NITROGEN SOURCE INVENTORY AND LOADING ESTIMATES FOR THE WAKULLA SPRING BMAP CONTRIBUTING AREA

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This assessment was conducted by the Florida Department of Environmental Protection's Ground Water Management Section of the Water Quality Evaluation and Total Maximum Daily Loads Program to assist in the development and implementation of the Upper Wakulla River Basin Management Action Plan to address the TMDL for nitrate. The results of this assessment, completed in November 2013 and updated in July 2014, are based on the information provided in the document.

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Table of Contents

List of Figures

List of Tables

List of Appendix Tables

List of Appendix Equations

Summary of Findings

The Florida Department of Environmental Protection has developed a Nitrogen Source Inventory and Loading Tool (NSILT) to identify and quantify the major sources contributing nitrogen to ground water in areas of interest. The tool is currently being used to estimate nitrogen loading to areas that contribute water to springs that are impaired by nitrate. This GIS- and spreadsheet-based tool provides spatial estimates of the relative contribution of nitrogen from various sources, and takes into consideration the transport pathways and processes affecting the various forms of nitrogen as they move from the land surface through soil and geologic strata that overlie and comprise the upper Floridan aquifer (UFA).

This report documents the nitrogen source inventory and loading results for the area designated for Wakulla Spring Basin Management Action Plan implementation. Wakulla Spring is one of the largest freshwater springs in the world, and is a major discharge point for water from the UFA. Wakulla Spring is the main source of water to the Wakulla River, which was identified as impaired by a biological imbalance caused by excessive concentrations of nitrate in the water.

The NSILT is being used in the Wakulla Spring and River BMAP to identify areas where nitrogen source reduction efforts could be focused to achieve the most beneficial effects on water quality. For the Wakulla Spring and River BMAP area, the NSILT was used to estimate nitrate loads from the following source categories:

- Atmospheric deposition.
- Sinking streams.
- Agricultural and nonagricultural fertilizer.
- Livestock waste.
- Septic systems.
- Wastewater application.

Details on the potential inputs and loads from these source categories are described in detail in this report. Estimates of nitrogen loading to ground water are a function of the rate of recharge to the UFA, the degree of aquifer confinement, and various environmental processes that can attenuate nitrate in the subsurface. For example, areas where the aquifer is unconfined typically have the highest ground-water recharge rates and hence ground water in these areas is more vulnerable to contamination than areas where the aquifer is semi-confined or confined. Thus, nitrate inputs in areas where the UFA is unconfined are multiplied by a higher weighting factor (0.9) than the weighting factors for areas where

the UFA is semi-confined (0.4) or confined (0.1). After accounting for recharge and aquifer confinement, estimated nitrogen loads to ground water are calculated by multiplying the recharge-weighted nitrogen by an attenuation factor that is specific for each source. These attenuation factors are based on information from previously published studies in Florida and elsewhere on various processes that remove nitrogen as it moves through the subsurface.

The NSILT results indicate that septic tanks presently contribute more nitrogen to ground water than all other source categories evaluated for the BMAP area, comprising almost 51% of the total nitrogen loads to the UFA. Septic tanks have lower environmental attenuation factors than other sources, which results in potentially more nitrogen reaching the UFA. In areas where the UFA is unconfined and semi-confined, septic tank is the leading nitrogen loading source category and in the confined areas, farm fertilizer is the leading source category followed by septic tank.

This report describes the methods, information, and data sources used in developing the NSILT to estimate nitrogen loads to ground water. The NSILT is an effective first step in quantifying nitrogen loads to ground water from various sources in areas of spring basins most susceptible to ground-water contamination. This tool can also be used to evaluate the nitrogen load reduction benefits of various management actions and nitrogen reduction scenarios.

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 ground water quality. Springs integrate ground water vertically, spatially, and temporally from the expanse of the aquifer system (Bush and Johnston 1988; Katz 1992; Davis 1996). To recharge into the aquifer, infiltrating water travels through the soil profile and underlying geological substrate, a process that influences nutrient concentrations in the infiltrating water by the time it reaches ground water.

Elevated nitrate concentrations in Florida's springs contribute to ecological imbalances in their receiving surface waters. This problem will continue if reductions in nitrogen source inputs are not achieved. Restoration plans to reduce nitrogen inputs must include activities that will address the major sources, and detailed loading information from nonpoint and point sources within springsheds is needed to identify priority projects and areas. This information would cover sources such as fertilizer applied to cropland and turf grass, septic tanks, the land application of treated domestic wastewater, atmospheric deposition, animal wastes, and stormwater runoff to sinkholes and other direct conduits to the aquifer.

To help identify and quantify the most significant contributing nitrogen sources to ground water, a Nitrogen Source Inventory and Loading Tool (NSILT) was developed to estimate nitrogen loading to ground water. This tool, as described in this report, provides summary information on nitrogen inputs and estimated loads of nitrogen to ground water, as well as information on the relative loads from regions within spring contributing areas based on their ground water recharge rates and capability to attenuate nitrogen. The results of this tool can be used in Basin Management Action Plans to identify areas where nitrogen source reduction efforts should be concentrated to achieve the most beneficial effects on water quality.

2. 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 United States Geological Survey (USGS). Wakulla Spring is a major discharge point for water from the upper Floridan aquifer (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 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.

The BMAP area generally includes the portion of the ground water contributing area for Wakulla Spring that lies within Florida (**Figure 1)**. This area covers almost 344,000 hectares (ha, or 848,000 acres) encompassing parts of four different counties: Leon, Wakulla, Gadsden, and Jefferson. Wakulla Spring is the major source of the Wakulla River, which flows southward and joins the St. Marks River before discharging into Apalachee Bay.

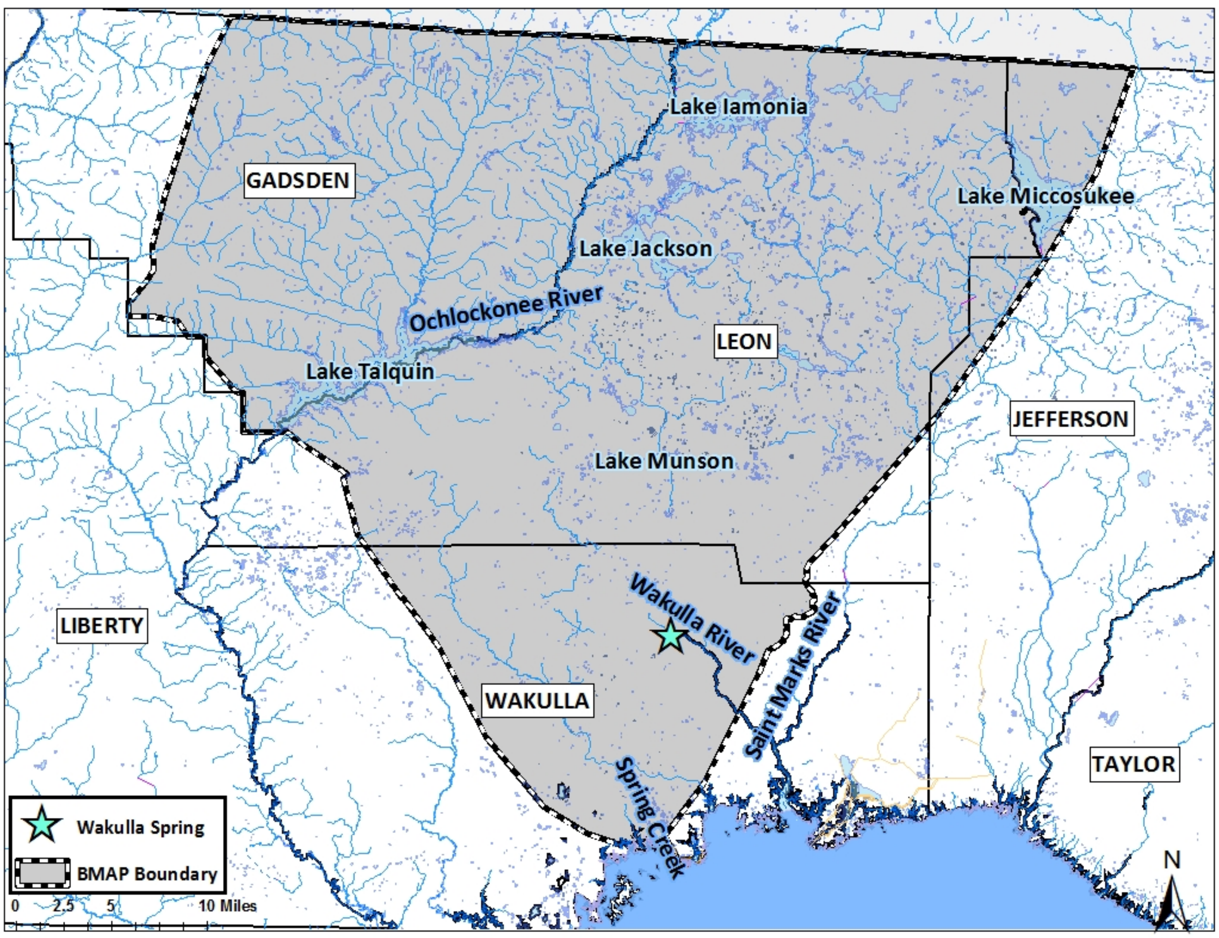

Figure 1: Wakulla Spring and River BMAP area

2.1 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 yearly potential evapotranspiration for the Tallahassee area was estimated to be about 46 inches per year (Davis *et al.* 2010). Thus, on average approximately 20 inches of precipitation per year infiltrate through the soil.

2.2 Hydrogeologic Setting

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 within these sediments and have characteristics that affect the movement of infiltrating water and nitrogen from the land surface to the UFA.

The BMAP area lies within the Coastal Plain physiographic province and is characterized by two main geomorphic zones. The Northern Highlands, which occurs north of the Cody Scarp (**Figure 2**), comprises an extensive upland area where surface drainage is perched above the UFA due to 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, occurs 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).

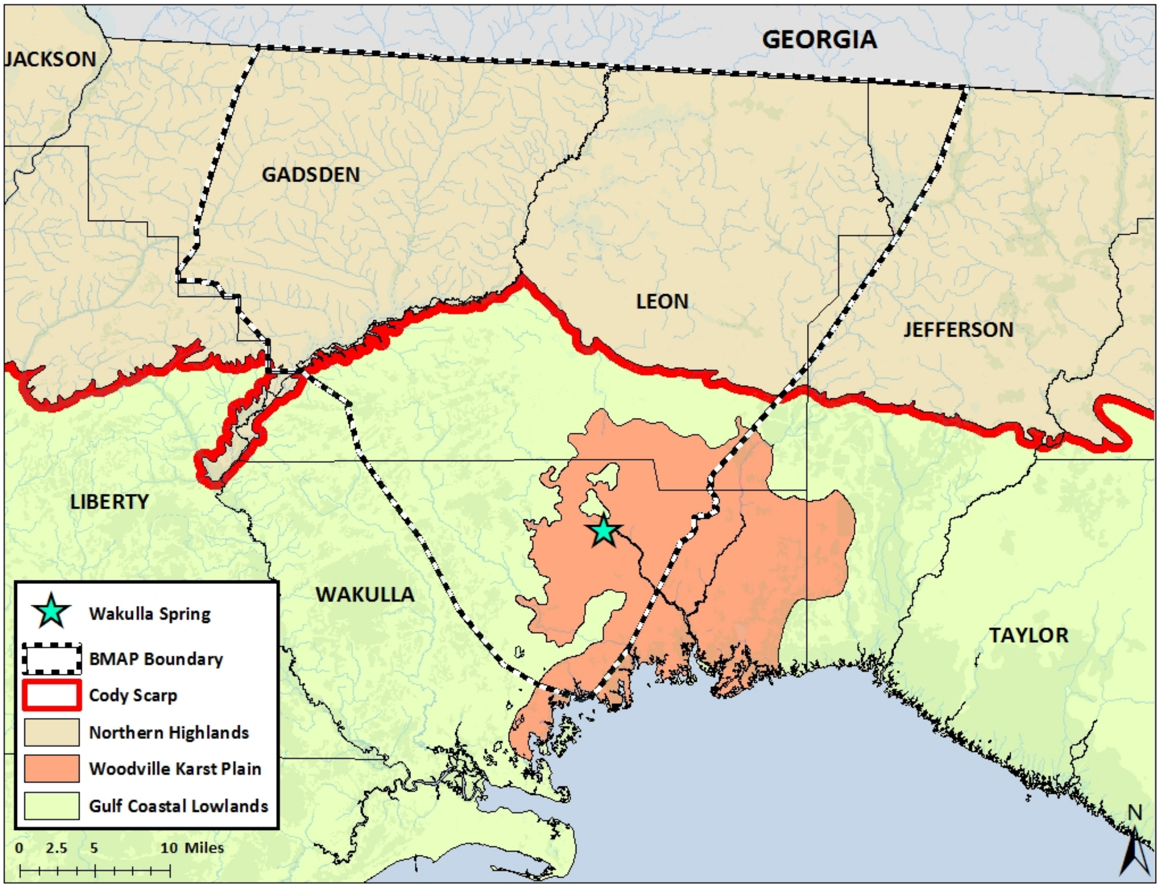

Figure 2: Physiographic regions in and around the Wakulla Spring and River BMAP area

The degree of confinement of the UFA in the BMAP area (**Figure 3**) is characterized on the thickness of overlying sediments as described by Miller (1986) and is broken into three categories: unconfined, semi-confined, 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 semi-confined. 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 areas 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 comprise 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 ground water 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).

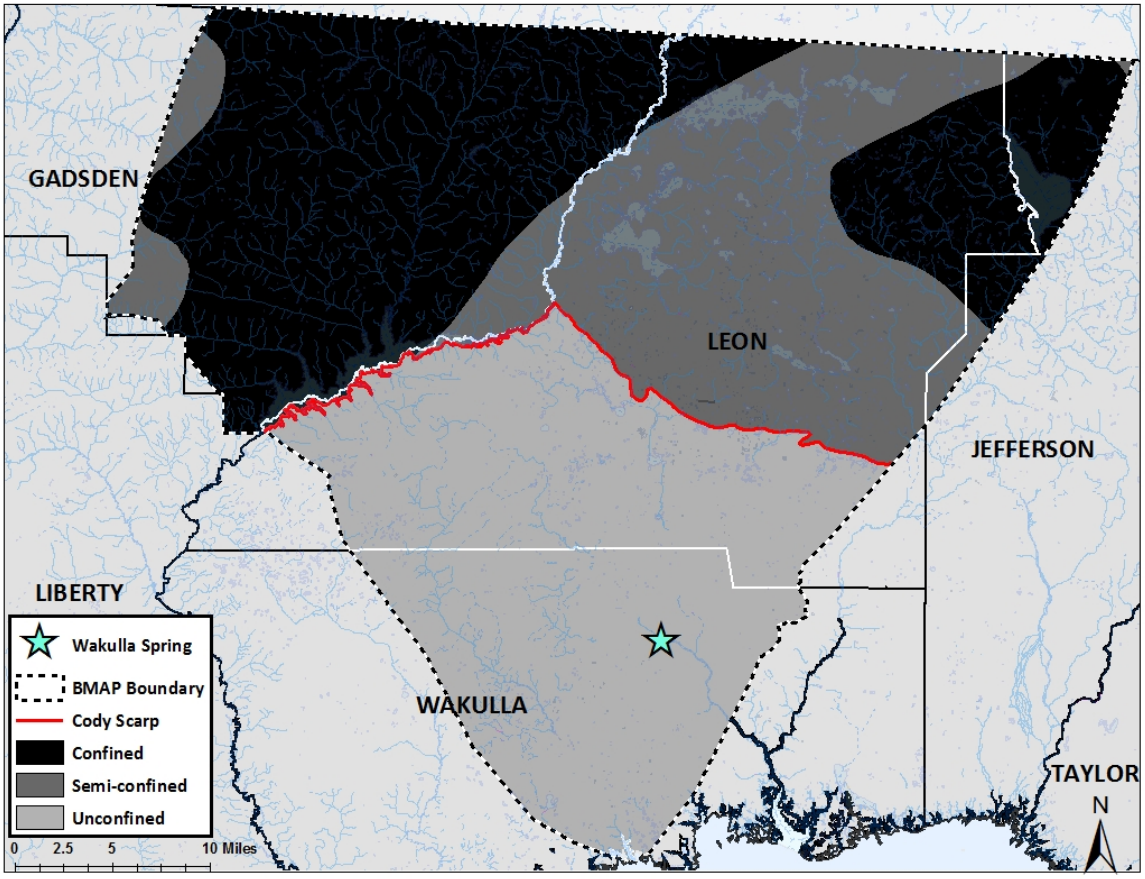

Figure 3: Recharge areas within the Wakulla Spring BMAP boundary. Recharge in the confined areas ranges from 0 to 2 inches, 3 to 8 inches in the semi-confined, and 9 to 20 inches in the unconfined.

