Draft

Revised Nitrogen Source Inventory and Loading Estimates for the Wakulla BMAP Area

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

This revised nitrogen source inventory is based on an updated methodology for the assessment of several nitrogen source categories, based on tools made available since the original report was written, as well as additional literature reviews. In addition, urban fertilizers were divided into two categories (urban turfgrass fertilizer and sports turfgrass fertilizer) and the methodology was updated to provide data for source categories identified in the Florida Springs and Aquifer Protection Act.

Disclaimer: Note that all values listed in this report are rounded, while the actual calculations were completed using whole numbers.

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Executive Summary

In 2014, 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, and agricultural fertilizers) in the Wakulla Spring and River Basin Management Action Plan (BMAP) area, which includes the groundwater contributing area (or springshed) for Wakulla Spring in Florida. Since then, DEP has used the NSILT methodology to develop 12 more nitrogen source inventories to support spring BMAP development.

Over the years, nitrogen sources in the Wakulla BMAP area have changed, and the methodology for estimating nitrogen loads has improved as a result of the incorporation of additional information and tools that provide better estimates of nitrogen loads from various sources. In addition, Wakulla Spring was designated an Outstanding Florida Spring under the 2016 Florida Springs and Aquifer Protection Act (Chapter 373, Section VIII, Florida Statutes), which requires the identification of additional source loads (sports turfgrass) and priority focus areas that must have their own nitrogen inventories. Because of these multiple changes, the nitrogen inventory for the Wakulla BMAP area has been significantly updated to meet statutory requirements, and to reflect current conditions and the refinements in methodology for estimating nitrogen loads. This report describes the current NSILT methodology and results and the changes from results in the previous version.

The NSILT results are 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 Wakulla Spring and Wakulla River. The NSILT is an Arc geographic information system (ArcGIS) and spreadsheet-based tool that provides spatial estimates of the relative current contributions 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 Upper Floridan aquifer (UFA). The NSILT does not account for legacy loads of nitrogen that may already be present in the aquifer and that continue to adversely impact groundwater quality.

The 2018 NSILT results indicate an estimated total load of 789,650 pounds of nitrogen per year (lb-N/yr) to the UFA in the Wakulla BMAP area. This load estimate is 4.5 % greater than the 753,643 lb-N/yr load estimate in the 2014 NSILT analysis. Most of the nitrogen input to the land surface in a year does not reach groundwater because of nitrogen attenuation processes and variations in the rate of aquifer recharge, which are related to the degree of confinement of the UFA. The revised (2018) estimated load to groundwater represents only 7.0 % of the amount of nitrogen input to the land surface.

In areas of the BMAP where the UFA is unconfined or semiconfined, recharge rates are higher than in areas where the aquifer is confined. Recharge rates are as follows: unconfined (greater than 9 inches per year [in/yr]), semiconfined (3 to 8 in/yr), and confined (0 to 2 in/yr). The UFA is more vulnerable to contamination in unconfined or semiconfined areas than in confined areas. To account for spatial variations in recharge rates to the UFA, nonattenuated 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 0.4 for medium rate recharge rate areas and 0.1 for low recharge rate areas.

Of the nitrogen source categories assessed, the highest estimated 2018 nitrogen loads to groundwater in the Wakulla BMAP area were from septic systems (34 %), followed by atmospheric deposition (27 %), farm fertilizer (21 %), and urban fertilizer (10 %). **Table 1** summarizes nitrogen loads by source in the 2018 assessment and compares them with values derived from the 2014 assessment for the same area.

The NSILT results provide a baseline understanding of current nitrogen loads to groundwater from existing sources in the Wakulla BMAP area and their relative contributions to nitrogen concentrations in the UFA. This tool can also be used to evaluate the nitrogen load reduction benefits of various management actions and nitrogen reduction projects at locations in the BMAP area and priority focus areas.

Table 1: Summary of 2018 NSILT loads to groundwater and comparison with 2014 results for the Wakulla BMAP area

Notes: Values are rounded. Estimated loads in lb-N/yr.
NA = Not assessed; combined with urban fertilizer

Source Category	2018 Estimated Load	2018 % of Total	2014 Estimated Load	2014 % of Total
Septic Systems	272,313	34	386,464	51
Atmospheric Deposition	212,134	27	98,452	13
Farm Fertilizer	161,985	21	58,848	
Urban Fertilizer	77,282	10	34,441	4.5
Sinking Streams/Lake Seepage	NA	NA	73,240	9.8
Wastewater Treatment Facilities	26,697	3	48,087	6.4
Sports Turf Fertilizer	15,398	2	NA	NA
Livestock Waste	23,840	3	54,115	7.2
Total	**789,650**		**753,643**	

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), the highly transmissive limestone aquifer that is the source of water flowing from the springs (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 Wakulla 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 systems, 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 current 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 estimate nitrogen loads to groundwater in the contributing area by considering the attenuation of various forms of nitrogen from sources and recharge rates to the UFA.

The NSILT does not account for legacy loads of nitrogen that may already be present in the aquifer and that continue to adversely impact groundwater quality in some areas. Several spring basin studies have reported increasing nitrate-N concentrations in groundwater and springs over time. Nitrogen that entered groundwater from past anthropogenic practices may slowly exit the groundwater flow system via springs, given that the average groundwater residence times in large spring basins in Florida can be on the order of decades (Katz et al. 1999; Katz 2004; Phelps 2004; Happell et al. 2006; Knowles et al. 2010).

The NSILT results are being used in the development and implementation of the *Basin Management Action Plan (BMAP) for Wakulla Spring and River* by helping to focus nitrogen source reduction efforts to achieve the greatest improvement in water quality. The revised nitrogen assessment results described in this report are based on more recent data and refinements in methodology compared to methods used in the original NSILT assessment developed for this area in 2014. The report also includes a representation of the results in categories consistent with those required under the Florida Springs and Aquifer Protection Act (Chapter 373, Part VIII, Florida Statutes [F.S.]).

1.1 Assessed Area

Wakulla Spring is one of the largest freshwater springs in the world, with an average discharge of 580 cubic feet per second (cfs) based on measurements made by the Northwest Florida Water Management District (NWFWMD) and U.S. Geological Survey (USGS). Wakulla Spring is a major discharge point for water from the UFA and includes a large contributing area. Wakulla Spring is the main source of water to the Wakulla River, which was identified as impaired because of a biological imbalance caused by excessive concentrations of nitrate in the water.

In 2012, a total maximum daily load (TMDL) for nitrate was developed as a water quality restoration target for the Wakulla River (Gilbert 2012). To address the TMDL, a BMAP is being developed that will include activities to address the elevated nitrogen concentrations measured in Wakulla Spring and River. To help stakeholders identify the most important sources of nitrogen to address under the BMAP, the NSILT was developed for the Wakulla Spring BMAP area, which was defined in 2014.

The BMAP area includes the portion of the Wakulla Springshed that lies in Florida plus potential groundwater contribution areas to the west, east, and south (**Figure 1**). This area covers almost 848,000 acres (344,000 hectares), encompassing parts of 4 different counties: Leon, Wakulla, Gadsden, and Jefferson. Wakulla Spring is the major source of water to the Wakulla River, which flows southward and joins the St. Marks River before discharging into Apalachee Bay.

1.2 Climate

The climate in this area is humid subtropical, with a 30-year mean annual temperature of 68 ^{o}F. and a 30-year mean annual rainfall of 63.2 inches measured at the National Oceanic and Atmospheric Administration (NOAA) weather station at Tallahassee Regional Airport (Gilbert 2010). The highest monthly rainfall typically occurs during June, July, and August, and the months with the least rainfall are April, October, and November. The average potential evapotranspiration for the Tallahassee area is 46 inches per year (in/yr) (Davis et al. 2010). Thus, on average 20 inches of precipitation per year infiltrate through the soil.

1.3 Hydrogeology and Aquifer Recharge

The geology of the area includes sedimentary formations of Tertiary through Quaternary age that consist of limestone, dolostone, clay, and sand of varying degrees of lithification (Miller 1986; Davis and Katz 2007). Several studies have provided detailed descriptions of the geologic and hydrogeologic setting of the region that includes the BMAP area (Hendry and Sproul 1966; Miller 1986; Davis 1996; Chelette et al. 2002; Davis et al. 2010). This report briefly describes several key hydrogeologic units that occur in these sediments and have characteristics that affect the movement of infiltrating water and nitrogen from the land surface to the UFA.

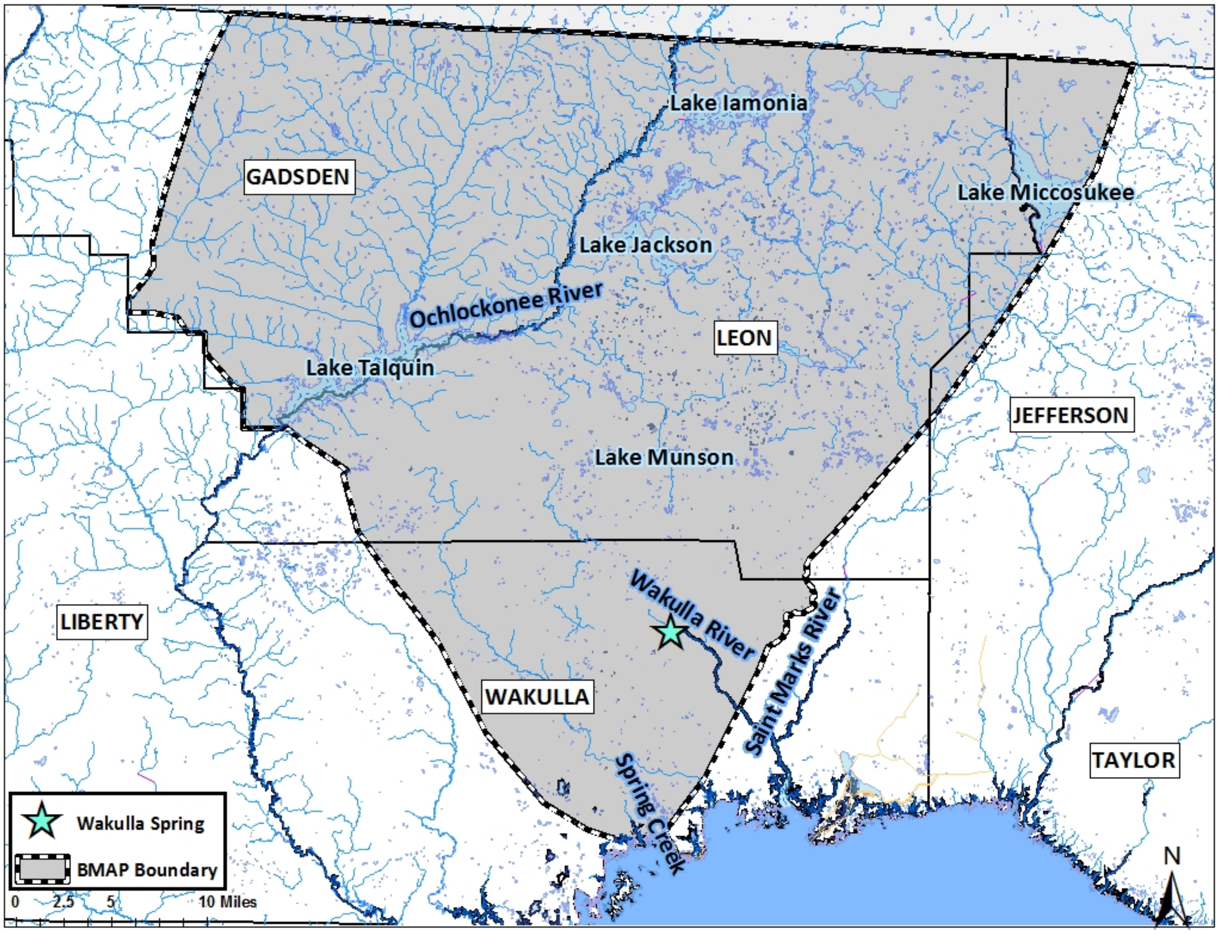


Figure 1: Wakulla Spring and River BMAP area

The BMAP area lies in the Coastal Plain physiographic province and is characterized by two main geomorphic zones. The Northern Highlands, located north of the Cody Scarp (**Figure 2**), comprise an extensive upland area where surface drainage is perched above the UFA because of the presence of relatively thick clayey sediments overlying the UFA. The Floridan aquifer system is composed of limestones and dolostones of Eocene to Miocene age, and is found in Florida and parts of Georgia, South Carolina, and Alabama. The UFA is more dynamic than the underlying Lower Floridan aquifer and is the source of spring flow and potable water supply in the region.

