Sources of Nitrate and Estimated Groundwater Travel Times to Springs of the Santa Fe River Basin

Revised Report

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List of Acronyms and Abbreviations

%	percent
ACEPD	Alachua County Environmental Protection Department
AMEC	AMEC Environment & Infrastructure, Inc.
BMP	Best Management Practices
CAFOs	concentrated animal feeding operations
FAS	Floridan aquifer system
FDEP	Florida Department of Environmental Protection
FDOH	Florida Department of Health
FGS	Florida Geological Survey
FLUCCS	Florida Land Use and Cover Classification System
ft	feet
GIS	Geographic Information Systems
IAS	Intermediate Aquifer System
ICU	Intermediate Confining Unit
kg/ha/yr	kilograms per hectare per year
L	liter
lb	pound
MACTEC	MACTEC Engineering and Consulting, Inc.
mg/L	milligrams per Liter
MH	mobile home
MSL	mean sea level
MT	metric ton (a metric ton is 1,000 kilograms or 2,205 pounds)
MT/yr	metric tons per year
N/yr	Nitrogen per year
N_2	Nitrogen gas
NO_3^-	Nitrate
NO3-N	Nitrate nitrogen
SDII	SDII Global Corporation
SFRS	Santa Fe River/Springs
SJRWMD	St. Johns River Water Management District
SRWMD	Suwannee River Water Management District
SWFWMD	Southwest Florida Water Management District
TMDL	Total Maximum Daily Load
TN	total nitrogen
UF IFAS	University of Florida Institute of Food and Agricultural Sciences
UFA	Upper Floridan aquifer
USGS	United States Geological Survey
WWTPs	wastewater treatment plants

Executive Summary

The lower Santa Fe River has been determined by the Florida Department of Environmental Protection (FDEP) to be impaired for nutrients and dissolved oxygen, with a Total Maximum Daily Load (TMDL) target of 0.35 milligrams per liter (mg/L) of nitrate (NO3) to protect aquatic ecosystems. At the request of the Alachua County Environmental Protection Department (ACEPD) and to facilitate prioritization of local initiatives for springs protection for the lower Santa Fe River, MACTEC Engineering and Consulting, Inc. (MACTEC now AMEC), developed an ArcGIS™ tool designed to estimate nitrate loadings to groundwater in the springsheds. MACTEC also conducted an evaluation of the sources of nitrogen based on land use and loading rates and modeled groundwater travel time in the upper Floridan aquifer. Best available data, 2004 water management district land use land cover, were used for the project.

The study area boundaries were the springsheds that were developed from those determined by SDII (2011) in their initial 2007-2008 work with modifications that focused on areas of known conduit flow. The Santa Fe River springsheds include parts of seven counties and three water management districts and cover approximately 550,000 acres (860 square miles). Groundwater recharge rates in the springsheds were determined by application of the MegaModel developed by the US Geological Survey to simulate groundwater flow in peninsular Florida.

Sources of nitrate loading to the groundwater in the springsheds are introduced from point and non-point sources. Two distinct approaches were used to estimate nitrate loadings to groundwater depending on source type. Point sources include disposal of domestic wastewater by septic systems and permitted wastewater treatment plants, while non-point sources in this springshed include leaching of fertilizer nitrogen and livestock waste. Pastureland, tree plantations and septic systems were found to be the largest sources of nitrate to springs of the lower Santa Fe River.

Point source (e.g. septic systems and permitted domestic wastewater treatment plants), loadings were estimated “per unit”. The number of septic systems within the springsheds was estimated from data provided by the Florida Department of Health (FDOH), and the loading from each system was estimated from published, nationwide, estimates. Water quality data for domestic wastewater treatment plant effluent was used to calculate loading rates of nitrate to groundwater within the springsheds.

Loadings estimates for non-point sources were based on land use and area. Representative groundwater concentrations associated with a variety of land uses were estimated based on published studies where nitrate has been monitored in groundwater under specific land uses. The most reliable data available to estimate groundwater concentrations associated with various land uses were selected, ideally well designed monitoring studies from Florida that isolate the effect of the specific land use from other surrounding sources.

Uncertainties in loading estimates of the most significant sources were presented. Loading estimates of pasture land use, which contributed almost half of the total nitrate loading, were based on data from the literature and may create a ± 25 to 50% margin of error in this study. Groundwater concentrations for the silviculture (tree plantation) are not well documented in this region and fertilization management practices are variable. Considering the error surrounding this land use’s loading estimates, silviculture may contribute between 5 and 25% of the total loading. Finally, septic systems were estimated to be between 15 and 20% of the total loading. The actual number of septic systems in the study area is uncertain. The ongoing efforts by FDOH to develop a statewide database of septic system locations would reduce the uncertainty.

Changes in land use from 1995 to 2004 were evaluated. Assuming trends in land use change continue, land use was predicted for the year 2030. Nitrate loadings in 1995 and 2030 were then estimated using simplified procedures. This analysis indicated that one of the most significant recent historical trends in land use, as it affects nitrate loading to groundwater, was the conversion of nearly

all land in row crop agriculture (vegetable crops) to other land uses from 1995 to 2005. The row crop land use generally produces relatively high nitrate loadings, so the virtual disappearance of this land use reduced loadings from 1995 to 2004. Loadings were projected to be little changed from 2004 to 2030, however, this trend is uncertain.

The MegaModel was used to estimate the time that it takes for groundwater to flow in the Upper Floridan aquifer (UFA) in the springsheds to the Santa Fe River. Estimated groundwater travel times are uncertain because porosity and hydraulic conductivity in karst limestone varies dramatically depending on the development of caves, caverns, fractures, sinking streams and other large solution features in the limestone. Uncertainties also exist due to scale and limitations of the model. Areas where travel time to the springs on the Santa Fe River is likely to be less than 25 years to 100 years include northwestern Alachua County, southern Columbia County and a small area of northeast Gilchrist County.

1.0 Introduction

In 2008 Alachua County requested MACTEC Engineering and Consulting, Inc. (MACTEC) to use the best available data from public and/or published sources to develop a Geographic Information Systems (GIS) application that would perform calculations that estimate nitrate loading to groundwater in the area contributing groundwater discharge to springs of the lower Santa Fe River Basin. This area is referred to as the springsheds. This GIS application would use publicly available data, and could be used by Alachua County to evaluate alternative measures to protect the springs from anthropogenic nutrient enrichment. Anthropogenic nutrient enrichment is the degradation of water quality by human introduction of excess nutrients resulting in growth of algae, reduction in water clarity, and other undesirable ecological effects. In springs, this process can result if nitrate is elevated in the groundwater that discharges to the springs. Loadings of nitrate to groundwater from fertilizer use; sanitary wastewater, including septic systems; and livestock management within the springsheds can alter the natural ecosystem of the springs and river. The application would:

- Include a variety of layers of geographic information relevant to defining the most important sources of nitrate to the lower Santa Fe River Basin and springsheds;
- Perform calculations to estimate nitrate loading to groundwater in the Basin and springsheds by land use;
- Produce graphical (e.g., pie chart) outputs illustrating the contribution of various land uses to total nitrate loading in the lower Santa Fe River Basin springsheds;
- Incorporate new information, such as updated land use or new research findings on the contributions of specific source types; and
- Support and facilitate Alachua County's decision-making regarding potential changes to the Alachua County Comprehensive Plan and related land development regulations as they pertain to springs protection, allowing evaluation by modification of selected inputs that may represent management actions, such as the implementation of Best Management Practices (BMPs).

Alachua County also requested that MACTEC prepare a map illustrating estimated groundwater travel time to the springs, and develop a plausible future land use scenario.

MACTEC recently completed a substantially similar project for the Wekiva River Basin and springsheds for the St. Johns River Water Management District (SJRWMD) (MACTEC, 2010a).

MACTEC, acquired by AMEC Environment & Infrastructure, Inc. in 2011, transferred applicable findings and procedures developed for the Wekiva Basin to the nitrate loading evaluation of the Santa Fe River Basin and springsheds.

MACTEC finalized its original report to Alachua County in September 2010 (MACTEC, 2010b), based on calculations performed primarily during 2009, using information available at that time. Since finalizing its 2010 report to Alachua County new information has become available that indicated a revision is warranted, and Alachua County requested AMEC to revise the report. The new information included:

- A peer review of MACTEC's 2010 report by Upchurch, dated October 28, 2011;
- MACTEC's preparation of its final report (MACTEC, 2010a) to SJRMWD presenting results of a similar study performed within the Wekiva River Basin; and
- The publication of related studies by others.

1.1 Study Area

1.1.1 Surface Water Resources

The project location is illustrated in Figure 1. The Santa Fe River basin, encompassing 1,384 square miles, is part of the larger Suwannee River basin in north central Florida (Clark *et al.*, 1964; Hunn and Slack, 1983). It includes nearly all of Bradford and Union Counties, and portions of Columbia, Alachua, Gilchrist, Clay, Baker, and Suwannee counties. The Santa Fe River forms the northern boundary of Alachua County. The Santa Fe River flows west from its headwaters in the Santa Fe Lake area of Alachua County, to its confluence with the Suwannee River near Branford. Its two major tributaries in the upper reaches of the watershed, New River and Olustee Creek, have their headwaters in southern Baker County (Clark *et al.*, 1964; Hunn and Slack, 1983). A third tributary, the Ichetucknee River is a clear, spring-fed stream located in the lower reaches of the watershed (lower Santa River) and a very popular recreational site.

The upper Santa Fe watershed, in the eastern part of the basin that contains numerous lakes and small streams, is dominated by surface water runoff. In O'Leno State Park, the river submerges underground at a feature known as River Sink, and reemerges approximately 3 miles away at River Rise Spring supplemented by ground water flow and gains significant flow from numerous springs, including the Ichetucknee River further down stream (Clark *et al.*, 1964; Hunn and Slack, 1983). Because ground water dominates its flow, the lower Santa Fe is for the most part a spring-fed river. Springs in the Santa Fe River Basin are among the most valued natural resources in north-central Florida (FL). SRWMD (1998) identified 60 springs of varying magnitude along the river. There are numerous swallets (where surface water flows into the aquifer) and resurgences (a spring formed when surface water that has been captured by a siphon or swallet re-emerges from the aquifer) that move river and spring water within the river system due to the karst nature of the lower Santa Fe River (FGS, 2006). In 1984 the Santa Fe River system was designated an Outstanding Florida Water (OFW) deserving of special protection because of its natural attributes (FDEP, 2008).

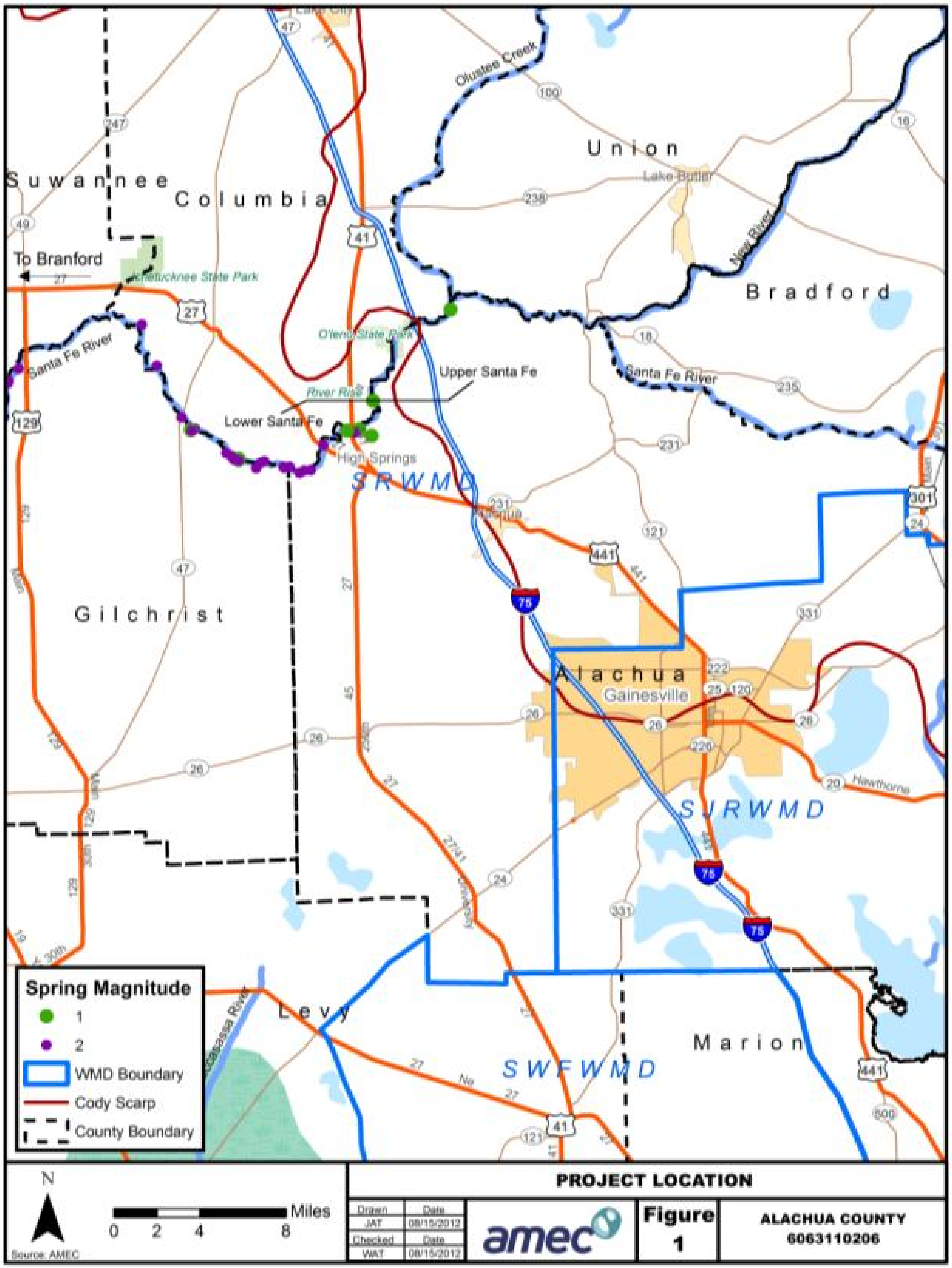
The lower Santa Fe River is defined as the reach below the Santa Fe River Rise (at River Rise Preserve State Park, north of High Springs) to its mouth at the Suwannee River near Branford, FL. The lower Santa Fe River has been determined by the Florida Department of Environmental Protection (FDEP) to be impaired for nutrients, with nitrogen identified as the limiting nutrient, and dissolved oxygen. FDEP (2008) has derived a draft Total Maximum Daily Load (TMDL) for nitrogen for the lower Santa Fe River, which is also intended to apply to all impaired springs in the Basin; however, there is insufficient data available at this time to classify any of the Basin's springs as impaired.

Discharge of Poe Springs to Santa Fe River

Because the lower Santa Fe River is predominantly spring-fed, and the springs themselves represent an important resource endangered by nutrient enrichment, the most important sources of nitrogen to its springs and the river is expected to be via discharge of nitrate from the Upper Floridan aquifer (UFA). Nitrate is a soluble form of nitrogen that migrates readily in groundwater.

1.1.2 Hydrogeology

The geology of the study area generally controls the location of springs and affects the hydrology of the river basin. The section below briefly describes the geology, regional physiography, aquifer systems, and boundaries of the study area.



PROJECT LOCATION

Figure 1

ALACHUA COUNTY
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The region is underlain by a series of marine and clastic deposits of sand, clay, and carbonates (limestone and dolostone). From oldest to youngest, the five primary geologic formations in the study area are the Avon Park Formation, the Suwannee Limestone (limited in extent to the northern region of the study area), the Ocala Limestone, the Hawthorn Group (eastern portion of the study area), and Plio-Pleistocene to Recent Terrace deposits (Clark, *et al*., 1964; Copeland, *et al.,* 2009). The oldest geologic formation exposed at the surface in Alachua County is the Ocala Limestone. In the northern and eastern portion of the Santa Fe River Basin, the Ocala Limestone is covered by upwards of 100 feet (ft) of Miocene-age deposits of the Hawthorn Group generally consisting of a series of interbedded sands, silts, clayey sands, sandy clays, carbonates (limestone and dolostone), and phosphates (Clark, *et al*., 1964; Scott, 1988). Above the Hawthorn Group, or directly contacting the Ocala Limestone where the sediments of the Hawthorn Group are absent, lie Plio-Pleistocene to Recent Terrace deposits comprised of sands and clays (Clark, *et al*., 1964). The Ocala Limestone in the upper Floridan aquifer or aquifer system is the primary source of groundwater to the springs on the Santa Fe River (SDII, 2011).

This description of the regional hydrogeology and physiography is based primarily on SDII (2011). Regionally the study area is located within the Coastal Plain physiographic province which is divided primarily into the Northern Highlands and the Gulf Coastal Lowlands physiographic regions (White, 1970). The Cody Scarp is the transition zone between the Northern Highlands and Gulf Coastal Lowlands.

The Northern Highlands physiographic province typically has broad, gently sloping topography and generally continuous high elevation plateaus approximately 100-200 ft above mean sea level (MSL) (White, 1970; SDII, 2011). Soils typically range from sand to clayey sand. The clayey sediments in the subsurface serve as the base for the surficial aquifer system (Clark, *et al*., 1964). These clay-rich sediments, which at depth constitute portions of the intermediate aquifer system and the intermediate confining unit, serve to retard infiltration and recharge of rainwater into the underlying Floridan aquifer system (FAS). The result is abundant surface-water features (streams, wetlands, lakes and ponds) throughout the Northern Highlands (SDII, 2011).