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 about 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 conditions (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 approximately 1 to more than 20 inches per year in the northern and southern parts of the BMAP area, respectively. The lowest rates of recharge to the UFA occur in the confined area (approximately 0 to 2 inches per year) and the highest rates occur in the unconfined area (approximately 9-20 per year). Intermediate rates of recharge of 3 to 8 inches per year occur where the UFA is semi-confined. 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.

2.3 Land Use and Population

Land use in the Wakulla BMAP area in 2009 was predominantly upland forests (50%). Other land use types, in order of decreasing percentages of the total, were water and wetland (24%), urban and built-up (14%), agriculture (6%), rangeland (3%), and transportation (2%). The land use data were based on the 2009/2010 Florida Ortho Quarterly Quad Aerial Imagery True color photography. The flight dates for each county varied: Leon County in January 2009, Jefferson County in January 2010, Gadsden County in February 2010, and Wakulla County in February to March 2010. Photo interpretation and ground-truthing were performed by the Florida Department of Environmental Protection's Water Resource Monitoring staff. Land use categories that are of particular interest to this evaluation as significant sources of nitrogen are within the agricultural and urban subcategories.

The estimated populations of the four counties in the BMAP area, based on the 2010 United States Census, are as follows: Leon (275,487), Gadsden (46,389), Jefferson (14,761), and Wakulla (30,776). Most of the population in Wakulla County is concentrated in the WKP, since most of the western half of Wakulla County and southwestern Leon County lie in the Apalachicola National Forest, which is not developed. According to the state's Office of Economic and Demographic Research, the populations of Leon and Wakulla Counties are projected to increase by approximately 7.5% and 15.7%, respectively, from 2010 to 2020. Also expected to increase along with population is the discharge of domestic wastewater, the number of new homes with septic tanks, and the use of fertilizer, which will contribute to additional loads of nitrogen to ground water.

3. Estimating Nitrogen Inputs

Estimated inputs of nitrogen include the amounts (in kilograms per year [kg/yr]) of nitrogen that are discharged or applied to the land from the major source categories: atmospheric deposition, wastewater facilities, septic tanks, fertilizer, and sinking streams.

3.1 Atmospheric Deposition

3.1.1 Wet Deposition

In the 1970s, atmospheric deposition was recognized as a significant nitrogen source, as acid rain and the other effects of air pollution were beginning to be understood. As a result, the National Atmospheric Deposition Program (NADP) was created in 1978 and now has over 250 stations throughout the United States. Samples are collected weekly at each station and analyzed for many different chemicals, including ammonia (NH_4) and nitrate (NO_3). There are two stations of interest for the BMAP area: FL14 in Quincy, FL, and FL23 in Sumatra, FL (**Figure 4**). Nitrogen deposition data from both sites were analyzed because of their close proximity to the BMAP area and because of the additional monitoring capacity at the Sumatra location for dry deposition. This is discussed in more detail later in this report.

The data for these stations, as well as others, are available to the public and can be obtained at the NADP website. Monthly data from 2009 to 2012[a] for both stations (FL14 and FL23) were downloaded and used in the nitrogen input calculations. Annual data were also available for download, but these were found to have errors related to periods with missing data. Missing data can be caused by issues with quality control or equipment maintenance. As a result, the monthly data were found to be more reliable overall. For years with complete monthly data, the annual data available through NADP are also reliable.

Nitrogen inputs are expressed as kilograms of nitrogen per year (kg-N/yr). The retrieved NADP data are in mg/L for both NO_3 and NH_4 and can be converted using Equations 1 and 2. **Appendix A** (**Table A-1**) contains the conversion factors that convert the NADP data in milligrams of nitrogen per liter (mg-N/L) to kilograms of nitrogen per hectare (kg-N/ha).

[a] The 2012 data were only available through October when these calculations were made.

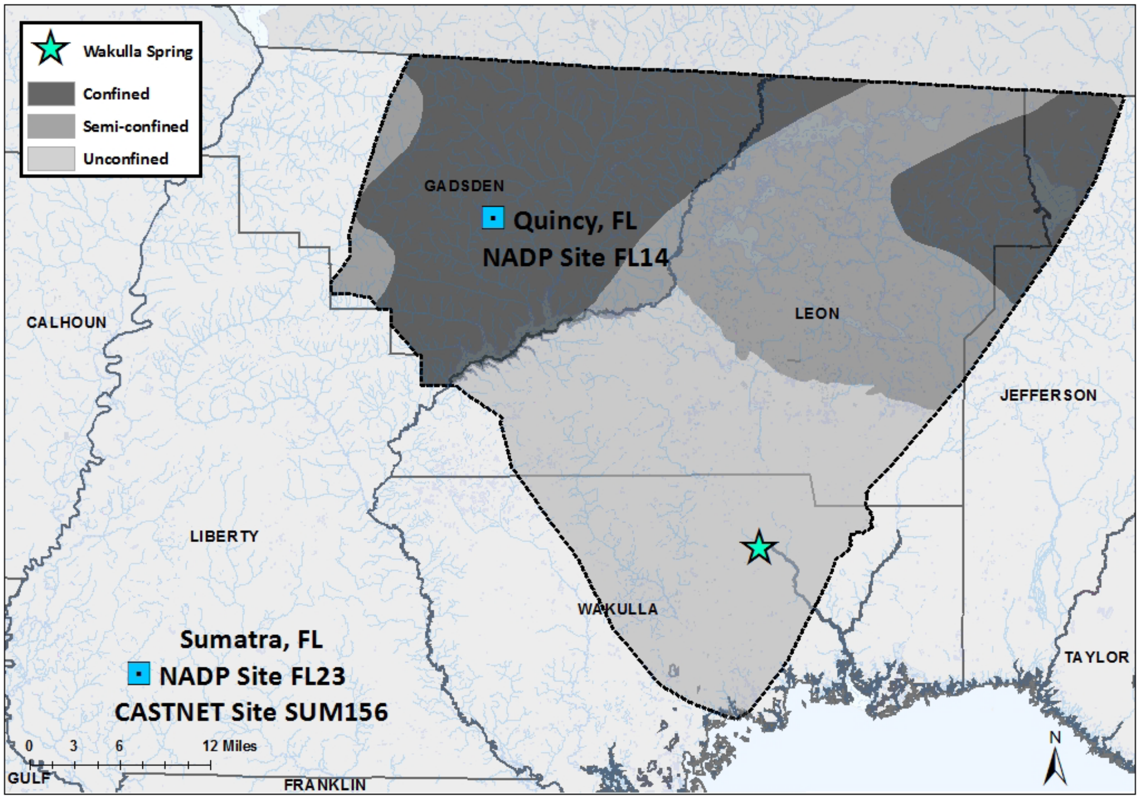

Figure 4: Atmospheric deposition monitoring stations for the NADP and Clean Air Status and Trends Network (CASTNET) programs

Equation 1: $$\frac{mg-NO_3}{L} \times 2.260e^{-4\,b} \times Rainfall\left(\frac{L}{ha}\right)^{c} \times 0.001^{d} = \frac{kg-N}{ha}\, NO_3$$

Equation 2: $$\frac{mg-NH_4}{L} \times 7.765e^{-4\,e} \times Rainfall\left(\frac{L}{ha}\right)_{C} \times 0.001^{D} = \frac{kg-N}{ha}\, NH_4$$

To determine the total yearly deposition, the monthly data were summed for each individual year. These annual totals were then averaged to determine the average annual wet deposition over the most recent 10-year period (2002–12). November and December data were not yet available for 2012, and so the concentrations for these months were projected based on the available 2012 data. The average concentration of NH_4 and NO_3 for January-October 2012 was calculated and used as the deposition for November and December.

Data from the two NADP monitoring stations were analyzed to evaluate the consistency and comparability between data measured at each station. At Station FL14, the annual NH_4 data ranged

[b] Conversion factor for mg-NO_3/L to g-N/L NO_3.
[c] To convert rainfall to L/ha, multiply rainfall (cm) by 10^5.
[d] Conversion factor for grams (g) to kg.
[e] Conversion factor for mg- NH_4/L to g-N/L NH_4.

from 0.93 to 1.74 kg-N/ha/yr, with average and median values of 1.31±0.32 and 1.25 kg-N/ha/yr, respectively. At Station FL23, the same data had an average value of 1.06±0.43 kg-N/ha/yr, a median of 1.06 kg-N/ha/yr, and a range of 0.59 to 1.63 kg-N/ha/yr. The differences between these data are minor, a conclusion that is supported by the overlapping errors associated with the averages.

The NO_3 data also showed a similar relation between the two monitoring stations. At FL14, the annual NO_3 data were measured between 1.28 and 1.73 kg-N/ha/yr. The average result was 1.42±0.21 kg-N/ha/yr, and the median was 1.34 kg-N/ha/yr. For FL23, the data ranged from 1.17 to 1.99 kg-N/ha/yr, with an average of 1.52±0.36 kg-N/ha/yr and a median of 1.46 kg-N/ha/yr.

After it was verified that the data from the individual stations were comparable, the calculated total nitrogen (TN) values for each station were averaged; these data are listed in **Table 1**. Given the close proximity of the stations and the consistency between their data, the average concentrations were used in determining the average annual yield of TN from atmospheric deposition. **Appendix A** (**Table A-2)** contains a complete listing of the wet deposition data.

Table 1: Average annual TN concentrations (kg-N/ha) measured in wet atmospheric deposition from NADP monitoring stations in northwest Florida

Year	FL14 (Quincy)	FL23 (Sumatra)	Average
2009	3.46	3.61	3.54
2010	2.50	2.67	2.58
2011	2.59	2.29	2.44
2012	2.36	1.76	2.06
Average ± std. dev	**2.73±0.50**	**2.58±0.78**	**2.66±0.63**

3.1.2 Dry Deposition

Dry deposition is monitored through CASTNET, which was established after the passage of the federal Clean Air Act Amendments in 1991. This program monitors ambient air chemistry, including rural ozone, and is the only nationwide program collecting reliable long-term data for acidic dry deposition (United States Environmental Protection Agency [EPA] 2013). NADP Station FL23 at Sumatra, FL, is also the location of CASTNET Site SUM156. The dry deposition data from this site are useful for estimating total atmospheric deposition of nitrogen in this analysis because it is the closest sampling site to the BMAP though it is located outside of the study area. Since the wet deposition from this station was comparable with that of the Quincy station located within the BMAP boundary, it was assumed that the dry deposition would be representative of deposition conditions throughout the BMAP area. Therefore, CASTNET Site SUM156 was used to estimate the dry deposition for the BMAP area.

The data for this site can be found on the CASTNET website. Total dry deposition and weekly data are available at this site. The total dry deposition data were only available through 2010 when calculations were made, but weekly data were available through May 2012. To include more data and remain consistent in calculating atmospheric deposition for the entire period, this analysis used the weekly data. Since the 2012 data only were available through May 2012, deposition was estimated for June to December 2012 by using the average value measured from January to May 2012. As was the case with wet deposition, the total yearly dry deposition was calculated and averaged to determine the annual average dry deposition.

Data from CASTNET Site SUM156 were calculated to estimate the average annual dry deposition influencing the BMAP area. **Appendix A** (**Table A-3**) contains a full listing of these data. NO_3 values ranged between 0.023 and 0.041 kg-N/ha/yr, with an average of 0.030 and median of 0.027 kg-N/ha/yr with a standard deviation of 0.01. NH_4 averaged 0.113±0.02 kg-N/ha/yr, with a median of 0.108 kg-N/ha/yr and a range of values from 0.099 to 0.137 kg-N/ha/yr.

3.1.3 Total Atmospheric Deposition of Nitrogen

After calculating the NO_3-N and NH_4-N (kg-N/ha/yr) for both wet and dry deposition, these two quantities were added together to estimate the annual TN attributed to atmospheric deposition (in kg-N/ha). The TN deposition rate (kg-N/ha/yr) was multiplied by the BMAP area to calculate an estimate of the N input from atmospheric deposition (in kg-N/yr). The result was the estimated annual average atmospheric deposition applied to the land surface of the Wakulla Spring BMAP area. **Table 2** lists the combined wet and dry deposition data. The fact that wet deposition nitrogen comprises 95% of the totals may be a result of greater accuracy in collecting information on wet deposition compared with dry deposition.

Based on this dataset, an estimated total of 2.80±0.61 kg-N/ha/yr was applied to the land surface within the Wakulla Spring BMAP boundary. As already established, varying degrees of recharge exist within the Wakulla BMAP area. **Table 3** lists the total input of atmospheric nitrogen per year.

Table 2: Annual total atmospheric deposition data in kg-N/ha. For both wet and dry deposition, projected values are included for 2012 due to incomplete data.

Year	NO_3	NH_4	Total N
2009	1.88	1.78	3.66
2010	1.47	1.24	2.71
2011	1.33	1.28	2.61
2012	1.32	0.90	2.22
Average ± std. dev.	**1.50±0.26**	**1.30±0.36**	**2.80±0.61**

Table 3: Nitrogen input from atmospheric deposition in the Wakulla Spring and River BMAP area divided by recharge area

Recharge Area	Land Area (ha)	Atmospheric Deposition (kg-N/yr)
Unconfined	121,214	339,424
Semi-confined	93,971	263,138
Confined	127,960	358,313
Total BMAP area	**343,146**	**960,875**

3.2 Wastewater Treatment Facilities

Wastewater treatment facilities (WWTFs) throughout the nation generate large quantities of nitrogen in their effluent, which is discharged to surface waterbodies, applied to the land surface, or injected into deep zones of saline aquifers. Discharges from 23 domestic WWTFs contribute nitrogen to the Wakulla BMAP Area (**Figure 5**). A single industrial facility with a design capacity of 20 MGD is located within the confined BMAP area. This facility was not included in these calculations because the minimal potential of nitrogen contribution to ground water resulting from the nontraditional remediation approaches in place. The facility has created a wetland for land application of the wastewater, greatly increasing nitrogen attenuation and therefore reducing the environmental impact of the facility. The Wastewater Facility Regulation (WAFR) database is maintained by the department's Water Resource Management staff as part of the Water Compliance Assurance Program and was the primary source for these data.