The Woodville Karst Plain (WKP) extends southward from the Cody Scarp in southern Leon County to the Gulf Coast. It is characterized as a flat or gently rolling surface of highly porous quartz sand overlying the limestone units (Suwannee Limestone and St. Marks Formation) of the UFA (Miller 1986; Rupert 1988). Limestone is generally located within 25 feet of the surface in most of the karst plain. The top of the limestone rock in both units has undergone extensive dissolution by chemically aggressive waters, resulting in the development of large cavity and conduit systems (Miller 1986). Consequently, the karst plain contains numerous wet and dry sinkholes, natural bridges, and disappearing streams (Rupert and Spencer 1988).

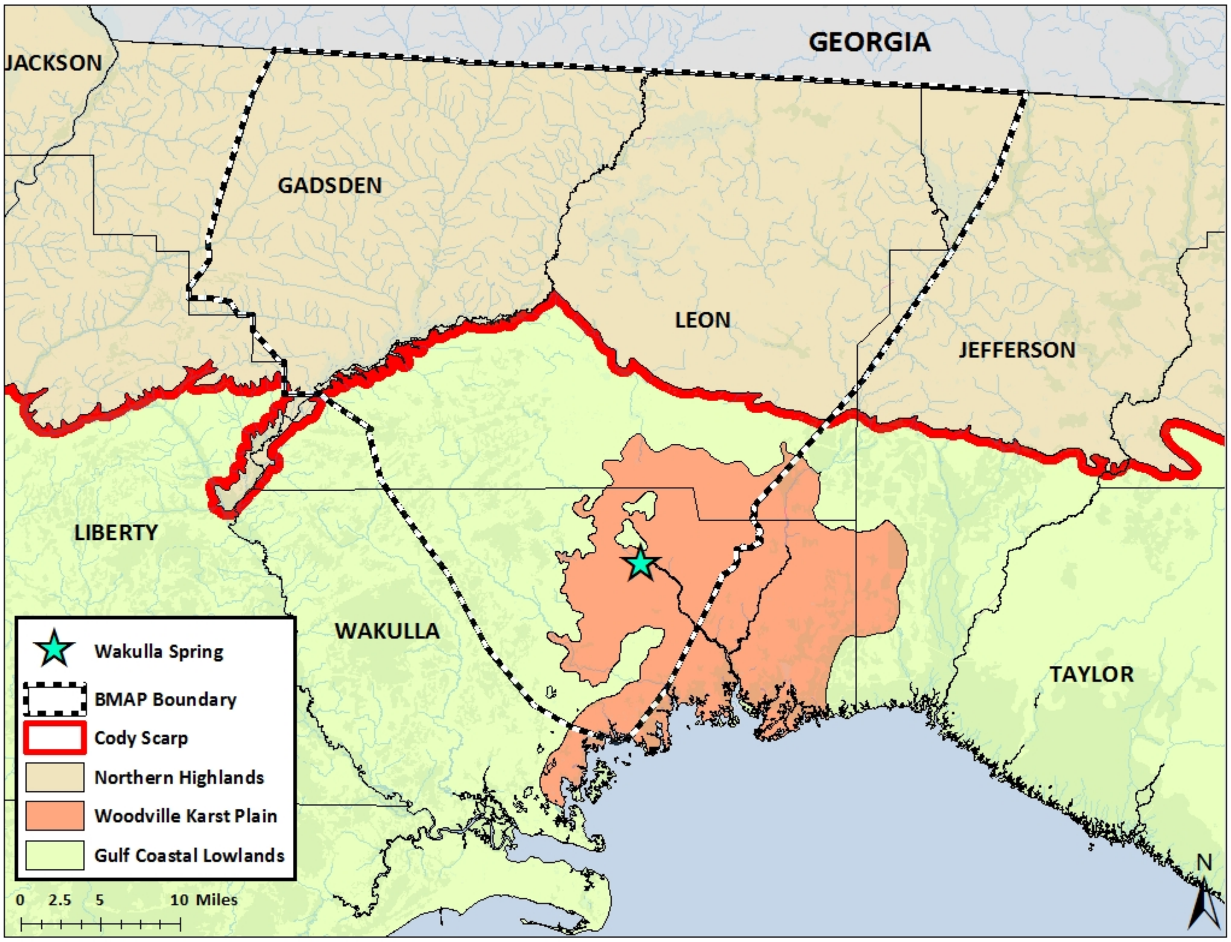


Figure 2: Physiographic regions in and around the Wakulla Spring and River BMAP area

The degree of confinement of the UFA in the BMAP area (**Figure 3**) is characterized based on the thickness of overlying sediments as described by Miller (1986) and is broken into three categories: unconfined, semiconfined, and confined. The UFA is unconfined where the aquifer crops out near the surface or where overlying sediments are sandy, thin, or absent. Where confining units are less than 100 feet thick and breached by sinkholes, the UFA is referred to as semiconfined. Where these units are greater than 100 feet thick, the UFA is considered to be confined.

The composition of the material overlying the UFA varies in the amounts of sand, marl, limestone, clay, and dolomite present. The sand layers readily transport infiltrating water and in some parts of the BMAP area serve as a surficial aquifer system when there is a confining unit beneath them. This confining unit, consisting of mostly clay and lower permeability dolomite beds, can significantly retard infiltrating water and comprises the intermediate aquifer system or the intermediate confining unit. The lithology, thickness, and integrity of this material have a controlling effect on the development of permeability and local groundwater flow (Bush and Johnston 1988). The UFA is most vulnerable to contamination from the land surface in areas where it is unconfined. Detailed maps showing vulnerability assessments for the UFA have been prepared for Leon County (Advanced Geospatial Inc. 2007) and Wakulla County (Advanced Geospatial Inc. 2009).

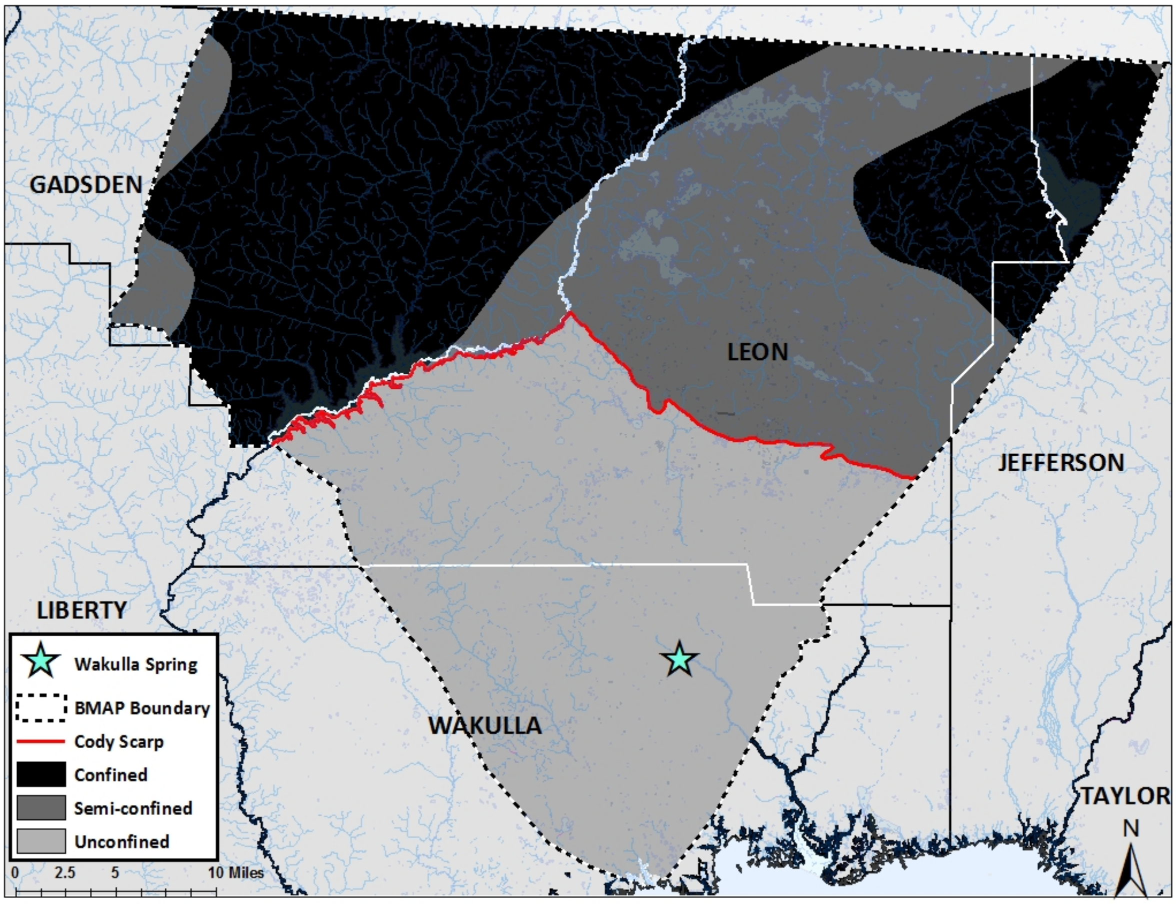


Figure 3: Recharge areas within the Wakulla Spring BMAP area boundary. Recharge ranges from 0 to 2 inches in confined areas, 3 to 8 inches in semiconfined areas, and 9 to 20 inches in unconfined areas.

Ground water in the UFA of the BMAP area generally flows from the northeast to the southwest or from north to south based on potentiometric surface maps for the UFA (Davis 1996; Davis et al. 2010). Extremely high transmissivities in the UFA (greater than 1,000 square feet per day [ft^2/d]) (Davis 1996) are associated with conduit systems for Wakulla Spring and account for a flattening of the potentiometric surface 3 to 4 miles south of the Cody Scarp. Wakulla Spring is a major discharge point for water from the UFA in the karst plain. Flows from Wakulla Spring fluctuate greatly depending on rainfall (Davis and Katz 2007; Davis et al. 2010).

The major source of recharge to the UFA is rainfall. The rate of recharge is largely governed by the permeability of the geologic material through which the infiltrating water migrates. Recharge to the UFA ranges from 1 to more than 20 in/yr in the northern and southern parts of the BMAP area, respectively. The lowest rates of recharge to the UFA occur in the confined area (0 to 2 in/yr), and the highest rates occur in the unconfined area (9 to 20 in/yr). Intermediate rates of recharge of 3 to 8 in/yr occur where the UFA is semiconfined.

In addition, several disappearing streams, such as Munson Slough, Lost Creek, and Fisher Creek, recharge the UFA through sinkholes. Fisher and Lost Creeks originate in the coastal lowlands and in the Apalachicola National Forest, respectively. Most major lakes in the springshed formed in solution depressions and provide recharge through seepage or sinkhole discharge. The larger sinkhole lakes in the BMAP area include Lake Jackson, Lake Iamonia, the Lafayette Chain of Lakes, and Lake Miccosukee.