The Gulf Coastal Lowlands physiographic province is characterized by relatively flat, karstic topography (sinkholes, sinking streams and springs) with carbonate rock (limestone and dolostone) at or near land surface and shallow, sandy soils with muck in many wetland areas (White, 1970; SDII, 2011). The Gulf Coastal Lowlands slopes gently from the Northern Highlands toward the coast with elevations from sea level to about 100 ft above MSL.

The Cody Scarp is the transition zone and forms a topographic break that separates the Northern Highlands (to the east and north of the Scarp) and the Gulf Coastal Lowlands/Western Valley (to the west and south) (Upchurch 2007; SDII, 2011). The Cody Scarp is a karst escarpment with as much as 80-100 ft of relief, characterized by active sinkhole formation, large sinkholes and lakes, springs, sinking streams and river resurgences (Upchurch, 2007; SDII, 2011). The scarp is the result of various erosional processes, which contribute to reducing the thickness of the Hawthorn Group sediments. The study area encompasses the Santa Fe River, the largest swallet-to-resurgence system in Florida, and numerous streams (e.g. Mill, Hogtown, Turkey, and Blues creeks) that flow underground through swallets (Upchurch, 2007). The Cody Scarp is the area where the Santa Fe River and these smaller streams go underground. Direct recharge of surface water from rainfall, which is weakly acidic, recharging the groundwater through swallets develops vertical and horizontal conduits. Dye traces have confirmed conduit connections in many parts of the region. In the study area the connection of the Mill Creek Sink cave system and Hornsby Springs on the Santa Fe River was reported by Butt, *et al*. (2006). In the portions of the study area close to swallets and springs, conduit flow may dominate and elevate aquifer hydraulic conductivity (Upchurch, 2007).

The general hydrogeologic regime is primarily influenced by the stratigraphy of the area. The hydrogeologic regime in North Central Florida is generally described in terms of three unit systems which are in descending order, the surficial aquifer system; the intermediate aquifer system (IAS) - intermediate confining unit (ICU); and the Floridan aquifer system (FAS) (Copeland *et al*., 2009). The surficial aquifer system is composed primarily of sand and clayey sands of Pliocene, Pleistocene and Recent age. The Miocene age Hawthorn Group intermediate aquifer system or intermediate confining unit, where present acts in turn as an aquitard, separating the surficial aquifer system from the underlying Oligocene, Eocene and Paleocene age confined FAS (Copeland *et al.*, 2009; SDII, 2011). West of the Cody Scarp the Hawthorn Group is generally absent and there is no surficial aquifer. In western Alachua County and the western portion of the Santa Fe River Basin, the FAS is generally unconfined or very poorly confined and exists under water table conditions.

Along the lower Santa Fe River groundwater in the Floridan aquifer or aquifer system flows out of the limestone aquifer as springs along the river. The Floridan aquifer in western Alachua County, southern Columbia and eastern Gilchrist counties is overlain by relatively thin undifferentiated sands (White, 1970; Upchurch 2007; SDII, 2011). These porous sands and karst features, such as swallets, permit high recharge and allow pollutants, such as nitrate, direct access to the Floridan aquifer (Chasar *et al.*, 2005; SDII, 2011). Karst features dominate the landscape in the western part of the study area, with sinkholes, springs, siphons resurgences and underwater caves present. A combination of diffuse matrix flow and conduit flow is present in study area and provides water to the springs and river. Conduit flow is well developed in the area of the Cody Scarp (discussed above) and along the Santa Fe River itself (Upchurch, 2007).

SDII reviewed available data, performed groundwater flow modeling, and subsequently used detailed potentiometric surface mapping to estimate the extent of springsheds contributing to the lower Santa Fe River. AMEC used the SDII findings to develop the study area for this project. Based on high resolution potentiometric surface data from September 2007 and May 2008, SDII was able to confirm a broad area where groundwater flows toward the Santa Fe River springs (SFRS), but their original evaluation (July, 2008) did not close the springshed boundaries to the northeast (SDII, 2011, see Figure 2). AMEC used the SDII springshed boundaries shown on Figure 2 where available; however, to the northeast AMEC considered groundwater travel times (see Section 5) to bound the springsheds/study area for the purpose of the current project (Figure 3). The Ichetucknee River and associated springs are their own unique system and for this study they were not considered. As presented in Section 5, groundwater travel times from the eastern springshed boundary in Bradford and northern Alachua County are approximately 1,000 years, too long to be of concern for springshed protection.

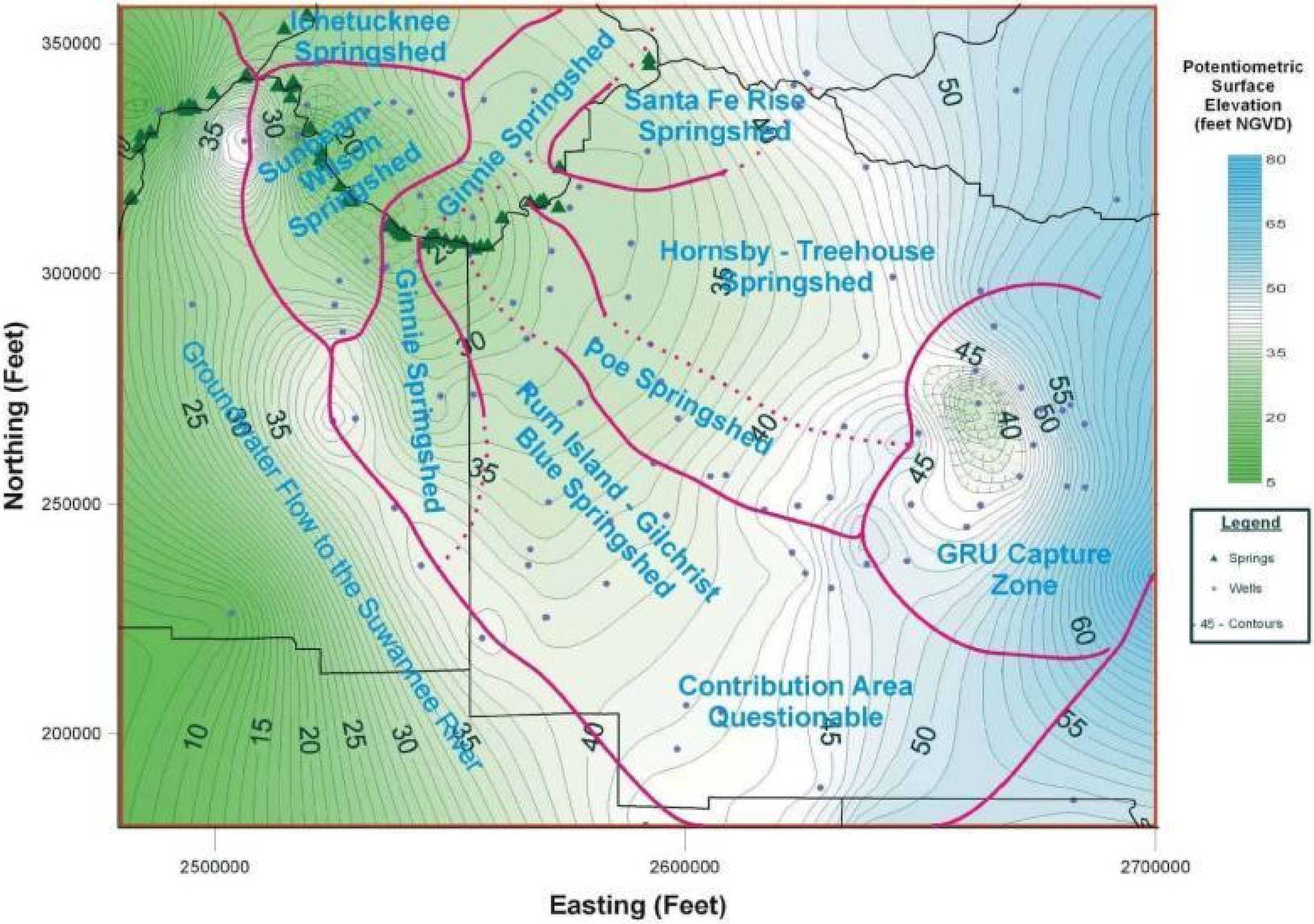
In September 2009, SDII revised their report and included additional details regarding springshed boundaries. This information was received after most calculations reported here had been completed, and it was not feasible to revise the calculations presented in this report in consideration of the revised SDII report. AMEC reviewed SDII's revised information and identified differences and considered how those revisions affect the reliability of information in this report. Generally, the additional springshed maps provided in SDII's (2011) revision are similar to the map used to define the study area for this report (Figure 2). Furthermore, the travel time estimates contained in Section 5 of this report as well as additional discussions by SDII (2011) also generally support the study area footprint. Specifically, SDII (2011) Figures 9 and 11, based on potentiometric data from September 2007 and May 2008, respectively, differ from Figure 2 as follows:

- Southern Boundary - Lower Santa Fe River springsheds are not shown extending as far south as Marion County in Figures 9 and 11 from SDII (2011) it extends further into Levy County; and
- Northeastern Boundary – In SDII (2011) Figures 9 and 11 the springsheds are bounded to the north and east (in Bradford and northern Alachua Counties), and shown to extend somewhat further east than shown on Figure 2 (in this report or SDII (2011) Figure 7).

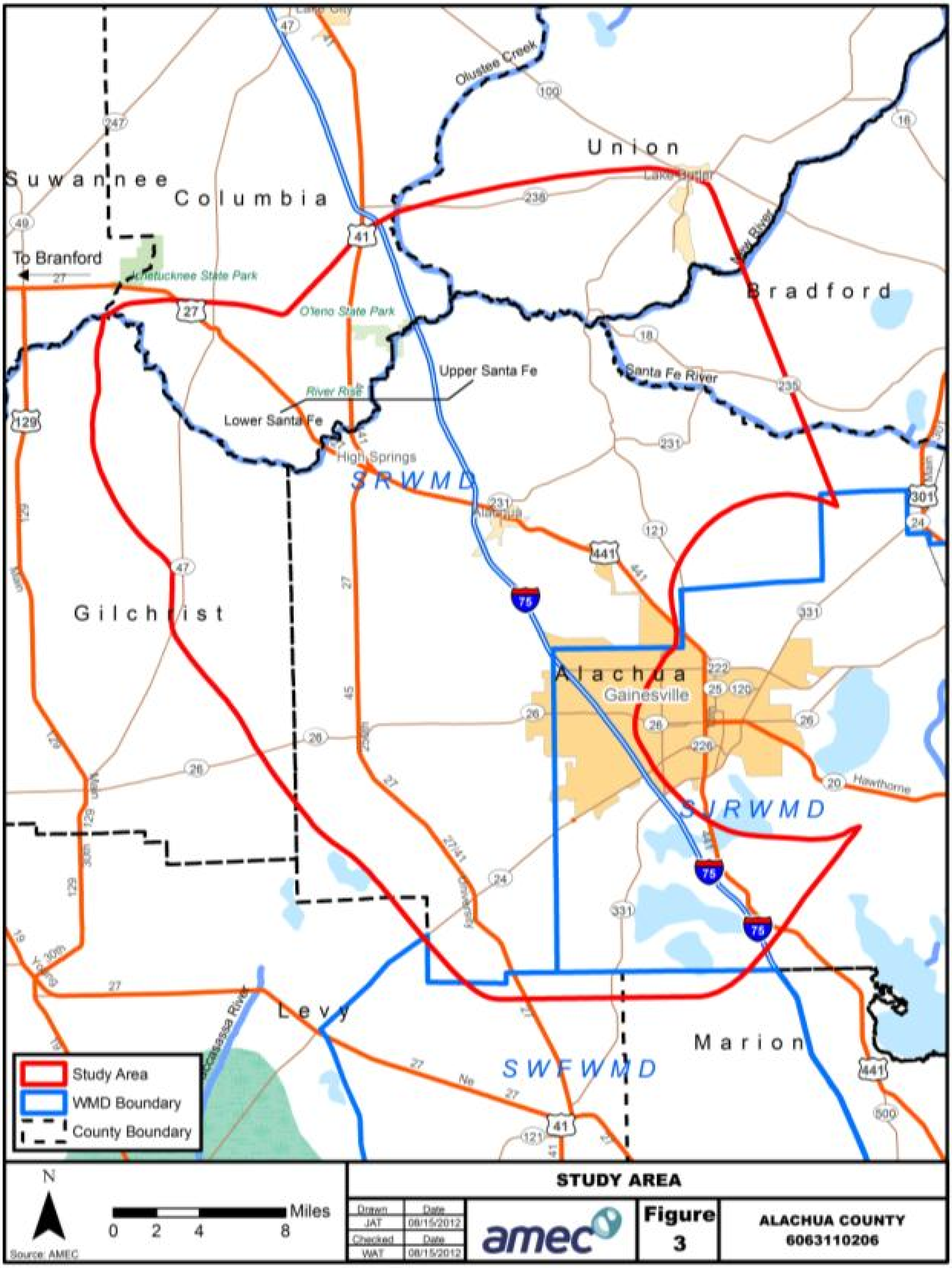
Southern Boundary - Section 5 shows that it takes more than 1,000 years for groundwater from the areas of southern Alachua and northern Marion Counties (included in this study, but not within SDII's revised springsheds) to travel to the Santa Fe River. According to SDII (2011) and Sepúlveda (2002) groundwater from this area may not migrate toward the springs at all. In either case (outside the springshed or very long travel times) these areas should not be prioritized for springshed protection.

Northeastern Boundary - Groundwater travel times from areas in Bradford County near the uncertain northeastern boundary of the springshed are shown, in Section 5, to exceed 1,000 years, and not of significant springshed protection concern. The UFA is confined in this area, so the areas to the northeast that are excluded from this study area footprint, would not contribute much water or surface-derived pollution to the springs (SDII, 2011; Upchurch, 2011). Exclusion of these areas in Bradford and northern Alachua Counties, whether technically within the springshed, or not, would not materially affect the findings reported here. Those areas have low recharge rates, and consequently would not have a major effect on loadings, even had that area been included in this study.

Figure 2. Springsheds of the Santa Fe Basin



Source: SDII, 2011. Figure 7-Springsheds in the vicinity of the Newberry Plain delineated through high-resolution potentiometric surface data from September 2007.



STUDY AREA

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JAT	08/15/2012
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Figure 3

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1.2 Sources of Nitrate to the Santa Fe River and Springs

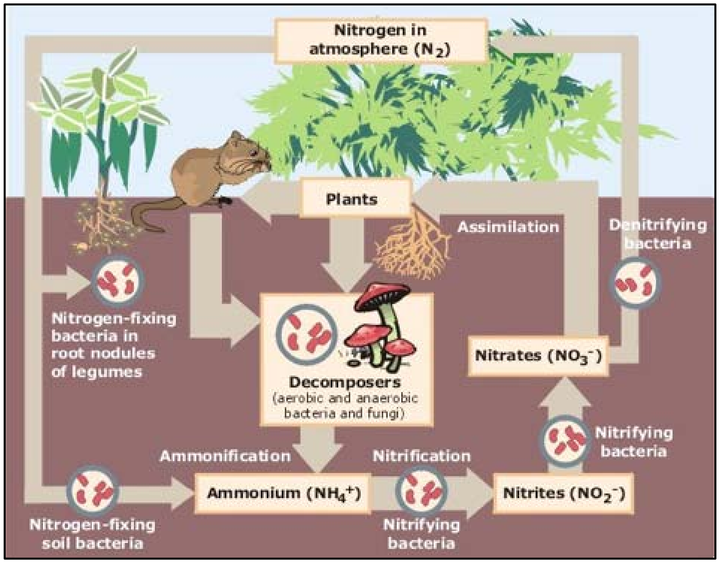
Nitrogen is an important plant nutrient, and a major ingredient in commercial fertilizers. Nitrogen is also associated with human and other animal waste, and is found in raw sewage and treated domestic effluents. Nitrate (NO_3^-) is a negatively charged ion consisting of nitrogen and oxygen. In the environment, nitrogen exists in several chemical forms, and biochemical processes can change the chemical form of the nitrogen in environmental media. Other forms include ammonia and organic nitrogen compounds, such as amino acids and proteins. Nitrogen gas (N_2) is the predominant compound that comprises the atmosphere. Nitrate, however, is generally considered the most problematic form as a water pollutant. Nitrate is highly soluble in water, so it migrates readily into and with groundwater. In drinking water, high concentrations of nitrate can be fatal to infants. In surface waters, nitrate is a nutrient that can be used as food by algae and other plants, and excessive growth of such plants may cause nuisance conditions in springs, lakes, and rivers, often referred to as eutrophication in surface water and nutrient enrichment in groundwater and springs.

The following source types were identified as potentially important sources of nitrate, and their contribution to groundwater in the Santa Fe River Basin was estimated:

- Domestic wastewater;
- Septic systems;
- Fertilizer – Agriculture;
- Fertilizer – Residential;
- Fertilizer – Golf Course;
- Fertilizer – Other; and
- Livestock.

Loadings (mass / time) by each source type were estimated using the best available information.

Figure 4. Nitrogen Cycle (USEPA, 2006a)



Nitrate is an anion that participates in the complex nitrogen cycle (Figure 4) in the earth's biosphere (see, for example, Loreti, 1988; the nitrogen cycle is also described on a variety of websites). Nitrate may be either created or destroyed in the biochemically active root zone, surface water, and groundwater.