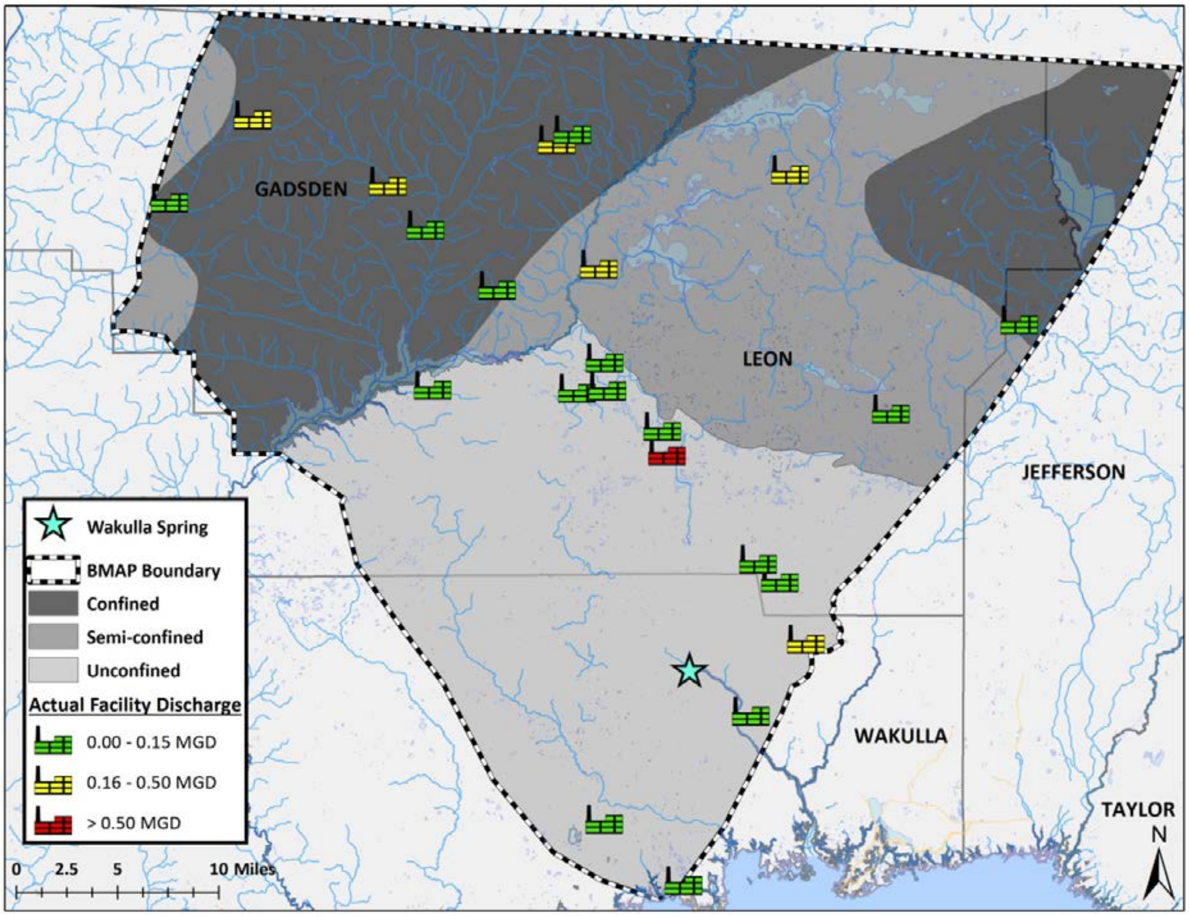

Figure 5: Map of the WWTFs included in the nitrogen loading evaluation

Most of the permitted WWTFs in the area are small compared to the larger, municipal facilities. The city of Tallahassee (COT) has the largest facilities in the BMAP area but one of them, the T. P. Smith Water Reclamation Facility, is the main facility. It receives partially treated effluent from the nearby Lake Bradford treatment plant and now 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. All data pertaining to the T.P. Smith facility were provided by the city of Tallahassee to ensure accuracy for the analysis.

Effluent data were obtained through the department's WAFR Discharge Monitoring Reports (DMRs). Smaller WWTFs (by volume) are not required to report effluent concentrations and therefore did not have any DMR data. These are largely the facilities with discharges less than 0.01 MGD. For facilities without any data or those facilities with only monitoring well data, an estimation of the effluent TN concentrations was required. In April 2009, the department collected effluent samples from 40 domestic wastewater facilities across the state as part of a cooperative study with the Water Reuse Foundation.

The study indicated the average effluent TN concentrations were 8.97 mg/L while the NO_3 concentration was 3.45 mg/L or 38.5% of the TN. These results were used as a rule of thumb for estimating the average TN concentration for effluent from a domestic wastewater facility when only NO_3 data are available in their permit records or if effluent data were not available.

For the WWTFs with available DMR data, the TN concentrations reported by the facilities were averaged to determine the annual average concentrations. Some facilities are only required to report NO_3 concentrations, in which case an estimation of the TN was calculated assuming the NO_3 comprises 38.5% of the TN. For the facilities without any reported effluent data, the TN concentration was estimated to be 8.97 based on department study results. Depending on the available data, annual average concentrations, both reported and estimated, were calculated using a year's worth of the most current data available.

The annual average facility effluent discharge was calculated based on the DMR reports, as well. For the years of available data, the reported annual average flows were used to calculate an average discharge for this study. The loading for all WWTFs was calculated using the average annual TN concentration and the average yearly flow from the facility. The average annual inputs of nitrogen from wastewater discharges were then estimated for the various recharge areas based on the locations of the wastewater application sites for the facilities. **Table 4** contains the summary information as well as the design capacity for each facility. Based on the most current available data for each facility, the estimated total input of nitrogen from wastewater facilities to the BMAP area is 73,907 kg-N/yr (54,219 kg-N/yr in unconfined, 12,546 kg-N/yr in semi-confined and 7,143 kg-N/yr in confined).

Table 4: Summary data for WWTFs in the Wakulla Spring and River BMAP area

N/A = Effluent data not available
*TN data estimated based on available NO_3 data
+Effluent data is not available; average TN value from department study used
§No data available; TN value from department study used

WWTF Name	Facility ID	Years of Available TN Effluent Data	Recharge Area	Annual Average TN (mg-N/L)	Annual Flow (MGD)	Nitrogen Input (kg-N/yr)
COT T.P. Smith Water Reclamation Facility	FLA010139	2011–12	Unconfined	2.17	16.33	48,961
Woodville Elementary School	FLA010136	2006–07	Unconfined	7.84*	0.003	30
Disc Village	FLA010137	2012	Unconfined	4.50	0.01	29
Western Estates	FLA010152	2010–11	Unconfined	7.60*	0.002	22
Lake Bradford Estates	FLA010148	N/A	Unconfined	8.97+	0.01	112
Sandstone Ranch WWTF	FLA010167	2002	Unconfined	6.52*	0.04	325
Oyster Bay Estates	FLA010237	2002–03	Unconfined	3.71*	0.03	161
River Plantation Estates	FLA010241	2009–10	Unconfined	11.95*	0.01	129
Winco Utilities, Inc.	FLA016544	N/A	Unconfined	8.97+	0.25	4,367
Fort Braden Elementary	FLA010138	2012	Unconfined	3.16*	0.011	17
Grand Village MH Park	FLA010151	2012	Unconfined	3.00*	0.025	27
Wakulla Middle School	FLA010229	N/A	Unconfined	8.97§	0.018	39
Killearn Lakes	FLA010173	2002–03	Semi-confined	23.83*	0.31	10,842
Lake Jackson	FLA010171	2005	Semi-confined	5.38*	0.28	1,609
Meadows-at-Woodrun	FLA010159	2002–12	Semi-confined	1.74	0.06	95
Gadsden East WWTF	FLA187941	N/A	Confined	8.97+	0.06	1,100
City of Gretna	FLA100781	2002	Confined	1.42	0.29	527
Havana	FLA100765	N/A	Confined	8.97+	0.19	2,022
Quincy	FL0029033	2012	Confined	5.37	0.64	3,183
Havana Middle School	FLA010085	2002–03	Confined	1.23*	0.001	3
Greensboro High School	FLA010074	2008–09	Confined	3.45*	0.005	22
Capital City Plaza	FLA010134	N/A	Confined	8.97+	0.02	245
Rentz Mobile Home Park	FLA010079	N/A	Confined	8.97§	0.012	42

3.3 Septic Tanks

Approximately a third of Florida's population utilizes onsite sewage treatment and disposal systems (OSTDS), also referred to as septic tanks. These systems can contribute to elevated nitrogen levels in ground water (Chang *et al.* 2010). In 2009, a contractor for the Florida Department of Health (FDOH) developed a model for estimating the number of septic tanks based on tax parcel data and known sewer service areas (Hall and Clancy 2009). The output of this model was provided in a Geographic Information System (GIS) geodatabase from which the locations of both the known and the estimated septic tanks can be mapped. This file was used to estimate the number of septic tanks in each of the three recharge areas in the Wakulla BMAP area.

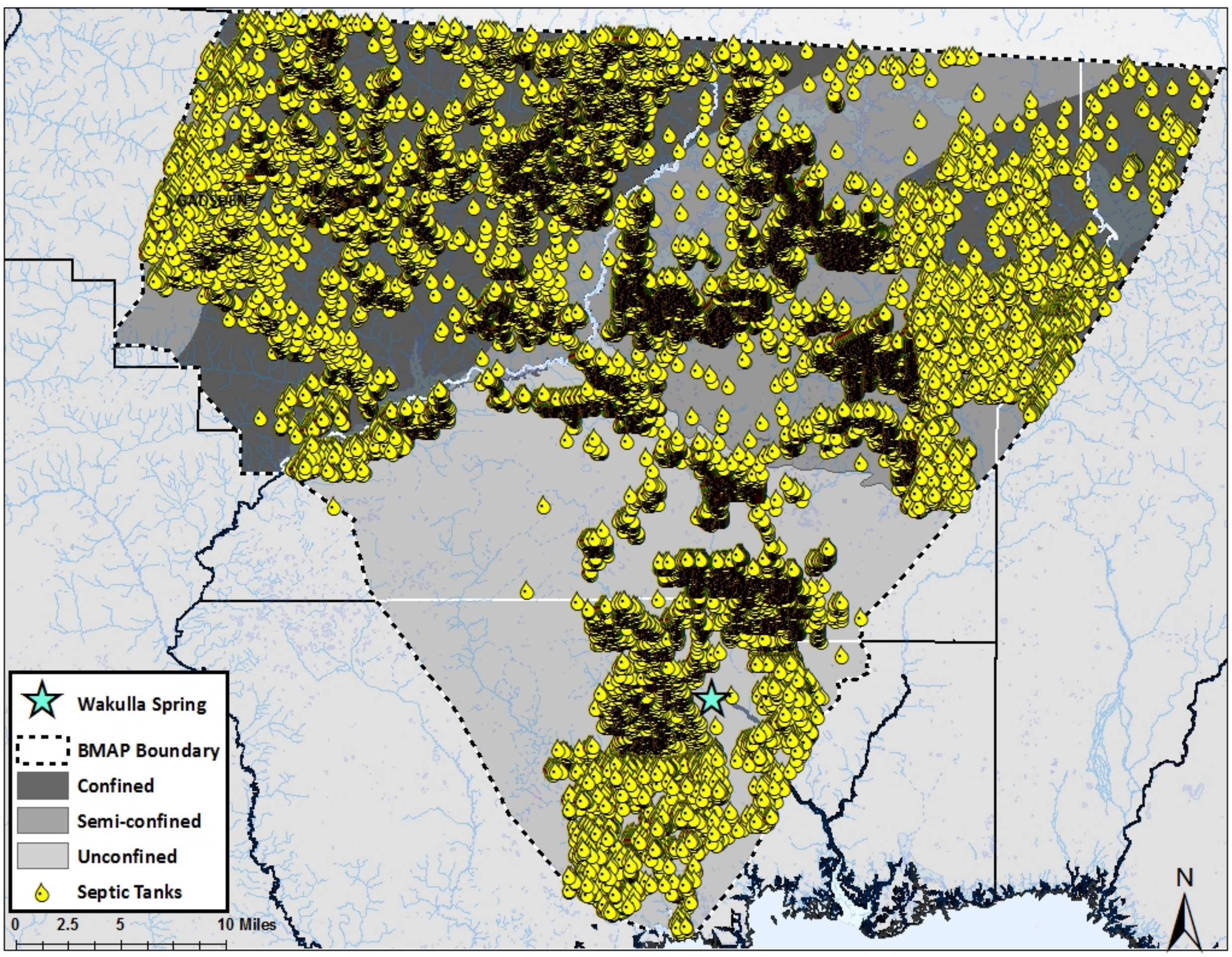

Figure 6: Distribution of septic tanks throughout the Wakulla BMAP area

The septic tank geodatabase has two different categories of septic tanks: known (based on permit records) and estimated. The estimated tanks were associated with land parcels located in areas where it was assumed that no sewer service existed. The sum of known and estimated septic tanks was used for these calculations and GIS mapping. **Figure 6** shows the distribution of septic tanks throughout the Wakulla BMAP area.

After establishing the number of septic tanks in the BMAP area, the population served by septic tanks was estimated using the 2010 United States Census Bureau data on population and household occupancy in each county. The Census makes a distinction between occupied and non-occupied households. The populations of Leon, Gadsden, Jefferson, and Wakulla Counties were divided by the number of occupied households in each county, resulting in the average number of people per household. In Leon County, 275,487 people occupied 110,945 households, resulting in an average of 2.48 people per household. In Wakulla County, the population was 30,776 people residing in 10,490 households, giving an average of 2.93 people per household. Gadsden County had 46,389 people in 16,952 houses, with an average of 2.74 people per household. In Jefferson County, there were 5,646 occupied households for 14,761 people, or 2.61 people per household.

Table 5: Estimated number of septic tanks in the Wakulla Spring and River BMAP area, by county and degree of UFA confinement (Hall and Clancy 2009)

Land Category	Number of Septic Tanks	Nitrogen Input (kg-N/yr)
Leon Unconfined	8,578	95,730
Leon Semi-confined	21,259	237,250
Leon Confined	2,112	23,570
Wakulla Unconfined	7,595	100,140
Gadsden Semi-confined	654	8,064
Gadsden Confined	11,719	144,495
Jefferson Semi-confined	92	1,081
Jefferson Confined	437	5,133
Total Unconfined	**16,173**	**195,871**
Total Semi-confined	**22,005**	**246,395**
Total Confined	**14,268**	**173,198**
Total BMAP Area	**52,446**	**615,463**

The number of people served by septic tanks within the BMAP area was estimated by multiplying the average number of people in each household (based on county) by the number of septic tanks in a given area. An annual loading factor of 4.5 kg-N/person was applied to the number of people utilizing septic tanks within the different subdivisions of the BMAP area (US EPA 2002; Roeder 2008; Toor et al 2011; Viers et al 2012)**. Table 5** provides a summary of the estimated septic tank nitrogen input.

3.4 Fertilizer

Applying fertilizer is a common practice throughout the nation on a variety of land uses, such as agriculture, urban, golf courses, and silviculture. Some of the nitrogen fertilizer not utilized by plants can leach through the soil zone to ground water, resulting in elevated nutrient concentrations (Bohlke 2002; Hochmuth *et al.* 2011). The most widely used approach to estimate nitrogen inputs to an area from fertilizer usage is to rely on county fertilizer sales data compiled by the Florida Department of Agriculture and Consumer Services (FDACS) (Chelette *et al.* 2002; Gronberg and Spahr 2012). This method has some limitations because fertilizer sold in one county may be transported to another county to be applied. Thus the calculations for the county in which the fertilizer is sold could be higher than what is actually applied. Since this information is not tracked, it is not known how much county-to-county transfer of fertilizer occurs, or if the volume of fertilizer transferred between counties is significant. However, in the absence of more detailed information regarding the actual usage of both urban and farm fertilizer, county fertilizer sales data are used to estimate nitrogen inputs to the Wakulla Springs and River BMAP area.

