# NITROGEN SOURCE INVENTORY AND LOADING ESTIMATES FOR THE WEEKI WACHEE SPRING AND RIVER CONTRIBUTING AREA


**Kirstin T. Eller and Brian G. Katz, Ph.D.**
**Division of Environmental Assessment and Restoration**
**Water Quality Evaluation and Total Maximum Daily Loads Program**
**Groundwater Management Section**
**Florida Department of Environmental Protection**


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**2600 Blair Stone Road**
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This assessment was conducted by the Florida Department of Environmental Protection Groundwater Management Section of the Water Quality Evaluation and Total Maximum Daily Loads (TMDL) Program to assist in the development and implementation of the Weeki Wachee Spring Basin Management Action Plan (BMAP) to address the TMDL for nitrate. The results of this assessment are based on the information provided in the document.

***Disclaimer****: Please note that all values listed in this report are rounded, while the actual calculations were completed utilizing whole numbers.*

For more information on this report, contact:

Kirstin Eller, Environmental Consultant
850/245–8652
kirstin.eller@dep.state.fl.us

Brian Katz, Ph.D., Environmental Scientist
850/245–8233
brian.katz@dep.state.fl.us

For more information on the Weeki Wachee Spring BMAP, contact:
Terry Hansen
850/245–8561
terry.hansen@dep.state.fl.us

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# SUMMARY OF FINDINGS

Weeki Wachee Spring is a first-magnitude spring that discharges water from the karstic Upper Floridan aquifer (UFA), creating the Weeki Wachee River in Hernando County, Florida. The spring discharged an estimated average of 174 cubic feet per second (cfs) from 1935 to 2004. There are a number of other smaller springs and seeps in the Weeki Wachee Spring basin, including Wilderness Spring, Salt Spring, Mud Spring, Hospital Spring, Jenkins Spring, and Little Spring.

Weeki Wachee Spring and Weeki Wachee River were identified as impaired because of ecological imbalances attributed to elevated nutrient concentrations. In 2014, a total maximum daily load (TMDL) of 0.35 milligrams per liter (mg/L) (Dodson and Bridger 2014) was developed to establish water quality restoration thresholds for both the spring and river. Elevated nitrate concentrations in the spring result from current and historical land use practices that have contributed large amounts of nitrogen to groundwater in the spring basin.

The Florida Department of Environmental Protection (DEP) developed a Nitrogen Source Inventory and Loading Tool (NSILT) to provide information on the major sources of nitrogen (atmospheric deposition, wastewater treatment facilities [WWTFs], urban fertilizers, septic systems, livestock wastes, agricultural fertilizers) in the groundwater contributing area for Weeki Wachee Spring. In addition, this tool is used to estimate nitrogen loads to groundwater from these sources in the spring contributing area.

NSILT is an ArcGIS- and spreadsheet-based tool that provides spatial estimates of the relative contribution of nitrogen from major nitrogen sources, and accounts for the transport pathways and processes affecting the various forms of nitrogen as they move from the land surface through the soil and geologic strata overlying the UFA.

This report describes the methods, information, and data sources used in developing the NSILT to estimate nitrogen loads to groundwater in the Weeki Wachee Spring contributing area. The information is provided as a planning tool for the development and implementation of a basin management action plan (BMAP), which addresses the nitrate impairment in Weeki Wachee Spring, Weeki Wachee River, and Aripeka Spring.

The NSILT is being used in the BMAP development process to identify source categories and areas where nitrogen source reduction efforts could be focused to achieve the most beneficial effects on water quality for Weeki Wachee Spring and Weeki Wachee River. The total annual nitrogen input to the land surface in the contributing area from all sources is 6.3 million pounds of nitrogen (lb-N). Urban and sports turfgrass fertilizers contributes 30% of the TN input. Other nitrogen sources, in order of decreasing nitrogen inputs to the land surface, include livestock waste (21%), farm fertilizer (19%), atmospheric deposition (18%), septic systems (10%), and wastewater treatment facility (1%).

The NSILT results indicate an estimated total annual load of 1,004,655 pounds of nitrogen to the UFA in the Weeki Wachee Spring groundwater contributing area, representing 16% of the amount of nitrogen inputs to the land surface. Most of the nitrogen in a given year does not reach groundwater due to nitrogen attenuation processes and variations in the rate of aquifer recharge. In areas of the Weeki Wachee springshed where recharge rates are categorized as low (0 to 3 inches per year [in/yr]) medium (3.01 to 10 in/yr) or high (greater than 10 in/yr), the UFA is more vulnerable to contamination than in areas where recharge rates are low.

Groundwater discharge areas were not included in the calculations of nitrogen loads to the groundwater contributing area, as these areas do not contribute nitrogen to the aquifer. To account for variations in recharge rates to the UFA, non-attenuated nitrogen inputs in high rate recharge areas are multiplied by a weighting factor of 0.9, while nitrogen inputs are multiplied by a weighting factor of 0.5 for medium rate recharge areas and 0.1 for low.

The highest estimated nitrogen loads in the groundwater contributing area to Weeki Wachee Spring are from urban turfgrass fertilizer (29%), followed by septic systems (28%) and farm fertilizers (16%). Sources contributing smaller amounts of nitrogen include atmospheric deposition (9%), livestock waste (9%), sport turfgrass fertilizer (4%), and the land application of treated wastewater (4%).

The NSILT results provide a baseline understanding of existing nitrogen loads to groundwater from multiple sources in areas where the Weeki Wachee Spring basin is most susceptible to groundwater contamination. This tool can also be used to evaluate the nitrogen load reduction benefits of various management actions and nitrogen reduction projects at various locations in the Weeki Wachee Spring contributing area.

# 1. Introduction

In Florida, springs provide sites of recreational and cultural value as well as sources of potable water, and afford a way to assess regional groundwater quality. Springs integrate groundwater vertically, spatially, and temporally from the Upper Floridan aquifer (UFA) (Bush and Johnston 1988; Katz 1992, 2004; Davis 1996). Rainfall that infiltrates into the subsurface and recharges the aquifer system contains nitrogen and other dissolved chemicals of concern originating from anthropogenic activities at or near the land surface. Groundwater with elevated nitrate concentrations flows toward Weeki Wachee Spring.

Elevated nitrate concentrations in Florida's springs contribute to water quality degradation in their receiving surface waters. This problem will continue if nitrogen inputs are not reduced. Restoration plans to reduce these inputs must include strategies to address the most significant nitrogen sources by obtaining detailed nitrogen loading information from sources in springsheds such as fertilizer applied to cropland and turfgrass, septic tanks, the land application of treated domestic wastewater, atmospheric deposition, and animal wastes.

To identify and quantify the major sources of nitrogen in groundwater contributing areas to springs, the Florida Department of Environmental Protection (DEP) developed the Nitrogen Source Inventory and Loading Tool (NSILT). This tool quantifies nitrogen inputs to the land surface based on the best available, current information on land uses, agricultural practices, urban fertilizer use, waste disposal methods, and atmospheric sources. The NSILT is also used to estimates nitrogen loads to groundwater in the contributing area by taking into account the attenuation of various forms of nitrogen from sources and recharge rates to the UFA. The NSILT results are used in the development and implementation of the basin management action plan (BMAP) for the Coastal Springs of Pasco and Hernando Counties—including Weeki Wachee Spring and River, Wilderness Spring, Salt Spring, Mud Spring, Hospital Spring, Jenkins Spring, and Little Spring—by helping to focus nitrogen source reduction efforts to achieve the greatest improvement in water quality.

## 1.1 Weeki Wachee Spring and Weeki Wachee River Basin

Weeki Wachee Spring is an historic and world-renowned tourist attraction located in Weeki Wachee Springs State Park. This first-magnitude spring is the primary source of water for the 7-mile-long Weeki Wachee River. Several smaller springs, including Little Spring and Hospital Spring, are located throughout the spring basin and along the river. The Weeki Wachee Spring pool is 165 feet by 210 feet and 45 feet deep over the spring vent. The spring vent is a small opening through exposed limestone rock at a depth of 185 feet (Dodson and Bridger 2014).

In 2009, Weeki Wachee Spring, the Weeki Wachee River, and other springs in the vicinity were verified as impaired because of ecological imbalances attributed to elevated nutrient concentrations. In 2014, a total maximum daily load (TMDL) was developed to establish a water quality restoration threshold for nitrate-N of 0.35 milligrams per liter (mg/L) for both Weeki Wachee Spring and River, and a TMDL of 0.23 mg/L for additional springs, including

Wilderness Spring, Salt Spring, Mud Spring, and Jenkins Spring (Dodson and Bridger 2014; Bridger and Dodson 2015).

Elevated nitrate concentrations in Weeki Wachee and other springs result from current and historical land use practices contributing nitrogen to the UFA, the highly transmissive limestone aquifer that is the source of water flowing from the springs. The NSILT is being used to provide stakeholders with current information on the sources of nitrogen in the Weeki Wachee Spring contributing area and the relative nitrogen contributions of each source to the UFA. More important, the NSILT is being used as a planning tool for the development and implementation of the BMAP for the Coastal Springs of Pasco and Hernando Counties to address the water quality impairment.

## 1.2 Weeki Wachee Spring Groundwater Contributing Area

Weeki Wachee Spring is located near the Gulf Coast of Florida in Hernando County (**Figure 1**). The groundwater contributing area for the spring lies in Hernando County in the north and Pasco County in the south. This area is largely based on the springshed boundary delineated by the Southwest Florida Water Management District (SWFWMD) (Jones et al. 1997) and is the source of groundwater flowing to Weeki Wachee Spring. The contributing area covers 162,714 acres. Land uses comprise 33% urban landscapes, 24% forested areas, 21% agriculture, and 16% wetlands and marshes. The remaining 6% includes waterbodies, rangeland, and miscellaneous land uses.

The Weeki Wachee Spring contributing area comprises most of the region addressed in the larger BMAP area for coastal springs in Hernando and Pasco Counties, as shown in **Figure 2**. A separate NSILT analysis will be conducted for the groundwater contributing area to Magnolia and Aripeka Springs in fall 2016.

## 1.3 Hydrogeology and Aquifer Recharge

The Floridan aquifer system in this area is composed of thick sequences of limestone and dolostone of Eocene to Miocene age that are exposed at or very near to (10 to 20 feet) the land surface (Dodson and Bridger 2014). The UFA is the predominant source of water discharging from Weeki Wachee Spring (Jones et al. 1997; Faulkner 1970).

The dissolution of the carbonate rocks that comprise the UFA has created numerous karst features (sinkholes, caves, and conduits) over geologic time in this area. These features, along with a thin layer of sediments overlying the UFA, allow water from the land surface to move directly and relatively rapidly into the aquifer.

Consequently, the movement of groundwater into the UFA responds relatively quickly to changes in rainfall and recharge, and groundwater flows directly to springs where conduits are present. Groundwater discharging from the springs originates from both nearby source areas and more distant areas in the springshed. As a result, Weeki Wachee spring water is a mixture of groundwater that has resided in the aquifer for varying amounts of time, ranging from days to several decades.

Most of the drainage within the Weeki Wachee springshed is internal, and rainwater that recharges the UFA infiltrates from the land surface directly into closed depressions or through thin overlying sediments into the unconfined limestone of the UFA. Jones *et al.* (1997) and Dodson and Bridger (2014) describe the hydrogeologic framework for this area in greater detail. Recharge rates to the UFA are affected by spatial variations in the hydrogeological characteristics of the surficial aquifer and intermediate confining unit, karst features, and average annual rainfall.

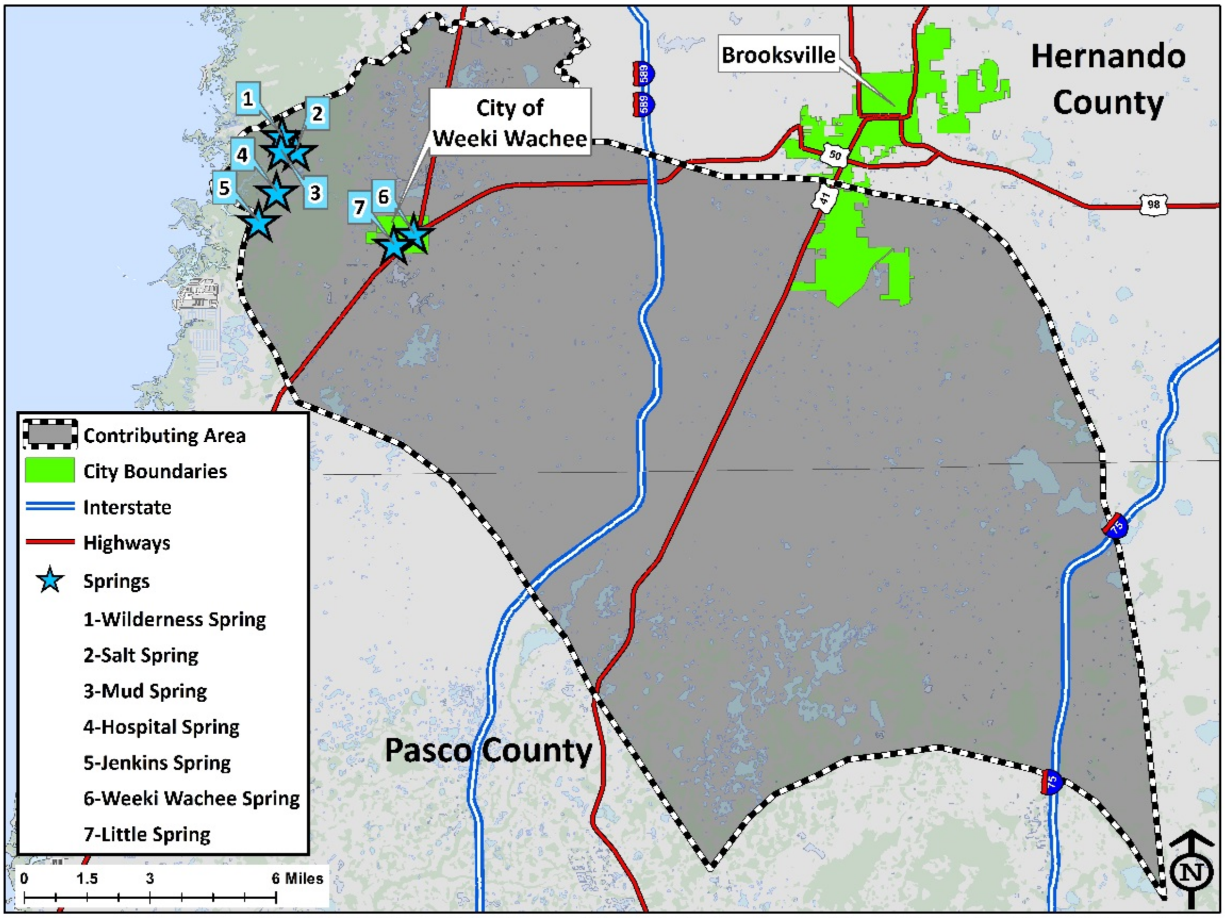


**Figure 1: Map showing the Weeki Wachee Spring and Weeki Wachee River contributing area**

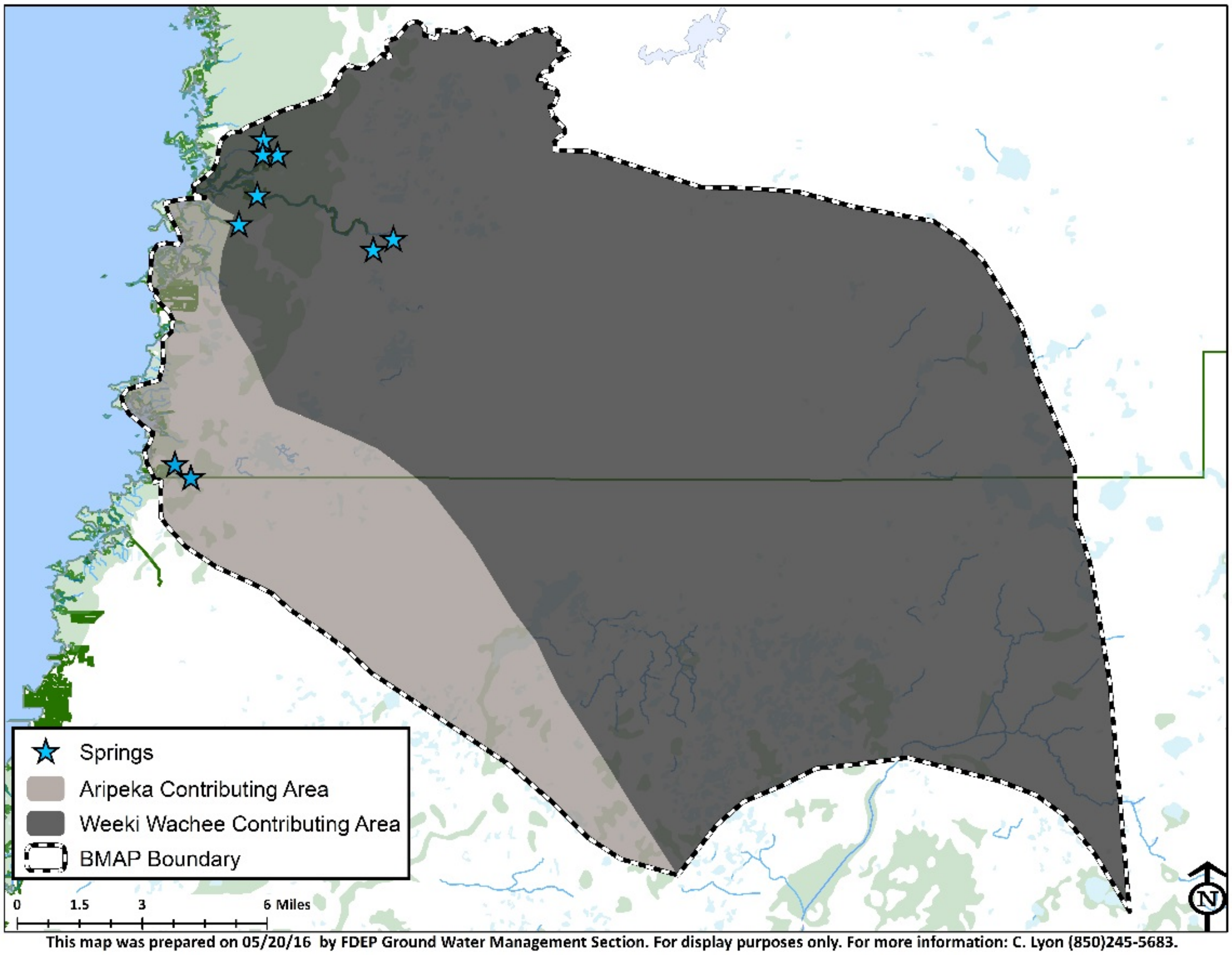


**Figure 2: BMAP area for the coastal springs of Pasco and Hernando Counties**

In 2002, the U.S. Geological Survey (USGS) developed a numeric model of the intermediate and Floridan aquifer systems based on well data from 1993–94 (Sepulveda 2002). The model area spans over 40,000 square miles of peninsular Florida and is composed of uniform model grid dimensions of 5,000-foot cells. The USGS raster-based data were smoothed to create 3 recharge rate categories in the Weeki Wachee BMAP area: low (0 to 3 inches per year [in/yr]), medium (3.01 to 10 in/yr), and high (10.01 in/yr or greater) (**Figure 3**). The amount of annual recharge affects the transport of nitrogen to the aquifer. Therefore, it is likely that more nitrogen would reach the aquifer annually in high recharge rate areas than in lower recharge rate areas, if both areas were to receive similar nitrogen inputs to the land surface.

