because they include 94 % of the septic systems in the Wekiva BMAP area. Spodosols consist of a shallow, sandy, leached upper horizon over a spodic horizon that consists of mixtures of organic matter, aluminum, and iron that can form a weakly cemented "hardpan" layer. In Florida, the Spodosols are characterized by a shallow fluctuating water table and can be somewhat poorly drained to very poorly drained. Spodosols underlie approximately 14 % of the septic systems in the BMAP area. Entisols in Florida are uniformly sandy with no distinct horizons, and in the BMAP area they are excessively to moderately well-drained. Entisols underlie approximately 80 % of the septic systems in the BMAP area.

Soil information for the area of interest was obtained from the U. S. Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS) Soil Survey Geographic (SSURGO) Database for Florida.[2] Entisols were found at 10 of the 11 sites. **Table 3** provides summary information for the study sites based on SSURGO information. At 9 of these sites, Candler fine sand is the soil series of the Entisol order that is present. The Candler series consists of very deep, excessively drained, very rapidly to rapidly permeable soils on uplands in peninsular Florida.3 Organic carbon content in Candler fine sand is 0.5 % to 2 % in the upper horizon.

The other Entisol site was classified as urban land because of soil disturbance. However, it was located close to an area of Astatula-Apopka fine sand, which has similar characteristics to Candler fine sand. At one of the study sites, the Spodosol order was present. This site is located in an area mapped as urban land, but the soil characteristics most closely match the Myakka and Eugallie fine sands that are found nearby. The Myakka series consists of very deep, very poorly or poorly drained moderately permeable soils that occur primarily in mesic flatwoods of peninsular Florida.4 At this site, the water table is within 2 ft of the land surface. A shallow water table is typical of Myakka soils, which have a seasonal high-water table of less than 18 inches. **Figure 3** shows the locations of the Spodosols and Entisols in the study site area. Soil borings were advanced at each of the study sites, and **Appendix A** provides descriptions of the material encountered.

[1] Gurpal, S.T., M. Lusk, and T. Obreza. 2015. *Onsite sewage treatment and disposal systems: Nitrogen.* Publication #SL348. Gainesville, FL: University of Florida Institute of Food and Agricultural Sciences (UF–IFAS).

[2] The SSURGO Soil Survey Geographic Database is a digital soil survey developed by the National Cooperative Soil Survey. The dataset includes georeferenced digital map data and computerized attribute data. Metadata can be found at https://catalog.data.gov/dataset/soil-survey-geographic-ssurgo-database-for-various-soil-survey-areas-in-the-united-states-.

[3] https://soilseries.sc.egov.usda.gov/OSD_Docs/C/CANDLER.html

[4] https://soilseries.sc.egov.usda.gov/OSD_Docs/M/MYAKKA.html.

Research has shown that the removal of nitrogen in the soil zone through denitrification and leaching are related to soil drainage class.[5] Denitrification is lowest and nitrogen leaching is highest in areas with soils that are excessively drained, somewhat excessively drained, or well drained. Leaching may occur in areas with moderately well-drained soils and is least likely to occur in soils that are poorly drained, somewhat poorly drained, or very poorly drained because of their greater potential for denitrification. The soils at 10 of the 11 sites are classified as excessively drained.

Table 3. Site soil summary

Site ID	Soil Type	Drainage Class	Order	Comments
A	Candler Fine Sand	Excessively drained	Entisol	
B	Candler Fine Sand	Excessively drained	Entisol	
C	Candler Fine Sand	Excessively drained	Entisol	
D	Candler Fine Sand	Excessively drained	Entisol	
E	Candler Fine Sand	Excessively drained	Entisol	
F	Candler Fine Sand	Excessively drained	Entisol	
G	Candler Fine Sand	Excessively drained	Entisol	
H	Candler Fine Sand	Excessively drained	Entisol	
I	Urban Land	Excessively drained	Entisol	Most likely disturbed Astatula-Apopka fine sands
J	Urban Land	Poorly Drained	Spodosol	Located close to Myakka and EauGallie fine sands
K	Candler Fine Sand	Excessively drained	Entisol	Nontypical, clay layer at 60 inches causing perched water table

[5] Otis, R.J. 2007. *Estimates of nitrogen loadings to groundwater from onsite wastewater treatment systems in the Wekiva Study Area, Task 2 Report, Wekiva Onsite Nitrogen Contribution Study.* Prepared by Otis Environmental Consultants for FDOH.

Hofstra, N., and A. F. Bouwman. 2005. Denitrification in agricultural soils: Summarizing published data and estimating global annual rates. *Nutrient Cycling in Agroecosystems* 72: 267–278.

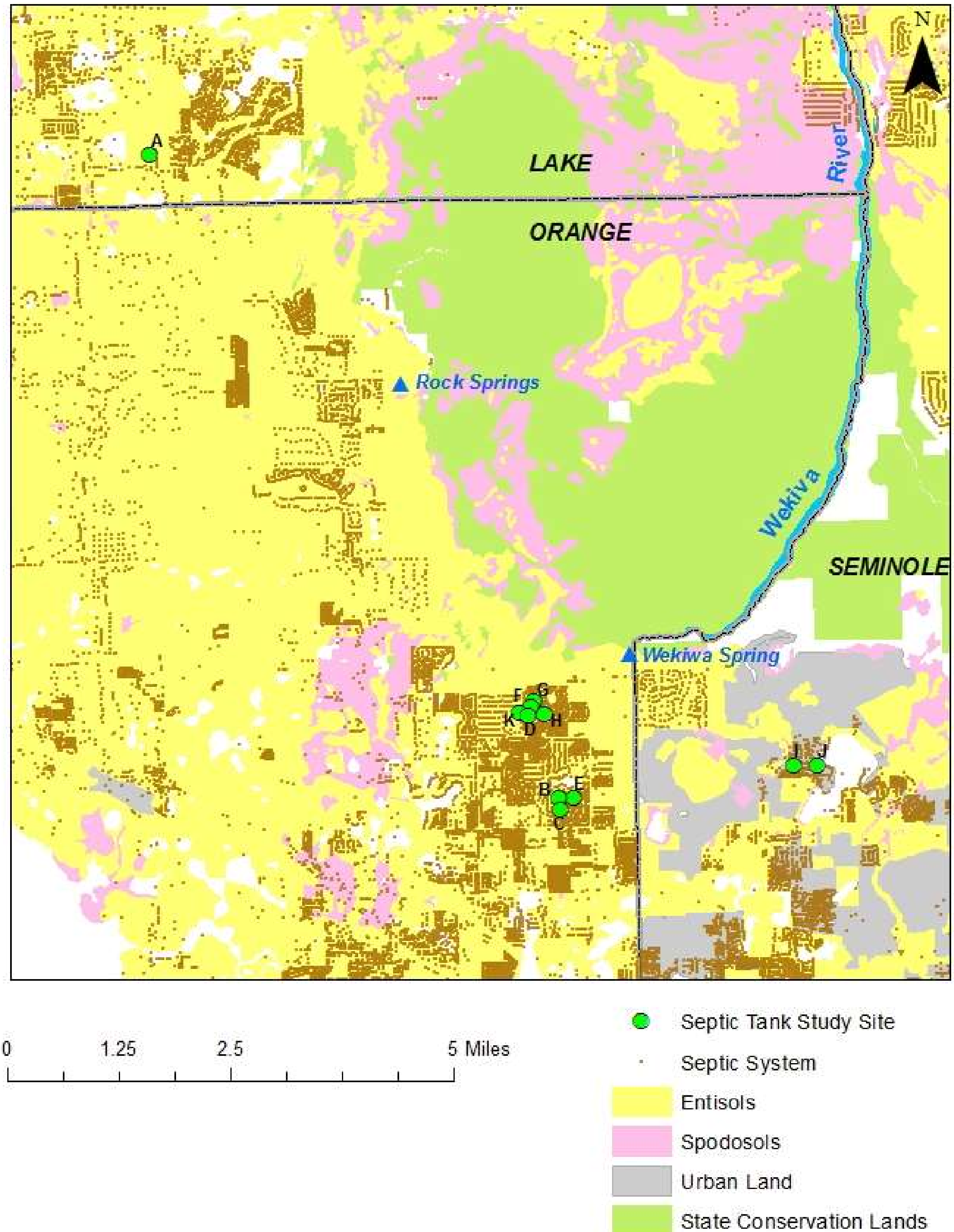

Figure 3. Soil orders in the study area

Hydrogeology

In this area, the hydrogeologic units include the surficial aquifer system; the intermediate aquifer system, or intermediate confining unit; and the Floridan aquifer system (**Table 4**).

Table 4. Hydrogeologic units in the Wekiva River area[6]

Hydrogeologic Unit	Epoch	Stratigraphic Unit	General Lithology
Surficial aquifer system	Holocene Pleistocene	Surficial sands and terrace deposits	Sand, clayey sand, and clay, with some shell locally
Intermediate aquifer system, or intermediate confining unit	Pliocene	Undifferentiated deposits	Sand, silt, clay, and shell
	Miocene	Hawthorn Group	Phosphatic clay, silt, sand, dolostone, and limestones
Floridan aquifer system	Eocene	Ocala limestone	Limestones and dolomitic limestones
		Avon Park Formation	Limestones and dolostone
		Oldsmar Formation	Limestones and dolostone
Lower confining unit	Paleocene	Cedar Keys Formation	Dolostone, some limestone; anhydrite occurs in lower

The surficial aquifer (SA) is not continuous throughout the study area, and at some locations it is intermittent (or perched), i.e., present in the rainy season and absent during dryer months. In the material encountered where the DEP wells were drilled, the surficial aquifer was present at depths varying from 5 to 25 ft. Where present, the top of the surficial aquifer (water table) ranged from very close to the land surface to greater than 30 ft below the land surface in the groundwater monitoring network in this area.

The intermediate aquifer/confining unit (ICU) can contain thin zones of dolomitic limestone or sandy material that contain water, but its main function is as a confining layer that retards the percolation of water to the underlying Floridan and provides some degree of protection to the Upper Floridan aquifer (UFA) against contamination from the surface (depending on its thickness and consistency). Based on lithologic descriptions of the material encountered while drilling the DEP and Orange County wells, the lower permeability Hawthorn Group material ranged from 40 to 170 ft in thickness.

The Floridan aquifer system is the source of water for potable supply and irrigation water in the area and is the source of water flowing from Wekiwa and Rock Springs and other springs in the area. The portion used by humans and contributing to springs (UFA) occurs in Eocene-age limestones generally at depths greater than 100 ft below the land surface. The top of the Ocala limestone is an irregular surface that marks the top of the UFA. At well boring locations near the study sites, the top of the UFA was encountered at depths ranging from 70 to greater than 200 ft below the land surface. The limestone of the UFA is not exposed at the land surface in the vicinity of the study area, but in areas where the limestone is relatively close to the land surface

[6] Toth, D.J., and C. Fortich. 2002. *Nitrate concentrations in the Wekiva Groundwater Basin with emphasis on Wekiwa Springs.* St. Johns River Water Management District Technical Publication SJ2002-2.

and has been subjected to dissolution, sinkholes and closed depressions are formed. Area lakes occur in many of these depressions, and they can serve as localized points of aquifer recharge.

The recharge, or replenishment, of water to the UFA occurs through the downward infiltration of water, either as diffuse infiltration through the geologic material or as focused recharge where sinkholes breach the confining material. The St. Johns River Water Management District (SJRWMD) created an updated recharge map for the UFA in 2015. The map estimates recharge rates based on the thickness of confining material in the ICU and the difference between hydraulic head in the SA and UFA.[7] High to moderate recharge to the UFA occurs where the aquifer is unconfined (ICU thickness of 20 to 50 ft) or semiconfined (ICU thickness of 50 to 100 ft). Where the ICU is greater than 100 ft in thickness, recharge is generally low to very low. In areas where the hydraulic head of the UFA is greater than the land surface elevation and the ICU is thin or not present, groundwater discharge occurs through springs or seepage.

Figure 4 shows the generalized areas of high (>10 inches per year [in/yr]), moderate (5–10 in/yr), and low (1–5 in/yr) recharge, as well as areas of discharge in the vicinity of the study sites. Sites A, B, C, and E are in high-recharge areas, and Sites D, F, G, H, I, J, and K are in areas of moderate recharge to the UFA.

In most of the study area, groundwater flow in the UFA is toward Wekiwa and/or Rock Springs based on a groundwater flow path analysis used by the SJRWMD to define the springs' common springshed. Groundwater elevation contour maps developed by the U.S. Geological Survey (USGS) and the Florida Geological Survey (FGS) were used to generate flow paths for multiple measurement dates to develop a springshed boundary that reflects fluctuations in groundwater flow over a range of conditions. **Figure 5** shows the groundwater elevation contours in the study area.

The Wekiwa-Rock Springs Springshed includes areas of more dynamic flow where infiltrating water has caused the dissolution and erosion of conduits in the limestone matrix and areas where the limestone is confined by layers of lower permeability material that inhibit the erosion of the limestone by percolating water. In areas where conduits do not exist, groundwater movement occurs in intergranular pore spaces in the limestone and is slower.

In 2014 and 2015, DEP conducted two tracer tests to evaluate groundwater flow rates to Rock and Wekiwa Springs.[8] In each test, a gaseous tracer (sulfur hexafluoride, or SF_6) was introduced into a well installed specifically for that purpose. The tracer was introduced into the UFA limestone at a well located 1.5 miles west (upgradient) of Rock Springs, and it arrived at the springs in less than 1 week, traveling at an estimated velocity of 980 ft per day. The tracer was introduced into the limestone at a well located 1.5 miles southwest (also upgradient) of Wekiwa

[7] Boniol, D., and K. Mouyard. 2015. *Recharge to the Upper Floridan aquifer in the St. Johns River Water Management District.* St. Johns River Water Management District Technical Fact Sheet SJ2016-FS1.

[8] DEP. June 30, 2016. *Summary report: Wekiva Basin groundwater tracer study for Rock and Wekiwa Springs.* Tallahassee, FL: Division of Environmental Assessment and Restoration.

Spring and arrived at the spring within 50 days, traveling at a significant but somewhat lower velocity (137 ft per day). **Figure 5** shows the locations of the SF_6 injection wells.

The difference in travel times may be related to differences between the development of conduits and level of confinement of the aquifer at the two locations. At the site near Rock Springs (located in an area of higher recharge), the aquifer is unconfined and there is significant development of conduits and enlarged pore spaces in the aquifer material. However, at the tracer injection site southwest of Wekiwa Spring, the aquifer is confined and in an area of moderate recharge, the limestone has been subjected to less erosion, and there are fewer and smaller conduits to allow the rapid movement of water.

Regardless, the rates of groundwater transport from both traces indicate that once nitrate reaches the aquifer, migration to either spring can be rapid. Based on the lower value, which is likely to be more representative of the aquifer throughout the springshed, groundwater travel velocity in the UFA could be more than 10 miles per year.

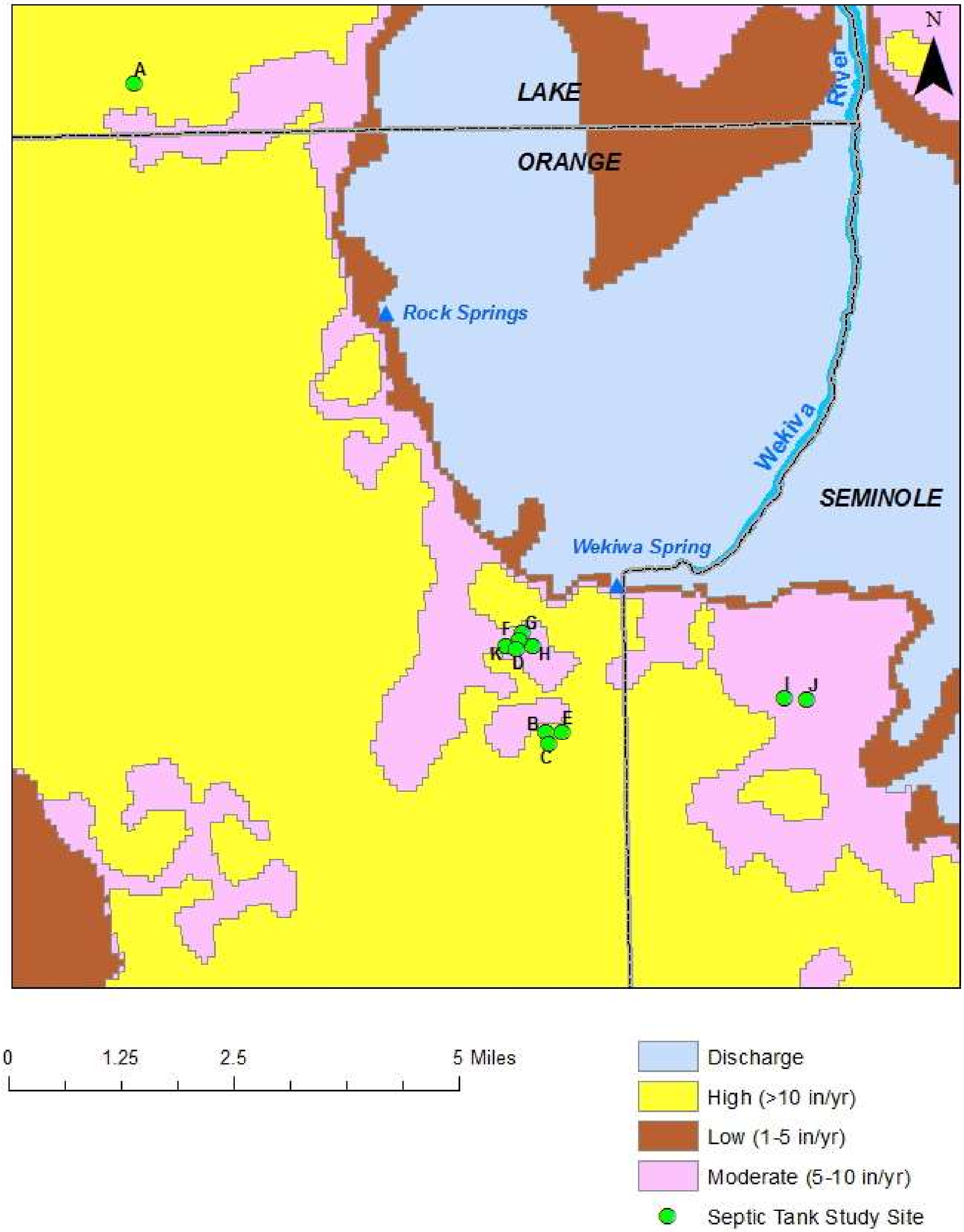

Figure 4. Recharge to the UFA

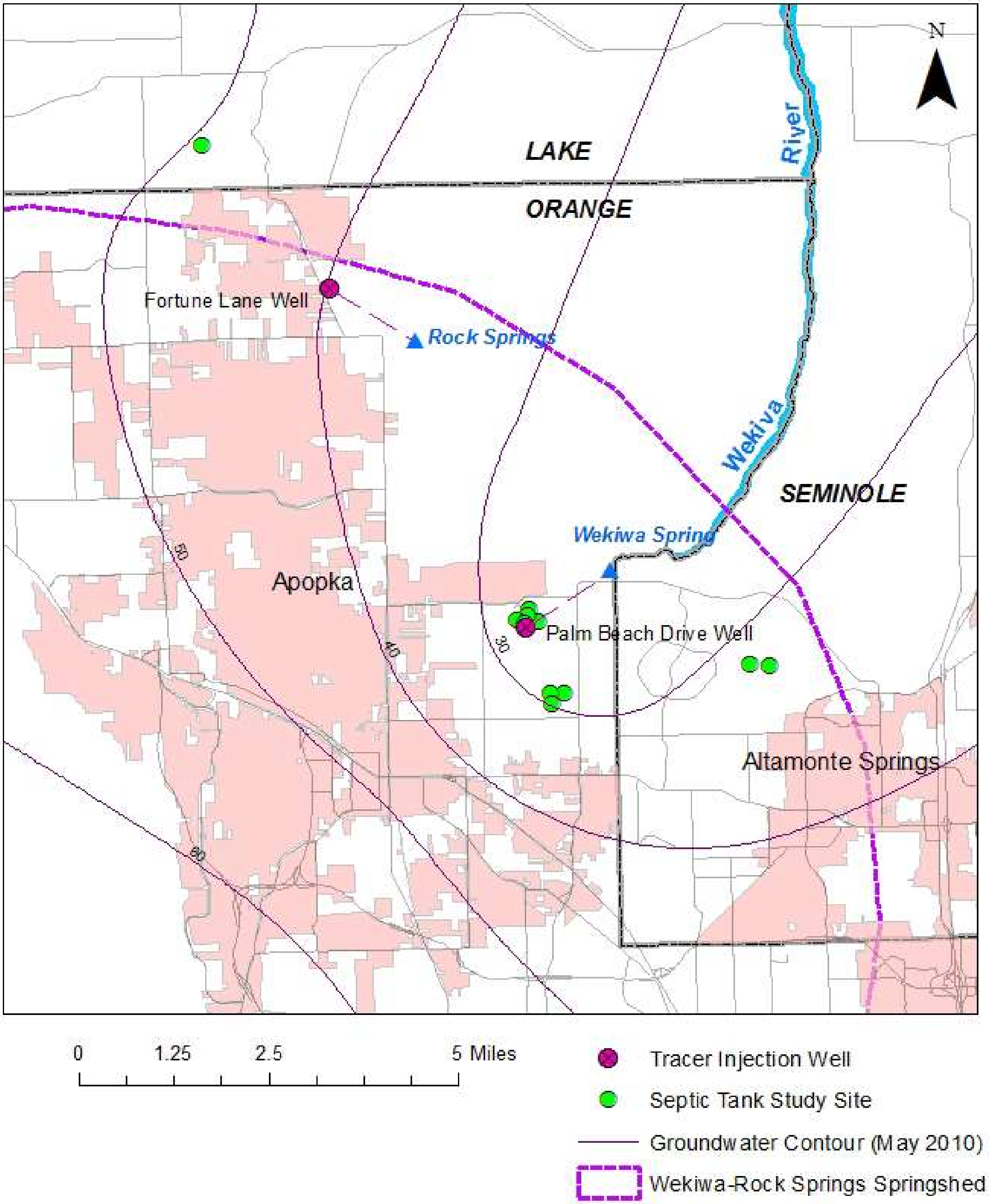

Figure 5. Groundwater elevation contours for the UFA and location of groundwater tracer test wells

Precipitation

Precipitation, which can directly or indirectly influence the results of this type of study, was considered in evaluating the results. **Figure 6** shows monthly precipitation from October 2015 to October 2016 from a rain gauge at the National Oceanographic and Atmospheric Administration (NOAA) network station at Mt. Plymouth, Florida, which is close to the study sites. During periods of higher precipitation, nitrogen leaching may be greater. During periods of lower precipitation, leaching may be less likely. However, site-specific factors such as fertilizer use patterns and irrigation frequency may make identifying direct relationships between precipitation and water quality monitoring results more complicated.

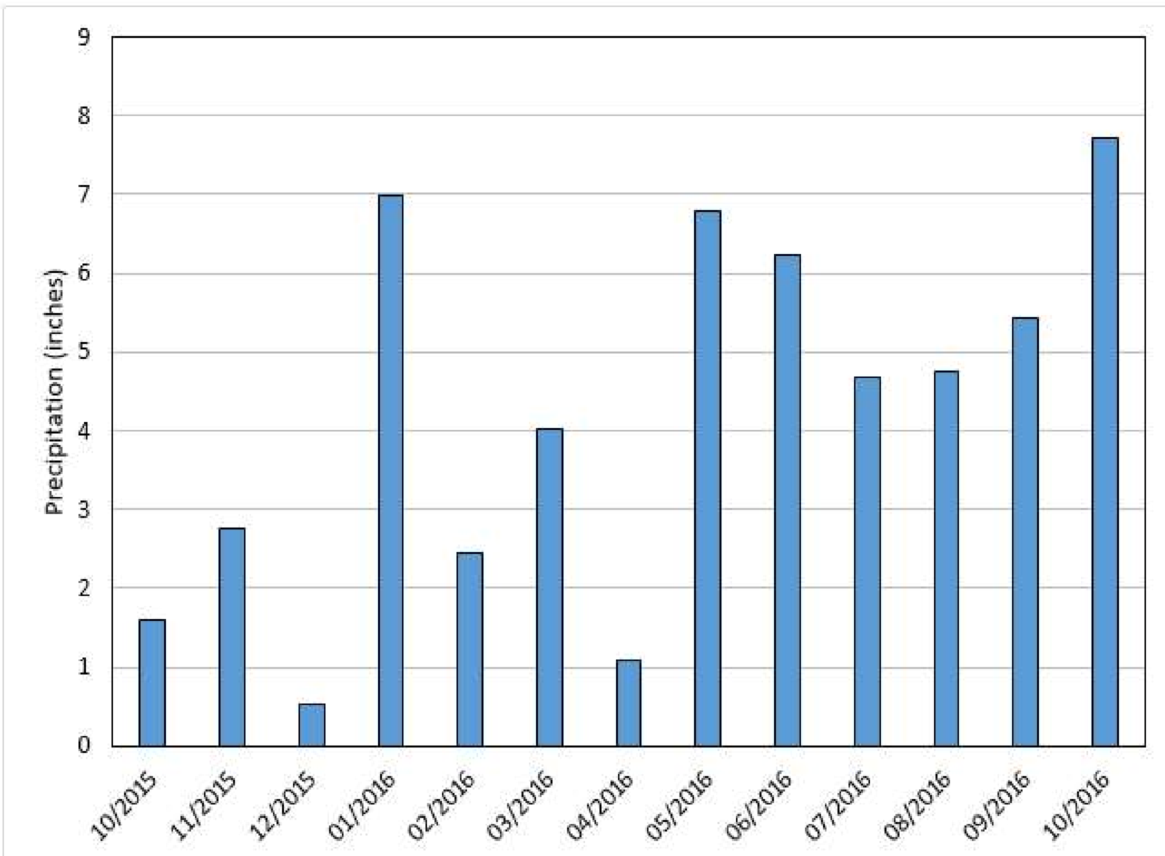

Figure 6. Monthly precipitation at Mt. Plymouth, FL (October 2015–October 2016)

Section 3. Study Findings

Nutrients in Septic Tanks

During the study, STE samples were collected bimonthly from eight of the study sites (A, B, C, E, F, G, I, and J) for the analysis of nitrogen species, chloride, and total phosphorus (TP). The septic systems at these sites receive all household wastewater, including "gray water." **Table 5** lists the average concentrations of total nitrogen (TN), chloride, and TP. **Figure 7** contains plots of all the sites with results for TN, chloride, and TP.

Table 5. Site average concentrations of TN, chloride, and TP in STE (in milligrams per liter [mg/L])

Site	Average TN	Average Chloride	TN/Chloride Ratio	Average TP
A	61	32	1.91	7.8
B	93	43	2.16	9.3
C	101	63	1.60	12
E	57	47	1.21	6.8
F	57	45	1.27	6.8
G	75	42	1.79	7.5
I	140	87	1.61	16
J	93	74	1.26	9.3
All Sites	**85**	**54**	**1.57**	**9.4**

Nitrogen

Nitrogen in the effluent comes mainly from human waste and food materials from kitchen sinks and dishwashers.[9] Average TN concentrations at the 8 sites with effluent data ranged from 57 to 140 mg/L, and the average TN concentration for all 8 sites was 85 mg/L. TN concentrations in STE from Sites A, E, F, and G are about the same as the average values found in previous studies. Hazen and Sawyer (2009) referenced a source that reported STE concentrations ranging from 26 to 124 mg/L, with an average concentration of 57.7 mg/L.[10] Harden and others (2010) reported an average TN concentration of 63.6 mg/L from 30 samples collected from 6 conventional septic tanks in a Florida study.[11]

[9] Gurpal, S.T., M. Lusk, and T. Obreza. 2015. *Onsite sewage treatment and disposal systems: Nitrogen.* Publication #SL348. Gainesville, FL: University of Florida Institute of Food and Agricultural Sciences.

[10] Hazen and Sawyer. August 2009. *Literature review of nitrogen reduction technologies for onsite sewage treatment systems. Florida Onsite Sewage Nitrogen Reduction Strategies Study Task A.2.* Prepared for FDOH Contract CORCL.

[11] Harden, H., J. Chanton, R. Hicks, and E. Wade. December 7, 2010. *Wakulla County Septic Tank Study Phase II report on performance based treatment systems.* Tallahassee, FL: Florida State University Department of Earth, Ocean and Atmosphere, DEP Agreement No. WM926.

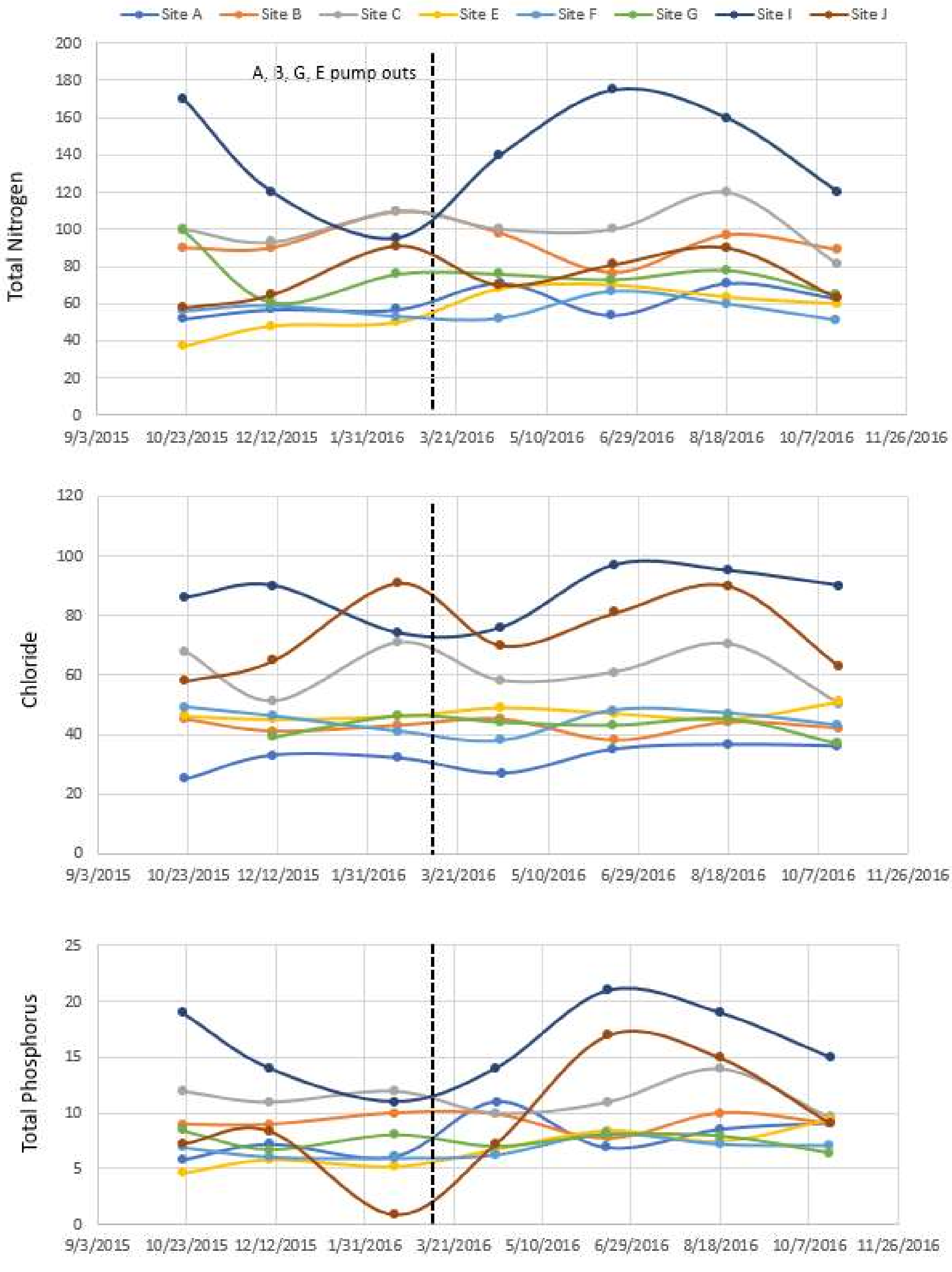

Figure 7. Nitrogen, chloride, and phosphorus concentrations in STE

The higher TN concentrations at the other sites (B, C, I, and J) could be related to lower water use by residents and less dilution of nitrogen from human waste by household water use. Advanced household water conservation measures such as low-volume showers, toilets, washing machines, and dishwaters could contribute to less dilution and higher nitrogen concentrations in the effluent stream. Household water use and the associated dilution of nitrogen may also be related to the number of residents served. In the STE, the predominant form of nitrogen is ammonia, making up 86 % to 96 % of the nitrogen in the samples.