Fertilizer volumes sold by county are available from FDACS. For this analysis, the data from two different reports were used: *Summary by County* and *Nutrients by County*. These are .pdf documents that contain historical annual sales records by county, based on the state fiscal year, (July 1 of one year to June 30 of the following year). The annual average fertilizer inputs were calculated using the data for the state fiscal year. For example, the FDACS report from July 2011 to June 2012 was used to calculate the loadings for 2012.

The total volume of fertilizer sold can be found in two FDACS reports. The total fertilizer sold for farm and nonfarm practices is in the *Summary by County* report, and the total nitrogen in the fertilizer sold is available in the *Nutrients by County* report. All FDACS fertilizer sales quantities are reported in tons. The total input to the land surface for farm fertilizer sold in each county (in kilograms per year) was calculated using to Equation 3. The amount of nitrogen sold as nonfarm or urban fertilizer was also calculated using the same approach.

Equation 3: $\left(\mathbf{fertilizer\ N\ \%}_{\text{County}} \times \boldsymbol{farm\ fertilizer}_{\boldsymbol{County}}\right) \times \mathbf{907.1847}^{f} = \boldsymbol{total\ N\ in\ farm\ fertilizer}_{\boldsymbol{County}}$

[f] Conversion factor for tons to kilograms.

The fertilizer percent nitrogen was calculated for each county by taking the N in the fertilizer sold and dividing it by the total fertilizer sold. This percentage varied both by year and among the four counties in the BMAP area. Overall, 10% of the total weight of fertilizer sold was nitrogen. In Leon County, the nitrogen content ranged between 5% and 10% with an average of 7.5%. In Wakulla County, the average nitrogen content was 1.2%, with a range of less than 1% to 2.4%. In Gadsden County, the nitrogen content ranged between 7% and 10%, with an average of 8.2%. In Jefferson County, the percentage of nitrogen in the fertilizer sold was higher than in the other counties, with an average 15% and a range of 11% to 20%. A detailed listing of data used in calculating these percentages can be found in **Appendix A** (**Table A-4** through **Table A-7**).

The final results of these calculations provide the total nitrogen inputs (kg-N/yr) from farm and nonfarm fertilizer for the entire county while only portions of each county are included in the BMAP area. To estimate the amount of nitrogen in fertilizer applied, the 2009–10 land use coverage was used to provide a breakdown of land uses that were likely to include fertilizer use in the BMAP area and its subdivisions. The land use/land coverage was created from the NWFWMD aerial photography.

Farm and urban land use areas that were likely to use fertilizer were calculated using relevant land use categories including row crops, field crops, hayfields, groves, nurseries and vineyards, tree nurseries, sod farms, and ornamentals for farmlands. The urban categories of interest were low-, medium- and high-density urban areas as well as golf courses. The land areas were calculated for the entire counties as well as the three categories of recharge within the portions of the counties in the BMAP area. These land areas were used to calculate a land use percentage relative to the whole county for both farm and urban lands in the different recharge areas. These percentages were applied to the calculated farm and nonfarm fertilizer usage for each county. For example, if 100,000 kg-N of fertilizer were sold for farm use in a particular county each year, but only 10% of the county farmlands were inside the BMAP area, it was assumed that an input of only 10,000 kg-N was contributed to the BMAP area. **Appendix A** contains detailed information on the land use percentages calculated for both the farm (**Table A-8**) and urban (**Table A-9**) fertilizer.

4.4.1 Farm Fertilizer

Farm fertilizer sales records show decreases in sales between 2009 and 2012 for all four counties. Of these four counties, Jefferson County reported the most fertilizer sold, with an average of 1,127,879 kg-N/yr and a range between 1,053,366 kg-N sold in 2011 and 1,189,809 kg-N sold in 2009. Gadsden County has the most agricultural land and had the second most average nitrogen fertilizer sold (460,080 kg-N/yr). Amounts of fertilizer sold in Leon County ranged from 56,411 kg-N sold in 2010 to 15,590 kg-N in 2012, with an average sales of 35,764 kg-N/yr for the four-year period. The sales in Wakulla County were the lowest, with an average of 2,253 kg-N/yr, ranging from 4,676 kg N in 2010 to 877 kg-N in 2012. In general, over the period evaluated, farm fertilizer sales records show decreases in sales between 2009 and 2012 for all four counties. This decrease in fertilizer used could be attributed to lower rates of fertilizer use on fields due to fertilizer prices, transition to land uses on agricultural lands that use less fertilizer or more fertilizer purchased out of county.

These sales data were used to approximate the fertilizer nitrogen inputs throughout the Wakulla BMAP area. The land use percentages for each recharge area in the four counties were multiplied by the total N sold in each county resulting in an estimation of the potential nitrogen input from farm practices. These data estimates are summarized in **Table 6.**

Table 6: Potential input of nitrogen as agricultural fertilizer in the BMAP area

[1] Leon County information: 3,470 ha in agricultural land uses; 35,764 kgN/yr sold.
[2] Wakulla County information: 815 ha in agricultural land uses; 2,253 kgN/yr sold.
[3] Gadsden County information: 8,494 ha in agricultural land uses; 460,080 kgN/yr sold.
[4] Jefferson County information: 9,580 ha in agricultural land uses; 1,127,879 kgN/yr sold..
\- = Empty cell/no data

Land Category	Farm Fertilizer Land Area (ha)	Farm Fertilizer Land %	Farm Fertilizer Nitrogen Input (kg-N/yr)
Leon[1] Unconfined	80	2.3	828
Leon[1] Semi-confined	1,920	55.3	19,791
Leon[1] Confined	1,435	41.4	14,789
Wakulla[2] Unconfined	725	88.9	2,003
Gadsden[3] Semi-confined	1,077	12.7	58,317
Gadsden[3] Confined	6,028	71	326,513
Jefferson[4] Semi-confined	204	2.1	24,008
Jefferson[4] Confined	973	10.2	114,536
Total Unconfined	**805**	**-**	**2,831**
Total Semi-confined	**3,201**	**-**	**102,117**
Total Confined	**8,436**	**-**	**455,837**
Total BMAP	**12,442**	**-**	**560,784**

4.4.2 Urban Fertilizer

Of the counties evaluated, Leon County had the largest amount of fertilizer sold for nonfarm or urban applications. An average of 144,922 kg-N/yr was sold in Leon County, with a range between 118,179 and 212,276 kg-N. Urban fertilizer sold in Gadsden County ranged from 80,477 to 106,689 kg-N, with an average of 92,545 kg-N/yr and nonfarm fertilizer sold in Jefferson County averaged 38,675 kg-N/yr (with a range of 32,978 to 48,480 kg-N). In Wakulla County, urban fertilizer sales were lower than in the other three counties. The average was 1,561 kg-N/yr, with a range between 301 and 2,851 kg-N. It is assumed that some of the fertilizer purchased for urban use in Wakulla County was purchased in Leon County, but out-of-county purchases cannot be quantified. The urban land use areas were multiplied by the total urban fertilizer nitrogen sold in each county to generally estimate the potential nitrogen input from urban applications, which is provided in **Table 7**.

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Table 7: Land use areas derived nitrogen input for urban lands in the BMAP area

[1] Leon County information: Nonfarm land use fertilizer application area: 26,244 ha; 144,922 kgN/yr sold.
[2] Wakulla County information: Nonfarm land use fertilizer application area: 8,128 ha; 1,561 kgN/yr sold.
[3] Gadsden County information: Nonfarm land use fertilizer application area: 8,356 ha; 92,545 kgN/yr sold.
[4] Jefferson County information: Nonfarm land use fertilizer application area: 38,675 ha; kgN/yr sold.
- = Empty cell/no data

Land Category	Urban Fertilizer Land Area(ha)	Urban Fertilizer Land %	Urban Fertilizer Nitrogen Input(kg-N/yr)
Leon[1] Unconfined	4,748	18.1%	26,219
Leon[1] Semi-confined	19,261	73.4%	106,363
Leon[1] Confined	1,961	7.5%	10,830
Wakulla[2] Unconfined	6,517	80.2%	1,252
Gadsden[3] Semi-confined	413	4.9%	4,576
Gadsden[3] Confined	6,623	79.3%	73,357
Jefferson[4] Semi-confined	92	2.0%	766
Jefferson[4] Confined	341	7.3%	2,842
Total Unconfined	**11,265**	-	**27,470**
Total Semi-confined	**19,766**	-	**111,705**
Total Confined	**8,925**	-	**87,029**
Total BMAP	**39,956**	-	**226,204**

3.5 Livestock Waste

Every five years the United States Department of Agriculture (USDA) releases a Census of Agriculture (CoA). This comprehensive report summarizes the agricultural practices and livestock populations for each state and county in the United States. These data are available online and can be sorted by state and county. The 2007 census report was used to evaluate livestock populations for this assessment. The 2012 census could not be used because it will not be released until 2014. Alternatively, the National Agricultural Statistics Service (NASS) also estimates the livestock populations on an annual basis. For Florida, these data are available online starting in 2007 for cattle only.

Literature-based per-animal inputs of nitrogen were used in this assessment. **Table 8** includes the livestock categories evaluated to estimate the nitrogen loading for the BMAP area and their estimated nitrogen loads per animal.

Table 8: Daily loading factors for livestock

Livestock	Estimated Per-Animal Input of Nitrogen (kg-N/day/animal)	References
Cattle, Including Calves	0.219	Goolsby *et al.* 1990; Katz *et al.* 1999; Chelette *et al.* 2002; Ruddy *et al.* 2006; Katz *et al.* 2009; Meyer 2012; Sprague and Gronberg 2013
Chicken, Broilers	0.072	Goolsby *et al.* 1990; Katz *et al.* 1999; Chelette *et al.* 2002; Ruddy *et al.* 2006; Katz *et al.* 2009; Meyer 2012; Sprague and Gronberg 2013
Chicken, Layers	0.0012	Goolsby *et al.* 1990; Katz *et al.* 1999; Chelette *et al.* 2002; Ruddy *et al.* 2006; Katz *et al.* 2009; Meyer 2012; Sprague and Gronberg 2013
Hogs	0.086	Goolsby *et al.* 1990; Katz *et al.* 1999; Chelette *et al.* 2002; Ruddy *et al.* 2006; Katz *et al.* 2009; Meyer 2012; Sprague and Gronberg 2013
Sheep, Including Lambs	0.09	Goolsby *et al.* 1990; Ruddy *et al.* 2006; Katz *et al.* 2009
Horses	0.124	Goolsby *et al.* 1990; Ruddy *et al.* 2006; Katz *et al.* 2009
Turkeys	0.0025	Goolsby *et al.* 1990; Ruddy *et al.* 2006; Katz *et al.* 2009; Sprague and Gronberg 2013
Goats	0.016	Katz *et al.* 2009

The CoA data are compiled for each county in the state and as was the case with fertilizer, land use percentages were used to determine the loading for the areas of interest within each county. The land in each county was divided using the same method described in **Section 3.4** for fertilizer. The following land use categories were used, as appropriate, to apportion the animal populations within counties to the recharge areas within each county: improved pastures, unimproved pastures, woodland pastures, cattle feeding operations, poultry feeding operations, specialty farms, horse farms, dairies and aquaculture. These are not the only possible lands on which livestock populations occur, but they are the most likely ones present in one or more of the counties of interest. A summary of these percentages is provided in **Table 9** with more detailed information in **Appendix A** (**Table A-15**).

Table 9: Livestock population estimates for Leon, Wakulla, Gadsden, and Jefferson Counties. Note that the aerial imagery analysis values are actual counts observed in each area and are not calculated using the land use percentages.

N/A = Not applicable; recharge area not present in applicable region of the county.

Recharge Area	Land Area (ha)	Land %	Cattle-CoA	Cattle-NASS	Cattle-Aerial Imagery	Horses-CoA	Horses-Aerial Imagery
Leon County	**2,904**	**100%**	**2,644**	**3,183**	**700**	**1,157**	**--**
Leon Unconfined	181	6.2%	164	199	76	72	27
Leon Semi-confined	1,815	62.5%	1,653	1,989	534	723	193
Leon Confined	877	30.2%	798	961	90	349	129
Wakulla County	**824**	**100%**	**1,080**	**1,000**	**562**	**261**	**--**
Wakulla Unconfined	712	86%	929	864	562	225	47
Gadsden County	**6,354**	**100%**	**4,782**	**5,600**	**2,519**	**406**	**--**
Gadsden Semi-confined	462	7.3%	349	407	220	30	8
Gadsden Confined	4,833	76%	3,634	4,260	2,299	309	288
Jefferson County	**6,291**	**100%**	**10,500**	**11,550**	**55**	**904**	**--**
Jefferson Semi-confined	117	1.9%	200	214	0	17	0
Jefferson Confined	269	4.3%	452	494	55	39	22

Spot checking of animal populations in representative areas of the BMAP area indicated that the CoA animal census data were not entirely representative of the actual livestock populations in the Wakulla BMAP area. As a cross-check on the CoA data, an aerial imagery analysis was completed to evaluate livestock populations. A grid was overlaid on the NWFWMD 2009 aerial imagery, with each cell including 900 square miles (30 miles by 30 miles). Using a scale of 1:4,900, pasturelands containing livestock animals are visible. The numbers of cows and/or horses present in a field were counted as the aerial photo was further enlarged. The aerial photographs shown in **Figure 7** provide examples of cows and horses in pastures counted using this method. Other livestock animals (pigs, goats, poultry, goats, sheep, lambs) evaluated using the CoA method were not counted because their populations in the BMAP area were minor based on the census. The CoA indicated that cows and horses had the largest populations and additionally have the largest nitrogen loading factors. Therefore, these two animal categories would have the highest nitrogen inputs in the BMAP area.