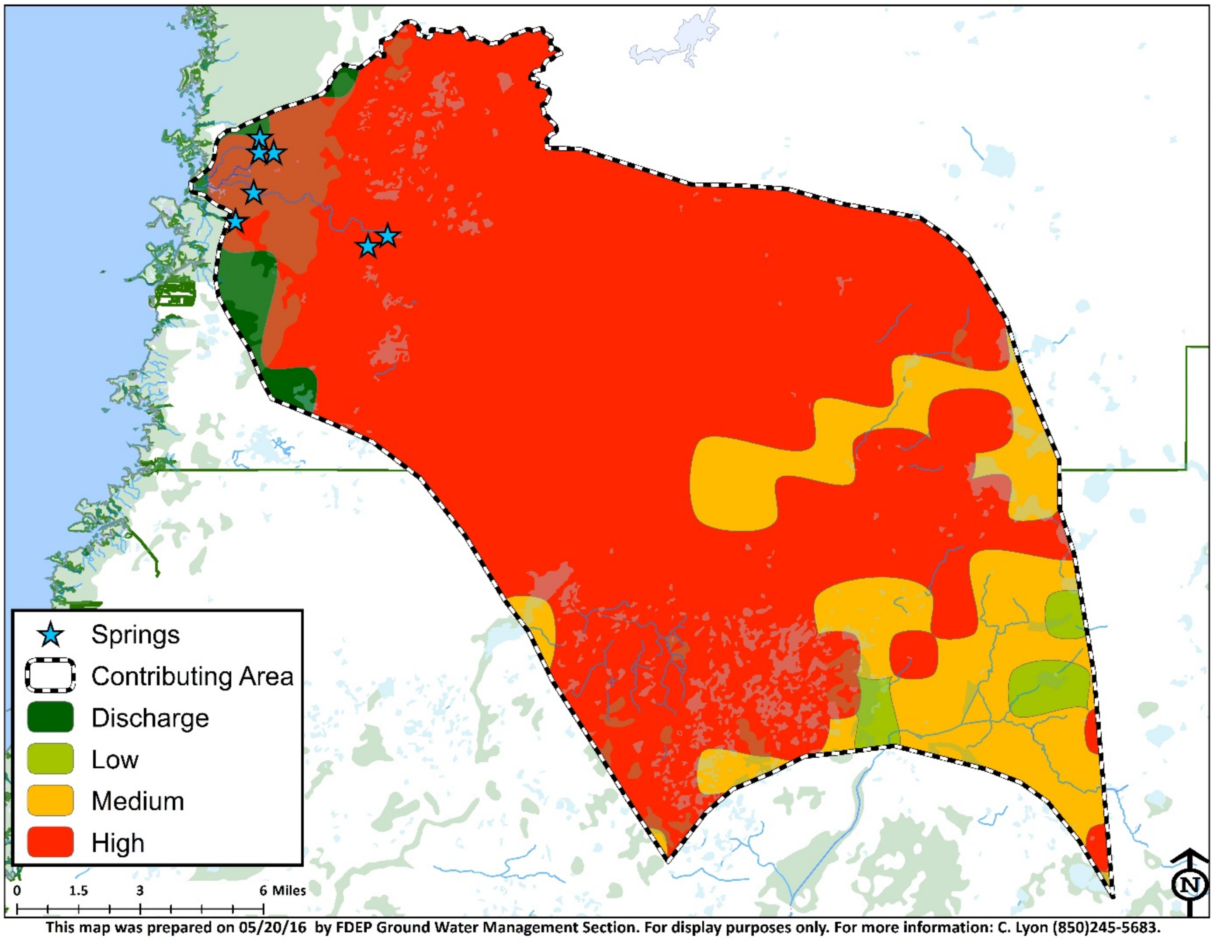


**Figure 3: UFA recharge rate categories in the Weeki Wachee Spring contributing area**

# 1.4 Land Use

Land use/land cover (LULC) was assessed with the most recent land use ArcGIS coverages obtained from the SWFWMD and county property appraisers. The Weeki Wachee Spring contributing area lies completely within the SWFWMD boundary. All land use classifications used by the SWFWMD were based on the Florida Land Use/Land Coverage and Forms Classification System (FLUCCS). The 2011 land use was created through the interpretation of digital imagery taken in December 2010. The land use classifications were determined through photo interpretation, editing, and quality check processes. **Table A.2** and **Table A.3** provide additional details of these data.

Additional land use information was obtained from the Hernando and Pasco County property appraisers. Staff from each county property appraiser's office conduct routine field visits to update and verify the land use classification of parcels for tax purposes. These visits occur at least every five years, although most parcels are visited more frequently. This system allows for continual updates and for 2014 data to be used for this analysis (**Table A.4** and **Table A.5**).

For the assessment of current land use, the property appraisers also provided detailed information on the specific agricultural practices used for estimating nitrogen contributions from fertilizer use on farmland. The land use information obtained from property appraisers is designated as "PA" in this report.

# 2. Estimating Nitrogen Inputs to the Land Surface

Nitrogen inputs to the land surface in the BMAP area were evaluated for atmospheric deposition, wastewater treatment facility (WWTF) land application sites, septic systems, urban and agricultural fertilizer application, and livestock waste. The methods used to estimate nitrogen inputs for each source are based on a detailed synthesis of information, including direct water quality measurements, census data, surveys, wastewater permits, published scientific studies and reports, and information obtained in meetings with agricultural producers.

In many cases, several assumptions and extrapolations were made for estimating nitrogen inputs from each source, and as a result the nitrogen inputs presented in this report are subject to further refinement as more detailed information becomes available. The approach and sources of information used to estimate the annual nitrogen input (in pounds per year [lb-N/yr]) to the land surface for each source category are discussed below.

## 2.1 Atmospheric Deposition

Atmospheric deposition is largely a diffuse, albeit continual, source of nitrogen. Nitrogen species and other chemical constituents are measured in wet and dry deposition at discrete locations around the U.S. In Florida, the Clean Air Status and Trends Network (CASTNET) has two stations that collect dry deposition data for analysis. Wet deposition data currently are collected at nine stations around the state as part of the National Atmospheric Deposition Program (NADP) National Trends Network (NTN).

Recently, Schwede and Lear (2014) developed a hybrid model for estimating the total atmospheric deposition (TDEP) of nitrogen and sulfur for the entire U.S. Deposition data from several monitoring networks—including CASTNET, the NADP Ammonia Monitoring Network, the Southeastern Aerosol Research and Characterization Network, and modeled data from the Community Multi-Scale Air Quality Model—are combined in a multistep process with National Trends Network wet deposition values to model total deposition in 16-kilometer (km) grid cells.

Multiple TDEP model runs are available, providing atmospheric data for individual and multiple years, with average values calculated for the multiyear models. The TDEP model run used for the NSILT includes data from 2011 to 2013. The total nitrogen (TN) data are available in a nationwide coverage (.e00) file and were converted into ArcGIS shapefiles for the purpose of this analysis. **Figure 4** illustrates the model results for TN deposition in the Weeki Wachee Spring contributing area. The total nitrogen deposition amounts in high, medium, and low recharge rate areas are 923,127 lb-N/yr; 197,713lb-N/yr; and 24,093 lb-N/yr, respectively.

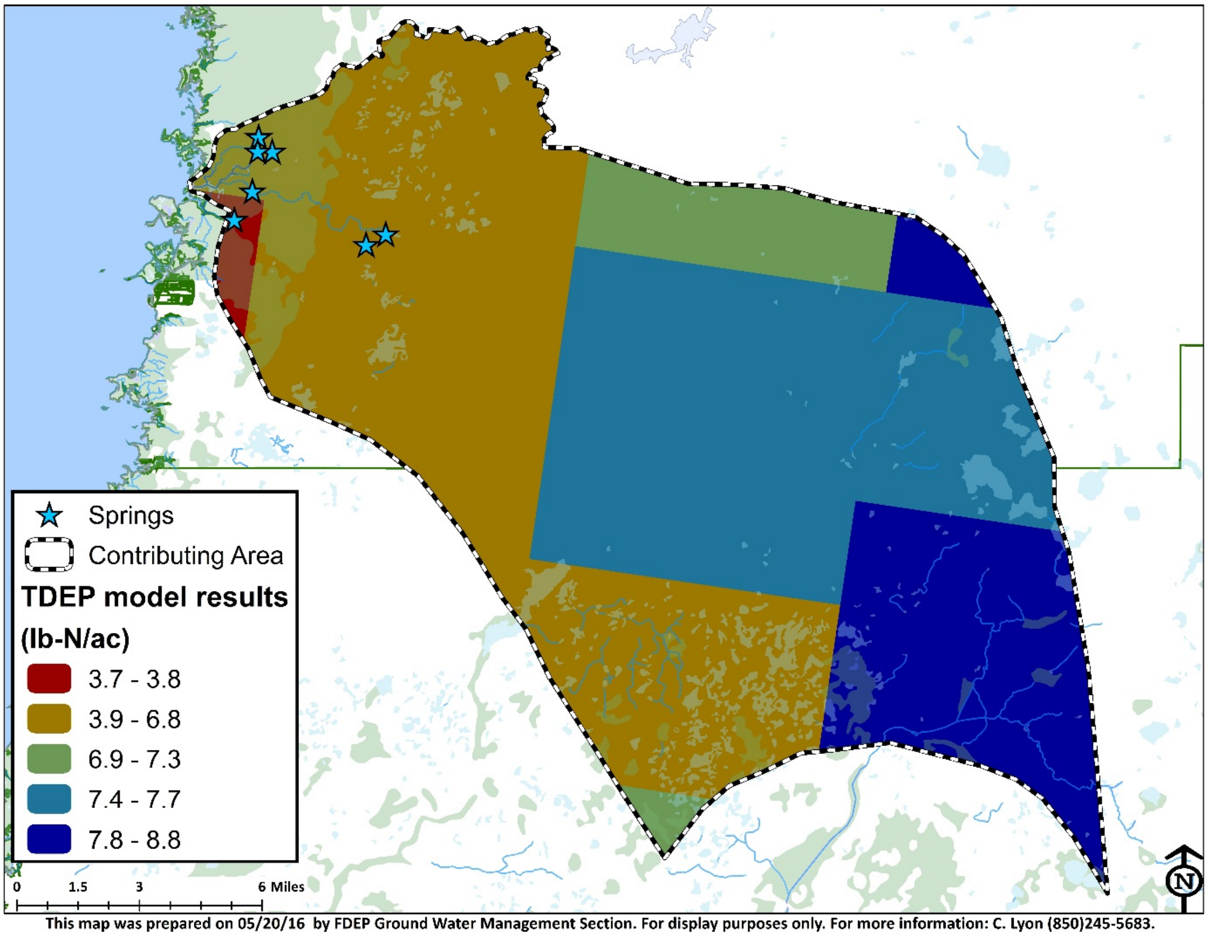


**Figure 4: Atmospheric deposition model results used for the NSILT**

## 2.2 Wastewater Treatment Facilities

WWTFs receive and treat domestic wastewater. In the Weeki Wachee Spring contributing area, treated effluent containing nitrogen from WWTFs is discharged to sprayfields, rapid infiltration basins (RIBs), and percolation ponds. While other areas in Florida use reclaimed water from WWTFs for irrigation and fertilization, these practices are not currently being used in this contributing area. There are 14 WWTFs located in the Weeki Wachee Spring contributing area, 3 in Pasco County and the remaining 11 in Hernando County. There are 2 facilities discharging more than 100,000 gallons of treated effluent per day (**Figure 5**). Additionally, there are 2 facilities located outside of the Weeki Wachee contributing area which distribute reclaimed water for irrigation within the contributing area.

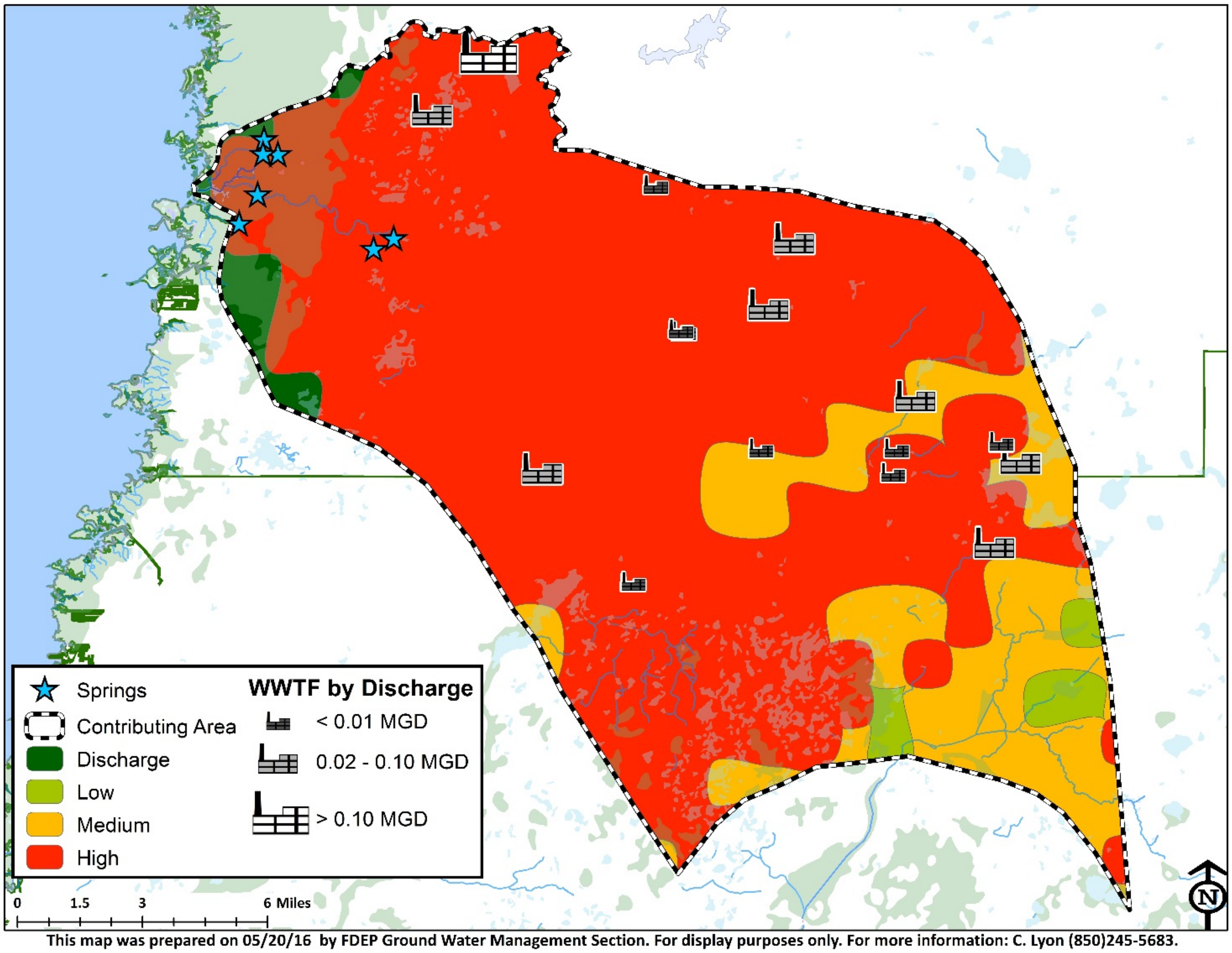


**Figure 5: Distribution of WWTFs in the Weeki Wachee Spring contributing area**

The required water-quality monitoring varies between facilities depending on permitting requirements, and not all facilities report the same type of data. The annual effluent input of nitrogen to the land surface was estimated using the average TN concentration and the discharge (volume), but this information was not always available for smaller facilities. Smaller WWTFs (<0.1 million gallons per day [MGD] by volume) are not always required to monitor and report TN effluent concentrations, and therefore not all these facilities had data available in the DEP Wastewater Facility Regulation (WAFR) Database.

For these, DEP estimated TN concentrations from nitrate-N ($NO_3$-N) data (assuming the $NO_3$-N concentration was 38.5% of the TN based on a 2009 cooperative study with the Water Reuse Foundation of 40 domestic WWTFs across the state). For this calculation, the $NO_3$-N value is divided by 0.385, resulting in an estimated TN concentration. The WWTF data were compiled for each facility and include the most recent complete year of data. The years of data vary with the individual facilities; however, the majority of the data is from 2013 to 2014.

For facilities permitted for the land application of treated wastewater, the reported annual average flows were used to calculate an average discharge for the evaluated year applied to sprayfields, RIBs, and absorption fields. For the purpose of this analysis, absorption fields are included with RIBs because they have similar processes that attenuate nitrogen. The nitrogen inputs for each WWTF were calculated using the average annual TN concentration and the average yearly flow from the facility. The average annual nitrogen inputs from wastewater facilities were estimated for each recharge rate category based on the location of the effluent treatment sites in the contributing area.

**Table 1** and **Table 2** summarize the nitrogen input data from facilities in the contributing area. In total, an estimated 39,796 lb-N/yr are applied to the land surface from these facilities in the high recharge rate areas, and an additional 602 lb-N/yr are applied in the medium recharge rate areas. Without any facilities located in the low-recharge areas, there is no attributable nitrogen input to the land surface.

