Priority Focus Area for Ichetucknee Springs

Division of Environmental Assessment and Restoration

Florida Department of Environmental Protection

September 2017

2600 Blair Stone Road, MS 3575
Tallahassee, Florida 32399-2400
www.dep.state.fl.us

More Information

The following individuals can provide more information about the priority focus area for Ichetucknee Springs:

Terry Hansen

Basin Coordinator

DEP Watershed Planning and Coordination Section

terry.hansen@dep.state.fl.us

850-245-8561

Richard Hicks, P. G.

Professional Geologist Administrator

DEP Groundwater Management Section

richard.w.hicks@dep.state.fl.us

850-245-8229

Introduction

Under the Florida Springs and Aquifer Protection Act, the Florida Department of Environmental Protection (department or DEP) is required to delineate priority focus areas (PFA) for all Outstanding Florida Springs that are identified as impaired. According to the Florida Springs and Aquifer Protection Act, adopted by the Florida Legislature in 2016 (Chapter 373, Part VIII, F. S.), *"'priority focus area' means the area or areas of a basin where the Floridan Aquifer is generally most vulnerable to pollutant inputs where there is a known connectivity between groundwater pathways and an Outstanding Florida Spring, as determined by the department in consultation with the appropriate water management districts, and delineated in a basin management action plan. Using the best data available from water management districts and other credible sources, the department, in coordination with the water management districts, shall delineate priority focus areas for each Outstanding Florida Spring or group of springs that contains one or more Outstanding Florida Springs and is identified as impaired in accordance with s. 373.807. In delineating priority focus areas, the department shall consider groundwater travel time to the spring, hydrogeology, nutrient load, and any other factors that may lead to degradation of an Outstanding Florida Spring. The delineation of priority focus areas must be completed by July 1, 2018, shall use understood and identifiable boundaries such as roads or political jurisdictions for ease of implementation, and is effective upon incorporation in a basin management action plan."*

Factors to consider in establishing these geographically bounded areas include:

- <u>Groundwater travel time to the spring</u>, which could be based on empirical data from tracer studies and/or predicted travel time from modeling, if such data or studies are available.
- <u>Hydrogeology</u>, which includes the spring's groundwater contributing area (or springshed), the amount of confining material protecting the Floridan Aquifer, the aquifer recharge characteristics, the capacity for the aquifer to transmit water, and other characteristics that help determine the aquifer vulnerability and the likelihood of adverse water quality impacts to springs.
- <u>Nutrient load to the spring</u>, which includes actual measured load in the water discharging from the spring as well as the potential nutrient load based on land uses in specific regions that would most probably influence water quality in the spring.
- <u>Other factors</u>, which include soil characteristics that are favorable for pollutant leaching to the aquifer in the springshed and the presence or absence of pollutant sources in the area.
- <u>Identifiable boundaries</u>, which include roads, natural boundaries, and political jurisdictions.

Delineation of the PFA for Ichetucknee Springs is described in the following section.

Steps in Delineating Ichetucknee Springs PFA

The PFA for the Ichetucknee Springs Group was developed using geographic information system (GIS) tools, spring-specific data, and published information to help identify the portion of the springs' contributing area that is most important from both the water quality restoration and protection perspectives. The following steps were taken to develop a draft PFA for review and input by stakeholders. The overlap of mapped characteristics that express high vulnerability, high potential for pollutant mobility, and likely pollutant sources provides the best assurance that the PFA includes the areas of greatest concern for water quality restoration and protection.

Step 1. Establish the springshed for the priority spring(s). The estimated springshed for Ichetucknee Springs used for this evaluation was developed by SDII Global Corporation for DEP and the Suwannee River Water Management District (SRWMD) in 2003.[1] The Ichetucknee Springs springshed and the PFA are shown in **Figure 1**. This map also shows the groundwater elevation contour map for the Floridan aquifer for May 2010. Contemporaneous groundwater flow gradients were part of the basis for the delineation of the springshed.

Step 2. Identify regions within the contributing area where greatest recharge occurs. Several GIS coverages developed by the USGS and water management districts delineate areas of high, medium, and low recharge to the Floridan aquifer system as well as areas of aquifer discharge. The areas to be considered in the PFA delineation are the areas of highest recharge to the aquifer, which could occur as diffuse infiltration through permeable geological material as well as focused recharge to sinkholes that breach confining layers. Pollutant sources in high recharge areas have the greatest potential for causing adverse impacts to the groundwater and springs because water is impeded the least as it infiltrates to the aquifer from the surface. In high recharge areas, recharge is 10 inches per year (in/yr) or greater. The area of high recharge shown in **Figure 2** is from a GIS coverage developed for a 2002 USGS model.[2]

[1] SDII Global Corporation, 2003. Delineation of Spring-water Source Areas in the Ichetucknee Springshed. Prepared for the Florida Department of Environmental Protection, SDII Project No. 3004390.

[2] Sepulveda, N. 2002. Simulation of Ground-Water Flow in the Intermediate and Floridan Aquifer Systems in Peninsular Florida. USGS Water Resources Investigation Report 02-4009.