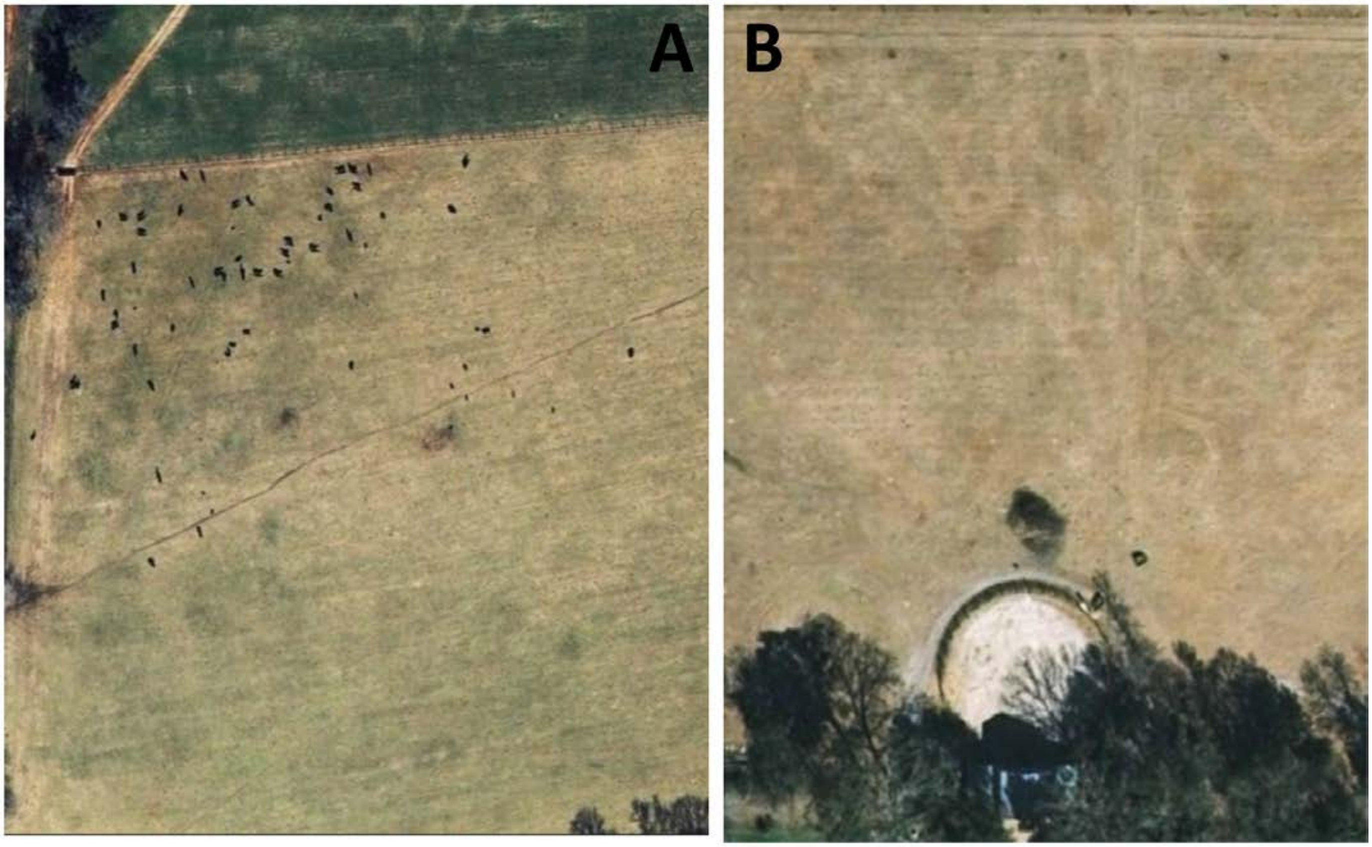

Figure 7: Examples of cows (A at left) and horses (B at right) in pastures as observed through the aerial imagery analysis

Annual averages of livestock populations were calculated using the CoA and NASS data for each county. **Table 9** contains these results for the BMAP boundary area as well as the aerial imagery analysis results. The CoA and NASS data are appropriated for each recharge area based on the full county data using land use percentages while the aerial imagery is the actual number of cattle and horses observed during the analysis. A more complete listing of livestock species populations from the CoA in the four counties can be found in **Appendix A** (**Table A-10** through **Table A-13**), while the NASS data are in **Table A-14**.

The data provided by the CoA and NASS are higher in all cases than what was actually observed through aerial analysis. While it is unrealistic to assume every cow and horse would be visible through aerial imagery, these data are thought to be more representative of the actual livestock populations in these areas. For this analysis, more confidence is placed with the aerial imagery analysis data, and therefore the loading estimates were calculated using this method with the following loading factors: 0.219 kg-N/cow/day and 0.124 kg-N/horse/day. A summary of the nitrogen inputs attributed to livestock is provided in **Table 10**.

Table 10: Summary of estimated nitrogen inputs from livestock waste by degree of confinement of the UFA in the Wakulla BMAP area.

Recharge Area	Number of Cattle	Number of Horses	Livestock Waste Nitrogen Inputs (kg-N/yr)
Unconfined	638	74	54,348
Semi-confined	754	201	69,368
Confined	2,444	439	215,230
Total BMAP Area	**3,836**	**714**	**338,946**

3.6 Sinking Streams

In karst areas, sinkholes can form and capture the flow of surface streams. Water from these sinking streams, also known as swallets, can have a detrimental impact on ground water quality. Contaminants in sinking streams flow directly into the UFA with little or no attenuation or degradation (Katz *et al.* 1997, 1998). There are four prominent sinking streams in the BMAP area: Lost Creek, Black Creek, Munson Slough, and Fisher Creek (**Figure 8**). Dye traces carried out by Hazlett-Kincaid have confirmed that Munson Slough (via Ames Sink), Fisher Creek, and Lost Creek have a direct connection to Wakulla Spring. To assess the nitrogen inputs attributed to these streams, discharge data as well as nitrogen concentrations were evaluated.

Discharge data for Fisher Creek (Station 02326993) and Lost Creek (Station 02327033) were obtained from the USGS National Water Information System. Discharge data were available for 2007–09 for Fisher Creek and for 2002–07 for Lost Creek. A gauging station located on Munson Slough is maintained by the NWFWMD, and data from 2002 to 2010 were obtained by request. Black Creek does not have an active gauging station, but discharge data were provided from a water quality study conducted from March 2009 to May 2009 (Kulakowski 2010).

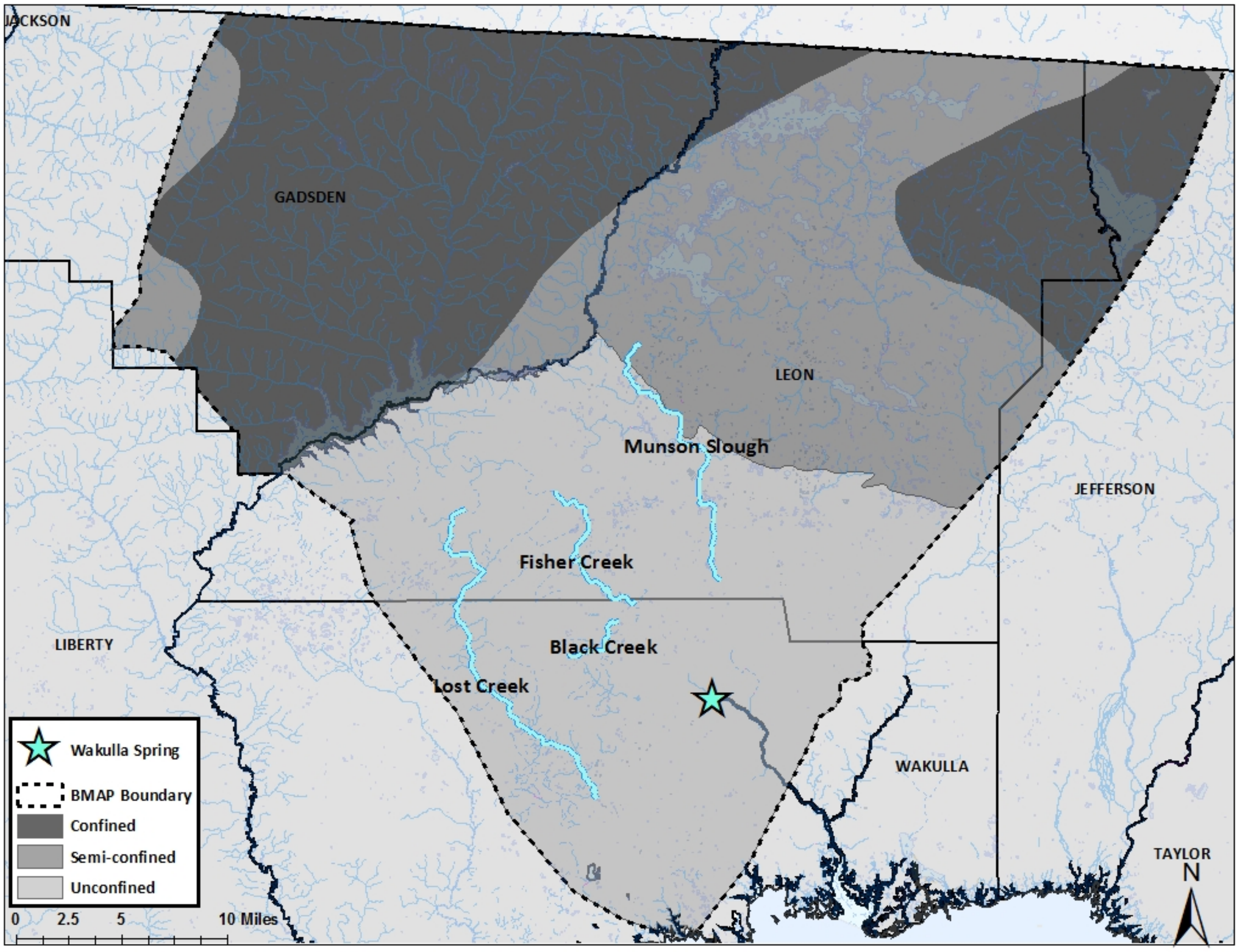

Figure 8: Map showing locations of sinking streams in Wakulla BMAP area

Water quality data have been collected on all of these streams intermittently throughout the period of interest. These data were obtained from STORET, and annual averages of nitrogen inputs were estimated using the monitoring stations closest to their swallets (where the streams disappear below the land surface). These streams can have large variations in their discharge throughout the year with flow increasing exponentially during high rain events. Median discharge values were calculated to account for this variability and accurately represent the flow conditions on an annual basis. Nitrogen inputs from the sinking streams were estimated by multiplying the median annual discharges by the average annual nitrogen concentrations. It is important to note that discharge and nutrient data were not necessarily measured at the same times or for the same years.

All four sinking streams are in the area where the UFA is unconfined. **Table 11** includes the annual median discharge and average TN data that were available for each of the sinking streams. The periods of stream discharge and monitoring dates vary between streams, but do provide an opportunity to evaluate sinking stream inputs of nitrogen to the aquifer and Wakulla Spring. **Table A-16** through **Table A-20** in **Appendix A** provides the raw data for these streams. The average TN concentrations measured in each of them are low and below the typical concentrations naturally found in blackwater streams (1.21 mg/L); therefore, the estimated inputs from these streams are not thought to be a significant contributor to the elevated nitrogen levels in Wakulla Spring (Hand *et al.* 2009).

Table 11: Annual discharge (cfs) and TN (mg/L) data for the sinking streams

Sinking Stream	Discharge-Median	Discharge-Minimum	Discharge-Maximum	Discharge-Years of Data	TN-Annual Average	TN-Years of Data	Annual Nitrogen Input (kg-N/yr)
Fisher Creek	7	0.0	587	2008–09	0.63	2007–11	3,867
Lost Creek	54	0.0	2,870	2002–05, 2007–09	0.66	2006–07, 2011–12	31,865
Black Creek	7	1.4	236	2009	1.07	2006, 2011–12	7,034
Munson Slough	4	0.001	1,669	2002–10	0.87	2008–11	3,374

3.7 Nitrogen Input Summary

Based on the information and assumptions described in the previous sections, over 2.8 million kg-N are input annually to the Wakulla BMAP area landscape. **Figure 9** illustrates the percentage of the total N input to the land surface attributed to the various nitrogen sources. Nitrogen inputs from atmospheric deposition (34%) and septic tanks (22%) were identified as the source categories having the greatest inputs of nitrogen followed by farm fertilizer (20%). Inputs from WWTFs (2%), livestock waste (12%), and urban fertilizer (8%) were all considerably lower.

Atmospheric deposition provides the largest input of nitrogen (34%) to the Wakulla BMAP area. Wet deposition, in general, contributes higher N inputs than dry deposition because water provides a direct pathway from the atmosphere to the ground. Although the nitrogen concentrations in atmospheric deposition are generally lower than in other sources, the volume of rainfall over the Wakulla BMAP area is large, resulting in high nitrogen inputs to the land surface. However, given the diffuse nature of its dispersal, nitrogen attributed to atmospheric deposition is readily attenuated by the environment. This reduces the impact of atmospheric deposition on ground water quality and nitrogen loading (discussed in **Section 4**).

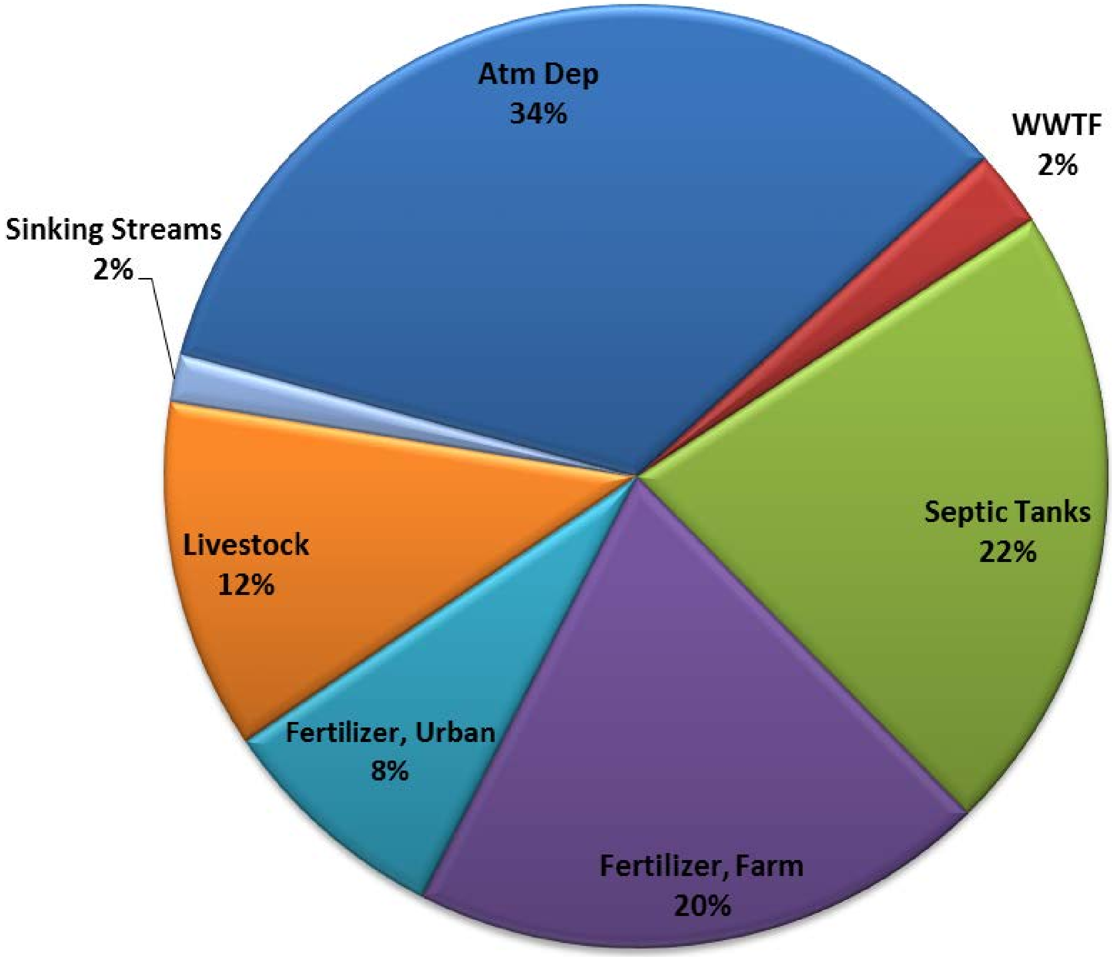

Figure 9: Relative nitrogen inputs to the land surface in the Wakulla Spring and River BMAP area from major source categories

4. Environmental Attenuation of Nitrogen and Loading to Ground Water

The nitrogen input calculations identify which sources are contributing the largest amount of nitrogen to the land surface. The final nitrogen loading estimates include two other considerations: the attenuation factor for each of the source categories and the rate of ground water recharge within the three areas of aquifer confinement (confined, semi-confined, and unconfined).