**Table 1: Data for Hernando County WWTFs in the Weeki Wachee contributing area**

* TN data estimated based on available $NO_3$ data.

| WWTF Name | Facility ID | Treatment Type | Recharge Area | Annual Average TN (mg-N/L) | Annual Flow (MGD) | Nitrogen Input (lb-N/yr) |
|---|---|---|---|---|---|---|
| **Hernando Subregional Airport** | FLA017223 | RIB | High | 13.23* | 0.74 | 29,740 |
| **Glen Water Reclamation Facility** | FLA012069 | RIB | High | 3.93 | 0.60 | 7,228 |
| **Camper's Holiday Association** | FLA012045 | RIB | Medium | 10.66* | 0.01 | 389 |
| **Lakewood Retreat** | FLA017033 | Sprayfield | Medium | 8.97 | 0.01 | 213 |
| **Topics RV Community** | FLA012065 | RIB | High | 4.99* | 0.01 | 146 |
| **Eckerd Academy** | FLA012039 | RIB | High | 20.78* | 0.002 | 127 |
| **Imperial Estates** | FLA012059 | RIB | High | 4.33* | 0.01 | 123 |
| **Camp-A-Wyle Resort** | FLA012044 | RIB | High | 4.38* | 0.01 | 115 |
| **CoGoP State Campground** | FLA012066 | RIB | High | 17.52* | 0.001 | 70 |
| **Big Tree MH and RV Village** | FLA012048 | RIB Absorption Field | High | 0.54* | 0.01 | 19 |
| **Eckerd Youth Challenge Program** | FLA186830 | Sprayfield | High | 1.40* | 0.002 | 10 |

**Table 2: Data for Pasco County WWTFs in the Weeki Wachee contributing area**

* TN data estimated based on available $NO_3$ data.

| WWTF Name | Facility ID | Treatment Type | Recharge Area | Annual Average TN (mg-N/L) | Annual Flow (MGD) | Nitrogen Input (lb-N/yr) |
|---|---|---|---|---|---|---|
| **Travelers Rest** | FLA012831 | RIB | High | 26.08* | 0.03 | 2,171 |
| **Big Oaks RV Park** | FLA012756 | RIB | High | 2.83* | 0.003 | 29 |
| **Shady Hills Elementary School** | FLA012719 | RIB | High | 9.33* | 0.001 | 20 |

Additionally, the Spring Hill WWTF (FLA012043), located in Hernando County within the Magnolia and Aripeka Springs contributing area, is permitted to distribute reclaimed water for irrigation. This reuse water is transferred to the Timber Pine Country Club in the Weeki Wachee contributing area and is therefore included in this analysis. Timber Pines comprises a 258-acre area, with 83% located in the high-recharge rate area and the remainder in the discharge area. The golf course uses 1.26 MGD of reclaimed water, with 1.05 MGD applied at a concentration of 16.9 mg-N/L in the high-recharge area, equaling an annual nitrogen input of 53,873 lb-N to the land surface.

Another facility, City of Brooksville Cobb Road WWTF (FLA012036), located in the Chassahowitzka contributing area also transfers reclaimed water into the Weeki Wachee contributing area to the golf course and residential areas of Southern Hills. Approximately 275 acres are irrigated associated with this property and are located in the high recharge rate area of Weeki Wachee. An estimated 0.51 MGD is applied at a concentration of 16.95 mg-N/L (projected TN value) equaling an annual nitrogen input of 26,375 lb-N to the land surface.

## 2.3 Septic Systems

On-site sewage treatment and disposal systems (OSTDS), commonly referred to as septic systems, are widely used throughout the Weeki Wachee Spring contributing area where municipal sewer is not available. These systems can contribute to elevated nitrogen concentrations in groundwater (Chang et al. 2010).

In 2009, a Florida Department of Health (FDOH) contractor developed a statewide model for estimating the number of septic systems based on tax parcel data and known sewer service areas (Hall and Clancy 2009). The model relied on septic system permit data from FDOH, as well as information from public utilities on their sewer collection systems and service areas, to estimate the type of service provided to individual land parcels not accounted for by a permit or sewer connection. For example, it was assumed that a septic system would be found in an area where sewer service was unlikely. The output of the model is provided in an ArcGIS geodatabase where the locations of both known and probable septic systems can be mapped.

The model may overestimate the number of septic systems. In some parts of Florida, the land use data used by Hall and Clancy (2009) projected future housing development. However, some of the parcels projected by the model to be subdivided remained intact as one parcel with one septic system rather than multiple septic systems. This resulted in a higher estimate of projected septic systems than what is actually in place.

To improve the accuracy of the septic system estimates, the model results were correlated with current land use information from property appraisers. Any parcel containing more than one septic system was further evaluated as follows:

- Parcels identified as single-family residential were reduced to only one septic system per parcel.
- Parcels with three or fewer septic systems and an associated land use likely to contain more than one septic tank (i.e., condominiums, multifamily dwellings, or businesses) were left unchanged.
- All remaining parcels were individually assessed using current aerial imagery to verify or correct the number of septic systems within the parcel boundary.

This final data layer was used to estimate the total number of septic systems for the medium and high recharge rate areas in the contributing area and is referred to as the "modified Hall and Clancy" dataset (**Figure 6**). As more information becomes available, this coverage can be further modified or replaced with more accurate coverage and included in future iterations of the model.

After the number of septic systems in the contributing area was determined, the population served by septic systems was estimated using the 2010 United States Census Bureau data for population and household occupancy in each county. The Census makes a distinction between occupied and nonoccupied households. The county population was divided by the number of occupied households in the county, resulting in an average number of people per occupied household (2.41 in Hernando County and 2.45 in Pasco County).

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), reducing nitrogen inputs to the septic system. To estimate the effective number of people per household and the associated nitrogen input to septic systems, population age distribution information was obtained for Hernando and Pasco Counties from the 2010 Census. In Hernando County, 53.0% of the population is of school or working age and, according to the Bureau of Labor Statistics, spends 43.5 hours or 25.9% of the week away from home and therefore are not using the septic system. This effectively reduces the number of people per household using septic systems in Hernando County by 13.7%, resulting in an adjusted number of 2.08 people per household. A similar calculation was made for Pasco County, which has a school or working age population of 60.5%, resulting in an adjusted number of 2.07 people per household (based on a reduction of 15.7%).

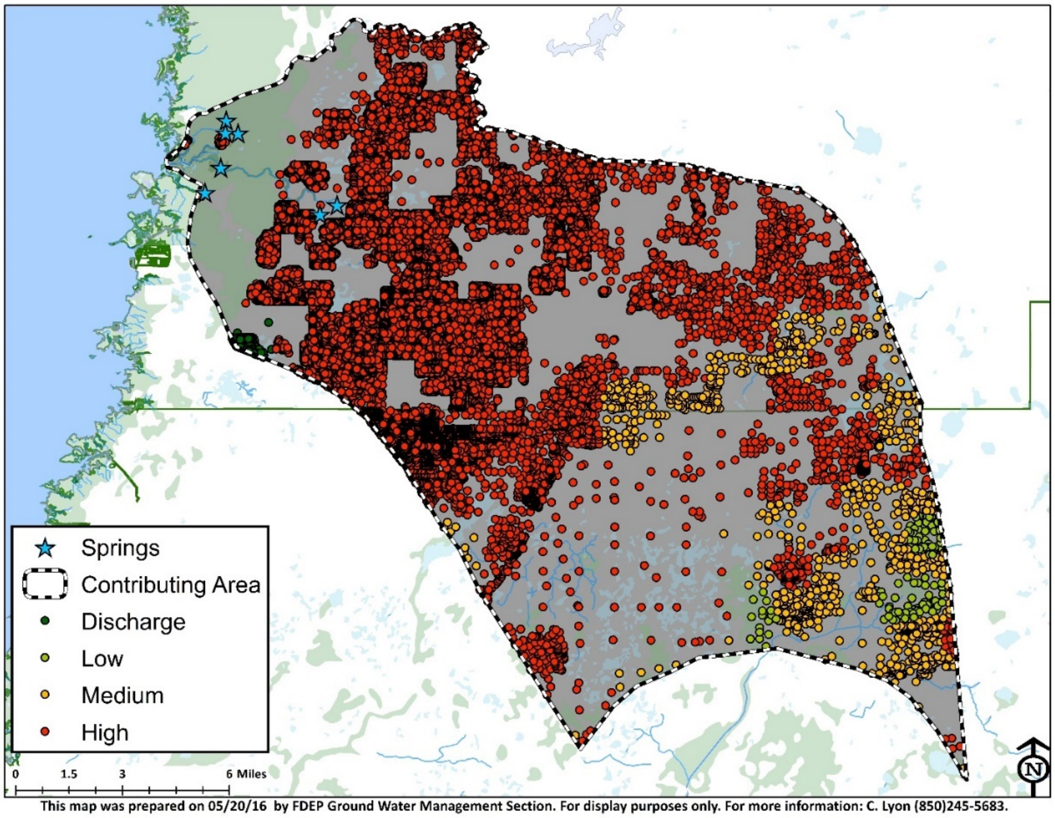


**Figure 6: Distribution of septic systems throughout the Weeki Wachee Spring BMAP area**

The total population in the Weeki Wachee contributing area served by septic systems was estimated by multiplying the estimated number of people per household by the number of septic systems. Several literature sources have reported a per capita contribution of 9.012 lb-N/yr, and this value was multiplied by the estimated number of people using septic tanks within the different regions of the contributing area (U.S. Environmental Protection Agency [EPA] 2002; Toor et al. 2011; Viers et al. 2012). **Table 3** summarizes the septic system data.

**Table 3: Estimated number of septic systems and associated input to the land surface**

| Land Category | Number of Septic Systems | Estimated Input to Land Surface (lb-N/yr) |
|---|---|---|
| **Hernando High Recharge** | 29,768 | 557,321 |
| **Hernando Medium Recharge** | 310 | 5,804 |
| **Pasco High Recharge** | 3,206 | 59,713 |
| **Pasco Medium Recharge** | 780 | 14,528 |
| **Pasco Low Recharge** | 137 | 2,552 |

# 2.4 Urban Turfgrass Fertilizer

## *2.4.1 Fertilizer Application Rates*

Fertilizers applied to turfgrass typically found in urban areas (including residential lawns and commercial and public green spaces) are referred to as urban turfgrass fertilizers (**Figure 7**). Results from surveys and workshops pertaining to fertilizer application on turfgrass in nearby counties were used to estimate the nitrogen application rates for urban turfgrass in the Weeki Wachee area.

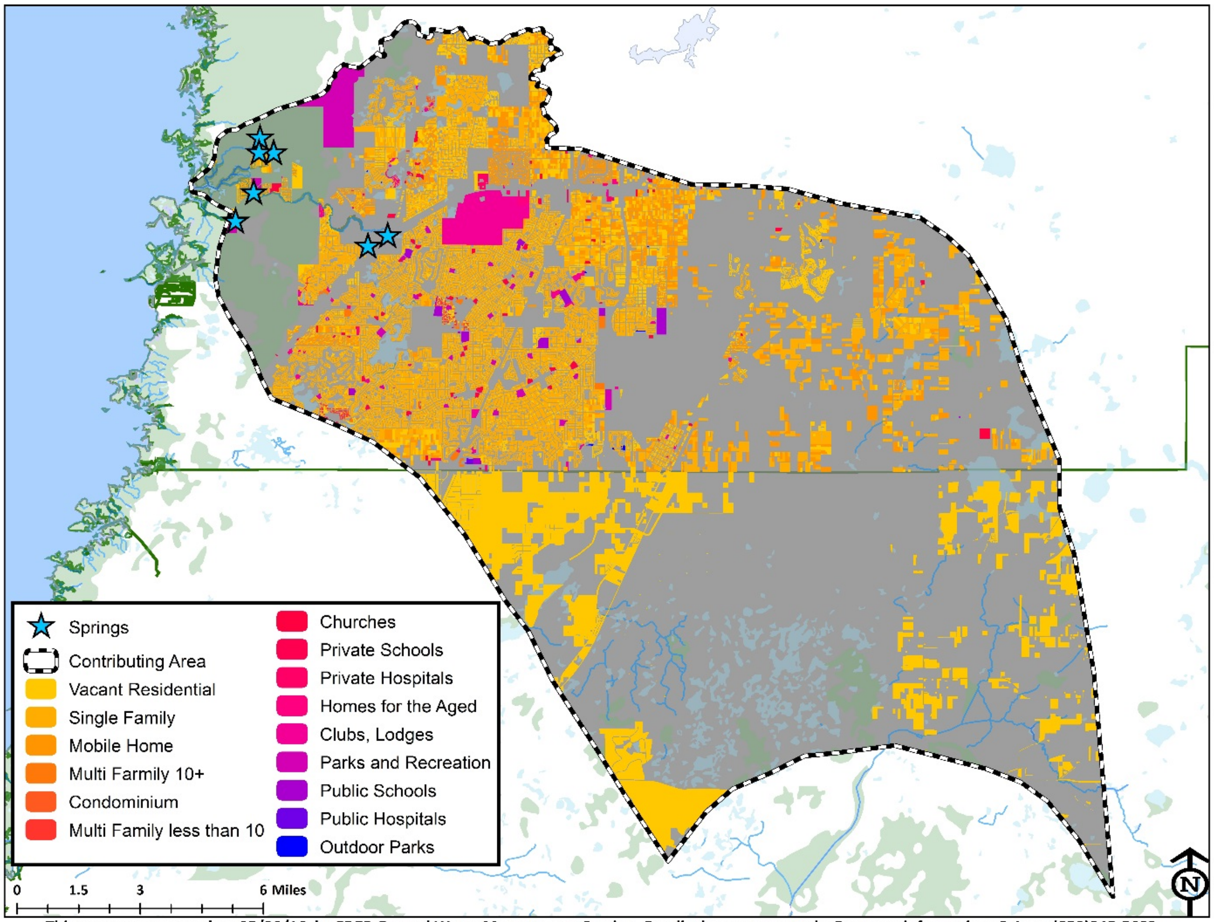


**Figure 7: Urban noncommercial lands in the Weeki Wachee Spring contributing area according to county property appraiser data**

Fertilizer is applied by either the homeowner or a hired lawn service company on residential properties and on other properties it may be applied by contractors or maintenance staff. In 2008, a SWFWMD contractor conducted a telephone survey about residential fertilizer use in Citrus County and southern Marion County. The results from this survey are used to estimate fertilizer application rates to all urban turfgrass in the Weeki Wachee area. According to the survey (Martin 2008), 68% of the population managed their own lawn care and applied lawn fertilizer 3 times a year at variable rates that may range as high as 45.56 lb-N/ac (**Table 4)**. Additionally, 32% of homeowners hired a lawn service company that typically applied fertilizer at rates consistent with the Green Industries Best Management Practices Manual recommendation of 21.78 lb-N/ac twice a year (Martin 2008; DEP 2010; Downs et al. 2012). Fertilizer application on commercial and public green spaces was assumed to be performed by trained staff using application rates and frequencies similar to those recommended in the Green Industries Best Management Practices Manual.

**Table 4: Estimated fertilizer application rates by homeowners from surveys completed in Citrus and Marion Counties**

* = Includes homeowners who fertilize based on visual appearance or best judgment.

| Basis for Application Rate | % of Population with Homeowner Applying Fertilizer | Estimated Fertilizer Application Rate (lb-N/ac) |
|---|---|---|
| **BMP Guidelines** | 15% | 21.78 |
| **Fertilizer Bag Label** | 59% | 34.78 |
| **No Fertilization** | 11% | 0 |
| **Other*** | 16% | 43.56 |

## *2.4.2 Nonresidential Parcel Estimations*

The acreage of public green space parcels receiving fertilizer applications was estimated to obtain nitrogen inputs for each category listed in **Table 5**. Parcel types assessed using the PA data include businesses, hotels, schools, churches, and other facilities. These data were combined with zoning data provided by Hernando and Pasco Counties. The zoning attributed to each parcel contains information on the amount of impervious surfaces (i.e., structures, pavement, etc.), referred to as the "max lot coverage." For each parcel, the max lot coverage was used to estimate the acreage of impervious and pervious land areas. For this analysis, it was assumed that all pervious acreage was fertilized by lawn service companies at the previously mentioned rate and frequency. Details of the PA data and max lot coverages are listed in **Appendix A**, **Table A.4** through **Table A.7**. **Table 5** summarizes these data.

**Table 5: Summary of the fertilizable urban land area and associated N input for nonresidential parcels**

* = Parcel type descriptions include forest-parks-recreational, outdoor parkland-recreational, and counties other than public schools.

| Parcel Type | Hernando High Recharge (acres) | Pasco High Recharge (acres) | Pasco Medium Recharge (acres) | Pasco Low Recharge (acres) | Total Input (lb-N/yr) |
|---|---|---|---|---|---|
| **Hotels** | 22 | | | | **945** |
| **Churches** | 364 | 31 | 13 | | **17,781** |
| **Schools** | 322 | 8 | | | **14,375** |
| **Hospitals** | 87 | | | | **3,807** |
| **Homes for the Aged** | 97 | | | | **4,244** |
| **Clubs, Lodges, Union Halls** | 1,558 | | | | **67,881** |
| **Parks and County Land*** | 1,766 | 2,270 | 590 | 31 | **202,839** |
| **TOTAL** | **4,217** | **2,309** | **603** | **31** | **311,871** |

### *2.4.3 Residential Parcel Estimations*

For residential parcels, including single and multifamily homes, the acreage (pervious area) receiving fertilizer applications was estimated in the same manner as for nonresidential parcels. Prior to applying the fertilizer application rates to the pervious land area, one other factor was taken into account: the probability that a homeowner will fertilize the lawn.

Based on socioeconomic studies, property value can be used as an indicator of turfgrass fertilization in residential areas (Kinzig et al. 2005, Law et al. 2004, Zhou et al. 2008, Cook et al. 2012). The range of property values for single-family homes was evaluated for the Weeki Wachee Spring contributing area and subdivided into three categories: high, medium, and low. **Table 6** lists the estimated probability of fertilization for each property value category.

**Table 6: Distribution of property values and the probability of fertilization for the Weeki Wachee Spring contributing area**

| Property Value Label | Property Value | Probability of Fertilization |
|---|---|---|
| **High** | > $150,000 | 90% |
| **Medium** | $50,001 – $150,000 | 75% |
| **Low** | ≤ $50,000 | 10% |

The probability that a homeowner will fertilize some or all of a property in a given year was based on socioeconomic studies of lawn care trends in urban environments (Kinzig et al. 2005; Grove et al. 2006; Carey et al. 2012). These factors were applied to the pervious acreage of residential properties to adjust the land area presumed to be fertilized. The land area presumed to receive fertilizer applications was multiplied by the annual application rate listed in **Table 4** to obtain the total input of nitrogen to the land surface in residential areas (**Table 7**).