1.4 Land Use

Based on the 2012–13 NWFWMD land use coverage available, land use in the Wakulla BMAP area is predominantly upland forests (50 %). Other land use types, in decreasing order, are wetlands and marshes (22 %), residential (14 %), agriculture (6 %), rangeland (3 %), and other (3 %). All land use classifications used by the NWFWMD were based on the Florida Land Use/Land Cover and Forms Classification System (FLUCCS). The 2012–13 land use coverage was created through the interpretation of digital imagery. The land use classifications were determined through photo interpretation, editing, and quality check processes. The original 2014 report used 2009 land use coverage. Between 2009 and 2013–14, land use percentages did not change significantly.

Additional land use information was obtained from the Leon, Wakulla, Gadsden, and Jefferson 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 the most recent data available to be used for this analysis.

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 estimated for atmospheric deposition, wastewater treatment facility (WWTF) land application sites, septic systems, urban turf fertilizer, sports turf fertilizer, agricultural fertilizer, livestock waste, and seepage from sinking streams and lakes. The methods used to estimate nitrogen inputs for these sources are based on a detailed synthesis of information, including direct water quality measurements, Census data, surveys, wastewater facility permits, published scientific studies and reports, and information obtained in meetings with agricultural producers.

For some source categories, the nitrogen inputs were calculated using several assumptions and extrapolations. In the future, these inputs may be revised if more detailed information becomes available. The approach and sources of information used to estimate the annual input (in 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 NTN wet deposition values to model total deposition in 16-kilometer (km) grid cells. At the time of the 2014 report, this model was not available, but it has since been used in subsequent NSILT evaluations to provide a more robust estimation of atmospheric nitrogen deposition.

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 2018 NSILT included 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 Wakulla BMAP area. **Table 2** summarizes the TN deposition amounts in high, medium, and low recharge rate areas.

This methodology differs significantly from the process used in 2014 for estimating atmospheric deposition in the basin. The previous methodology relied on available 2009–12 monthly or weekly wet and dry deposition data for nitrate-nitrogen and ammonia-nitrogen collected at two

CASTNET sites located in Florida: one in Quincy, in Gadsden County, and the other in Sumatra, in Liberty County. The calculated input values, which included an average of monthly wet deposition data at the two sites for wet deposition and an average of weekly dry deposition data collected at the Liberty County site, were then used to estimate nitrogen deposition in the high-, medium-, and low-recharge areas. These amounts were considerably lower than the values obtained by using the TDEP model results.

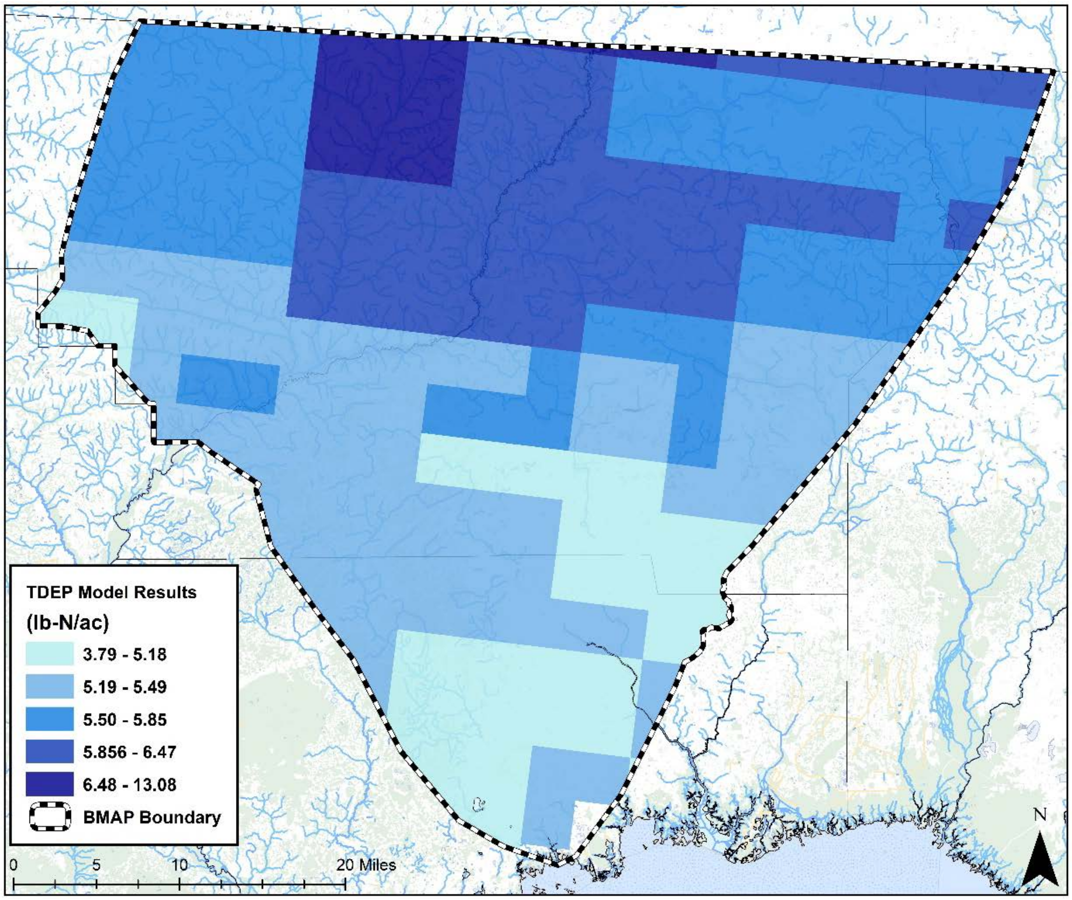


Figure 4: Atmospheric deposition model results used for the 2018 NSILT analysis

Table 2: Comparison of nitrogen input from atmospheric deposition by recharge area based on TDEP model results and 2014 methods

Recharge Area	Land Area (acres)	2018 Estimated Input from TDEP Model (lb-N/yr)	2014 Estimated Input from Previous Methodology (lb-N/yr)
Unconfined	299,525	1,554,295	748,302
Semiconfined	232,207	1,342,085	580,120
Confined	316,195	1,856,428	789,945
Total	847,927	4,752,808	2,118,367

2.2 Wastewater Treatment Facilities

WWTFs receive and treat domestic and industrial wastewater. In the Wakulla BMAP area, treated effluent containing nitrogen from domestic WWTFs is discharged to sprayfields, absorption fields, and rapid infiltration basins (RIBs); used for reclaimed wastewater irrigation; and in one instance (for an industrial facility) discharged to a treatment wetland. There are 23 domestic facilities discharging nitrogen-enriched effluent in the Wakulla BMAP area (**Figure 5**). A single industrial facility discharging nitrogen-enriched water is located in the BMAP area where the UFA is confined. This facility, which has a design capacity of 20 million gallons per day (mgd), was not included in these calculations because there is a minimal potential for nitrogen contribution to groundwater as a result of the nontraditional remediation approaches in place. The facility has a constructed wetland for nitrogen removal.

The City of Tallahassee (COT) has the largest facility in the area by volume, the T.P. Smith Water Reclamation Facility. The facility is permitted to treat up to 26.5 MGD of raw wastewater and currently receives and treats 17 MGD of water to advanced wastewater standards. The facility provides advanced nitrogen treatment to the entire waste stream for city customers before the effluent is pumped to the COT Southeast Farm sprayfield, located in southern Leon County where the UFA is unconfined. The facility is also permitted to provide reclaimed water to the Southwood area, where it is used to irrigate a golf course and green spaces.

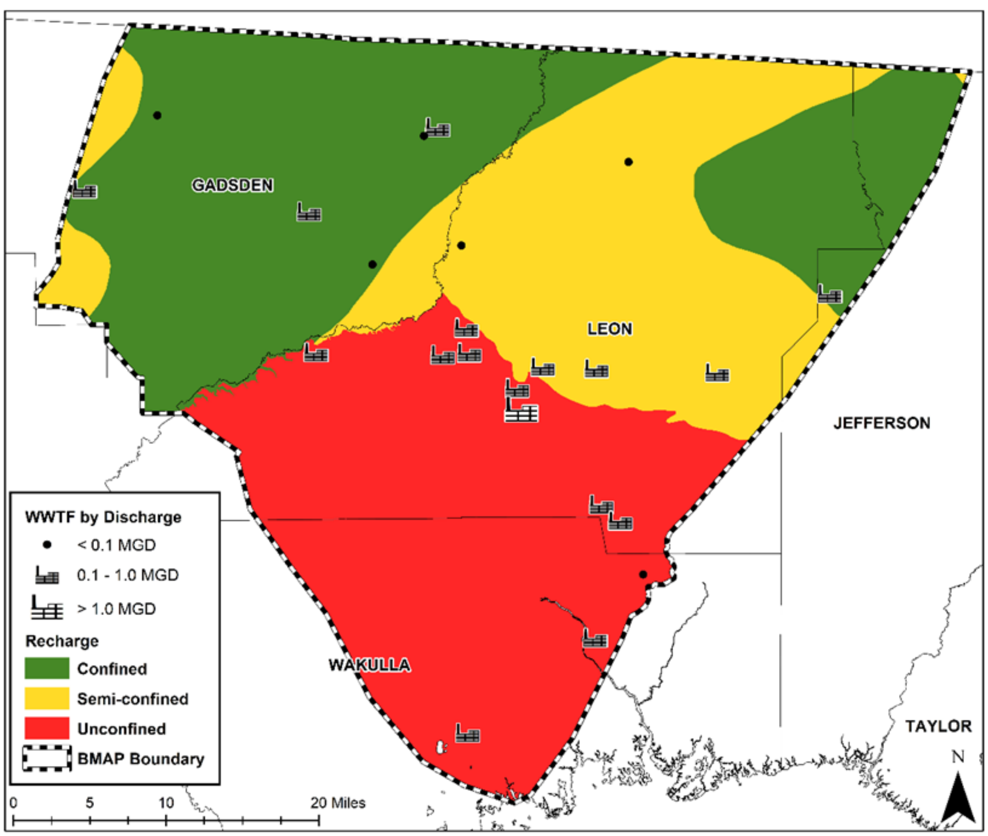


Figure 5: Distribution of WWTFs in the Wakulla BMAP area

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 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 the data from a 2009 cooperative study with the Water Reuse Foundation of 40 domestic WWTFs across the state). For this calculation, the NO_3-N value was divided by 0.385, resulting in an estimated TN concentration. The WWTF data were compiled for each facility and included the most recent complete year of data. While the number of years of data available varied with the individual facilities, the data in the 2018 assessment were collected between 2016 and 2017. The 2014 assessment was based on data from 23 facilities collected from 2004 to 2012. The same methodology was used to estimate WWTP inputs for this assessment and the one completed in 2014. However, facility inputs in this report were broken out by effluent disposal type for attenuation purposes (further discussed in **Section 3.1**).

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, absorption fields, or reuse areas. For the purpose of this analysis, absorption fields are included with RIBs because they have similar processes that attenuate nitrogen.

The nitrogen input for each WWTF was calculated using the average annual TN concentration and the average yearly flow from the facility. The average annual nitrogen inputs from all wastewater facilities in each recharge rate category were calculated based on their treatment site locations and individual inputs.

Table 3 summarizes the nitrogen input data for facilities in the BMAP area. In total, an estimated 122,424 lb-N/yr are applied to the land surface from these facilities. These are divided among unconfined (88,172 lb-N/yr), semiconfined (24,632 lb-N/yr) and confined (9,620 lb-N/yr) recharge areas. In the 2014 report, the estimated total input from wastewater facilities was 162,937 lb-N/yr. The decrease in total input is mainly because of improved nitrogen removal by the treatment process at the T.P. Smith Water Reclamation Facility.

Table 3: Summary data for WWTFs in the Wakulla BMAP area

* TN data estimated based on available NO_3 data.