Nitrogen is an essential nutrient and in its more mobile forms nitrogen is readily utilized by plants and bacteria. However, excess amounts of nitrogen can leach to ground water or be discharged to surface waters before being assimilated (Nolan *et al.* 1997). The methods utilized to estimate nitrogen inputs to the land surface have been described in the previous sections. To estimate the amount of nitrogen loading to ground water (and potentially to Wakulla Spring), the amount of nitrogen attenuation as it moves from the land surface to the ground water system must be considered.

4.1 Attenuation Factors

Nitrogen attenuation can occur by several naturally occurring physical, chemical, or biological processes such as volatization, biodegradation, dispersion, dilution, adsorption, and cation exchange (ammonium). These processes occur to varying degrees depending on how the nitrogen is introduced, soil properties, and other factors (Cockx and Simonne 2011; Costa *et al.* 2002; Dudley 2009). Due to this variability, specific attenuation factors are applied to each of the nitrogen source types. The attenuation factors utilized for this assessment were obtained from previous studies in Florida and in other areas that are described in the literature. These factors, shown in **Table 12,** represent the percentage of the nitrogen mass that is removed by processes occurring in the environment and prevented from reaching the aquifer.

Table 12: Attenuation factors applied to the nitrogen loading calculations. These percentages represent the amount of nitrogen removed by the environment.

Nitrogen Source Category	Attenuation Factor	Source
Atmospheric Deposition	90%	Katz *et al.* 2009; Lombardo Associates 2011; H.T. Odum Florida Springs Institute 2011
WWTFs	60%	Katz *et al.* 2009; Lombardo Associates 2011; H.T. Odum Florida Springs Institute 2011
Septic Tanks	40%	Otis *et al* 2007; Katz *et* al 2009; Katz *et al* 2010; Lombardo Associates 2011
Farm Fertilizer	70%	Goolsby *et al.* 1999; Katz *et al.* 2009; H.T. Odum Florida Springs Institute 2011; Lombardo Associates 2011
Urban Fertilizer	80%	Goolsby *et al.* 1999; Katz et al 2009; H.T. Odum Florida Springs Institute 2011; Lombardo Associates 2011
Livestock Waste	75%	Goolsby *et al.* 1999; Katz *et al.* 1999; Baton *et al.* 2005; Katz et al 2009; Lombardo Associates 2011
Sinking Streams	20%	Estimated in this study

To estimate loading to ground water, the previously mentioned nitrogen inputs at the land surface from each category are multiplied by their associated attenuation factors. For example, atmospheric deposition has 90% environmental attenuation (*e.g.,* uptake by vegetation). This means that 10% of the atmospheric nitrogen input to the land surface would reach ground water. However another factor, recharge rate, would also need to be considered to develop an estimated load to the UFA.

4.2 Recharge and Aquifer Confinement

The amount of water that recharges the UFA depends on amount of rainfall, evapotranspiration, runoff, and subsurface hydrogeologic properties. The final step in estimating nitrogen loads to ground water is to assign weighting factors representing the amounts of recharge for the three categories of aquifer confinement. Davis *et al*. (2011) reported that of 20 inches of rainfall that infiltrate on an annual basis, 18 inches reach the UFA in unconfined areas (90%), 8 inches reach the UFA in semi-confined areas (40%) and 2 inches reach the UFA in confined areas (10%). The amount of recharge is estimated from the annual average rainfall minus the evapotranspiration and runoff.

In semi-confined and confined areas, the amount of evaportranspiration is the same as in unconfined areas, but the amount of runoff is higher due to the higher clay content in soil and geologic material overlying the UFA in the area. Because of the higher recharge rate, the infiltration of water to the UFA in areas where the aquifer is unconfined can have a much greater impact on ground water and spring water quality and quantity than in areas where the aquifer is confined and the rate if recharge is lower. In the areas where the UFA is semi-confined, the overall rate of recharge and potential for nutrient loading lie between the values for the unconfined and confined settings.

For calculating loads to ground water, the following recharge factors were applied to each source category for the three confinement areas: unconfined (0.9), semi-confined (0.4), and confined (0.1). These factors are based on the recharge characteristics specific to the aquifer conditions in the Wakulla Spring area. Different recharge factors may be assigned to other areas, based on the geological and hydrological characteristics unique them.

4.3 Nitrogen Loads to Ground Water

The final nitrogen loading estimates to ground water are obtained by applying the recharge factors to the attenuated nitrogen inputs for source categories within the three confinement regimes. **Table 13a, Table 13b,** and **Table 13c** show the inputs, the intermediate step with attenuation factors applied and the final estimated loads to the UFA with both attenuation and recharge factors applied. **Table A-21, Table A-22,** and **Table A-23** in **Appendix A** provide a complete breakdown of these calculations.

Table 13a: Estimated nitrogen inputs by nitrogen source category to the UFA in Wakulla Spring and River BMAP area

N/A = Not applicable

Recharge Category	Atmospheric Deposition	WWTFs	Septic Tanks	Farm Fertilizers	Urban Fertilizers	Livestock	Sinking Streams	Total
Unconfined	339,424	54,219	195,871	2,831	27,470	54,348	46,140	**720,303**
Semi-confined	263,138	12,546	246,395	102,117	111,705	69,368	N/A	**805,268**
Confined	358,313	7,143	173,198	455,837	87,029	215,230	N/A	**1,296,750**
Total Input	**960,875**	**73,907**	**615,463**	**560,784**	**226,204**	**338,946**	**46,140**	**2,822,321**

Table 14b: Estimated nitrogen after application of attenuation factors to the UFA in Wakulla Spring and River BMAP area

- = Empty cell/no data
N/A = Not applicable

Recharge Category	Atmospheric Deposition	WWTFs	Septic Tanks	Farm Fertilizers	Urban Fertilizers	Livestock	Sinking Streams	Total
Attenuation Factors	*90%*	*60%*	*40%*	*70%*	*80%*	*75%*	*20%*	-
Unconfined	33,942	21,688	117,522	849	4,945	13,587	36,912	**229,995**
Semi-confined	25,648	5,018	147,189	23,433	22,188	17,342	N/A	**249,487**
Confined	32,262	2,759	100,839	102,391	16,837	52,460	N/A	**350,572**
Total	**91,853**	**29,465**	**365,550**	**126,672**	**44,519**	**83,389**	**36,912**	**752,997**

Table 15c: Estimated load to ground water after application of recharge factors to the UFA in Wakulla Spring and River BMAP area

N/A = Not applicable

Recharge Category	Atmospheric Deposition	WWTFs	Septic Tanks	Farm Fertilizers	Urban Fertilizers	Livestock	Sinking Streams	Total
Unconfined	30,548	19,519	105,770	764	4,945	12,228	33,221	**206,995**
Semi-confined	10,526	2,007	59,135	12,254	8,936	6,937	N/A	**99,795**
Confined	3,583	286	10,392	13,675	1,741	5,381	N/A	**35,057**
Total	**44,657**	**21,812**	**175,297**	**26,693**	**15,622**	**24,546**	**33,221**	**341,847**

The final loading results show that estimated nitrogen load to the UFA in the Wakulla Spring BMAP area (341,847 kg/yr) is approximately 12 percent of the input to land surface. This difference is due to the various attenuation mechanisms and the retardation of infiltrating water by the geologic material. The breakdown of estimated loads by source category is shown in **Figure 10**.

The results indicate that the nitrogen load from the septic tank source category comprises approximately 50.8% of the sum of all source category loads evaluated for the BMAP area overall. The next largest percentages are from atmospheric deposition (13%) and sinking streams (10%). Septic tanks have a lower environmental attenuation factor and most septic tanks in the BMAP area lie within the semi-confined and unconfined areas, resulting in more nitrogen reaching the UFA.

Figure 11 provides a summary of the estimated loads of nitrogen to the recharge areas and a breakdown of source category loads of nitrogen within each of the three recharge areas. The nitrogen loads to the UFA from sources in the unconfined area are much greater (61%) than the loads in the semi-confined (29%) and confined (10%) areas due to the high rate of recharge that occurs where the UFA is unconfined.

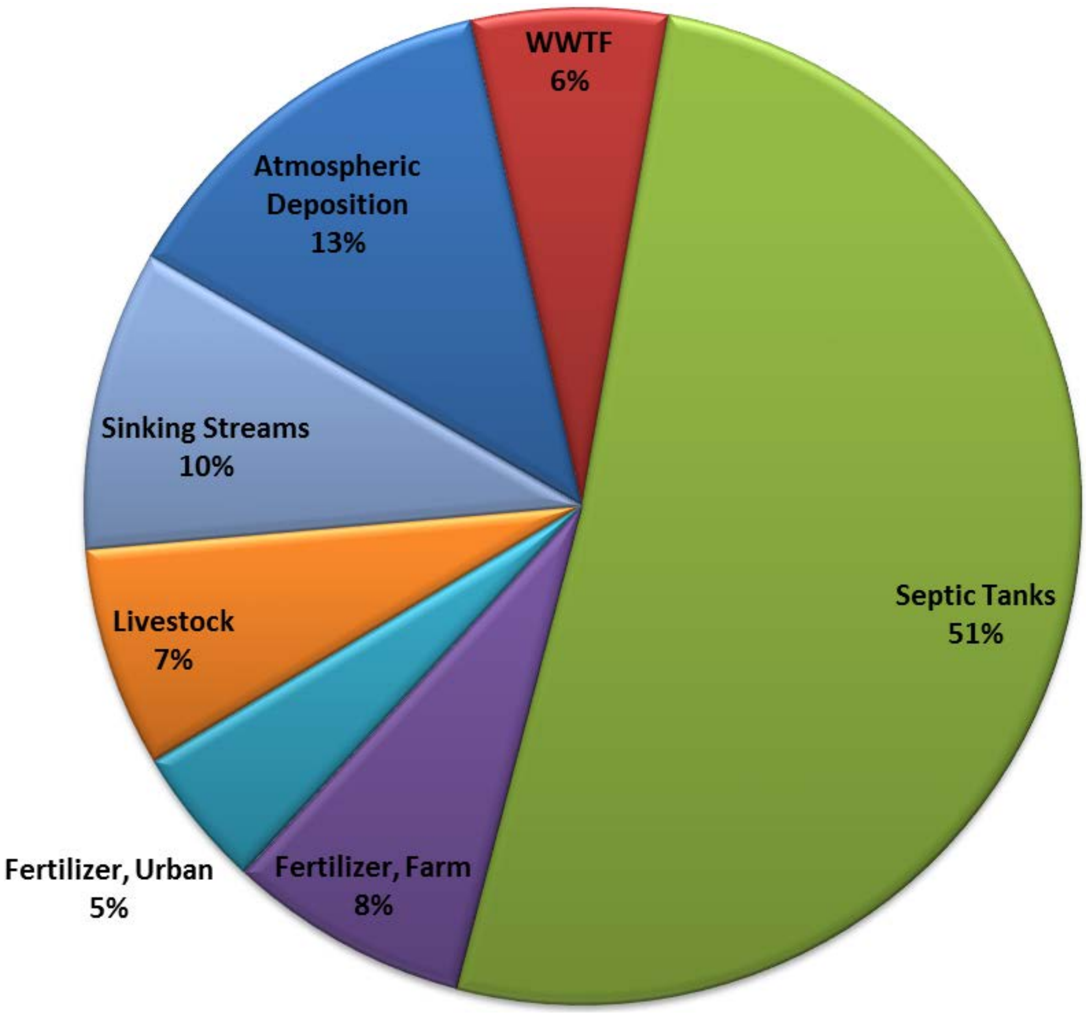

Figure 10: Relative nitrogen loads to the UFA contributed from the nitrogen source categories evaluated for the Wakulla Spring and River BMAP area

The data indicate the nitrogen load from the septic tank source category is significant in all three of the recharge areas and is the dominant nitrogen loading source to the UFA in the semi-confined (59%) and unconfined (51%) areas. According to the results, septic tank loading to ground water is the greatest of the source categories evaluated. The atmospheric deposition and wastewater source categories also have significant nitrogen loads to the UFA in the unconfined area. In the semi-confined area, nitrogen loads from the urban fertilizer and atmospheric deposition source categories are also significant, but they are much lower than the loads from the septic tank category. In the confined area, agricultural fertilizer and septic tanks are the two source categories with the highest percentage of the total load to the UFA but this recharge area contributes a relatively small percentage of the total nitrogen load to the BMAP area.

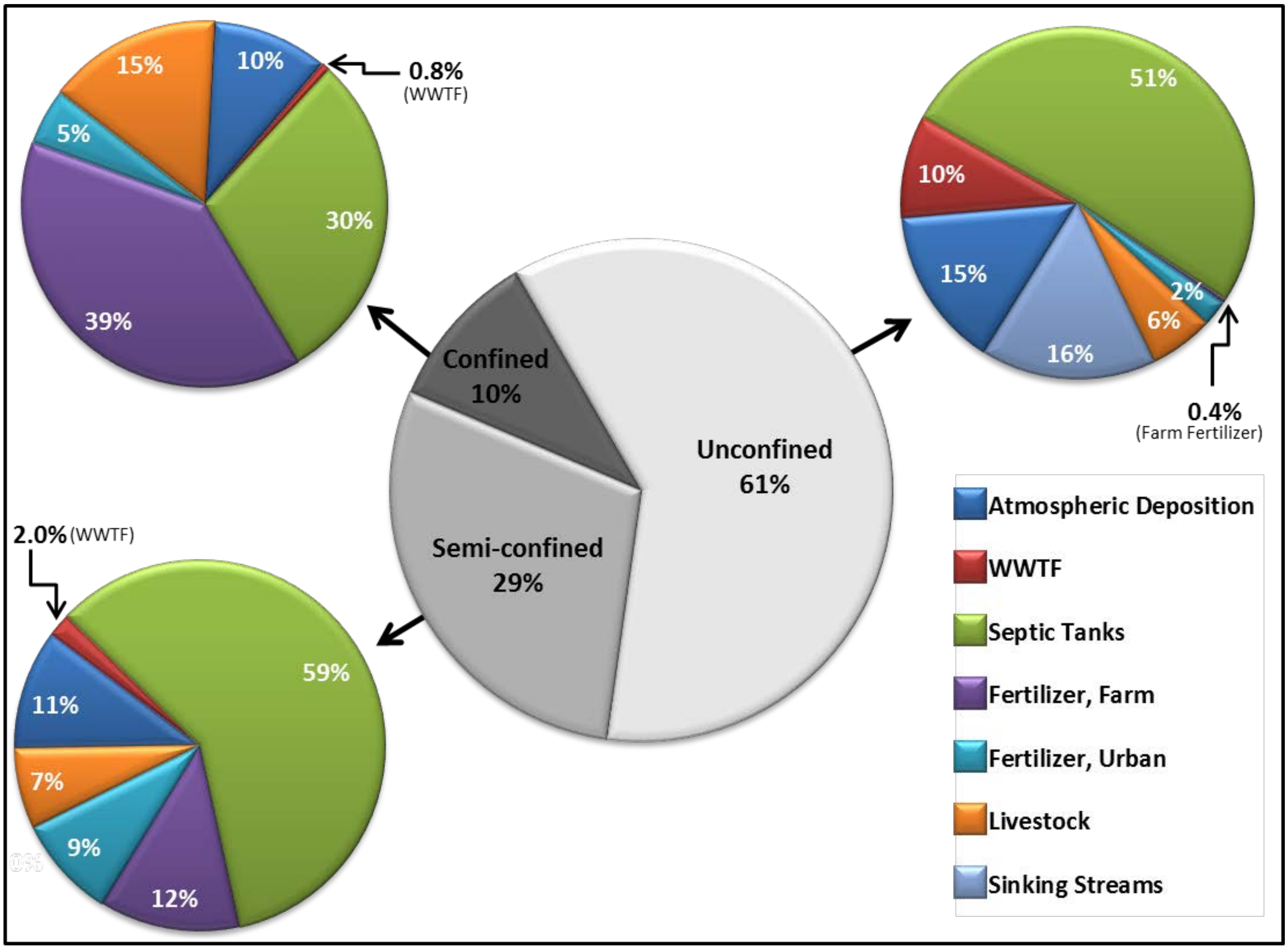

Figure 11: Loading percentages attributed to the recharge areas and nitrogen source categories within the Wakulla Spring and River BMAP area