**Table 7: Summary of urban fertilizer data attributed to residential parcels**

| Parcel Type | Hernando High Recharge (acres) | Hernando Medium Recharge (acres) | Pasco High Recharge (acres) | Pasco Medium Recharge (acres) | Pasco Low Recharge (acres) | Total Input (lb-N/yr) |
|---|---|---|---|---|---|---|
| **Single-Family Residential** | 10,461 | 811 | 2,092 | 713 | 105 | **1,070,410** |
| **Multifamily Residential** | 153 | | 451 | 106 | 6 | **54,047** |
| **Mobile Home** | 1,894 | 237 | 1,275 | 306 | 24 | **281,992** |
| **Condominium** | 4 | | | | | **317** |
| **Vacant Residential** | 918 | 62 | 1,245 | 290 | 24 | |
| **TOTAL** | **13,431** | **1,111** | **5,063** | **1,414** | **158** | **1,406,767** |

## 2.5 Sports Turfgrass Fertilizer

Fertilizer applied to sports turfgrass areas is another potential source of nitrogen. These areas fall into two main categories that were evaluated separately: golf courses and sporting facilities such as baseball, football, and soccer; and other fields where fertilizers are likely applied.

To estimate the nitrogen input for golf courses, surveys completed by course managers and superintendents were used to provide basic information about fertilizer practices. Of the golf courses in the contributing area, 44% provided detailed information about fertilizer applications (see **Appendix B** for the survey). The results indicated that golf courses apply nitrogen fertilizer at an average rate of 43.0 lb-N/ac/yr.

For the remaining 56% of the golf courses, the NSILT used a statewide annual average application rate (previously vetted by golf course professionals) of 141.1 lb-N/ac/yr (or 72% of the course area at 4.5 lb-N/1,000 ft$^2$) (Sartain 2002; DEP 2007). In total, all golf courses in the contributing area apply fertilizers at a rate of 194,022 lb N/yr to the land surface in high recharge rate areas and an additional 2,769 lb N/yr in medium recharge rate areas. **Table 8** summarizes the input to the land surface from each golf course in the contributing area.

**Table 8: Summary of urban fertilizer input for golf courses**

* = Received response to survey.

| Golf Club Name | County | High-Recharge Fertilizable Land Area (acres) | Medium- Recharge Fertilizable Land Area (acres) | Average Application Rate (lb-N/ac) | Total Input (lb-N/yr) |
|---|---|---|---|---|---|
| **Brookridge*** | Hernando | 187 | | 176 | **32,844** |
| **Glen Lakes*** | Hernando | 125 | | 7 | **602** |
| **Heather*** | Hernando | 46 | | 89 | **4,875** |
| **Hernando Oaks*** | Hernando | 139 | | 141 | **19,624** |
| **High Point*** | Hernando | 70 | | 78 | **5,489** |
| **Oak Hills** | Hernando | 184 | | 141 | **26,029** |
| **Rivard** | Hernando | 95 | | 141 | **13,469** |
| **Seven Hills** | Hernando | 129 | | 141 | **18,164** |
| **Silverthorn** | Hernando | 176 | | 141 | **24,768** |
| **Southern Hills Plantation** | Hernando | 162 | | 141 | **22,824** |
| **Spring Hill** | Hernando | 159 | | 141 | **22,374** |
| **Timber Pines*** | Hernando | 215 | | 10 | **684** |
| **Travelers Rest RV*** | Pasco | 16 | 20 | 141 | **5,045** |

Sports facilities were assessed based on PA land use data. The parcel types likely to contain these facilities were identified and evaluated based on aerial imagery. In total, 88 acres of land were associated with sporting facilities in the Hernando County high-recharge areas (43 acres in parcel type forest-parks-recreational, and 45 acres in parcel type schools-public-county). It was assumed that these lands are fertilized at rates applied by lawn service companies, as described in **Section 2.4**, resulting in 3,851 lb-N/yr applied to the land surface. **Table 9** summarizes all sports turfgrass fertilizer calculations.

**Table 9: Summary of total sports turfgrass fertilizer nitrogen applied to the land surface**

| Land Type | High Recharge | Medium Recharge | TOTAL |
|---|---|---|---|
| **Golf Courses** | 194,022 | 2,769 | **196,791** |
| **Sporting Facilities** | 3,851 | | **3,851** |
| **TOTAL** | **197,872** | **2,769** | **200,642** |

## 2.6 Livestock Waste

The Weeki Wachee contributing area contains a small number of livestock farms, mostly cow-calf operations. Agricultural practices specific to this area were obtained through meetings with agricultural producers and stakeholders. Typical cattle stocking rates in Hernando and Pasco Counties were estimated as 1 cow per 6 to 8 acres of pasture (based on a stakeholder meeting in Lecanto, Florida, July 2014). The pasture acreage for these operations was estimated using PA data and includes improved, semi-improved, and native pastures. **Table 10** lists the estimated pasture acreage and the associated cattle populations within the contributing area boundary.

For other livestock animals, the populations were estimated using data from the U.S. Department of Agriculture (USDA), which publishes a Census of Agriculture (CoA) every five years. This comprehensive report provides summary data on the agricultural practices and livestock populations for each state and county in the U.S. The 2012 CoA report was used to provide data on livestock populations for this assessment. However, since the CoA reports entire county data, additional analyses were carried out for the groundwater contributing area for Weeki Wachee Spring.

**Table 10: PA pasture data and estimated cattle populations based on stocking rates**

| County | Property Code | PA Land Description | Estimated Improvement | High-Recharge Area (acres) | Medium-Recharge Area (acres) | Low-Recharge Area (acres) | Estimated Cattle Population |
|---|---|---|---|---|---|---|---|
| **Hernando** | 60 | Improved Pastureland | Improved | 7,586 | 1,817 | | 1,344 |
| **Pasco** | 60 | Improved Pastureland | Improved | 12,137 | 11,031 | 1,477 | 3,521 |
| **Pasco** | 61 | Grazing land Soil Capab II | Improved Below Average | 700 | 283 | 267 | 179 |
| **Pasco** | 62 | Grazing land Soil Capab III | Partially Improved | 553 | 4 | 100 | 94 |
| **Pasco** | 63 | Grazing land Soil Capab IV | Native | 984 | 370 | 283 | 234 |
| **Pasco** | 64 | Grazing land Soil Capab V | Native Hammock | 2,276 | 1,151 | | 490 |
| **Pasco** | 65 | Grazing land Soil Capab VI | Overflow Prairie | 2,525 | 342 | | 410 |

To estimate the number of livestock animals in the contributing area, the SWFWMD land use coverage was used to identify land use categories likely to contain livestock, i.e., pastures, feeding operations, and specialty farms. These land areas were totaled for Hernando and Pasco Counties and subdivided by recharge rate category. The livestock area summations were used to calculate a land use percentage for the entire county area for livestock operations in the two recharge rate categories.

These percentages were applied to the populations provided by the CoA to estimate the number of animals in the contributing area and in the medium and high recharge rate areas of Hernando and Pasco Counties (**Table 11** and **Table 12**, respectively). For example, if 10,000 cows were reported for a particular county in the CoA, but only 10% of the livestock lands in that county were inside the BMAP area, it was assumed that the contributing area contained 1,000 cows.

**Table 11: WMD land use percentages and miscellaneous livestock population data for Hernando County**

| Land Category | Land Area (acres) | Land Use % | Horses | Broiler Chickens | Goats | Hogs | Sheep | Turkeys |
|---|---|---|---|---|---|---|---|---|
| Hernando County | 33,851 | | 2,080 | 546 | 1,034 | 328 | 318 | 0 |
| High Recharge | 13,447 | 40% | 826 | 217 | 411 | 130 | 126 | |
| Medium Recharge | 8,947 | 26% | 550 | 144 | 273 | 87 | 84 | |

**Table 12: WMD land use percentages and miscellaneous livestock population data for Pasco County**

| Land Category | Land Area (acres) | Land Use % | Horses | Broiler Chickens | Goats | Hogs | Sheep | Turkeys |
|---|---|---|---|---|---|---|---|---|
| Pasco County | 84,673 | | 2,008 | 604 | 1,410 | 165 | 251 | 63 |
| High Recharge | 18,715 | 22% | 444 | 134 | 312 | 36 | 55 | 14 |
| Medium Recharge | 17,856 | 21% | 423 | 127 | 297 | 35 | 53 | 13 |
| Low Recharge | 5,233 | 6% | 124 | 37 | 87 | 10 | 16 | 4 |

Nitrogen waste factors were assigned for each animal type and applied to the estimated livestock populations to estimate the nitrogen input to the land surface. The nitrogen waste factors in lb N/day per animal were as follows: cattle, 0.337; broiler chickens, 0.159; layer chickens, 0.003; goats, 0.035; hogs, 0.190; sheep, 0.198; turkeys, 0.006; and horses, 0.273 (Goolsby et al. 1999; Katz et al. 1999; Chelette et al. 2002; Ruddy et al. 2006; Meyer 2012; Sprague and Gronberg 2013). **Table 13** lists the TN input to the land surface attributable to livestock waste for the medium and high recharge rate areas in the contributing area.

**Table 13: Estimated nitrogen applied as animal waste to the land surface in the contributing area**

| Land Category | Cattle | Horses | Broiler Chickens | Goats | Hogs | Sheep | Turkeys | Total N Input (lb-N/yr) |
|---|---|---|---|---|---|---|---|---|
| **Hernando–High Recharge** | 6,027 | 82,334 | 12,588 | 5,247 | 9,036 | 9,129 | | **124,362** |
| **Hernando–Medium Recharge** | 1,722 | 54,781 | 8,375 | 3,491 | 6,012 | 6,074 | | **80,456** |
| **Pasco–High Recharge** | 336,932 | 44,225 | 7,748 | 3,981 | 2,529 | 4,009 | 30 | **485,527** |
| **Pasco–Medium Recharge** | 231,611 | 42,195 | 7,392 | 3,799 | 2,413 | 3,825 | 29 | **373,385** |
| **Pasco–Low Recharge** | 37,380 | 12,366 | 2,166 | 1,113 | 707 | 1,121 | 9 | **78,928** |
| **Total Contributing Area** | **613,673** | **192,258** | **235,901** | **17,632** | **20,698** | **24,160** | **68** | **1,142,659** |

## 2.7 Farm Fertilizer

Nitrogen in agricultural fertilizer is applied at widely varying rates, depending on the crop, time of year, and individual farm practices. The PA offices in Hernando and Pasco Counties provided detailed information on the types of crops grown in the area. Nitrogen inputs to the land surface were estimated based on the type of crops grown in each PA land use category and the recommended nitrogen application rates for crops by the University of Florida Institute of Food and Agricultural Sciences (UF–IFAS) (Hochmuth and Hanlon 2000, 2010, 2013; Wright et al. 2011; Mylavarapu et al. 2012; Liu et al. 2012). **Table 14** and **Table 15** summarize the nitrogen inputs to the land surface from fertilizers applied to cropland for the medium and high recharge rate areas in the Weeki Wachee Spring contributing area in Hernando and Pasco Counties, respectively.

## 2.8 Summary of Estimated Nitrogen Inputs to the Land Surface

**Figure 8** summarizes the relative contributions of nitrogen (in percent) from the major sources in the Weeki Wachee Spring contributing area. The total annual nitrogen input to the land surface from all sources is 6.3 million lb-N. Urban turf fertilizers comprise 27% of the TN input to the land surface in the contributing area. Other nitrogen sources, in order of decreasing contributions of nitrogen inputs to the land surface, include farm fertilizer (22%), livestock waste (21%), atmospheric deposition (18%), septic systems (10%), sports turfgrass fertilizer (3%), and WWTFs (1%).

**Table 14: Summary of crop types and nitrogen application rates for Hernando County in the Weeki Wachee Spring contributing area**

| Property Code | PA Land Description | Estimated Crop Type | N Application Rate (lb-N/ac) | High-Recharge Area (ac) | Medium-Recharge Area (ac) | Total Input (lb-N/yr) |
|---|---|---|---|---|---|---|
| **51** | Cropland Soil Capability I | Hay, Berries, Watermelons | 80 | 1,128 | 565 | **135,460** |
| **60** | Improved Pastureland | Improved Pasture | 60 | 7,586 | 1,817 | **141,051** |
| **66** | Orchard Groves | Orchards | 150 | 310 | 165 | **71,174** |
| **69** | Ornamentals | Ornamentals | 80 | 375 | 14 | **31,150** |

**Table 15: Summary of crop types and nitrogen application rates for Pasco County in the Weeki Wachee Spring contributing area**

| Property Code | PA Land Description | Estimated Crop Type | N Application Rate (lb-N/ac) | High-Recharge Area (ac) | Medium-Recharge Area (ac) | Low-Recharge Area (ac) | Total Input (lb-N/yr) |
|---|---|---|---|---|---|---|---|
| **51** | Cropland Soil Capability I | Hay Crop | 80 | 939 | 1,107 | 242 | **183,038** |
| **53** | Cropland Soil Capability III | Hay Crop | 80 | 24 | 57 | | **6,430** |
| **60** | Improved Pastureland | Improved Pasture | 60 | 12,137 | 11,031 | 2,127 | **367,487** |
| **61** | Grazing Land soil Capab II | Improved Below Average | 25 | 700 | 283 | 267 | **7,813** |
| **62** | Grazing Land soil Capab III | Partial Improved | 0 | 553 | 4 | 100 | |
| **63** | Grazing Land soil Capab IV | Native | 0 | 984 | 370 | 283 | |
| **64** | Grazing Land soil Capab V | Native/ Hammock | 0 | 2,276 | 1,151 | | |
| **65** | Grazing Land soil Capab VI | Marsh Overflow Prairie | 0 | 2,525 | 342 | | |
| **66** | Orchard Groves | Orchards | 150 | 630 | 561 | 147 | **200,733** |
| **69** | Ornamentals | Ornamentals | 80 | 172 | 72 | | **21,954** |

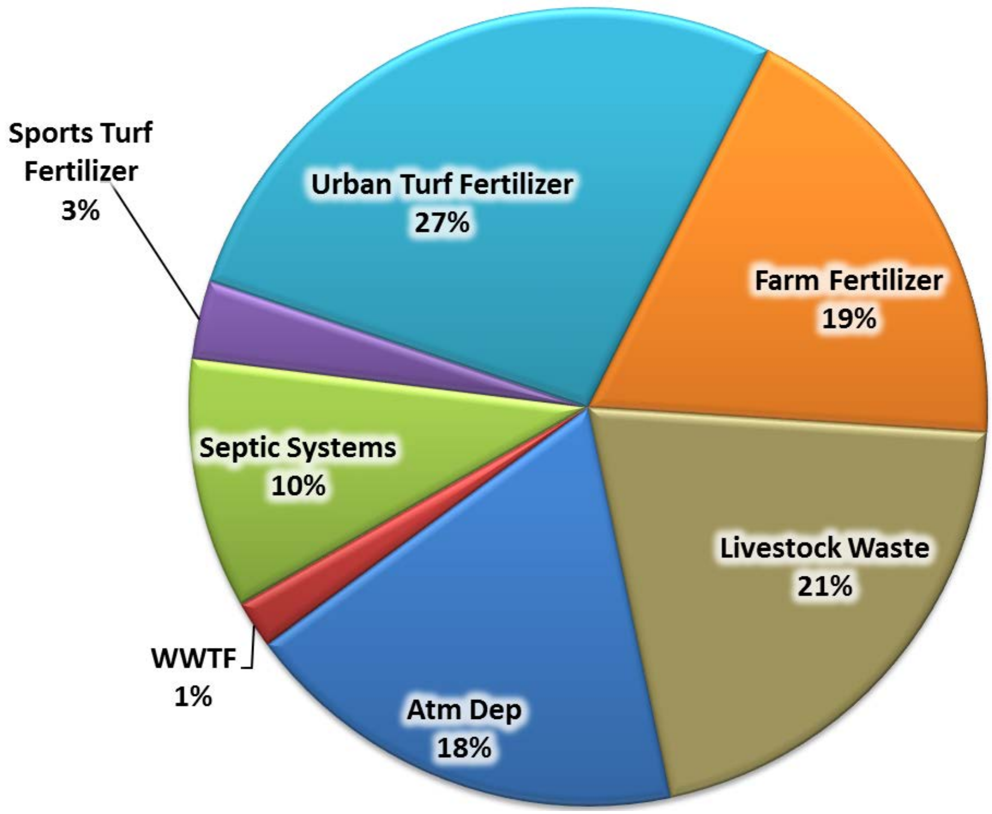


**Figure 8: Relative nitrogen inputs to the land surface in the Weeki Wachee Spring contributing area from major anthropogenic source categories in lb-N/yr**

# 3. Nitrogen Attenuation and Loading to Groundwater

The movement of nitrogen from the land surface to groundwater is controlled by biological and chemical processes that occur as part of the nitrogen cycle, as well as hydrogeological processes. Many of these processes attenuate (impede or remove) the amount of nitrogen transported to groundwater. An understanding of how water moves through the subsurface and the processes that transform the different forms of nitrogen is essential for estimating nitrogen loading to groundwater from various sources (Liao et al. 2012; Wang et al. 2013).

To estimate the amount of nitrogen loading to the aquifer in the Weeki Wachee Spring contributing area, DEP applied two nitrogen attenuation factors. The specific biochemical attenuation factor (BAF) is applied to each nitrogen source category to account for biochemical processes that remove or transform the different forms of nitrogen. The hydrogeological attenuation factor (HAF) accounts for spatial variations in subsurface geological properties that affect the rate of water recharging the UFA. Both factors control the amount of nitrogen reaching the UFA annually and in the groundwater moving to Weeki Wachee Spring.

## 3.1 Biochemical Attenuation

Several near-surface biochemical processes increase nitrogen availability for plants, including fixation (the conversion of atmospheric nitrogen to a plant-available form), mineralization (the conversion of organic nitrogen to ammonium), and nitrification (the conversion of ammonium to nitrate). Losses of nitrogen from the root zone can result from denitrification, volatilization, immobilization, and cation exchange (affecting ammonium). These processes occur to varying degrees depending on how the form of nitrogen is introduced, soil properties, and several other factors (Cockx and Simonne 2011; Costa et al. 2002; Horsley Witten Group 2009).

Specific BAFs were used to account for the various processes that affect the movement of nitrogen from each source category in the subsurface and were obtained through an extensive literature review of relevant studies throughout Florida as well as other areas with similar environmental characteristics. Additionally, research scientists in Florida (UF–IFAS, universities, and USDA Agricultural Research Service [ARS]), and local stakeholders provided additional guidance. The biochemical attenuation factors, listed in **Table 16**, represent the average percentage of the nitrogen attenuated or removed by subsurface processes and thus reducing the amount of nitrogen reaching groundwater.

As a first step in estimating loading to groundwater, the nitrogen inputs at the land surface from each category, discussed previously, are multiplied by their respective biochemical attenuation factors (**Table 16**). For example, atmospheric deposition has an average nitrogen attenuation of 90% (mainly from uptake by vegetation). This means that only 10% of the atmospheric nitrogen input to the land surface has the potential to infiltrate to groundwater.