Chloride

Chloride in the effluent comes from sodium chloride in human waste as well as chlorine in treated water and chloride compounds in household chemicals and food products. Average chloride concentrations at the sites ranged from 32 to 87 mg/L, and the average for all sites was 54 mg/L. Sites A, E, F, and G had lower chloride concentrations as well as lower TN concentrations.

As with the preceding discussion for TN, the range in chloride concentrations observed in STE samples from the sites could be a function of dilution by household water use. In this study, the value of chloride in the effluent is that it can be used as a tracer to help evaluate the degradation of nitrogen in the drainfield and soil zone. Chloride concentrations in the environment are primarily reduced by dilution, and thus soil pore water concentrations of chloride can be compared with corresponding nitrogen concentrations and chloride/TN ratios in the STE to help understand the amount of nitrogen reduction that occurs through dilution compared with denitrification and other attenuation mechanisms.

Phosphorus

Phosphorus in the effluent stream comes from human waste as well as a variety of household chemicals, detergents, and cleaners. However, with the elimination of phosphorus in laundry detergents in 1994 and dishwashing detergents in 2010, as much as 75 % of the phosphorus in household wastewater now comes from toilet water.[12] Average TP concentrations at the sites ranged from 6.8 to 16 mg/L, and the average for all sites was 9.4 mg/L. Sites A, E, F, and G had lower TP concentrations. Phosphorus concentrations in effluent can be related to the amount of phosphorus-containing materials in the waste stream as well as dilution by water use. Since the sites with lower TP concentrations also had lower TN and chloride concentrations, dilution appears to be greater at these 4 sites.

Septic Tank Pumping

Septic tank pumping to remove accumulated solids has always been part of the routine maintenance of septic systems. Excessive accumulations of solids can migrate into drainfields and shorten their lives. To prevent this, the septic tank industry recommends removing the material at regular intervals, with frequency based on septic tank volume and household size. In general, many entities recommend a pump-out frequency of 3 to 5 years. Studies have shown

[12] National Environmental Services Center. Summer 2013. Phosphorus and onsite wastewater systems. *Pipeline*. Volume 24. No. 1.

that the removal of some nitrogen occurs in septic tanks through ammonification and the removal of solids, and as a rule of thumb this accounts for a 10 % reduction in TN in the raw wastewater.[13]

There have been assertions that regular septic tank pumping may also improve treatment efficiency, and the study included an evaluation of this potential benefit. The septic tanks at four of the study sites (A, B, E, and G) had not been pumped out in more than 3 years and were selected for this part of the study. They were pumped in March 2016, about halfway through the study, to provide the opportunity to monitor water quality before and after pump-outs. The other four sites (C, F, I, and J) were used as controls to evaluate seasonal effects. **Table 6** lists the measured concentrations of TN, chloride, and TP for all sites before and after the pump-outs, and **Figure 8** shows TN concentration trends before and after pumping for Sites A, B, E, and G.

In addition, **Table 6** lists median concentrations in STE before and after the pumping occurred for all 8 sites and the percent change in concentrations. The results of this evaluation are mixed. The STE concentrations at 2 of the 4 sites that had pump-outs (Sites B and G) showed modest decreases in TN concentrations. Before-and-after pumping comparisons for Sites B and G showed 7 % and 8 % reductions in TN, 2 % and 2 % reductions in chloride, and "no change" and 13 % reductions in TP, respectively. The STE at only one other site (Site C), a control site, showed decreases over the same periods (1 % TN, 5 % chloride, 8 % TP). The other sites showed increases, some quite significant.

Table 6. Average nutrient concentrations (mg/L) in STE before and after septic tank pump-outs

[1] Septic tank pumped in March 2016. Other sites are controls.

Site	TN Before	TN After	% Change	Chloride Before	Chloride After	% Change	TP Before	TP After	% Change
A[1]	55	65	+18	30	34	+13	6	9	+5
B[1]	97	90	-7	43	42	-2	9	9	0
C	101	100	-1	63	60	-5	12	11	-8
E[1]	45	65	+44	46	48	+4	5	8	+60
F	56	65	+18	45	48	+7	6	8	+33
G[1]	79	73	-8	43	42	-2	8	7	-13
I	128	149	+16	83	90	+8	15	17	+13
J	77	106	+38	71	76	+7	5	12	+140

[13] Harden, H., J. Chanton, R. Hicks, and E. Wade. December 2010. *Wakulla County Septic Tank Study Phase II report on performance based treatment systems.* DEP Agreement No. WM926. Tallahassee, FL: Florida State University, Department of Earth, Ocean and Atmospheric Science.

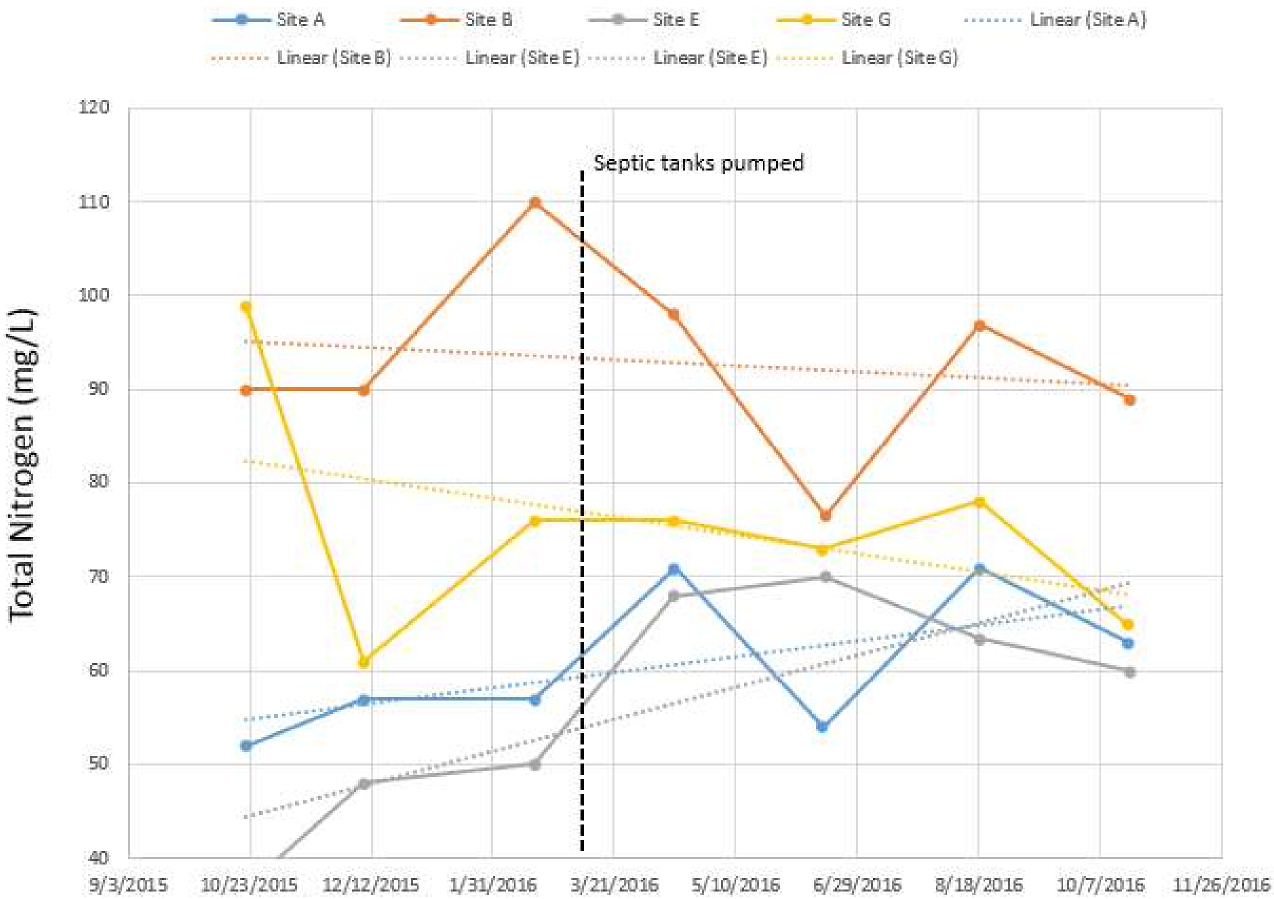

Figure 8. TN concentration trends in septic tanks before and after pump-out (in mg/L)

Nutrients in Soil

Soil pore water data were collected bimonthly from lysimeters installed beneath or at the edges of drainfields and at background locations at the 11 study sites. Optimally, to evaluate the influence of soil treatment on nutrients in the drainfield leachate, the lysimeters would be precisely located to intercept water percolating downward. Unfortunately, the optimal placement of lysimeters was not possible at several of the sites. At those sites with drainfields consisting of pipe in rock construction, thick gravel beds surrounding the drainfield made it difficult or impossible to install lysimeters close to the perforated pipe.

Another factor encountered in the study that is common to gravity-fed drainfield systems was the uneven distribution of effluent flow to drainfields. This resulted in excessive dilution and unrepresentative findings from the parts of drainfields not regularly receiving effluent. An additional challenge to monitoring with lysimeters was low soil moisture and the lack of sufficient sample volume during periods of low rainfall or no irrigation. The datasets for several sites were significantly limited because of these conditions, which resulted in fewer samples being collected. However, with repeated visits to the sites for sampling, it was possible to obtain meaningful data from most sites to evaluate nutrient attenuation related to the drainfields and other influences that factored into the observed results. The discussion below describes the information gained from each of the sites, with an emphasis on the results for TN, chloride, and TP.

Nitrogen is the constituent of greatest concern because the area springs are impaired by the most mobile form of nitrogen, nitrate. Ammonia is the predominant form of nitrogen in STE, but in the presence of oxygen and nitrifying bacteria in the drainfields and shallow, well-aerated soils, ammonia nitrogen is rapidly converted to ammonia gas and nitrate (often reported in the laboratory data as the combination of nitrate and nitrite [NO_3-NO_2]). In the soil column, the nitrate concentration can be further reduced through denitrification, plant uptake, and dilution. In the discussion below, TN is used when comparing nitrogen results from the STE and those from the lysimeters and wells.

Chloride, in this study, is not considered a pollutant but an indicator of the influence of STE and other sources such as fertilizer. Dilution is the primary mechanism for reducing chloride concentrations because it is not reduced by bacteria or soil adsorption. Thus, comparing the chloride and TN results for the monitoring points can be helpful in differentiating between nitrogen reductions caused by dilution and reductions caused by other factors. If the anomalous results caused by fertilizer interference are eliminated, and if it is assumed that the ratio of chloride to TN in the effluent is an initial condition and that decreases in chloride and TN caused by dilution are proportional, at some sites it is possible to estimate the amount of the TN decrease attributable to nitrification, denitrification, and adsorption that occurred between the septic tank and the monitoring points.

In STE, phosphorus occurs mainly as organic phosphorus. After application and exposure to the elements, the mineralization of organic phosphorus occurs, converting it to the more mobile and plant-available inorganic form, orthophosphate. Orthophosphate can also occur naturally in soil and geologic material. When phosphorus-containing leachate migrates through the soil column, phosphorus can be taken up by plant roots, can be chemically bound to soil particles, or can leach to groundwater.

Phosphorus is far less mobile than nitrogen, but it is also more persistent. Once the amount of phosphorus applied to a site exceeds the capacity of the soil to adsorb it, the phosphorus continues to leach through the soil column and may eventually reach groundwater. However, even in groundwater phosphorus mobility is impeded, as it is adsorbed to soil particles and precipitates when in contact with calcium carbonate media (limestone).

Table 7 lists summary statistics for TN, chloride, and TP concentrations for soil pore water samples collected from lysimeters at the individual study sites. TN concentrations ranged from 0.43 to 254 mg/L, chloride concentrations ranged from 0.04 to 2,600 mg/L, and TP concentrations ranged from 0.008 to 8.2 mg/L.

Table 7. Summary statistics for soil pore water samples (in mg/L)

Max = Maximum; Min = Minimum; Avg = Average

Site	Max TN	Min TN	Avg TN	Max Chloride	Min Chloride	Avg Chloride	Max TP	Min TP	Avg TP
A	132	0.96	37	81	0.04	26	3.6	0.034	0.89
B	254	1.5	49	180	1.6	33	3.6	0.008	0.32
C	67	0.83	19	67	6.5	30	1.2	0.033	0.38
D	22	1.3	6.0	28	2.7	13	2.1	0.053	1.2
E	103	0.74	22	94	2.9	37	1.9	0.11	0.77
F	112	7	42	56	1.3	18	6.1	0.047	1.8
G	152	2.2	49	2600	5.8	234	7.9	0.04	1.8
H	10	1.5	6.3	92	1.9	24	0.12	0.021	0.07
I	69	0.6	8.5	120	3.9	21	2.3	0.048	0.80
J	56	0.56	4.0	96	2.2	24	0.12	0.015	0.038
K	192	0.43	31	260	1.3	55	8.2	0.32	3.0

Site A

Site A is in southeastern Lake County south of the Town of Sorrento. The residence has a drainfield consisting of infiltration chambers in rows that were installed when the house was constructed in 2004 (**Table 1**). Part of the drainfield is overlain by a flowerbed, and part is overlain by a lawn of zoysia grass. A network of four shallow lysimeters and one deep lysimeter was installed between drainfield rows, and one background shallow lysimeter was installed at a remote location in the front yard. The drainfield serves two residents, and the water supply comes from an onsite potable well. The homeowners maintain the yard and lawn, and there is an irrigation system for watering the lawn. **Figure 9** shows the layout of the septic system and monitoring stations. **Figure 10** shows the results for TN, chloride, and TP for all lysimeters and for the STE.

The TN and chloride results from the lysimeters at Site A indicate that AL2S/AL2D and AL4S are located at points in the drainfield that most frequently receive infiltrating effluent. Lower TN and chloride levels at AL1S and AL3S indicate that these areas of the drainfield were not receiving much infiltrating water from the septic tank. The results from L5S, the background lysimeter installed in a lawn area, do not indicate that much (if any) lawn fertilization occurred at that location, but the TN and chloride data from AL4S and AL2S/AL2D, which have concentrations significantly higher than the STE concentrations, indicate that fertilizer was applied to plants or the lawn prior to the April 2016 sampling date.

The bias in the shallow lysimeters created by the additional nitrogen and chloride (perhaps as potassium chloride fertilizer) hinders interpretation of drainfield influence at AL2S/AL2D and AL4S. However, a comparison of the results from the 2 clustered lysimeters (AL2S and AL2D) does provide some insight into nitrogen attenuation over the 5-ft depth interval separating them (5- to 10-ft depth below the land surface). Average chloride concentrations for AL2S and AL2D were similar (38 and 42 mg/L, respectively). However, there was an 8 mg/L difference in average TN (37 mg/L for L2S and 29 mg/L for AL2D). This decrease with depth is most likely caused by attenuation mechanisms other than dilution (nitrification, denitrification, and adsorption). **Figure 11** shows a plot of TN concentrations in samples from AL2s and AL2D. The nitrogen time series plot for lysimeter AL2D appears to correspond with the STE trend, and data from this lysimeter were used for model calibration, which is discussed in a subsequent section.

TP results for Site A show that most lysimeter concentrations were significantly lower than the average STE value of 7.8 mg/L, indicating little leaching of phosphorus at those locations. However, average concentrations for AL2S and AL2D (0.2 and 2.0 mg/L, respectively) were significantly higher than background (< 0.1 mg/L at AL5S).

Figure 9. Septic system and monitoring devices at Site A

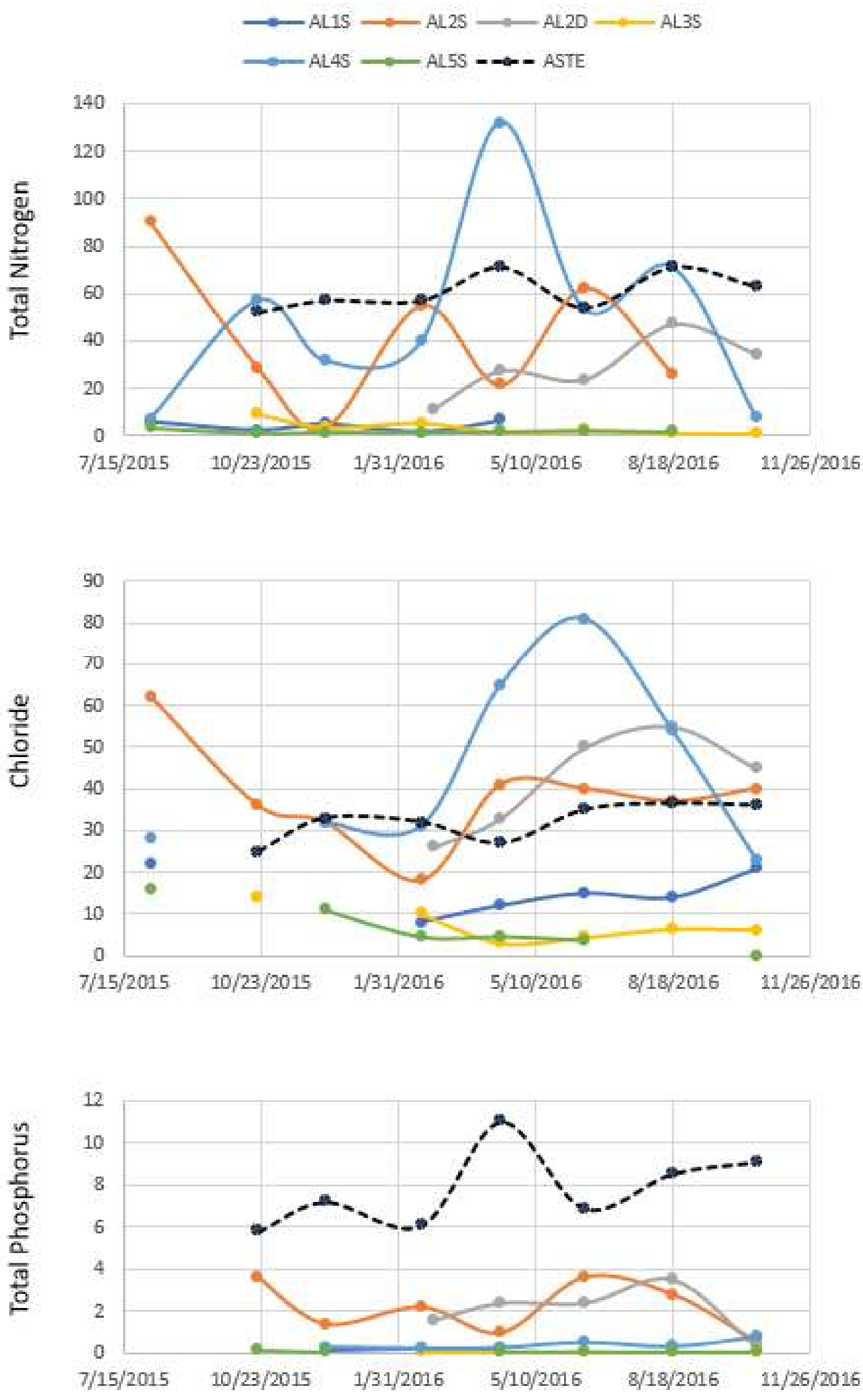

Figure 10. Lysimeter and STE monitoring results for TN, chloride, and TP at Site A (in mg/L)

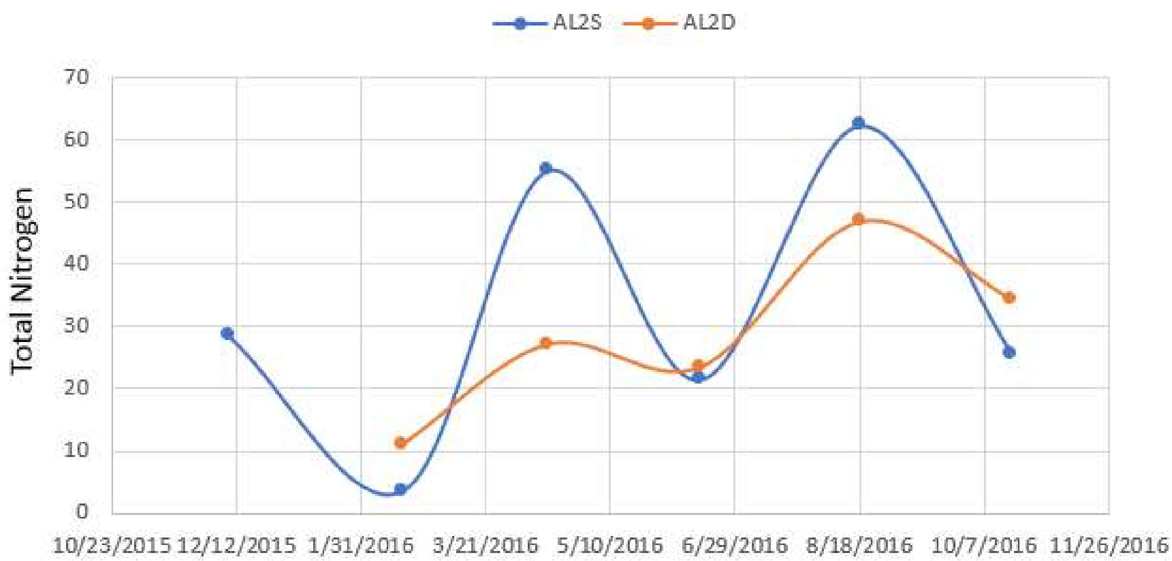

Figure 11. Plot showing TN concentrations (in mg/L) in paired lysimeters AL2S (5-ft depth) and AL2D (10-ft depth).

Site B

Site B is situated in a residential neighborhood in unincorporated Orange County east of Apopka. The drainfield consists of infiltration chambers installed in a bed configuration that replaced the original drainfield in 2009 (**Table 1**). The drainfield area is covered by a lawn of St. Augustine grass and has adjacent bedded plant areas. A network of 4 shallow lysimeters and 2 deep lysimeters (10- and 15-ft depths) was installed at locations at the edge of the drainfield, and 1 background shallow lysimeter was installed at a remote location in the front yard. The drainfield serves 3 residents, and the water source is city water. The homeowners do their own yard work and lawn maintenance, and there is an in-place irrigation system. **Figure 12** shows the layout of the septic system and monitoring stations. **Figure 13** displays the results for TN, chloride, and TP for all lysimeters and for the STE. **Figure 14** shows plotted TN results for the clustered lysimeters.

The TN and chloride results from the lysimeters at Site B indicate that BL1S, BL3S, BL3D, and BL3E are located at points adjacent to the drainfield that receive infiltrating effluent. Lysimeters BL3S/BL3D appear to be most significantly influenced. Lysimeters BL2S and BL4S are less influenced by the drainfield based on chloride and TN concentrations, and lysimeter BL5S was installed at the background location.

As with Site A, the influence of fertilizer applications during part of the study period complicated the interpretation of the data from the drainfield area because of additional inputs of nitrogen and chloride. This influence appears to be expressed in data from several of the lysimeters collected in June, August, and, to a lesser extent, October 2016. Average TN and chloride values from shallow lysimeter BL3S (excluding outliers from fertilizer influence) are very similar to average values for the STE, suggesting that this lysimeter is very close to a portion of the drainfield where most of the effluent is collected. The average values from the deeper lysimeter at this location (BL3D), excluding fertilizer-related outliers, indicate a 38 % reduction in TN and a 19 % reduction in chloride compared with the STE average. This suggests that nitrogen was attenuated by factors such as denitrification and dilution between 5 and 10 ft. Average concentrations in samples from BL1S, excluding fertilizer-related outliers, show a 78 % reduction in TN and a 75 % reduction in chloride compared with the STE average values, with most of that reduction associated with dilution but also some reduction from other mechanisms such as denitrification.

Monitoring results after a fertilizer application in August 2016 showed the rates of leaching and attenuation of applied nitrogen at shallow depths, as reflected in the data from lysimeters BL2S and BL5S. TN concentrations in BL2S and BL5S of 235 and 254 mg/L, respectively, decreased by 95 % to 98 % between the August and October sampling dates. In the 10-ft interval at lysimeter BL3D, TN concentrations decreased from 122 to 79 mg/L, a 35 % decrease over the 2-month interval, and in the 15-ft interval at lysimeter BL3E, TN concentrations decreased by 10 %, from 41 to 37 mg/L. These decreases were mainly due to dilution.

Phosphorus results for Site B show that most lysimeter concentrations were significantly lower than the average STE value of 9.3 mg/L, which indicates little leaching of phosphorus at those locations. However, increases in TPin August and October 2016 samples from lysimeter BL1S are most likely may be related to leaching of phosphorus in applied fertilizer, since significant increases in TN and chloride were observed in other lysimeters in the same months.

Figure 12. Septic system and monitoring devices at Site B

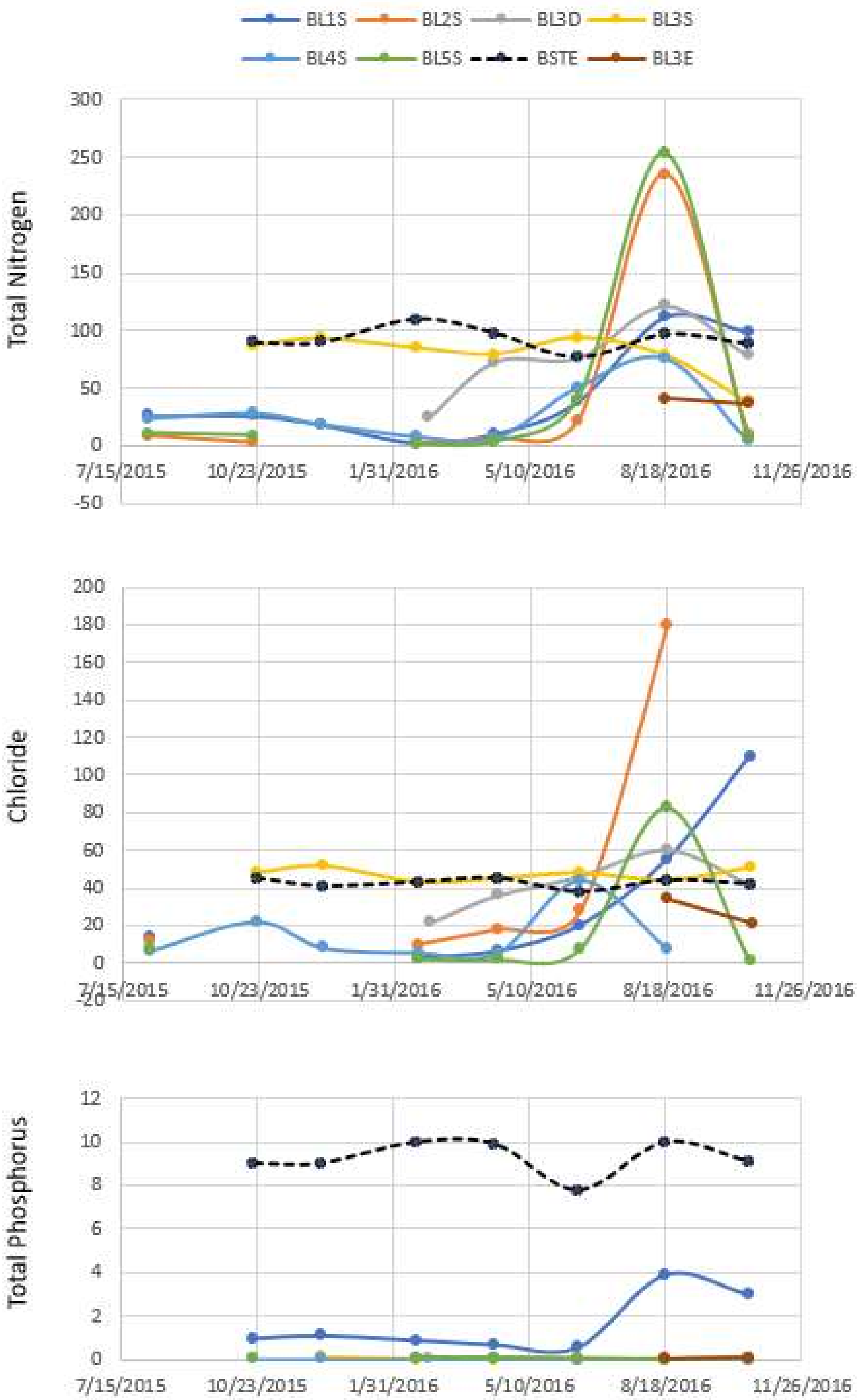

Figure 13. Lysimeter and STE monitoring results for TN, chloride, and TP at Site B (in mg/L)

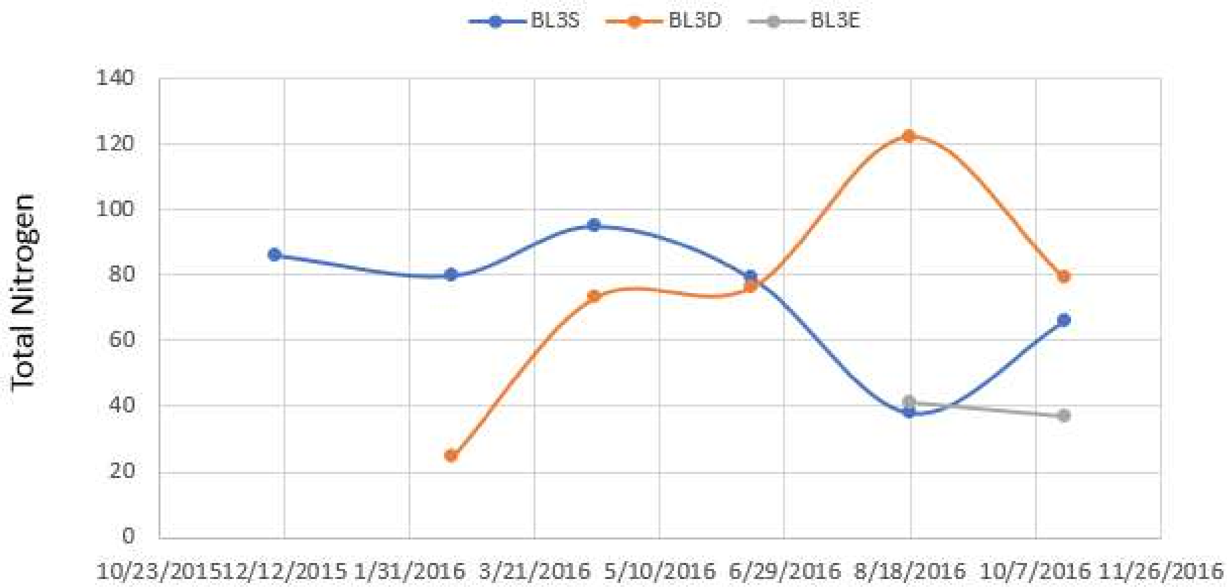

Figure 14. Plot showing TN concentrations (in mg/L) in paired lysimeters BL3S (5-ft depth), BL3D (10-ft depth), and BL3E (15-ft depth)

Site C

Site C is in the same residential neighborhood as Site B, in unincorporated Orange County east of Apopka. The drainfield consists of infiltration chambers installed in a bed configuration that replaced the original drainfield in 2010 (**Table 1**). A lawn of St. Augustine grass covers the entire drainfield area. A network of three shallow lysimeters was installed at locations at the edge of the drainfield, and one background shallow lysimeter was installed at a remote location in the front yard. The septic system serves three residents, and the water source is city water. An irrigation system is used to water the lawn. The homeowners do their own yard and lawn maintenance. **Figure 15** shows the layout of the septic system and monitoring stations. **Figure 16** shows the results for TN, chloride, and TP for all lysimeters and for the STE.