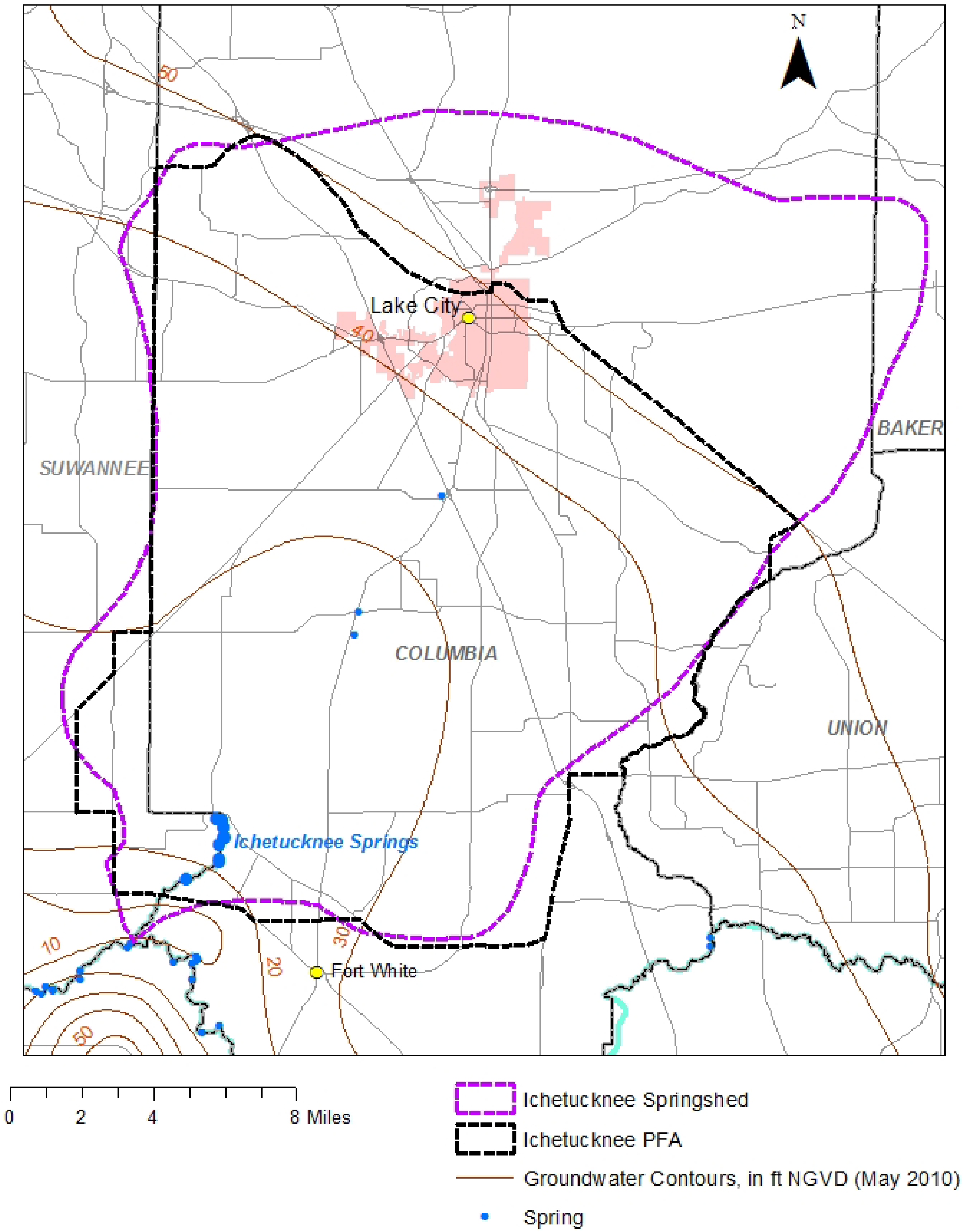

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Figure 1. Ichetucknee Springs springshed, priority focus area, and groundwater elevation contours