WWTF Name	Facility ID	County	Treatment Type	Recharge Area	Annual Average TN (mg-N/L)	Annual Flow (mgd)	Nitrogen Input (lb-N/yr)
T.P. Smith Water Reclamation Facility	FLA010139	Leon	Reuse	Unconfined	1.5	17.28	78,672
			Reuse	Semiconfined	1.5	0.32	1,458
			Sprayfield	Unconfined	2	0.02	72
Lake Bradford Estates MHP WWTF	FLA010148	Leon	RIB	Unconfined	0.67	0.01	30
Disc Village WWTP	FLA010137	Leon	RIB	Unconfined	3.64	0.00	52
Woodville Elementary School WWTP	FLA010136	Leon	RIB	Unconfined	8.03	0.00	26
Meadows-at-Woodrun WWTF	FLA010159	Leon	RIB	Semiconfined	1.27	0.03	111
Sandstone Ranch WWTF	FLA010167	Leon	RIB	Unconfined	1.32	0.05	213
Western Estates MHP WWTP	FLA010152	Leon	RIB	Unconfined	0.48	0.02	26
Fort Braden Elementary School WWTP	FLA010138	Leon	RIB	Unconfined	1.84	0.01	36
Grand Village Mobile Home Park WWTP	FLA010151	Leon	RIB	Unconfined	1.47	0.01	28
Lake Jackson WWTP	FLA010171	Leon	RIB	Semiconfined	8.88	0.26	6,907
Killearn Lakes WWTP	FLA010173	Leon	Sprayfield	Semiconfined	10.07	0.53	16,156
Capital City Plaza WWTP	FLA010134	Jefferson	RIB	Confined	1.93	0.02	118
Gadsden East WWTF	FLA187941	Gadsden	RIB	Confined	9.26	0.14	3,946
Rentz MHP WWTP	FLA010079	Gadsden	RIB	Confined	8.97	0.01	139
Greensboro High School WWTP	FLA010074	Gadsden	RIB	Confined	6.23	0.00	60
Havana Middle School WWTP	FLA010085	Gadsden	RIB	Confined	5.67	0.00	28
Gretna, City of – WWTP	FLA100781	Gadsden	Reuse	Confined	1.24	0.26	982
Havana WWTF	FLA100765	Gadsden	Sprayfield	Confined	8.97	0.16	4,347
Wakulla Middle School WWTP	FLA010229	Wakulla	RIB	Unconfined	8.97	0.00	68
River Plantation Estates WWTP	FLA010241	Wakulla	RIB	Unconfined	8.59	0.01	216
Winco Utilities, Inc. WWTP	FLA016544	Wakulla	Sprayfield	Unconfined	8.97	0.32	8,732

2.3 Septic Systems

Onsite sewage treatment and disposal systems (OSTDS), commonly referred to as septic systems, are widely used throughout the Wakulla BMAP area where municipal sewer is not available. These systems can contribute to elevated nitrogen concentrations in groundwater (Chang et al. 2010).

The 2014 NSILT analysis used OSTDS counts derived from the Hall and Clancy model, which estimated the number of septic systems based on tax parcel data and known sewer service areas (Hall and Clancy 2009). However, This model has been found to provide higher-than-actual counts of septic systems in some areas. The septic tank estimate in the 2018 NSILT evaluation was obtained from a more recent product released in 2016 developed by the Florida Department of Health (FDOH).

In 2014, FDOH began the Florida Water Management Inventory (FLWMI), a statewide project to develop geographic information system (GIS) mapping attributes for water use and wastewater treatment method for all parcels by county. The results of this inventory can be obtained from FDOH.

Results from the 2016 release of the FLWMI were used to estimate the total number of septic systems within the BMAP area boundary. ArcGIS files provided the locations of both known and estimated septic systems. **Table 4** lists the comparison of OSTDS counts taken from the Hall and Clancy model and the FLWMI. Also provided are results from a Leon County OSTDS database. The comparison in **Figure 6** shows the distribution of septic systems by county within the BMAP area boundary. There was a 5 % difference between total counts for the Hall and Clancy and FLWMI inventory methods, resulting in a small decrease in the number of septic systems from the 2014 assessment.

Table 4: Comparison of estimated number of septic systems in the Wakulla BMAP area, by county

NA = Not applicable (the Leon County database was used for comparison only for the Leon County portion of the BMAP area).

Data Source	Leon County	Wakulla County	Gadsden County	Jefferson County	Total
2014 NSILT (Hall and Clancy)	31,949	7,595	12,373	529	**52,446**
FDOH FLWMI	31,606	7,904	10,116	381	**50,007**
Leon County	31,757	NA	NA	NA	**NA**

After the number of septic systems in the contributing area was obtained, the population served by septic systems was calculated using the 2010 U.S. Census Bureau data for population and household occupancy in each county. The Census makes a distinction between occupied and unoccupied home units. The census also provides information on the total population and the population of just owner- and renter- occupied homes, referred to as the occupied population. The difference between the sum of owner- and renter-occupied housing population and the total population is the population living in group quarters. Group quarters include "…college residence halls, residential treatment centers, skilled nursing facilities, group homes, military barracks, correctional facilities and workers' dormitories" (2010 Census). Since most of the group facilities listed are unlikely to use an OSTDS for wastewater disposal, it is more appropriate to use the occupied population in these calculations. The occupied population was divided by the number of occupied homes in the county, resulting in an average number of people per occupied household (2.35 in Leon County, 2.61 in Wakulla County, 2.61 in Gadsden County, and 2.38 in Jefferson County).

The total population in the Wakulla BMAP area served by septic systems was calculated by multiplying the number of people per household (adjusted for occupied populations) 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 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 5** summarizes the 2018 septic system data and estimated nitrogen inputs.

The number of people served by septic systems was not adjusted for occupied populations in the 2014 NSILT analysis but this adjustment has since been incorporated into all other spring NSILTs. This reduction in residential septic system use provides a much more realistic input for estimating the load to groundwater. The input of 1,101,075 lb-N/yr is 19 % lower than the total input used for the 2014 NSILT analysis (1,356,850 lb-N/yr).

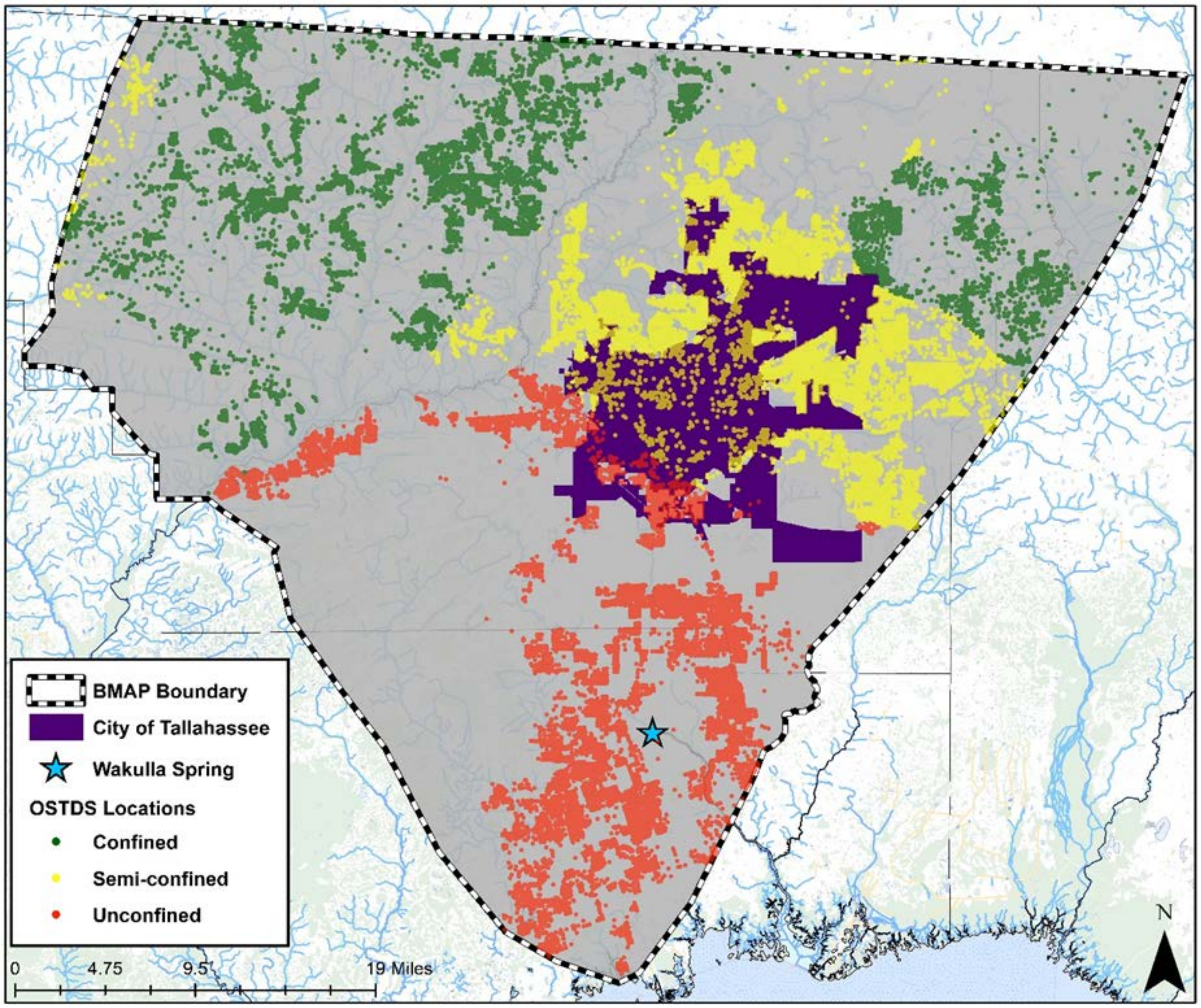


Figure 6: Distribution of septic systems in the Wakulla Spring BMAP area

Table 5: Number of septic systems and estimated associated inputs

Confinement Category	Number of Septic Systems	Estimated Input to Septic Systems (lb-N/yr)
Unconfined	16,830	374,739
Semiconfined	21,149	449,089
Confined	12,028	277,247
Total	**50,007**	**1,101,075**

2.4 Urban Turfgrass Fertilizer

2.4.1 Changes in Methodology

The 2014 NSILT used Florida Department of Agriculture and Consumer Services (FDACS) by-county fertilizer sales data to estimate the nitrogen input to the land surface from fertilizer, which was broken out between farm use and urban use. The 2015 and 2016 fertilizer sales records had reporting errors, which voided the accuracy of the data. The method based on fertilizer sales also assumes that fertilizer sold in a county is used in the same county, resulting in additional errors.

Since the development of the 2014 NSILT for the Wakulla BMAP area, the methodology used for estimating nitrogen inputs from urban fertilizer has significantly improved. In addition, the urban turfgrass methodology was updated to include the assessment of inputs from the sports turfgrass fertilizer category, as required by the 2016 springs legislation. The updated urban turfgrass methodology used in the 2018 NSILT is consistent with the NSILTs completed for other spring BMAPs and allows the nitrogen contribution from fertilizer to be attributed to the correct source (urban or sports). The farm fertilizer input, discussed in a subsequent section, was also recalculated using tools other than fertilizer sales data.

The newer methodology resulted in an estimated input from both urban and sports turfgrass of 719,179 lb-N/yr. The estimated input from urban turfgrass in 2014 was 498,695 lb-N/yr. The newer methodology resulted in a 31 % increase for this category. The newer approach considers the fertilizer application rate, the likelihood of a parcel to receive fertilizer, and the area of impervious surface likely to receive fertilizer.

2.4.2 Estimated 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. **Figures 7** and **8** show the areas assessed for turfgrass fertilization (including sports turf) for the 2014 and 2018 NSILT analyses, respectively. Results from surveys and workshops on fertilizer application for turfgrass in nearby counties were used to estimate the 2018 NSILT nitrogen application rates for urban turfgrass in the Wakulla BMAP area. 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 2016, a COT contractor conducted a telephone survey to solicit information about residential fertilizer use in Leon County (TAPP 2016). This survey provided information on urban turf fertilizer application practices in the BMAP area. Information was also obtained from a 2008 study by a SWFWMD contractor in the Springs Coast region (Martin 2008) and a 2009 fertilizer use survey in the Wekiva River Basin by the University of Central Florida Stormwater Management Academy (Suoto 2009). Some information about fertilizer use was obtained from each survey, although none of them provided a complete picture.