**Table 16: BAFs applied to the nitrogen input calculations**

* = Both sports and urban turfgrass.
** These percentages represent the average amount of nitrogen removed by the environment over varying soil characteristics.

| N Source Category | BAF** | Literature References |
|---|---|---|
| **Atmospheric Deposition** | 90% | Katz et al. 2009; Lombardo Associates 2011; Howard T. Odum Florida Springs Institute 2011 |
| **WWTFs-RIBs** | 25% | Merritt and Toth 2006; Sumner and Bradner 1996 |
| **WWTFs-Sprayfield** | 60% | Katz et al. 2009; Lombardo Associates 2011; Howard T. Odum Florida Springs Institute 2011 |
| **WWTFs-Reuse** | 75% | Jordan et al. 1997; Candela et al. 2007; Rahil and Antonopoulos 2007 |
| **Urban Fertilizer*** | 80% | Goolsby et al. 1999; Erikson et al. 2001; Barton and Colmer 2006; Katz et al. 2009 |
| **Septic Systems** | 50% | Poiani et al. 1996; Aravena and Robertson 1998; Tomasko et al. 2001; Corbett et al. 2002; Otis 2007; Toor et al. 2011 |
| **Livestock Waste** | 90% | Dubeux et al. 2007; Silveira et al. 2007; Burns et al. 2009; Dubeux et al. 2009; Obour et al. 2010; Sigua 2010; Sigua et al. 2010; Silveira et al. 2011; Woodard et al. 2011; White-Leech et al. 2013a; White-Leech et al. 2013b |
| **Farm Fertilizer** | 80% | McNeal et al. 1995; Wang and Alva 1996; Paramasivam and Alva 1997; Newton et al. 1999; Hochmuth 2000a; Hochmuth 2000b; Simonne et al. 2006; He et al. 2011; Liu et al. 2013 |

## 3.2 Hydrogeological Attenuation

Any non-attenuated nitrogen remaining (usually in the form of nitrate) after taking into account biochemical attenuation processes can readily leach to groundwater. Leaching to groundwater is a function of the properties of the soil and unsaturated zone, such as composition (particle size, organic matter content), texture, drainage, wetness, and thickness. The rate of groundwater recharge (from rainfall or irrigation water) ultimately controls how rapidly nitrogen moves from below the root zone to the UFA. The amount of water recharging the UFA each year also depends on the amount of rainfall, evapotranspiration, and runoff, in addition to subsurface hydrogeological properties.

The final step in estimating nitrogen loads to groundwater is to account for the additional attenuation associated with the rate of recharge in a given year. The recharge rate can be geospatially assessed and incorporates soil and unsaturated zone properties (recharge rates are based on a USGS recharge map discussed in **Section 1.3, Aquifer Recharge**). Therefore, the rate of recharge to the UFA is used in the NSILT as an aggregated indicator of the various hydrogeological processes that can further attenuate the movement of nitrate to groundwater. In areas with lower annual recharge rates, the vertical movement of water and associated chemical constituents is impeded, which may allow for increased biological uptake and denitrification (Liao et al. 2012; Wang et al. 2013).

In contrast, for areas with higher recharge rates, water spends less time in the soil/root zone, decreasing the opportunity for biochemical attenuation. This likely results in the increased leaching of nitrogen as well as a higher potential for nitrogen transport to the aquifer in a given year (Scanlon et al. 2002; Liao et al. 2012).

Additional nitrogen attenuation factors related to recharge rates were arbitrarily assigned as follows: 90% in high recharge rate areas (≥10 in/yr), 50% in medium recharge rate areas (3.01 to 10 in/yr), and 10% in low-recharge areas (0 to 3 in/yr) (Sepulveda 2002). For example, in high-rate recharge areas, 90% of the non-attenuated nitrogen mass is assumed to reach the aquifer in a year, while only 50% of the non-attenuated nitrogen mass is assumed to reach the aquifer annually in medium rate recharge areas. These attenuation factors are based on the recharge characteristics specific to the hydrogeological conditions in the Weeki Wachee Spring contributing area.

## 3.3 Estimated Nitrogen Loads to Groundwater

**Table 17**, **Table 18**, and **Table 19** summarize estimated annual nitrogen inputs, attenuation factors, and loads to the UFA, respectively, in the Weeki Wachee Spring contributing area and its recharge-based subdivisions. The results indicate an estimated annual load of 1,004,655 lb-N to the UFA in the BMAP area, representing 16% of the amount of nitrogen inputs to the land surface. As discussed previously, the difference is due to various nitrogen attenuation processes and variations in the quantity and movement of water recharging the aquifer. The results indicate that the greatest annual load of nitrogen to the UFA in the BMAP area comes from urban turfgrass fertilizers (29% of the total estimated load to groundwater), followed by septic systems at 28%.

**Figure** 9 shows the relative contribution of estimated annual loads of nitrogen to the UFA by source category. The NSILT results indicate that most of the nitrogen load to groundwater originates from fertilizers and septic systems, which is consistent with nitrogen isotopic and other chemical data. Nitrogen-isotope signatures in water samples collected in 2013 indicated that elevated nitrate-N concentrations in groundwater originate from a mix of both inorganic (fertilizer) and organic (human and animal waste) sources, but with a significant influence from inorganic sources (Dodson and Bridger 2014). Aquifer recharge rates have strongly influenced the loading of nitrogen to the UFA in the groundwater contributing area.

**Figure 10** summarizes the estimated nitrogen loads to groundwater for the medium and high recharge rate areas, including a breakdown for each source category. The majority of the nitrogen loading to groundwater in the Weeki Wachee Spring contributing area (90%) occurs in high rate recharge areas. For both the medium and low rate recharge areas, the dominant sources of nitrogen loading to groundwater are livestock waste and farm and urban fertilizers.

### Table 17: Estimated inputs to the land surface by nitrogen source category in the Weeki Wachee Spring contributing area (lb-N/yr)

| Recharge Category | Atmospheric Deposition | WWTF-RIB | WWTF-Sprayfield | WWTF-Reuse | Septic Systems | Sports Turf Fertilizer | Urban Turf Fertilizer | Farm Fertilizers | Livestock Waste | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|
| High | 923,127 | 39,786 | 10 | 80,249 | 617,033 | 197,872 | 1,516,859 | 653,917 | 737,277 | **4,766,130** |
| Medium | 197,713 | 389 | 213 | | 20,332 | 2,769 | 190,272 | 449,232 | 484,054 | **1,344,974** |
| Low | 24,093 | | | | 2,552 | | 11,508 | 65,327 | 78,928 | **182,407** |
| **TOTAL** | **1,154,547** | **40,155** | **222** | **80,249** | **639,916** | **200,642** | **1,718,639** | **1,168,475** | **1,300,259** | **6,293,733** |

### Table 18: Average biochemical attenuation factors by source category in the Weeki Wachee Spring contributing area (lb-N/yr)

| Recharge Category | Atmospheric Deposition | WWTF-RIB | WWTF-Sprayfield | WWTF-Reuse | Septic Systems | Sports Turf Fertilizer | Urban Turf Fertilizer | Farm Fertilizers | Livestock Waste | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|
| *BAF* | *90%* | *25%* | *60%* | *75%* | *50%* | *80%* | *80%* | *80%* | *90%* | |
| High | 92,313 | 29,840 | 4 | 20,062 | 308,517 | 39,574 | 303,372 | 130,783 | 73,728 | **998,192** |
| Medium | 19,771 | 292 | 85 | | 10,166 | 554 | 38,054 | 89,846 | 48,405 | **207,174** |
| Low | 3,371 | | | | 1,276 | | 2,302 | 13,065 | 7,893 | **26,945** |
| **TOTAL** | **115,455** | **30,132** | **89** | **20,062** | **319,958** | **40,128** | **343,728** | **233,695** | **130,026** | **1,212,249** |

### Table 19: Load to groundwater with recharge factors applied by nitrogen source category in the Weeki Wachee Spring contributing area (lb-N/yr)

§ = Combination of all WWTF subcategories: RIBs, sprayfields, and reuse.

| Recharge Category | HAF | Atmospheric Deposition | WWTF§ | Septic Systems | Sports Turf Fertilizer | Urban Turf Fertilizer | Farm Fertilizer | Livestock Waste | TOTAL |
|---|---|---|---|---|---|---|---|---|---|
| High | 90% | 83,081 | 44,915 | 277,665 | 35,617 | 273,035 | 117,705 | 66,355 | **898,373** |
| Medium | 50% | 9,886 | 189 | 5,083 | 277 | 19,027 | 44,923 | 24,203 | **103,587** |
| Low | 10% | 241 | | 128 | | 230 | 1,307 | 789 | **2,694** |
| **TOTAL** | | **93,208** | **45,105** | **282,875** | **35,894** | **292,292** | **163,935** | **91,347** | **1,004,655** |

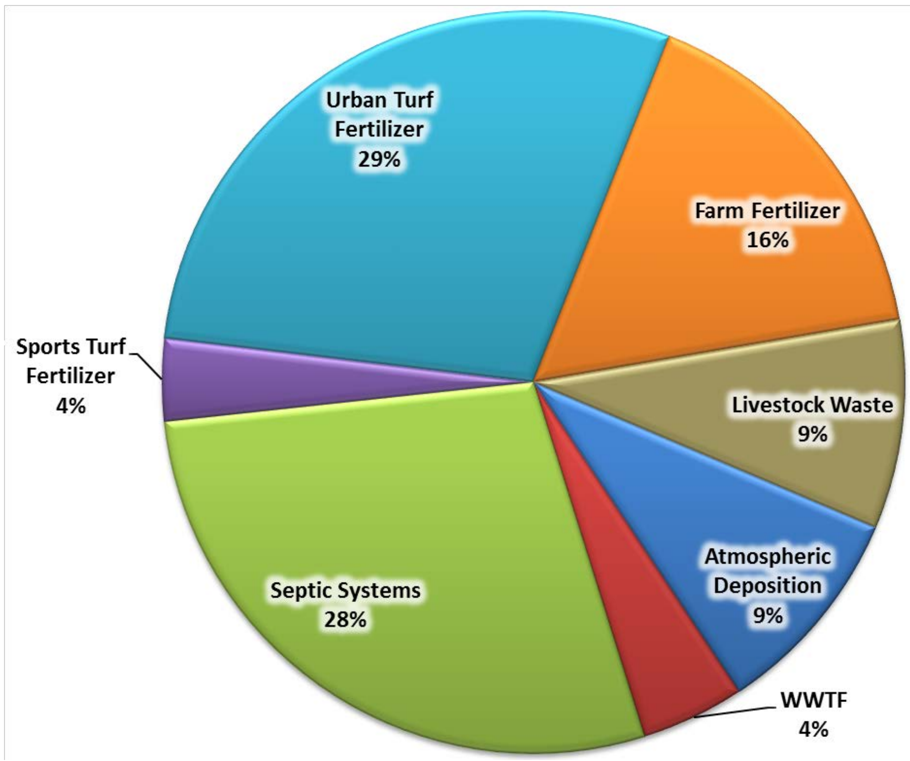


**Figure 9: Relative percent contributions of nitrogen loading to groundwater for source categories in the Weeki Wachee Spring contributing area**

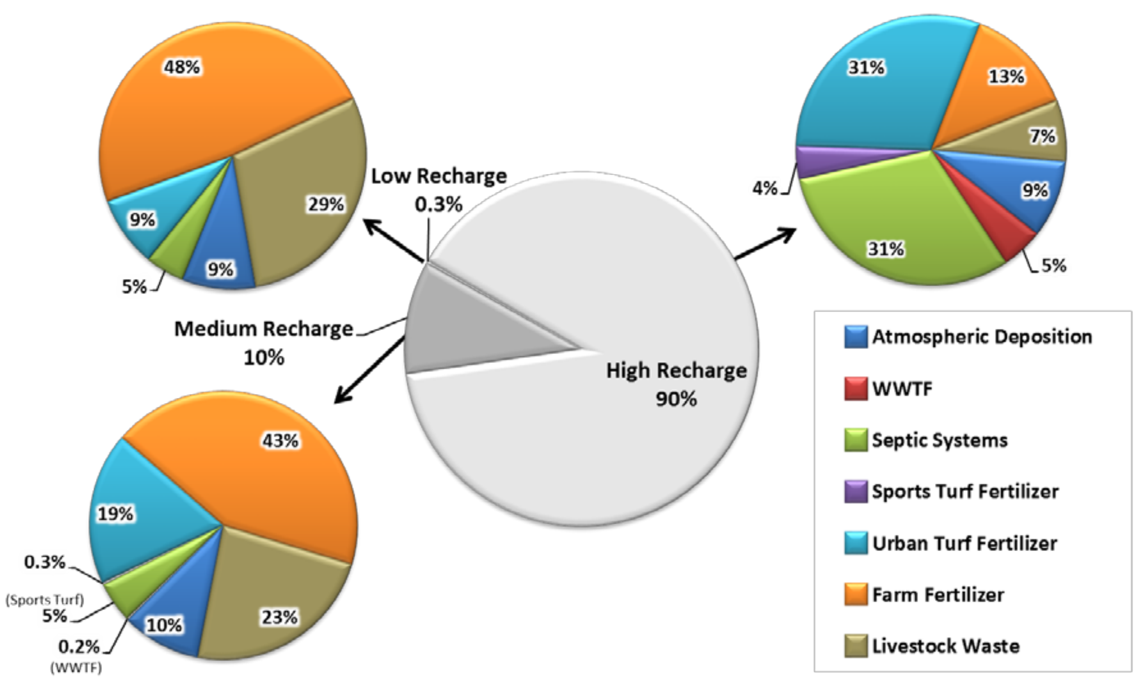


**Figure 10: Estimated annual nitrogen loading to groundwater by recharge category**

## 3.4 Accounting for Uncertainty in Nitrogen Attenuation Factors in Estimating Loading to Groundwater

The pie charts (**Figure 9** and **Figure 10**) provide information about the relative contribution of nitrogen loading to groundwater from each source. However, if the contribution from one nitrogen source category were to increase or decrease, the contribution of all the other sources would change proportionally. The amount of nitrogen attenuation for each source can vary substantially, both spatially and with depth in the subsurface, and can affect the amount of nitrogen leaching to groundwater and its relative contribution. The range (or uncertainty) in nitrogen attenuation can result from variability in soil properties, crop types, agricultural practices, nitrogen storage, the volatilization of ammonia to the atmosphere, uptake by vegetation, denitrification, and other removal processes. The density of nitrogen sources can also dramatically affect the attenuation potential of the environment.

Given the relatively large range in nitrogen attenuation for each source, DEP opted to use an average attenuation factor estimated based on land use practices and hydrogeological conditions in the Weeki Wachee Spring contributing area. Greater emphasis was placed on information on nitrogen attenuation from studies in central Florida, other locations in Florida, or areas with very similar soil and vegetation characteristics. **Table 20** lists the range in nitrogen attenuation for each source.

**Table 20: Range of environmental attenuation of nitrogen from a detailed literature review**

* = Both sports and urban turfgrass.

| N Source Category | Minimum BAF | Average BAF Used To Estimate N loads to Groundwater | Maximum BAF |
|---|---|---|---|
| **Atmospheric Deposition** | 85% | 90% | 95% |
| **WWTFs-RIBs** | 10% | 25% | 40% |
| **WWTFs-Sprayfield** | 50% | 60% | 75% |
| **WWTFs-Reuse** | 50% | 75% | 85% |
| **Septic Systems** | 40% | 50% | 75% |
| **Livestock Waste** | 80% | 90% | 95% |
| **Farm Fertilizers** | 50% | 70% | 85% |
| **Urban Fertilizers*** | 50% | 80% | 85% |

Using the minimum and maximum BAFs in **Table 20**, DEP estimated a corresponding range of nitrogen loading to groundwater from each source in the contributing area (**Figure 10**).

Even with the relatively large range in nitrogen attenuation for each source, the total estimated nitrogen load to groundwater in the Weeki Wachee springshed greatly exceeds the target load (TMDL) estimated for Weeki Wachee Spring. The target N load is based on the most recent discharge data and the TN concentration discharging from the spring vent.

For Weeki Wachee, the discharge is 185.6 cfs (USGS gauge station 02310545; April 2012–April 2013), and the adopted TMDL is 0.28 mg/L for the spring and river (Dodson and Bridger 2014), resulting in a target nitrogen load of 102,178 lb-N/yr. Using the maximum nitrogen attenuation factors for each source, the total load to groundwater in the contributing area is 635,269 lb-N/yr, which is considerably higher than the TMDL target nitrogen load for Weeki Wachee Spring (**Figure 12**).