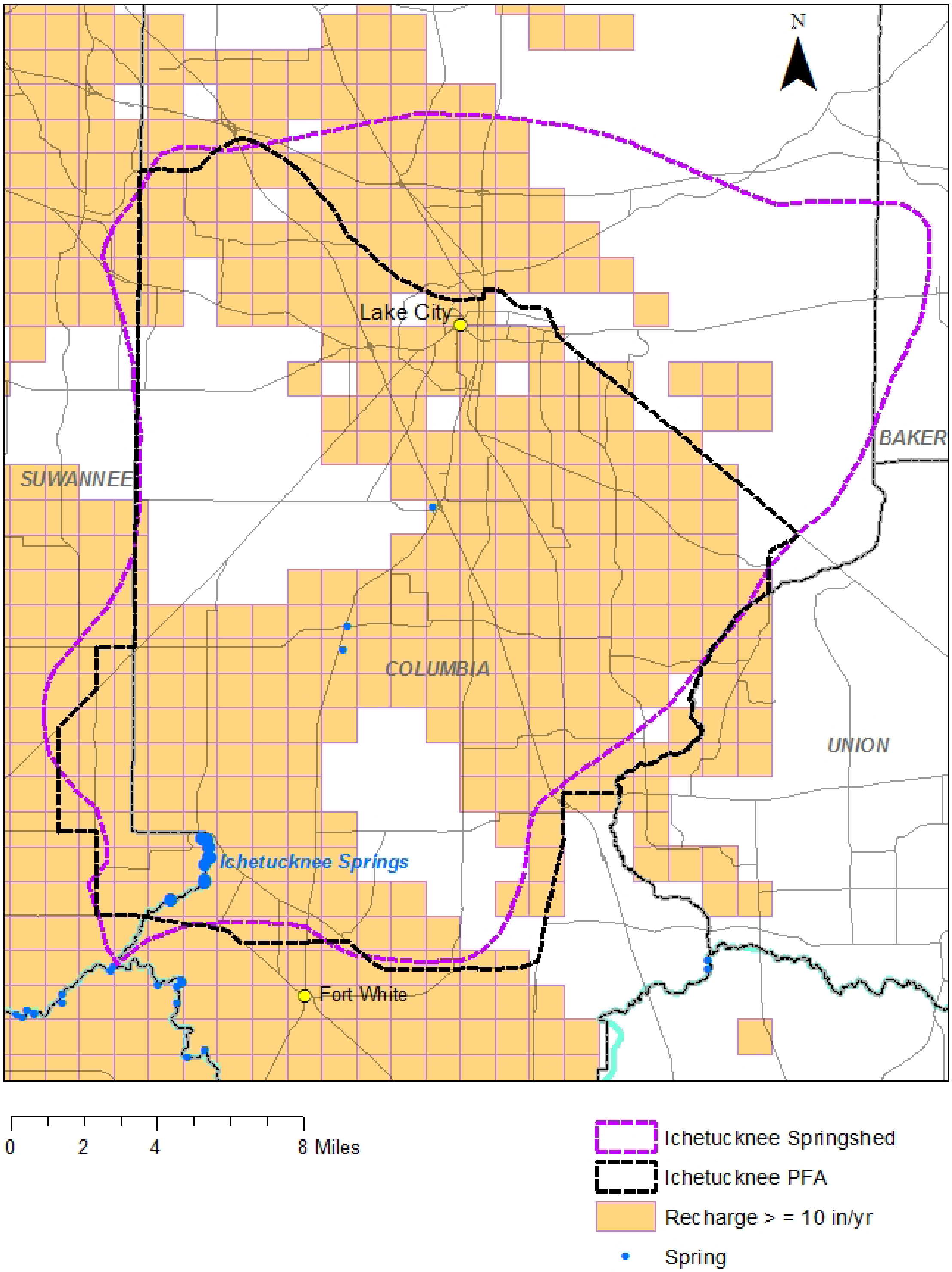

Figure 2. Areas of high recharge to Floridan aquifer (≥10 inches/year) based on USGS 2002 methodology in Ichetucknee Springs area

Step 3. Identify regions within the springshed where the Floridan Aquifer is most vulnerable. The Florida Geological Survey (FGS) developed the statewide Florida Aquifer Vulnerability Assessment (FAVA) model to provide a spatial coverage of aquifer vulnerability ranges across an area.[3] Later, Advanced GeoSpatial Incorporated was contracted by the Ichetucknee Partnership under a DEP grant to develop a more detailed version of this aquifer vulnerability assessment, using the same methodology, for Columbia County.[4] Most of the springshed for Ichetucknee Springs is in Columbia County. According to the Columbia County-specific FAVA model for the Floridan aquifer system, the Floridan aquifer beneath most of the springshed area in Columbia County occurs is classified as either "more vulnerable" or "vulnerable" except for an area in the northeastern part of the county which is identified as "less vulnerable". These areas are shown in **Figure 3**. As an additional step in helping define areas of greatest vulnerability of the aquifer, local points of recharge through sinkholes and linear karst features were mapped by using the statewide Digital Elevation Model (DEM). The DEM is based on the Light Imaging, Detection, and Ranging (LIDAR) remote sensing method. In much of the springshed, closed topographic depressions form as solution or collapse sinkholes and water flowing into these features can more rapidly reach the aquifer and erode and enlarge conduits in the limestone. These can be expressed in linear arrays across the landscape. A major linear feature in this springshed is the historical Ichetucknee Trace, which originates just south of Lake City and extends southwestward to the headspring area. Dry or intermittent stream traces, such as the Ichetucknee Trace, are indicative of associated subterranean conduit networks. Some sink features known as "swallets" provide a direct conduit for surface water discharge into the aquifer. Swallets are sinkholes that capture stream flow. The FGS completed a project to map all known swallets in the state and produced a GIS layer that includes their locations. The DEM map (2009) and swallets in the Ichetucknee Springs region are shown in **Figure 4**. Several swallets lie along the Ichetucknee Trace and those identified in the figure have been linked to Ichetucknee Springs by dye traces (which are discussed in a following section).

Step 4. Consider nitrogen load. Nitrate-nitrogen is the major nutrient of concern in Florida's spring systems due to its pervasive nature in groundwater, its mobility, and its availability for uptake by aquatic flora when it is discharged from springs. Excess concentrations of nitrate nitrogen in the spring water have contributed to excessive growth of algae in the spring runs and the Ichetucknee River. The source of flow from most springs in Florida is groundwater from the Floridan aquifer system. This groundwater comes mainly from local precipitation that recharges the aquifer in the springshed area. The nitrate originates from atmospheric deposition and anthropogenic sources in the combined springshed.

A recent mean nitrate concentration, based on May 1, 2017 readings from a nitrate sensor in the Ichetucknee River downstream from the springs group, was 0.50 milligrams per liter (mg/L).

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[3] Arthur, J. D., Wood, H. A. R., Baker, A. E., Cichon, J. R., Raines, G. L., 2007, Development and Implementation of a Bayesian-based Aquifer Vulnerability Assessment in Florida: Natural Resources Research, Vol. 16, No. 2., P. 93-107. Also for more information go to http://www.dep.state.fl.us/geology/programs/hydrogeology/fava.htm.