According to the Leon County survey, most of the surveyed residents (68 %) did not fertilize their lawns, 17 % applied fertilizer to their own lawns, and 15 % had lawn service contractors apply fertilizer (TAPP 2016).

The Leon County survey did not provide any information on the frequency or rate of fertilizer nitrogen application. In the Wekiva area, fertilizer was applied an average of 2.88 times a year at variable rates (Suoto et al. 2009). **Table 6** lists the estimated application rates, used in the 2018 NSILT, by residents who did apply nitrogen fertilizer. The lowest values from both Martin (2008) and Souto et al. (2009) were used because applying the residential turfgrass fertilization rates from central Florida to the Wakulla area may overestimate fertilizer N input because a relatively low percentage of homeowners in the TAPP survey fertilize their own lawns. Lawn service companies are supposed to apply fertilizer at rates no more than the *Green Industries Best Management Practices (BMP) 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 lawn service professionals or trained staff using application rates and frequencies similar to those recommended in the *Green Industries BMP Manual*. For estimating the urban, non-residential fertilizer input in the Wakulla BMAP area, an average application rate of 21.78 lb-N/yr was used.

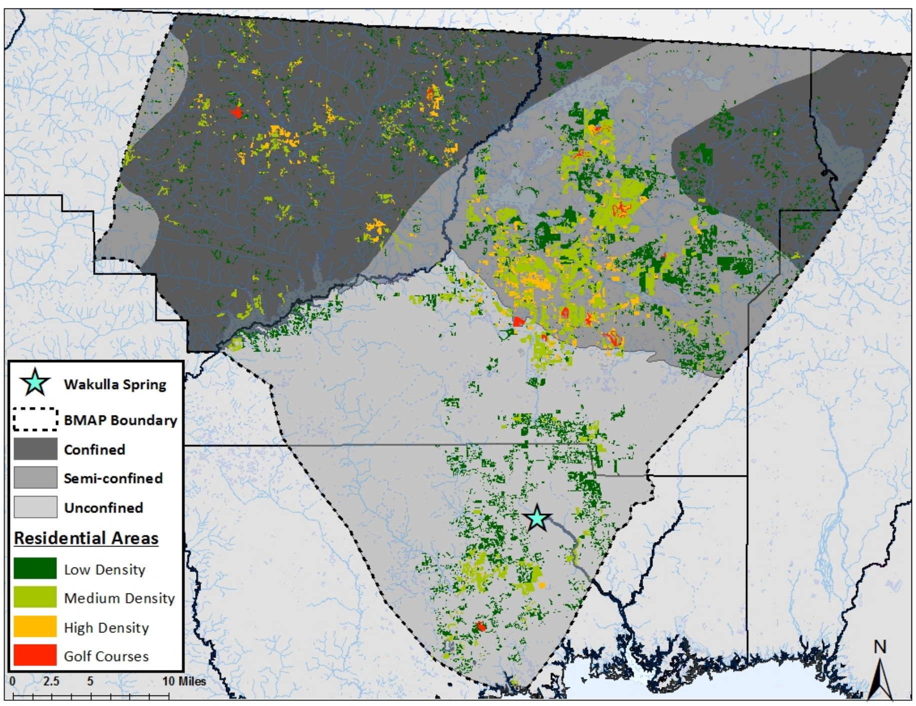


Figure 7: Urban lands in the Wakulla Springshed used in the 2014 NSILT analysis, based on NWFWMD land use coverage

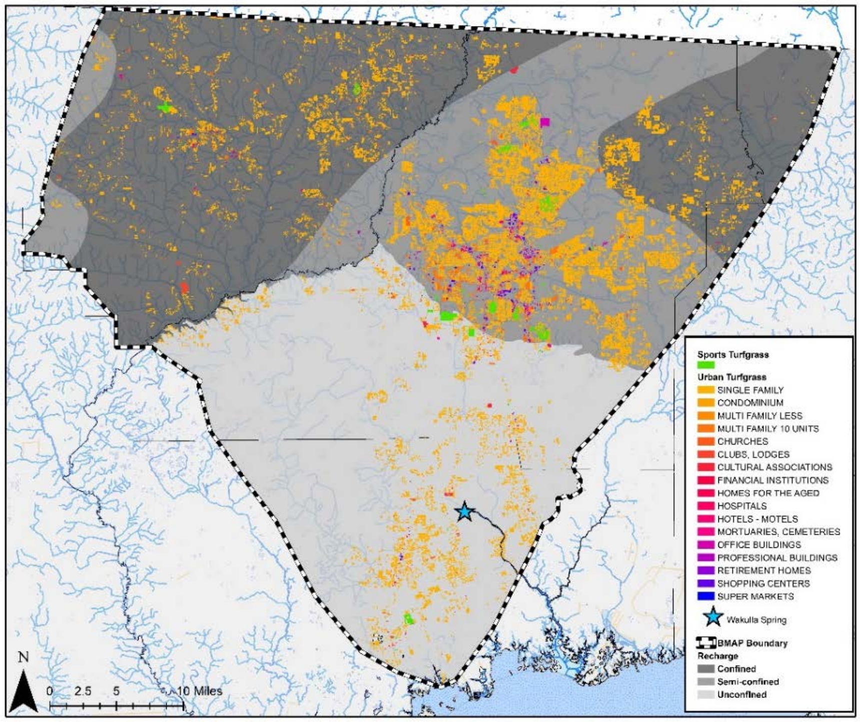


Figure 8: Urban lands in the Wakulla BMAP area used in the 2018 NSILT analysis, based on county property appraiser data

Table 6: Estimated fertilizer application rates by homeowners from surveys

Notes: Lowest values taken from both Martin (2008) and Souto et al. (2009) to represent the low fertilization practices in the area.
* Other includes application rates based on estimation from visual appearance of lawn, advice from a neighbor, or educated guess.

Basis for Application Rate	% of Surveyed Population and Basis for Fertilizer Rate Selection	Estimated Rate (lb-N/ac)
Green Industry BMP Guidelines	20	22
Fertilizer Bag Label	75	30
Other *	5	44

2.4.3 Nonresidential Parcel Estimations

The acreage of public green space receiving fertilizer applications was estimated to obtain nitrogen inputs for each category listed in **Table 7**. Parcel types assessed using the PA data included businesses, hotels, schools, churches, and other facilities. These data were combined with zoning data provided by Leon, Wakulla, Gadsden, and Jefferson Counties. The zoning attributed to each parcel contains information on the impervious surface areas (i.e., structures, pavement, etc.), referred to as the "max lot coverage." For each parcel, the max lot coverage was used to calculate 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.

Table 7: Summary of urban land area and associated fertilizer nitrogen input for nonresidential parcels

* = Parcel type descriptions include Office Buildings 1 story and multistory, Professional Buildings, and Financial Institutions.

Parcel Type	Leon Unconfined (acres)	Leon Semi-Confined (acres)	Leon Confined (acres)	Wakulla Unconfined (acres)	Gadsden Semi-Confined (acres)	Gadsden Confined (acres)	Jefferson Semi-Confined (acres)	Jefferson Confined (acres)	Total Input (lb-N/yr)
Hotels	2	103		3	1	4		12	5,463
Churches	115	661	24	152	20	181	4	12	50,887
Schools									
Hospitals		58				5			2,759
Homes for the Aged		18		3		12			1,400
Clubs, Lodges, Union Halls		27		49		292		4	16,246
Shopping Centers	23	457		9		7			21,651
Office Buildings*	132	1,245	38	54	22	23			65,926
Total	**272**	**2,570**	**63**	**270**	**43**	**524**	**4**	**27**	**164,332**

2.4.4 Residential Parcel Estimations

For residential parcels such as single- and multifamily homes, the acreage receiving fertilizer applications is calculated in the same manner as nonresidential parcels. Prior to applying the fertilizer application rates to the pervious land area, two factors are taken into account: (1) the percentage of a property that a homeowner will fertilize, and (2) the probability that a homeowner will use fertilizer.

While homeowners may apply fertilizer to all the pervious area on their property (lawns and beds), this is less likely for those with larger lot sizes. For this analysis, it was assumed that the owners of properties with greater than one acre of pervious land area would regularly apply fertilizer to no more than one acre.

Property value may also be a factor when considering the likelihood of fertilizer application. Previous socioeconomic studies have shown that property value is a reliable indicator of the probability that a homeowner will apply fertilizer to a property (Kinzig et al. 2005; Law et al. 2004; Zhou et al. 2008; Cook et al. 2012). Properties with higher assessed values tend to be fertilized more than properties with lower assessed values. To account for this, the range of property values for single-family homes was evaluated for the contributing area and subdivided into three categories based on property value specific to the county: high, medium, and low. **Table 8** lists the probability of fertilization for each property value category based on the literature.

Table 8: Distribution of property values and the probability of fertilization for the Wakulla BMAP area

Property Value Label	Leon County Property Value	Wakulla County Property Value	Gadsden County Property Value	Jefferson County Property Value	Probability of Fertilization (%)
High	> $205,000	> $144,000	> $110,000	> $191,000	90
Medium	$87,001 – $205,000	$74,001 – $144,000	$42,001 – $110,000	$59,001 – $191,000	75
Low	≤ $87,000	≤ $74,000	≤ $42,000	≤ $59,000	10

The probability of fertilization percentage represents the probability that a homeowner will fertilize some or all of a property in a given year. These percentages were assigned 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 are applied to the pervious acreage of residential properties to calculate the land area presumed to be fertilized. The land area potentially receiving fertilizer was multiplied by the nitrogen application rate and frequency listed in **Table 6** to obtain the estimated input of nitrogen in fertilizer to the land surface on residential parcels. **Table 9** summarizes these data.

Table 9: Summary of acres receiving fertilizer and estimated input of nitrogen attributed to residential parcels

Parcel Type	Leon Unconfined (acres)	Leon Semi-Confined (acres)	Leon Confined (acres)	Wakulla Unconfined (acres)	Gadsden Semi-Confined (acres)	Gadsden Confined (acres)	Jefferson Semi-Confined (acres)	Jefferson Confined (acres)	Total Input (lb-N/yr)
Single-Family Residential	1,194	13,528	974	1,994	99	2,717	23	90	431,523
Multifamily Residential	18	481	1	9	3	25		1	11,263
Condominium		138		5					2,986
Vacant Residential	133	533	62	187	21	258	2	22	
Total	**1,345**	**14,680**	**1,037**	**2,195**	**124**	**3,000**	**25**	**113**	**445,772**

2.5 Sports Turfgrass Fertilizer

Fertilizer applied to sports turfgrass areas is another potential source of nitrogen. Sports turfgrass was combined with the urban turfgrass category in the 2014 assessment. As discussed before, this category is included in the 2018 NSILT analysis because it was specified as a nitrogen source category in the Florida Springs and Aquifer Protection Act.

Sports turfgrass areas assessed for nitrogen fertilizer inputs include golf courses, recreational facilities (baseball, softball, football, and soccer fields) and other recreational areas where fertilizers are likely applied.

The evaluation included 11 golf courses. To estimate the nitrogen fertilizer input to golf courses, a survey was conducted to obtain fertilizer use information from golf course superintendents in the area. Of those surveyed, only 3 superintendents responded with detailed information about fertilizer use. The results indicated that nitrogen fertilizer was being applied at an average rate of 71.0 lb-N/ac/yr. This average accounts for higher application in some areas (greens, tees, fairways) and much lower application in others (rough).

The average rate of 71.0 lb-N/ac/yr was used for the remaining golf courses in the NSILT analysis (assuming 72 % of the course area is fertilized)(Sartain 2002; DEP 2007). The total input of nitrogen from all golf courses in the BMAP area was 16,438 lb N/yr to the land surface in unconfined areas, 70,291 lb N/yr in semiconfined areas, and an additional 8,403 lb N/yr in confined areas. **Table 10** summarizes the input to the land surface from each golf course in the contributing area.