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Appendices

Appendix A: Tables

Table A-1: Useful conversion factors

Convert from	To	Multiply by
NO_3 mg/L	NO_3 g-N/L	2.260 X 10^{-4}
NH_4 mg/L	NH_4 g-N/L	7.765 X 10^{-4}
mg	g	0.001
g	kg	0.001
mg	kg	1 X 10^{-6}
acre	hectare	0.4046873
m^2	hectare	0.0001
cm^3	L	0.001
tons	kg	907.1847
ft^3	L	28.31685
second	year	3.170979 X 10^{-8}
Rainfall (cm)	Rainfall (L/ha)	10^4

Table A-2: Wet deposition data, 2002–12

- = Empty cell/no data

NH_4 (mg/L)

Year	FL14	FL23	AVG
2002	1.29	1.21	1.25
2003	1.36	1.29	1.32
2004	1.28	0.97	1.12
2005	1.31	1.38	1.34
2006	1.88	1.87	1.88
2007	1.62	0.83	1.23
2008	1.23	0.70	0.96
2009	1.35	1.31	1.33
2010	1.49	1.21	1.35
2011	1.87	1.70	1.78
2012	1.70	0.77	1.24
Average	**1.49**	**1.20**	**1.35**

NO_3 (mg/L)

Year	FL14	FL23	AVG
2002	7.82	7.80	7.81
2003	7.20	6.36	6.78
2004	7.19	5.36	6.27
2005	6.52	7.29	6.91
2006	8.10	8.48	8.29
2007	7.29	5.35	6.32
2008	6.23	5.34	5.78
2009	5.61	6.19	5.90
2010	5.93	5.86	5.89
2011	6.24	6.42	6.33
2012	8.53	4.76	6.65
Average	**6.97**	**6.29**	**6.63**

TN (kg-N/ha)

Year	FL14	FL23	AVG
2002	2.59	3.07	2.83
2003	3.15	3.67	3.41
2004	2.76	2.79	2.78
2005	3.20	4.00	3.60
2006	2.93	3.15	3.04
2007	2.06	2.05	2.05
2008	2.51	2.32	2.42
2009	3.46	3.61	3.54
2010	2.50	2.67	2.58
2011	2.59	2.29	2.44
2012	2.36	1.76	2.06
Average	**2.74**	**2.85**	**2.80**

Precipitation (cm)

Year	FL14	FL23	AVG
2002	136.66	152.63	144.645
2003	136.8	187.25	162.025
2004	149.16	137.92	143.54
2005	152.08	181.15	166.615
2006	111.44	133.71	122.575
2007	91.65	116.15	103.9
2008	162.28	161.34	161.81
2009	169.94	176.41	173.175
2010	115.88	145.68	130.78
2011	114.31	118.09	116.2
2012	-	-	-
Average	**134.02**	**151.03**	**142.53**

Table A-3: Dry deposition data from SUM156, 2002–12

Year	NO3 FLUX (kg-no3/ha)	NO3 FLUX (kg-N/ha)	NH4 FLUX (kg-nh4/ha)	NH4 FLUX (kg-N/ha)	Total N (kg-N/ha)
2002	0.133	0.030	0.237	0.184	0.952
2003	0.101	0.023	0.215	0.167	0.890
2004	0.127	0.029	0.240	0.186	0.889
2005	0.112	0.025	0.264	0.205	0.934
2006	0.117	0.026	0.232	0.181	0.876
2007	0.154	0.035	0.197	0.153	0.743
2008	0.142	0.032	0.151	0.117	0.614
2009	0.127	0.029	0.127	0.099	0.427
2010	0.103	0.023	0.136	0.105	0.501
2011	0.113	0.026	0.177	0.137	0.663
2012	0.179	0.041	0.144	0.112	0.552
Average	**0.128**	**0.029**	**0.193**	**0.150**	**0.731**

Table A-4: Fertilizer sales data for Leon County, 2002–12

Year	Total Fertilizer (tons)	Total N All Fertilizer (tons)	Total N All Fertilizer (kg-N)	% N in Fertilizer	Farm Fertilizer (kg-N)	Nonfarm Fertilizer (kg-N)
2002	2,529.33	247.53	224,555.43	9.8%	91,512.38	133,042.16
2003	2,772.77	271.82	246,590.95	9.8%	86,608.36	159,982.59
2004	3,007.78	275.02	249,493.94	9.1%	28,143.12	221,350.82
2005	4,416.7	548.41	497,509.16	12.4%	67,979.89	429,529.27
2006	3,195.57	423.65	384,328.80	13.3%	77,402.88	306,925.92
2007	2,834.45	303.12	274,985.83	10.7%	53,985.29	221,000.53
2008	2,588.03	240.51	218,186.99	9.3%	60,367.46	157,819.53
2009	2,629.28	271.43	246,237.14	10.3%	33,961.94	212,276.14
2010	2,108.32	199.07	180,593.26	9.4%	56,410.55	124,183.56
2011	3,447.04	178.73	162,141.12	5.2%	37,093.53	125,048.07
2012	2,999.7	147.45	133,764.38	4.9%	15,590.01	118,179.27
Average	**2,957**	**282**	**256,217.00**	**9.5%**	**55,368.67**	**200,848.90**

Table A-5: Fertilizer sales data for Wakulla County, 2002–12

Year	Total Fertilizer (tons)	Total N All Fertilizer (tons)	Total N All Fertilizer (kg-N)	% N in Fertilizer	Farm Fertilizer (kg-N)	Nonfarm Fertilizer (kg-N)
2002	271.61	30.58	27,741.71	11.3%	12,004.28	15,736.41
2003	357	31.66	28,721.47	8.9%	17,450.91	11,270.56
2004	288.16	27.67	25,101.80	9.6%	12,104.89	12,996.91
2005	97.35	8.27	7,502.42	8.5%	3,082.66	4,419.76
2006	222.7	25.79	23,396.29	11.6%	16,550.75	6,845.54
2007	254.46	20.9	18,960.16	8.2%	7,744.71	11,215.45
2008	194.45	12.95	11,748.04	6.7%	5,942.59	5,805.45
2009	224.59	3.44	3,120.72	1.5%	269.57	2,851.15
2010	1,357.97	5.5	4,989.52	0.4%	4,675.81	313.74
2011	1,558.68	3.85	3,492.66	0.2%	3,191.32	301.34
2012	164.97	4.03	3,655.95	2.4%	876.92	2,779.03
Average	**453.8127**	**15.87636364**	**14,402.79**	**6.3%**	**7,626.76**	**6,775.94**

Table A-6: Fertilizer sales data for Gadsden County, 2002–12

Year	Total Fertilizer (tons)	Total N All Fertilizer (tons)	Total N All Fertilizer (kg-N)	% N in Fertilizer	Farm Fertilizer (kg-N)	Nonfarm Fertilizer (kg-N)
2002	16,122.28	1,000.08	907,257.27	6.2%	886,706.19	20,551.09
2003	17,335.09	1,157.8	1,050,338.45	6.7%	1,011,886.62	38,451.82
2004	15,072.67	928.95	842,729.23	6.2%	807,610.36	35,118.87
2005	12,867.91	841.16	763,087.48	6.5%	724,709.27	38,377.61
2006	16,896.61	977.06	886,373.88	5.8%	800,684.73	30,936.46
2007	19,150.76	1,259.57	1,142,662.63	6.6%	1,081,967.88	60,694.76
2008	11,363.96	718.19	651,530.98	6.3%	625,541.32	25,989.66
2009	7,267.58	539.71	489,616.65	7.4%	403,520.53	86,096.80
2010	10,070.95	695.37	630,829.02	6.9%	524,140.03	106,689.00
2011	8,743.33	717.29	650,714.51	8.2%	553,796.47	96,918.05
2012	4,655.08	484.29	439,340.48	10.4%	358,864.69	80,476.73
Average	**12,686.02**	**847.22**	**768,589.15**	**7.0%**	**707,220.73**	**56,390.99**

Table A-7: Fertilizer sales data for Jefferson County, 2002–12

Year	Total Fertilizer (tons)	Total N All Fertilizer (tons)	Total N All Fertilizer (kg-N)	% N in Fertilizer	Farm Fertilizer (kg-N)	Nonfarm Fertilizer (kg-N)
2002	11,821.07	2,013.98	1,827,051.84	17.0%	1,784,886.62	42,165.22
2003	12,739.43	2,134.68	1,936,549.04	16.8%	1,868,994.80	67,554.23
2004	12,434.2	2,067.58	1,875,676.94	16.6%	1,789,949.90	85,727.04
2005	7,435.26	1,278.28	1,159,636.06	17.2%	1,095,378.71	64,257.34
2006	9,703.11	1,706.6	1,548,201.41	17.6%	1,400,579.05	147,623.95
2007	8,746.09	1,647.12	1,494,242.06	18.8%	1,414,979.37	79,262.69
2008	6,710.28	1,290.77	1,170,966.80	19.2%	1,085,816.11	85,150.69
2009	6,930.13	1,364.98	1,238,288.97	19.7%	1,189,808.99	48,479.98
2010	11,503.6	1,234.45	1,119,874.15	10.7%	1,086,892.01	32,978.25
2011	11,050.43	1,202.83	1,091,188.97	10.9%	1,053,366.18	37,819.83
2012	7,117.92	1,341.37	1,216,870.34	18.8%	1,181,447.70	35,422.64
Average	**9,653.775**	**1,571.15**	**1,425,322.42**	**17.2%**	**1,359,281.77**	**66,040.17**

Table A-8: Farm fertilizer land use percentages in Leon, Wakulla, Gadsden, and Jefferson Counties

\- = Empty cell/no data
U = Unconfined; S = Semi-confined; C = Confined

Leon County

Land Use Type	Leon County (ha)	U	S	C
2140: Row Crops	27	1	22	4
2150: Field Crops	2,587	20	1,397	1,169
2153: Hay Fields	669	51	388	229
2230: Other Groves	51		6	13
2400: Nurseries and Vineyards	17	6	11	
2410: Tree Nurseries	27	3	5	19
2420: Sod Farms	68	-	68	-
2430: Ornamentals	23	-	23	1
Total	**3,470**	**80**	**1,920**	**1,435**
% of County Fertilized Land	**-**	**2.3%**	**55.3%**	**41.4%**

Wakulla County

Land Use Type	Wakulla County (ha)	U
2140: Row Crops	17	13
2150: Field Crops	166	140
2153: Hay Fields	592	550
2230: Other Groves	10	9
2400: Nurseries and Vineyards	3	3
2410: Tree Nurseries	20	3
2420: Sod Farms	-	-
2430: Ornamentals	6	6
Total	**815**	**725**
% of County Fertilized Land	**-**	**88.9%**

Gadsden County

Land Use Type	Gadsden County (ha)	S	C
2140: Row Crops	495	91	305
2150: Field Crops	884	69	705
2153: Hay Fields	5,819	862	3,836
2230: Other Groves	179	1	128
2400: Nurseries and Vineyards	24	-	19
2410: Tree Nurseries	30	-	30
2420: Sod Farms	446	22	420
2430: Ornamentals	617	31	586
Total	**8,494**	**1,077**	**6,028**
% of County Fertilized Land	**-**	**12.7%**	**71.0%**

Jefferson County

Land Use Type	Jefferson County (ha)	S	C
2140: Row Crops	401	9	12
2150: Field Crops	2,953	73	850
2153: Hay Fields	5,021	121	69
2230: Other Groves	1,086	2	10
2400: Nurseries and Vineyards	32	-	8
2410: Tree Nurseries	87	-	5
2420: Sod Farms	-	-	-
2430: Ornamentals	-	-	19
Total	**9,580**	**204**	**973**
% of County Fertilized Land	**-**	**2.1%**	**10.2%**

Table A-9: Urban fertilizer land use percentages in Leon, Wakulla, Gadsden, and Jefferson Counties

- = Empty cell/no data
U = Unconfined; S = Semi-confined; C = Confined

Leon County

Land Use Type	Leon County (ha)	U	S	C
1110: Low Density, Single Family	7,583	512	5,983	1,015
1120: Low Density, Mobile Home	1,053	754	156	43
1130: Low Density, Mixed Units	4,106	1,608	1,585	829
1210: Medium Density, Single Family	8,937	562	8,329	45
1220: Medium Density, Mobile Home	622	487	134	-
1230: Medium Density, Mixed	999	581	374	28
1310: High Density, Single Family	1,085	72	1,013	-
1320: High Density, Mobile Home	136	100	35	-
1330: High Density, Low Rise	1,270	34	1,236	-
1340: High Density, High Rise	10		10	-
1350: High Density, Mixed	1		1	-
1820: Golf Courses	442	37	405	-
Total	**26,244**	**4,748**	**19,261**	**1,961**
% of Urban Land	**-**	**18.1%**	**73.4%**	**7.5%**

Wakulla County

Land Use Type	Wakulla County (ha)	U
1110: Low Density, Single Family	1,994	1,593
1120: Low Density, Mobile Home	976	855
1130: Low Density, Mixed Units	2,891	2,498
1210: Medium Density, Single Family	921	702
1220: Medium Density, Mobile Home	370	305
1230: Medium Density, Mixed	780	452
1310: High Density, Single Family	60	2
1320: High Density, Mobile Home	3	1
1330: High Density, Low Rise	27	18
1340: High Density, High Rise	-	-
1350: High Density, Mixed	52	39
1820: Golf Courses	51	51
Total	**8,128**	**6,517**
% of Urban Land	**-**	**80.2%**

Gadsden County

Land Use Type	Gadsden County (ha)	S	C
1110: Low Density, Single Family	1,449	89	1,183
1120: Low Density, Mobile Home	733	56	530
1130: Low Density, Mixed Units	1,884	102	1,245
1210: Medium Density, Single Family	804	13	742
1220: Medium Density, Mobile Home	203	17	174
1230: Medium Density, Mixed	1,921	102	1,589
1310: High Density, Single Family	406	1	387
1320: High Density, Mobile Home	156	2	144
1330: High Density, Low Rise	62	3	51
1340: High Density, High Rise	-	-	-
1350: High Density, Mixed	626	30	469
1820: Golf Courses	111	-	111
Total	**8,356**	**413**	**6,623**
% of Urban Land	**-**	**4.9%**	**79.3%**

Jefferson County

Land Use Type	Jefferson County (ha)	S	C
1110: Low Density, Single Family	1,539	50	216
1120: Low Density, Mobile Home	311	13	11
1130: Low Density, Mixed Units	2,117	29	82
1210: Medium Density, Single Family	170	-	33
1220: Medium Density, Mobile Home	5	-	-
1230: Medium Density, Mixed	456	-	-
1310: High Density, Single Family	5	-	-
1320: High Density, Mobile Home	5	-	-
1330: High Density, Low Rise	9	-	-
1340: High Density, High Rise	-	-	-
1350: High Density, Mixed	-	-	-
1820: Golf Courses	28	-	-
Total	**4,645**	**92**	**341**
% of Urban Land	**-**	**2.0%**	**7.3%**