[4] Advanced GeoSpatial Inc., 2009. Columbia County Aquifer Vulnerability Assessment. http://www.adgeo.net/ccava.php

This concentration in the river represents a composite of water quality from multiple spring vents, as well as nutrient uptake by river vegetation, but is mostly influenced by nitrate discharges from the largest springs by volume, Ichetucknee Head Spring and Blue Hole Spring. The river concentration is approximately 1.5 times greater than Florida's numeric nitrate criterion for spring vents (0.35 mg/L) and the nitrate concentration-based Total Maximum Daily Load for the Santa Fe River system. The load of nitrogen from these springs depends on concentration and flow. Using the 0.50 mg/L nitrate concentration from the real-time monitoring station on the Ichetucknee River and the latest measured discharge for the river of 308 cubic feet per second, the estimated daily load of nitrate nitrogen for the springs group was 823 pounds of nitrogen per day. Using these data, an estimated total nitrogen load (as nitrate) from the Ichetucknee Springs Group would be about 0.3 million pounds per year (lb/yr), assuming nitrate concentrations and discharge remain relatively stable.

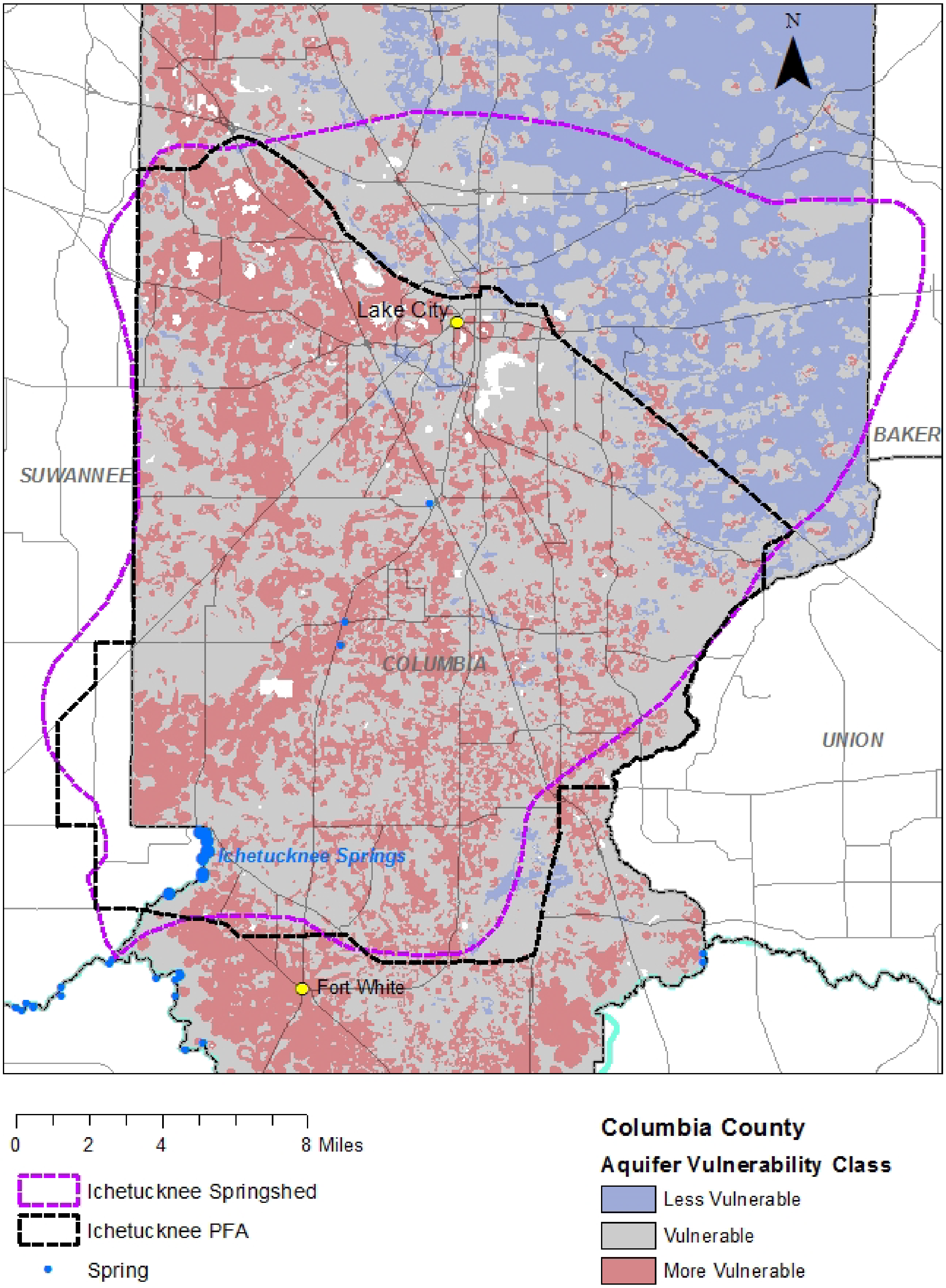

Figure 3. Floridan aquifer vulnerability in the Ichetucknee Springs area based on the Columbia County Aquifer Vulnerability Assessment