Table 10: Summary of urban fertilizer input of nitrogen attributed to golf courses

* Received response to survey.

Golf Club Name	County	Unconfined Land Area (ac)	Semiconfined Land Area (ac)	Confined Land Area (ac)	Average Application Rate (lb-N/ac)	Total Input (lb-N/yr)
Seminole	Leon	124	206		71	**16,827**
Southwood	Leon		277		71	**14,090**
Summerbrooke	Leon		171		71	**8,716**
Capital City	Leon		189		71	**9,628**
Hilaman*	Leon		122		63	**3,895**
Jake Gaither*	Leon	119			67	**1,787**
Killearn	Leon		269		71	**13,714**
Golden Eagle	Leon		171		71	**8,727**
Cross Creek	Leon		20		71	**1,024**
Wildwood	Wakulla	163			71	**8,321**
Havana	Gadsden			92	71	**4,684**
Quincy*	Gadsden			195	83	**3,719**

Sports facilities were assessed based on PA land use data. The parcel types likely to contain sports facilities were identified and evaluated based on aerial imagery. PA classifications likely to include sports facilities include schools, clubs/lodges, forest/parks/recreational, colleges, and outdoor parkland/recreational. Any sports turfgrass acreage that fell within a parcel previously identified as urban turfgrass was subtracted from the urban turfgrass acreage to avoid double counting.

In total, 320 ac of land were associated with sports facilities in the Wakulla BMAP area, with 108 ac in the unconfined region, 186 ac in the semiconfined region, and 26 ac in the confined region. It was assumed that turf areas at sports facilities are fertilized at rates applied by lawn service companies (21.78 lb-N/ac twice a year), as described in **Section 2.4**, resulting in 13,943 lb-N/yr applied to the land surface. **Table 11** summarizes all sports turfgrass fertilizer calculations.

Table 11: Summary of total sports turfgrass fertilizer nitrogen applied to the land surface

Land Type	Unconfined (lbs)	Semiconfined (lbs)	Confined (lbs)	Total
Golf Courses	16,438	70,291	8,403	95,132
Sporting Facilities	4,690	8,100	1,153	13,943
Total	21,129	78,391	9,555	109,075

2.6 Livestock Waste

Every five years the U.S. Department of Agriculture (USDA) releases a Census of Agriculture (CoA). This comprehensive report provides summary information about the agricultural practices and livestock populations for each state and county in the U.S. These data are available online and can be sorted by state and county. The 2012 census report was used in the 2018 NSILT analysis, while 2007 was the most recent census available for the 2014 report. Spot checking of animal populations, reported in the CoA, via aerial imagery was not conducted for the 2018 NSILT as it was for the 2014 NSILT. Over the years, census records have improved, and it was assumed that the more recent CoA populations were more accurate that those from the earlier survey. This was confirmed when the 2012 data were cross-referenced with the populations reported in the 2016 Annual Survey of Agriculture (published by the USDA).

The countywide livestock populations in the Wakulla BMAP area were calculated using data from the CoA and land use data. To count the number of livestock animals in the contributing area, the NWFWMD land use coverage was used to identify land use categories likely to contain livestock. The following land use categories were used, as appropriate, to apportion the animal populations to the recharge areas in each county: improved pastures, unimproved pastures, woodland pastures, cattle feeding operations, poultry feeding operations, specialty farms, horse farms, dairies, and aquaculture. These land areas were totaled for all counties and subdivided by recharge rate category. The livestock area summations were used to calculate the percentages of countywide livestock areas found in the BMAP area and the unconfined, semiconfined, and confined areas within it.

These percentages were applied to the populations provided by the CoA to calculate the number of animals in the BMAP area (**Table 12**). For example, if 10,000 cows were reported for a 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 12: Water management district land use percentages and livestock population in the Leon, Wakulla, Gadsden, and Jefferson County portions of the BMAP area

	Leon Unconfined	Leon Semi-Confined	Leon Confined	Wakulla Unconfined	Gadsden Semi-Confined	Gadsden Confined	Jefferson Semi-Confined	Jefferson Confined
Land Area (ac)	1,490	6,918	2,852	3,818	880	8,940	287	1,127
Land %	13	60	25	62	7	74	1	6
Cattle	175	812	335	402	185	1,876	164	643
Calves	94	437	180	217	99	1,010	84	331
Donkeys	6	29	12	37	8	81	2	7
Horses	116	537	221	171	41	412	18	69
Chicken, Broilers	4	17	7				3	11
Chicken, Layers	102	475	196	414	70	711	19	76
Goats	62	286	118	163	31	319	11	45
Hogs				72	9	95	5	22
Sheep	13	60	25	33	4	39	4	14
Turkey				23				1

The methodology for estimating nitrogen input from livestock waste was similar for both the 2014 and 2018 NSILT analyses. Daily nitrogen waste factors were obtained from the literature for each animal type and applied to the livestock populations to calculate the nitrogen input to the land surface. The nitrogen waste factors in lb N/day per animal for the 2018 assessment were as follows: cattle, 0.337; calves, 0.068; donkeys, 0.100; broiler chickens, 0.002; 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 BMAP area. The 2018 estimated input from animal waste was 798,786 lb N/day, which is 6 % greater than the livestock input used in the 2014 NSILT analysis (747,248 lb-N/yr).

Table 13: Estimated nitrogen applied as animal waste to the land surface in the Wakulla BMAP area

	Leon Unconfined	Leon Semi-Confined	Leon Confined	Wakulla Unconfined	Gadsden Semi-Confined	Gadsden Confined	Jefferson Semi-Confined	Jefferson Confined	Total Input (lbs)
Adult Cattle	21,056	97,774	40,311	49,007	22,701	230,710	20,145	79,088	**560,791**
Calves	1,153	5,352	2,207	2,651	1,217	12,364	1,031	4,048	**30,023**
Donkeys	227	1,055	435	1,350	290	2,948	66	257	**6,628**
Horses	11,524	53,514	22,063	17,015	4,040	41,053	1,750	6,869	**157,827**
Chicken, Broilers	3	12	5				2	8	**30**
Chicken, Layers	112	520	214	453	77	779	21	84	**2,260**
Goats	787	3,653	1,506	2,087	401	4,070	145	569	**13,218**
Hogs				4,959	647	6,578	380	1,492	**14,056**
Sheep	937	4,351	1,794	2,406	279	2,838	263	1,032	**13,900**
Turkey				50			1	2	**53**
Total	**35,798**	**166,231**	**68,536**	**79,978**	**29,651**	**301,340**	**23,803**	**93,449**	**798,786**

2.7 Farm Fertilizer

2.7.1 Changes in Methodology

In the 2014 NSILT for the Wakulla BMAP area, county fertilizer sales data and land use were used to provide a rough estimate of the amount of nitrogen applied as fertilizer in the area. Since then, a much more robust methodology has been developed and used in the other spring NSILT analyses. For most of the assessments, an agricultural land use planning tool developed by FDACS was used: the Florida Statewide Agricultural Irrigation Demand (FSAID) Geodatabase. Datasets used to generate the FSAID include the most recent land use/land cover from the water management districts, consumptive use permit (CUP) polygons from the water management districts, USDA cropland data layer (CDL) data, USDA National Agricultural Imagery Program (NAIP) aerial imagery, USDA National Agricultural Statistics Service (NASS) data, Google Earth imagery, and USGS field-verified irrigated areas data. Florida Department of Revenue (FDOR) parcel data and FDACS Division of Plant Industry (DPI) data were also used to remove areas no longer categorized as agricultural. The FSAID geodatabase and its metadata were used to calculate the total acreage and types of agricultural lands within the BMAP area boundary.

The 2014 NSILT used information on fertilizer sales and water management district land use coverage to estimate the amount of nitrogen from fertilizer applications. As stated previously, the fertilizer sales data for 2015 and 2016 had reporting errors, and so this information was not used in this 2018 NSILT analysis. Another issue with using fertilizer sales data is that fertilizer used in an area is not necessarily purchased in that county, which could result in a significant underestimate of the nitrogen input for an area.

For the 2018 NSILT analysis, the estimated annual amount of nitrogen applied as fertilizer was multiplied by agricultural land use areas to estimate the potential nitrogen input from farm practices. Using the acreages of classified crop types and their associated fertilizer application rates provides more detailed estimates compared with the use of county fertilizer sales data. (See section 2.7.3) In total, 3,735,999 lb-N/yr were applied to the land surface from these facilities. These were divided among unconfined (227,374 lb-N/yr), semiconfined (848,091 lb-N/yr), and confined (2,660,533 lb-N/yr) recharge areas. **Table 14** further breaks out the total input by cropland and pastureland. The total input from farm fertilizer was more than 3 times greater than the input from the 2014 report, which was 1,236,317 lb-N/ac.

Table 14: Estimated nitrogen input from farm fertilizer, by agronomic land type

Land Type	Unconfined (lb-N)	Semiconfined (lb-N)	Confined (lb-N)	Total Input (lb-N)
Cropland	203,764	792,308	2,567,317	3,563,389
Pastureland	23,610	55,784	93,216	172,610
Total	227,374	848,091	2,660,533	3,735,999

2.7.2 Pastureland

For this analysis, lands classified by the FSAID as improved pasture, grass/pasture, or horse farms were assumed to be fertilized pasture. Information compiled from University of Florida Institute of Food and Agricultural Sciences (UF–IFAS) surveys indicated that 21 % of horse farms apply fertilizer at least once a year, while 26 % apply fertilizer every few years or as needed (J. Cohen, Marion County UF–IFAS Extension Service, personal communication, 2013). As is the case with horse farms, cattle farm managers also apply fertilizers to pastures and use their lands for forage hay production on a rotating basis. The application rates of fertilizer to improved pasture vary and depend on the use of individual fields (such as hay production, animal forage, or idle between uses).

This information was used to identify the fertilization practices on pastureland for other areas of the state where detailed information was not available. For the Wakulla area, the lands identified by FSAID as improved pasture, grass/pasture, or horse farms were assumed only to be fertilized at 25 % of the total acreage. A similar method, discussed in the following section, was used for lands classified as cropland/pastureland. Calculations of average annual fertilizer applications to pasture were developed based on information from meetings with FDACS and UF–IFAS members and are listed in **Table 15**. The table lists nitrogen input from all identified pasturelands in the BMAP area, including those that do not receive fertilizer.

Table 15: Summary of pastureland acreage and assumed annual nitrogen application rates for the Wakulla BMAP area

* Pasture types assumed not to receive fertilizer.
Note: Total acreage listed in table. Only 25 % of the total acreage was assessed when calculating input.

FSAID Classification	Application Rate (lb-N/ac)	Leon Unconfined (ac)	Leon Semi-Confined (ac)	Leon Confined (ac)	Wakulla Unconfined (ac)	Gadsden Semi-Confined (ac)	Gadsden Confined (ac)	Jefferson Semi-Confined (ac)	Jefferson Confined (ac)	Total Input (lbs/yr)
Improved Pasture	60	166	2,291	1,223	1,329	520	3,144	152	235	**135,929**
Grass/Pasture	80					17	587			**12,075**
Herbaceous/ Dry Prairie*	0		38	32		50	626			
Horse Farms	100	40	395	216	8		127	45	155	**24,606**
Specialty Farms*	0		26		3		59			
Unimproved Pastures*	0	20	304	12	70	7	205	15	21	
Woodland Pastures*	0	78	620	435	1,045	100	1,210	186	49	

2.7.3 Cropland

Nitrogen inputs to the land surface were estimated based on the type of crops grown in each FSAID land use category and the nitrogen application rates for crops, listed in **Table 16**. After discussions with FDACS and UF-IFAS, these application rates were established to represent fertilizer practices based on the assumption that not all land owners use UF-IFAS recommended rates (Hochmuth and Hanlon 2000, 2010, 2013; Wright et al. 2011; Mylavarapu et al. 2015; Liu et al. 2012; David Wright, personal communication, 2018). The table summarizes the nitrogen inputs to the land surface from fertilizers applied to cropland for the unconfined, semiconfined, and confined recharge rate areas in the Wakulla BMAP area.