The TN and chloride results from the lysimeters at Site C indicate that CL1S and CL2S are located at points adjacent to the drainfield that receive infiltrating effluent. Lysimeter CL2S, also adjacent to the drainfield, was less influenced by the drainfield effluent based on chloride and TN concentrations. Lysimeter CL4S was installed at the background location. Based on results from the background lysimeter, there was little to no additional input of nitrogen, chloride, or phosphorus from fertilizer during the study period. Compared with the average TN concentration for the STE (100 mg/L), the TN concentrations in lysimeters CL1S and CL2S were 71 and 29 % lower, respectively.

Based on a relationship between the chloride/TN ratios from average values for the STE and lysimeters, it was possible to roughly estimate the percentage of nitrogen change at each of the locations caused by dilution. At CL1S (30 mg/L average TN concentration), about a third of the difference could be attributed to dilution, and at CL2S (32 mg/L average TN concentration) dilution accounted for about half of the difference. Other factors such as denitrification and plant root uptake would account for the remaining fractions.

TP concentrations at all of the lysimeter locations were considerably lower than the STE average value (11 mg/L), and none of the detections indicated other source contributions.

Figure 15. Septic system and monitoring devices at Site C

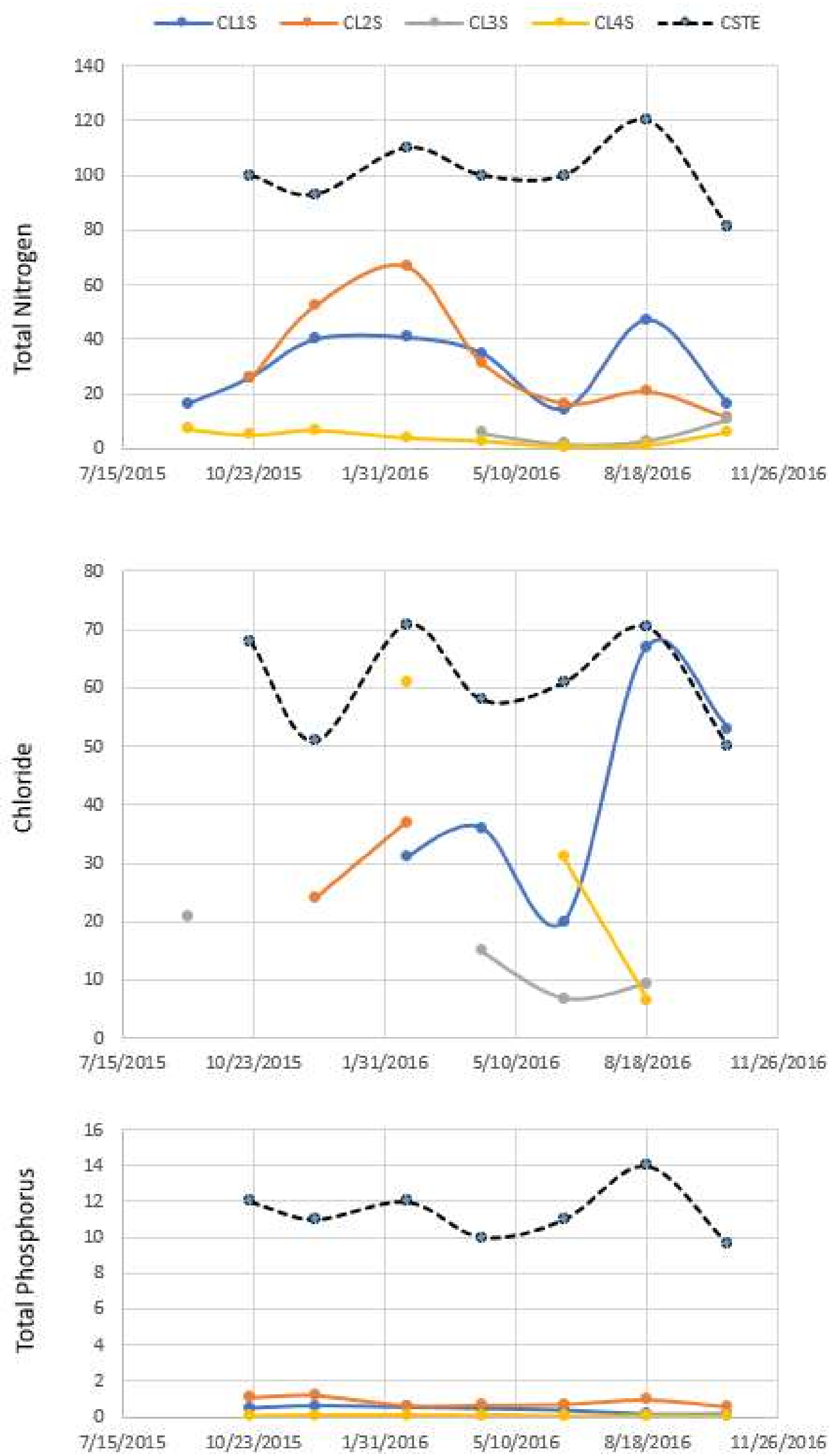

Figure 16. Lysimeter and STE monitoring results for TN, chloride, and TP at Site C (in mg/L)

Site D

Site D is also located in a residential neighborhood in unincorporated Orange County east of Apopka. The drainfield consists of perforated plastic pipe in a gravel bed. This is the original drainfield, constructed in 1990 (**Table 1**). The entire drainfield area is overlain by lawn consisting of zoysia grass. Two shallow lysimeters were installed at locations at the edge of the gravel bed, and one background shallow lysimeter was also installed at a remote location in the front yard. The drainfield serves two residents, there is a lawn irrigation system, and water is provided from public supply. Lawn maintenance is contracted. **Figure 17** shows the layout of the septic system and monitoring stations. **Figure 18** shows the results for TN, chloride, and TP in all lysimeters and for the STE.

Like several other study sites, at this site the gravel bed and septic tank underlie most of the front yard of the home, allowing very limited access for lysimeter installation. Lysimeters DL1S and DL2S were installed downhill of the drainfield at the edge of the gravel bed and may at times intersect infiltrating leachate from the drainfield, although fertilizer applications appear most likely to be responsible for detected concentrations based on the plotted data. The TN concentrations in samples from the background lysimeter (DL3S) indicate that fertilizer was not a significant source of nitrogen in the soil pore water at this location, but fluctuations in chloride values may indicate the release of potassium chloride in response to precipitation events.

No STE monitoring was conducted at this site, but based on average STE concentrations for the other sites with data, the concentrations of TN, chloride, and TP in lysimeter samples at Site D were lower, indicating that the lysimeters were not close to the active drainfield. Average TN concentrations for lysimeters DL1S, DL2S, and DL3S were 6.8. 8.4, and 2.7 mg/L, respectively, compared with the STE average of 84.6 mg/L. For chloride, average concentrations for lysimeters DL1S, DL2S, and DL3S were 15, 10, and 13 mg/L, respectively, compared with the STE average of 54 mg/L. TP concentrations, some of which were higher than background for other sites, were still considerably lower than the average STE concentration, ranging from 0.06 to 1.9 mg/L, compared with the STE average concentration of 9.4 mg/L.

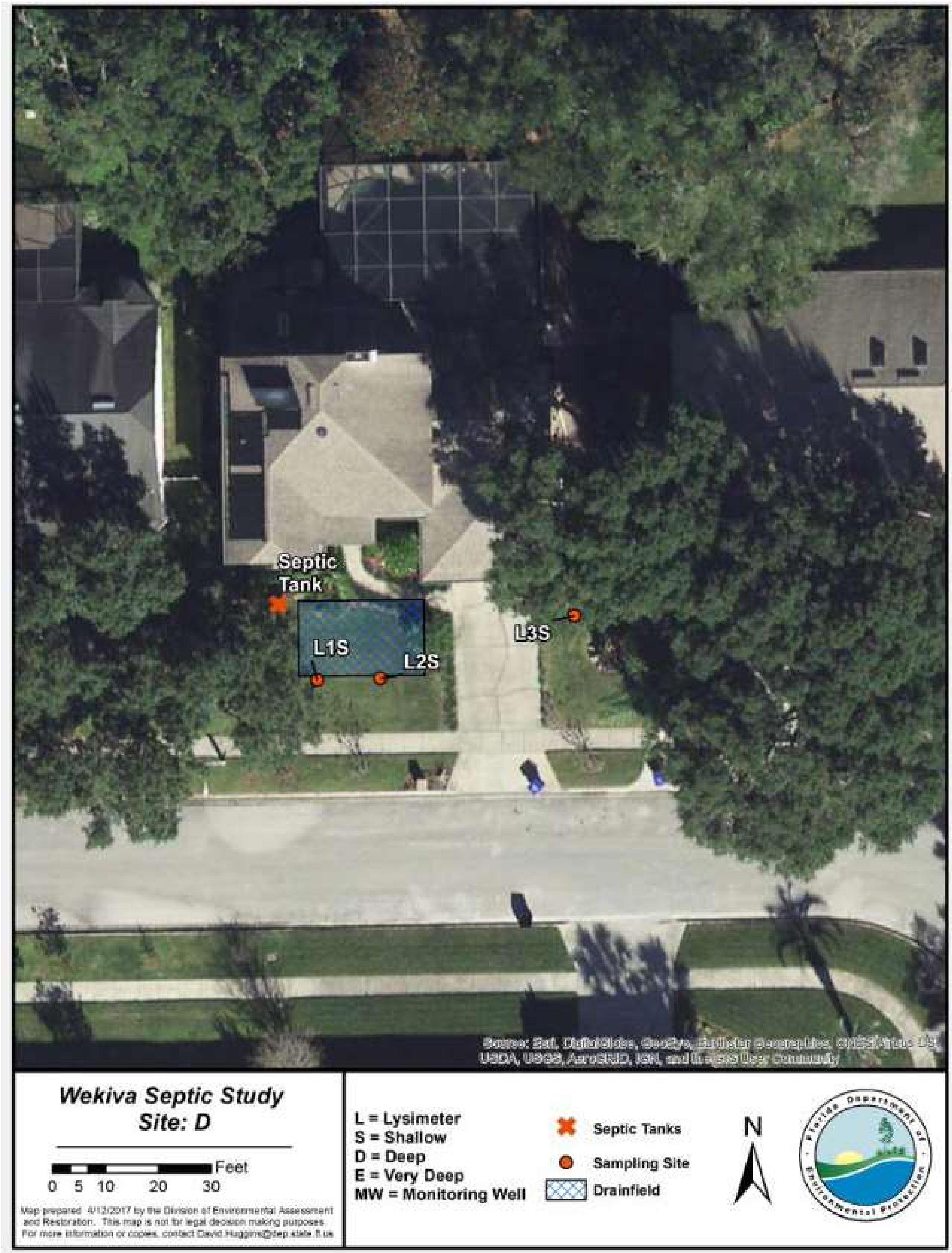

Figure 17. Septic system and monitoring devices at Site D

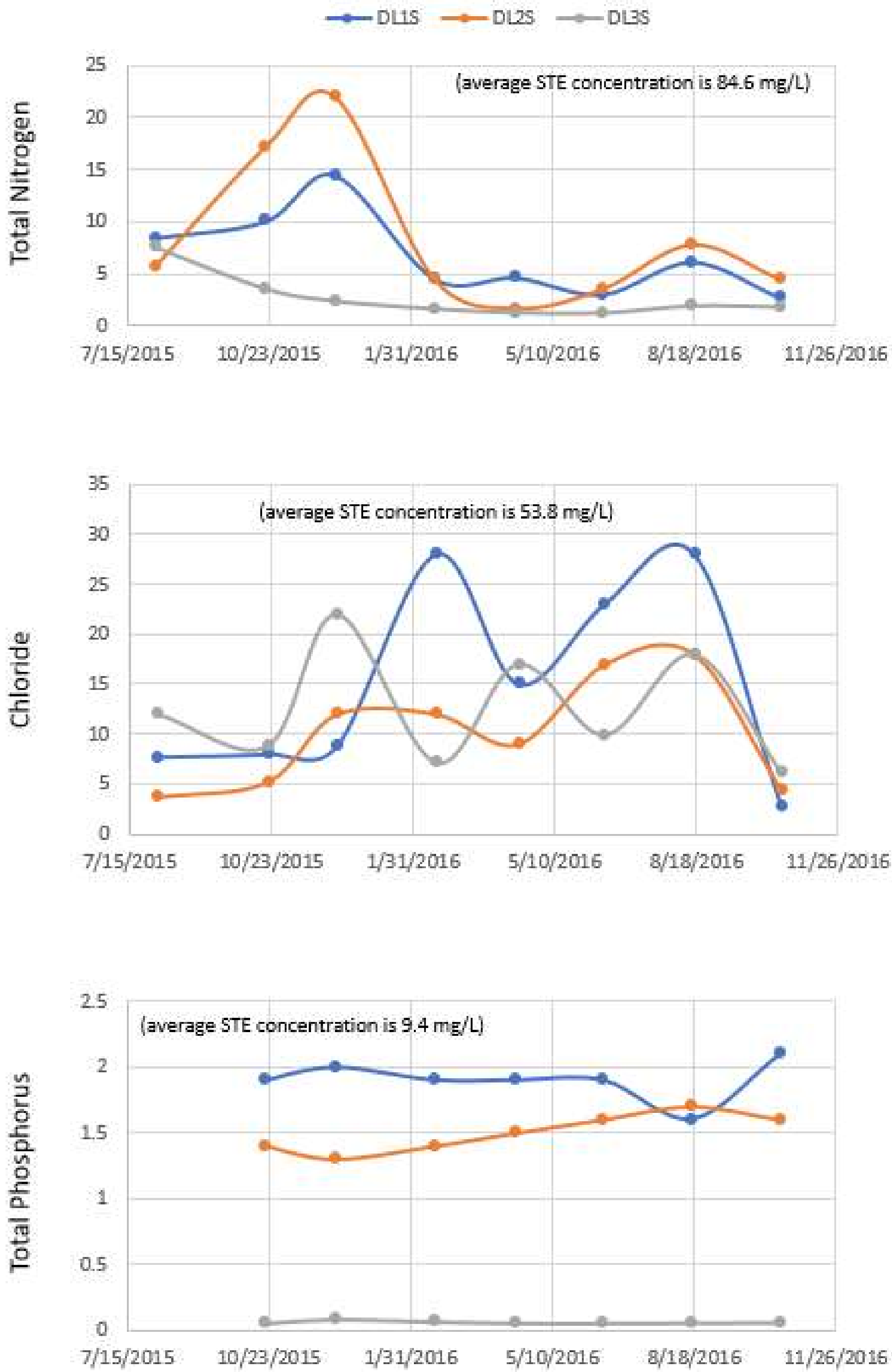

Figure 18. Lysimeter and STE monitoring results for TN, chloride, and TP at Site D (in mg/L)

Site E

Site E is in the same residential neighborhood as Sites B and C in unincorporated Orange County east of Apopka. The drainfield, installed in 1989, consists of perforated plastic pipe in a gravel bed (**Table 1**). It is overlain by a small area of lawn covered by St. Augustine grass and beds of shrubbery and ferns. Three shallow lysimeters and one deep lysimeter were installed along the edge of the gravel bed, and one background shallow lysimeter was installed at a remote location in the front yard. One of the lysimeters (EL2S) was not productive. The drainfield serves two residents, the lawn has an irrigation system, and the residence receives water from public supply. The homeowners maintain their own lawn and beds, and there is an irrigation system. **Figure 19** shows the layout of the septic system and monitoring stations. **Figure 20** displays the results for TN, chloride, and TP for all lysimeters and for the STE. **Figure 21** contains a plot of the TN concentrations in the samples from the paired lysimeters.

The TN and chloride results from the lysimeters indicate that EL1S most reliably provided data reflective of drainfield leachate influence. Deep lysimeter EL1D, however, appeared to be influenced by fertilizer contributions during the latter part of the study period, when TN and chloride values were higher than the STE concentration. Lysimeter EL3S, also adjacent to the drainfield, was less influenced by the drainfield effluent based on chloride and TN concentrations during part of the study period but later appeared to be influenced by fertilizer contributions as TN and chloride concentrations increased. Lysimeter EL4S, installed at the background location, appeared to show a response to fertilizer application based on chloride increases observed in June and August 2016. However, the results indicated little to no additional input of nitrogen during the study period.

Compared with the average TN concentration for the STE (100 mg/L), the average TN concentration in lysimeter EL1S was 39 % lower. Based on a relationship between the chloride/TN ratios from average values for the STE and lysimeters, it was possible to roughly estimate the percentage of nitrogen change at this lysimeter location caused by dilution. The average STE concentration of TN was 57 mg/L. At EL1S (35 mg/L average TN concentration), the TN concentration was 39 % lower, and roughly 10 % of the TN reduction could be attributed to dilution, with most of the reduction associated with denitrification and other factors. At the corresponding deeper lysimeter (EL1D), the average TN concentration from the period preceding fertilizer influence was 8.1 mg/L, which was 86 % lower than the effluent concentration. A rough analysis indicates that dilution was responsible for a greater percentage of the TN reduction in EL1D, roughly 60 %.

TP concentrations at all the lysimeter locations were considerably lower than the STE average value (6.8 mg/L), and none of the detections indicated significant influence in response to fertilizer applications.

Figure 19. Septic system and monitoring devices at Site E

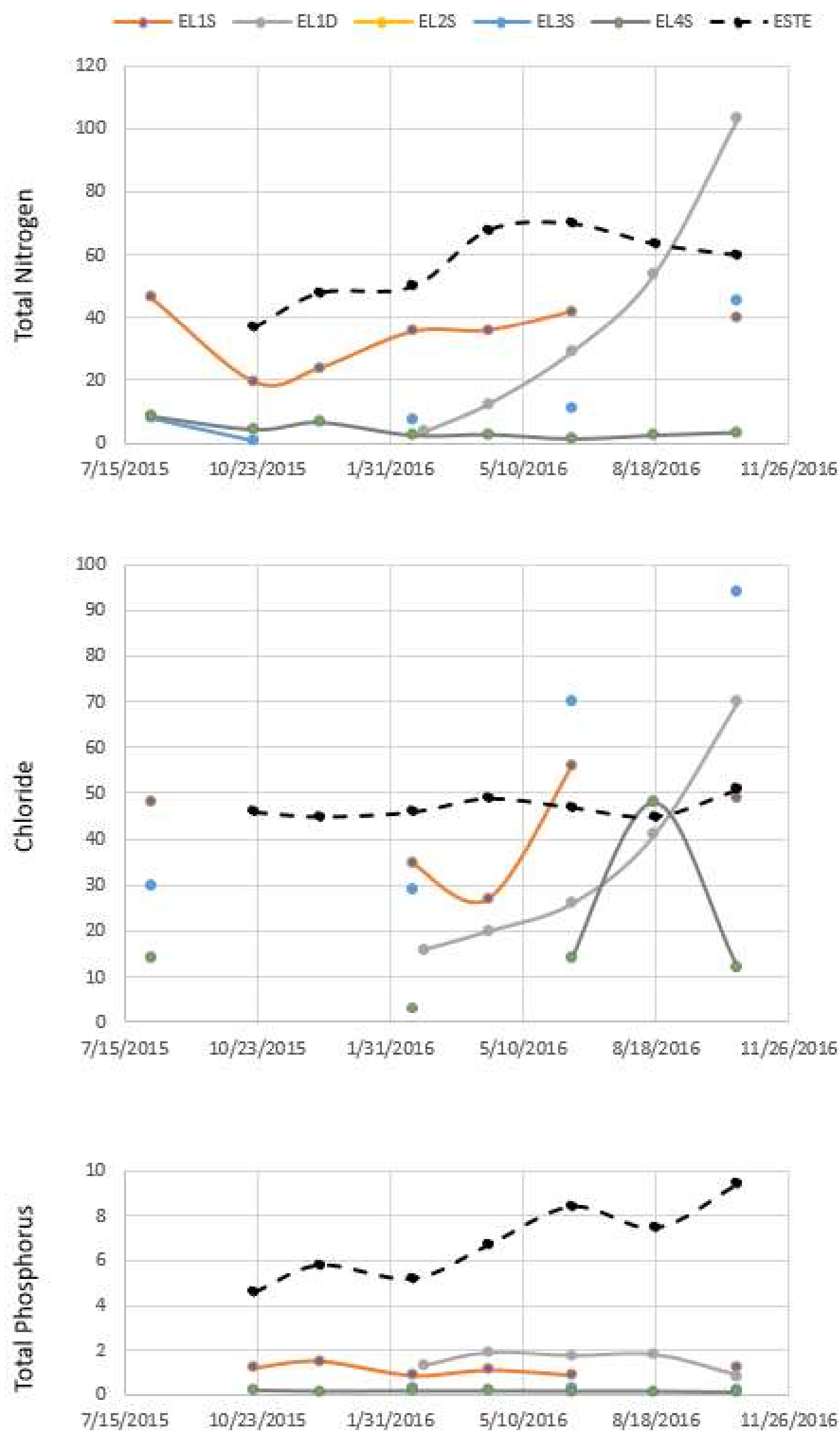

Figure 20. Lysimeter and STE monitoring results for TN, chloride, and TP at Site E (in mg/L)

Figure 21. Plot showing TN concentrations (in mg/L) in paired lysimeters EL1S (5-ft depth) and EL1D (10-ft depth)

Site F

Site F is in a residential neighborhood in unincorporated Orange County east of Apopka. The drainfield consists of infiltration chambers installed in a bed, with additional chambers added as a later modification to provide more drainfield capacity. The drainfield was installed as a repair in 2010 (**Table 1**). It was entirely overlain by lawn, which initially was in poor condition and patchy. Four shallow lysimeters and one deep lysimeter were installed along the edges of the drainfield, and one background shallow lysimeter was installed at a remote location in the front yard. The drainfield serves four residents, there is an irrigation system, and the residence obtains water from public supply. The homeowners maintain the lawn and yard. **Figure 22** shows the layout of the septic system and monitoring stations. **Figure 23** shows the results for TN, chloride, and TP for all lysimeters and for the STE. **Figure 24** shows a plot of TN concentrations in the samples from the paired lysimeters.

Lysimeters FL1S, FL2S, FL3S, FL4S, and FL2D were installed at locations that might intercept infiltrating leachate from the drainfield, and lysimeter FL5S was installed at a background location. The nitrogen and chloride results from all the lysimeters indicated that several fertilizer applications influenced the soil pore water chemistry during most of the study period, with TN and chloride concentrations exceeding the STE concentration in some instances. It appears, based on the data from background lysimeter FL5S, that the data for some of the lysimeters from the October 2015 and October 2016 sampling events was less influenced by the addition of nutrients from fertilizer. At those times, potential STE influence could be reflected in data from FL1S (24 mg/L TN in October 2016), FL2S (20 mg/L TN on October 2016), and FL2D (11 mg/L TN in October 2016). The chloride/TN ratios for these locations in October 2016, compared with those of the STE, indicate that the difference in TN is largely caused by dilution, assuming the nitrogen is from the drainfield. The results for the two clustered lysimeters F2S and F2D were very similar when both were sampled on the same dates, with TNaverage concentrations of 54 and 55 mg/L, respectively, and chloride averages of 20 and 24 mg/L, respectively. These results show little attenuation occurring in the 5-ft interval between the two sampling depths.

Phosphorus results for some of the lysimeters at Site F may also show some influence by fertilizer applications in the underlying soil pore water, as evidenced by data from FL1S, FL2S, and FL2D. Lysimeters with the highest average TP concentrations were FL2S (4.1 mg/L) and FL2D (3.0 mg/L). The average TP concentration in the STE was 6.8 mg/L.

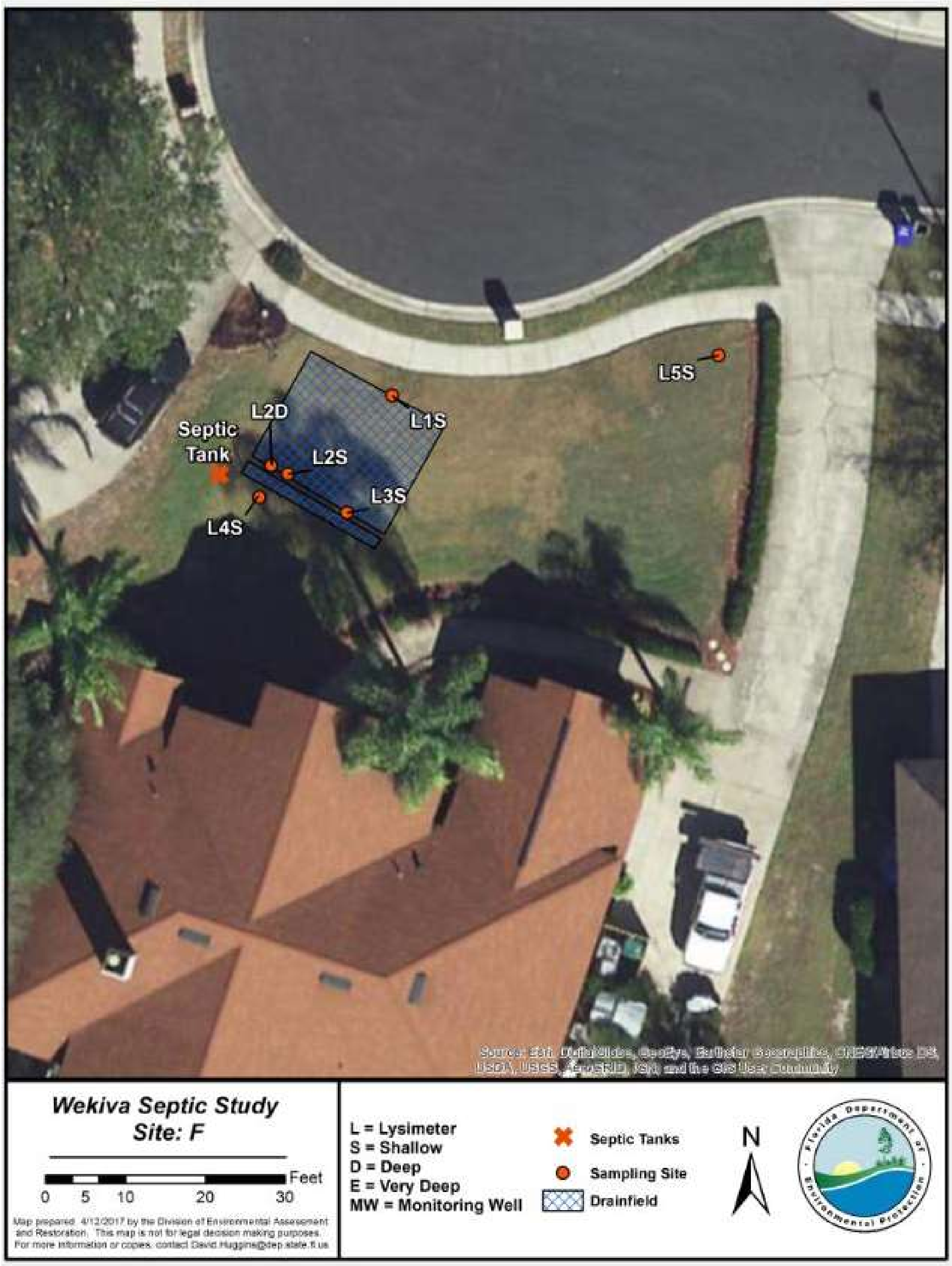

Figure 22. Septic system and monitoring devices at Site F

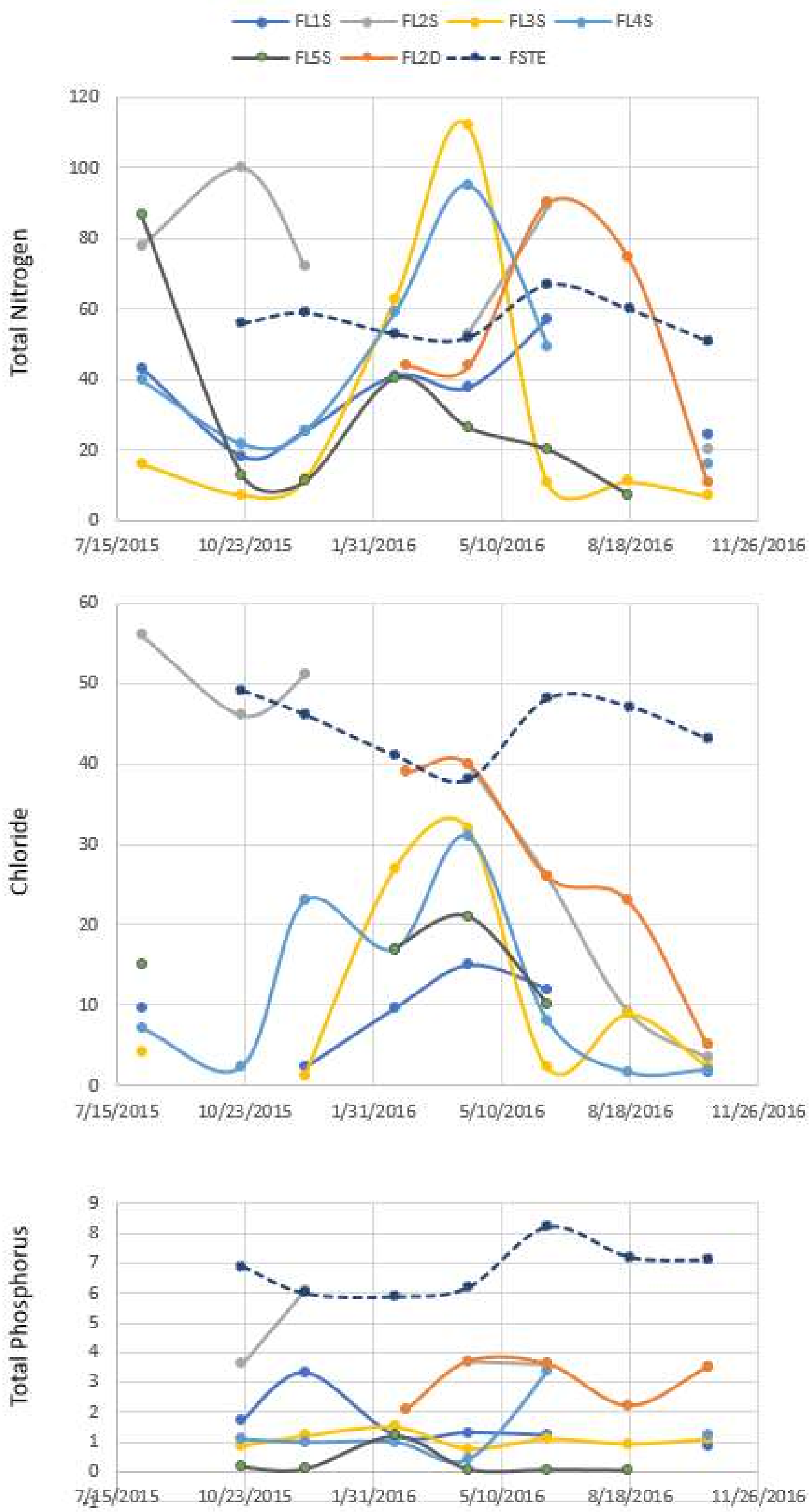

Figure 23. Lysimeter and STE monitoring results for TN, chloride, and TP at Site F (in mg/L)

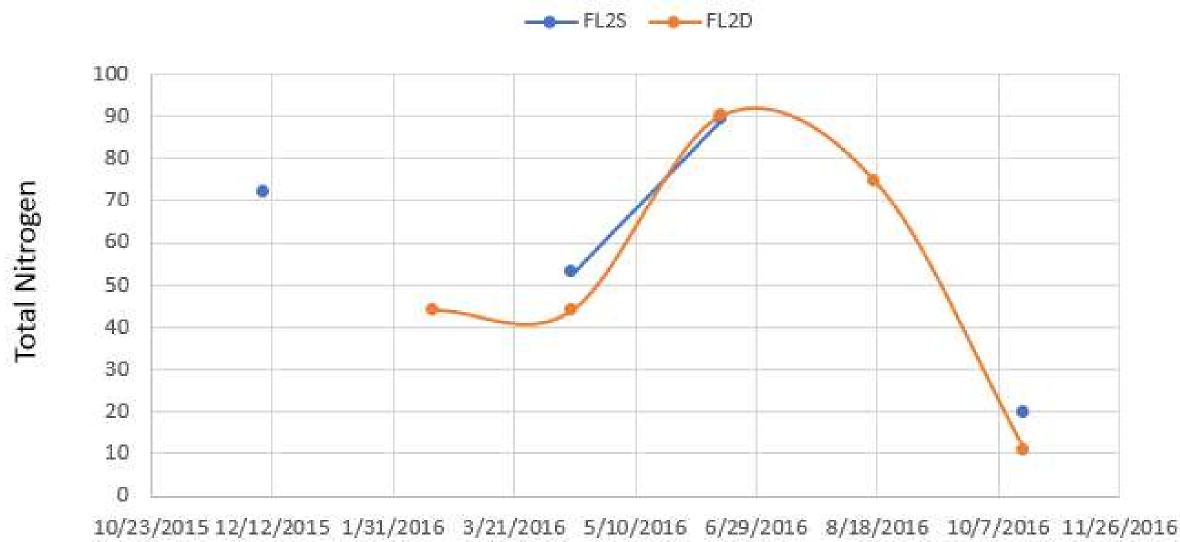

Figure 24. Plot showing TN concentrations (in mg/L) in paired lysimeters FL2S (5-ft depth) and FL2D (10-ft depth).