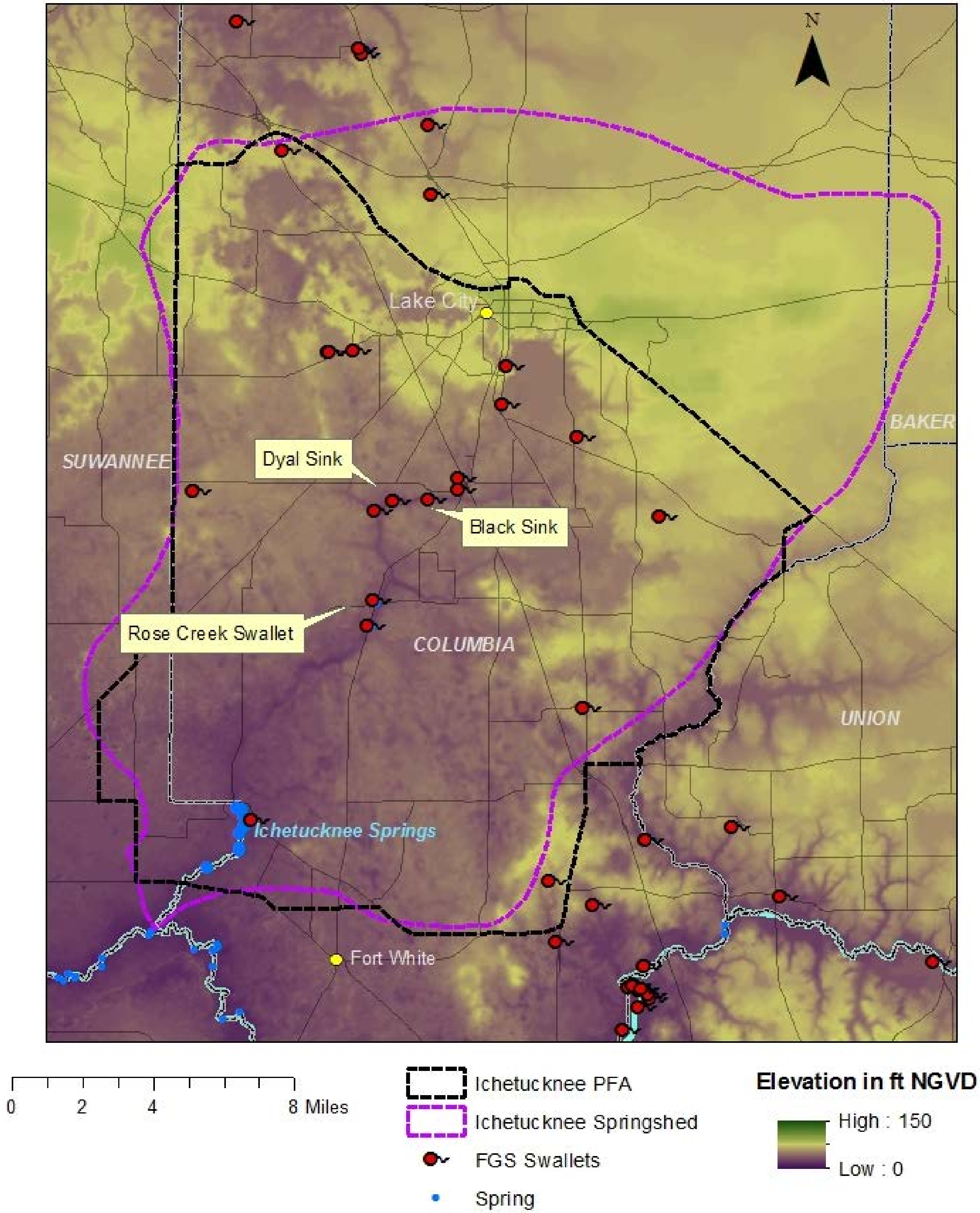

Figure 4. Digital elevation model and FGS-mapped swallets in Ichetucknee Springs area

DEP is developing a nitrogen source inventory for the Ichetucknee Springs contributing area to serve as a tool for developing remediation strategies and projects for reducing nitrogen loads to the springs. Typical sources of nitrogen in spring contributing areas include inorganic fertilizer, livestock waste, onsite treatment and disposal systems (OSTDS or septic systems), treated domestic wastewater, and atmospheric deposition. A previous inventory of nitrogen sources in the springshed conducted by USGS showed that the main sources of nitrogen loading to the groundwater in the Ichetucknee Springs springshed were inorganic fertilizer and animal waste.[5]

Step 5. Consider groundwater travel time in creating PFA boundaries. To the extent possible, PFAs should include parts of contributing areas that have demonstrated or anticipated short travel times to the springs. Springs occur in areas of karst terrain where surface and subsurface erosion of the limestone can develop complex networks of solution channels and conduits in the aquifer material. In parts of this springshed, groundwater can move rapidly through these conduits from points where the water enters the aquifer to the spring vents. Dye trace work has documented rapid rates of groundwater movement within the area of the Ichetucknee Trace. Karst Environmental Services (KES) measured groundwater travel from a swallet along the trace (Rose Sink) to the springs at a rate of approximately 1 mile per day.[6] A later dye trace conducted by KES provided further evidence of connection between swallets further to the north (Black and Dyal Sinks) to the Rose Creek Cave System and the Ichetucknee Springs.[7]

Step 6. Identify regions within the contributing area where soil conditions are most favorable for leaching of nitrogen from surface sources. Nitrogen has been identified as the target nutrient for spring restoration. Research has shown that nitrogen removal in the soil zone through denitrification and its tendency to leach can be related to soil drainage class.[8] Denitrification is lowest and leaching of nitrogen is highest in areas with soils that are excessively drained, somewhat excessively drained, or well drained. Leaching may occur in areas with moderately well drained soils and leaching of nitrogen is least likely to occur in areas where soils are poorly drained, somewhat poorly drained or very poorly drained because of their greater potential for denitrification. The portions of the contributing area where soil conditions are more favorable for nitrogen leaching can be mapped using the U. S. Department of Agriculture Natural Resources Conservation Service soil survey geographic (SSURGO) database for Florida.[9] These

[5] Katz, B., Sepulveda, A. A., and Verdi, R. J., 2009. Estimating Nitrogen Loading to Ground Water and Assessing Vulnerability to Nitrate Contamination in a Large Karstic Springs Basin, Florida. Journal of the American Water Resources Association DOI: 10.1111/j.1752-1688.2009.00309.x. Vol 45. Issue 3.