Cropland/pastureland is a broad classification. Based on aerial imagery, lands falling under this classification range from unimproved pastures to row crops. To account for this variability, 70 % of the total acreage was used to calculate the fertilized acreage for cropland/pastureland areas. However, 3 large plantations are listed under this category. Areas inside these plantations are used to grow row crops, but the remainder of the land is forested and does not receive fertilizer at rates and frequencies comparable to agronomic crops. Assuming the entire plantation is fertilized would grossly overstate fertilizer input. These three areas were assessed individually at 20 % of the total acreage.

Table 16: Summary of cropland acreage and assumed annual nitrogen application rates for the Wakulla BMAP area

* **Notes:** Acreage listed in table represents the adjusted acreage assumed to be fertilized. Adjustments were based off the assumption that 70% of the total acreage for "Cropland/Pastureland" is fertilized, with the exception of 3 large plantations that are assumed to be fertilized at 20% of total acreage.

FSAID Classification	Application Rate (lb-N/ac)	Leon Unconfined (ac)	Leon Semi-Confined (ac)	Leon Confined (ac)	Wakulla Unconfined (ac)	Gadsden Semi-Confined (ac)	Gadsden Confined (ac)	Jefferson Semi-Confined (ac)	Jefferson Confined (ac)	Total Input (lbs/yr)
Container Nursery	90			9		67	1,047		8	**101,839**
Cotton	60					350	340			**41,394**
Cropland and Pastureland*	60	116	4,477	1,948	159	425	2,861	147	2,847	**778,778**
Field Crops	90		98	5	22	3	387			**46,367**
Field Corn	210									
Field Nursery	90		3	26			123			**13,723**
Hay	160	65	927	321	988	477	6,029	94	389	**1,486,476**
Mushrooms Spring and Fall	151						4			**622**
Nurseries and Vineyards	90		50		9	4	5		20	**7,900**
Ornamentals	90	15	158	2	38	132	1,595		113	**184,891**
Other Groves (Pecan, Avocado, Coconut, Mango, etc.)	90						757	4	107	**78,103**
Peanuts	20						290			**5,791**
Peppers	200					53				**10,556**
Pole Beans and Pepper	160						9			**1,374**
Row Crops	106		100	5	21	956	3,788	93	7	**526,937**
Small Grains	100						56			**5,592**
Small Veg	151			32		26	57			**17,414**
Sod	50		171			110	1,123			**70,201**
Tomatoes	200						206			**41,141**
Tomatoes and Peppers	200						93			**18,700**
Tomatoes and Watermelon	200						56			**11,294**
Tomatoes Fall	200					35				**7,072**
Tomatoes Fall and Spring	200						53			**10,637**
Tree Nurseries	90	5		208	3		13		3	**20,881**
Vegetables	151		7	6	55	154	280			**75,705**

2.8 Sinking Waterbodies

2.8.1 Sinking Streams

Sinking streams were included as a contributing source in the 2014 NSILT to be consistent with the source assessment categories used in a previous nitrogen inventory conducted by the NWFWMD. However, the nitrogen concentrations from Fisher Creek, Black Creek, and Lost Creek, which are all located in natural areas, are not from anthropogenic sources and cannot be remediated. The TN concentrations for these waterbodies measured below the typical concentrations naturally found in blackwater steams, and so the inputs from these streams are not thought to be a significant contributor to the elevated nitrogen levels in Wakulla Spring (Hand et al. 2009). The 20th percentile total nitrogen concentration for typical blackwater streams in Florida (0.78 milligrams per liter [mg/L]) is considered a natural background condition. According to McGlynn and Deyle (2016), total nitrogen concentrations in Lost Creek, Fisher Creek and Black Creek ranged between 0.700 and 0.755 mg/L, reflecting natural background conditions.

Based on this information, the sinking streams in the BMAP are not contributing anthropogenic N to the UFA and were therefore excluded from the 2018 NSILT analysis. The sinking stream contribution from Munson Slough, which is a sinking stream receiving water from Lake Munson, was also evaluated in the 2014 NSILT. Its potential nitrogen input was combined with Lake Munson in the McGlynn and Deyle (2016) assessment and is also included as part of the Lake Munson seepage contribution discussed below.

2.8.2 Sinking Lakes

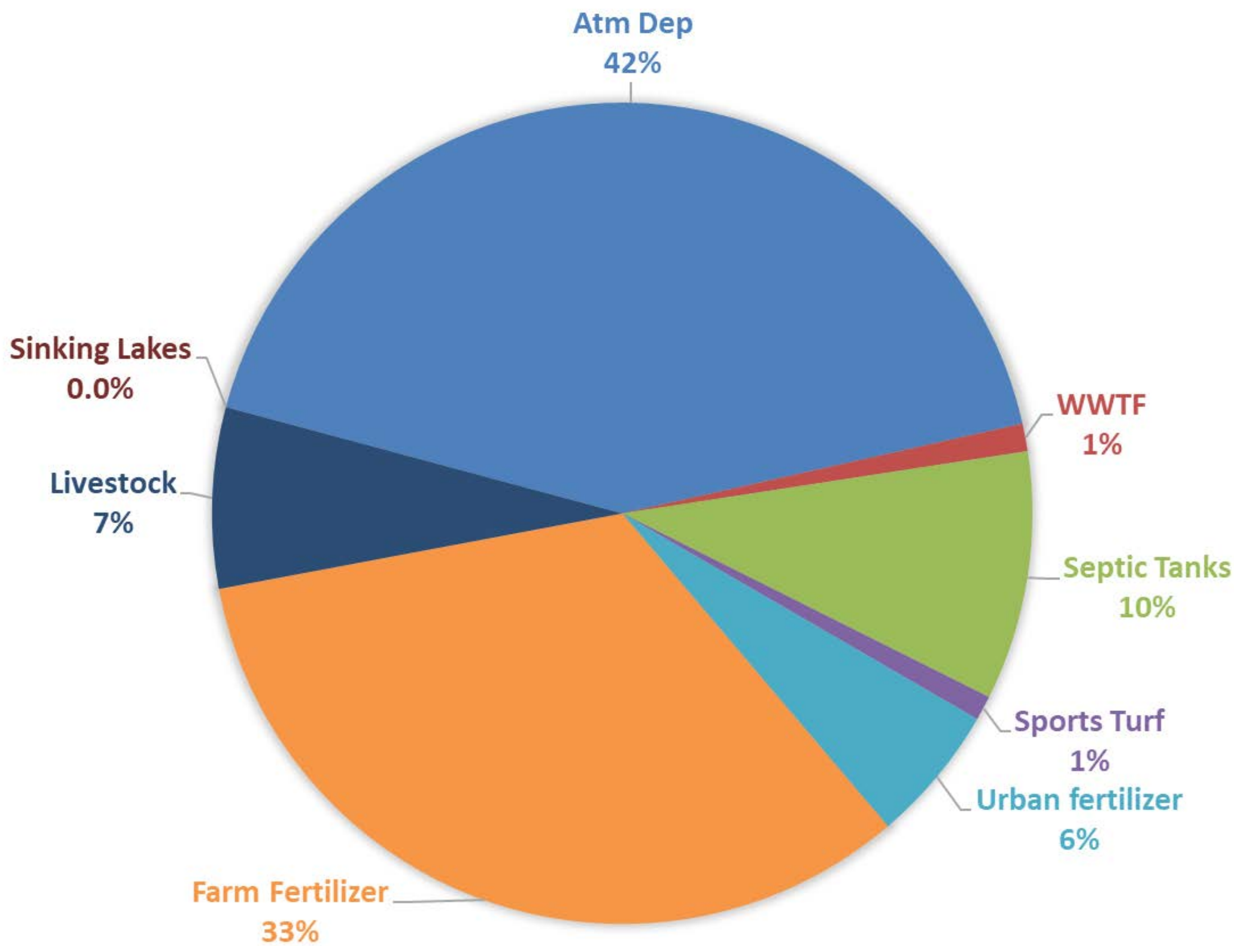
The findings from a recent study by McGlynn and Deyle (2016) suggest that large urban sinkhole lakes may contain both anthropogenic and background sources of nitrogen. In the BMAP area, Lakes Munson, Lafayette, and Jackson were identified by McGlynn and Deyle as the lakes that could contribute anthropogenic concentrations of nitrogen via lake leakage to the UFA. All three waterbodies are located within a semiconfined area of the UFA.

Unfortunately, there is insufficient data available at this time to reliably calculate nitrogen inputs and loads from the sinking lakes. The periods of discharge (leakage) estimates and nitrogen monitoring dates currently published in McGlynn and Deyle (2016) vary greatly among these waterbodies. However, findings from the study by McGlynn and Deyle (2016) point out the need to collect more specific information on the rates of lake leakage and the amount of nitrogen attenuation as nitrogen moves through the lake and into the UFA . With this additional information, we would be able to potentially assess the inputs of nitrogen to the aquifer from sinkhole lakes in future NSILT calculations. Therefore, in the 2018 NSILT, we assume that the nitrogen contribution from sinking lakes is accounted for in the estimates of nitrogen inputs and loading from atmospheric deposition.

2.9 Summary of Estimated Nitrogen Inputs to the Land Surface

Figure 9 summarizes the relative inputs of nitrogen (in percent) from the major sources in the Wakulla BMAP area. The estimated total annual nitrogen input to the land surface from all sources was 11,230,270 lb-N. Atmospheric deposition comprised 42 % of the TN input to the land surface in the contributing area. Other nitrogen sources, in decreasing order, included farm fertilizer (33 %), septic tanks (10 %), livestock (7 %), urban turfgrass fertilizer (6 %), sports turfgrass fertilizer (1 %), and WWTF land application sites (1 %). The estimated total input to groundwater was 11,230,270 lb-N/yr, a 45 % increase from 2014 (6,222,153 lb-N/yr).

Figure 9: Relative nitrogen inputs to the land surface in the Wakulla BMAP 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 calculate the amount of nitrogen loading to the aquifer in the Wakulla BMAP 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 hydrogeological properties that affect the rate of water infiltrating through geologic media to recharge the UFA. Both attenuation factors control the amount of nitrogen reaching the UFA annually and in the groundwater moving to Wakulla Spring.

3.1 Biochemical Attenuation

3.1.1 Biochemical Attenuation Factors

Several near-surface biochemical processes within the nitrogen cycle 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. The BAFs used in the 2014 NSILT analysis were based on the best available information at that time. However, the 2018 NSILT BAFs were obtained through a further, extensive literature review of relevant studies conducted in Florida as well as other areas with similar environmental characteristics. Additionally, research scientists in Florida (UF–IFAS, other universities, and USDA Agricultural Research Service [ARS]) and local stakeholders provided additional guidance. **Table 17** compares the BAFs used in each NSILT evaluation. The BAF values represent the average percentage of the nitrogen attenuated or removed by subsurface processes and not available to leach, 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 BAFs (**Table 18**). For example, atmospheric deposition has an average nitrogen attenuation of 90 % (mainly from uptake by vegetation). This means that 10 % of the atmospheric nitrogen input to the land surface has the potential to infiltrate to groundwater.

Table 17: Comparison of BAFs applied to the nitrogen input calculations for the 2014 and 2018 NSILT analyses

* Both sports and urban turfgrass. However, sports turf was not included in the 2014 NSILT analysis.
** The 2014 NSILT analysis assumed one BAF for all WWTF effluent regardless of land application type.
*** These percentages represent the average amount of nitrogen removed by the environment over varying soil characteristics, based on the most recent literature review and stakeholder feedback.