Site G

Site G is in the same residential neighborhood as Site F in unincorporated Orange County east of Apopka. The drainfield consists of perforated plastic pipe in a gravel bed that was installed in 1996 (**Table 1**). It is entirely overlain by bedded plants. Two shallow lysimeters and two deep lysimeters were installed at the edge of the gravel bed, and one background shallow lysimeter was installed at a remote location in the front yard. The septic system serves three residents. Water to the residence comes from public supply. The homeowners maintain their own yard and lawn, and there is an irrigation system. **Figure 25** shows the layout of the septic system and monitoring stations. **Figure 26** shows the results for TN, chloride, and TP for all lysimeters and for the STE. **Figure 27** shows a plot of TN concentrations in the samples from the clustered lysimeters.

Lysimeters GL1S, GL2S, GL2D, and GL2E were installed at locations that might intercept infiltrating leachate from the drainfield, and lysimeter GL3S was installed at a background location. The TN and chloride results from all the lysimeters at Site G except GL3S (the background site) indicate that several fertilizer applications influenced the soil pore water chemistry during most of the study period, with TN and chloride concentrations significantly higher than the STE concentration in some instances. Many of the results therefore represent a contribution from the combined sources.

However, it appears that based on the similarity of TN/chloride ratios for some data and trend information corresponding with the STE trend for TN, that some of the data from GL1S (February 2016) and GL1D (February and April 2016) may be more related to STE leachate and less influenced by the fertilizer contribution. The data for GL1S and GL1D for February 2016 show the lysimeter TN concentrations (41 and 44 mg/L, respectively) to be 42 % to 46 % lower than the corresponding STE concentration (76 mg/L). GL1D showed very similar results in April 2016. With no decrease in chloride between the lysimeters and effluent, this reduction would not be related to dilution, but could be caused by denitrification and other factors. The results for the 2 clustered lysimeters, GL1S and GL1D, were very similar when both were sampled on the same dates, indicating that little attenuation occurred in the 5-ft interval between the 2 sampling depths.

TP results for GL1S appear to show some influence from septic tank and/or fertilizer applications. The average TP concentration in GL1S was 5.8 mg/L compared with the average TP concentration of 7.5 mg/L in the STE. TP concentrations in the other lysimeters were much lower.

Figure 25. Septic system and monitoring devices at Site G

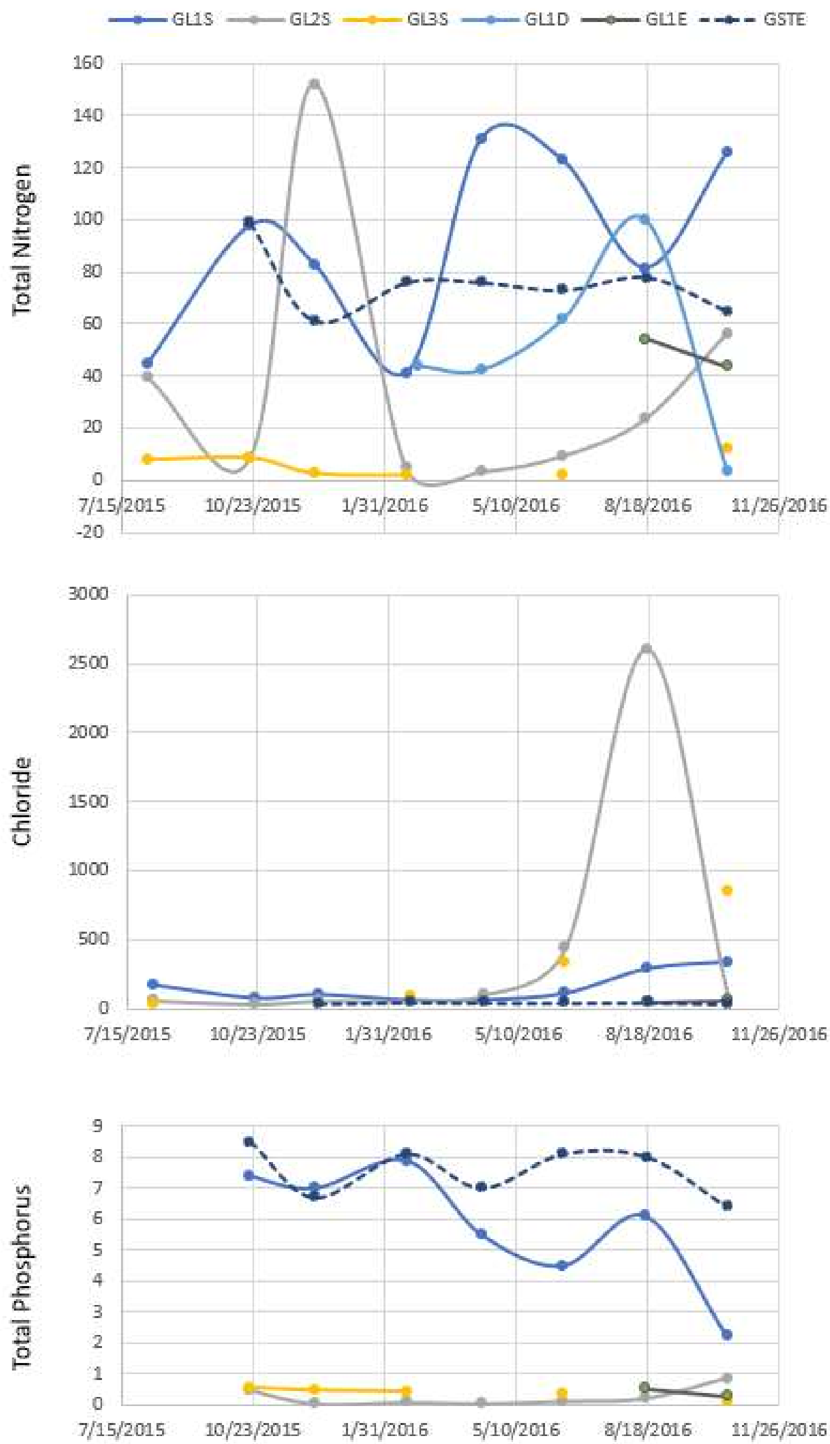

Figure 26. Lysimeter and STE monitoring results for TN, chloride, and TP at Site G (in mg/L)

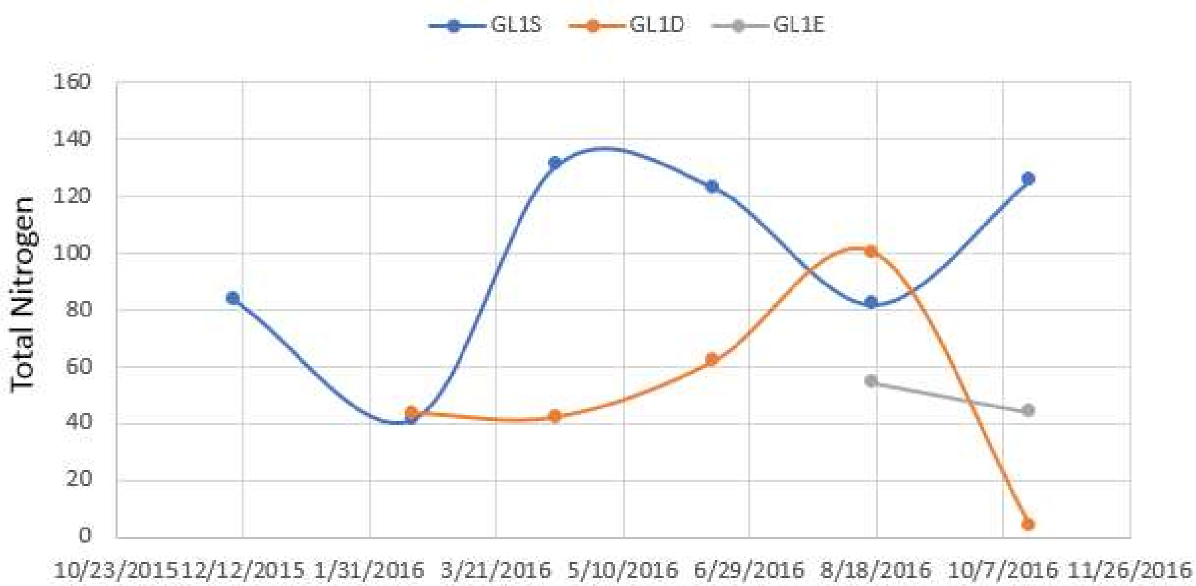

Figure 27. Plot showing TN concentrations (in mg/L) for lysimeters GL1S (5-ft depth), GL1D (10-ft depth), and GL1E (15-ft depth)

Site H

Site H is in the same residential neighborhood as Sites F and G in unincorporated Orange County east of Apopka. The drainfield consists of perforated plastic pipe in a gravel bed. The gravel bed surrounding the drainfield lies beneath almost the entire front yard of the home and is quite thick, making it difficult to select sampling locations. Three shallow lysimeters were installed at the site, two adjacent to the gravel bed and one at a background location. After sampling these lysimeters four times, it was decided, with concurrence from the homeowner, to discontinue the sampling.

The results from the site indicate moderate influence by fertilizer use in the soil pore water, with the highest TN concentration found at the background location. There was no indication from the data that any of the lysimeters at this site were receiving water from the drainfield.

Site I

Site I is in western Seminole County northwest of Longwood. The drainfield consists of infiltration chambers in rows installed as a repair in 1999 (**Table 1**). The entire drainfield lies beneath a lawn consisting of St. Augustine grass. A network of three shallow lysimeters was installed between drainfield rows, and one background shallow lysimeter was installed at a remote location in the front yard. The septic system served one to two residents during the study period. The home is served by a well, and the yard has an irrigation system. Lawn and yard maintenance are contracted. **Figure 28** shows the layout of the septic system and monitoring stations. **Figure 29** shows the results for TN, chloride, and TP for all lysimeters and for the STE.

The TN and chloride results indicate that lysimeters IL1S and IL3S are located at points in the drainfield that at times received infiltrating effluent. Lower TN and chloride levels at IL2S indicate that this area of the drainfield did not receive infiltrating water from the septic tank. The fluctuation in results and lack of available soil moisture to collect samples (as evidenced by missing data in the plots from some locations, in **Figure 29**) may be caused by low water use and consequently low flow to the drainfield. Low water use appears to be supported by the higher-than-typical average concentrations of TN (140 mg/L) and chloride (87 mg/L) observed in the STE. The septic tank at Site I had the highest concentrations of all study sites, most likely because of less dilution from water use in the home. Dry soil conditions could also be related to infrequent irrigation. The results from L4S, the background lysimeter installed in a lawn area, were sparse because of a lack of moisture in the soil, but the TN data showed little influence from lawn fertilization at that location.

Although far from ideal, the TN data from lysimeter IL3S provide the best information for evaluating nitrogen attenuation at this site. The average TN concentration for the study period in samples from IL3S (21 mg/L), compared with the STE concentration, is 85 % lower. Based on the TN/chloride ratios, dilution by infiltrating rainwater and irrigation water would account for approximately 40 % of the decrease, leaving about 60 % caused by denitrification and other attenuation factors.

TP results for Site I show that most lysimeter concentrations were significantly lower than the average STE value of 16 mg/L, indicating low leaching of phosphorus at those locations. However, average concentrations for IL2S and IL3S (1.7 and 1.1 mg/L, respectively) are significantly higher than background (< 0.1 mg/L at IL4S).

Figure 28. Septic system and monitoring devices at Site I

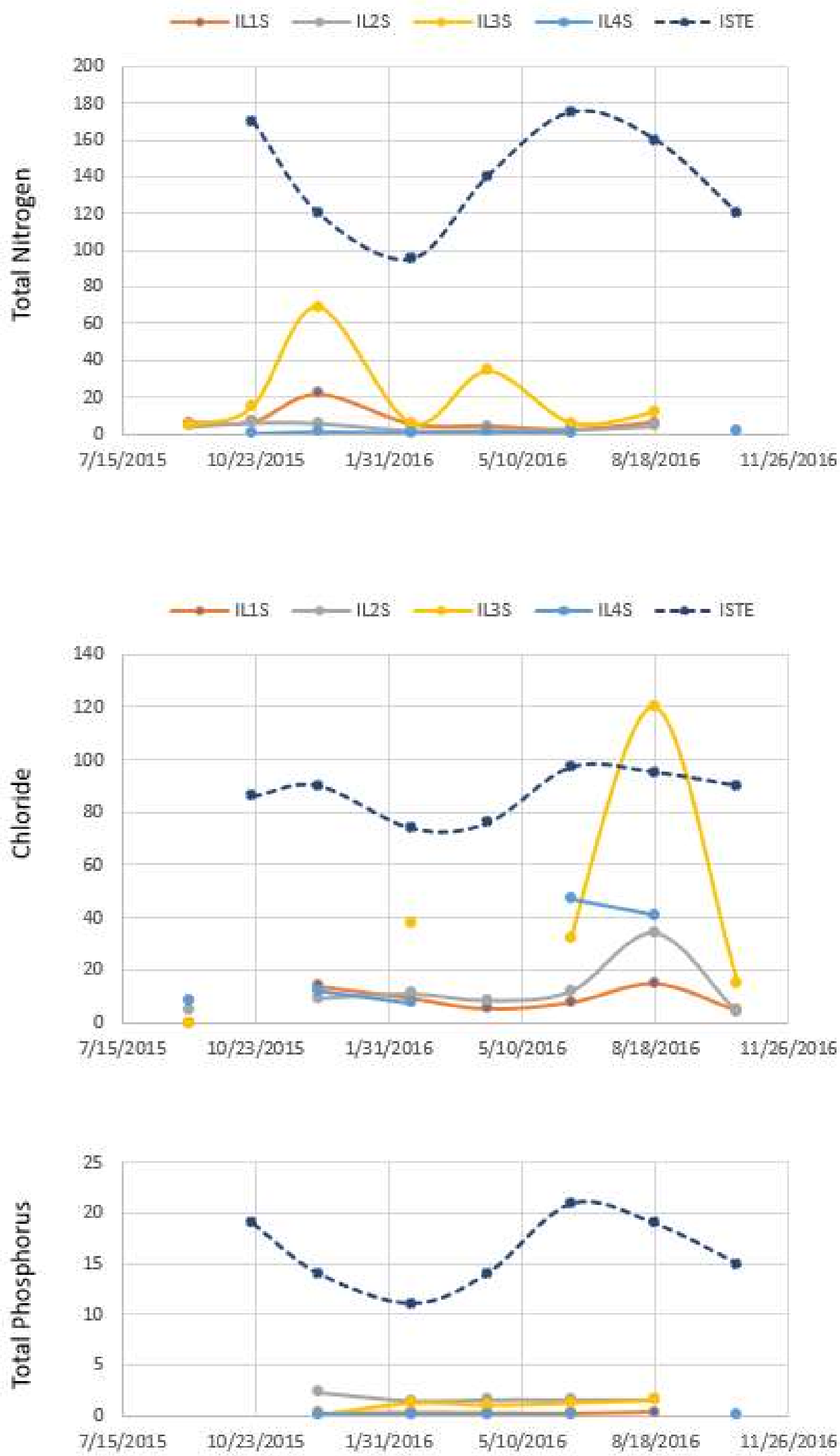

Figure 29. Lysimeter and STE monitoring results for TN, chloride, and TP at Site I (in mg/L)

Site J

Site J is in western Seminole County northwest of Longwood and adjacent to Lake Brantley. The residence has a mounded drainfield because of poor soil drainage and shallow seasonal high-water table conditions. The drainfield consists of a constructed mound with perforated drain pipe in a gravel bed. It receives effluent pumped from the septic tank located near the house. The septic system and drainfield were constructed when the home was built in 2000 (**Table 1**). The drainfield mound is situated in an open area and is covered by low-growing native grasses. A network of three shallow lysimeters was installed along the edges of the mound, and one background shallow lysimeter was installed at a remote location in the front yard. Lysimeter depth was limited by the shallow water table. A shallow monitoring well was also installed adjacent to the mound. The septic system serves two residents. The home is served by a well, and the yard has an irrigation system that uses lake water. Yard maintenance is contracted. **Figure 30** shows the layout of the septic system and monitoring stations. **Figure 31** shows the results for TN, chloride, and TP for all lysimeters and for the STE.

The TN and chloride results from the lysimeters at the edge of the drainfield mound (JL1S, JL2S, and JL3) showed that they did not consistently intercept infiltrating water from the drainfield, most likely because the thick gravel bed prevented their installation close enough to the active part of the drainfield. JL1S provided results that are difficult to interpret. One explanation is that they may represent intermittent drainfield influence that occurred during a period of higher water use in the home that increased the volume of water going to the drainfield.

However, the shallow monitoring well (JMW1), installed later in the study and intercepting shallow groundwater at an interval only a few feet lower than the lysimeter depth, provided results more representative of the infiltrating water when compared to the STE concentrations. TN results from the background lysimeter (JL4S) showed little to no influence from lawn fertilization at that location. The TN data from JMW1 from the August and October 2016 sampling events provided the best information for evaluating nitrogen attenuation. The average TN concentration for the samples from JMW1 (61 mg/L), compared with the STE average concentration, was 35 % lower. Chloride levels in JMW1 were higher than the STE average concentration but nearly the same as the August 2016 sampling, suggesting that reductions in nitrogen were not caused by dilution but by denitrification and other factors. Chloride concentrations in the lysimeters, including background, increased during the study period. The reason for this increase is not known.

TP results for Site J show that all the lysimeter concentrations were significantly lower than the average STE value of 9.3 mg/L, indicating low leaching of phosphorus at those locations. However, the average TP concentration for JMW1 (2.0 mg/L) was significantly higher than background (0.03 mg/L at JL4S).

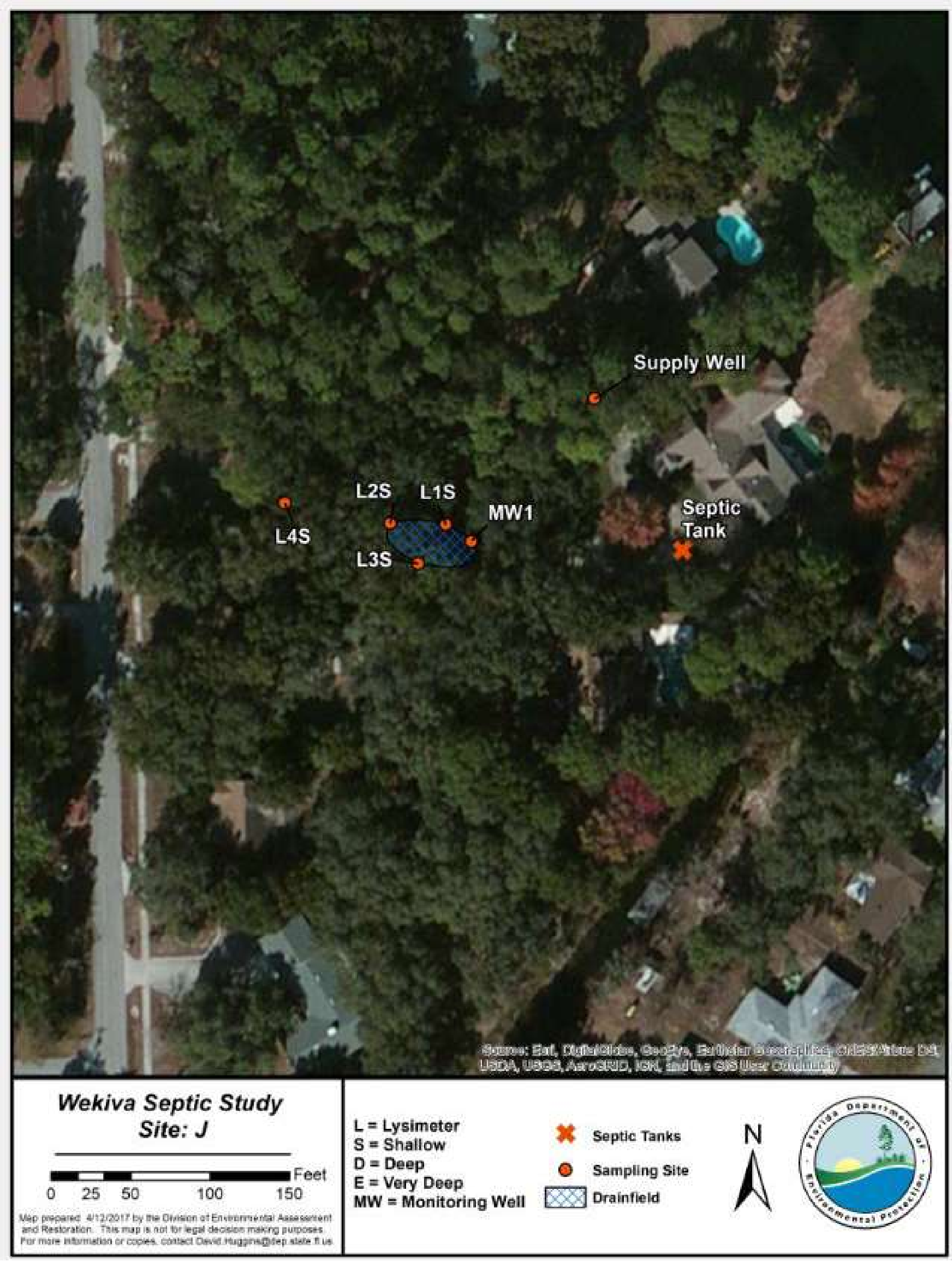

Figure 30. Septic system and monitoring devices at Site J

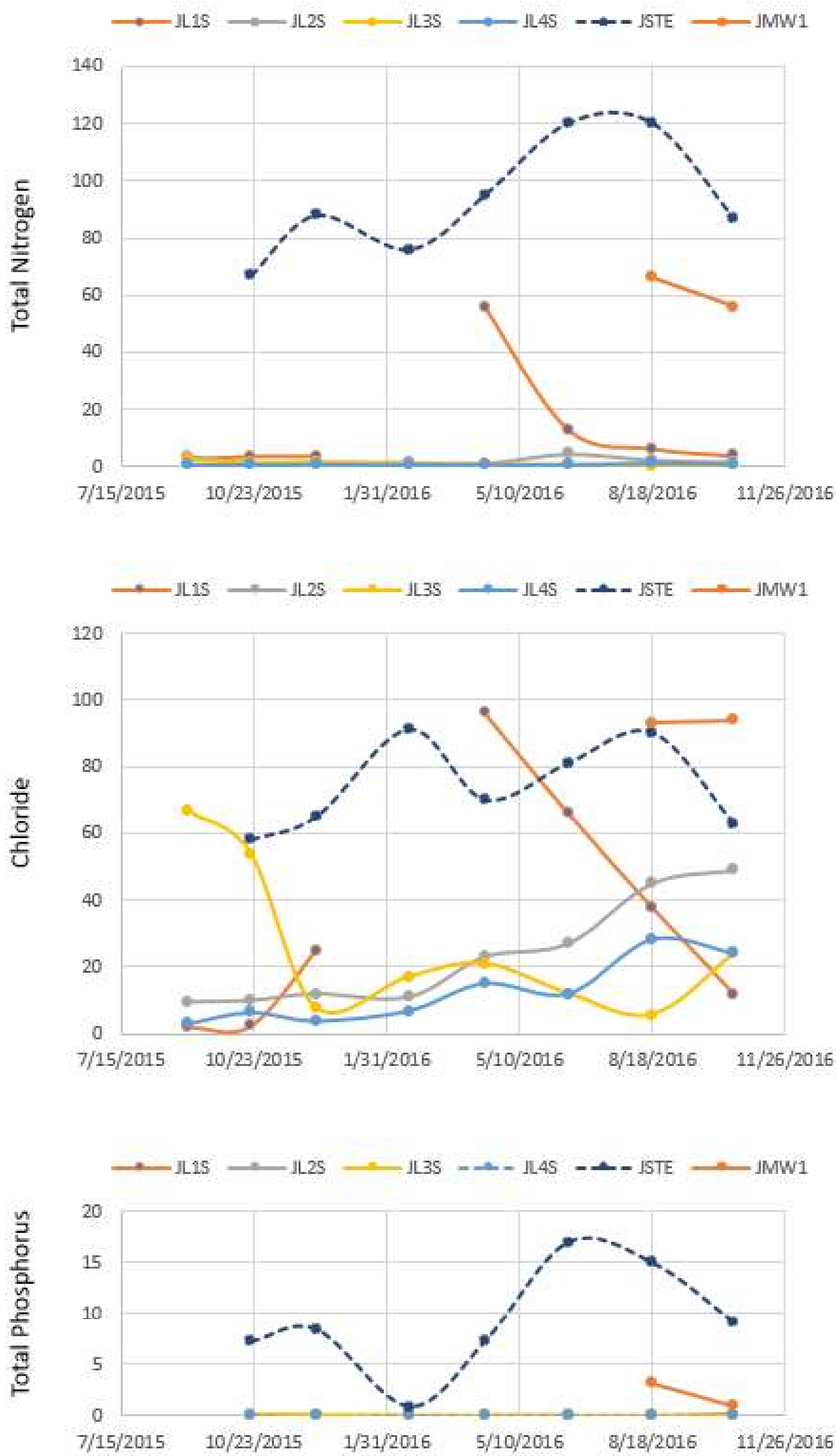

Figure 31. Lysimeter, monitoring well and STE monitoring results for TN, chloride, and TP at Site J (in mg/L)

Site K

Site K is in a residential neighborhood in unincorporated Orange County east of Apopka. The drainfield consists of perforated plastic pipe in a gravel bed that was installed in 1996 (**Table 1**). It is entirely overlain by a mulched area of bedded plants (azaleas and giant liriope). Four shallow lysimeters were installed at the edge of the gravel bed, and one background shallow lysimeter was installed at a remote location in the front yard. A monitoring well was installed into a shallow zone of perched water. The septic system serves two residents. Water to the residence comes from public supply. The homeowners maintain their own yard and lawn, and there is an irrigation system. **Figure 32** shows the layout of the septic system and monitoring stations. **Figure 33** shows the results for TN, chloride, and TP for all lysimeters and for the STE.

The TN and chloride results from two of the lysimeters at the edge of the gravel bed (KL1S and KL4S) appear to represent infiltrating water from the drainfield. However, data from KL4S were influenced by fertilizer application during part of the study period. Lysimeter KL1S is situated in an open area less likely to receive fertilizer applied to the plants. Data from lysimeters KL2S and KL3S appear to reflect less influence. The background lysimeter, installed at a location outside the planted area, showed little evidence of fertilizer influence (TN average of 3.6 mg/L and chloride average of 1.8 mg/L).

Due to dry soil conditions, adequate sample volumes were difficult to obtain from KL5S and several other locations. However, a perched water table was encountered several feet below the lysimeter depth. During the initial soil boring at this site, a clay layer was encountered at a depth of approximately 7 ft. Saturated sand above the clay layer indicated a perched water table. Later in the study, a shallow monitoring well (JMW1) was installed in the perched zone about 20 ft downhill from the edge of the drainfield. JMW1 had sufficient water to be sampled on one occasion but was dry on other sampling dates.

STE samples were not collected at Site K because of the difficulty in accessing a sampling port. Therefore, the average of STE concentrations from the other sites was used for comparison purposes. The average TN and chloride concentrations for KL1S for the study period were 49 and 53 mg/L, respectively. Compared with the average STE concentrations for TN and chloride (85 and 54 mg/L, respectively), there was a 44 % decrease in TN. The minimal decrease in chloride suggests that no dilution contributed to this reduction and that the nitrogen reduction was caused by denitrification and other factors. The application of fertilizer to the plant beds in early 2016 strongly influenced the results from KL4S through summer 2016 (with TN and chloride concentrations as high as 192 and 260 mg/L, respectively, in August 2016). However, this influence had completely diminished by October 2016 based on TN and chloride data. TN and chloride results for JMW1 from the October 2016 sampling episode showed some influence by the septic system and/or fertilizer use based on the detected concentration of TN (4.3 mg/L) and chloride (20 mg/L).

TP concentrations at several lysimeter locations appeared to be influenced by infiltrating effluent and/or fertilizer contributions, particularly those in KL4S and KL1S (average concentrations of

5.8 and 2.4 mg/L, respectively). No phosphorus samples were collected from background lysimeter (KL5S) because of low sample volume, but the average concentration for KL2S was 0.36 mg/L and likely reflected unaffected background pore water chemistry.