[6] Butt, P. L., Hayes, A. W., Morris, T. L., and Skiles, W. C. 2003. Summary of the Results of the Rose Creek Swallet to Ichetucknee Springs Dye Trace Study, August-September 1997.

[7] Karst Environmental Services, 2003. Dyal and Black Sinks Dye Trace, Columbia County Florida, May-September 2003. Prepared for Florida Department of Environmental Protection.

[8] Otis, R. J., 2007. Estimates of Nitrogen Loadings to Groundwater from Onsite Wastewater Treatment Systems in the Wekiva Study Area, Task 2 Report Wekiva Onsite Nitrogen Contribution Study. Prepared by Otis Environmental Consultants for Florida Department of Health.
Hofstra, N. and Bowman, 2005. Denitrification in Agricultural Soils: Summarizing Published Data and Estimating Global Annual Rates. Nutrient Cycling in Agroecosystems (2005) 72: 267-278.

[9] SSURGO Soil Survey Geographic Database is a digital soil survey developed by the National Cooperative Soil Survey. The dataset includes georeferenced digital map data and computerized attribute data. Metadata can be

soil characteristics tend to occur in areas where aquifer recharge is highest and vulnerability is greatest. **Figure 5** shows areas where there is a high to moderate potential for nitrogen leaching to groundwater. High leaching potential soils include the excessively drained, somewhat excessively drained and well drained SSURGO drainage classes. Moderate leaching potential soils are in the moderately well drained class. Most of the springshed contains moderately well drained soils, where nitrogen leaching could be a problem.

Step 7. Identify regions within the contributing area to exclude or include based on land use and potential for pollutant sources to occur. Conservation lands, wetlands, and undeveloped open land that are protected from development are land areas that in some cases may be excluded from the PFA if there is no expectation that they would include pollutant sources affecting springs in the foreseeable future and they are under protection. The largest conservation area in the springshed is a portion of the federal Osceola National Forest. The springshed also includes a portion of the Ichetucknee Springs State Park, several SRWMD conservation lands and the Columbia County-owned Alligator Lake park. Conservation lands from the Florida Natural Areas Inventory Conservation Lands (FNAI Managed Areas) GIS layer are shown in **Figure 6**.

The Ichetucknee Springs springshed includes large areas in agricultural land uses. It also includes urban land use, most of which is in the Lake City area. Delineation of the PFA includes consideration of areas with significant potential for nitrogen leaching to groundwater based on the sources of nitrogen that occur there. Agricultural lands can include fertilizer use and livestock that can contribute significant nitrogen inputs. Urban lands can include higher densities of OSTDS, domestic wastewater and urban fertilizer use, all of which can be sources of nitrogen to the aquifer and springs. Mapped urban and agricultural lands (based on the 2013-2014 SRWMD land use-land cover GIS coverage) are shown in **Figure 7.**

found at this link: https://catalog.data.gov/dataset/soil-survey-geographic-ssurgo-database-for-various-soil-survey-areas-in-the-united-states-