Nitrogen gas, N_2, comprises about 78 percent (%) of the atmosphere. Nitrogen is essential for many biological processes, but is not readily available to plants or animals in the N_2 form. In nature, N_2 is converted to biologically usable forms (ammonium, nitrate or nitrite ions) by some algae and bacteria, a process called nitrogen fixation. These anionic forms can be taken up by plants, which convert them to amino acids and proteins, a process known as assimilation; while the reverse reaction, decomposition of organic nitrogen into inorganic nitrogen, is known as mineralization. Decomposition in anaerobic environments generally yields ammonia or ammonium ions, a process called ammonification. Nitrification is the process whereby microorganisms convert organic nitrogen[1] to nitrate and nitrite. Nitrification is favored in aerobic

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[1] Organic nitrogen, such as proteins, amino acids, and urea, includes nitrogen in organic compounds found within living organisms and decaying plant and animal tissues.

environments, while ammonification is more likely to occur in reducing environments[2]. Finally, denitrification is a biochemical process that converts nitrate or nitrite ions back to nitrogen gas, completing the nitrogen cycle (Cohen, *et* al., 2007). Denitrification depends on the availability of electron donors used by autotrophic bacteria. The electron donors, typically pyrite or ferrous silicates, are rare in the Florida environment. Additionally, when calcium, pH, alkalinity and/or specific conductance are high, denitrification is less likely to occur. All of these parameters are characteristically high in Floridan aquifer groundwater. While denitrification has been shown to occur in the shallow groundwaters of Florida whenthe water table is near the surface (McNeal, *et al*., 1995; Crandall, 2000), generally speaking it is negligible. Cohen, *et* al., (2007) state that "nitrates in groundwater are effectively nonreactive (no biological or chemical attenuation) meaning that once nitrate enters the groundwater, it will emerge somewhere. In Florida, this location is primarily springs."

In soils, organic nitrogen and ammonia are more likely to be associated with solids than nitrate, which is highly soluble and not sorbed to any significant extent (Loreti, 1988). Although ammonium ion is soluble, it is more readily sorbed to soils, and thus not as leachable as nitrate (Cohen, *et* al., 2007). This is one reason that nitrate represents a more significant water quality concern than other forms of nitrogen.

To compare various chemical forms of nitrogen it is customary to express amounts in terms of the mass of nitrogen in the chemical. For example the mass of nitrogen in nitrate is referred to as nitrate nitrogen (NO3-N).

Based on the importance of these processes in the environment, nitrate cannot be considered a conservative (never changing) constituent. Nitrate applied as fertilizer may be assimilated by plants, or denitrified and returned to the atmosphere. Ammonium in fertilizers or in animal waste may be converted to nitrate in soil or water, and so on.

The target nitrogen species evaluated in this project is nitrate, the most prevalent form of nitrogen in groundwater and springs affected by nutrient enrichment, and which is readily available to aquatic plants, including algae, upon discharge to springs. Although it was not feasible in this project to account for all the complex biochemistry of the nitrogen cycle, a limited attempt was made to account for assimilation by plants and other processes that occur in the root zone. Specifically it was not assumed that all fertilizer N applied to the land surface would reach groundwater of the Santa Fe River springsheds as nitrate.

Not all nitrogen inputs to the Santa Fe River and springs could be quantified or modeled due to the complexity of the system. Nitrate sources in the Santa Fe River basin include direct runoff into surface waters and indirect sources from groundwater and springs. Upchurch (2011) specifically cites the lack of the MegaModel to account for inputs from rivers and streams along the Cody Scarp. This "focused recharge" in the form of swallets (sinking streams) and the associated nutrient inputs is not included. The Santa Fe River itself is a source of nitrate where it enters the FAS at River Sink and reemerges combined with groundwater at River Rise (Upchurch, 2011). The loading factors for these sources have not been addressed in this report.

Another potential source of nitrogen not quantified in this report is soil storage. Bruland *et al.* (2008) evaluated soil storage of nitrate-nitrogen in the Santa Fe River basin and found that land use was a more important contributor to soil NO3-N concentration than soil order (category). Sandy Entisols, a soil order common in the Gulf Coastal Lowlands of the western Santa Fe River springshed, are well drained soils indicative of high groundwater recharge. These soils reportedly have little ability to retain nutrients and are not considered a major source of NO3-N. Entisols are over 90% sand,

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[2] A reducing environment is one characterized by little or no free oxygen. In soils, reducing environments are more common in wetlands and where soils are rich in organic matter.

acidic, with low organic matter content, and little cation exchange capacity (CEC) to retain cations and limited or no ability to retain anions such as NO3-N (Bruland *et al*., 2008).

1.3 GIS Application

An application was developed for delivery to Alachua County that estimates loadings of nitrate to groundwater. This ArcGIS™ tool was designed by AMEC for use by Alachua County. The tool was developed to estimate nitrate loadings for the Santa Fe River Springsheds. The boundaries of the springsheds were developed from those determined by SDII (2011) in consultation with Alachua County Environmental Protection Department (ACEPD) and the best available information on groundwater flow direction and travel times. The springsheds include parts of seven counties and three water management districts and is approximately 550,000 acres (860 square miles).

The application was developed using the Model Builder tool available with ArcGIS™ Version 9.2 and is expected to be compatible with version 9.2 or higher. The data used by the tool includes a land use layer, a recharge layer and a base table that includes NO3-N concentrations. All of these datasets can be altered for modeling future scenarios. Land use and recharge layers could also be replaced entirely as long as the schema for the new layers matched the original layers. All spatial data has been clipped to the springsheds boundary.

The land use layer delivered to the ACEPD uses Florida Land Use and Cover Classification System (FLUCCS) codes and descriptions and is a combination of several county and water management district datasets from the year 2004 that have been merged into a common schema. The recharge layer is taken from the United States Geological Survey (USGS) MegaModel (Sepúlveda, 2002) with recharge measured in inches per year. The recharge layer grid is based on cells of 5,000 ft, and combines two layers from the MegaModel:

- FLF2 - Simulated vertical leakage from the Intermediate IAS / ICU to the UFA; and
- RECH3 - Simulated recharge to the unconfined areas of the UFA.

Where the UFA is unconfined FLF2 is zero. Where the UFA is confined, RECH3 is zero. Within the MegaModel the UFA is considered to be unconfined in areas where the ICU is absent or very thin. Sepúlveda's (2002) primary source for defining the boundary between the confined and unconfined UFA within the lower Santa Fe springsheds study area was Miller (1986) with additional information from Groszos, *et al*. (1992) and Spechler, *et al.* (1993). Recharge rates to the unconfined UFA were calibrated to accurately reproduce the potentiometric surface of the unconfined UFA within bounds defined by a generalized water budget. The calibration period was August 1993 through July 1994, when rainfall within 4% of the 30-year average rainfall (1961-1990) and the UFA exhibited relatively small fluctuations in potentiometric surface, indicating the Florida Aquifer system was at steady-state conditions. The recharge rates to the confined portion of the UFA were calculated by the calibrated model, based on head difference between the water table and the UFA and the vertical leakance of the ICU.

This application provides ACEPD with the ability to examine the effect of land use changes or application of BMPs on nitrate loadings to the springs. BMPs can be simulated by specifying the percent reduction in loading expected from application of the BMP.

1.4 Past and Projected Land Use

Land use has been summarized for 1995 and 2004, and trends in land use changes were analyzed to develop an estimate of land use in 2030. Effects of trends in land use on loadings to the springs are evaluated. Information on past and projected future land use is presented in Section 4.

1.5 Groundwater Travel Time

To facilitate prioritization of BMPs or other county initiatives for springs protection, groundwater travel time to the springs / Santa Fe River was determined throughout the springsheds and presented in maps. Estimates of groundwater travel times, which are based on flow through the UFA as specified by Sepúlveda (2002), are presented in Section 5.

2.0 Loading Estimation Methods and Information Sources

Nitrate loadings to groundwater attributable to fertilizer use were estimated by reviewing representative research studies where concentrations of nitrate were measured in groundwater or leachate from specific land uses. This information was used to estimate a representative groundwater concentration associated with that land use. This representative groundwater concentration was assumed to represent the impact of fertilizer applications on groundwater within each land use. The resultant groundwater concentrations were overlaid on a map showing groundwater recharge rates to estimate the rate of nitrate loading to groundwater. The land use data layers were developed by the SJRWMD, the Suwannee River Water Management District (SRWMD), and the Southwest Florida Water Management District (SWFWMD); while the recharge rate layer is based on information supplied by the USGS (Sepúlveda, 2002). The same procedure was used to estimate loading from livestock waste, using measured groundwater concentrations under pasture land and feedlots. This estimation approach practically eliminates the need to address the complex biogeochemical processes affecting nitrogen in soils and surface waters (see Section 1.2).

All NO3-N effluent from domestic wastewater facilities were assumed to represent loadings, i.e., assumed to reach groundwater. This assumption is conservative, and limitations of this assumption are discussed in the report. Approximately 70% of the waste nitrogen discharged from septic systems was assumed to reach groundwater as nitrate. Anderson and Otis (2000) indicate the actual percentage may range from 50 to 90%.

Nitrate loadings to groundwater have been estimated using two distinct approaches:

a) For fertilizer and livestock source types, loading is estimated in proportion to acres in land uses where these source types are predominant. A representative groundwater concentration for that land use is multiplied by groundwater recharge rate, which varies throughout the springsheds, and the acres in that land use. The resulting loading may then be attributed to the predominant source type of that land use. For most developed land uses, e.g., residential, agricultural crops, tree plantations, commercial, institutional, and recreational, the resultant loading is attributed primarily to fertilizer use. For land uses where livestock are supported (e.g., pasture, feedlots, dairies) the resultant loading is attributed primarily to livestock waste.

b) For treated domestic wastewater, including permitted wastewater facilities and septic system discharges, loading is calculated by the treatment unit, i.e., actual monitored effluent discharges of permitted domestic wastewater facilities and a specific loading rate for each septic system.

2.1 Land Use-Based Loadings

All land uses in the springsheds are assumed to contribute some nitrate to the springs. Even undeveloped land will produce some low levels of nitrate due to atmospheric deposition and / or natural processes. Major land use categories in the springsheds include residential, commercial, institutional, recreational, industrial, mining, cropland, pasture, orchards and nurseries, concentrated animal feeding operations (CAFOs) including aquaculture, transportation, utilities, undeveloped, and water bodies. The FLUCCS codes that are associated with each of these major land use loading categories is detailed in Attachment A. Of these, the following are assumed to contribute to nitrate loading primarily as the result of fertilizer use:

- Residential;
- Commercial, institutional, recreational;
- Cropland;
- Orchards and nurseries; and
- Roads.

The following land uses are assumed to contribute to nitrate loading primarily from livestock waste:

- Pasture and
- CAFOs.

The following land uses are assumed to contribute very low nitrate loading rates, limited to effects of atmospheric deposition and / or other natural processes:

- Industrial;
- Mining;
- Undeveloped;
- Utilities; and
- Water bodies.

Some transportation land uses, such as terminals, railroads, and airports are assumed to be "like" industrial land, in that relatively little fertilizer is used, and they were assigned to the last of the three groupings, which has very low nitrate loading rates.

Nitrate loadings to groundwater from all land uses are estimated using the following equation:

$$\text{Load [metric tons (MT) per year (yr), MT/yr]} = \text{Area}_{LU} \times \text{Recharge Rate} \times \text{NO3}_{LU} \times \text{CF}$$

Where:

Area_{LU} = Area in a given land use (acres)
Recharge Rate = Rate of groundwater recharge to the UFA (inches/year)
NO3_{LU} = Concentration of NO3-N in the water table aquifer associated with the land use milligrams per Liter (mg/L)
CF = Units conversion factor = 0.0001028 (L MT/acre inch mg)

This calculation is performed for each GIS polygon with a specific land use (e.g., parcels). Then all polygons with the same land use are summed to produce loading per land use throughout the springsheds.

2.1.1 Inputs to Land Use-Based Loading Estimates

Figure 5 is a map showing the distribution of land use by the major land use categories defined in Section 2.1. The land use map was developed as described in Section 1.3. Figure 6 summarizes the portions of the springsheds/study area within these major land use categories.

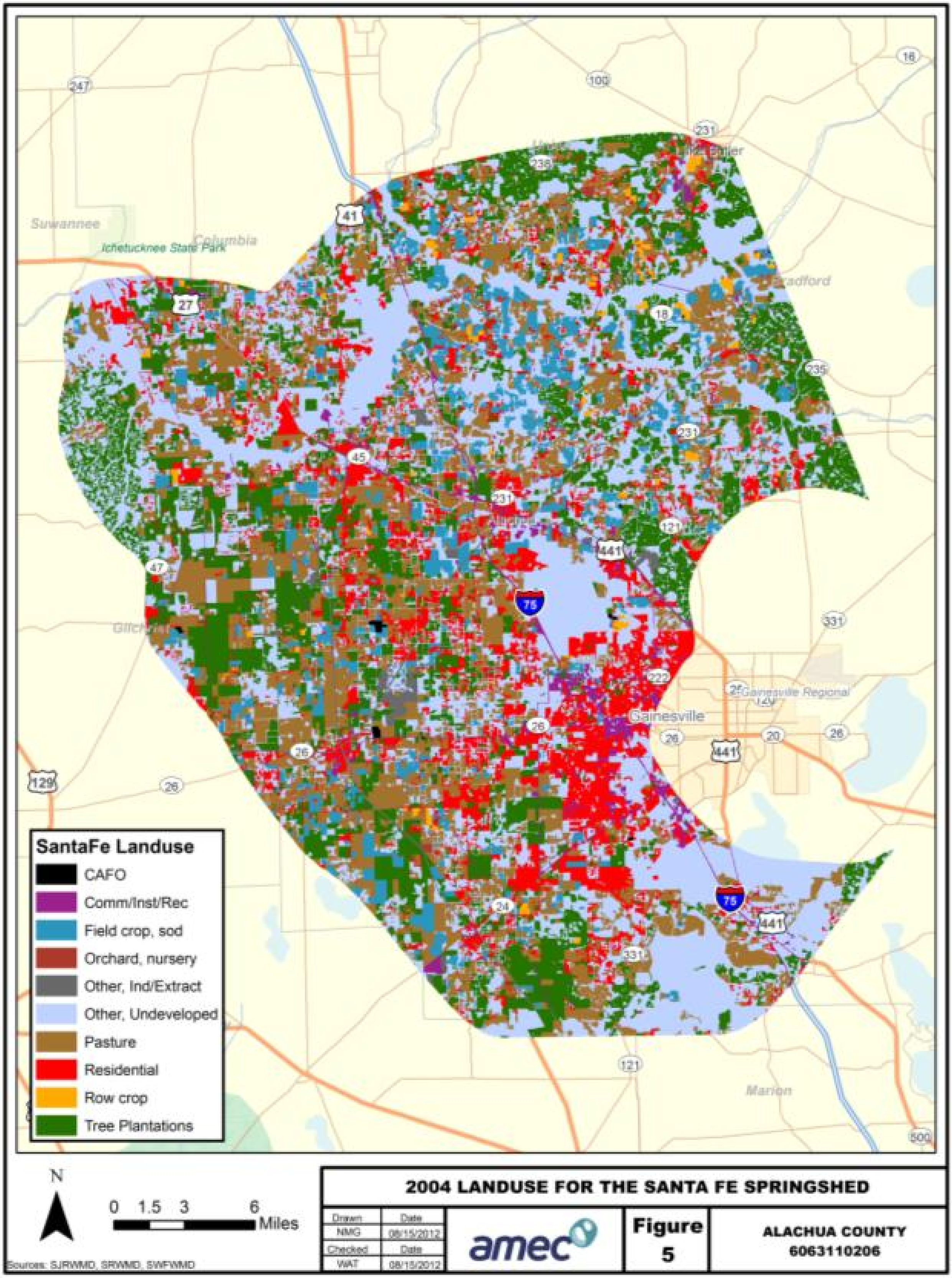
The rate of groundwater recharge to the UFA is given by Sepúlveda (2002), and consists of two separate GIS layers output by Sepúlveda: one for unconfined portions of the Upper Floridan and the second for confined portions of the UFA. The unconfined portion of the Upper Floridan is generally to the west of the Cody Scarp that runs northwest-southeast through Alachua County, with the exception of a small area located in central eastern Gilchrist County referred to as the Waccasassa Flats (Figure 7). Recharge rates ranged from approximately 2 to 20 inches per year, and were in general higher near and west of the Cody Scarp. The Cody Scarp also closely approximates the boundary between the unconfined and confined UFA, as discussed in Sections 1.2 and 1.4 and approximated within the MegaModel (Sepúlveda, 2002).

The concentration of nitrate in the water table aquifer associated with each land use is based primarily on MACTEC (2010a). The following subsections present the basis for the groundwater nitrate concentrations used in the GIS application, and the values used in the application as delivered to ACEPD. If new data becomes available that indicates these values should be revised, the GIS application allows for replacement of the values selected by AMEC with more appropriate nitrate concentrations. MACTEC (2010a) provides additional details on the basis of the selected groundwater nitrate concentrations. The summaries below are limited to the basis of the values selected for this application.

Concentrations of Nitrate in Recharging Groundwater

Each of the land use categories is assigned a groundwater concentration at the water table. The groundwater concentrations assigned to each land use are based primarily on a review of the literature conducted by MACTEC (2010a) for the SJRWMD in a similar project focused on the Wekiva River Basin in central Florida. Estimated groundwater concentrations are intended to represent area sources of contamination associated with the land use, not point source contamination due to such sources as septic systems or wastewater disposal facilities. This approach was used to characterize loadings associated with fertilizer use and livestock waste.

Whereas the primary load estimation calculation for groundwater was based on land use, attribution (partitioning) to specific source types was specified according to the primary source presumed to be contributing NO_3-N to groundwater for each land use. For undeveloped land, the source type was identified as “Natural or Unattributed”. For most land uses, the source type was assumed to be fertilizer use. For pasture, groundwater loadings were assigned to livestock waste, although some fertilizer is applied to pasture land.