Figure 32. Septic system and monitoring devices at Site K

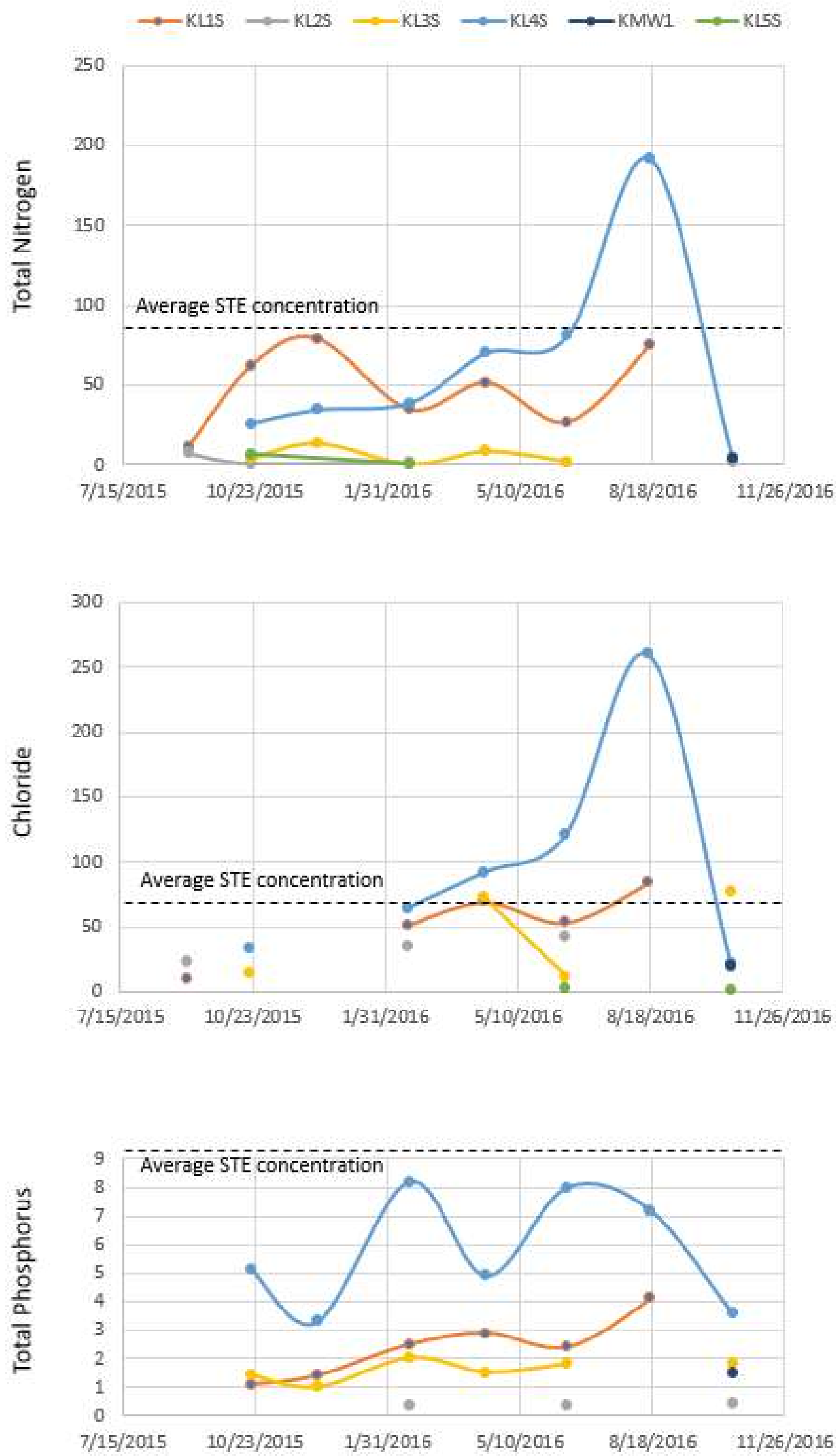

Figure 33. Lysimeter, monitoring well, and STE monitoring results for TN, chloride, and TP at Site K (in mg/L)

Nutrients in Groundwater

Groundwater data collected coincidentally with this study included the results of routine groundwater monitoring by Orange County, data from DEP sampling of potable wells at residences involved in the study, and data from recently installed wells in the study area by Orange County and DEP. **Table 8** contains information about the wells that were monitored, and **Figure 34** shows their locations. Historical groundwater monitoring results from this area are also discussed in this section.

In 1999, the SJRWMD and the USGS collected groundwater samples from 50 wells as part of a study to evaluate sources of nitrogen in the Wekiwa Springs groundwater contributing area. Of those, samples from 22 wells (44 % of the wells sampled) contained elevated concentrations of nitrate-nitrogen above the background concentration for the area (0.2 mg/L). The higher concentrations were found in wells west of Lake Apopka in an agricultural area.[14] Wells sampled near the septic tank study sites had nitrate concentrations ranging from 0.01 to 2.0 mg/L.

The Wekiwa-Rock Springs springshed includes part of the historical Central Florida ridge citrus growing area that had an associated groundwater contamination issue from fertilizer use. From the late 1980s through the early 2000s, there were many exceedances of the drinking water standard for nitrates in private wells near citrus groves or former grove locations. Between 1988 and 2012, about 2,300 wells in the Wekiwa-Rock springshed were sampled, according to DEP's database of wells sampled by the health department, and samples from 146 wells (about 6 % of the wells sampled) exceeded the 10 mg/L drinking water standard for nitrate. About 1,000 wells sampled (43%) had nitrate detections greater than 0.2 mg/L. Today, there are only about 1,800 acres of citrus in the springshed, mostly in the southern part, and other activities are believed to be more significant existing sources of nitrate in the springs.

Residential fertilizer was believed to be one of those sources. Thirteen of the monitoring wells in Orange County's groundwater monitoring network were originally installed as part of a study to evaluate the influence of urban fertilizer on shallow groundwater quality. That study, conducted by MACTEC for DEP and the SJRWMD in the Apopka-Altamonte Springs areas, included the installation and sampling of a network of 24 shallow wells in residential subdivisions mostly on central sewer and 2 wells in natural areas. These wells were installed in the surficial aquifer to depths ranging from 10 to 48 ft and were sampled quarterly for 1 year. Nitrate concentrations in these wells averaged 2.4 mg/L during the study, with the highest concentrations detected in samples from a well adjacent to a golf course.[15]

[14] Toth, D.J., and C. Fortich. 2002. *Nitrate concentrations in the Wekiva Groundwater Basin with emphasis on Wekiwa Springs.* St. Johns River Water Management District Technical Publication SJ2002-2.

[15] MACTEC. March 2010. *Final report, Wekiva River Basin nitrate sourcing study.* Prepared for the SJRWMD and DEP. MACTEC Project No. 6063090160A.

Table 8. Information on wells used for water quality sampling

NA = Not available; S = Surficial aquifer; I = Intermediate aquifer; U = Upper Floridan aquifer

Site/Station	Location	Surrounding Land Use	Well Depth (ft)/ Aquifer
Site J (JMW1)	Longwood	Medium-density residential/septic tank use area	15/S
Site K (KMW1)	Apopka area	Medium-density residential/septic tank use area	9/S
Site A (Supply Well)	Sorrento	Medium-density residential/septic tank use area	136/U
Site I (Supply Well)	Longwood	Medium-density residential/septic tank use area	180/U
Site J (Supply Well)	Longwood	Medium-density residential/septic tank use area	NA/U
Peeler	Apopka area	Medium-density residential/septic tank use area	NA/U
PMW1	Apopka area	Medium-density residential/septic tank use area	39/S
BW-02	Wekiwa Spring State Park	Conservation land	12/S
MW-01	Apopka	Medium-density residential/sewer service	14/S
MW-02	Apopka	High-density residential/sewer service	30/S
MW-03	Apopka area	Medium-density residential and golf course/ septic tank use area	45/S
MW-04	Apopka area	Medium-density residential and golf course/ sewer service	48/S
MW-06	Apopka area	Medium-density residential and commercial/ septic tank use area	20/S
MW-07	Apopka area	Medium-density residential and commercial/ septic tank use area	20/S
MW-11	Apopka area	Medium-density residential/ sewer service	35/S
MW-14	Apopka	Medium-density residential/sewer service	15/S
MW-15	Apopka	Medium-density residential/sewer service	32/S
MW-17	Apopka	High-density residential/sewer service	15/S
MW-20	Apopka	Medium-density residential/sewer service	20/S
MW-22	Apopka	Medium-density residential/sewer service	27/S
Fortune Lane (U)	Unincorporated Orange County	Medium-density residential/septic tank use area adjacent to nurseries	110/F
Palm Beach (S)	Apopka area	Medium-density residential/septic tank use area	34/S
Palm Beach (D)	Apopka area	Medium-density residential/septic tank use area	210/U
MW-A(I)	Apopka area	Medium-density residential and golf course/ sewer service	75/I
MW-B(S)	Apopka area	Medium-density residential/septic tank use area	40/S
MW-B(U)	Apopka area	Medium-density residential/septic tank use area	135/U
MW-C(U)	Apopka area	Medium-density residential/sewer service	175/U
MW-C(I)	Apopka area	Medium-density residential/sewer service	90/I
MW-D(U)	Apopka area	Pasture and silviculture	180/U
MW-D(S)	Apopka	Pasture and silviculture	40/S
MW-E(U)	Apopka area	Medium-density residential/septic tank use area	85/U

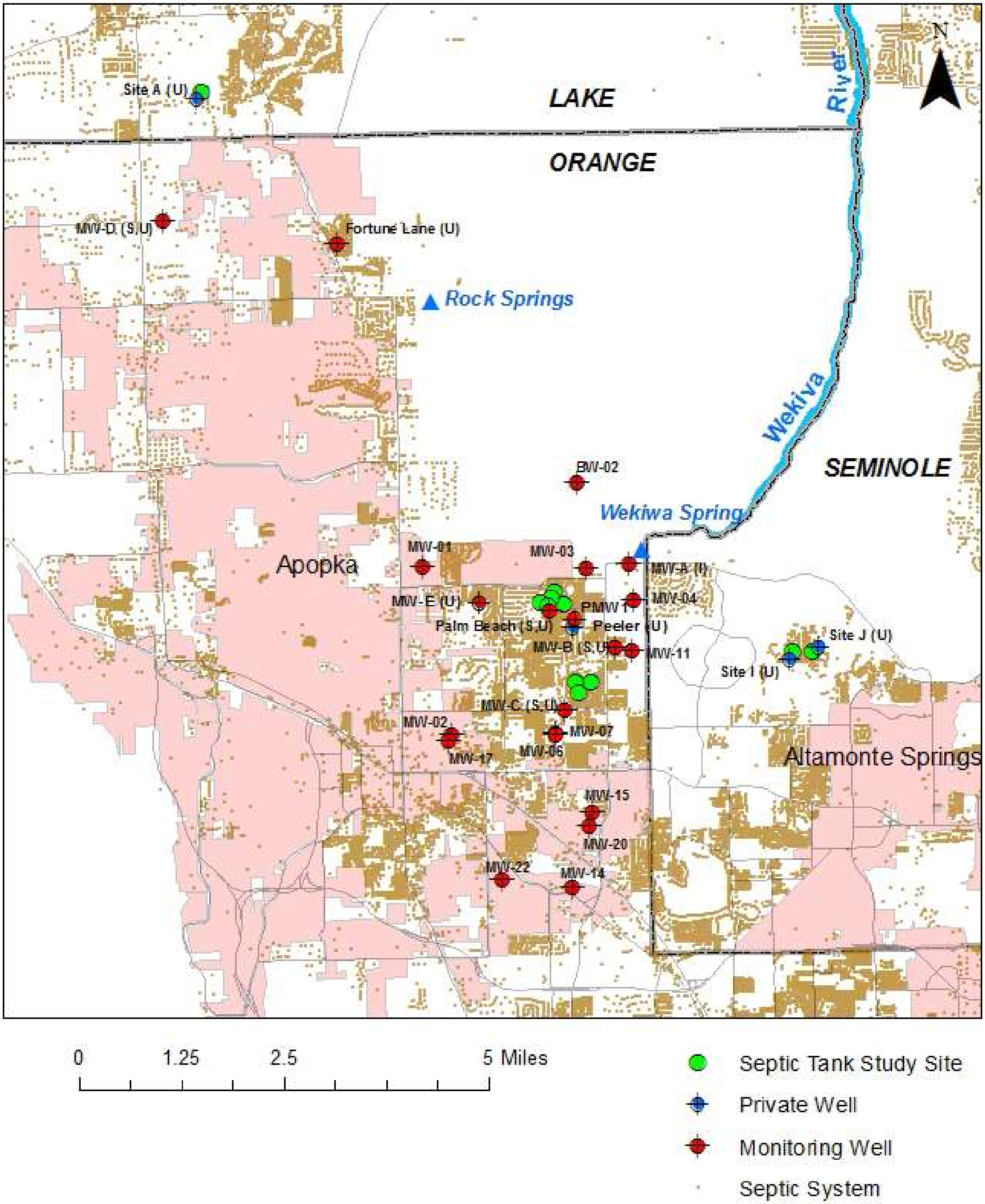

Figure 34. Groundwater monitoring stations in study area

Table 9. Groundwater quality summary for nitrogen and phosphorus

Notes: Reported concentrations are in mg/L. ND = Not detected. Blank field = No sample collected. During this period MW-15 was dry.

Site	Number of Samples	Aquifer	TN Average	Nitrate Average
Site A	1	Floridan	1.8	1.8
Site I	1	Floridan	0.09	ND
Site J	1	Floridan	0.59	0.51
Peeler	1	Floridan	0.1	0.02
PMW1	2	Surficial	5.0	3.9
BW-02	11	Surficial	0.57	0.01
MW-01	11	Surficial	2.6	0.03
MW-02	10	Surficial	1.7	1.6
MW-03	1	Surficial	0.22	0.04
MW-04	5	Surficial	13	13
MW-06	11	Surficial	1.2	1.0
MW-07	11	Surficial	2.0	1.6
MW-11	11	Surficial	3.0	2.7
MW-14	10	Surficial	0.18	0.01
MW-15	0	Surficial		
MW-17	10	Surficial	0.51	0.23
MW-20	11	Surficial	3.9	3.7
MW-22	11	Surficial	3.0	2.9
MW-A(I)	1	Intermediate	ND	ND
MW-B(S)	1	Surficial	2.7	0.90
MW-B(U)	1	Floridan	1.3	1.1
MW-C(I)	1	Intermediate	ND	ND
MW-C(U)	1	Floridan	0.13	0.13
MW-D(S)	1	Surficial	2.1	2.1
MW-D(U)	1	Floridan	ND	ND
MW-E(U)	1	Floridan	ND	ND
Fortune Lane (U)	2	Floridan	ND	ND
Palm Beach (U)	2	Floridan	0.19	ND
Palm Beach (S)	2	Surficial	1.5	1.5

In recent years, the wells in the former MACTEC network monitored by Orange County (MW-1 through MW-22; **Table 9**) had a similar average concentration of nitrate (2.4 mg/L). Based on the land use, the main nitrogen source in the surficial aquifer at the sites where detections occurred is expected to be residential fertilizer, except in the single well adjacent to a golf course, where detections could be related to turf fertilization and possibly also residential fertilizer use.

This report also includes recent data from newer monitoring wells installed by DEP (Fortune Lane [U], Palm Beach [S] and [U] in **Figure 34**) and Orange County (MW-A[I], MW-B[S] and

[U]; MW-C [I] and [U], MW-D[U], and MW-E[U] in **Figure 34**). These wells were installed in clusters to monitor water quality in the surficial (S) and intermediate (I) aquifers, where present, and the Upper Floridan (U) aquifer. The two DEP wells were used in the SF_6 tracer study described in an earlier section. Both DEP well sites are surrounded by residential development served by septic systems, and one (Fortune Lane [U]) is near several commercial plant nurseries.

The newer Orange County wells were installed at locations that provide information from multiple depths and various land uses and are generally close to the septic tank study sites. The dataset also includes a DEP monitoring well (PMW1) installed in the surficial aquifer at a residential site in the study area that is part of an alternative drainfield monitoring study. Groundwater data reported here also include results from residential supply wells at three of the study sites and the drainfield monitoring site, which were all installed in the UFA (Sites A, I, J, and Peeler) (**Figure 34**). Two shallow wells installed as part of the septic tank study (JMW1 and KMW1) were discussed in a previous section of the report and are not included in the water quality results table.

Orange County and DEP have 16 wells with data from the surficial aquifer. Eight are in residential areas served by sewer, 6 are in residential areas served by OSTDS, and 2 are in conservation areas or rural settings. Nitrate concentrations in the samples from residential areas served by sewer range from 0.01 to 13 mg/L, with a median concentration of 2.2 mg/L. Excluding the well adjacent to the golf course, the median was 1.6 mg/L. Samples from residential areas served by septic systems ranged from 0.04 to 3.9 mg/L, with a median concentration of 1.2 mg/L. Nitrate concentrations in samples from the 2 wells in rural/conservation area settings were very low to below detection limits. TN concentrations were similar in many samples but slightly higher in a few samples that contained other forms of nitrogen.

There are 10 wells with data from the UFA. All but 2 are in residential areas served by septic systems. Nitrate concentrations in samples from these wells ranged from below detection limits to 1.8 mg/L. The highest concentration was from study Site A, which is in a residential area surrounded by existing and former agricultural land. For comparison purposes, the 2016 average nitrate concentrations in Wekiwa and Rock Springs (discharging water from the UFA) were 1.0 and 1.2 mg/L, respectively.[16]

There are two wells with data from the intermediate confining unit/aquifer (Orange County's MW-A(I) and MW-C(I), both located in residential areas served by sewer. Neither had detectable concentrations of nitrate or TN.

[16] St. Johns River Water Management District Environmental Data Retrieval Tool, available at http://webapub.sjrwmd.com/agws10/edqt/.

Section 4. Nitrogen Attenuation Modeling

Results from the effluent and soil pore water sampling conducted in this study were used to help calibrate a model with significant potential as a restoration planning tool in areas where loadings from septic systems are a concern. The Soil Treatment Unit Model for Florida (STUMOD-FL) incorporates soil type, water table depth, and drainfield information to estimate nitrogen attenuation in the drainfield and vadose zone. The original model, developed by Colorado School of Mines researchers (STUMOD), was customized for Florida-specific conditions as part of the FDOH Florida Onsite Nitrogen Reduction Strategies (FOSNRS) Study.[17]

STUMOD-FL is a spreadsheet tool with an interface that allows the user to evaluate the influence of a range of septic systems operating conditions and site conditions specific to Florida (**Figure 35**). The model provides populated default values to assist users with limited site knowledge, but also allows the user to modify input parameters when calibration data are available. Model outputs provide insight into the soil treatment, groundwater fate and transport, and provide quantitative estimates of nitrogen removal as affected by a range of conditions. The model and its customization for Florida soils is described in greater detail in the report to FDOH.[18] STUMOD-FL can be used as a screening tool to evaluate the transport and fate of nitrogen as it moves from a septic tank drainfield through the unsaturated zone to the water table. The model can account for several nitrogen transformation and attenuation processes, including ammonium sorption, nitrification, and denitrification.

DEP uses the Nitrogen Source Inventory and Loading Tool (NSILT) to estimate spatial nitrogen inputs to the land surface from various sources in spring areas. This tool applies literature-based nitrogen (N) attenuation factors to the input from each source to estimate nitrogen loading to groundwater. The literature-based attenuation factor typically used for septic systems is 50 %. STUMOD-FL, calibrated using data from this study and a previous study in the Wekiva Basin, was used to help refine the attenuation factor for the nitrogen inventory developed for the Wekiwa-Rock Springs groundwater contributing area. With STUMOD-FL, it was possible to account for spatial variations in soil drainage properties, water table depth, and other factors that could affect nitrogen transport to groundwater from septic tank drainfields.

[17] Hazen and Sawyer and Colorado School of Mines. June 2014. *Florida onsite sewage nitrogen reduction strategies study. Task D.10. White paper, Validate/refine complex soil model.* Prepared for FDOH Onsite Sewage Programs, FDOH Contract CORCL.

[18] http://www.floridahealth.gov/environmental-health/onsite-sewage/research/d10.pdf

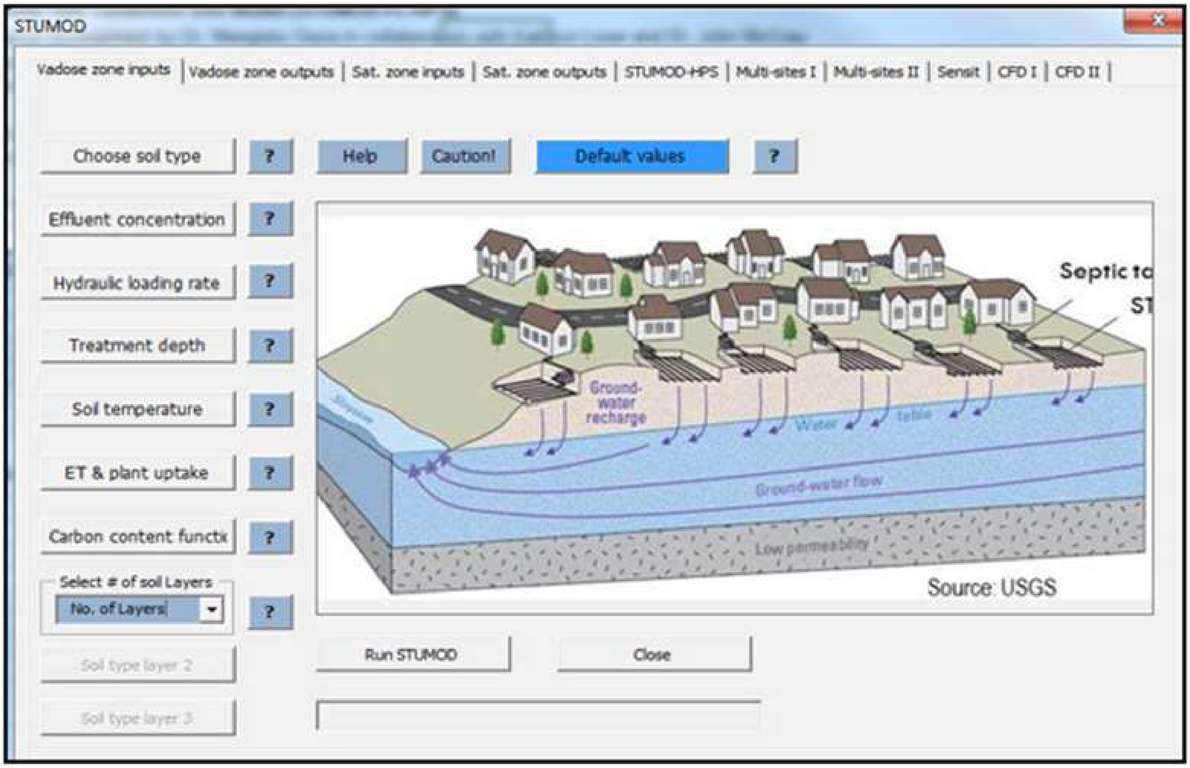

Figure 35. User interface showing parameters used in STUMOD-FL to estimate nitrogen fate and transport from OSTDS

STUMOD-FL Calibrations

It is not possible to use STUMOD-FL for modeling each of the individual septic systems in the springshed. However, if the default parameters in the tool are used, or need to be adjusted for a specified set of conditions, it could be useful for providing a first-level screening analysis to evaluate the potential nitrogen loading from smaller areas in the springshed. To evaluate the influence of STUMOD-FL input variables and its ability to accurately estimate nitrogen concentrations in the subsurface and nitrogen loading to ground water from septic systems in the Wekiwa-Rock Springshed, STUMOD-FL model results were compared with measured nitrogen concentration data in pore water and shallow ground water collected from this study and a previous study in the same area.

Figures 36 through **40** show the results of the STUMOD-FL comparisons and calibrations for several of the drainfield study sites. **Table 10** lists inputs and modeled scenarios that seem to provide the best representation based on site data. The monitoring stations used in evaluating modeled results have nitrogen information for both STE and shallow lysimeters, or in one case a monitoring well. At each site, several shallow lysimeters were installed at a depth of approximately 2 ft (61 centimeters [cm]) below the drainfield. Lysimeter data from 5 of the 11 sites were selected for STUMOD-FL runs. The monitoring stations selected for the analysis were appropriately located to receive STE. From them, average values used in the model runs were taken from periods when fertilizer influence on the concentrations in the lysimeter or well appeared to be low or were at sites where fertilizer was not used near the drainfield. Since STUMOD-FL cannot incorporate dilution, chloride concentrations in the effluent and station samples were used to estimate percent reduction caused by dilution, and that percentage was subtracted from the TN concentration in the pore water used for modeling.

STUMOD-FL did reasonably well in predicting the TN concentration in soil pore water samples collected from lysimeters at specified depths below a septic tank drainfield at 4 of the sites (A, B, E, and J). The TN concentrations in these samples were adjusted for dilution and possible denitrification. However, with TN data from only 1 depth interval over a relatively short period to determine the efficacy of the model, there are numerous plausible modeling scenarios that would generate a concentration profile to intersect the measured TN concentration.

For example, at Site E-L1S (TN of STE=56.7 mg/L; lysimeter depth is 2 ft [61 cm] beneath the bottom of the drainfield; measured TN concentration of 34.8 mg/L from the lysimeter) can be simulated with a model that uses a sandy clay loam soil with STUMOD-FL default parameters, or by using model runs with sandy soils with ranging permeabilities and a higher denitrification rate (V) than the model default value (Vmax =5.0 vs. STUMOD-FL default value Vmax=3.32). Using the higher denitrification rate resulted in closer matches between the measured TN concentration in lysimeters and the STUMOD-simulated TN concentration.

Additional plausible models could generate output that would match the TN concentration in the lysimeter by tweaking other model input parameters, such as the hydraulic loading rate, soil temperature, vegetative uptake, or carbon content. Measured TN data at more depths at these sites would be needed to help constrain the various parameters to reduce the number of plausible models. At Site I (IL3S), the only model that could simulate the high STE TN concentration (140 mg/L) and the low TN concentration (21 mg/L) in the shallow lysimeter would need to have a clay loam soil (low saturated hydraulic conductivity, or Ksat) and an unrealistically high denitrification rate. At Site I, the nitrogen concentrations detected in the lysimeter beneath the drainfield are likely being significantly diluted by rainwater, which is a condition STUMOD-FL cannot simulate.

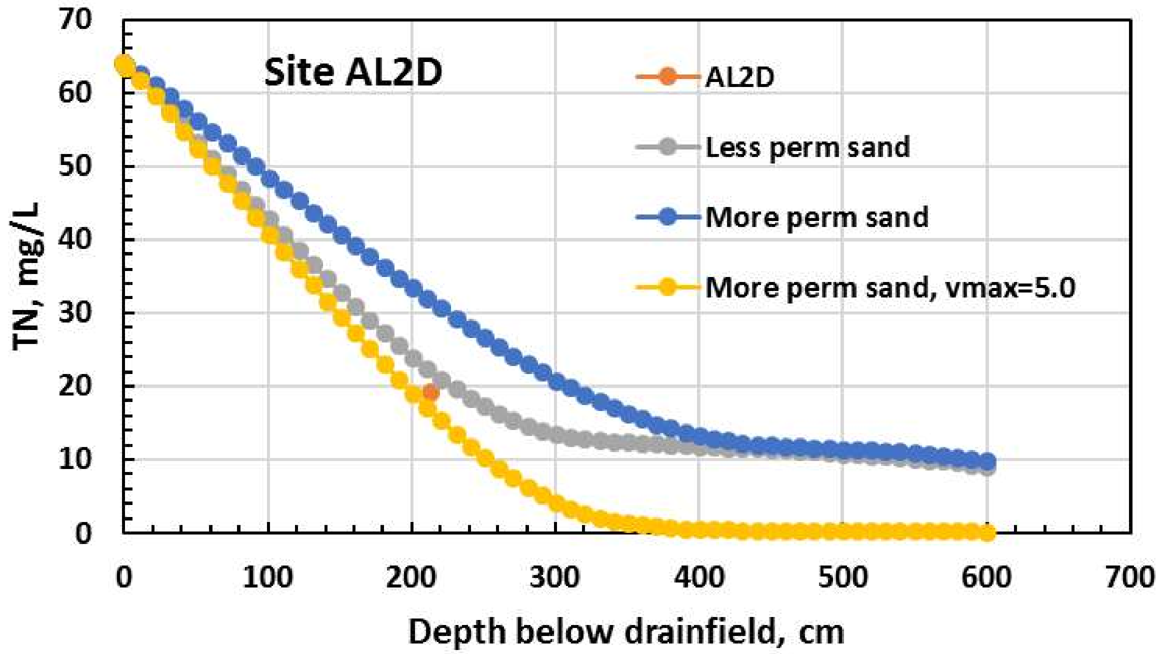

Figure 36. STUMOD-FL simulations of TN attenuation with calibration from deeper lysimeter at Site A

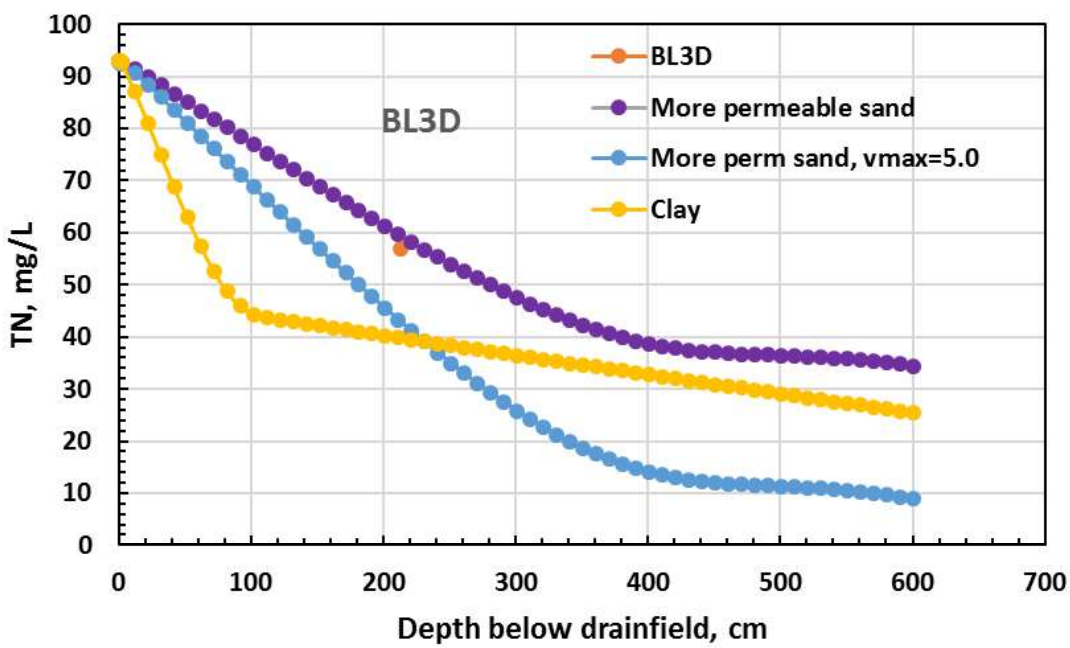

Figure 37. STUMOD-FL simulations of TN attenuation with calibration from deeper lysimeter at Site B