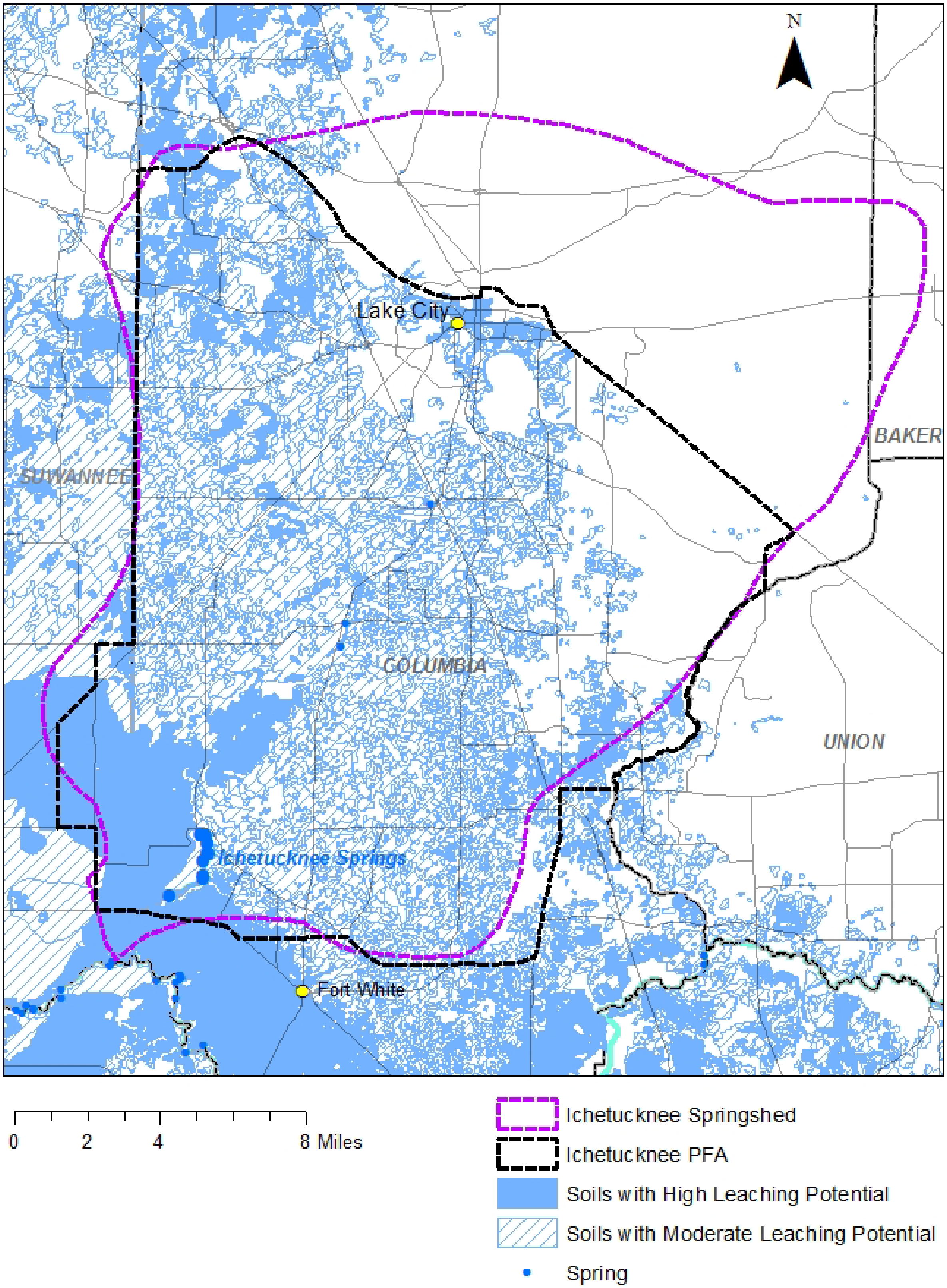

Figure 5. High and moderate nitrogen leaching potential soils in Ichetucknee Springs area