Sources: SJRWMD, SRWMD, SWFWMD

2004 LANDUSE FOR THE SANTA FE SPRINGSHED

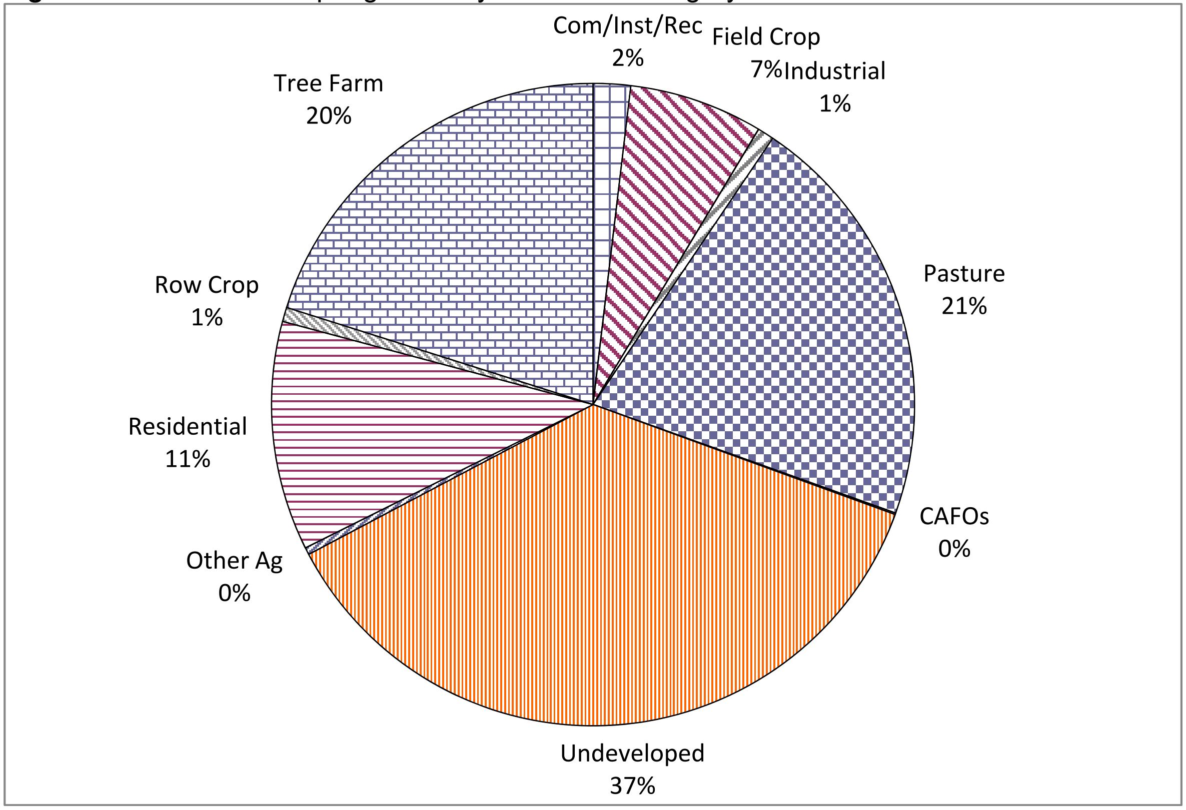
Drawn	Date
NMG	08/15/2012
Checked	Date
WAT	08/15/2012

amec

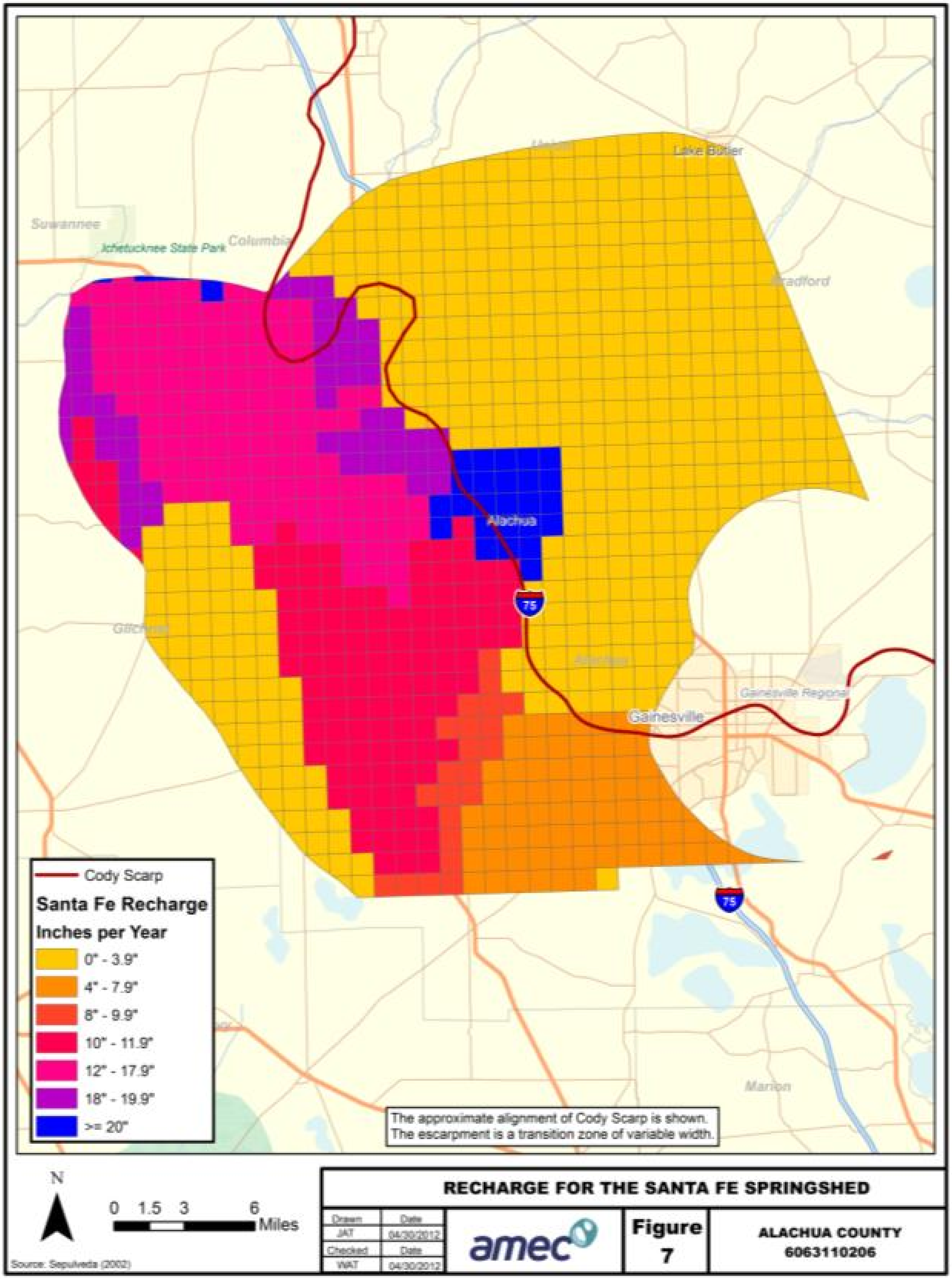
Figure 5

ALACHUA COUNTY
6063110206

Figure 6. Portion of Springsheds by Land Use Category



See Attachment A for definitions of land use categories.
Created by: NMG Checked by: WAT



The approximate alignment of Cody Scarp is shown.
The escarpment is a transition zone of variable width.

Source: Sepulveda (2002)

RECHARGE FOR THE SANTA FE SPRINGSHED

Figure 7

For most land uses these estimates are based on published studies from locations outside the Santa Fe River Basin, and, in some cases, from outside the state of Florida. Representative data from Florida locations were used if available.

One major land use category is assigned groundwater nitrate concentrations different from the values used by MACTEC (2010a). At the request of ACEPD, AMEC conducted additional literature review and estimated groundwater concentrations for tree plantation land uses as part of the scope of work for this study. As a result, the groundwater concentrations for tree plantation land uses differ in the Santa Fe basin model than the values used by MACTEC (2010a) in the Wekiva basin. Groundwater concentrations associated with all other land uses are the same as those used by MACTEC (2010a), and the basis for these values is described in detail there. In the following subsections, the basis for all land-use based groundwater concentrations is summarized. For additional details on the basis, please refer to MACTEC (2010a).

Residential Fertilizer

MACTEC (2007) estimated groundwater concentrations associated with residential fertilizer use from monitoring of small artificial turf grass research plots published by Morton, *et al*. (1988) and Snyder *et al*. (1984). These research studies determined leaching from plots that were managed differently (different rates of fertilizer application and irrigation) across a span of possible residential turf grass management practices. MACTEC (2007) interpreted those research studies and estimated the proportion of residents that would use fertilizer and irrigate at different rates. The latter estimates were based on best engineering judgment. This approach was adopted because MACTEC (2007) did not identify any field scale monitoring programs that had actually measured nitrate concentrations in residential areas unaffected by septic system discharges.

The residential land use may also be associated with loadings from septic systems, but these loading are estimated separately (see Section 2.2.2).

Since the residential fertilizer loading was relatively significant in the Wekiva basin, MACTEC (2007) identified the lack of field scale monitoring data for residential land uses as a significant uncertainty affecting the estimates of loadings in the Wekiva basin and recommended that the second phase of the Wekiva Nitrate Sourcing Study should conduct such monitoring. In 2008, FDEP funded the recommended study, which was technically supervised by the SJRWMD and performed by MACTEC. Results of this study were published in 2009 (MACTEC, 2009).

Twenty-four (24) shallow wells were installed in residential areas unaffected by septic systems within the springshed of Wekiwa Springs. Two (2) shallow wells were installed on undeveloped natural areas on state lands (Wekiwa Springs State Park and Rock Springs Run State Reserve). Most of these wells were sampled four (4) times between October 2008 and July 2009, and samples were analyzed for nutrient constituents of residential fertilizer and other water quality parameters.

Nitrate nitrogen (NO3-N) concentrations in the residential area wells averaged 2.4 mg/L during the study, significantly greater than observed in the natural reference areas (0.3 mg/L). Supplementary analyses of stable isotopes of nitrogen and oxygen in the wells with the highest nitrate concentrations supports the conclusion that these wells were not affected by organic wastewater discharges (e.g., domestic sanitary wastewater, reclaimed water, or animal wastes). One of the wells may be affected by fertilizer use and irrigation practices on an adjacent golf course. This well had the highest nitrate concentrations observed in the study, averaging 10 mg/L, and was about 125 ft from the golf course. Excluding this well from the others, for which the primary source of nitrate is residential fertilizer use, the average groundwater concentration in residential areas unaffected by organic wastewater discharges is 2.0 mg/L.

Therefore, the groundwater concentration attributed to residential fertilizer use in the Santa Fe basin is 2 mg/L (MACTEC, 2009).

Commercial, Institutional, and Recreation Land Uses

Due to a lack of information on groundwater concentrations for commercial and services, institutional, recreational, and transportation, communication, and utilities land uses, these land uses were assumed to have similar groundwater concentration to those occurring in residential land uses because significant portions of these land uses are maintained in turfgrass. Since these land uses, combined, represent only 2% of the Santa Fe basin springsheds; errors in estimation of groundwater concentrations under these land uses would not contribute significantly to total uncertainty in nitrate loading.

Golf courses are a subset of recreational land use with relatively high nitrate loadings to groundwater. Groundwater concentrations have been monitored at a number of golf courses nationwide, and leachate quality has been monitored from experimental turfgrass plots designed to simulate golf course landscape management practices. Of the variety of monitoring studies available, the study by Swancar (1996) a USGS study of groundwater impacts of nine central Florida golf courses was used. Swancar's results are generally consistent with results reported outside of Florida (e.g. Flipse and Bonner, 1985; Petrovic, 1995; Branham, *et al*., 1995; Rufty and Bowman, 2004). From the Swancar (1996) data, MACTEC (2010a) estimated that groundwater NO3-N concentrations associated with golf course land use would be 8 mg/L.

Agricultural Land Uses

Representative groundwater concentrations associated with row and vegetable crops, tree crops (citrus), nurseries, pasture, and CAFOs were estimated from field scale monitoring studies of groundwater concentrations associated with these land uses. Available monitoring studies were reviewed, and well designed studies specific to a given land use from Florida or the Southeastern U.S. were selected to represent the groundwater impacts of these land uses (MACTEC, 2010a).

Loadings for all agricultural land uses were attributed to fertilizer use, with the exception of pasture and CAFOs, which are attributed to animal waste. A portion of loadings from pasture are likely to be associated with fertilizer use, but apportionment between these source types was not estimated.


Field Crop Land Use – Western Alachua County

Row Crops

Concentrations observed by the University of Florida Institute of Food and Agricultural Sciences (UF IFAS) and SRWMD (2006) in Suwannee County and by Hubbard and Sheridan (1989) in the southeastern coastal plain were considered representative by MACTEC (2010a), and an average concentration of 23 mg/L NO_3-N is assumed under row crops.

Field Crops

Although limited information was identified by MACTEC (2010a) regarding concentrations under field crops, leaching rates that have been reported from wheat [15 kilograms per hectare per year (kg/ha/yr); Riley, *et al*., 2001] and alfalfa (7 kg/ha/yr; Randall and Mulla, 2001) are substantially less than those associated with row crops and are consistent with groundwater concentrations of approximately 4 mg/L.

Tree Crops

Orchards producing fruit (e.g., citrus, apples, pecans) comprise less than 0.15% of land use in the Santa Fe springsheds, and thus are not significant. MACTEC (2010a) concluded that a groundwater

NO3-N concentration of 15 mg/L was representative for this land use, based on monitoring conducted by McNeal, *et al*. (1995) and Lamb, *et al*. (1999).

Nurseries

As summarized by MACTEC (2010a), Yeager and Cashion (1993) conducted a comprehensive monitoring survey of 29 container nurseries in six states, including Florida (Yeager, *et al*., 1993) and found groundwater concentrations on and downgradient of nurseries consistently in the range of 5 to 7 mg/L. It was assumed that a representative groundwater concentration associated with nurseries is 6 mg/L.

Pasture

Limited data are available to estimate groundwater nitrate concentrations under pasture in Florida. Ator and Ferrari (1996) compiled and analyzed groundwater concentrations of NO_3-N from more than 850 sites in the Mid-Atlantic Region (including parts of Delaware, Maryland, New Jersey, New York, North Carolina, Pennsylvania, Virginia, and West Virginia) and categorized the sites by land use. The median concentration in pasture lands was 5.5 mg/L, and not significantly different from areas in row or field crops. They concluded that field rotation or the close proximity of crops and pastures within agricultural areas leads to a mixed-agricultural effect on groundwater quality.

The groundwater concentration associated with pasture for the Santa Fe basin was assumed to be 5.5 mg/L, based on MACTEC (2010a). It will be shown that pasture land is a major contributor to estimated nitrate loadings in the Santa Fe basin, and the limited basis for the estimated groundwater concentration suggests that this factor contributes significant uncertainty to the estimated nitrate loadings in the Santa Fe basin.

CAFOs

Concentrated animal feeding operations were defined to include poultry feeding operations, cattle feedlots, dairies and aquaculture operations. A very small portion of the Santa Fe springsheds are used for such operations (< 0.08%), but may have disproportionate nitrate loadings. Poultry feeding operations use the most Santa Fe springsheds acreage (286 acres) within this category, in contrast to the Wekiva basin where cattle feedlots and dairies were more predominant. Therefore the study by Hatzell (1995) who monitored groundwater near poultry (broiler) farms in North Central Florida was used as the basis for groundwater nitrate concentrations associated with CAFOs in the Santa Fe springsheds. Hatzell (1995) found that concentrations averaged 13 mg/L.

Tree Plantations (Silviculture)

Tree plantations are a major land use within the springsheds/study area, comprising 20% of the total area. At the request of ACEPD, AMEC reviewed relevant literature to estimate groundwater concentrations expected in the tree plantation land use category. FDACS (2008) recommends application of 56 kg/ha/yr, total Nitrogen (TN), to tree plantations. MACTEC (2010a) provides both assumed (i.e., recommended) fertilizer application rates for a variety of land use categories, as well as the associated shallow groundwater concentrations that have been observed in these land uses. From this information, a general relationship between fertilizer application rates and shallow groundwater concentrations was developed. From this relationship, silviculture land uses may be expected to exhibit shallow groundwater concentrations of 2 mg/L. Minogue, *et al*. (2007) describe experiments conducted to evaluate the effectiveness of silviculture BMPs. In these experiments, they observed concentrations of approximately 2 mg/L after application of 75 kg/ha/yr. Based on this information, the estimated shallow groundwater concentration under tree plantation land uses is 2 mg/L. This estimate is relatively uncertain, and may be modified if better information becomes available.

Summary

Groundwater concentrations assumed to be representative of various land uses as discussed in this subsection are summarized in Table 1 and are summarized below.

Table 1. Representative NO3-N Groundwater Concentrations Assigned by Land Use

Land Use	NO3-N (mg/L)
Row crop	23.0
Citrus (other)[1]	15.0
CAFO	13.0
Golf course (recreational)[2]	8.0
Orchard, nursery	6.0
Pasture	5.5
Field crop, sod	4.0
Commercial/Institutional/Recreational	2.0
Residential	2.0
Tree Plantations	2.0
Industrial/transportation/undeveloped (other)[1]	0.1

[1] subsequently grouped as “other”
[2] Golf course is a subset of recreational
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2.2 Domestic Wastewater

Nitrate loading from domestic sanitary wastewater were estimated by the number of units times the groundwater nitrate loadings per unit. Domestic sanitary wastewater may be collected by sewering and treated in a permitted wastewater facility, or treated and discharged on-site by septic systems.