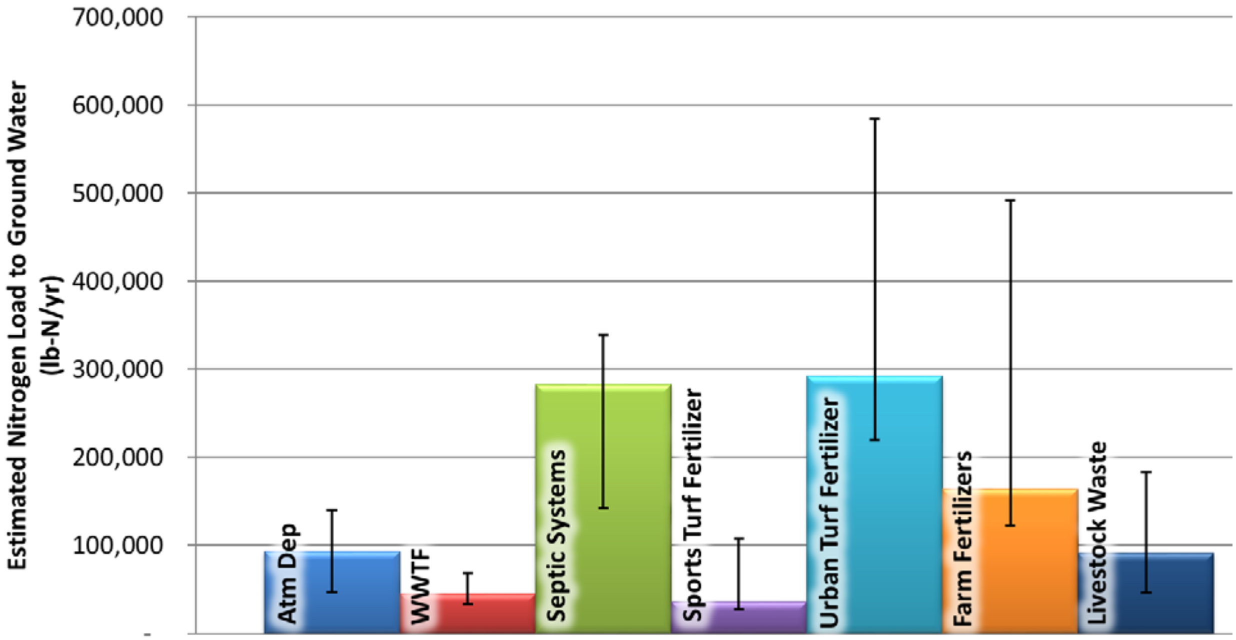


**Figure 11: Influence of the range of attenuation factors on estimated nitrogen loads to groundwater from each category in the Weeki Wachee Spring contributing area**

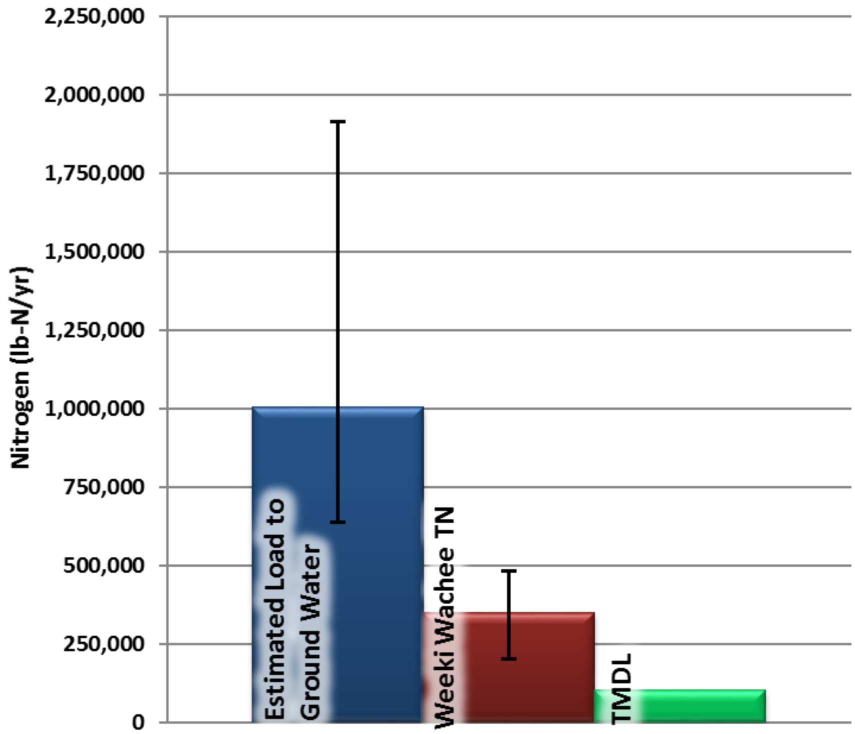


**Figure 12: Estimated nitrogen load to groundwater compared with the current nitrogen discharging from Weeki Wachee Spring, Little Spring, and Hospital Spring and the TMDL goal**

# 4. REFERENCES

Aravena, R. and W.D. Robertson. 1998. Use of multiple isotope tracers to evaluate denitrification in ground water: Study of nitrate from a large-flux septic system plume. *Ground Water* 36(6): 975–982.

Barton, L., and T.D. Colmer. 2006. Irrigation and fertilizer strategies for minimizing nitrogen leaching from turfgrass. *Agricultural Water Management* 80: 160–175.

Bridger, K., and J. Dodson. 2015. *Coastal springs of Pasco and Hernando Couties: Magnolia-Aripkeka Springs Group, Jenkins Creek Spring, Wilderness-Mud-Salt Springs Group (WBIDs 1391B, 1389, and 1382G).* Draft TMDL report. Tallahassee, FL: Florida Department of Environmental Protection.

Burns, J.C., M.G. Wagger, and D.S. Fisher. 2009. Animal and pasture productivity of 'Coastal' and 'Tifton 44' Bermudagrass at three nitrogen rates and associated soil nitrogen status. *Agronomy Journal* 101 (1): 32–40.

Bush, P.W., and R.H. Johnston. 1988. *Ground-water hydraulics, regional flow, and ground-water development of the Floridan aquifer system in Florida and parts of Georgia, South Carolina, and Alabama.* U.S. Geological Survey Professional Paper 1403-C.

Candela, L., S. Fabregat, A. Josa, J. Suriol, N. Vigues, and J. Mas. 2007. Assessment of soil and groundwater impacts by treated urban wastewater reuse: A case study: Application in a golf course (Girona Spain). *Science of the Total Environment* 374: 26–35.

Carey, R.O., G.J. Hockmuth, C.J.Martinez, T.H. Boyer, and V.D. Nair et al. 2012. A review of turfgrass fertilizer management practices: implications for urban water quality. *HortTechnology* 22(3):280–291.

Chang, N.B., M. Wanielista, A. Daranpob, F. Hossain, and Z. Xuan et al. 2010. *Onsite sewage treatment and disposal systems evaluation for nutrient removal.* Tallahassee, FL: Florida Department of Environmental Protection, Bureau of Watershed Restoration.

Chelette, A.R., T.R. Pratt, and B.G. Katz. 2002. *Nitrate loading as an indicator of nonpoint source pollution in the lower St. Marks–Wakulla Rivers watershed.* Northwest Florida Water Management District Water Resources Special Report 02-1.

Cockx, E.M., and E.H. Simonne. 2011. *Reduction of the impact of fertilization and irrigation on processes in the nitrogen cycle in vegetable fields with BMPs.* HS948. Gainesville, FL: University of Florida Institute of Food and Agricultural Sciences.

Cook, E.M., S.J. Hall, and K.L. Larson. 2012. Residential landscapes as social-ecological systems: A synthesis of multi-scalar interactions between people and their home environment. *Urban Ecosyst* 15: 19–52.

Corbett, D.R., K. Dillon, W. Burnett, and G. Schaefer. 2002. The spatial variability of nitrogen and phosphorus concentration in a sand aquifer influenced by onsite sewage treatment and disposal systems: A case study on St. George Island, Florida. *Environmental Pollution* 117:337–345.

Costa, J.E., G. Heufelder, S.Foss, N.P. Milham, and B. Howes. 2002. Nitrogen removal efficiencies of three alternative septic system technologies and a conventional septic system. *Environment Cape Cod* 5(1): 15–24.

Davis, J.H. 1996. *Hydrogeologic investigation and simulation of ground-water flow in the UFA of north-central Florida and southwestern Georgia and delineation of contributing areas for selected city of Tallahassee, Florida, water-supply wells.* U.S. Geological Survey Water-Resources Investigations Report 95-4296.

Dodson, J., and Bridger, K. 2014. *Nutrient TMDLs for Weeki Wachee Spring and Weeki Wachee River (WBIDs 1382B and 1382F).* Final TMDL report. Tallahassee, FL: Florida Department of Environmental Protection.

Downs, PE, J St. Germain and N Pick. 2012. *Focus Group for Northern Counties Springs Study: Final Report*. Southwest Florida Water Management District: 52 p.

Dubeux, J.C.B., Jr., L.E. Sollenberger, B.W. Mathews, J.M. Scholberg, and H.Q. Santos. 2007. Nutrient cycling in warm-climate grasslands. *Crop Science* 47: 915–928.

Dubeux, J.C.B., Jr., L.E. Sollenberger, L.A. Gaston, J.M.B. Vendramini, S.M. Interrante, and R.L. Stewart, Jr. 2009. Animal behavior and soil nutrient redistribution in continuously stocked Pensacola bahiagrass pastures managed at different intensities. *Crop Science* 49: 1503–1510.

Erikson, J.E., J.L. Cisar, J.C. Volin, and G.H. Snyder. 2001. Comparing nitrogen runoff and leaching between newly established St. Augustine turf and an alternative residential landscape. *Crop Science* 41: 1889–1895.

Faulkner, G.L. 1970. *Geohydrology of the Cross-Florida Barge Canal with special reference to the Ocala vicinity.* U.S. Geological Survey Water-Resources Investigations Report I-73.

Florida Department of Environmental Protection. 2007. *Best management practices for the enhancement of environmental water quality on Florida golf courses*. Tallahassee, FL.

———. 2010. *Florida Friendly Best Management Practices for Protection of Water Resources by the Green Industries*. Tallahassee, FL.

Goolsby, D.A., W.A. Battaglin, G.B. Lawrence, R.S. Artz, and B.T. Aulenbach et al. 1999. *Flux and sources of nutrients in the Mississippi-Atchafalaya River Basin.* National Oceanic and Atmospheric Administration Coastal Ocean Program No. 17.

Grove, J.M, M.L Cadenasso, W.R. Burch, S.T.A. Pickett, K. Schwarz, J. O'Neil-Dunne, and M. Wilson. 2006. Data and methods comparing social structure and vegetation structure of urban neighborhoods in Baltimore, Maryland. *Society and Natural Resources* 19: 117–136.

Hall, P., and S.J. Clancy. 2009. *The Florida statewide inventory of onsite sewage treatment and disposal systems (OSTDS): A report on the status of knowledge of the number and locations of OSTDS in each county and best management practices for improving this knowledge.* Prepared for the Florida Department of Health, Bureau of Onsite Sewage Programs, by EarthSTEPS and GlobalMind.

He, J., M.D. Dukes, G.J. Hochmuth, J.W. Jones, and W.D. Graham. 2011. Evaluation of sweet corn yield and nitrogen leaching with CERES-maize considering input parameter uncertainties. *Transaction of the American Society of Agricultural and Biological Engineers* 54(4):1257–1268.

Hochmuth, G.J., and E.A. Hanlon. 2000. *IFAS standardized fertilization recommendations for vegetable crops.* Circular 1152. Gainesville, FL: University of Florida Institute of Food and Agricultural Sciences.

———. 2010. *Commercial vegetable fertilization principles.* SL319. Gainesville, FL: University of Florida Institute of Food and Agricultural Sciences.

———. 2013. *A summary of N, P, and K research with watermelon in Florida.* SL 325. Gainesville, FL: University of Florida Institute of Food and Agricultural Sciences.

Horsley Witten Group. 2009. *Evaluation of turfgrass nitrogen fertilizer leaching rates in soils on Cape Cod, Massachusetts.* Prepared for Brian Dudley, Department of Environmental Protection, Hyannis, MA. Sandwich, MA.

Howard T. Odom Florida Springs Institute. 2011. *Wakulla Spring–An adaptive management strategy.* Prepared for the Wakulla Springs Working Group. Gainesville, FL.

Jones, G.W., S.B. Upchurch, K.M. Champion, and D.J. Dewitt. 1997. *Water quality and hydrology of Homosassa, Chassahowitzka, Weeki Wachee, and Aripeka Spring Complexes, Citrus and Hernando Counties, Florida. Origin of increasing nitrate concentrations.* Southwest Florida Water Management District.

Jordan, M.J., H.J. Nadelhoffer, and B. Fry. 1997. Nitrogen cycling in forest and grass ecosystems irrigated with 15N-enriched wastewater. *Ecological Applications* 7 (3): 864–881.

Katz, B.G. 1992. *Hydrochemistry of the upper Floridan aquifer, Florida.* U.S. Geological Survey Water-Resources Investigations Report 91-4196.

———. 2004. Sources of nitrate contamination and age of water in large karstic springs of Florida. *Environmental Geology* 46: 689–706.

Katz, B.G, H.D. Hornsby, J.F. Boklke, and M.F. Mokray. 1999. *Sources and chronology of nitrate contamination in spring waters, Suwannee River Basin, Florida.* U.S. Geological Survey Water-Resources Investigations Report 99-4252.

Katz, B.G., A.A. Sepulveda, and R.J. Verdi. 2009. Estimating nitrogen loading to ground water and assessing vulnerability to nitrate contamination in a large karstic springs basin, Florida. *Journal of the American Water Resources Association* 45: 3.

Kinzig, A.P., P. Warren, C. Martin, D. Hope and M. Katti. 2005. The effects of human socioeconomic status and cultural characteristics on urban patterns of biodiversity. *Ecology and Society* 10 (1).

Knowles, L. 1996. *Estimation of evapotranspiration in the Rainbow Springs and Silver Springs basins in north-central Florida.* U.S. Geological Survey Water-Resources Investigations Report 96-4024.

Law, N.L, L.E. Band, and J.M. Grove. 2004. Nitrogen input from residential lawn care practices in suburban watersheds in Baltimore County, MD. *Journal of Environmental Planning and Management* 47 (5): 737–755.

Liao, L., C.T. Green, B.A. Bekins, and J.K. Bohlke. 2012. Factors controlling nitrate fluxes in groundwater in agricultural areas. *Water Resources Research* 48: 1–18.

Liu, G.D., E.H. Simonne, and G.J. Hochmuth. Revised 2013. *Soil and fertilizer management for vegetable production in Florida.* Document HS711. Gainesville, FL: University of Florida Institute of Food and Agricultural Sciences.

Lombardo Associates. 2011. *Onsite sewage treatment and disposal and management options.* Newton, MA.

Martin, T. 2008. *Lawn care behavior, Crystal River/Weeki Wachee Spring and Rainbow River survey.* Final report prepared for the Southwest Florida Water Management District.

McNeal, B.L, C.D. Stanley, W.D. Graham, P.R. Gilreath, D. Downey, and J.F. Creighton. 1995. Nutrient loss trends for vegetable and citrus fields in west-central Florida: 1. Nitrate. *Journal of Environmental Quality* 24(1): 95–100.

Merritt, M., and D.J. Toth. 2006. *Estimates of upper Floridan aquifer recharge augmentation based on hydraulic and water-quality data (1986–2002) from the Water Conserv II RIB systems, Orange County, Florida.* St. Johns River Water Management Special Publication SJ2006-SP3, Palatka, FL.

Meyer, L.H. 2012. *Quantifying the role of agriculture and urbanization in the nitrogen cycle across Texas.* University of Texas graduate thesis.

Mylavarapu, R., D. Wright, G. Kidder, and C.G. Chambliss. 2012. *UF/IFAS standardized fertilization recommendations for agronomic crops.* SL 129. Gainesville, FL: University of Florida Institute of Food and Agricultural Sciences.

Newton, G.L., J.C. Johnson, Jr., J.G. Davis, G. Vellidis, R.K. Hubbard, and R. Lowrance. 1995. *Nutrient recoveries from varied year-round applications of liquid dairy manure on sprayfields.* 32nd Dairy Production Conference. Gainesville, FL.

Newton, G.L., G.J. Gascho, G. Vellidis, R.N. Gates, and R.K. Hubbard et al. 1999. *Nutrient balance for triple-crop forage production systems fertilized with dairy manure or commercial fertilizer.* Water Resource Conference. Athens, GA: University of Georgia.

Obour, A.K., M.L. Silveira, J.M.B. Vendramini, M.B. Adjei, and L.E. Sollenberger. 2010. Evaluating cattle manure application strategies on phosphorus and nitrogen losses from a Florida spodosol. *Agronomy Journal* 102(5): 1511–1520.

Otis, R.J. 2007. *Estimates of nitrogen loadings to groundwater from onsite wastewater treatment systems in the Wekiva Study Area.* Otis Environmental Consultants, LLC.

Paramasivam, S., and A.K. Alva. 1997. Leaching of nitrogen forms from controlled-release nitrogen fertilizers. *Communications in Soil Science and Plant Analysis* 28(17&18): 1663–1674.

Poiani, K.A., B.L. Bedord, and M.D. Merrill. 1996. A GIS-based index for relating landscape characteristics to potential nitrogen leaching to wetlands. *Landscape Ecology* 11:237–255.

Rahil, M.H., and V.Z. Antonopoulos. 2007. Simulating soil water flow and nitrogen dynamics in a sunflower field irrigated with reclaimed wastewater. *Agricultural Water Management* 92: 142–150.

Roeder, E. 2008. Sources of nitrogen: Estimates for inputs and loads to ground water in the Wekiva Study Area. *Florida Journal of Environmental Health.*

Ruddy, B.C., D.L. Lorenz, and D.K. Mueller. 2006. *County-level estimates of nutrient inputs to the land surface of the conterminous United States, 1982–2001.* U.S. Geological Survey Scientific Investigations Report 2006-5012.

Sartain, J.B. 2002. *Recommendations for N, P, K and Mg for Golf Course and Athletic Field Fertilization Based on Mehlich III Extractant.* Document SL 191. Gainesville, FL: University of Florida Institute of Food and Agricultural Sciences

Scanlon, B.R., R.W. Healy, and P.G. Cook. 2002. Choosing appropriate techniques for quantifying groundwater rechage. *Hydrogeology Journal* 10:18–39.

Schwede, D.B., and G.G. Lear. 2014. A novel hybrid approach for estimating total deposition in the United States. *Atmospheric Environment* 92: 207–220.

Sepulveda, N. 2002. *Simulation of ground-water flow in the intermediate and Floridan aquifer systems in peninsular Florida.* U.S. Geological Survey Water-Resources Investigations Report 02-4009.

Sigua, G.C. 2010. Sustainable cow-calf operations and water quality: A review. *Agron. Sustain. Dev.* 30: 631–648.

Sigua, G.C., R.K. Hubbard, S.W. Coleman, and M. Williams. 2010. Nitrogen in soils, plants, surface water and shallow groundwater in a bahiagrass pasture of southern Florida, USA. *Nutrient Cycling in Agroecosystems* 86: 175–187.

Silveira, M.L., V.A. Haby, and A.T. Leonard. 2007. Response of coastal bermudagrass yield and nutrient uptake efficiency to nitrogen sources. *Agronomy Journal* 99: 707–714.

Silveira, M.L., A.K. Obour, J. Arthington, and L.E. Sollenberger. 2011. The cow-calf industry and water quality in south Florida: A review. *Nutrient Cycling in Agroecosystems* 89: 439–452.

Simonne, E., M. Dukes, G. Hochmuth, B. Hochmuth, D. Studstill, and A. Gazula, 2006. Monitoring nitrate concentration in shallow wells below a vegetable field. *Proc. Fla. State Hort. Soc.* 119: 226–230.

Sprague, L.A., and J.M. Gronberg. 2013. Estimation of anthropogenic nitrogen and phosphorus inputs to the land surface of the conterminous United States—1992, 1997, and 2002. U.S. Geological Survey Scientific Investigations Report 2012-5241.

Sumner, D.M., and L.A. Bradner. 1996. *Hydraulic characteristics and nutrient transport and transformation beneath a rapid infiltration basin, Reedy Creek Improvement District, Orange County, Florida.*

Tomasko, D.A., D.L. Bristol, and J.A. Ott. 2001. Assessment of present and future nitrogen loads, water quality, and seagrass (*Thalassia testudinum*) depth distribution in Lemon Bay, Florida. *Estuaries* 24 (6A):926–938.