N Source Category	2014 BAF (%)	2018 BAF (%)***	2018 Literature References
Atmospheric Deposition	90	**90**	Katz et al. 2009; Lombardo Associates 2011; Howard T. Odum Florida Springs Institute 2011
WWTFs–RIBs **	60	**25**	Merritt and Toth 2006; Sumner and Bradner 1996
WWTFs–Sprayfield**	60	**60**	Katz et al. 2009; Lombardo Associates 2011; Howard T. Odum Florida Springs Institute 2011
WWTFs–Reuse**	60	**75**	Jordan et al. 1997; Candela et al. 2007; Rahil and Antonopoulos 2007
Urban Fertilizer*	80	**70**	Goolsby et al. 1999; Erikson et al. 2001; Barton and Colmer 2006; Katz et al. 2009
Septic Systems	40	**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	75	**90**	Dubeux et al. 2007, 2009; Silveira et al. 2007; Burns 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, 2013b
Farm Fertilizer	70	**80**	McNeal et al. 1995; Wang and Alva 1996; Paramasivam and Alva 1997; Newton et al. 1999; Hochmuth 2000a, 2000b; Simonne et al. 2006; He et al. 2011; Liu et al. 2013

3.1.2 Accounting for Uncertainty in Nitrogen Attenuation Factors

If the contribution from one nitrogen source category were to increase or decrease, the contribution of nitrogen from 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 the source's 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 (such as the number of septic tanks per acre) can also dramatically affect the amount of attenuation in the subsurface.

Given the relatively broad range in nitrogen attenuation for each source, DEP opted to use an average attenuation factor based on land use practices and hydrogeological conditions in the Wakulla BMAP area. Greater emphasis was placed on information on nitrogen attenuation from studies in northwest Florida, other locations in Florida, or areas with very similar soil and vegetation characteristics. **Table 18** lists the range in nitrogen attenuation for each source.

Table 18: 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–Sprayfields	50	60	75
WWTFs-Reuse	50	75	85
Septic Systems	40	50	75
Livestock Waste	80	90	95
Farm Fertilizer	50	80	85
Urban Fertilizer*	50	70	85

3.2 Hydrogeological Attenuation

Nitrogen (usually in the form of nitrate) that is not attenuated by biochemical attenuation processes can 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. Davis et al. (2011) reported that of 20 inches of rainfall that infiltrate annually, 18 inches reach the UFA in unconfined areas, 8 inches reach the UFA in semiconfined areas, and 2 inches reach the UFA in confined areas.

The final step in estimating nitrogen loads to groundwater is to account for the additional attenuation associated with the rate of recharge in a year. The recharge rate can be geospatially assessed and incorporates soil and unsaturated zone properties 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 increased nitrogen leaching 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 (hydrogeological) nitrogen attenuation factors related to recharge rates were arbitrarily assigned as follows: 90 % in unconfined recharge rate areas (9 to 20 in/yr), 40 % in semiconfined recharge rate areas (3 to 8 in/yr), and 10 % in confined recharge areas (0 to 2 in/yr) (Sepulveda 2002). For example, in high rate recharge areas, 90 % of the nonattenuated nitrogen mass is assumed to reach the aquifer in a year, while only 40 % of the nonattenuated 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 Wakulla BMAP area.

3.3 Estimated Nitrogen Loads to Groundwater

Tables 19, **20** and **21** summarize estimated annual nitrogen inputs, attenuation factors, and loads to the UFA, respectively, in the Wakulla BMAP area by recharge rate classification. The results indicate an estimated annual load of 789,650 lb-N to the UFA in the BMAP area, representing 7.0 % of the amount of nitrogen inputs to the land surface. As discussed previously, the difference+ is caused by 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 septic systems (34 % of the total estimated load to groundwater), followed by atmospheric deposition at 27 %.

Figure 10 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 septic systems (34 %) and fertilizers (31 % from farm and urban fertilizer sources). Aquifer recharge rates strongly influence the loading of nitrogen to the UFA in the groundwater contributing area.

Figure 11 summarizes the estimated nitrogen loads to groundwater for all 3 of the recharge rate areas, including a breakdown for each source category. The majority of the nitrogen loading to groundwater in the Wakulla BMAP area occurs in unconfined areas, where septic tanks and atmospheric deposition are the dominant sources of nitrogen loading. For the semiconfined areas, the dominant sources of nitrogen loading to groundwater are septic systems and farm fertilizer, and the dominant source in confined areas is farm fertilizer.

Table 19: Estimated inputs to the land surface by nitrogen source category in the Wakulla BMAP area (lb-N/yr)

Recharge Category	Atmospheric Deposition	WWTF–RIBs	WWTF–Sprayfields	WWTF–Reuse	Septic Systems	Sports Turf Fertilizer	Urban Turf Fertilizer	Farm Fertilizer	Livestock Waste	Total
Unconfined	1,554,295	696	8,804	78,672	374,739	21,129	90,996	227,374	115,775	**2,472,480**
Semiconfined	1,342,085	7,018	16,156	1,458	449,089	78,391	412,664	848,091	219,685	**3,374,637**
Confined	1,856,428	4,291	4,347	982	277,247	9,555	106,444	2,660,533	463,325	**5,383,153**
Total	**4,752,808**	**11,309**	**20,503**	**2,440**	**1,101,075**	**109,075**	**610,104**	**3,735,999**	**798,786**	**11,230,270**

Table 20: Average BAFs by source category in the Wakulla BMAP area (lb-N/yr)

Recharge Category	Atmospheric Deposition	WWTF–RIBs	WWTF–Sprayfields	WWTF–Reuse	Septic Systems	Sports Turf Fertilizer	Urban Turf Fertilizer	Farm Fertilizer	Livestock Waste	Total
BAF (%)	*90*	*25*	*60*	*75*	*50*	*70*	*70*	*80*	*90*	
Unconfined	155,429	522	3,522	19,668	187,370	6,339	27,299	45,475	11,578	**457,200**
Semiconfined	134,208	5,264	6,463	364	224,544	23,517	123,799	169,618	21,968	**709,747**
Confined	185,643	3,218	1,739	246	138,623	2,867	31,933	532,107	46,333	**942,708**
Total	**475,281**	**18,008**	**23,446**	**40,556**	**550,538**	**32,722**	**183,031**	**747,200**	**79,879**	**2,109,655**

Table 21: Load to groundwater with recharge factors applied by nitrogen source category in the Wakulla BMAP area (lb-N/yr)

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

Recharge Category	HAF (%)	Atmospheric Deposition	WWTFs §	Septic Systems	Sports Turf Fertilizer	Urban Turf Fertilizer	Farm Fertilizer	Livestock Waste	Total
Unconfined	90	139,887	21,340	168,633	5,705	24,569	40,927	10,420	**411,480**
Semiconfined	40	53,683	4,836	89,818	9,407	49,520	67,847	8,787	**283,899**
Confined	10	18,564	520	13,862	287	3,193	53,211	4,633	**94,271**
Total		**212,134**	**26,697**	**272,313**	**15,398**	**77,282**	**161,985**	**23,840**	**789,650**

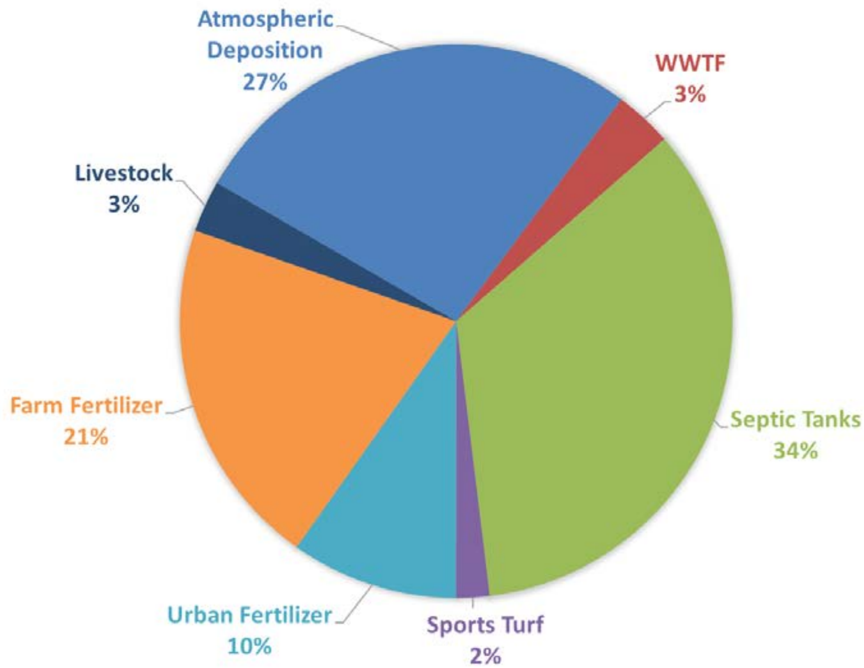


Figure 10: Relative percent contributions of nitrogen loading to groundwater for source categories in the Wakulla BMAP area

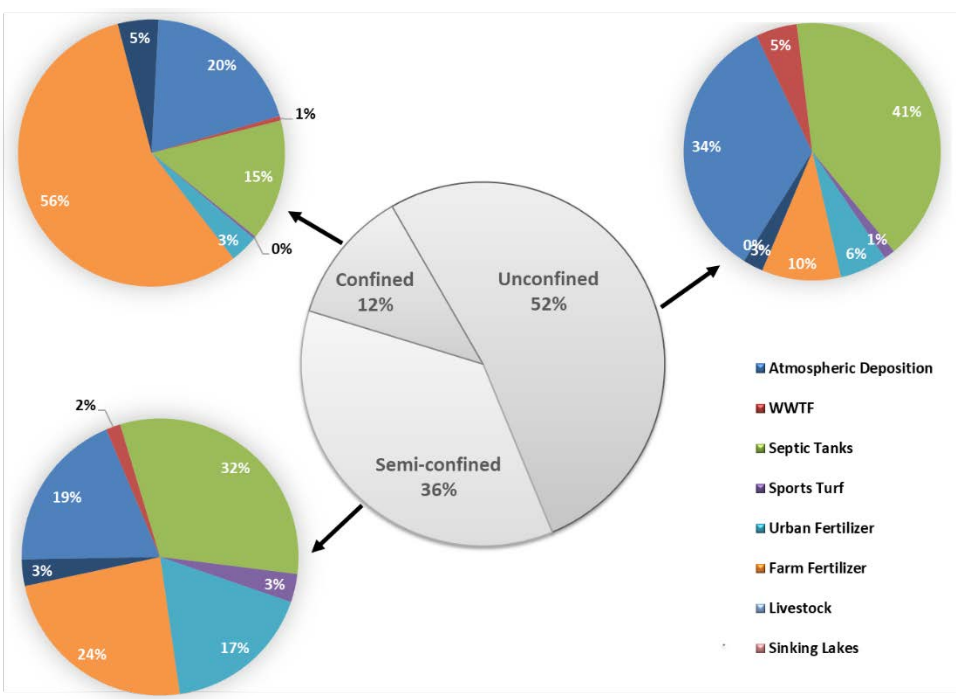


Figure 11: Estimated annual nitrogen loading to groundwater by recharge category

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Appendices

Appendix A: Important Links

Cover:
DEP home page – http://www.dep.state.fl.us

p. 2:
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Section 2.3, Septic Systems:
FDOH Florida Water Management Inventory website: http://www.floridahealth.gov/environmental-health/onsite-sewage/research/flwmi/index.html
U.S. Census Bureau website: https://www.census.gov/
U.S. Department of Labor Bureau of Labor Statistics website: https://www.bls.gov/cps/

Section 2.6, Livestock Waste:
U.S. Department of Agriculture Census of Agriculture website: https://www.agcensus.usda.gov/

Section 2.7.2, Changes in Methodology:
Florida Department of Agriculture and Consumer Services, Florida Statewide Agricultural Irrigation Demand Geodatabase website:
http://www.freshfromflorida.com/Business-Services/Water/Agricultural-Water-Supply-Planning