2.2.1 Permitted Wastewater Facilities

A total of 12 permitted wastewater facilities are located within the Santa Fe springsheds. These facilities were identified by ACEPD, and ACEPD also provided monitoring data for flow and TN for each facility. These facilities are listed in Table 2, ranked in order of mean annual loading in kilograms per year of TN. After verifying that all discharges impact the groundwater table (i.e., none discharge into a river where the nitrogen would be carried outside of the springsheds), TN concentrations were multiplied by corresponding average flow values, and then prorated for the length of time in between sampling sessions to get a total loading for the time period. This was summed and averaged across each individual period of record to get the values in Table 2. The three largest wastewater treatment plants (WWTPs), Lake Butler, Alachua, and Newberry, represent almost 96% of the permitted facility loading. Sunshine mobile home (MH) park is no longer in operation, the plant closed in 2005.

Table 2. Permitted Wastewater Facilities

Facility Name	Mean Annual Loading	
	Lb NO3-N/yr	**(MT NO3-N/yr)**
Lake Butler WWTP[1]	11,543	5.240
Alachua WWTP	11,107	5.043
Newberry WWTP	5,697	2.587
High Springs WWTP	718	0.326
Arredondo MH Park	369	0.167
Camp McConnell	52	0.023
Sunshine MH Park[2]	45	0.020
FL Welcome Station	33	0.015
Ft. White High School	20	0.009
Archer Homes	20	0.009
Camp Kulaqua	15	0.007
Archer Community School	11	0.005
Total Annual Loading	29,630	13.452

[1] Loadings represent discharge to groundwater. The Lake Butler facility discharges to groundwater in the surficial aquifer, in an area where the Floridan is confined. Therefore its impact on springs may be relatively less than facilities discharging in areas where the Floridan is unconfined.
[2] No longer in service, plant closed in 2005.
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Two major wastewater treatment facilities in Alachua County are the Gainesville Regional Utilities Main Street and Kanapaha Water Reclamation Facilities. The Main Street facility discharges to Sweetwater Branch, which recharges the UFA, however, this area is within the GRU capture zone and outside of the study area. The Kanapaha facility effluent is disposed by deep well injection at depths of 450-1,200 feet, which is below the portion of the upper Floridan aquifer that supplies water to the springs on the Santa Fe River. These facilities discharge greater amounts of NO3-N than the facilities quantified in Table 2, but these discharges do not migrate toward the Santa Fe River springs and would be well outside the modeled 100-year groundwater travel time area (see Section 5.0). Discharge from the Main Street facility is approximately 31 MT NO3-N/yr, while the Kanapaha facility discharges approximately 69 MT NO3-N/yr.

2.2.2 Septic Systems

The Florida Department of Health (FDOH) maintains a database with the estimated number of septic systems by county. The database does not include the locations of the septic systems. The springsheds of the Santa Fe basin encompass portions of several counties, and the FDOH database cannot be used to estimate the number of septic systems within the Santa Fe springsheds. FDOH has recently undertaken to construct a state-wide GIS database that would include septic system locations. That project had not been completed prior to performing calculations for the current study, and the GIS map of septic systems is not yet available. When this product becomes available it could be used to augment the approach used here to estimate the number of septic systems in the springsheds.

The approach used to estimate the number of septic systems in the Santa Fe springsheds was based on the assumption that the density of septic systems (tanks/acre) is a function of land use. FDOH has completed a GIS map for the Wekiva Study Area (a major portion of the Wekiva River basin studied by MACTEC, 2010a). From this map, MACTEC (2010a) determined the density of septic systems by land use. MACTEC (2010a) demonstrated that this procedure realistically estimates the total number of septic systems by county, which can be compared to the FDOH inventory. MACTEC (2010a) used the septic system densities by land use to estimate the total number of septic systems in Orange and Lake Counties, and found the procedure was accurate within approximately 10%. During this study, the septic system density procedure was used to estimate the total number of septic systems in Alachua County at 49,828 septic systems, while the

FDOH inventory estimated 39,226 in 2004; and the Alachua County Health Department staff estimated 40,000 to 45,000 in 2008. These comparisons indicate that the procedure for estimating septic systems within the study area is probably conservative and may overestimate the total number of septic systems. It is likely that Alachua County has a higher proportion of its population served by central sewer systems than was observed in the Wekiva River basin. However, a large portion of the population served by central sewer in Alachua County is in the City of Gainesville, and much of the city is not within the springsheds. Therefore the degree of conservatism may be somewhat less than indicated by the County-wide comparison, which overestimated by about 28%.

Applying this procedure to the Santa Fe springsheds, the total number of septic systems in the study footprint is estimated to be 39,714. Each tank was assumed to release 20 pounds (lb) of nitrogen per year (N/yr) to the environment (Roeder, 2006; Anderson, 2006). According to Anderson and Otis (2000), 50 to 90% of the N released from septic systems reaches the water table. In this study it was assumed that 70% of the N released by septic systems is delivered to groundwater as NO3-N, i.e., 14 lb/yr per system (0.0064 MT/yr).

3.0 Estimated Loadings of Nitrate to the Santa Fe Springsheds by Land Use and Source Type

Nitrate loadings to groundwater within the Santa Fe River springsheds/study area were estimated using procedures described in Section 2. Results are provided in Table 3 and illustrated in Figure 8. Pasture land use was estimated to be contributing 43% of the total nitrate loading in the study area, while CAFOs contribute a negligible nitrate loading of less than 1%. Fertilizer applied to tree plantations, field and row crops, residential, commercial, institutional, recreational, and orchard/nursery and other land uses is estimated to contribute approximately 38% of total loading. Sanitary wastewater, including septic systems (17%) and permitted wastewater facilities (1%), comprises 18%.

Table 3. Estimated Nitrate Loadings to the Santa Fe River Springsheds in 2004

Category	Loading (lb/yr)	Loading (MT/yr)	Loading (percent)	Uncertainty in Loading**
Pasture	1,363,000	618	43	±30%
Septic*	557,000	252	17	±30%
Tree Plantations	445,000	202	14	±50%
Field crop, sod	297,000	134	9	NE
Residential	229,000	104	7	NE
Row crop	156,000	71	5	NE
Comm/Inst/Rec	39,000	18	1	NE
Orchard, nursery	37,000	17	1	NE
Other***	37,000	17	1	NE
Wastewater Facilities	30,000	13	1	NE
CAFO	13,000	6	0	NE
Total	**3,203,000**	**1452**	**100**	

*Based on 14 lb/yr per system (0.0064 MT/yr)
** Uncertainty estimates are semi-quantitative based on review of information presented.
*** Other land uses include citrus, industrial, transportation, undeveloped (see Table 1)
NE = error not estimated because the source type contributes less than 10% of total loading. In addition these source terms are judged to be less uncertain than the source types for which uncertainty estimates are provided.
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Uncertainty in Estimated Loadings

As described in Section 2, estimated loadings in this report are subject to substantial uncertainties. Land use based loadings are estimated by multiplying a representative groundwater concentration for a mapped land use ($NO3_{LU}$) times the recharge rate by location within the springsheds (see equation in Section 2.1). Relative (percentage) errors in either recharge rate or NO3-N groundwater concentration ($NO3_{LU}$) contribute an equivalent relative percentage error in the loading estimates. Section 3.1.1 summarizes the contribution to uncertainty in loadings dues to uncertainty in groundwater concentration, and Section 3.1.2 summarizes uncertainties in recharge rates.

Domestic wastewater loadings are based on monitoring data from a limited number of permitted facilities and are relatively reliable.. On the other hand loadings from septic systems are more uncertain – these are calculated by multiplying an estimated number of septic systems within the springsheds by a loading rate per system. Neither the total number of septic systems nor

Pasture Land Use – Western Alachua County

the loading rate per system is known precisely.

The largest portion of the uncertainty in the *total loading estimates* is derived from uncertainties in the estimated groundwater concentrations (by land use) and in the groundwater recharges rates; since more than 80% of the estimated NO3-N loading is derived from these data sources. The nature of the uncertainties is most effectively characterized by examining the largest sources; pasture, septic, and tree plantations.

The groundwater concentrations used to estimate loadings in the lower Santa Fe springsheds are not based on monitored concentrations from within the springsheds. Rather they are based on the assumption that various land uses have a characteristic effect on groundwater quality at the water table within that land use, and the estimated concentrations are derived from selected monitoring data that characterize that land use. Within any land use, groundwater concentrations of NO3-N can vary depending on climate, soil types, land management practices, and the period of time that land use and management has persisted.

To some extent the effects of climate and soil type variations are mitigated by preferentially using data from Florida where possible, but not all land uses can be adequately characterized using data only from Florida. Nonetheless, research summarized by MACTEC (2010a) shows that groundwater concentrations under such land uses as row crops, field crops, and golf courses are relatively consistent in widespread North American locations. For example, groundwater NO3-N concentrations associated with row crop agriculture in Suwannee County, Florida, the southeastern Coastal Plain, and in Wisconsin range from 20 to 26 mg/L. Nitrate-nitrogen from field crop land uses range from about 3 mg/L under alfalfa in Minnesota to 5 mg/L under wheat in northern Mexico. Additionally, groundwater NO3-N concentrations reported from Florida golf courses are generally consistent with results reported from outside of Florida. Groffman, *et al*. (2009) observed similar concentration of NO3-N in leachate from residential turfgrass in Maryland as MACTEC (2010a) observed in groundwater in the springshed of Wekiwa Spring (FL).

The effects of land management practices can be significant and may lead to errors in loading estimates. In this study, all pasture land is assigned a representative groundwater concentration, which does not account for the fact that some pasture land is not routinely fertilized, while other “improved pasture” may receive significant fertilizer applications. Residential fertilizer use also varies substantially by homeowner. These uncertainties are expected to be mitigated by the relatively robust data sets that were used to support the estimates of representative groundwater concentrations which have been based on an average of a large number of measured concentrations, with the presumption that the average can be relied upon as representative of the land use. For example, 850 site samples were used to estimate a representative concentration in pasture land and 84 samples from 24 sites, which span a range of intensity of fertilizer use and irrigation, were used to estimate a representative concentration in residential land use.

Section 4 demonstrates significant changes in land use throughout the lower Santa Fe springsheds from 1995 to 2004. When land use change occurs, the loading rates are expected to transition slowly from the rate characteristic of the former land use to that of the current land use as nitrogen is either released or accumulated in the soil profile. The modeling approach does not account for changes in soil storage that occur when land use or management practices change. These calculations assume the effect of the change is immediate.

Source-Specific Uncertainties

The following subsections summarize available information regarding uncertainty in loading estimates for the source types that contribute the greatest loadings, and correspondingly may contribute significant uncertainty to relative and absolute source attribution.

Pasture

As discussed in Section 2, loading from pasture is relatively uncertain, and since pasture is estimated to be a major contributor to total NO3-N loading in the lower Santa Fe springsheds, the total loading estimate is relatively uncertain. The best data identified to characterize groundwater concentrations associated with the pasture land use is from the mid-Atlantic region, and the source document (Ator and Ferrari, 1996) indicated that groundwater concentrations in pasture land use may be affected by row or field crop land uses, which both have relatively high NO3-N concentrations. Error in applying these data to the study area could be ± 30%. The estimates are somewhat more likely to be too high than too low, because the data source may be influenced by land uses with somewhat higher loadings. Because this land use is common in the study area, it is possible the actual loading from this land use could result in a 15% error in total loading, and the relative contribution of this land use could be considerably less or more than indicated by the results of this study. Loading from pasture land use is also uncertain due to uncertainties in recharge rate (see further discussion in Section 3.1.2).

Septic Systems

Loading from septic systems are calculated by multiplying a discharge rate per septic system times the number of septic systems in the Santa Fe springsheds. Significant uncertainty may be associated with both inputs to the calculation (discharge per system and number of systems). Both are addressed in this subsection.

The estimates presented in this report were performed based on studies by Anderson and Otis (2000), Anderson (2006), and Roeder (2006) indicating that each septic system discharged 14 lb NO3-N per system per year. That estimate was based on nationwide data. After these calculations were performed additional studies became available. MACTEC (2010a) summarized and interpreted monitoring studies originally presented by Ellis & Associates, Inc. (2007). Ellis & Associates monitored groundwater impacts of three (3) septic systems in the Wekiva River Basin. From these data, MACTEC (2010a) calculated an average discharge of 16.3 lb NO3-N per septic system per year, while the Ellis & Associates data suggests that the value used may be an underestimate. Although the Ellis & Associates data are clearly preferred for MACTEC's (2010a) study of the Wekiva River Basin, these data are not necessarily superior to the 14 lb/yr estimate. The difference between the two available estimates indicate that the uncertainty in the discharge per system is approximately 15%..

Section 2.2.2 presents information indicating that the estimated total number of septic systems in the Santa Fe springsheds may be off or uncertain by 10 to 28%. The number of systems is more likely to be an overestimate.

Since the discharge per system is more likely to be underestimated, while the number of systems is more likely to be overestimated, the loading rate may in fact be fairly accurate. Assuming, however that there is no particular bias, a random combination of uncertainty of 15% in the discharge per system and a 25% uncertainty in the number of systems indicates that the total loading is uncertain by approximately 30% based on first order error analysis. In the context of the total loadings presented in Table 3, a 30% error in loading from septic systems would produce a 5% error in the total springsheds loading.

Tree Plantation (Silviculture)

As discussed in Section 2, loading from tree plantations is relatively uncertain, and since tree plantations are estimated to be a major contributor to total NO3-N loading in the lower Santa Fe springsheds, the total loading estimate is relatively uncertain. The estimated groundwater concentrations could be in error by as much as ± 50% because they are estimated from the FDACS-recommended fertilization rate rather than monitored groundwater concentrations, and actual fertilization practice may differ from the recommended rate. Since silviculture is a common land use in the study area, and is estimated to contribute 14% of total loading, this uncertainty could result in a 5 to 10% error in total loading, and the silviculture land use could contribute between 5 and 25% of the total loading. Loading from silviculture land use is also uncertain due to uncertainties in recharge rate (see further discussion in Section 3.1.2).

Loadings for Remaining Source Categories

Uncertainties in loading from all remaining source categories listed in Table 3 are substantially less than the uncertainties associated with categories discussed above for two reasons:

- The relative contributions of all remaining source categories are substantially less than the categories discussed above. Pasture, septic systems, and tree plantations are estimated to contribute 74% of the total loading, while none of the remaining categories contribute as much as 10% to the total loading.
- The data used to estimate loadings for the remaining categories are relatively reliable. Source-specific monitoring data from Florida are available and were used to estimate the representative concentrations of NO3-N in groundwater associated with each land use. Wastewater discharge rates and effluent water quality data from the lower Santa Fe springsheds are available and were used to estimate the loading from permitted wastewater facilities.

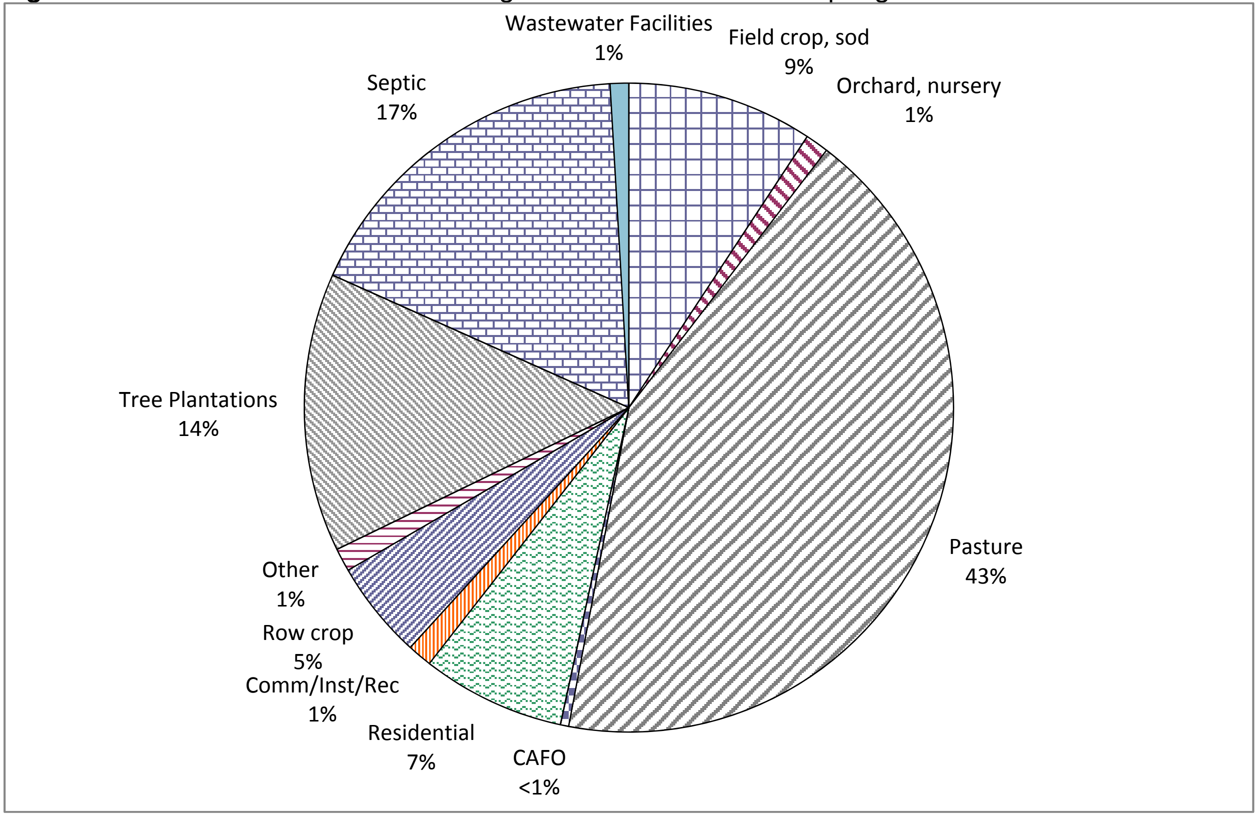
Uncertainty in Groundwater Recharge Rates

Loading from all source categories except permitted wastewater facilities and septic systems are proportional to groundwater recharge rates. Groundwater recharge rates were provided by Sepúlveda (2002), a model application referred to as the MegaModel. The MegaModel simulates groundwater for most of peninsular Florida. As a result its resolution is relatively coarse. The recharge layer grid is based on cells of 5,000 ft so some geologic structures and hydrogeologic processes that change significantly over distances of less than 5,000 ft cannot be represented precisely. Sepúlveda (2002) states that “model results should be interpreted at scales larger than the representative grid cell”. In other words, small scale phenomena, including localized features that can focus recharge, such as swallets, are not precisely represented by the model. This limitation does not invalidate the model.