Toor, G.S., M. Lusk, and T. Obreza. 2011. *Onsite sewage treatment and disposal systems: Nitrogen.* SL 348. Gainesville, FL: University of Florida Institute of Food and Agricultural Sciences.

U.S. Environmental Protection Agency. 2002. *Onsite wastewater treatment systems manual.* EPA/625/R-00/008. Washington, DC: Office of Water.

Viers, J.H, D. Liptzin, T.S. Rosenstock, W.B. Jensen, and A.D. Hollander et al. 2012. *Nitrogen sources and loading to groundwater.* Technical Report 2. California State Water Resources Control Board.

Wang, F.L., and A.K. Alva. 1996. Leaching of nitrogen from slow-release urea sources in sandy soils. *Soil Science Society of America Journal* 60: 1454–1458.

Wang, L., A.S. Butcher, M.E. Stuart, D.C. Gooddy, and J.P. Bloomfield. 2013. The nitrate time bomb: A numerical way to investigate nitrate storage and lag time in the unsaturated zone. *Environmental Geochemistry and Health* 35:667–681.

White-Leech, R., K. Liu, L.E. Sollenberger, K.R. Woodard, and S.M. Interrante. 2013a. Excreta deposition on grassland patches. I. Forage harvested, nutritive value, and nitrogen recovery. *Crop Science* 53: 688–695.

———. 2013b. Excreta deposition on grassland patches. II. Spatial pattern and duration of forage responses. *Crop Science* 53: 696–703.

Woodard, K.R., L.E. Sollenberger, D.A. Graetz, C.G. Chambliss, and J.M. Scholberg. 2006. *Verification of interim BMPs for nitrogen fertilization of hayfields within the Suwannee River Water Management District and confirmation of interim BMP for maximum nitrogen fertilization of hayfields in the Suwannee River Water Management District.* Final report for the Florida Department of Agriculture and Consumer Services projects.

Woodard, K.R., and L.E. Sollenberger. 2011. Broiler litter vs. ammonium nitrate as nitrogen source for bermudagrass hay production: Yield, nutritive value, and nitrate leaching. Crop Science 51: 1342–1352.

Wright, D.L., E.B. Whitty, and C.G. Chambliss. 2011. *Fertilization of agronomic crops.* SS-AGR-152. Gainesville, FL: University of Florida Institute of Food and Agricultural Sciences.

Zhou, W., A. Troy, and M. Grove. 2008. Modeling residential lawn fertilization practices: Integrating high resolution remote sensing with socioeconomic data. *Environmental Management* 41: 742–752.

# APPENDICES

## Appendix A: Tables

**Table A.1: Useful conversion factors**

| Convert from | To | Multiply by |
|---|---|---|
| **Pounds** | kilograms | 0.4535924 |
| **$NO_3$ milligrams per liter** | $NO_3$ grams-nitrogen per liter | 2.260 X 10-4 |
| **$NH_4$ milligrams per liter** | $NH_4$ grams-nitrogen per liter | 7.765 X 10-4 |
| **milligrams** | grams | 0.001 |
| **grams** | kilograms | 0.001 |
| **milligrams** | kilograms | 1 X 10-6 |
| **acre** | hectares | 0.4046873 |
| **square meters** | hectares | 0.0001 |
| **cubic centimeters** | liters | 0.001 |
| **tons** | kilograms | 907.1847 |
| **cubic feet** | liters | 28.31685 |
| **second** | year | 3.170979 X 10-8 |
| **rainfall (centimeters)** | rainfall (liters per hectare) | 104 |

**Table A.2: Summary of SWFWMD land use data in Hernando County**

| Land Use Code | Land Use Description | Hernando County | High Recharge | Medium Recharge | Discharge |
|---|---|---|---|---|---|
| **2100** | Cropland and Pastureland | 31,912 | 12,727 | 8,773 | 0 |
| **2300** | Feeding Operations | 393 | 96 | 0 | 0 |
| **2500** | Specialty Farms | 1,547 | 625 | 174 | 0 |
| **2140** | Row Crops | 105 | 96 | 7 | 0 |
| **2200** | Tree Crops | 877 | 229 | 249 | 0 |
| **2400** | Nurseries and Vineyards | 1,279 | 417 | 105 | 0 |
| **1100** | Residential Low Density <2 Dwelling Units | 41,835 | 15,798 | 2,270 | 0 |
| **1200** | Residential Medium Density 2–5 Dwelling Units | 24,602 | 19,448 | 0 | 275 |
| **1300** | Residential High Density | 5,388 | 3,817 | 52 | 1,040 |
| **1800** | Recreational | 939 | 515 | 0 | 14 |
| **1820** | Golf Courses | 2,567 | 1,638 | 0 | 212 |

## Table A.3: Summary of SWFWMD land use data in Pasco County

| Land Use Code | Land Use Description | Pasco County | High Recharge | Medium Recharge | Low Recharge |
|---|---|---|---|---|---|
| **2100** | Cropland and Pastureland | 82,029 | 18,245 | 17,652 | 5,209 |
| **2300** | Feeding Operations | 856 | 55 | 135 | 23 |
| **2500** | Specialty Farms | 1,788 | 415 | 69 | 0 |
| **2140** | Row Crops | 74 | 9 | 37 | 0 |
| **2200** | Tree Crops | 7,371 | 587 | 1,091 | 196 |
| **2400** | Nurseries and Vineyards | 994 | 223 | 171 | 0 |
| **1100** | Residential Low Density <2 Dwelling Units | 54,042 | 6,982 | 2,869 | 729 |
| **1200** | Residential Medium Density 2–5 Dwelling Units | 27,410 | 3,440 | 43 | 43 |
| **1300** | Residential High Density | 27,687 | 117 | 49 | 0 |
| **1800** | Recreational | 1,924 | 24 | 0 | 0 |
| **1820** | Golf Courses | 3,276 | 36 | 36 | 0 |

**Table A.4: Summary of land use provided by the Hernando County property appraiser office**

| Property Code | Description | High-Recharge Area | Medium-Recharge Area | Discharge Area |
|---|---|---|---|---|
| **0** | VACANT RESIDENTIAL | 5,495 | 180 | 23 |
| **1** | SINGLE FAMILY | 14,371 | 978 | 167 |
| **2** | MOBILE HOME | 3,893 | 340 | |
| **3** | MULTI FAMILY 10 UNITS OR MORE | 110 | | |
| **4** | CONDOMINIUM | 24 | | |
| **5** | COOPERATIVES | | | |
| **6** | RETIREMENT HOMES | | | |
| **7** | MISC RES(BOARDING HOMES,CAMPS) | | | |
| **8** | MULTI FAMILY LESS THAN 10 UNIT | 75 | | |
| **10** | VACANT COMMERCIAL | 526 | 1 | 4 |
| **11** | STORES, 1 STORY | 194 | 1 | 2 |
| **12** | STORE/OFFICE/OR RESID COMBIN | 15 | | |
| **13** | DEPARTMENT STORE | 5 | | 1 |
| **15** | SHOPPING CENTERS (REGIONAL) | 6 | | |
| **16** | SHOPPING CENTERS (COMMUNITY) | 51 | | 2 |
| **17** | OFFICE BUILDINGS, 1 STORY | 127 | | 1 |
| **18** | OFFICE BUILDINGS, MULTI STORY | 11 | | |
| **19** | PROFESSIONAL BUILDINGS | 189 | | |
| **20** | AIRPORTS, BUS TERM, MARINAS, | 1 | | |
| **21** | RESTAURANT AND CAFETERIAS | 43 | | 2 |
| **22** | DRIVE IN RESTAURANTS | 17 | | 2 |
| **23** | FINANCIAL INSTITUTIONS | 24 | | 1 |
| **25** | SERVICE SHOP, RADIO & TV REPIR | 4 | | |
| **26** | SERVICE STATIONS | 23 | | |
| **27** | AUTO SALES, REPAIR & STORAGE | 54 | | |
| **28** | PARKING LOTS, COMM, MH PARKS | 47 | 4 | |
| **29** | WHOLESALE OUTLETS, PRODUCE | 1 | | |
| **30** | FLORIST, GREENHOUSES | 3 | | |
| **32** | THEATERS, (ENCLOSED) AUDITORIM | 2 | | |
| **33** | NIGHT CLUBS, COCKTAIL LOUNGES | 2 | | |
| **34** | BOWLING ALLEYS, SKATING RINKS | 3 | | |
| **35** | TOURIST ATTR. OTHER ENTERTNMT | 2 | | |
| **36** | CAMPS | 4 | 2 | |
| **38** | GOLF COURSES, DRIVING RANGES | 64 | | 4 |
| **39** | HOTELS - MOTELS | 7 | | |
| **40** | VACANT INDUSTRIAL | 22 | | |
| **41** | LIGHT MANUFACTURING | 34 | | |
| **44** | PACKING PLANTS, FRUIT & VEGE | 1 | | |

| Property Code | Description | High-Recharge Area | Medium-Recharge Area | Discharge Area |
|---|---|---|---|---|
| **46** | OTHER FOOD PROCESSING, CANDY | 1 | | |
| **48** | WAREHOUSING, DISTRIBUTION | 145 | 1 | |
| **49** | OPEN STORAGE, NEW AND USED | 12 | | |
| **51** | CROPLAND SOIL CAPABILITY CLS I | 65 | 40 | |
| **54** | TIMBER NATURAL STAND | 183 | 26 | 2 |
| **55** | TIMBER PLANTED | 58 | 5 | |
| **56** | TIMBERLAND | 2 | | |
| **59** | WOODS - NATIVE PASTURE | 95 | 36 | |
| **60** | IMPROVED PASTURE LAND | 342 | 98 | |
| **65** | GRAZING LAND SOIL CAPAB VI | 1 | | |
| **66** | ORCHARD GROVES | 20 | 13 | |
| **67** | POULTRY, BEES, HOGS IN FIELD | 3 | | |
| **69** | ORNAMENTALS | 22 | 2 | |
| **70** | VACANT INSTITUTIONAL | 59 | | 1 |
| **71** | CHURCHES | 63 | | |
| **72** | SCHOOLS, COLLEGES PRIVATE | 11 | | |
| **73** | HOSPITALS PRIVATELY OWNED | 5 | | |
| **74** | HOMES FOR THE AGED | 25 | | |
| **75** | CHARITABLE/NON PROFIT | 3 | | |
| **76** | MORTUARIES, CEMETERIES, CREMAT | 16 | 2 | |
| **77** | CLUBS, LODGES, UNION HALLS | 67 | | 1 |
| **80** | VACANT GOVERNMENTAL | 82 | 1 | |
| **81** | MILITARY | 4 | | |
| **82** | FOREST PARKS RECREATIONAL | 41 | | 4 |
| **83** | SCHOOLS - PUBLIC COUNTY | 13 | | |
| **85** | HOSPITALS | 1 | | |
| **86** | COUNTIES OTHER THAN PUBLIC SCH | 59 | | |
| **87** | STATE OTHER THAN MILITARY FORE | 134 | | 19 |
| **88** | FEDERAL OTHER THAN MILITARY | 1 | | |
| **89** | MUNICIPAL OTHER THAN PARKS | 3 | | |
| **90** | LEASEHOLD INTERESTS | 204 | | |
| **91** | UTIL,RR,GAS,COMMICATIONS,ELECT | 122 | | 2 |
| **94** | RIGHT OF WAY STREETS/ROADS | 586 | 19 | 39 |
| **95** | RIVERS AND LAKES, SUBMERGED | 57 | 1 | 4 |
| **96** | DRA,LIFT STAT,MARSH,BORROWPIT | 1,324 | 2 | 16 |
| **97** | OUTDOOR PARKLAND/REC | 11 | | |
| **99** | ACREAGE NOT CLASSIFIED | 365 | 41 | 2 |

**Table A.5: Summary of land use provided by the Pasco County property appraiser office**

| Property Code | Description | High-Recharge Area | Medium-Recharge Area | Low-Recharge Area |
|---|---|---|---|---|
| **0** | VACANT RESIDENTIAL | 1,824 | 427 | 38 |
| **1** | SINGLE FAMILY | 3,029 | 1,055 | 157 |
| **2** | MOBILE HOME | 1,912 | 448 | 34 |
| **3** | MULTI FAMILY 10 UNITS OR MORE | | | |
| **4** | CONDOMINIUM | | | |
| **5** | COOPERATIVES | | | |
| **6** | RETIREMENT HOMES | | | |
| **7** | MISC RES(BOARDING HOMES,CAMPS) | | | |
| **8** | MULTI FAMILY LESS THAN 10 UNIT | 686 | 152 | 10 |
| **10** | VACANT COMMERCIAL | 205 | 36 | 1 |
| **11** | STORES, 1 STORY | 10 | 18 | 5 |
| **12** | STORE/OFFICE/OR RESID COMBIN | 57 | 13 | 0 |
| **13** | DEPARTMENT STORE | | | |
| **14** | SUPER MARKETS | | | |
| **15** | SHOPPING CENTERS (REGIONAL) | | | |
| **16** | SHOPPING CENTERS (COMMUNITY) | | | |
| **17** | OFFICE BUILDINGS, 1 STORY | 4 | 2 | |
| **18** | OFFICE BUILDINGS, MULTI STORY | 1 | | |
| **19** | PROFESSIONAL BUILDINGS | 1 | 10 | |
| **20** | AIRPORTS, BUS TERM, MARINAS, | | | |
| **21** | RESTAURANT AND CAFETERIAS | | | |
| **22** | DRIVE IN RESTAURANTS | | | |
| **23** | FINANCIAL INSTITUTIONS | | | |
| **24** | INSURANCE COMPANY NATL REG OFF | | | |
| **25** | SERVICE SHOP, RADIO & TV REPIR | 6 | 4 | |
| **26** | SERVICE STATIONS | | | |
| **27** | AUTO SALES, REPAIR & STORAGE | 4 | | |
| **28** | PARKING LOTS, COMM, MH PARKS | 124 | 33 | |
| **29** | WHOLESALE OUTLETS, PRODUCE | | | |
| **30** | FLORIST, GREENHOUSES | | | |
| **31** | THEATERS, (DRIVE IN) STADIUMS | | | |
| **32** | THEATERS, (ENCLOSED) AUDITORIM | | | |
| **33** | NIGHT CLUBS, COCKTAIL LOUNGES | 2 | 3 | 2 |
| **34** | BOWLING ALLEYS, SKATING RINKS | | | |
| **35** | TOURIST ATTR. OTHER ENTERTNMT | | | |
| **36** | CAMPS | | | |
| **37** | RACE TRACKS, HORSE, AUTO OR DO | | | |
| **38** | GOLF COURSES, DRIVING RANGES | | | |

| Property Code | Description | High-Recharge Area | Medium-Recharge Area | Low-Recharge Area |
|---|---|---|---|---|
| **39** | HOTELS - MOTELS | | | |
| **40** | VACANT INDUSTRIAL | 19 | 43 | |
| **41** | LIGHT MANUFACTURING | 20 | 9 | |
| **42** | HEAVY INDUSTRIAL, HEAVY EQUIP | | | |
| **43** | LUMBER YARDS, SAWMILLS | | | |
| **44** | PACKING PLANTS, FRUIT & VEGE | | | |
| **45** | CANNERIES, FRUIT & VEGETABLE | | | |
| **46** | OTHER FOOD PROCESSING, CANDY | | | |
| **47** | MINERAL PROCESSING, PHOSPHATE | 22 | | |
| **48** | WAREHOUSING, DISTRIBUTION | 43 | 51 | |
| **49** | OPEN STORAGE, NEW AND USED | | | |
| **50** | IMPROVED AGRICULTURAL | | | |
| **51** | CROPLAND SOIL CAPABILITY CLS I | 939 | 1,107 | 242 |
| **52** | CROPLAND SOIL CAPABILITY II | | | |
| **53** | CROPLAND SOIL CAPABILITY III | 24 | 57 | |
| **54** | TIMBER NATURAL STAND | 11,015 | 512 | 45 |
| **55** | TIMBER PLANTED | 604 | 311 | |
| **56** | TIMBERLAND | | | |
| **57** | TIMBERLAND | | | |
| **58** | TIMBERLAND | | | |
| **59** | WOODS - NATIVE PASTURE | | | |
| **60** | IMPROVED PASTURE LAND | 12,137 | 11,031 | 1,477 |
| **61** | GRAZING LAND SOIL CAPAB II | 700 | 283 | 267 |
| **62** | GRAZING LAND SOIL CAPAB III | 553 | 4 | 100 |
| **63** | GRAZING LAND SOIL CAPAB IV | 984 | 370 | 283 |
| **64** | GRAZING LAND SOIL CAPAB V | 2,276 | 1,151 | |
| **65** | GRAZING LAND SOIL CAPAB VI | 2,525 | 342 | |
| **66** | ORCHARD GROVES | 630 | 561 | 147 |
| **67** | POULTRY, BEES, HOGS IN FIELD | | | |
| **68** | DAIRIES, FEED LOTS,PENNED HOGS | 432 | 455 | 173 |
| **69** | ORNAMENTALS | 172 | 72 | |
| **70** | VACANT INSTITUTIONAL | 1 | 1 | |
| **71** | CHURCHES | 31 | 13 | |
| **72** | SCHOOLS, COLLEGES PRIVATE | | | |
| **73** | HOSPITALS PRIVATELY OWNED | | | |
| **74** | HOMES FOR THE AGED | | | |
| **75** | CHARITABLE/NON PROFIT | | | |