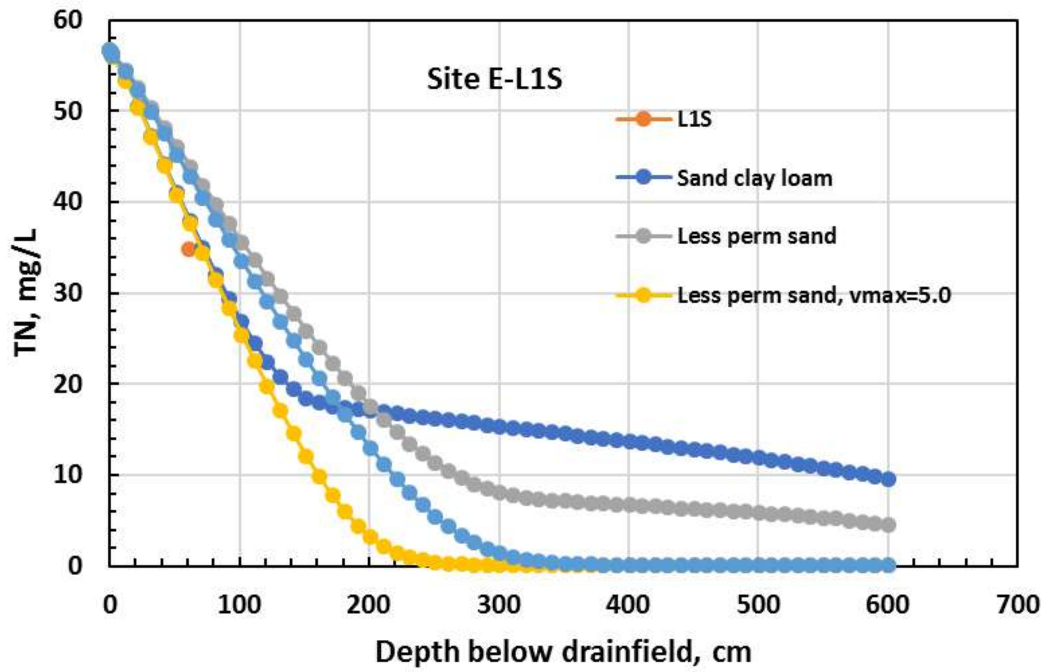

Figure 38. STUMOD-FL simulations of TN attenuation with calibration from shallow lysimeter at Site E

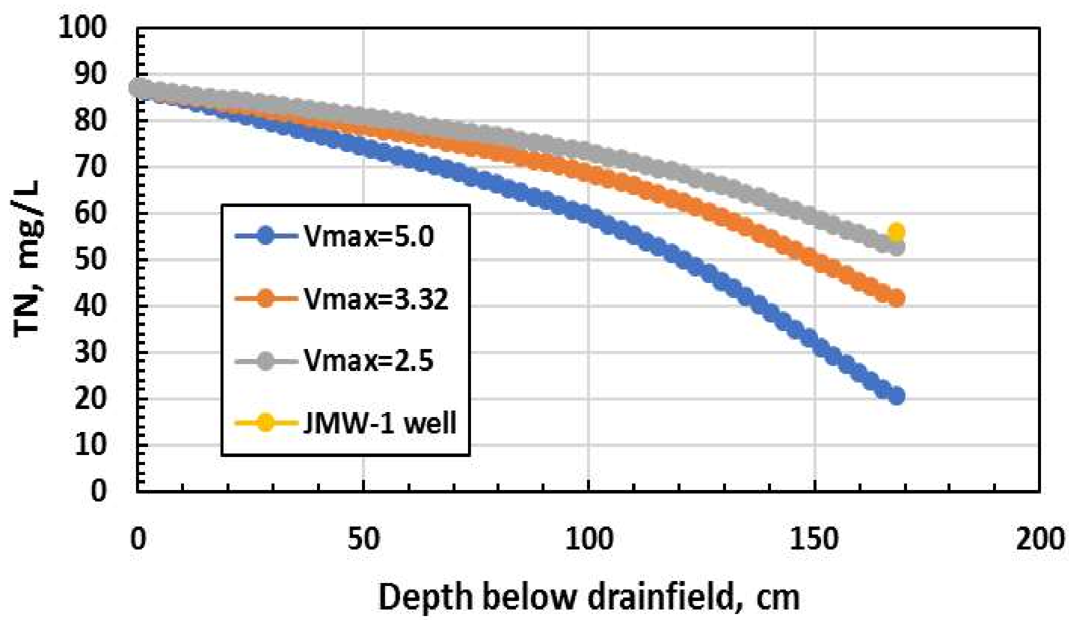

Figure 39. STUMOD-FL simulations of TN attenuation with calibration from shallow monitoring well at Site J

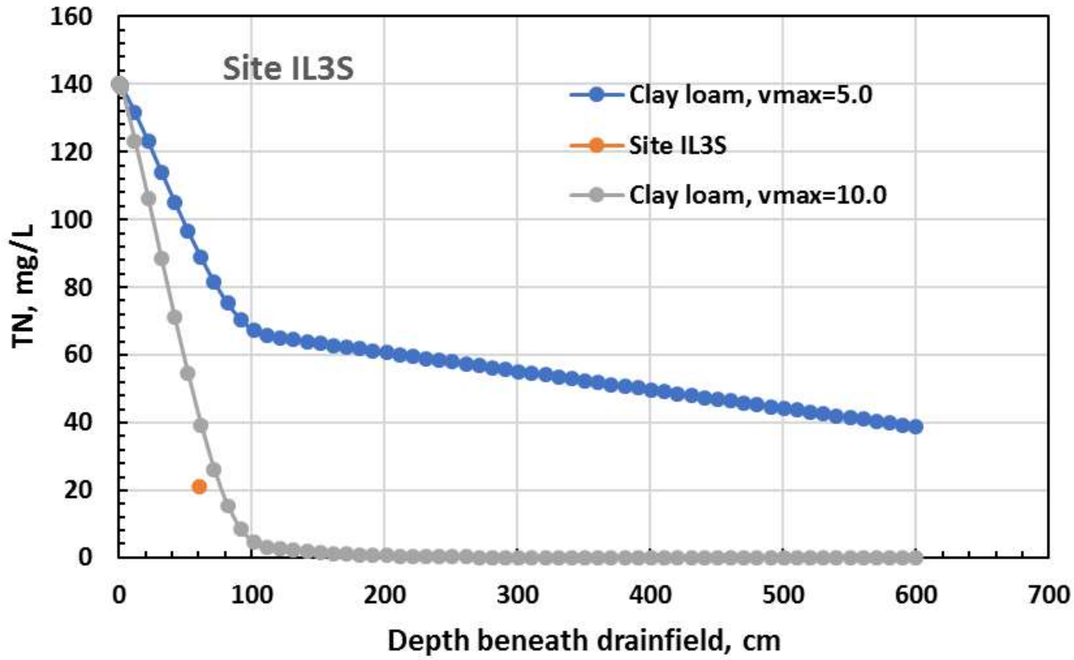

Figure 40. STUMOD-FL simulations of TN attenuation with calibration from shallow lysimeter at Site I

Table 10. STUMOD-FL calibration values and modeled TN results for selected drainfield study sites

Note: Water table depth for Sites A, B, E, and I was assumed to be 600 cm (~20 ft) below the land surface.

Site	Station	Depth (cm) Below Drainfield/Matrix	Measured TN Concentration (mg/L)	STUMOD-FL Modeled TN Result (mg/L)	Soil Texture and Permeability/ Denitrification Factor (Vmax)
Site A	STE	NA/STE	64		
Site A	A/AL2D	213/pore water	19.2	17.0–22.3	More permeable sand, Vmax=5.0
Site B	STE	NA/STE	93		
Site B	B/BL3D	213/pore water	57.4	59.7	More permeable sand, Vmax=3.32
Site E	STE	NA/STE	56.7		
Site E	E/EL1S	61/pore water	34.8	34.5	Less permeable sand, Vmax=5.0; Sandy clay loam
Site J	STE	NA/STE	87		
Site J	J/JMW1	167/groundwater	56	52.7	More permeable sand, Vmax=2.5
Site I	STE	NA/STE	140		
Site I	IL3S	61/pore water	21.1	21.0	Clay loam; Vmax=10

STE does not migrate evenly in drainfields and seeps into underlying soil preferentially because of the unlevel conditions of the header pipe. Lysimeters are often not effective at measuring water quality in effluent as it migrates downward, making it difficult to compare modeled results with measured nitrate concentrations in pore water samples. Furthermore, the considerable variability of nitrogen concentrations in STE among sites would require running STUMOD-FL for a range of effluent concentrations or using a average or median N concentration representative of all septic tank systems in an area.

Data were available for STUMOD-FL calibration from a previous septic tank study for a residential site in Orange County (Longhill Drive site, Apopka, FL). FDOH conducted the study to evaluate nitrogen loading from OSTDS at 3 sites in the Wekiva River Basin.[19] The Orange County site was selected for STUMOD-FL calibrations because of its proximity to the other 11 septic tank sites in the current study. This site is in the same subdivision as several of the study sites (sites E, F, and H).

The surficial soils at this site are the same as those at most of the DEP study sites (Candler fine sand). At greater depth, there was a discontinuous layer of sandy clay close to and beneath the drainfield. The overall lithology was characterized by a surficial layer of fine sand to approximately 6 ft below land surface followed by interfingering layers of clay loam, loamy sands, and fine sands to a depth of approximately 32 ft. An organic-rich clay layer extended to within 1 ft of the observed water table elevation at the time of sampling. Aley et al. (2007) present additional information about groundwater quality from other borings in delineation of the STE plume at this site.

Water samples were collected at the water table and at several depth intervals below the water table beneath the septic tank drainfield at the site (Boring DFB2). During the February 2007 sampling period, the water table was at a depth of approximately 21 ft. **Figure 41** and **Table 11** show the results of the STUMOD-FL calibrations for the site. The average TN concentration of the STE was 69 mg/L (range of 61 to 75 mg/L), and the TN concentration at the water table was 54 mg/L. Assuming all of the detected TN was related to the STE and no additional input from fertilizer, here was a relatively minor amount of denitrification beneath the drainfield. This required the denitrification rate (Vmax) in the model to be lowered to 1.0 (from the default value of 3.32) to match the TN concentration at the water table. TN concentrations below the water table decreased substantially because of dilution.

[19] Aley, A. C., M. Mechling, G.S. Pastrana, and F.B. Fuller. 2007. *Multiple nitrogen loading assessments from onsite waste treatment and disposal systems within the Wekiva River Basin*. Tallassee, FL. Florida Department of Health, Bureau of Environmental Health, Onsite Sewage Programs.

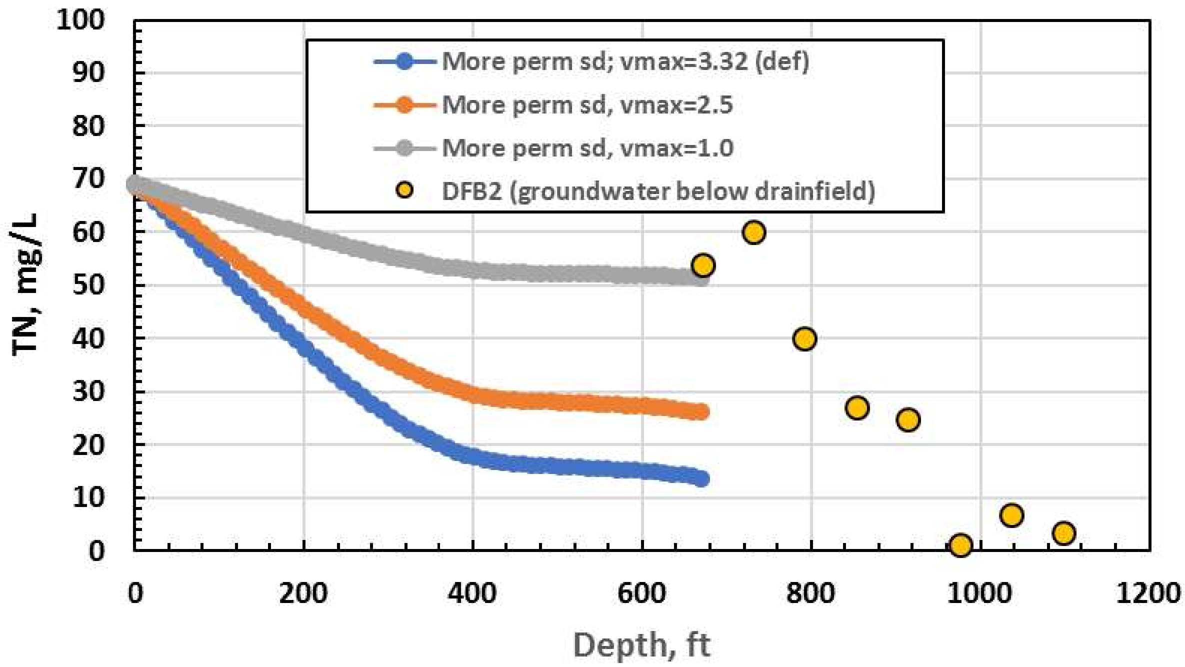

Figure 41. STUMOD-FL simulations of TN concentrations in groundwater at several depths beneath a septic tank drainfield at a selected site in Orange County (Aley et al. 2007)

Table 11. STUMOD-FL modeling results for the Orange County site in the Wekiva Basin using data from the Aley et al. (2007) septic tank study

Site	STE TN Concentration (mg/L)	Measured TN Concentration at Water Table (mg/L)	STUMOD-FL Modeled Concentration at Water Table (mg/L)	Water Table Depth (cm)	Soil Texture and Permeability/ Denitrification Factor Used
Orange County	69	54.0	51.3	670	More permeable sand; Vmax=1.0

Based on the results from these two STUMOD-FL calibration/comparison efforts, using measured TN data for the two studies and given the large variability of TN concentrations in STE and lysimeters among studied sites, several parameters in STUMOD-FL would need to be adjusted for each site individually to match the observed nitrogen concentrations in the unsaturated zone and nitrogen concentrations entering the water table. Obviously, this would be impractical for most areas with large numbers of septic tanks. Therefore, a modified STUMOD-FL method was developed to estimate spatial TN loading to groundwater for large areas such as spring basins and BMAP areas. **Appendix C** provides the methodology and the results of an estimation of nitrogen attenuation from septic systems in the entire Wekiwa-Rock Springs Springshed.

Section 5. Summary of Findings

The study included sampling at 11 residential septic systems in the Wekiva River Basin. These included 10 conventional gravity-fed systems and 1 mounded system. The conventional systems included 5 older pipe-in-gravel-bed systems and 5 newer systems consisting of infiltration chambers. The study included the bimonthly collection of STE samples from 8 sites and soil pore water sampling at the drainfields of all 11 sites. The significant findings of the study are as follows:

- The bimonthly STE sampling showed the following:
  - STE at some of the sites had much TN concentrations that were significantly higher than typical values from the literature, but STE concentrations at others were more typical. The average total nitrogen (TN) concentrations from the 8 sites ranged from 57 to 140 mg/L. The average TN concentration for all sites included in the study was 85 mg/L, which is approximately 20 mg/L higher than the typical TN concentration for septic tanks in the literature. Nitrogen concentrations in STE are related to the input concentrations and the amount of dilution caused by water use in the homes.
  - Septic tank pumping does not appear to influence the nitrogen concentration in the STE. To evaluate the influence of septic tank pumping on subsequent nutrient concentrations in the STE, four of the septic tanks were pumped midway through the study and the other four sites were not pumped out and were used as a control. After pumping, TN concentrations at three of the sites increased and at one site they decreased. TN concentrations also increased at three control sites and decreased at one control sites. Compared with the average TN value for the period prior to pumping, average TN concentrations in the STE for the period after pumping were lower from two of the sites that were pumped and higher from two of the sites that were pumped. Pumping does not appear to have a significant influence on TN concentration. Findings for chloride and TP concentrations were similar, and it appears that dilution may be the biggest influence on nutrient and chloride concentrations in the STE.
- Soil pore water samples were collected bimonthly from suction lysimeters installed adjacent to the drainfields and at background locations. Most samples were collected from 2 ft below the edges of drainfields. The bimonthly lysimeter sampling results showed the following.
  - Detected TN concentrations ranged as high as 254 mg/L, and the average TN concentration for all sites, including background, was 25 mg/L. Nitrate is the primary form of nitrogen in all the lysimeter samples.

- At sites where detected nitrogen concentrations in the lysimeters (and in one case a shallow well) were most representative of infiltrating STE, nitrogen concentrations measured at a depth of 2 ft below the drainfields were about 35 to 46 % of the nitrogen concentrations in the STE. These reductions were due mainly to nitrification, denitrification and adsorption. Information on attenuation was used in the soil attenuation modeling. Key results from these sites are as follows:
  - At Site E, 39 % of nitrogen was reduced with 9 % of the reduction due to dilution.
  - At Site G, 42 % to 46 % of nitrogen was reduced in shallow and deep lysimeters with no dilution.
  - At Site J, where there is a shallow water table, 35 % of the nitrogen was reduced in a shallow well with no dilution.
  - At Site K, 44 % of nitrogen was reduced with no dilution.
- Nitrogen leached from applied fertilizer was the cause of elevated TN concentrations on some measurement dates at several of the sites. Many of the detected concentrations were greater than the STE concentrations, and TN concentrations in some background lysimeters were elevated on some measurement dates. Periods of strong fertilizer influence made the interpretation of soil attenuation of nitrogen from septic systems difficult to impossible at some sites. Periods of significant fertilizer influence occurred at sites A, B, F, G, and K.
- Septic system influence at several of the sites and lysimeter locations could not be evaluated because the lysimeters did not intersect infiltrating water from the drainfields. This was because thick layers of gravel impeded the installation of the lysimeters close enough to active drainfields, or contributed to unequal flow in drainfields. Three of the sites (D, H, and I) provided mainly information on background influences with only diluted nitrogen concentrations related to drainfield effluent.
- Nitrogen attenuation in unsaturated soil with depth was evaluated at 4 of the sites by comparing results from clustered lysimeters pulling samples from 5- and 10-ft depth intervals and 2 sites at 15-ft intervals. These results were variable, as follows:
  - At Site A, during a period of less fertilizer influence, a 22 % decrease between 5 and 10 ft was observed with no dilution, and the highest TN concentration at a 10-ft interval was 45 mg/L.
  - At Site B, during a period of less fertilizer influence, a 35 % decrease between 5 and 10 ft was observed, mostly because of factors other than dilution. Fertilizer influence prevented the

evaluation of STE influence at samples from the 15-ft interval. The highest TN concentrations in the 10- and 15-ft interval samples were 79 and 41 mg/L, respectively.

- At Site E, a significant difference was noted between TN concentrations at 5- and 10-ft intervals mainly because of dilution, except after fertilizer events. The highest TN concentration at the 10-ft interval was 103 mg/L, after a fertilizer event.
- At Site F, fertilizer influence was evident in results from both paired lysimeters, with elevated TN concentrations in samples from both depth intervals. The highest TN concentration at the 10-ft interval was 75 mg/L.
- At Site G, there was little difference between TN concentrations in samples from the 5- and 10-ft intervals during periods of less fertilizer influence. It was not possible to evaluate corresponding levels at the 15-ft interval because of fertilizer influence. The highest TN concentrations at the 10- and 15-ft intervals were 100 and 54 mg/L, respectively, after fertilizer events.

- The vertical mobility and dissipation of nitrogen in the soil were observed in data from the clustered lysimeters as nitrate leached through the soil column. At some sites, nitrogen and chloride concentrations in shallow and deep lysimeters were very similar on sampling dates, suggesting minimal attenuation in the soil between them. However, at some sites the plotted data showed a delayed response to introduced TN in the deeper lysimeters.
- Phosphorus concentrations in the soil pore water samples were significantly lower than the corresponding STE concentrations at most of the sites. The sites with the highest average TP concentrations were those with fertilizer-related fluctuations in nitrogen concentrations, and it is likely that elevated phosphorus may also be fertilizer related. The highest TP concentrations were found in the soils at Sites K, G, and F. These were approximately 20 % to 30 % of the average STE concentration. Further attenuation of phosphorus occurs in the soil column and aquifer material.

This report also includes summary data from monitoring wells in the vicinity of the septic tank study sites. These included groundwater monitoring data collected by Orange County and DEP and a discussion of historical monitoring in the area. The results include the following:

- SJRWMD and USGS conducted a comprehensive groundwater monitoring effort of 50 sites in the Wekiva Basin in 1999. In the area of this septic tank study, nitrate nitrogen concentrations detected in wells ranged from 0.01 to 2.0 mg/L.

- The study included monitoring results for the surficial aquifer at 16 sites, including 8 wells in residential areas served by public sewer and 6 wells in residential areas on septic tanks. The median nitrate concentration in samples from wells in the sewered area, excluding an outlier related to golf course influence, was 1.6 mg/L. The median value for samples from wells in residential areas on septic tanks was 1.2 mg/L.

- Data from 10 wells installed in the UFA were included. These consisted of monitoring wells and private supply wells that were sampled one or two times. Concentrations of nitrate in samples from the UFA ranged from below detection limits to 1.8 mg/L.

- Data from 2 monitoring wells in the intermediate confining unit were also included. Nitrate was not detected in either sample.

Monitoring data from the septic tank study sites were used to evaluate a soil attenuation model customized for Florida soil conditions. The following is a summary of the evaluation of this modeling tool:

- The STUMOD-FL calibrations using data from two septic tank studies demonstrate that "one size does not fit all." The STUMOD-FL default parameters are not effective in simulating TN concentrations in the subsurface that mirror measured TN concentrations in lysimeters or groundwater beneath a septic tank drainfield. At each site, several STUMOD-FL parameters, such as the denitrification rate (Vmax), could be adjusted to produce plausible models that simulate measured TN concentrations beneath the drainfield.

- Without detailed measurements of denitrification in the unsaturated zone beneath a drainfield, it is impossible to know if adjusting the denitrification rate parameter is realistic to force a match with the observed TN concentrations in lysimeters or groundwater. Some of the variability in TN concentrations in lysimeters is caused by their inherent ineffectiveness in collecting leachate from the septic tank drainfield. For groundwater samples at or below the water table, TN concentrations can be affected by other factors such as recharge, dilution at the water table, and or preferential flow pathways.

Appendices

Appendix A. Soil Descriptions

Table A-1. Soil depth and description by study site

Site ID	Depth (inches)	Description	Comments
A	0–12	Surface layer very dark grayish brown fine sand	Candler fine sand
A	12–24	Yellowish brown fine sand	
A	24–36	Yellowish brown fine sand to 30 inches, brownish yellow fine sand below	
A	36–48	Brownish yellow fine sand	
A	48–60	Same as above	
A	60–72	Same as above	
A	72–84	Yellow fine sand	
A	84–96	Yellow fine sand	
B	0–12	Surface layer very dark grayish brown fine sand	Candler fine sand
B	12–24	Grayish brown fine sand	
B	24–36	Same as above	
B	36–48	Brownish yellow fine sand	
B	48–60	Same as above	
B	60–72	Same as above	
B	72–84	Yellow fine sand	
B	84–96	Yellow fine sand	
B	96–108	Brownish yellow fine sand	
C	0–12	Surface layer dark grayish brown fine sand	Candler fine sand
C	12–24	Grayish brown fine sand	
C	24–36	Same as above	
C	36–48	Light grayish brown fine sand	
C	48–60	Dark brownish yellow fine sand	
C	60–72	Brownish yellow fine sand	
C	72–84	Yellow fine sand	
C	84–96	Same as above	
C	96–108	Brownish yellow fine sand	
D	0–12	Surface layer grayish brown fine sand	Candler fine sand
D	12–24	Pale brown fine sand	
D	24–36	Brownish yellow fine sand	
D	36–48	Same as above	
D	48–60	Yellow fine sand	
D	60–72	Same as above	
D	72–84	Same as above	
D	84–96	Pale yellow fine sand	

Site ID	Depth (inches)	Description	Comments
D	96–108	Very pale yellow fine sand	
E	0–12	Surface layer dark grayish brown fine sand	Candler fine sand
E	12–24	Grayish brown fine sand	
E	24–36	Same as above	
E	36–48	Brownish yellow fine sand	
E	48–60	Same as above	
E	60–72	Same as above	
E	72–84	Yellow fine sand	
E	84–96	Yellow fine sand	
E	96–108	Pale yellow fine sand	
F	0–12	Surface layer grayish brown fine sand	Candler fine sand
F	12–24	Brownish yellow fine sand	
F	24–36	Same as above	
F	36–48	Same as above	
F	48–60	Yellow fine sand	
F	60–72	Same as above	
F	72–84	Brown fine sand	
F	84–96	Same as above	
F	96–108	pale brown fine sand	
G	0–12	Surface layer very dark grayish brown fine sand	Candler fine sand
G	12–24	Same as above	
G	24–36	Dark grayish brown fine sand to 6 inches, brownish yellow fine sand below	
G	36–48	Brownish fine sand	
G	48–60	Same as above	
G	60–72	Yellow fine sand	
G	72–84	Same as above	
G	84–96	Same as above	
G	96–108	Same as above	
H	0–12	Surface layer very dark grayish brown fine sand	Candler fine sand
H	12–24	Dark grayish brown fine sand	
H	24–36	Brownish yellow fine sand	
H	36–48	Same as above	
H	48–60	Same as above	
H	60–72	Yellow fine sand	
H	72–84	Same as above	
H	84–96	Brownish yellow fine sand	
H	96–108	See above	
I	0–12	Surface layer very dark grayish brown fine sand	Urban land
I	12–24	Brownish yellow fine sand	

Site ID	Depth (inches)	Description	Comments
I	24–36	Same as above	
I	36–48	Same as above	
I	48–60	Yellow fine sand	
I	60–72	Same as above	
I	72–84	Pale yellow fine sand	
I	84–96	Same as above	
I	96–108	Same as above	
J	0–12	Surface layer of very dark gray fine sand	Urban land
J	12–24	Very pale brown fine sand	
J	24–36	Pale yellow fine sand	
J	36–48	Pale yellow fine sand to 6 inches, dark reddish brown fine sand below	
J	48–60	Dark reddish brown fine sand (moist)	
J	60–72	Reddish brown fine sand (moist)	
J	72–84	Brown fine sand (saturated)	
K	0–12	Surface layer very dark grayish brown fine sand	Candler fine sand
K	12–24	Grayish brown fine sand	
K	24–36	Same as above	
K	36–48	Brownish yellow fine sand	
K	48–60	Same as above over yellowish gray clayey fine sand	
K	60–72	Yellowish gray clayey sand grading to yellowish gray clay, saturated	
K	72–84	Yellowish-gray clay, saturated	

Appendix B. Laboratory Data

Table B-1. Laboratory results for lysimeters and wells sampled during the study

Notes:
All concentrations reported in mg/L. Missing data indicate that the sample was not analyzed because of insufficient water sample volume.
TKN = Total Kjeldahl nitrogen. Q = Data qualifiers. A = Value reported is the average of two or more determinations. I = Reported value is between laboratory method detection limit and laboratory practical quantitation limit. U = Material was analyzed for but not detected. The reported value is the method detection limit for the sample analyzed. Y = The laboratory analysis was performed on an unpreserved or improperly preserved sample. The data may not be accurate.