The MegaModel, represented the best publicly available model to support these calculations when they were performed. As discussed by Sepúlveda (2002), “because Florida comprises several Water Management Districts, most ground-water modeling efforts have been focused within the boundaries of individual Districts, thus reducing the potential to simulate inter-District ground-water flow”. This identified limitation of available models directly applies to the springsheds of the lower Santa Fe which encompass areas within the Suwannee, St. Johns River, and Southwest Florida Water Management Districts. AMEC reviewed the information available from the MegaModel, and understands that it is generally consistent with published information about the hydrogeology of the springsheds, including available observations and other models. Alternative data sets, e.g., the SJRWMD East Central Florida model, SJRWMD North Central Florida model, and SRWMD North Florida model are either not readily available or do not cover the full footprint of the springsheds.

Sepúlveda (2002) compared measured and simulated heads at more than 1,600 control points; compared measured and simulated base flows in rivers at 10 USGS gaging stations; and compared measured and simulated spring flows in 156 springs. Heads were generally accurate within 5 ft, and spring flows were simulated within 4% of measured flows. These extensive comparisons, and relatively accurate simulation, demonstrate that the model can be relied upon at the scale of the lower Santa Fe springsheds, and the MegaModel’s springsheds average recharge rate (8.55 inches/yr) is reliable for the 1993-4 calibration period, which was also shown to be representative of a 30-year period from 1961 through 1990. AMEC’s loading model was re-run using a spatially invariant recharge rate of 8.55 inches/yr across the entire lower Santa Fe springsheds as a sensitivity test, and the total loading rate changed only 4%. Therefore any errors in the spatially varying recharge rates are small compared with the potential errors that may be generated by uncertainties in groundwater concentrations under pasture land and tree plantations, and the loadings from septic systems.

Figure 8. Estimated Nitrate Loadings to the Santa Fe River Springsheds in 2004



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4.0 Past and Projected Land Use and Effect on Nitrate Loading

Trends in land use within the Santa Fe Springsheds were used to project future land use to the year 2030. Loadings associated with historical (1995) and projected future land use (2030) were estimated and compared with the 2004 loadings. Despite simplified loadings estimation procedures for 1995 and 2030, the 2004 loadings estimates, which were calculated more precisely, were reproduced to within about 5%. This analysis shows that loading rates were probably considerably higher in 1995 than they were in 2004, but projected changes in land use are not likely to cause significant changes in loadings of nitrate to the springs during the next 20 years, barring major changes in nitrogen inputs to groundwater.

4.1 Past and Projected Land Use

Land use categories (FLUCCS) were grouped in “groundwater loading categories” that are unique in the way that those FLUCCS codes are processed in the loading model. For example, row crop agriculture typically uses much more fertilizer and irrigation than field crop (hay, turf farms); and row crop land uses have greater loading rates than field crop. Concentrated animal feeding operations, defined to include feedlots, dairies, and aquaculture, have relatively high loadings per acre. On the other hand commercial, institutional, and recreational land uses are assumed, in the loadings model, to have similar loading as residential areas, except they may have different pervious areas. Since these land uses comprise a small fraction of the total acreage, they are grouped; but separated from residential because their rate of change in acreage may be different from residential.

Some parcels were coded differently in 1995 and 2004, even though their land use has not changed. For example, San Felasco Hammock and Paynes Prairie Preserve State Parks were categorized as undeveloped in 1995, but as recreational in 2004. The recreational land use in the loading model is simulated as if it comprised playing fields, picnic grounds, etc., with managed turf grass. Therefore, for purpose of the groundwater loading model, it is more appropriate to characterize these conservation lands as undeveloped, rather than recreational. Such modifications were made as appropriate. Therefore these groupings reflect what is significant to the loading model, but consideration was also given to separating land uses whose rate of change may differ because they are affected by different socioeconomic factors.

Acreage in the Groundwater Loading Land Use Categories in 1995 and 2004 are shown in Table 4, which is sorted by 2004 acreage. Between 1995 and 2004, the State of Florida, Alachua County, and other private entities have acquired significant acreage as conservation land. These may include land in agriculture, pasture, or tree farms prior to 2004. As a result, the undeveloped category increased in acreage from 1995 to 2004 (increase of approximately 13,000 acres, or 7% of the 1995 acreage). The largest part of this 13,000 acre increase in undeveloped land from 1995 to 2004 came from the tree farm category (7,500 acres). AMEC does not expect this growth in undeveloped acreage to continue.

Acreage in pasture was relatively stable from 1995 to 2004, decreasing by approximately 3,600 acres or 3% of the 1995 acreage. A similar decrease in tree farm acreage of 3,000 acres also occurred, and this was due to conversion to undeveloped (presumably conservation land).

Residential land use increased by 6,200 acres, representing an 11% increase from 1995 residential acreage. The increase in residential came from a wide variety of land uses, but the largest conversion to residential came from pasture (2,700 acres) and tree farms (1,900 acres).

Table 4. Land Use Changes from 1995 to 2004

Groundwater Loading Land Use Category	Acres (1995)	Acres (2004)	Percent Change
Undeveloped	189,800	202,644	↑7%
Pasture	122,567	116,145	↓5%
Tree Farm	114,071	111,005	↓3%
Residential	57,490	63,688	↑11%
Field Crop	10,116	37,164	↑267%
Com/Inst/Rec	9,718	10,365	↑7%
Industrial	3,965	4,600	↑16%
Row Crop	41,974	3,948	↓91%
Other Agriculture	1,907	1,961	↑3%
CAFOs	328	417	↑27%

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Notes: Com/Inst/Rec = Commercial, Institutional, and Recreational
CAFOs = Concentrated Animal Feeding Operations, including feedlots, dairies, and aquaculture

The largest percentage change in any land use was the substantial loss of acreage in row crop agriculture. This category decreased by 38,000 acres, from 1995 acreage of 42,000. More than 90% of the land used for row crop agriculture in 1995 is now used differently. Row crop agriculture has been converted to field crop agriculture (16,000 acres), pasture (14,000 acres), and tree farms (5,000) acres. These changes, plus conversion of pastureland to field crop, increased field crop acreage by 27,000 acres up to a total of 37,000 acres, a near quadrupling of acreage in this category from 1995 to 2004.

Commercial/institutional/recreational, industrial, other agriculture (e.g., nurseries), and CAFOs all increased by less than 1,000 acres each.

Initially, AMEC evaluated a simple linear extrapolation of land use trends to 2030, based on the changes observed from 1995 to 2004. Such a simple model, however, is not realistic. First, a linear projection of the rate of change of row crop acreage would result in an estimate of negative row crop acreage by 2030, a nonsensical result. Large increases in undeveloped land and field crop agriculture would also be predicted by a simple linear extrapolation model, results which are judged to be unrealistic. Therefore, AMEC applied a modified linear change analysis, with the following features:

a) It was assumed that total undeveloped acres will remain unchanged. Any acquisitions of conservation land will be counterbalanced by more intensive use of currently undeveloped land.
b) It was assumed that row crop agriculture in the study area will not disappear altogether, but rather remain at 2004 acreage.
c) Since row crop acreage would no longer be available for conversion to other uses, all land uses that realized gains from conversion of row crop acreage would have their growth rates reduced accordingly.
d) The observed dramatic increase in field crop acreage, while pasture was slowly declining, could not be sustained. A significant portion of field crop acreage is used for livestock feed locally. It was assumed that the combination of field crop and pasture would increase gradually, and the portion of each in their combined acreage would remain steady, maintaining a balance of locally produced feed to livestock.
e) Finally, since undeveloped acreage was arbitrarily held constant in the original linear extrapolation, while in reality it appeared to be increasing, the difference was made up by increasing tree farm acreage. The concept behind this adjustment is that the apparent reduction in tree farm acreage was coming from conservation conversion (e.g., Alachua County Forever). It was assumed this trend would not continue. The selection of the tree farm category to be the

"beneficiary" of an expected reduction in net conservation land is supported by the finding that the largest source of conversion to undeveloped from 1995 to 2004 was from tree farm.

f) The remaining categories increased linearly at the 1995 to 2004 rate, after correcting for the lack of row crop acreage as a source for conversion.

Given these constraints, each category changes at a constant number of acres per year. Table 5 provides the rate of change for each category. Resulting changes in acreage by category as a portion of the total study area acreage are not very large, as illustrated in Figure 9.

Table 5. Rate of Change Projected from 2004 to 2030

Groundwater Loading Land Use Category	Acreage Change per Year
Residential	540
Com/Inst/Rec	61
Industrial	49
Undeveloped	0
Pasture	(716)
Row Crop	0
Field Crop	(229)
Other Ag	(3)
CAFOs	9
Tree Farm	290

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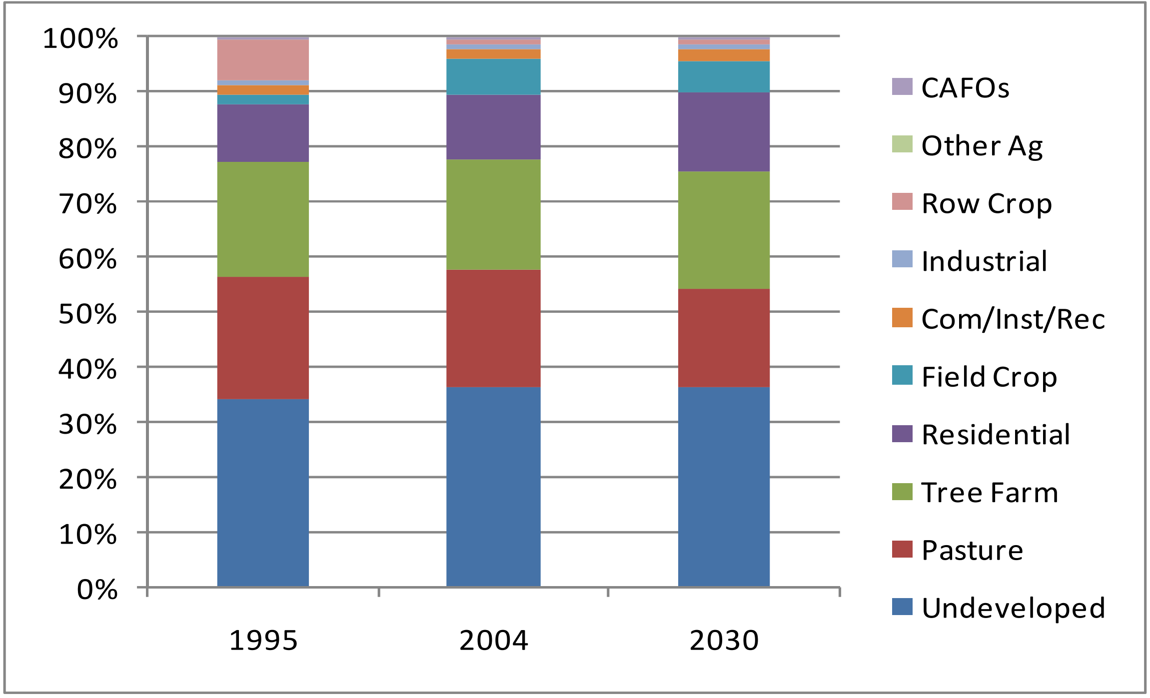
Figure 9. Projected Change in Land Use within the Santa Fe River Springshed 2004 - 2030



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4.2 Effect of Land Use Changes on Nitrate Loading to the Santa Fe Springsheds

The historical and projected changes in land use within the springsheds have an effect on nitrate loadings to groundwater in the springsheds. The procedure used to estimate loadings in 2004 cannot be precisely reproduced for the 2030 projection because specific locations where land use is likely to change has not been estimated by the procedures described in Section 4.1. The loading rates depend on recharge rates, which depend on location of a land use within the springsheds. Therefore an alternative, and less accurate procedure was developed to estimate how past and projected land use changes may affect loading rates. The accuracy of the alternative procedure was also investigated.

The alternate procedure is based on the following simplifying assumptions:
1. Recharge rates do not vary with location within the springsheds;
2. Loadings from permitted wastewater facilities are the same in 1995 and 2030 as in 2004;
3. The number of septic systems in the springsheds/study area in 1995 = estimated number of septic systems in the study area in 2004 x {septic systems in Alachua County (1995) ÷ septic systems in Alachua County (2004)} where the County totals are from FDOH (2009); and
4. The number of septic systems will increase at the same rate (number/yr) from 2004 to 2030 as occurred from 1995 to 2004.

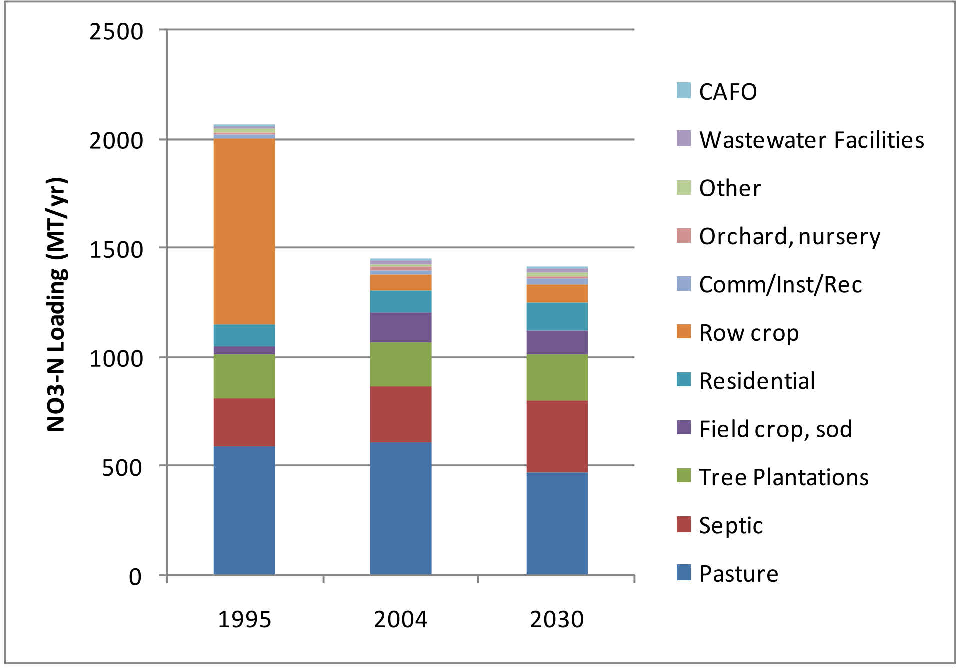
Potential errors introduced by assumption 1, above, have been estimated by using the same assumption and preparing an alternative estimate of 2004 loading, which may be compared with the loadings based on spatially varying recharge rates – the procedure used for the more accurate estimate of 2004 loadings (Section 2.1). Loadings estimated by multiplying spatially varying recharge rates by concentrations that vary with land use as described in Section 2.1 total 1189 MT/yr. Applying the springsheds average recharge rate from the MegaModel of 8.55 inches/yr, rather than the spatially varying recharge would change the land use based loading total to 1141 MT/yr, a difference of 48 MT/yr, implying that use of simplifying assumption 1 would cause an error of 3%.

Potential errors introduced by assumption 2 are likely to be quite small since permitted wastewater facilities only contributed 13.5 MT/yr in 2004, or 1% of total loadings. It may be anticipated that loadings from permitted wastewater facilities could be higher in both 1995 and 2030 than they were in 2004. Loadings could have been higher in 1995 than today if enhanced wastewater treatment systems were installed between 1995 and 2004 at any of the permitted facilities. On the other hand, in the absence of regulatory changes, the contribution of permitted wastewater facilities is likely to be higher in 2030 than 2004 due to an increase in population served by central sewer systems, which may be expected with population growth. In any case, the contribution of permitted wastewater facilities is expected to be a very small component of total loading in both 1995 and 2030.

Errors associated with assumptions 3 and 4 above were not estimated. As discussed in Section 2.2.2, the number of septic systems in the springsheds study area is relatively uncertain in the base year 2004. The procedure for estimation in 1995 probably does not, of itself, introduce significant errors. Projection of the number of septic systems in 2030 is relatively uncertain.

Applying these assumptions, the nitrate loadings were estimated for the major categories of land use, and contribution of septic systems in 1995 and 2030. Results are illustrated in Figure 10. The analysis indicates that loadings were probably substantially higher in 1995 than they were in 2004, with a best estimate of 2,071 MT/yr in 1995, 43% higher than in 2004. The most important difference is the much greater contribution from row crop agriculture, a land use that generates high nitrate loading rates, and whose acreage decreased by 91% from 1995 to 2004.

Figure 10. Estimated Past and Projected Nitrate Loadings



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Loadings are estimated to remain relatively unchanged between 2004 and 2030. Residential land use is projected to increase, and this would increase the contribution of residential fertilizer, and septic systems. On the other hand, pasture land use is projected to decrease, offsetting the projected increases from residential fertilizer and septic systems.