Table A-10: Gadsden County livestock populations from the CoA, 2002 and 2007

- = Empty cell/no data

Livestock	Amount	2002	2007	Average
Cattle, Cows, Beef	1 to 9 head	326	-	326
Cattle, Cows, Beef	10 to 19 head	-	418	418
Cattle, Cows, Beef	20 to 49 head	959	1,193	1,076
Cattle, Cows, Beef	50 to 99 head	804	1,103	954
Cattle, Cows, Beef	100 to 199 head	-	600	600
Cattle, Cows, Beef	200 to 499 head	-	-	-
Cattle, Cows, Beef	Total	2,710	2,500	2,605
Cattle Including Calves	1 to 9 head	-	88	88
Cattle Including Calves	10 to 19 head	551	226	389
Cattle Including Calves	20 to 49 head	941	1,593	1,267
Cattle Including Calves	50 to 99 head	1,543	1,973	1,758
Cattle Including Calves	100 to 199 head	-	2,551	2,551
Cattle Including Calves	200 to 499 head	-	-	-
Cattle Including Calves	Total	4,564	5,000	4,782
Chicken, Broilers	Total	-	-	-
Chicken, Layers	Total	70	351	211
Ducks	Total	22	-	22
Geese	Total	25	14	20
Goats	Total	365	723	544
Hogs	Total	551	97	324
Sheep Including Lambs	Total	66	116	91
Turkeys	Total	18	5	12
Horses	Total	-	406	406

Table A-11: Jefferson County livestock populations from the CoA, 2002 and 2007

- = Empty cell/no data

Livestock	Amount	2002	2007	Average
Cattle, Cows, Beef	1 to 9 head	202	244	223
Cattle, Cows, Beef	10 to 19 head	278	413	346
Cattle, Cows, Beef	20 to 49 head	748	1,045	897
Cattle, Cows, Beef	50 to 99 head	889	1,888	1,389
Cattle, Cows, Beef	100 to 199 head	1,085	1,333	1,209
Cattle, Cows, Beef	200 to 499 head	1,500	-	1,500
Cattle, Cows, Beef	Total	4,702	4,000	4,351
Cattle Including Calves	1 to 9 head	190	263	227
Cattle Including Calves	10 to 19 head	283	384	334
Cattle Including Calves	20 to 49 head	1,098	1,789	1,444
Cattle Including Calves	50 to 99 head	1,272	-	1,272
Cattle Including Calves	100 to 199 head	1,410	3,055	2,233
Cattle Including Calves	200 to 499 head	2,932	3,019	2,976
Cattle Including Calves	Total	11,000	10,000	10,500
Chicken, Broilers	Total	-	43	43
Chicken, Layers	Total	544	1,046	795
Ducks	Total	75	86	81
Geese	Total	-	158	158
Goats	Total	600	1,057	829
Hogs	Total	431	239	335
Sheep Including Lambs	Total	532	271	402
Turkeys	Total	304	19	162
Horses	Total	645	1,163	904

Table A-12: Leon County livestock population data from the CoA, 2002 and 2007

- = Empty cell/no data

Livestock	Amount	2002	2007	Average
Cattle, Cows, Beef	1 to 9 head	214	168	191
Cattle, Cows, Beef	10 to 19 head	115	179	147
Cattle, Cows, Beef	20 to 49 head	331	556	444
Cattle, Cows, Beef	50 to 99 head	-	343	343
Cattle, Cows, Beef	100 to 199 head	-	-	-
Cattle, Cows, Beef	200 to 499 head	-	-	-
Cattle, Cows, Beef	Total	1,500	1,246	1,373
Cattle Including Calves	1 to 9 head	107	164	136
Cattle Including Calves	10 to 19 head	609	358	484
Cattle Including Calves	20 to 49 head	371	1,018	695
Cattle Including Calves	50 to 99 head	263	-	263
Cattle Including Calves	100 to 199 head	-	-	-
Cattle Including Calves	200 to 499 head	-	-	-
Cattle Including Calves	Total	2,841	2,447	2,644
Chicken, Broilers	Total	50	-	50
Chicken, Layers	Total	436	500	468
Ducks	Total	80	221	151
Geese	Total	15	48	32
Goats	Total	201	698	450
Hogs	Total	493	330	412
Sheep Including Lambs	Total	72	77	75
Turkeys	Total	25	44	35
Horses	Total	-	1,157	1,157

Table A-13: Wakulla County livestock population data from the CoA, 2002 and 2007

- = Empty cell/no data

Livestock	Amount	2002	2007	Average
Cattle, Cows, Beef	1 to 9 head	122	141	132
Cattle, Cows, Beef	10 to 19 head	106	282	194
Cattle, Cows, Beef	20 to 49 head	226	-	226
Cattle, Cows, Beef	50 to 99 head	187	-	187
Cattle, Cows, Beef	100 to 199 head	-	-	-
Cattle, Cows, Beef	200 to 499 head	-	-	-
Cattle, Cows, Beef	Total	641	500	571
Cattle Including Calves	1 to 9 head		126	126
Cattle Including Calves	10 to 19 head	219	55	137
Cattle Including Calves	20 to 49 head	218	566	392
Cattle Including Calves	50 to 99 head	277	-	277
Cattle Including Calves	100 to 199 head	-	-	-
Cattle Including Calves	200 to 499 head	-	-	-
Cattle Including Calves	Total	1,159	1,000	1,080
Chicken, Broilers	Total	-	-	-
Chicken, Layers	Total	272	436	354
Ducks	Total	40	-	40
Geese	Total	72	-	72
Goats	Total	388	361	375
Hogs	Total	454	180	317
Sheep Including Lambs	Total	8	-	8
Turkeys	Total	4	-	4
Horses	Total	-	261	261

Table A-14: Cattle population data from NASS, 2007–12

Year	Leon County	Gadsden County	Wakulla County	Jefferson County
2007	5,000	5,000	1,000	10,000
2008	4,000	5,000	1,000	10,000
2009	3,000	6,000	1,000	12,000
2010	2,000	6,000	1,000	13,600
2011	2,000	5,500	1,000	11,500
2012	3,100	6,100	1,000	12,200
Average	**3,183**	**5,600**	**1,000**	**11,550**

Table A-15: Livestock land use percentages in Leon, Wakulla, Gadsden, and Jefferson Counties

- = Empty cell/no data
U = Unconfined; S = Semi-confined; C = Confined

Leon County

Land Use Type	Leon County (ha)	U	S	C
2110: Improved Pastures	2,246	138	1,381	696
2120: Unimproved Pastures	196	13	135	48
2130: Woodland Pastures	352	24	230	99
2310: Cattle Feeding Operations	-	-	-	-
2320: Poultry Feeding Operations	-	-	-	-
2500: Specialty Farms	-	-	-	-
2510: Horse Farms	110	7	69	34
2520: Dairies	-	-	-	-
2540: Aquaculture	-	-	-	-
Total	**2,904**	**181**	**1,815**	**877**
% of County Livestock Land	**-**	**6.2%**	**62.5%**	**30.2%**

Wakulla County

Land Use Type	Wakulla County (ha)	U
2110: Improved Pastures	649	557
2120: Unimproved Pastures	23	23
2130: Woodland Pastures	131	116
2310: Cattle Feeding Operations	-	1
2320: Poultry Feeding Operations	-	-
2500: Specialty Farms	1	-
2510: Horse Farms	20	14
2520: Dairies	-	-
2540: Aquaculture	1	1
Total	**824**	**712**
% of County Livestock Land	**-**	**86.4%**

Gadsden County

Land Use Type	Gadsden County (ha)	S	C
2110: Improved Pastures	3,168	203	2,460
2120: Unimproved Pastures	1,278	98	913
2130: Woodland Pastures	1,454	109	1,093
2310: Cattle Feeding Operations	31	22	-
2320: Poultry Feeding Operations	10	-	10
2500: Specialty Farms	20	-	20
2510: Horse Farms	382	29	334
2520: Dairies		-	-
2540: Aquaculture	12	-	4
Total	**6,354**	**462**	**4,833**
% of County Livestock Land	**-**	**7.3%**	**76.1%**

Jefferson County

Land Use Type	Jefferson County (ha)	S	C
2110: Improved Pastures	5,419	44	207
2120: Unimproved Pastures	243	2	4
2130: Woodland Pastures	385	51	23
2310: Cattle Feeding Operations	-	-	-
2320: Poultry Feeding Operations	-	-	-
2500: Specialty Farms	5	-	-
2510: Horse Farms	197	19	34
2520: Dairies	42	-	-
2540: Aquaculture	1	-	-
Total	**6,291**	**117**	**269**
% of County Livestock Land	**-**	**1.9%**	**4.3%**

Table A-16: Sinking streams discharge data

Site	Year	N	Median Q (L/s)	Minimum Q (L/s)	Maximum Q (L/s)
Fisher Creek	2008	366	81	0.00	16,621.99
Fisher Creek	2009	273	311	42.48	16,565.36
Black Creek	2009	92	208	39.93	6,680.34
Munson Slough	2002	365	78	0.03	40,768.78
Munson Slough	2003	365	233	10.41	16,350.19
Munson Slough	2004	365	122	2.57	12,748.38
Munson Slough	2005	365	249	8.55	25,907.49
Munson Slough	2006	341	68	0.24	17,509.93
Munson Slough	2007	365	23	0.27	14,804.93
Munson Slough	2008	334	27	0.86	47,262.11
Munson Slough	2009	325	368	44.87	24,619.47
Munson Slough	2010	166	204	33.18	17,091.65
Lost Creek	2002	365	1982	56.63	76,455.50
Lost Creek	2003	365	1812	82.12	73,340.64
Lost Creek	2004	366	1529	0.00	33,980.22
Lost Creek	2005	273	2888	124.59	70,508.96
Lost Creek	2007	344	82	28.32	25,541.80
Lost Creek	2008	366	481	28.32	66,827.77
Lost Creek	2009	273	680	28.32	81,269.36

Table A-17: Summary of Munson Slough nutrient data from the southernmost monitoring station (mg/L)

Station Name	Year	NO3	NO3 + NO2	NO2	NH4	TKN	TN
21FLLEONLCLMS5303284302	2008	0.045	0.03235	0.00076	0.019	0.89	0.92235
21FLLEONLCLMS5303284302	2009	0.16	0.069	0.025	0.02	0.42	0.489
21FLLEONLCLMS5303284302	2010	0.175	0.1625	0.025	0.05375	1.0875	1.25
21FLLEONLCLMS5303284302	2011	0.025	0.025	0.025	0.11	1.1	1.125

Table A-18: Summary of Lost Creek nutrient data from the southernmost monitoring stations (mg/L)

Station Name	Year	NO3 + NO2	NH4	TKN	TN
21FLBRA 995-B	2006	0.017738462	0.0215385	0.3475	0.3651333
21FLBRA 995-B	2007	0.00645	0.01	1.05	1.05645
21FLPNS 2327033	2011	0.0176	0.0118	0.358	0.3756
21FLPNS 2327033	2012	0.006	0.012	0.84	0.846

Table A-19: Summary of Black Creek nutrient data from the southernmost monitoring station at SR 267 (mg/L)

Year	NO3 + NO2	NH4	TKN	TN
2006	0.02248	0.0731	0.9225	0.94585
2011	0.014	0.052	0.855	0.869
2012	0.004	0.019	1.4	1.404

Table A-20: Summary of Fisher Creek nutrient data from the southernmost monitoring station 21FLLEONLCNF3031384393 (mg/L)

Year	NO_3	$NO_3 + NO_2$	NO_2	NH_4	TKN	TN
2007	0.004	0.004	0.00076	0.013	0.66	0.664
2008	0.004	0.00825	0.00076	0.017	0.5825	0.59075
2009	0.025	0.013333	0.00884	0.027667	0.566667	0.58
2010	0.025	0.02975	0.025	0.0495	0.6575	0.68725
2011	0.025	0.025	0.025	0.02	0.58	0.605

Table A-21: Final summary of loading source data to the UFA (kg/ha), by county

- = Empty cell/no data

County	Area (ha)	Atmospheric Deposition	WWTFs	Septic Tanks	Farm Fertilizer	Urban Fertilizer	Livestock	Sinking Streams
Leon	165,141	25,502	19,835	110,049	3,042	13,445	7,110	33,422 (Leon and Wakulla combined)
Wakulla	57,603	14,517	1,691	54,076	541	225	10,586	33,422 (Leon and Wakulla combined)
Gadsden	105,279	4,014	276	10,605	16,793	1,833	6,715	-
Jefferson	15,123	623	10	567	6,317	118	135	-

Table A-22: Final summary of loading source data to the UFA (kg/ha), by degree of confinement and recharge

- = Empty cell/no data

County	Area (ha)	Atmospheric Deposition	WWTFs	Septic Tanks	Farm Fertilizer	Urban Fertilizer	Livestock	Sinking Streams
Unconfined	121,214	30,548	19,519	105,770	764	4,945	12,228	33,422
Semi-confined	93,971	10,526	2,007	59,135	12,254	8,936	6,937	-
Confined	127,960	3,583	286	10,392	13,675	1,741	5,381	-

Table A-23: Final summary of total loading source estimates to the UFA (kg/ha)

- = Empty cell/no data

County	Area (ha)	Atmospheric Deposition	WWTFs	Septic Tanks	Farm Fertilizer	Urban Fertilizer	Livestock	Sinking Streams
Total Area	343,146	44,657	21,812	175,297	26,693	15,622	24,546	33,422
Percentages	-	13.1%	6.4%	51.2%	7.8%	4.6%	7.2%	9.8%

Appendix B: Equations

Equation B- 1: Input to land surface from atmospheric deposition

$$\boldsymbol{Atmospheric\ Deposition\ Input\ (kg-N) = Deposition\ Rate\ \left(\frac{kg-N}{ha}\right) \times Land\ Area\ (ha)}$$

Equation B- 2: Input to land surface from wastewater treatment facilities

$$WWTF\ (kg-N) = Annual\ Discharge\ \left(\frac{L}{year}\right) \times Average\ TN\ (\frac{kg-N}{L})$$

Equation B- 3: Input to land surface from septic tanks

$$Septic\ Tanks\ (kg-N) = \#\ of\ tanks\ \times Average\ County\ household\ population\ (\frac{people}{household}) \times 4.5\ (\frac{kg-N}{person})$$

Equation B- 4: Input to land surface from fertilizer

$$Fertilizers\ (kg-N) = N\ sold\ in\ county\ \left(\frac{kg-N}{year}\right) \times Landuse\ \%$$

Equation B- 5: Input to land surface from livestock waste

$$Livestock\ waste\ (kg-N) = animal\ count\ \times daily\ animal\ loading\ \left(\frac{kg-N}{animal}\right) \times 365\ (\frac{day}{year})$$

Equation B- 6: Input to land surface from sinking streams

$$Sinking\ Streams\ (kg-N) = Discharge\ \left(\frac{L}{year}\right) \times average\ TN\ (\frac{kg-N}{year})$$

Equation B- 7: Estimating unattentuated nitrogen

$$Unattenuated\ N = Input\ to\ land\ surface\ (kg - N) \times (1 - Attenuation\ factor)$$

Equation B- 8: Estimating load to ground water

$$Load\ to\ Ground\ Water\ (kg - N) = Unattenuated\ N\ (kg - N) \times Recharge\ factor$$