Station ID	Date	Chloride	Q	Ammonia	Q	TKN	Q	Nitrate + Nitrite	Q	TN	TP	Q
AL1S	8/4/2015	22.00		0.021		2.300		3.900		6.200		
AL1S	10/21/2015			0.290				2.300		2.300		
AL1S	12/9/2015			0.180		1.800		3.300		5.100	0.14	
AL1S	2/17/2016	7.90		0.080		0.970		0.500		1.470	0.19	
AL1S	4/15/2016	12.00		0.091	Y	1	Y	5.8	Y	6.8	0.15	Y
AL1S	6/15/2016	15.00										
AL1S	8/18/2016	14.00										
AL1S	10/18/2016	21.00										
AL2D	2/26/2016	26.00		0.010		1.200		10.000		11.200	1.6	
AL2D	4/15/2016	33.00		0.034		1.2		26		27.2	2.4	
AL2D	6/15/2016	50.00		0.021		1.5		22		23.5	2.4	
AL2D	8/18/2016	55.00		0.022		2	I	45		47	3.5	
AL2D	10/18/2016	45.00		0.015		1.400		33.000		34.400	0.34	
AL2S	8/4/2015	62.00		0.028		3.000		4.400		7.400		
AL2S	10/21/2015	36.00		0.084		2.000	I	88.000		90.000	3.6	
AL2S	12/9/2015	32.00		0.051		0.640	I	28.000		28.640	1.4	
AL2S	2/17/2016	18.00		0.070		2.700		0.960		3.660	2.2	
AL2S	4/15/2016	41.00		0.013		1.1	I	54		55.1	1	
AL2S	6/15/2016	40.00		0.11		1.5		20		21.5	3.6	
AL2S	8/18/2016	37.00		0.038		1.3	I	61		62.3	2.8	
AL2S	10/18/2016	40.00		0.023		1.700		24.000		25.700	0.6	
AL3S	8/4/2015	14.00		0.010		0.860		8.300		9.160		
AL3S	10/21/2015			0.065	Y			3.700	Y	3.700		

Station ID	Date	Chloride	Q	Ammonia	Q	TKN	Q	Nitrate + Nitrite	Q	TN	TP	Q
AL3S	12/9/2015	10.00		0.018		0.810		4.600		5.410	0.063	
AL3S	2/17/2016	2.90		0.072		0.630		0.960		1.590	0.059	
AL3S	4/15/2016	4.30		0.054		0.67		1.7		2.37	0.049	
AL3S	6/15/2016	6.30		0.029		0.63		0.61		1.24	0.052	
AL3S	8/18/2016	6.10		0.043		0.63		0.44		1.07	0.038	
AL3S	10/18/2016	3.00		0.079		0.700		0.260		0.960	0.034	
AL4S	8/4/2015	28.00		0.016		1.000		6.200		7.200		
AL4S	10/21/2015			0.160				57.000		57.000		
AL4S	12/9/2015	32.00		0.041		0.610		31.000		31.610	0.31	
AL4S	2/17/2016	31.00		0.016		3.600		36.000		39.600	0.24	
AL4S	4/15/2016	65.00		0.046		2	I	130		132	0.27	
AL4S	6/15/2016	81.00		0.046		3.1		50		53.1	0.54	
AL4S	8/18/2016	54.00		0.021		1	I	70		71	0.33	
AL4S	10/18/2016	23.00		0.036		2.700		5.000		7.700	0.8	
AL5S	8/4/2015	16.00		0.021		1.900		2.300		4.200		
AL5S	10/21/2015			0.120		2.500		0.750		3.250	0.16	
AL5S	12/9/2015	11.00		0.029		0.780		0.180		0.960	0.054	
AL5S	2/17/2016	4.60		0.099		1.200		0.190		1.390		
AL5S	4/15/2016	4.70		0.045		0.8		0.54		1.34	0.086	
AL5S	6/15/2016	3.80		0.035		1.1		0.5		1.6	0.079	
AL5S	8/18/2016			0.036		1		1.1		2.1	0.065	
AL5S	10/18/2016	0.04		0.040		1.200		0.340		1.540	0.07	
ASTE	10/21/2015	25.00		43.000		52.000		0.004	U	52.004	5.8	
ASTE	12/9/2015	33.00		60.000		57.000		0.011	J	57.011	7.2	
ASTE	2/17/2016	32.00		52.000		57.000		0.009	I	57.009	6.1	
ASTE	4/15/2016	27.00		66		71		0.006	I	71.006	11	
ASTE	6/15/2016	35.00		51		54		0.004	U	54.004	6.9	
ASTE	8/18/2016	36.50		64		71		0.006	I	71.006	8.55	
ASTE	10/18/2016	36.00		63.000		63.000		0.005	I	63.005	9.1	

Station ID	Date	Chloride	Q	Ammonia	Q	TKN	Q	Nitrate + Nitrite	Q	TN	TP	Q
A-SUPPLY WELL	9/3/2015	7.70		0.016		0.080	U	0.150		0.230		
BL1S	8/4/2015	14.00		0.014		1.300		25.000		26.300		
BL1S	10/21/2015			0.065		2.300		24.000		26.300	0.98	
BL1S	12/9/2015			0.047		1.900		17.000		18.900	1.1	
BL1S	2/17/2016	2.90		0.042		1.200		1.800		3.000	0.9	
BL1S	4/14/2016	6.40		0.033		1.3		9.3		10.6	0.69	
BL1S	6/16/2016	20.00	U	0.017	U	1.4		37	I	38.4	0.56	U
BL1S	8/18/2016	55.00		0.012		2.3	I	110		112.3	3.9	
BL1S	10/19/2016	110.00		0.007		0.820	I	99.000		99.820	3	
BL2S	8/4/2015	12.00		0.028		1.300		7.600		8.900		
BL2S	10/21/2015			0.061				2.900		2.900		
BL2S	2/17/2016	10.00		0.028		1.000		1.400		2.400	0.046	
BL2S	4/14/2016	18.00		0.033		1.2		5.4		6.6	0.052	
BL2S	6/16/2016	28.00		0.009		1.4		20		21.4	0.028	I
BL2S	8/18/2016	180.00		0.018		5.5	I	230		235.5	0.029	
BL2S	10/19/2016			0.026		1.600		9.000		10.600	0.073	
BL3D	2/26/2016	22.00		0.005	I	0.490	I	24.000		24.490	0.056	
BL3D	4/14/2016	36.00		0.005		0.8		72		72.8	0.09	
BL3D	6/16/2016	46.00		0.007		1.1		75	U	76.1	0.019	
BL3D	8/18/2016	60.00		0.12		2	U	120		122	0.02	
BL3D	10/19/2016	42.00		0.067		0.800	I	78.000		78.800	0.012	
BL3E	8/18/2016	34.00		0.005	I	1.1		40		41.1	0.072	
BL3E	10/19/2016	21.00	A	0.009		0.740	I	36.000		36.740	0.1	
BL3S	8/4/2015	48.00		0.009		1.100	I	87.000		88.100		
BL3S	10/21/2015	52.00		0.047		0.920	I	93.000		93.920	0.12	
BL3S	12/9/2015	43.00		0.150		0.800	U	85.000		85.800	0.015	
BL3S	2/17/2016	45.00		0.012		0.800	U	79.000		79.800	0.012	
BL3S	4/14/2016	48.00		0.024		0.85		94		94.85	0.017	
BL3S	6/16/2016	44.00		0.022		0.87		78		78.87	0.012	

Station ID	Date	Chloride	Q	Ammonia	Q	TKN	Q	Nitrate + Nitrite	Q	TN	TP	Q
BL3S	8/18/2016	51.00		0.1		0.98	I	37		37.98	0.008	
BL3S	10/19/2016	54.00		0.024		1.900	I	64.000		65.900	0.011	
BL4S	8/4/2015	12.00		0.011		0.780	i	23.000		23.780		
BL4S	10/21/2015	6.30		0.010		1.200		27.000		28.200	0.026	
BL4S	12/9/2015	22.00		0.010		0.760		18.000		18.760	0.025	
BL4S	2/17/2016	8.10		0.009		0.660		7.400		8.060	0.029	
BL4S	4/14/2016	5.50		0.014		0.63		5.6		6.23	0.037	
BL4S	6/16/2016	5.30		0.006		1.3		49		50.3	0.017	I
BL4S	8/18/2016	44.00		0.02		1.4	I	74		75.4	0.014	
BL4S	10/19/2016	7.20		0.015		0.610		4.100		4.710	0.012	
BL5S	8/4/2015	8.00		0.011		0.800		10.000		10.800		
BL5S	10/21/2015			0.026		0.840		8.000		8.840	0.076	
BL5S	2/17/2016	2.40		0.034		0.380		1.100		1.480	0.1	
BL5S	4/14/2016	1.90		0.033		0.4		2.8		3.2	0.086	
BL5S	6/16/2016	7.30		0.022		0.4		40		40.4	0.053	I
BL5S	8/18/2016	83.00		0.027		4	U	250		254	0.016	
BL5S	10/19/2016	1.60		0.100		0.750		5.400		6.150	0.062	
BL5S				0.020		1.000		11.000		12.000	0.11	
BSTE	10/21/2015	45.00		93.000		90.000		0.006	I	90.006	9	
BSTE	12/9/2015	41.00		99.000		90.000		0.016		90.016	9	
BSTE	2/17/2016	43.00		93.000		110.000		0.004	U	110.004	10	
BSTE	4/14/2016	45.00		76		98		0.004		98.004	9.9	
BSTE	6/16/2016	38.00		65.5		76.5		0.004		76.504	7.75	
BSTE	8/18/2016	44.00		85		97		0.004	U	97.004	10	
BSTE	10/19/2016	42.00		84.000		89.000		0.004	U	89.004	9.1	
CL1S	9/3/2015			0.013		1.300		15.000		16.300		
CL1S	10/21/2015			0.026		2.000		24.000		26.000	0.5	
CL1S	12/9/2015			0.018		1.900		38.000		39.900	0.63	
CL1S	2/17/2016	31.00		0.048		1.600		39.000		40.600	0.55	

Station ID	Date	Chloride	Q	Ammonia	Q	TKN	Q	Nitrate + Nitrite	Q	TN	TP	Q
CL1S	4/14/2016	36.00		0.038		6		29		35	0.48	
CL1S	6/16/2016	20.00		0.03		1.6		13		14.6	0.39	
CL1S	8/18/2016	67.00		0.022		1.1	I	46		47.1	0.18	
CL1S	10/19/2016	53.00		0.056		1.400		15.000		16.400	0.19	
CL2S	10/21/2015			0.072		2.600		23.000		25.600	1.1	
CL2S	12/9/2015	24.00		0.083		2.500		50.000		52.500	1.2	
CL2S	2/17/2016	37.00		0.098		1.700		65.000		66.700	0.63	
CL2S	4/14/2016			0.021		1.5		30		31.5	0.66	
CL2S	6/16/2016			0.009		1.5		15		16.5	0.7	
CL2S	8/18/2016			0.028		2.9		18		20.9	0.96	
CL2S	10/19/2016			0.022		1.600		9.600		11.200	0.56	
CL3S	9/3/2015	21.00										
CL3S	4/14/2016	15.00		0.075		1.1		4.7		5.8	0.071	
CL3S	6/16/2016	6.80	U	0.009		0.89	U	0.76		1.65	0.052	U
CL3S	8/18/2016	9.50		0.019		0.92		2		2.92	0.068	
CL3S	10/19/2016			0.043		1.300		9.500		10.800	0.065	
CL4S	9/3/2015			0.011		0.830		6.500		7.330		
CL4S	10/21/2015			0.027		0.940		4.100		5.040	0.065	
CL4S	12/9/2015			0.022		1.300		5.600		6.900	0.094	
CL4S	2/17/2016	61.00		0.039		0.850		3.200		4.050	0.096	
CL4S	4/14/2016			0.031		0.76		2.1		2.86	0.085	
CL4S	6/16/2016	31.00		0.013		0.81		0.017		0.827	0.058	
CL4S	8/18/2016	6.50		0.036		1.2		0.065		1.265	0.038	
CL4S	10/19/2016			0.023		0.960		5.300		6.260	0.033	
CSTE	10/21/2015	68.00		100.000		100.000		0.004	U	100.004	12	
CSTE	12/9/2015	51.00		90.000		93.000		0.027	I	93.027	11	
CSTE	2/17/2016	71.00		100.000		110.000		0.004	U	110.004	12	
CSTE	4/14/2016	58.00		88		100		0.004		100.004	10	
CSTE	6/16/2016	61.00		96	U	100	U	0.004	U	100.004	11	I

Station ID	Date	Chloride	Q	Ammonia	Q	TKN	Q	Nitrate + Nitrite	Q	TN	TP	Q
CSTE	8/18/2016	70.50		120		120		0.004	U	120.004	14	
CSTE	10/19/2016	50.00		79.000		81.000		0.004	U	81.004	9.6	
DL1S	8/4/2015	7.70		0.018		1.500		7.000		8.500		
DL1S	10/21/2015	8.00		0.160		1.500		8.600		10.100	1.9	
DL1S	12/9/2015	8.80		0.120		1.500		13.000		14.500	2	
DL1S	2/17/2016	28.00		0.060		1.300		3.300		4.600	1.9	
DL1S	4/15/2016	15.00		0.012		1.4		3.3		4.7	1.9	
DL1S	6/15/2016	23.00	A	0.03		1.3	J	1.8		3.1	1.9	
DL1S	8/17/2016	28.00		0.023		1.4		4.8		6.2	1.6	
DL1S	10/18/2016	2.70	A	0.014		1.300		1.500		2.800	2.1	
DL2S	8/4/2015	3.70		0.029		2.600		3.100		5.700		
DL2S	10/21/2015	5.20		0.025		2.200		15.000		17.200	1.4	
DL2S	12/9/2015	12.00		0.040		2.000		20.000		22.000	1.3	
DL2S	2/17/2016	12.00		0.073		2.200		2.300		4.500	1.4	
DL2S	4/15/2016	9.00		0.034		0.08	U	1.6		1.68	1.5	
DL2S	6/15/2016	17.00		0.03		2.8		0.72		3.52	1.6	
DL2S	8/17/2016	18.00		0.025		3.6		4.2		7.8	1.7	
DL2S	10/18/2016	4.30		0.035		2.600		1.900		4.500	1.6	
DL3S	8/4/2015	12.00		0.010		0.710		6.900		7.610		
DL3S	10/21/2015	8.80		0.040		0.930		2.700		3.630	0.054	
DL3S	12/9/2015	22.00		0.035		0.760		1.700		2.460	0.08	
DL3S	2/17/2016	7.10		0.071		0.870		0.850		1.720	0.065	
DL3S	4/15/2016	17.00		0.027		0.59		0.76		1.35	0.054	
DL3S	6/15/2016	9.90		0.066		0.56		0.74		1.3	0.053	
DL3S	8/17/2016	18.00		0.031		0.69		1.3		1.99	0.056	
DL3S	10/18/2016	6.10		0.048		0.790		1.100		1.890	0.058	
EL1D	2/26/2016	16.00		0.013		1.700		2.000		3.700	1.3	
EL1D	4/14/2016	20.00		0.076		3		9.5		12.5	1.9	
EL1D	6/16/2016	26.00		0.052		2.05		27		29.05	1.75	

Station ID	Date	Chloride	Q	Ammonia	Q	TKN	Q	Nitrate + Nitrite	Q	TN	TP	Q
EL1D	8/17/2016	41.00		0.14		2.9		51		53.9	1.8	
EL1D	10/19/2016	70.00		0.021		3.300	I	100.000		103.300	0.84	
EL1S	8/4/2015	48.00		0.032		2.500		44.000		46.500		
EL1S	10/21/2015			0.077		3.600		16.000		19.600	1.2	
EL1S	12/9/2015			0.130		3.900		20.000		23.900	1.5	
EL1S	2/17/2016	35.00		0.097		3.500		32.000		35.500	0.86	
EL1S	4/14/2016	27.00		0.12		3		33		36	1.1	
EL1S	6/16/2016	56.00		0.037		4		38		42	0.87	
EL1S	8/17/2016											
EL1S	10/19/2016	49.00		0.042		5.800		34.000		39.800	1.2	
EL2S	8/4/2015											
EL2S	10/21/2015											
EL2S	12/9/2015											
EL2S	2/26/2016											
EL3S	8/4/2015	30.00		0.032		3.100		4.900		8.000		
EL3S	10/21/2015			0.093				0.740		0.740		
EL3S	2/17/2016	29.00		0.040		4.000		3.600		7.600	0.26	
EL3S	6/16/2016	70.00		0.058		6.2		4.6		10.8	0.3	
EL3S	10/19/2016	94.00		0.071		6.200		39.000		45.200	0.24	
EL4S	8/4/2015	14.00		0.100		2.300		6.300		8.600		
EL4S	10/21/2015			0.037		2.200		2.100		4.300	0.2	
EL4S	12/9/2015			0.074		2.500		4.100		6.600	0.16	
EL4S	2/17/2016	2.90		0.021		1.700		0.720		2.420	0.17	
EL4S	4/14/2016			0.043		1.9		0.8		2.7	0.17	
EL4S	6/16/2016	14.00		0.012	U	1.1		0.19		1.29	0.16	
EL4S	8/17/2016	48.00		0.021		1.9		0.54		2.44	0.15	
EL4S	10/19/2016	12.00		0.018		2.000		1.400		3.400	0.11	
ESTE	10/21/2015	46.00		39.000	Y	37.000	Y	0.004	UY	37.004	4.6	Y
ESTE	12/9/2015	45.00		42.000		48.000		0.004	U	48.004	5.8	

Station ID	Date	Chloride	Q	Ammonia	Q	TKN	Q	Nitrate + Nitrite	Q	TN	TP	Q
ESTE	2/17/2016	46.00		42.000		50.000		0.008	I	50.008	5.2	
ESTE	4/14/2016	49.00		53		68		0.004		68.004	6.7	
ESTE	6/16/2016	47.00	U	57		70	U	0.004		70.004	8.4	
ESTE	8/18/2016	45.00		53.5		63.5		0.004	U	63.504	7.45	
ESTE	10/19/2016	51.00		49.000		60.000		0.004	U	60.004	9.4	
FL1S	8/4/2015	9.70		0.027		3.200		40.000		43.200		
FL1S	10/21/2015			0.080		3.100		15.000		18.100	1.7	
FL1S	12/9/2015	2.30		0.100		7.300		18.000		25.300	3.3	
FL1S	2/17/2016	9.60		0.018		3.000		38.000		41.000	1.2	
FL1S	4/14/2016	15.00		0.032		3.6		34		37.6	1.3	
FL1S	6/15/2016	12.00		0.01		3.2		54		57.2	1.2	
FL1S	10/18/2016	1.60		0.021		4.300		20.000		24.300	0.86	
FL2D	2/26/2016	39.00		0.033	I	0.920	I	43.000		43.920	2.1	
FL2D	4/14/2016	40.00		0.006		0.95	I	43		43.95	3.7	
FL2D	6/15/2016	26.00		0.015		1.2	I	89		90.2	3.6	
FL2D	8/17/2016	23.00		0.03		1.5	I	73		74.5	2.2	
FL2D	10/18/2016	5.00	A	0.022		1.400		9.300		10.700	3.5	
FL2S	8/4/2015	56.00		16.000		19.000		59.000		78.000		
FL2S	10/21/2015	46.00		0.039		1.100	I	99.000		100.100	3.6	
FL2S	12/9/2015	51.00		0.027		0.900	I	71.000		71.900	6.1	
FL2S	4/14/2016	40.00		0.018		0.89	I	52		52.89	3.7	
FL2S	6/15/2016	26.00		0.015		1.2	I	88		89.2	3.6	
FL2S	8/17/2016	9.20										
FL2S	10/18/2016	3.40		0.017		2.900		17.000		19.900	3.5	
FL3S	8/4/2015	4.10		0.035		3.100		13.000		16.100		
FL3S	10/21/2015			0.058		3.000		4.300		7.300	0.86	
FL3S	12/9/2015	1.30		0.038		2.400		9.300		11.700	1.2	
FL3S	2/17/2016	27.00		0.038		2.500		60.000		62.500	1.5	
FL3S	4/14/2016	32.00		0.014		2	U	110		112	0.76	

Station ID	Date	Chloride	Q	Ammonia	Q	TKN	Q	Nitrate + Nitrite	Q	TN	TP	Q
FL3S	6/15/2016	2.30		0.029		2.6		8.2		10.8	1.1	
FL3S	8/17/2016	8.90		0.015		2.4		8.8		11.2	0.92	
FL3S	10/18/2016	2.40		0.017		2.400		4.600		7.000	1.1	
FL4S	8/4/2015	7.10		0.022		2.700		37.000		39.700		
FL4S	10/21/2015	2.40		0.110		2.800		19.000		21.800	1.1	
FL4S	2/17/2016	17.00		0.026		2.100		57.000		59.100	1	
FL4S	4/14/2016	31.00		0.03		1.9	I	93		94.9	0.44	
FL4S	6/15/2016	8.10		0.035		2.1		47		49.1	3.4	
FL4S	8/17/2016	1.70										
FL4S	10/18/2016	2.00		0.019		2.000		14.000		16.000	1.2	
FL4S	12/9/2016	23.00		0.025		2.400		23.000		25.400	1	
FL5S	8/4/2015	15.00		0.031		3.400		83.000		86.400		
FL5S	10/21/2015			0.130		3.500		9.500		13.000	0.15	
FL5S	12/9/2015			0.140		4.000		7.100		11.100	0.089	
FL5S	2/17/2016	17.00		0.046		2.400		38.000		40.400	1.2	
FL5S	4/14/2016	21.00		0.055		2.4		24		26.4	0.078	
FL5S	6/15/2016	10.00		0.056		2.1		18		20.1	0.068	
FL5S	8/17/2016			0.096		3.4		3.9		7.3	0.047	
FSTE	10/21/2015	49.00		47.000		56.000		0.004	U	56.004	6.9	
FSTE	12/9/2015	46.00		57.000		59.000		0.004	U	59.004	6	
FSTE	2/17/2016	41.00		43.000		53.000		0.004	I	53.004	5.9	
FSTE	4/14/2016	38.00		44		52		0.004	U	52.004	6.2	
FSTE	6/15/2016	48.00		59		67		0.004	U	67.004	8.2	
FSTE	8/18/2016	47.00		51		60		0.004	U	60.004	7.2	
FSTE	10/18/2016	43.00		48.000		51.000		0.004	U	51.004	7.1	
GL1D	2/26/2016	44.00		0.003	I	0.590	I	43.000		43.590	0.34	
GL1D	4/14/2016	50.00		0.025		1.2		41		42.2	0.53	
GL1D	6/15/2016	82.00		0.032		1.8	I	60		61.8	0.54	
GL1D	8/17/2016	120.00		0.055		0.97	I	99		99.97	0.23	

Station ID	Date	Chloride	Q	Ammonia	Q	TKN	Q	Nitrate + Nitrite	Q	TN	TP	Q
GL1D	10/18/2016	5.80		0.045		1.000		2.600		3.6	0.76	
GL1E	8/17/2016	44.00		0.005	I	1.2	I	53		54.2	0.51	
GL1E	10/18/2016	60.00		0.054		0.760	I	43.000		43.76	0.27	
GL1S	8/4/2015	170.00		0.023		2.400		42.000		44.4		
GL1S	10/21/2015	74.00		0.160		1.700		96.000		97.7	7.4	
GL1S	12/9/2015	100.00		0.051		1.000	I	82.000		83.000	7	
GL1S	2/17/2016	59.00		0.890		2.200		39.000		41.2	7.9	
GL1S	4/14/2016	61.00		19		21		110		131	5.5	
GL1S	6/15/2016	110.00		0.009		2.8	I	120		122.8	4.5	
GL1S	8/17/2016	290.00		0.018		3.6		78		81.6	6.1	
GL1S	10/18/2016	340.00		0.029		5.700		120.000		125.7	2.2	
GL2S	8/4/2015	59.00		0.010		1.500		38.000		39.5		
GL2S	10/21/2015	34.00		0.021		2.400		6.000		8.4	0.47	
GL2S	12/9/2015	56.00		0.008		2.000	U	150.000		152.000	0.04	
GL2S	2/17/2016	56.00		0.016		2.000		2.600		4.6	0.086	
GL2S	4/14/2016	100.00		0.023		2.4		1		3.4	0.048	
GL2S	6/15/2016	440.00		0.054		6.5		2.9		9.4	0.12	
GL2S	8/17/2016	2600.00		0.13		20		3.6		23.6	0.21	
GL2S	10/18/2016	63.00		0.015		2.400		54.000		56.400	0.86	
GL3S	8/4/2015	29.00		0.015		1.800		6.000		7.800		
GL3S	10/21/2015			0.120		2.800		5.700		8.500	0.53	
GL3S	12/9/2015			0.079		2.800		0.100		2.900	0.46	
GL3S	2/17/2016	85.00		0.140		2.100		0.097		2.197	0.42	
GL3S	6/15/2016	340.00		0.023		2.3		0.03		2.33	0.36	
GL3S	10/18/2016	850.00		0.039		2.800		9.200		12.000	0.12	
GSTE	10/21/2015			87.000		99.000		0.004	I	99.004	8.5	
GSTE	2/17/2016	46.00		66.000		76.000		0.004	U	76.004	8.1	
GSTE	4/14/2016	44.00		65		76		0.004	U	76.004	7	
GSTE	6/15/2016	43.00		64		73		0.008	I	73.008	8.1	

Station ID	Date	Chloride	Q	Ammonia	Q	TKN	Q	Nitrate + Nitrite	Q	TN	TP	Q
GSTE	8/18/2016	45.00		63		78		0.004	U	78.004	8	
GSTE	10/18/2016	37.00		47.000		65.000		0.004	U	65.004	6.4	
GSTE	12/9/2016	39.00		67.000		61.000		0.004	U	61.004	6.7	
HL1S	8/4/2015	8.70		0.015		1.400		7.100		8.500		
HL1S	10/21/2015					2.100		2.100		4.200	0.06	
HL1S	12/9/2015			0.020		2.400		3.100		5.500	0.067	
HL1S	2/17/2016	14.00		0.029		1.300		8.400		9.700	0.08	
HL2S	8/4/2015	7.50		0.010		0.680		6.100		6.780		
HL2S	10/21/2015			0.039		1.100		3.700		4.800	0.021	
HL2S	12/9/2015			0.014		0.860		4.500		5.360	0.021	
HL2S	2/17/2016	92.00		0.017		0.710		7.500		8.210	0.048	
HL3S	8/4/2015	1.90										
HL3S	10/21/2015			0.052		1.400		2.600		4.000	0.11	
HL3S	12/9/2015	22.00		0.052		1.200		9.100		10.300	0.12	
HL3S	2/17/2016			0.032		0.570		0.940		1.510	0.11	
IL1S	9/3/2015	~		0.026		1.500		4.500		6.000		
IL1S	10/21/2015			0.059				6.300		6.300		
IL1S	12/9/2015	14.00		0.023		1.800		20.000		21.800	0.33	
IL1S	2/17/2016	9.40		0.045		1.400		3.800		5.200	0.35	
IL1S	4/14/2016	5.30		0.044		1.5		2.6		4.1	0.34	
IL1S	6/16/2016	7.80	U	0.031		1.8		0.41		2.21	0.33	
IL1S	8/18/2016	15.00		0.043		3.5		2.7		6.2	0.37	
IL1S	10/19/2016	4.60										
IL1S	9/3/2015	~		0.026		1.500		4.500		6.000		
IL2S	9/3/2015	4.40		0.028		1.900		2.400		4.300		
IL2S	10/21/2015			0.059				6.300		6.300		
IL2S	12/9/2015	9.20		0.098		3.100		2.900		6.000	2.3	
IL2S	2/17/2016	11.00		0.053		1.500		0.580		2.080	1.5	
IL2S	4/14/2016	8.50		0.032		1.7		0.54		2.24	1.6	

Station ID	Date	Chloride	Q	Ammonia	Q	TKN	Q	Nitrate + Nitrite	Q	TN	TP	Q
IL2S	6/16/2016	12.00	U	0.027		2		0.38	I	2.38	1.6	
IL2S	8/18/2016	34.00		0.024		2.7		1.9		4.6	1.6	
IL2S	10/19/2016	3.90										
IL3S	9/3/2015	~		0.026		1.900		2.700		4.600		
IL3S	10/21/2015			0.270				15.000		15.000		
IL3S	12/9/2015			0.330		4.200		65.000		69.200	0.048	
IL3S	2/17/2016	38.00		0.072		2.200		3.800		6.000	1.3	
IL3S	4/14/2016			0.11		4.3		30		34.3	1.1	
IL3S	6/16/2016	32.00	U	0.062		5.9		0.17		6.07	1.3	
IL3S	8/18/2016	120.00		0.065		8.8		3.4		12.2	1.6	
IL3S	10/19/2016	15.00										
IL4S	9/3/2015	~		0.048		1.400		1.100		2.500		
IL4S	9/3/2015	8.20										
IL4S	10/21/2015			0.051				0.600		0.600		
IL4S	12/9/2015	12.00		0.068		1.300		0.140		1.440	0.1	
IL4S	2/17/2016	7.30		0.031		0.920		0.067		0.987	0.067	
IL4S	4/14/2016			0.081		1.2		0.04		1.24	0.069	
IL4S	6/16/2016	47.00		0.025		1		0.073		1.073	0.056	U
IL4S	8/18/2016	41.00										
IL4S	10/19/2016			0.079		1.700		0.300		2.000	0.083	
ISTE	10/21/2015	86.00		140.000		170.000		0.004	U	170.004	19	
ISTE	12/9/2015	90.00		100.000		120.000		0.004	U	120.004	14	
ISTE	2/17/2016	74.00		75.000		95.000		0.004	U	95.004	11	
ISTE	4/14/2016	76.00		130		140		0.004	U	140.004	14	
ISTE	6/16/2016	97.00		160		175		0.004	U	175.004	21	
ISTE	8/18/2016	95.00		150		160		0.006	I	160.006	19	
ISTE	10/19/2016	90.00		130.000		120.000		0.004	I	120.004	15	
I-SUPPLY WELL	9/3/2015	23.00		0.005		0.086	I	0.004	U	0.090		
JL1S	9/3/2015	2.20		0.013		0.630		2.200		2.830		

Station ID	Date	Chloride	Q	Ammonia	Q	TKN	Q	Nitrate + Nitrite	Q	TN	TP	Q
JL1S	10/21/2015	2.40		0.041		0.850		3.000		3.850	0.043	
JL1S	12/9/2015	25.00		0.020		1.200		2.700		3.900	0.052	
JL1S	4/14/2016	96.00		0.034		0.9	I	55		55.9	0.035	
JL1S	6/16/2016	66.00		0.035	U	0.98		12		12.98	0.028	
JL1S	8/18/2016	38.00		0.019		1.2		5.2		6.4	0.018	
JL1S	10/19/2016	12.00		0.034		0.820		3.100		3.920	0.12	
JL2S	9/3/2015	9.60		0.020		1.300		2.600		3.900		
JL2S	10/21/2015	10.00		0.021		1.200		0.022		1.222	0.048	
JL2S	12/9/2015	12.00		0.009		1.200		0.230		1.430	0.027	
JL2S	2/17/2016	11.00		0.011		0.800		0.540		1.340	0.03	
JL2S	4/14/2016	23.00		0.01		0.92		0.016		0.936	0.024	
JL2S	6/16/2016	27.00		0.015		1.5		3.1		4.6	0.028	
JL2S	8/18/2016	45.00		0.013		2.2		0.018		2.218	0.022	
JL2S	10/19/2016	49.00		0.014		1.500		0.005	I	1.505	0.015	
JL3S	9/3/2015	67.00		0.030		2.400		0.300		2.700		
JL3S	10/21/2015	54.00		0.022		1.500		0.004	U	1.504	0.074	
JL3S	12/9/2015	7.80		0.014		1.700		0.004	U	1.704	0.059	
JL3S	2/17/2016	17.00		0.030		1.000		0.004	U	1.004	0.044	
JL3S	4/14/2016	21.00		0.019		0.92		0.009	I	0.929	0.038	
JL3S	6/16/2016	12.00	U	0.01		0.8		0.019		0.819	0.033	
JL3S	8/18/2016	5.70		0.003	I	0.56		0.004	I	0.564	0.03	
JL3S	10/19/2016	24.00	A	0.008		0.770		0.005	I	0.775	0.023	
JL4S	9/3/2015	3.00		0.012		0.790		0.120		0.910		
JL4S	10/21/2015	6.40		0.025		0.790		0.004	U	0.794	0.05	
JL4S	12/9/2015	3.90		0.018		0.900		0.012		0.912	0.015	
JL4S	2/17/2016	6.90		0.033		0.800		0.050		0.850	0.046	
JL4S	4/14/2016	15.00		0.012		0.91		0.005	I	0.915	0.036	
JL4S	6/16/2016	12.00		0.009	U	0.81		0.004		0.814	0.042	
JL4S	8/18/2016	28.00		0.006		1.5		0.006	I	1.506	0.033	

Station ID	Date	Chloride	Q	Ammonia	Q	TKN	Q	Nitrate + Nitrite	Q	TN	TP	Q
JL4S	10/19/2016	24.00		0.010		1.100		0.005	I	1.105	0.022	
JL2S	10/19/2016	49.00		0.014		1.500		0.005	I	1.505	0.015	
JMW1	8/18/2016	93.00		0.005		1.3	I	65		66.3	3.2	
JMW1	10/19/2016	94.00		0.006		0.880		55.000		55.880	0.96	
JSTE	10/21/2015	58.00		70.000		67.000		0.004	U	67.004	7.2	
JSTE	12/9/2015	65.00		78.000		88.000		0.004	U	88.004	8.4	
JSTE	2/17/2016	91.00		68.000		76.000		0.004	U	76.004	0.85	
JSTE	4/14/2016	70.00		85		95		0.004	U	95.004	7.2	
JSTE	6/16/2016	81.00		100	U	120		0.004		120.004	17	
JSTE	8/18/2016	90.00		110		120		0.009	I	120.009	15	
JSTE	10/19/2016	63.00		81.000		87.000		0.004	U	87.004	9.1	
J-SUPPLY WELL	9/3/2015	32.00		0.008		0.080	U	0.510		0.590		
KL1S	9/3/2015	10.00		0.010		2.300		9.100		11.400		
KL1S	10/21/2015			0.120		2.200		60.000		62.200	1.1	
KL1S	12/9/2015			0.280		0.667		78.000		78.667	1.4	
KL1S	2/17/2016	51.00		0.021		1.400	I	33.000		34.400	2.5	
KL1S	4/15/2016	69.00		0.016		1.3	I	50		51.3	2.9	
KL1S	6/15/2016	53.00		0.013		1.5		25		26.5	2.4	
KL1S	8/17/2016	84.00		0.005		2	I	73		75	4.1	
KL2S	9/3/2015	23.00		0.021		1.600		5.500		7.100		
KL2S	10/21/2015							0.520		0.520		
KL2S	2/17/2016	35.00		0.065		1.200		0.084		1.284	0.35	
KL2S	6/15/2016	42.00		0.01		0.95		0.065		1.015	0.32	
KL2S	10/18/2016	19.00		0.017		1.300		0.090		1.390	0.4	
KL3S	10/21/2015	15.00	A	0.021		2.100		1.800		3.900	1.4	
KL3S	12/9/2015			0.044		3.200		10.000		13.200	0.99	
KL3S	2/17/2016							0.430		0.430	2	
KL3S	4/15/2016	72.00		0.026		1.5		6.8		8.3	1.5	
KL3S	6/15/2016	12.00		0.014		1.1	J	0.83		1.93	1.8	

Station ID	Date	Chloride	Q	Ammonia	Q	TKN	Q	Nitrate + Nitrite	Q	TN	TP	Q
KL3S	10/18/2016	77.00		0.015		1.800		2.000		3.800	1.8	
KL4S	10/21/2015	33.00		0.070		3.700		22.000		25.700	5.1	
KL4S	12/9/2015			0.099		4.000		30.000		34.000	3.3	
KL4S	2/17/2016	64.00		0.008		1.400		37.000		38.400	8.2	
KL4S	4/15/2016	92.00		0.007		0.8	U	69		69.8	4.9	
KL4S	6/15/2016	120.00		0.01		1.1	I	79		80.1	8	
KL4S	8/17/2016	260.00		0.025		1.6	U	190		191.6	7.2	
KL4S	10/18/2016	22.00		0.012		1.400		2.900		4.300	3.6	
KL5S	10/21/2015							6.700		6.700		
KL5S	2/17/2016			0.440				0.510		0.510		
KL5S	6/15/2016	2.20										
KL5S	10/18/2016	1.30										
KMW1	10/19/2016	20.00		0.290		3.800		0.450		4.250	1.5	

Appendix C. Regional Application of STUMOD-FL: Using STUMOD-FL to Estimate Nitrogen Loading to Groundwater from Septic Tank Systems in the Wekiva-Rock Springs Basin

Introduction

The NSILTs developed by DEP can be used to estimate spatial nitrogen inputs to the land surface from various sources in designated BMAP areas for water quality impaired springs. A nitrogen attenuation factor is applied to the N input from each source to estimate nitrogen loading to groundwater. Based on an extensive literature search that included septic tank studies in northern Florida and elsewhere, an overall nitrogen attenuation factor of 50 % is used in the NSILT to estimate nitrogen loading to groundwater from septic tank systems. In addition, a spatially varying factor based on the rate of recharge to the UFA is applied to the nonattenuated nitrogen load to estimate a final nitrogen load to groundwater from each source.