5.0 Groundwater Travel Time

AMEC estimated travel time via the upper Floridan aquifer (UFA) to the Santa Fe River/Springs (SFRS). In the immediate vicinity of the SFRS the UFA consists of numerous solution cavities. Within this area, flow does not adhere to classical porous media fluid dynamics – Darcy's Law is not satisfied. Cave systems in the vicinity of four of the springs have been mapped, and have been shown to extend as much as one mile from the main spring vent [Florida Geological Survey (FGS), 2009]. Groundwater travel time through such caverns will be very short, approximately one month or less. Martin (2003) found that groundwater travels from Santa Fe River Sink to River Rise in less than 1 week. Swallets[3] are numerous throughout the region. The FGS (2006) conducted a partial survey of the region and identified 222 swallets, of which 39 lie within the springsheds boundary. Physiographically, the swallets are located in an area known as the 'marginal zone', characterized by thick sediments from the Northern Highlands allowing well defined stream systems to occur, which then disappear into the subsurface as the sediments thin over porous limestone bedrock (Butt, *et al*., 2006). This boundary is geologically referred to as the Cody Scarp. Swallets within this region are presumed to be connected to the UFA system (FGS, 2006). Dye trace investigations have demonstrated that water flowing into Mill Creek Sink (located within the city of Alachua, FL) and Lee Sink (located in San Felasco Hammock Preserve State Park southeast of Alachua, FL) reach Hornsby Springs (located on the Santa Fe River) in 12 to 13 days and approximately one month, respectively (Butt, *et al*., 2006). These features, specifically swallets, caves, and areas where dye trace have revealed rapid flow rates, indicate an area of very rapid conduit flow to the SFRS and are shown on Figure 11. From these data, AMEC estimated an area within which travel time to the springs is less than one month, which for purpose of developing a map of groundwater travel times, is virtually instantaneous. The estimate of groundwater travel time is critically dependent on the extent of such conduit flow, and the area affected by conduit flow (presented in Figures 11 and 12) is very uncertain. Conduit flow is most important in proximity to the springs and decreases east and north of the Cody Scarp (Upchurch, 2007; SDII, 2011).

Outside this area of conduit flow, Darcy's Law is used to estimate travel time. A literature review was conducted to obtain regional estimates for several of the parameters (transmissivity, horizontal hydraulic conductivity, and porosity) used in the calculation of travel time by Darcy's Law. The literature review values for transmissivity, horizontal hydraulic conductivity, and porosity were then compared to values used in the USGS MegaModel (Sepúlveda, 2002), which are discussed below. The literature review indicated that values used in the MegaModel are comparable to values reported by others.

The porosity of the UFA was estimated from the literature and applied globally to the entire project area. Effective porosity values for the UFA reported in the literature ranged from 0.05 to 0.45 (Davis and Katz, 2007; Katz, *et al.*, 1999; Martin 2006). This range is consistent with the range reported for karst limestone by Freeze and Cherry (1979) of 0.05 to 0.50. Table 6 summarizes information reviewed in estimating porosity. With limited information regarding porosity values in the study area, a mid-range value of 0.22 was used. Sensitivity to porosity, which is poorly defined, represents the greatest uncertainty in the groundwater travel time estimates.

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[3] Swallets are points where a stream system loses all or part of its water to the subsurface.

Table 6. Summary of Sources for Upper Floridan Aquifer Hydraulic Properties

Source	**Location**	**Porosity**	**Horizontal Hydraulic Conductivity (ft/day)**	**Transmissivity (ft^2/day)**
Clark, *et al*. (1964)	7 locations within springsheds	NA	NA	5,800 – 402,000
Hunn and Slack (1983)	2 locations within springsheds	NA	NA	29,000 – 41,000
GeoSolutions, Inc. (1993)	Newberry (within springsheds)	NA	NA	9,000 – 24,000
Sepúlveda (2002)	Within springsheds	NA	5.5 – 3,600*	5,000 – 3,000,000
Katz, *et al*. (1999)	Lower Santa Fe	0.05 - 0.4	NA	NA
Davis & Katz (2007)	Tallahassee	0.07	NA	NA
Martin (2006)	Santa Fe	0.1 - 0.45	2 - 6,500	NA
Schneider, *et al*. (2008)	North Florida	NA	5 - 10,000	2,000 – 10,000,000
Grubbs & Crandall (2007)	Taylor County	NA	80 - 1,200	1,600 – 1,000,000

NA = Not Available
*calculated by AMEC from information provided by Sepúlveda (2002)

AMEC has reviewed the information available from the MegaModel, and understands that it is generally consistent with published information about the hydrogeology of the springsheds, including available observations and other models. The MegaModel indicates that the UFA in southern Alachua County and northern Marion County does not flow toward the SFRS. This area is included in the study area footprint based on the findings of SDII (2011). The SDII study is probably more accurate on this point, since it focused solely on the SFRS, while the MegaModel is relatively coarse and addresses all of peninsular Florida.

Sepúlveda (2002) developed and calibrated a model (the “MegaModel”) to groundwater flow conditions in peninsular Florida. The model’s input files specify hydraulic properties (hydraulic head, transmissivity, and thickness) of the UFA throughout the Santa Fe springsheds study area on a 1 square mile grid system. Outputs include calculated hydraulic head of the UFA on the same grid system. Whereas aquifer parameters used by Sepúlveda (2002) are consistent with values reported by others (see Table 6), the gridded parameters defined and calibrated by Sepúlveda (2002) were used to calculate travel time. Figure 12 shows the gridded map of UFA horizontal hydraulic conductivity values used to estimate groundwater travel time. Alternative data sets, e.g., the SJRWMD East Central Florida model, SJRWMD North Central Florida model, and the SRWMD North Florida model, are either not readily available or do not cover the full footprint of the springsheds.

Throughout the springsheds, the travel time from location A to location B (between two adjacent grid points) along a flow path towards the conduit flow boundary via the UFA is given by:

$$\text{Travel Time}_{A,B}\ (\text{yr}) = n_{UFA} * X^2 / [HC_{UFA} * (HEAD_A - HEAD_B)]$$

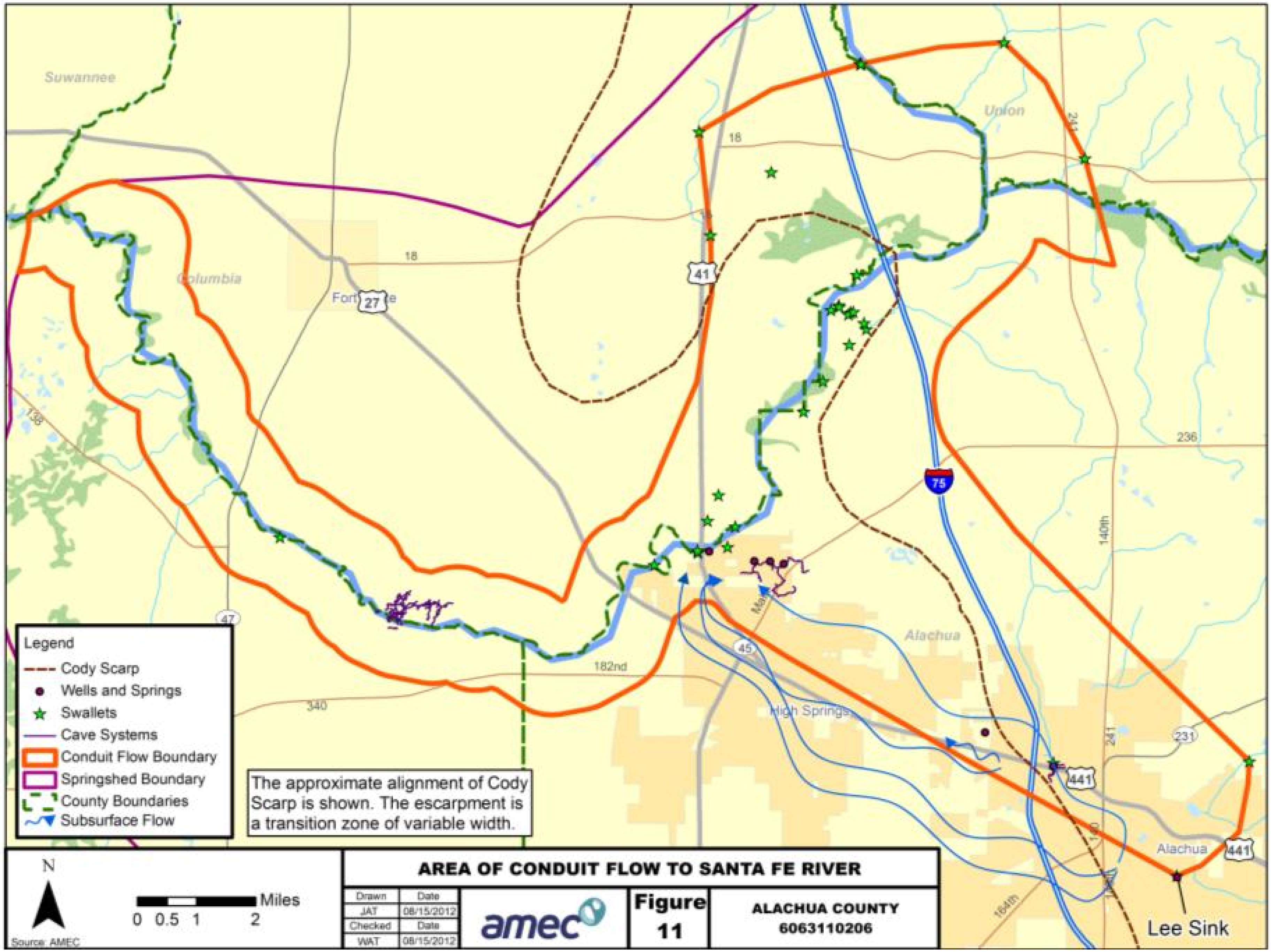
Where:

$\text{Travel Time}_{A,B}$ = Travel Time between any two points (A→B) along a groundwater flow path
n_{UFA} = effective porosity of the UFA (dimensionless)
$*$ = multiplication operator (times)
X = Horizontal Distance from location A to location B (towards the conduit flow boundary, ft)
HC_{UFA} = Horizontal Hydraulic Conductivity of the UFA at location A (ft/year)
= Transmissivity of UFA (ft^2/day) ÷ Thickness of UFA (ft)*365.25
$HEAD_{A,B}$ = Hydraulic Head at location A or B (ft)

To apply this equation AMEC used ArcGIS compatible information provided to us by the USGS characterizing inputs and outputs associated with the MegaModel (Sepúlveda, 2002).

The result of these calculations is shown in Figures 13 and 14. Figure 13 shows the entire springsheds, with contours shown for travel times of 100 and 1,000 years. Figure 14 shows a portion of the springsheds where travel times are generally less than 100 years, and show contours for travel time of 25 and 100 years.

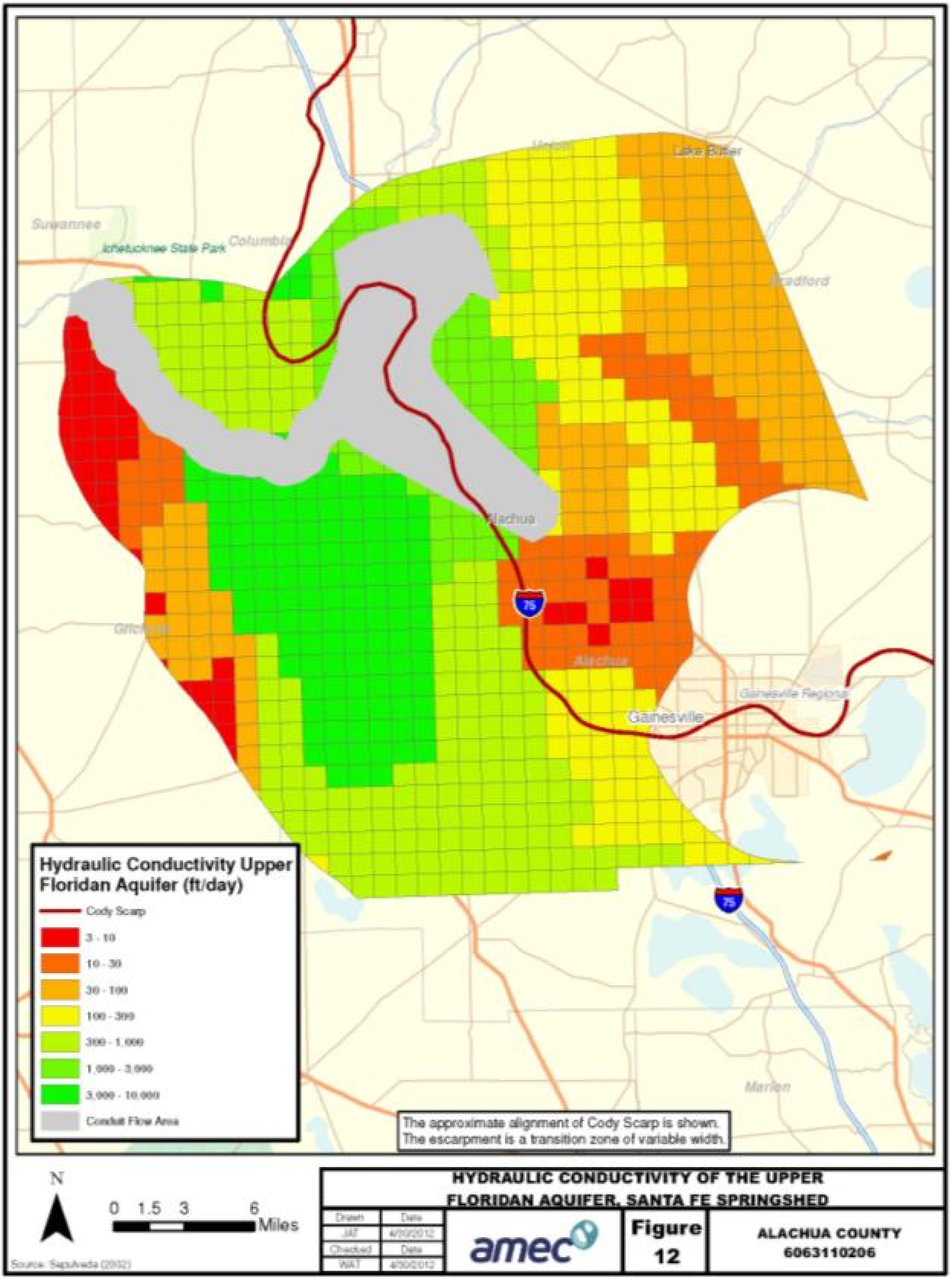
There is one area in particular where travel times determined by the MegaModel may be underestimated. This area is between Alachua and northwest Gainesville and between US 441 and I-75. In this area modeled travel times are calculated to be >1,000 years, but may be less if karst features result in conduit flow in the UFA within this area. The conduit flow boundary was defined by presence of karst features, especially swallets, and encompasses areas where conduit flow has been demonstrated by dye studies. Dye trace evidence extends as far southeast as Lee Sink. Known swallets in the Blues, Turkey and Hogtown creeks watersheds and other karst features extend further to the southeast than Lee Sink, but conduit flow has not been confirmed by dye studies, so Lee Sink was set as the southeast limit of the conduit flow area. It is possible that conduit flow conditions occur further southeast than Lee Sink (Figure 11). If so, groundwater travel times may be less than shown in Figures 13 and 14 in the area between Alachua and northwest Gainesville.



The approximate alignment of Cody Scarp is shown. The escarpment is a transition zone of variable width.

AREA OF CONDUIT FLOW TO SANTA FE RIVER

Figure 11

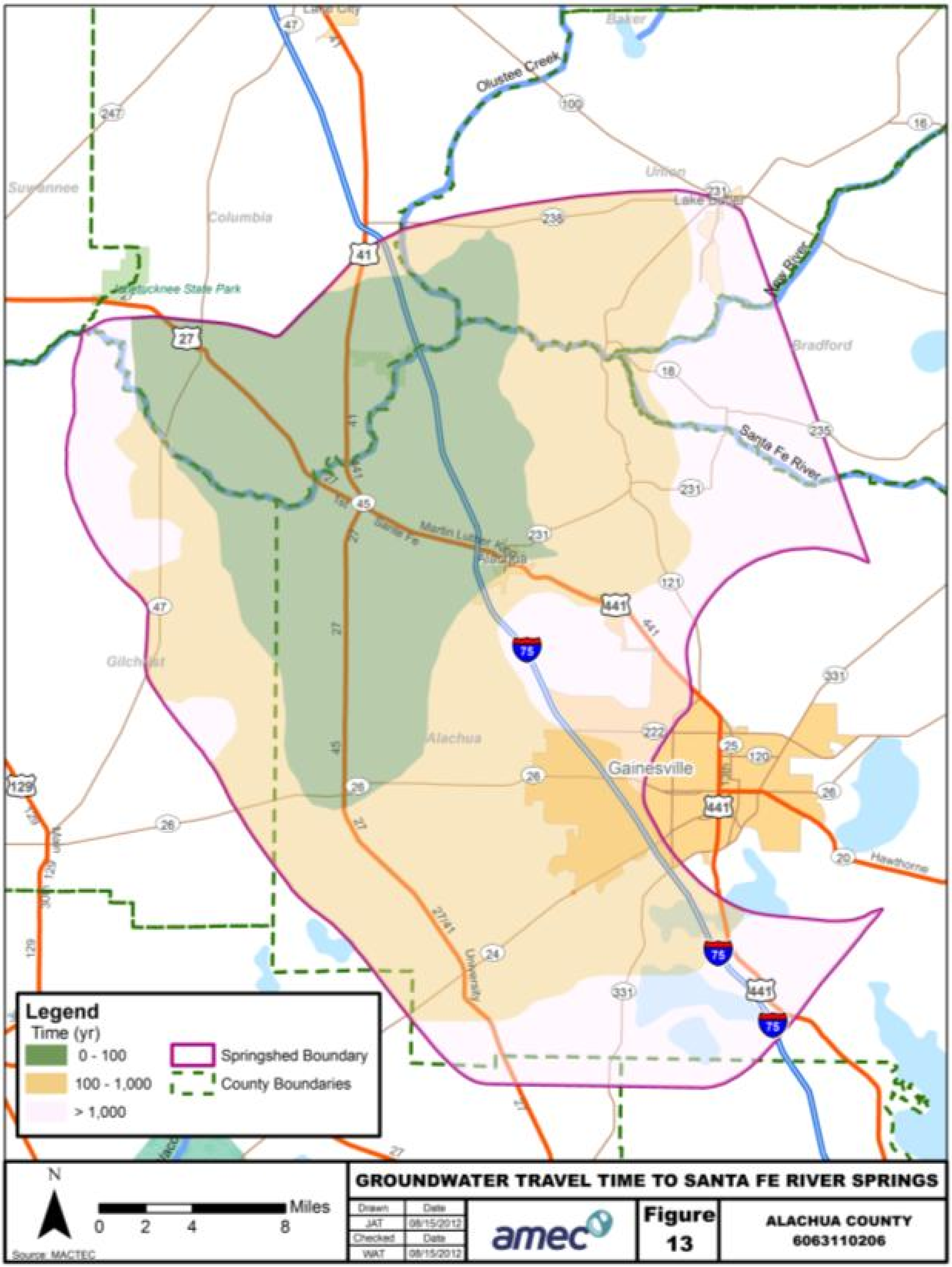


The approximate alignment of Cody Scarp is shown.
The escarpment is a transition zone of variable width.