## Table A.6: Hernando County zoning data

| Zoning Code | Zoning Description | % Maximum Lot Coverage |
|---|---|---|
| **AC** | AC Agricultural Commercial District | |
| **AG** | AG Agricultural District | |
| **AR** | AR Agricultural Residential District | |
| **AR1** | AR1 Agricultural Residential District | |
| **AR2** | AR Agricultural Residential District | |
| **C1** | C1 General Commercial District | |
| **C2** | C2 Highway Commercial District | |
| **C3** | C3 Neighborhood Commercial District | |
| **C4** | C4 Heavy Highway Commercial District | |
| **CITY** | City | |
| **CM1** | CM1 Marine Commercial District | |
| **CM2** | CM2 Heavy Marine Commercial District | |
| **CPDP** | CPDP (Combined) | |
| **CV** | CV Conservation District | |
| **I1** | I1 Industrial District | |
| **I2** | I2 Heavy Industrial District | |
| **M** | M Mining District | |
| **OP** | OP Office-Professional District | |
| **PDP(AF)** | PDP (Aviation Facilities) | |
| **PDP(CM)** | PDP (Commercial Marine) | |
| **PDP(CP)** | PDP (Corporate Park) | |
| **PDP(GC)** | PDP (General Commercial) | |
| **PDP(GHC)** | PDP (General Highway Commercial) | |
| **PDP(HC)** | PDP (Highway Commercial) | |
| **PDP(HHC)** | PDP (Heavy Highway Commercial) | |
| **PDP(HID)** | PDP (Heavy Industrial) | |
| **PDP(IND)** | PDP (Industrial) | |
| **PDP(LI)** | PDP (Light Industrial) | |
| **PDP(MF)** | PDP (Multifamily) | 0.35 |
| **PDP(MH)** | PDP (Mobile Home) | 0.35 |
| **PDP(NC)** | PDP (Neighborhood Commercial) | |
| **PDP(OP)** | PDP (Office/Professional) | |
| **PDP(OP)** | PDP (Single-Family) | 0.35 |
| **PDP(PSF)** | PDP (Public Service Facility Overlay District) | |
| **PDP(REC)** | PDP (Recreational) | |
| **PDP(RR)** | PDP (Resort Residential) | 0.35 |
| **PDP(RUR)** | PDP (Rural) | |
| **PDP(SF)** | PDP (Single-Family) | 0.35 |
| **PDP(SU)** | PDP (Recreational) | |

| Zoning Code | Zoning Description | % Maximum Lot Coverage |
|---|---|---|
| **PDP(SU)** | PDP (Single-Family) | |
| **PDP(SU)** | PDP (Special Use) | |
| **R1A** | R1A Residential District | 0.35 |
| **R1B** | R1B Residential District | 0.35 |
| **R1C** | R1C Residential District | 0.35 |
| **R1MH** | R1MH Residential Single-Family Manufactured Housing | |
| **R2** | R2 Residential District | 0.35 |
| **R2.5** | R2.5 Residential District | 0.35 |
| **R3** | R3 Residential District | 0.45 |
| **R4** | R4 Residential District | 0.45 |
| **RC** | RC Recreational Commercial District | |
| **RM** | RM Residential Mobile Home District | 0.35 |
| **RR** | Residential District | 0.45 |

**Table A.7: Pasco County zoning data**

| Zoning Code | Zoning Description | % Maximum Lot Coverage |
|---|---|---|
| **AC** | Agricultural District | 0.15 |
| **AC1** | Agricultural District | 0.15 |
| **AR** | Agricultural-Residential District | 0.25 |
| **AR1** | Agricultural-Residential District | 0.25 |
| **AR5** | Agricultural-Residential District | 0.3 |
| **AR5MH** | Agricultural-Mobile Home District | 0.3 |
| **C1** | Neighborhood Commercial District | 0.5 |
| **C2** | General Commercial District | 0.5 |
| **C3** | Commercial/Light Manufacturing District | 0.5 |
| **ER** | Estate-Residential District | 0.35 |
| **ER1** | Estate-Residential District | 0.35 |
| **I1** | Light Industrial Park District | 0.5 |
| **I2** | Light Industrial Park District | 0.5 |
| **MF1** | Multiple Family Medium Density District | 0.4 |
| **MF2** | Multiple Family High Density District | 0.55 |
| **MF3** | Multiple Family High Density District | 0.55 |
| **PO1** | Professional Office District | 0.35 |
| **PO2** | Professional Office District | 0.35 |
| **R1** | Rural Density Residential District | 0.35 |
| **R1MH** | Mobile Home District | 0.35 |
| **R2** | Low Density Residential District | 0.65 |
| **R2MH** | Mobile Home District | 0.35 |
| **R3** | Medium Density Residential District | 0.65 |
| **R4** | High Density Residential District | 0.65 |
| **RMH** | Mobile Home District | 0.35 |

Table A.8: 2012 CoA livestock populations for Hernando and Pasco Counties

| CoA Population | Hernando County | Pasco County |
|---|---|---|
| **Beef Cattle** | 11,402 | 21,509 |
| **Calves** | 4,397 | 8,352 |
| **Dairy Cows** | | 1,092 |
| **Horses** | 2,080 | 2,008 |
| **Broiler Chickens** | | 604 |
| **Goats** | 1,034 | 1410 |
| **Hogs** | 328 | 165 |
| **Sheep** | 318 | 251 |
| **Turkey** | | 63 |

**Appendix B - Golf Course Questionnaire**
**Florida Department of Environmental Protection**
**Ground Water Management Section**
**850-245-8652**

**This survey is designed to gather data on nitrogen (N) application rates. All information is optional, remains confidential and is not utilized for any regulatory purposes**.

This form is available electronically, for an e-mail version please contact us at the addresses listed at the bottom.

---

## CONTACT INFORMATION

Name

Are you the course Superintendent?

- ◯ YES
- ◯ NO

Preferred Method of Contact

- ☐ Email
- ☐ Phone

Email Address

Phone Number

---

## GOLF COURSE INFORMATION

Golf Course Name

What is the closest city or town?

Does your golf course follow the BMP manual?

◯ YES ◯ NO

What is the total area of the course?

◯ Sq ft ◯ Acre

---

## GREENS (including practice greens)

Total Area of Greens ◯ Sq ft ◯ Acre

N Application Rate each Year per ◯ 1000 sq ft ◯ acre

N Application Rate each Application per ◯ 1000 sq ft ◯ acre

Number of Applications per Year

What is the type of grass planted?

## TEES

Total Area of Tees ☐ ○ Sq ft ○ Acre

N Application Rate each Year ☐ per ○ 1000 sq ft ○ acre

N Application Rate each Application ☐ per ○ 1000 sq ft ○ acre

Number of Applications per Year ☐

What is the type of grass planted? ☐

---

## FAIRWAYS **(including driving ranges)**

Total Area of Fairways ☐ ○ Sq ft ○ Acre

N Application Rate each Year ☐ per ○ 1000 sq ft ○ acre

N Application Rate each Application ☐ per ○ 1000 sq ft ○ acre

Number of Applications per Year ☐

What is the type of grass planted? ☐

---

## ROUGH

Total Area of Rough ☐ ○ Sq ft ○ Acre

N Application Rate each Year ☐ per ○ 1000 sq ft ○ acre

N Application Rate each Application ☐ per ○ 1000 sq ft ○ acre

Number of Applications per Year ☐

What is the type of grass planted? ☐

---

## OTHER AREAS

What is the area of the course sand traps? ○ Sq ft ○ Acre ☐

What is the area of the course water bodies? ○ Sq ft ○ Acre ☐

---

What types of fertilizer are utilized?

☐ Slow Release ☐ Ammonium Nitrate ☐ Urea based

☐ Other ☐

Does your golf course have a:

☐ Rain Gauge ☐ Weather Station ☐ Neither

Are irrigation rates adjusted based on rainfall?

○ YES ○ NO

Please describe how grass clippings are treated.

---

## REUSE WATER

Is reuse water utilized?

○ YES

○ NO, skip remainder of this section

What facility provides reuse water?

Do you know the average N concentration?

○ YES ○ NO

If yes, please list

Do you know the volume used per year?

○ YES ○ NO

If yes, please list

Are fertilizer rates adjusted based on the N concentration of the reuse water?

○ YES ○ NO

If yes, please describe how

Thank you very much for your time. Please send the completed questionnaire to one of the addresses below.

Kirstin Eller: Kirstin.Eller@dep.state.fl.us
Brian Katz: Brian.Katz@dep.state.fl.us
Celeste Lyon: Celeste.Lyon@dep.state.fl.us

Ground Water Management Section
Golf Course Questionnaire
2600 Blair Stone Rd MS 3575
Tallahassee, FL 32399

# Appendix C: Comparison of Methods and Results for the NSILT and Jones et al. (1997)

In 1997, the SWFWMD Ambient Ground Water Quality Monitoring Program conducted a study to determine the sources of increasing nitrate concentrations in Weeki Wachee Spring (Jones et al.1997). The study objectives were to delineate the areas where nitrate was entering the aquifer system, identify the land uses contributing nitrate, and determine management actions to slow or reduce nitrate loading to groundwater in the Weeki Wachee Spring contributing area.

This appendix compares the methods and results from the SWFWMD study and the DEP NSILT. In addition, several factors are listed to account for the differences in estimated nitrogen inputs for the two studies. This comparison provides insights into how the relative contributions of nitrogen may have changed for various potential nitrogen sources and land uses over the past 20 years.

**Study Area**

- The NSILT used the spring contributing area largely based on the Weeki Wachee springshed. This area encompasses 162,714 acres of land with varying degrees of associated recharge. However, the analysis used only data from high-, medium-, and low-recharge areas.
- The Jones et al. (1997) study area comprised 390 square miles, or 249,599 acres, with no acreage estimates for the varying recharge areas.
- The study areas used in both methods were based on the same shape of the springshed and groundwater flow direction to the spring vent. However, the Jones et al. (2007) study area was nearly 50% larger than that of the NSILT study area. This size difference influenced the inputs calculated for each method.

**Atmospheric Deposition**

- The NSILT used data from the multiyear TDEP model developed by the EPA. The annual nitrogen input to the land surface from atmospheric deposition was 1,144,933 lb-N.
- The SWFWMD study (Jones et al. 1997) used an average wet deposition concentration of 1.0 mg/L of total N, based on 9 rainfall samples collected from a station in northwestern Citrus County, north of Weeki Wachee Spring. Using an average annual rainfall of 56 inches, researchers calculated a total of 1,585 tons/yr, or 3,147,000 lbs, over the entire study area.

- The SWFWMD estimate was larger by 2,002,067 lb-N/yr, likely because of the higher nitrogen concentration in rainfall used in the study. Several factors may have accounted for these differences, including the period when the rainfall was collected or differences in collection and analytical methods.

**Septic Systems**

- The NSILT relied on the modified estimate of septic systems by Hall and Clancy (2009). An average of 2.08 people contribute to each septic system in Hernando County and 2.07 people in Pasco County. With an annual input of 9.92 lb-N/person, this equaled an input of 20.6 lb-N per septic system. With 34,201 systems in the contributing area, 704,391 lb-N were applied to the land surface every year.

- Jones et al. (2007) estimated 12,400 septic systems within the boundary area based on an aerial imagery survey. With 3 people per household and an average nitrogen input of 55 lb-N/yr per tank, the total input attributable to septic systems was 341 tons/yr or 682,000 lb-N/yr. Additionally, Jones et al. (2007) incorporated the input from the land spreading of septage waste, which was determined to be a very minor source of nitrogen equaling 7.1 tons-N or 1,576 lb-N/yr.

- There were two main differences between these methods: the number of estimated septic systems and the annual input per system. The NSILT analysis included almost 3 times the number of septic systems compared with Jones et al. (1997). This could be attributable to the more accurate counting methods used for the NSILT as well as population growth in the area. Additionally, the annual input per system used by the SWFWMD was over double compared with that used by DEP. The combination of these factors resulted in a similar estimate for septic systems, with a difference of only 22,391 lb-N/yr. The addition of land spreading of septage also increased the Jones et al. (2007) septic system estimation in a minor way, given the small contribution of this source.

**Urban Turfgrass Fertilizers**

- The NSILT relied on regional fertilizer application rates for the pervious land area associated with urban land uses. The estimated TN input was 1,718,639 lb-N/yr over the 21,991 acres fertilized within the contributing area.

- Jones et al. (1997) used FDACS annual fertilizer sales data. The residential acreage was calculated from land use maps developed from 1990 aerial photography. It was assumed the fertilizer was applied evenly across this acreage, resulting in 426,000 lb-N/yr applied within the Weeki Wachee Spring study area.

- The higher NSILT calculation is likely due to a combination of factors, including the different methods used, the increased urbanization of the area over the past 20 years, and the inclusion of nonresidential urban land uses in the NSILT calculations.

**Sports Turfgrass Fertilizer**

- For the NSILT, 13 golf courses covering 1,581 acres were identified. A combination of survey data provided by the golf courses and an average application rate of 86.8 lb-N/ac resulted in an input to the land surface of 196,791 lb-N/yr. Calculations for sporting facilities were made based on fertilization rates for lawn service companies. These added 3,851 lb-N/yr, for a total of 200,642 lb-N/yr attributable to sports turfgrass fertilizers.

- Jones et al. (1997) included 10 golf courses covering a total of 853 acres. The authors used an application rate of 260 lb-N/acres based on a study completed in Sarasota Bay, for a total of 222,000 lb-N/yr, or 111 tons-N/yr.

- The difference of 21,358 lb-N/yr was likely due to changing trends in golf course maintenance over the past 20 years. While the golf course acreage was largely in the NSILT area, the application rates were lower, resulting in a lower input to the land surface.

**Wastewater Treatment Facilities**

- The NSILT used reported effluent data from 14 facilities in the contributing area. These had a combined actual flow of 2.4 MGD, with an average nitrogen concentration of 9.73 mg/L. The annual input attributable to these facilities equaled 40,185 lb-N/yr. An additional 80,249 lb-N is attributed to reclaimed water distribution within the contributing area from facilities in the Magnolia and Aripeka Springs contributing area and the Chassahowitzka Spring contributing area. The assessment did not include input associated with domestic WWTF residuals because of the lack of supporting data.

- Jones et al. (1997) evaluated WWTFs in two different categories: sewage effluent disposal and the land disposal of sludge. The total effluent disposal was estimated by assessing 27 facilities with an average flow of 6.8 MGD. The total input was estimated using an average nitrogen concentration of 40 mg/L, equaling 320,000 lb-N/yr. Additionally, 194,000 lb-N/yr were calculated for the land spreading of sludge in the study area.

- There is a very large difference between the two studies because the Jones et al. (1998) study used the much higher effluent concentration and included the sludge estimate. Additionally, since the first study was completed, considerable advances in waste treatment were made and applied in this area that would contribute to the lower effluent concentration used in the NSILT.

**Farm Fertilizers**

- To obtain nitrogen inputs from farm fertilizers, the NSILT used property appraiser data, known crops grown in the area, and agricultural producer feedback, as well as UF IFAS–recommended fertilizer application rates. The 39,036 acres of cropland and pastures in the contributing area contributed 1,168,475 lb-N/yr.

- Jones et al. (1997) estimated fertilization for citrus, row crops, and pasturelands. Row crops were calculated based on a fertilizer application rate of 170 lb-N/ac/yr over 423 acres. Citrus fertilization was based on the application of 180 lb-N/ac/yr over 700 acres. Pastureland was estimated using FDACS fertilizer sales data. The amount of fertilizer attributable to row crops and citrus was subtracted from the amount of reported fertilizer sold for farming practices. The remaining fertilizer was assumed to be used for pasture fertilization. The estimated pasture acreage in the study area was not disclosed. In the Weeki Wachee Spring study area, the nitrogen attributed to farm fertilization equaled 722,000 lb-N/yr.

- The results from these two methods were comparable, with a difference of 553,525. The application rates used for the Jones et al. (1997) study were higher; however, the acreage utilized in the NSILT was considerably larger. These differences resulted in a similar estimated nitrogen input for farm fertilizer.

## Livestock Waste

- The NSILT included cattle as well as other livestock animals within the BMAP boundary. Based on stocking rates gathered from feedback from cattle farmers, the cattle population was 4,989. Additional livestock animal populations estimated from the 2012 CoA were assigned to the contributing area based on the distribution of livestock lands (such as improved pasture). Daily waste factors were applied based on the nitrogen content for each animal. The total input to the land surface equaled 1,142,659 lb-N/yr.

- The SWFWMD separated livestock waste estimates into 3 different categories: poultry, dairies, and cattle. FDACS estimated the animal populations, and daily waste factors were applied. Poultry produces 0.053 lb-N/day/animal, resulting in an annual input of 856 tons, or 1,712,000 lb-N. Dairy cows produce 0.45 lb-N/day/1,000 lb of body weight, equaling a total input of 98 tons/yr, or 196,000 lb-N/yr. Cattle, which were assumed to represent beef cattle, have a daily waste factor of 0.33 lb-N/1,000 of body weight, with an associated input of 1,015 tons/yr, or 2,030,000 lb-N/yr. The individual Weeki Wachee Spring study area populations were not specified. In total, Jones et al. (1997) calculated livestock waste at 3,938,000 lb-N/yr.

- There was a large difference between these two estimates (2,795,341 lb-N/yr). The daily waste factors used in both studies were comparable and likely did not contribute to the discrepancy. Without knowing the exact population used in the Jones et al. (2007) study, DEP could not directly determine the population differences. However, this was the most likely factor leading to such a large difference. Although poultry farming in Hernando County has dramatically decreased since the 1990s and was not even calculated in the NSILT due to vastly incorrect populations reported in the CoA (see **Section 2.5**), this decrease in poultry farming contributed to a difference of almost 3 million pounds.

## Stormwater

- The NSILT did not estimate the influence of stormwater-sourced nitrogen on groundwater.

- Jones et al. (1998) calculated that 76,000 lb-N/yr runs off from golf courses, residential areas, commercial properties, and cropland via stormwater.

### Comparison of TN Inputs

The TN inputs to the land surface calculated by Jones et al. (1998) were 9,727,000 lb-N/yr (based on 249,599 acres of land area, resulting in an average of 39 lb-N/ac). The two sources that contributed the highest percentages of nitrogen to the land surface were livestock waste (42%) and atmospheric deposition (33%).

The NSILT estimated TN inputs of 6,293,733 lb-N/yr to the land surface (162,714 acres) in the Weeki Wachee Spring BMAP area, or an average of 39 lb-N/ac. The three sources contributing the largest percentages of nitrogen inputs to the land surface were urban turfgrass fertilizer (27%), atmospheric deposition (18%), and farm fertilizers (19%). **Table C.1** compares the relative percentages calculated using both methods.

As described above, there were notable differences between the two studies in the methods used to estimate nitrogen inputs to the land surface. The biggest differences were attributable to the study area sizes, the development of more accurate methods to identify land uses, and the application of nitrogen for different land use practices.

The SWFWMD study (Jones et al. 1997) provided an important baseline for comparison with the nitrogen inventory for the Weeki Wachee Spring contributing area. Current information on the nitrogen source inventory and nitrogen loads to groundwater generated from the NSILT for the Weeki Wachee Spring BMAP will be used to determine where present-day nitrogen loading to groundwater can be reduced to restore water quality in Weeki Wachee Spring and River.

**Table C.1: Comparison of nitrogen input percentages to the land surface calculated by the NSILT and Jones et al. (1997)**

| N Loading Category | NSILT (2016) | Jones et al. (1997) |
|---|---|---|
| **Atmospheric Deposition** | 18% | 33% |
| **Septic Systems** | 10% | 7% |
| **WWTFs** | 1% | 2% |
| **Urban Turfgrass Fertilizers** | 27% | 5% |
| **Sports Turfgrass Fertilizers** | 3% | 2% |
| **Farm Fertilizers** | 19% | 8% |
| **Livestock Waste** | 21% | 42% |
| **Stormwater** | 0% | 1% |