The Soil Treatment Unit Model (STUMOD) is another method that can be used to estimate nitrogen loading to groundwater from septic tanks. STUMOD is a spreadsheet-based tool that was developed to estimate the concentrations of nitrogen species and the mass of TN at specified depths in the unsaturated zone beneath OSTDS, or septic tanks (McCray et al. 2010; Geza et al. 2013). STUMOD-FL incorporates soil types and other environmental conditions typically found in Florida. This Florida-specific model, developed as part of the FOSNRS Study (FDOH 2015), is described in more detail in Appendix C-1.

STUMOD-FL can be used as a screening tool to evaluate the transport and fate of nitrogen as it moves from a septic tank drainfield through the unsaturated zone to the water table. The model can account for several nitrogen transformation and attenuation processes, including ammonium sorption, nitrification, and denitrification. Consequently, by incorporating results from STUMOD-FL in the NSILT method, it is possible to account for spatial variations in soil drainage properties, water table depth, and other factors that could affect nitrogen transport to groundwater from septic tank drainfields.

With approximately 38,000 septic tanks in the Wekiva area, it is not feasible to run STUMOD-FL for every septic system or for individual neighborhoods. Therefore, the default model parameters can provide a first-level screening analysis to delineate areas with the highest nitrogen load. Based on the results from these two STUMOD-FL calibration/comparison efforts using measured nitrogen data for the two studies and given the large variability of nitrogen concentrations in STE among studied sites, STUMOD-FL would need to be calibrated for each site individually to match observed nitrogen concentrations in the unsaturated zone and nitrogen concentrations entering the water table. Obviously, this would be impractical for most areas with large numbers of septic tanks. Therefore, a modified STUMOD-FL method is described below to estimate spatial N loading to groundwater.

Modified Spatial Method Using STUMOD for Estimating N Loads to Groundwater from OSTDS

The modified spatial method contains the following steps:

- GIS methods were implemented to select water table depth estimates and soil types for all septic tank locations in the Wekiwa-Rock Springs Springshed.
- Each septic tank system was assigned a nitrogen removal value (% N remaining) based on a look-up table that contained STUMOD-FL model results for various combinations of water table depths and soil types.
- After these steps, spatial ranges of recharge to the UFA were incorporated as weighting factors to calculate an initial loading estimate.
- Finally, the model-generated percentage of N remaining at each site was applied to the input of N from each OSTDS to produce the final loading estimate.

Spatial Data Sources

Table C-1a lists the input datasets used to estimate spatial nitrogen inputs and loading to groundwater. Point data for the location of approximately 38,000 OSTDS were provided by the FDOH Florida Water Management Inventory. Soil physical parameters were obtained from the SSURGO Database available from the USDA NRCS. A map of depth to the water table for the SJRWMD was used to estimate the water table depth. The 2015 recharge areas layer for the UFA was used to delineate recharge categories for the final weighting of STUMOD-FL estimates.

Table C-1a. Spatial data sources

Dataset	Geometry	Source
OSTDS Locations	Point	DEP
Soils – SSURGO	Polygon	USDA NRCS
Depth to Water Table	Raster	SJRWMD
UFA Recharge Areas	Raster	SJRWMD

Incorporation of STUMOD-FL Model Results

The STUMOD-FL look-up table contains 4 water table depth classes (1 ft, 2 ft, 6 ft, and free drainage/greater than 6 ft), 3 soil textures (more permeable sand, less permeable sand, and sandy clay loam), and several drainfield configurations. Soil texture was assigned as sandy clay loam, less permeable sand, and more permeable sand according to soil series texture classifications provided in the FOSNRS D7 report.

Water table depths were assigned using an overlay of the OSTDS location point data with the depth to water table raster. Depth to water table values were further refined to match the conditions used in the look-up table model runs, in which the "water table depth" was the depth to water below the infiltrative surface (the typical drainfield is assumed to be 2 ft below ground surface). The corrected depths were classified to match the lookup table classes of 1 ft, 2 ft, and ≥ 6 ft. Hazen and Sawyer (2014) report that for all free drainage conditions, maximum nitrogen concentration and total mass flux are provided at 6 ft below the infiltrative surface. Model simulations assuming free drainage were found to substantially underestimate nitrogen transport and attenuation. Therefore, all septic tank locations in this analysis with a water table depth greater than 6ft were classified as 6 ft instead of free drainage.

The remaining percentage of TN load from each tank was assigned by joining the look-up table to the OSTDS location points with soil classification and water table depth. All OSTDS were assigned the "bed equal" drainfield configuration because this is assumed to be representative of the area. "Bed unequal" is a common drainfield configuration in the area. However, the values provided in the look-up table for "bed equal" were most representative of the actual monitoring results.

Weighting Load Reduction by Recharge

Percent load concentrations were converted to a fraction of TN remaining at the water table and weighted by recharge category from the Upper Floridan Aquifer Recharge Areas layer. Weights of 0.9, 0.5, 0.1, and 0.1 were assigned to septic tanks located in high-recharge, medium-recharge, and low-recharge areas, respectively. Weighting by recharge category is intended to account for hydrogeological factors that affect attenuation that are not already accounted for by the STUMOD-FL model, and is consistent with the NSILT approach.

Final Estimated N Load to Groundwater

The concentration of TN remaining at the water table for each OSTDS point is simply a fraction of the starting effluent load. The NSILT was used to calculate the amount of TN produced by each OSTDS. The TN produced from each tank was calculated (people per household multiplied by the per capita annual N produced in waste to septic tank [lbs/yr/person] concentration).

- The population served by septic systems was estimated using the 2010 U.S. Census Bureau data for population and household occupancy in each county. The county population was divided by the number of occupied households in the county to obtain an average number of people per occupied household. However, many people with a home septic system potentially have access to a facility connected to a sewer system during their weekly routine (i.e., work, school), thus reducing nitrogen inputs to their septic systems. Population age distribution information was obtained by county from the 2010 Census and time spent away from home was provided by the Bureau of Labor Statistics, to estimate the effective number of people per household and the associated nitrogen input to septic systems.

- The U.S. Environmental Protection Agency (EPA) has reported a per capita contribution of 9.012 lb-N/yr (EPA 1992).

For each OSTDS feature, the assigned percent TN remaining at the water table is applied to the amount of TN produced, resulting in the estimated TN load to groundwater.

Results

The majority (55 %) of the septic tank locations (points) were assigned an attenuation of 52 %, with the highest and lowest attenuation rates being 28 % and 100 %, respectively. **Figure C-1a** shows the range of attenuation for OSTDS in the springshed. **Figure C-1b** shows the fraction of TN remaining at the water table weighted by recharge. **Figure C-1c** shows the final load to groundwater. The total annual load to groundwater from OSTDS in the Wekiwa-Rock Springs Springshed is 312,731 lb-N/yr. **Table C-1b** lists the breakdown of estimated N loads to groundwater by county and recharge volume.

Table C-1b. Load to groundwater in lb-N/yr in high-, medium-, and low-recharge areas in the three counties

Portion of Springshed	High Recharge	Medium Recharge	Low Recharge	TN Load (lb/yr)
Orange County	241,558	47,121	1,276	289,955
Lake County	428	355	72	855
Seminole County	16,003	5,789	130	21,922
Total	**257,990**	**53,264**	**1,478**	**312,732**

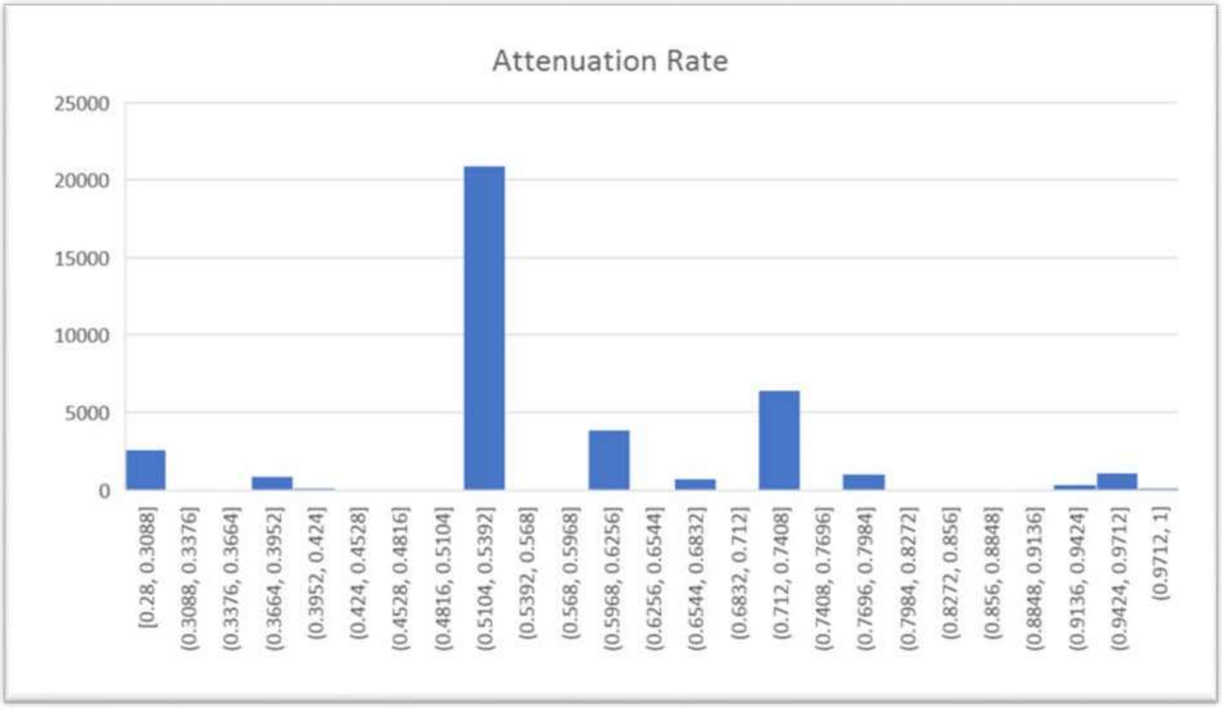

Figure C-1a. Attenuation range for the OSTDS units in the springshed

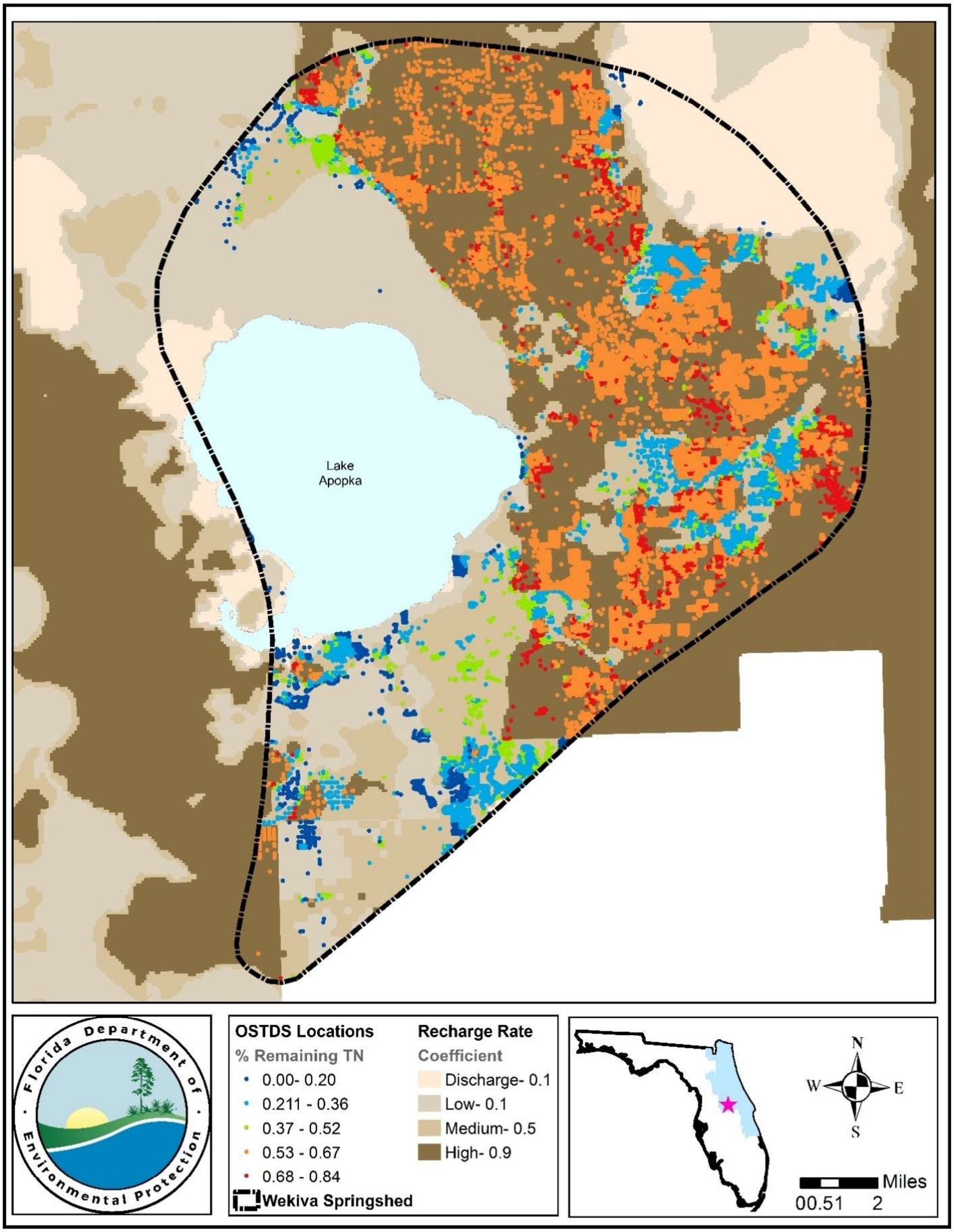

Figure C-1b. TN as a percent of original effluent load

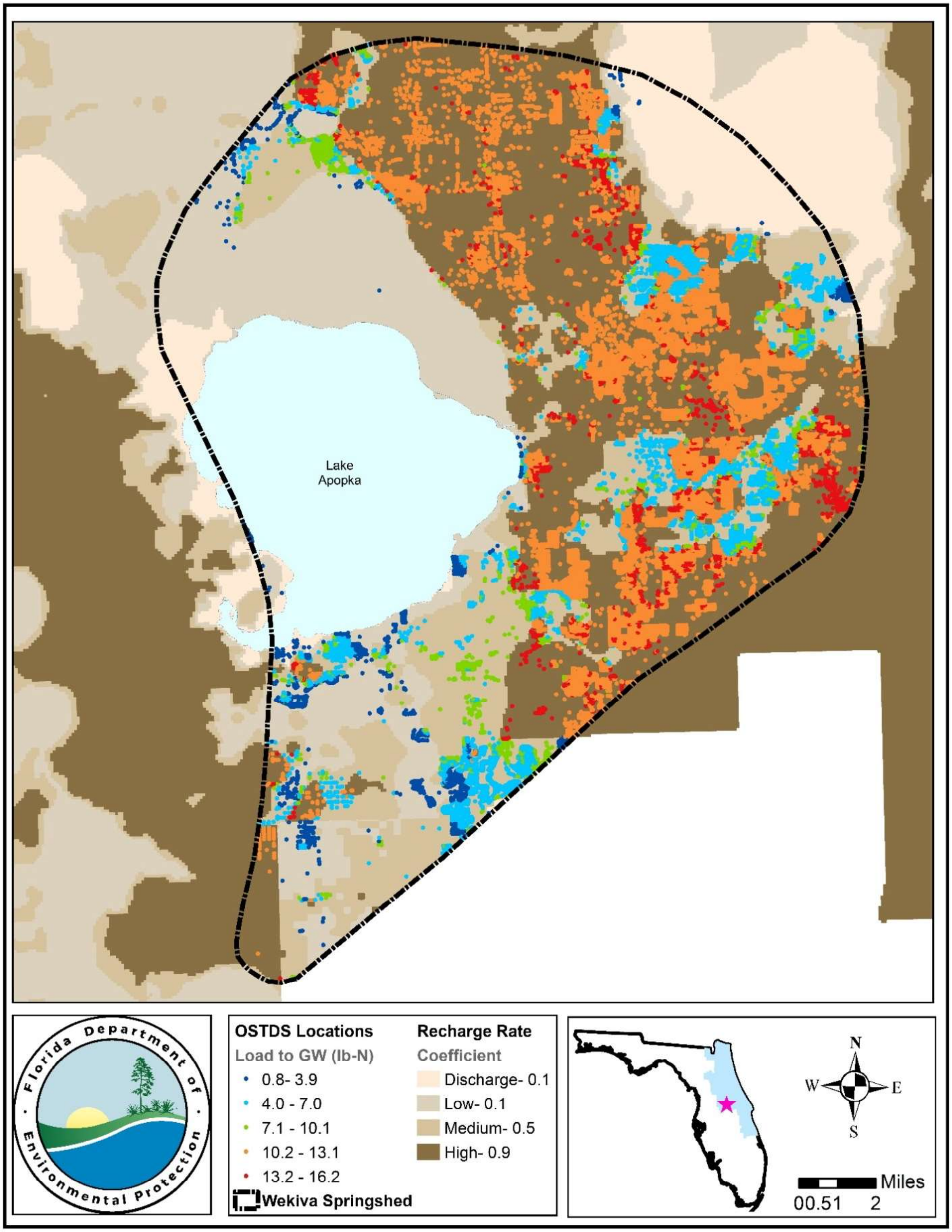

Figure C-1c. TN load to groundwater from OSTDS

Conclusions

The revised STUMOD-FL estimates provide a range of N attenuation rates (28 % to 100 %). However, the majority (55 %) of the septic systems had a N attenuation of 52 %, which closely matches the 50 % overall N attenuation rate used in previous NSILT calculations. The main advantage of using the modified STUMOD-FL spatial estimates is that a map can be developed showing the areas of highest nitrogen loading from septic tanks within the BMAP boundary.

For example, for an area with 6,000 septic tanks, if 2,000 of these tanks were located where sandy soils and shallow depth to water were present, the nitrogen attenuation rate would be 20 %. The remaining 4,000 septic tanks could have a nitrogen attenuation rate of 52 % because of different soil and water table depth conditions, and STUMOD-FL would be able to account for this variability. Further work to refine the N load estimations to groundwater using STUMOD-FL should include additional model calibrations for areas where N data are available for soil pore water, groundwater, soil type, and effluent concentrations.

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Appendix C-1

The developers of STUMOD performed an extensive literature review and statistical analyses of these data to include default input parameters for nitrogen transport and transformation for the biomat and native soil layers. The spreadsheet tool contains a graphical user interface that includes default values for most input parameters, but these parameters can be modified if detailed site-specific data are available. The model also allows the user to include up to three layers with varying soil properties and to calculate parameter sensitivity analyses.

STUMOD-FL incorporates soil types and other environmental conditions typically found in Florida. This Florida-specific model was developed as part of the FOSNRS Study (FDOH 2015). STUMOD-FL can be used as a screening tool to evaluate the transport and fate of nitrogen as it moves from a septic tank drainfield through the unsaturated zone to the water table. STUMOD-FL accounts for several nitrogen transformation and attenuation processes, including ammonium sorption, nitrification, and denitrification.

The user interface, shown in **Figure C-1a**, allows for the use of default values or selected values for soil type, number of soil layers, OSTDS effluent N concentration, hydraulic loading rate, depth to water table, soil temperature, evapotranspiration and plant uptake of N, and carbon content in effluent. STUMOD-FL includes two major components: an unsaturated (vadose) zone module and a saturated zone module (HPS). This report focuses on the use of the model to evaluate the transport and fate of nitrogen as it moves downward through the unsaturated zone to the water table.

The model uses an analytical solution to calculate the profile of pressure based on Darcy's equation and the relation between suction head, unsaturated hydraulic conductivity, and soil moisture. The soil moisture profile, which is calculated from the pressure profile, is used to account for the effect of soil moisture content on nitrification and denitrification calculations. Also included in the model are rate adjustment factors for organic carbon, temperature, and moisture. A simplification of the advection dispersion equation is used to simulate the transport of nitrogen species in ground water.

STUMOD-FL accounts for several nitrogen transformation and attenuation processes, including ammonium sorption, nitrification, and denitrification. Input parameters for the unsaturated zone include nitrogen concentration in STE, properties for various Florida soil types, hydraulic loading rate, soil temperature, evapotranspiration and plant uptake of nitrogen, organic carbon content, and septic tank drainfield dimensions.

The STUMOD developers performed an extensive literature review and statistical analyses of these data to include default input parameters for nitrogen transport and transformation for the biomat and native soil layers. The spreadsheet tool contains a graphical user interface that includes default values for most input parameters, but these parameters can be modified if detailed site-specific data are available. The table in **Appendix C-2** contains a complete list of all input parameters.

The model also allows the user to include up to three layers with varying soil properties. It assumes steady-state conditions, vertical flow in the unsaturated zone, and nitrogen transport by advection. The model also allows the user to calculate parameter sensitivity analyses.

The mass balance–derived loading estimates from STUMOD-FL-HPS are based on several assumptions such as vertical flow, steady-state pressure in the unsaturated (vadose) zone, soil moisture conditions for various soil types, and nitrogen transport by advection at steady state conditions. Default values for the many parameters in the model are based on data compiled from an extensive review of the literature (Geza et al. 2014). The user interface, shown in **Figure C-1d**, allows the use of default values or selected values for soil type, number of soil layers, OSTDS effluent N concentration, hydraulic loading rate, depth to water table, soil temperature, evapotranspiration and plant uptake of N, and carbon content in effluent.

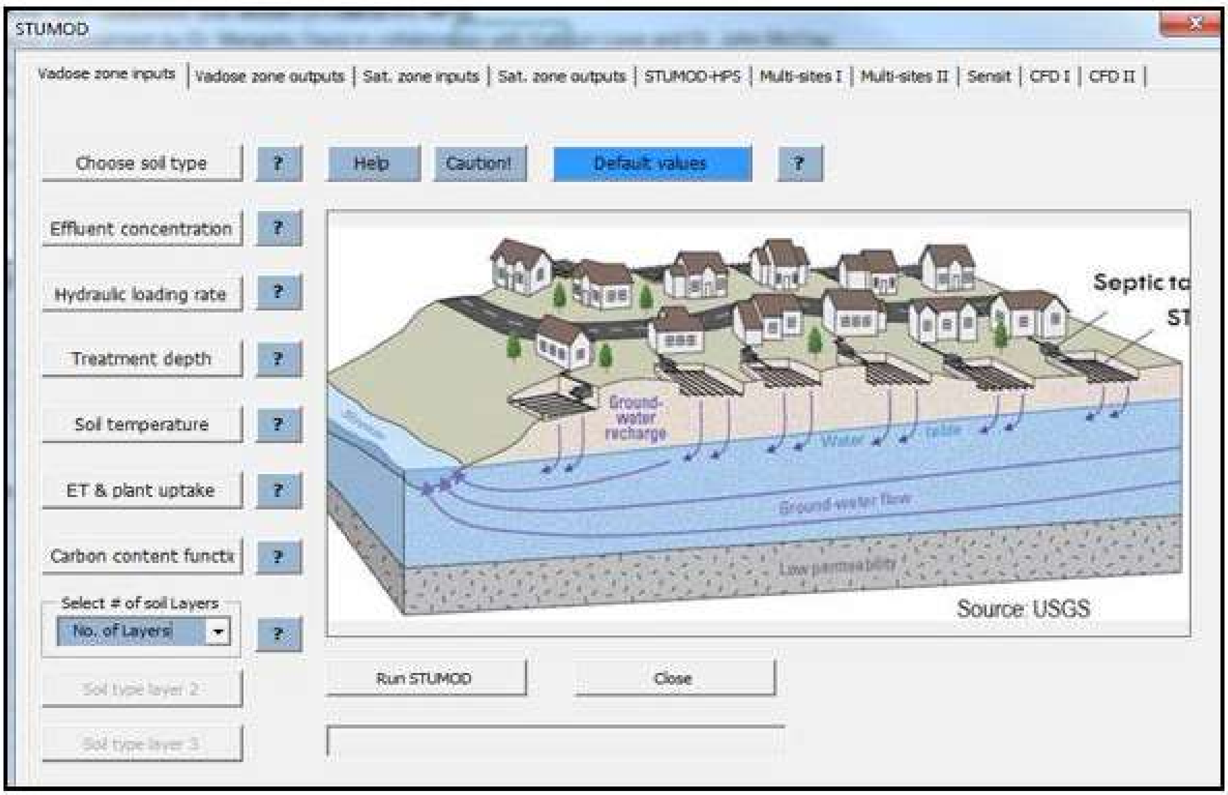

Figure C-1d. User interface showing parameters used in STUMOD to estimate nitrogen fate and transport from OSTDS

Appendix C-2

Table C-2a. List of input parameters in STUMOD-FL-HPS and defaults for permeable sand

Parameter	Symbol	Defaults
Soil type		sand more permeable
Hydraulic loading rate	HLR	2
Parameter a in Gradner's analytical equation for pressure distribution (also referred to as aG)	aG	0.06
Parameter a in the soil water retention function (*also* referred to as aVG)	aVG	0.024
Saturated hydraulic conductivity (also referred to as Ksat)	Ks	670.8
Residual soil moisture (also referred to as qr)	qr	0.013
Saturated soil moisture (also referred to as qs)	qs	0.3874
Parameter n in the soil water retention function	n	2.52
Parameter m in the soil water retention function	m	0.603174603
Tortuosity parameter	l	0.5
Effluent ammonium-nitrogen concentration	Co NH4	60
Effluent nitrate-nitrogen concentration	Co NO3	0.001
Empirical exponent for nitrification	e2	1
Empirical exponent for nitrification	e3	1
Maximum nitrification rate	kr max	2.5
Half-saturation constant for ammonium-nitrogen	Km,nit	5
Empirical coefficient for temperature function for nitrification (also referred to as bnit)	bnit	0.186
Value of the soil water response function at saturation	fs	0
Value of the soil water response function at wilting point	fwp	0
Relative saturation at wilting point	swp	0
Relative saturation for biological process (lower limit)	sl	0.5
Relative saturation for biological process (upper limit)	sh	0.85
Empirical exponent for denitrification	ednt	1.5
Maximum denitrification rate	Vmax	2.58
Half-saturation constant for nitrate-nitrogen	Km,dnt	5
An empirical coefficient for temperature function (also referred to as bdnt)	bdnt	0.186
A threshold relative saturation (dimensionless)	sdn	0
Soil temperature	T	22
Adsorption Isotherm	kd	0.35
Optimum soil temperature for nitrification (also referred to as Topt-nit(oC))	Topt-nit	25
Optimum soil temperature for denitrification (also referred to as Topt-dnt(oC))	Topt-dnt	25
Treatment depth	Soil depth	60

Parameter	Symbol	Defaults
Elemental depth	Dz	0.966666667
Rate adjustment coefficient for denitrification (0 to 1)- calculated value	ftdnt	0.967074253
Rate adjustment coefficient for nitrification (0 to 1) - calculated value	ftnit	0.967074253
Bulk density	rho	1.51
Retardation factor for ammonium-nitrogen when Kd=0, R=1, otherwise R>1	R'(NH4)	1
Retardation factor for nitrate-nitrogen when Kd=0, R=1, otherwise R>2	R (NO3)	1
Minimum NH4 concentration	MinCNH4	0.001
Minimum NO3 concentration	MinCNO3	0.001
Maximum daily temperature (used in Hargreaves equation for ET)	Tmax	30
Maximum daily temperature (used in Hargreaves equation for ET)	Tmin	20
Average daily temperature (used in Hargreaves equation for ET)	Tavg	25
Latitude (La)	La	28.16862668
ET parameter calculated from La, M=14.9423 – 0.0098La – 0.00175(La)^2	M	13.27787228
ET parameter calculated from La, C1=-0.5801 + 0.1834 La – 0.00066La	C1	4.062334924
ET parameter calculated from La, C2 = 3.1365 – 0.00489 La + 0.00061(La)^2	C2	3.047157179
ET parameter calculated from La, C3 = 0.597 – 5.36 – 10-6(La)^2	C3	0.477198622
ET parameter calculated from La, C4 = 2.9588 – 0.00909 La + 0.00024(La)^2	C4	2.89318035
Order of the month, January = 1	J	6
***S*uction when ET = half the potential evapotranspiration**	h50	-800
A calibration parameter influencing the degree of dependence of ET on soil moisture	p1	3
Root depth from the land surface	root depth	30
Plants' ability to take water against gradient, 0 = non-compensated, 1 = fully compensated	wc	1
Potential nutrient demand (kg/ha/yr)	Rp	0
Maximum allowed solution concentration in ET	Cmax	60
Minimum nutrient concentration required for active uptake to take effect	Cmin	0
K_m is the Michaelis–Menten constant [ML^{-3}]	Km	0.5
Critical nutrient stress index	πc	1
R_a is the daily extraterrestrial radiation in equivalent millimeters (mm) of water evaporation for a day (mm/day)	Ra	17.78385447
Potential evapotranspiration (PET) (cm/day)	PET	0.553601809
The combined stress factor (0 to 1) from moisture stress and root distribution	w	0.708790087
	w'	0.708790087
Actual ET (cm/day)	ET	0.392387575
Passive root nutrient uptake rates [$ML^{-2}T^{-1}$]	Pa	0

Parameter	Symbol	Defaults
The potential active uptake	Ap	0
A nutrient stress index	π	0.934902249
Active root nutrient uptake rates [ML−2T−1]	Aa	0
	π'	0.934902249
The total compensated active root nutrient uptake rate	Aac	0
Total uptake (active and passive)	Total	0
	Carbon function	
Concentration of carbon in STE	Co STE	25
Sorption rate for carbon	Kd	0
Biodegradation rate for fast degrading fraction of carbon	Kb1	0.5
Biodegradation rate for moderately degrading fraction of carbon	Kb2	0.3
Biodegradation rate for slow degrading fraction of carbon	Kb3	0.25
Upper limit of slow degrading BDOC (mg/L) = (1-fdf) * Co	Cfdf	19
Slow degrading concentration (mg/L) = (sdf* Co)	csdf	9
Fraction of fast biodegradable portion of carbon	fdf	0.25
Refractory fraction	sdf	0.35
Calibration parameter for response function for moderately degrading zone	α1	0.1
Calibration parameter for response function for fast degrading zone	α2	0.1
Calibration parameter for response function for soil carbon	Co Soil	2