HYDRAULIC CONDUCTIVITY OF THE UPPER FLORIDAN AQUIFER, SANTA FE SPRINGSHED

Figure 12

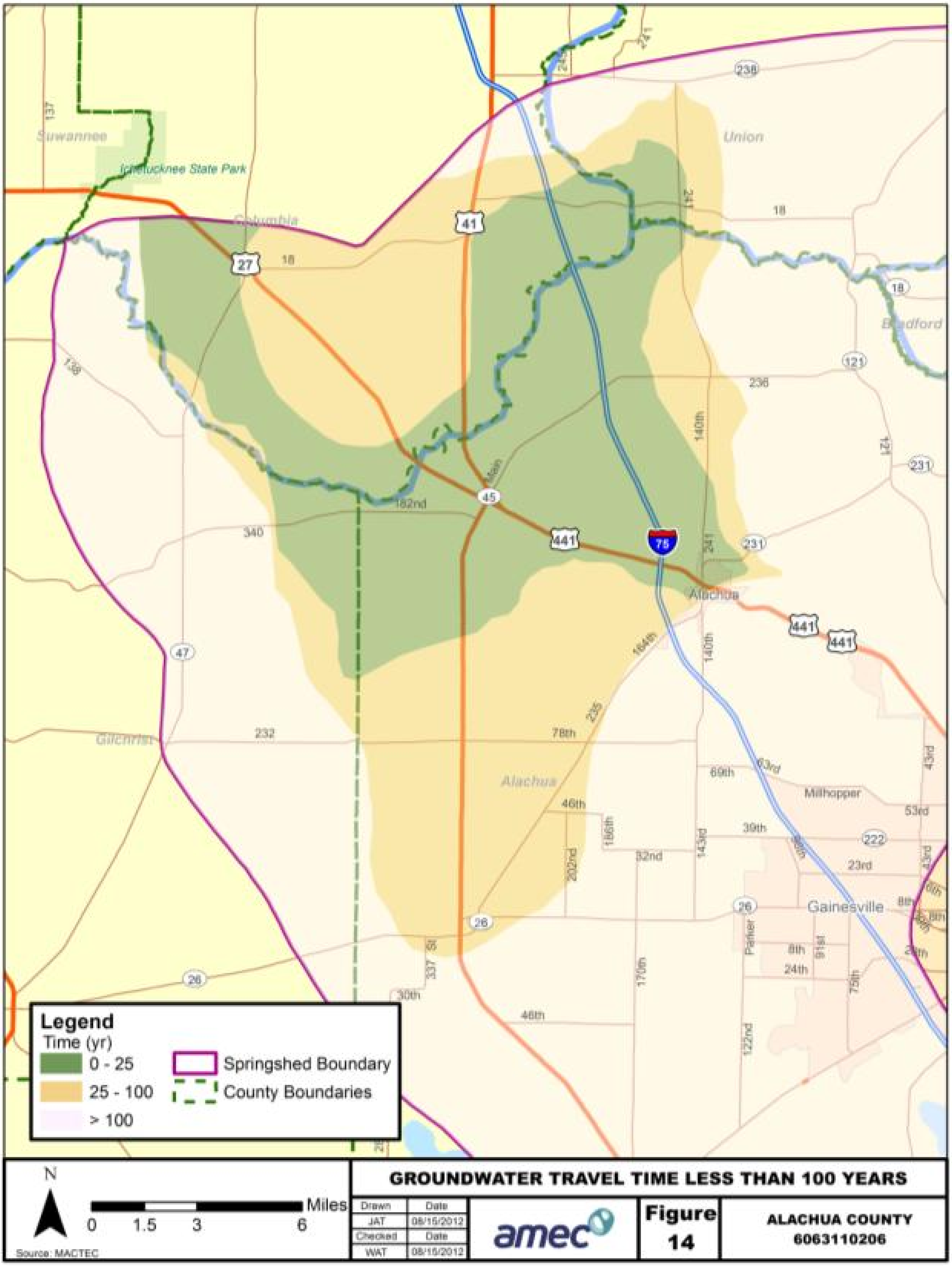
Source: Sepulveda (2002)



GROUNDWATER TRAVEL TIME TO SANTA FE RIVER SPRINGS

Figure 13

ALACHUA COUNTY
6063110206



GROUNDWATER TRAVEL TIME LESS THAN 100 YEARS

Drawn	Date
JAT	08/15/2012
Checked	Date
WAT	08/15/2012

amec

Figure 14

ALACHUA COUNTY
6063110206

6.0 Summary

Nitrate loadings to groundwater within the springsheds of the lower Santa Fe River in 2004 were estimated. Loadings were also roughly estimated for 1995 and projected, based on trends in land use, to 2030. Groundwater travel times were also estimated from areas within the springsheds to the Santa Fe River.

Best available information were used to develop a GIS application that

- Estimates loadings of nitrate to groundwater in the springsheds of the lower Santa Fe River;
    - Excludes springs discharging to Ichetucknee River, which lies outside of the study area; and
- Produces pie charts illustrating relative contribution of various source types.

The GIS application was installed on computers of the ACEPD. The application can be used by Alachua County to evaluate alternative management decisions, e.g.

- Revisions to the County's Comprehensive Plan;
- Land development regulations;
- Effects of Best Management Practices; and
- Specific development proposals.

The study area was defined using best available information and intended to represent the springsheds of the lower Santa Fe River, excluding areas discharging to springs of the Ichetucknee River. The study area was based primarily on delineation of the springsheds by SDII (2011) using data from 2007. Boundaries of the springsheds are uncertain, and can change in response to groundwater use and climatic variations (e.g., drought). Areas near the uncertain boundaries are of somewhat less management concern for two reasons:

- Near the eastern boundary, the Upper Floridan aquifer is confined and less vulnerable to surficial sources of nitrate; and
- Near the southern boundary, the groundwater travel time to the river is likely to be more than 1,000 years.

Conceptually, two distinct approaches were used to estimate nitrate loadings to groundwater, depending on the type of source:

- Non-point, or area, sources include leaching of fertilizer nitrogen and livestock waste; and
- Point sources include disposal of treated domestic wastewater by septic systems and permitted sewage treatment plants. These source types are only released to the environment after treatment.

For non-point sources, loadings were based on land use and area. Representative groundwater concentrations associated with a variety of land uses were estimated based, primarily, on published studies where nitrate has been monitored in groundwater under specific land uses. The most reliable data available to estimate groundwater concentrations associated with various land uses would be well designed monitoring studies from Florida that isolate the effect of the specific land use from other surrounding sources. Relatively reliable data from Florida were available for citrus, nurseries, row crop, golf courses, CAFOs, and residential land uses. Somewhat less reliable data were available to estimate groundwater concentrations associated with pasture, field crop (e.g., hay and grains), and silviculture land uses. These concentrations are multiplied by groundwater recharge rates obtained from a groundwater model developed, calibrated, and published by the USGS. GIS software is used to overlay a land use map and a recharge rate map to perform the required calculations.

For point sources (septic systems and permitted sewage treatment plants), loadings are estimated "per unit". The number of septic systems within the springsheds was estimated from data provided by the Florida Department of Health, and the loading from each system was estimated from published, nationwide, estimates. Permitted sewage treatment plants are required to monitor nitrate in their effluents and report these results to the FDEP. These data were acquired to calculate discharges of nitrate to groundwater within the springsheds.

The most important uncertainties affecting the estimated nitrate loadings within the study area depend on the uncertainties in the input data and the site-specific importance of various source types within the study area. The most important uncertainties appear to be as follows:

- Groundwater concentrations for the pasture land use, which is estimated to contribute 43% of the total nitrate loading, were based on data from the mid-Atlantic states. Error in applying these data to the study area could be ± 25 to 50%. Because this land use is common in the study area, it is possible the actual loading from this land use could result in a 20% error in total loading, and the relative contribution of this land use could be considerably less or more than indicated by the results of this study. This uncertainty could be reduced by monitoring of groundwater quality in areas used for pasture in the study area, or elsewhere in Florida.
- Groundwater concentrations for the silviculture (tree plantation) land use were estimated from IFAS Extension recommended fertilizer application rates, considering the relationship between fertilizer application rates and groundwater concentrations for other land uses with reliable groundwater monitoring data. The estimated groundwater concentrations could be in error by as much as ± 50%. Since silviculture is a common land use in the study area, and is estimated to contribute 14% of total loading, this uncertainty could result in a 5 to 10% error in total loading, and the silviculture land use could contribute between 5 and 25% of the total loading. This uncertainty could be reduced by monitoring of groundwater quality in areas used for tree plantations in the study area, or elsewhere in Florida.
- The number of septic systems in the study area is uncertain and could be 10% more or less than the number estimated from the best available data. Since septic systems are estimated to contribute 17% of total nitrate loading, this uncertainty could affect total loading by about 2%, and the relative contribution of septic systems could be between 15 and 20% of the total. This uncertainty could be reduced by ongoing efforts by FDOH to develop a statewide database of septic system locations.

Changes in land use from 1995 to 2004 were evaluated. Assuming trends in land use change continue, land use was predicted for the year 2030. Nitrate loadings in 1995 and 2030 were then estimated using simplified, and less accurate, procedures. This analysis indicated that the most significant historical trend in land use, as it affects nitrate loading to groundwater, is the conversion of nearly all land in row crop agriculture (vegetable crops) to other land uses from 1995 to 2005. The row crop land use generally produces relatively high nitrate loadings, so the virtual disappearance of this land use reduced loadings from 1995 to 2004. Loadings were projected to be little changed from 2004 to 2030.

The time that it takes for UFA groundwater to flow from any location in the springsheds to the Santa Fe River was estimated. Estimated groundwater travel times are highly uncertain because porosity in karst limestone varies dramatically depending on the development of caves, caverns, and other large solution features in the limestone. The best available information was used to estimate an area in which karst features are so well developed that groundwater flows very rapidly (conduit flow area). Within this area, groundwater travel times were assumed to be less than one month. Outside this area, groundwater is assumed to travel more slowly. Even outside this area, the porosity is not well defined by site-specific measurements, and therefore travel times are very uncertain. Figure 14 shows areas where travel time to the springs and the Santa Fe River is likely to be less than 25 and 100 years, respectively, and therefore may require additional measures to protect springs from pollution.

7.0 References

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Attachment A
Land Use Key

FLUCCS CODES ASSOCICATED WITH LOADING CATEGORIES

CAFO

2310: ODC - CATTLE FEEDING OPERATIONS
2320: ODC - POULTRY FEEDING OPERATIONS
2520: DAIRIES
2540: AQUACULTURE

Row crop

2140: ROW CROPS
2160: MIXED CROP

Pasture

2110: CROPLAND AND PASTURELAND
2110: IMPROVED PASTURES
2120: UNIMPROVED PASTURES
2130: WOODLAND PASTURES
2510: HORSE FARMS

Orchard, nursery

2200: TREE CROPS
2210: CITRUS GROVES
2230: OTHER GROVES (PECAN, AVOCADO, COCONUT, MANGO ETC)
2400: NURSERIES AND VINEYARDS
2410: TREE NURSERIES
2430: ORNAMENTALS
2500: SPECIALTY FARMS

Field crop, sod

2150: FIELD CROPS
2153: HAY FIELDS

Tree Plantations

4400: TREE PLANTATIONS
4410: CONIFEROUS PLANTATIONS
4430: FOREST REGENERATION AREAS

Comm/Inst/Rec
1400: COMMERCIAL AND SERVICES
1423: JUNK YARDS
1454: CAMPGROUNDS
1460: OIL & GAS STORAGE (EXCEPT AREAS ASSOC. WITH IND*
1480: CEMETERIES
1490: COMMERCIAL AND SERVICES UNDER CONSTRUCTION
1700: INSTITUTIONAL
1820: GOLF COURSES
1850: PARKS AND ZOOS
1860: COMMUNITY RECREATIONAL FACILITIES
1890: OTHER RECREATIONAL (STABLES, GO-CARTS, ...)
8110: AIRPORTS
8120: RAILROADS
8130: BUS AND TRUCK TERMINALS
8140: ROADS AND HIGHWAYS
8170: OIL, WATER OR GAS LONG DISTANCE TRANSMISSION LIN*
8200: COMMUNICATIONS
8320: ELECTRICAL POWER TRANSMISSION LINES
8340: SEWAGE TREATMENT
8350: ODC - SOLID WASTE DISPOSAL
8360: TREATMENT PONDS (NON-SEWAGE)
8370: SURFACE WATER COLLECTION PONDS
8390: UTILITIES UNDER CONSTRUCTION

Residential
1100: RESIDENTIAL, LOW DENSITY - LESS THAN 2 DWELLING*
1110: MDC - LOW DENSITY, FIXED SINGLE FAMILY UNITS
1120: MDC - LOW DENSITY, MOBILE HOME UNITS
1130: MDC - LOW DENSITY, MIXED UNITS (FIXED AND MOBILE*
1180: RURAL RESIDENTIAL
1190: LOW DENSITY UNDER CONSTRUCTION
1200: RESIDENTIAL, MEDIUM DENSITY - 2-5 DWELLING UNIT*
1210: MEDIUM DENSITY, FIXED SINGLE FAMILY UNITS
1220: MEDIUM DENSITY, MOBILE HOME UNITS
1230: MEDIUM DENSITY, MIXED UNITS
1290: MEDIUM DENSITY, UNDER CONSTRUCTION
1300: RESIDENTIAL, HIGH DENSITY - 6 OR MORE DWELLING *
1310: HIGH DENSITY, FIXED SINGLE FAMILY UNITS (> 6 DU/*
1320: HIGH DENSITY, MOBILE HOME UNITS
1330: HIGH DENSITY, MULTIPLE DWELLING UNITS, LOW RISE *
1390: HIGH DENSITY UNDER CONSTRUCTION

Other

Other, Industrial/Extractive

8300: UTILITIES
8310: ELECTRICAL POWER FACILITIES
8330: WATER SUPPLY PLANTS (INCLUDING PUMPING STATIONS)
1520: TIMBER PROCESSING
1530: MINERAL PROCESSING
1540: OIL AND GAS PROCESSING
1550: OTHER LIGHT INDUSTRIAL
1551: BOAT BUILDING AND REPAIR
1560: OTHER HEAVY INDUSTRIAL (SHIP REPAIR, SHIP BUILDI*
1562: PRE-STRESSED CONCRETE PLANTS
1564: CEMENT PLANTS
1590: INDUSTRIAL UNDER CONSTRUCTION
1600: EXTRACTIVE
1620: SAND AND GRAVEL PITS
1630: ROCK QUARRIES
1631: LIMEROCK
1650: MDC - RECLAIMED LANDS
1660: HOLDING PONDS

Other, Undeveloped

1900: OPEN LAND
1910: UNDEVELOPED LAND WITHIN URBAN AREAS
1920: INACTIVE LAND WITH STREET PATTERN BUT NO STRUCT*
2600: OTHER OPEN LANDS <RURAL>
2610: FALLOW CROP LAND
3100: HERBACEOUS UPLAND NONFORESTED
3200: SHRUB AND BRUSHLAND
3300: MIXED RANGELAND
4100: UPLAND CONIFEROUS FORESTS
4110: PINE FLATWOODS
4120: LONGLEAF PINE - XERIC OAK
4130: SAND PINE
4140: PINE-MESIC OAK
4200: UPLAND HARDWOOD FORESTS
4200: UPLAND HARDWOOD FORESTS
4210: XERIC OAK
4270: LIVE OAK
4300: UPLAND HARDWOOD FORESTS CONTINUED
4340: HARDWOOD CONIFEROUS - MIXED
4370: AUSTRALIAN PINE
5100: STREAMS AND WATERWAYS
5200: LAKES
5300: RESERVOIRS
5500: MAJOR SPRINGS
6110: BAY SWAMPS
6130: GUM SWAMPS

Other (continued)
6140: TITI SWAMPS
STREAM AND LAKE SWAMPS (BOTTOMLAND)
6170: MIXED WETLAND HARDWOODS
6210: CYPRESS
6250: HYDRIC PINE FLATWOODS
6300: WETLAND FORESTED MIXED
6410: FRESHWATER MARSHES
6430: WET PRAIRIES
6440: EMERGENT AQUATIC VEGETATION
6460: MIXED SCRUB-SHRUB WETLAND
7400: RU - DISTURBED LANDS
7410: RURAL LAND IN TRANSITION WITHOUT POSITIVE INDIC*
7420: BORROW AREAS
7430: SPOIL AREAS