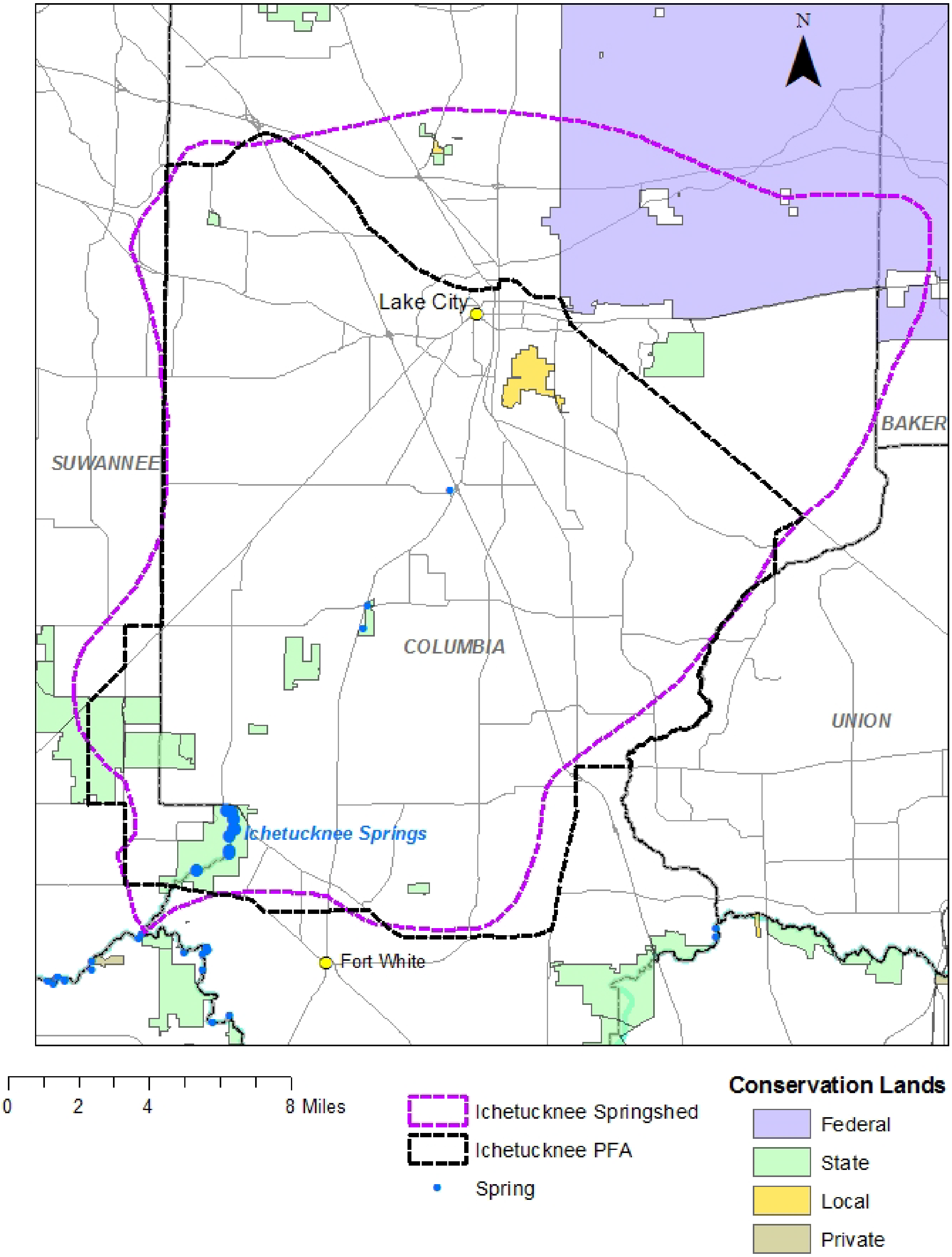

Figure 6. Conservation lands and priority focus area

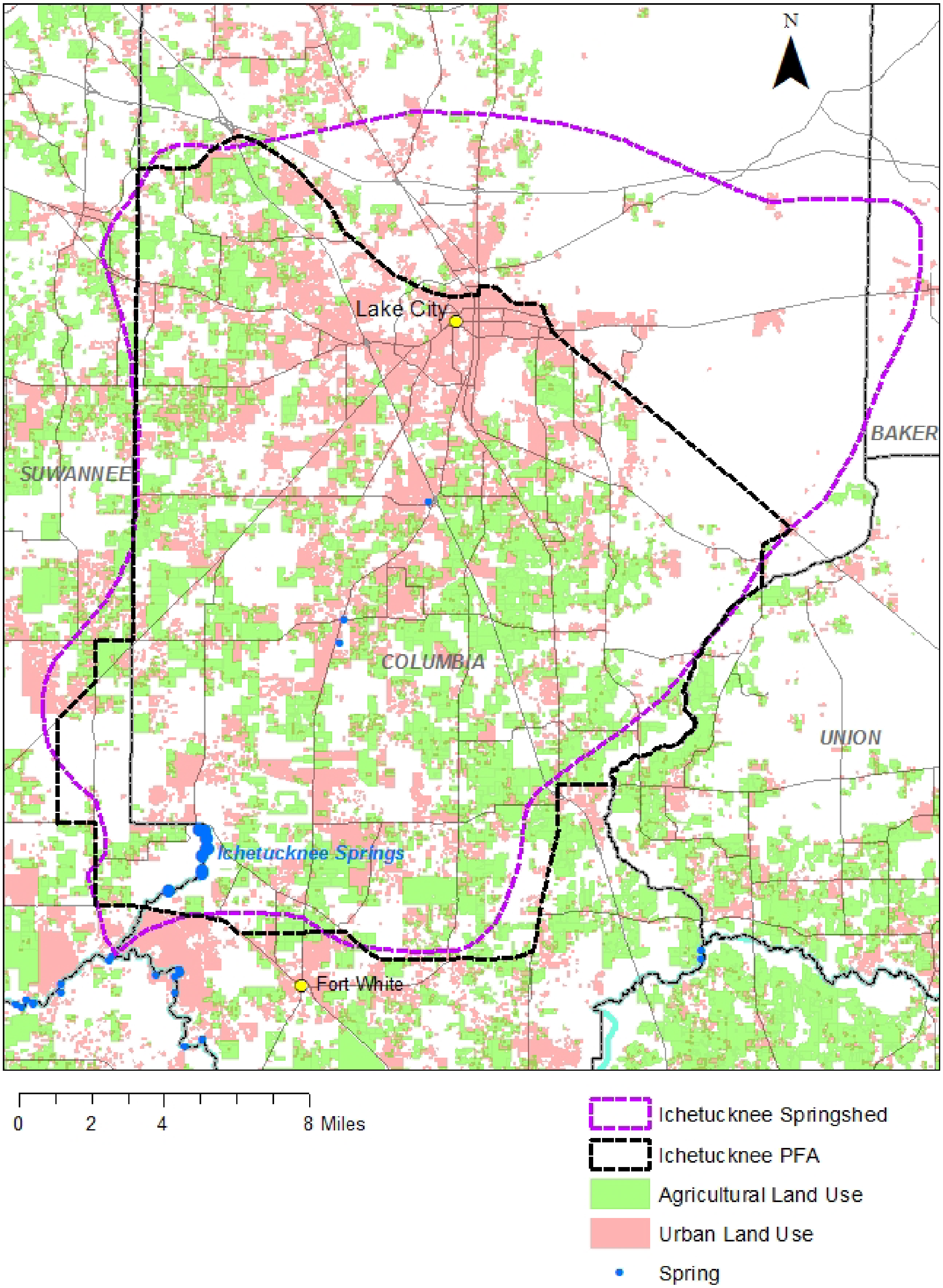

Figure 7. Urban and agricultural land use areas and priority focus area

Onsite treatment and disposal systems can be potentially significant sources of nutrients to be considered when delineating the PFA. OSTDS in the area are shown in **Figure 8**. Their locations are based on a GIS coverage developed as part of the Florida Department of Health's Florida Water Management Inventory Project (http://www.floridahealth.gov/environmental-health/onsite-sewage/research/flwmi/index.html).

DEP-regulated wastewater facilities are also significant nutrient sources to be considered. Existing domestic wastewater facilities, including large ones with design flows greater than or equal to 0.1 million gallons per day (mgd), are shown in **Figure 8** because they also have potential for contributing nitrogen to groundwater. These facilities can also have significant inputs of nitrogen. DEP regulated wastewater facility information for the springshed was obtained from the DEP wastewater facility regulation (WAFR) information management system.

PFA Boundary for Ichetucknee Springs

For stakeholders to implement restoration and protection actions in the PFA, the boundary must be clearly defined and associated with features easily recognizable on a map. The boundary of the Ichetucknee Springs PFA was made to conform to easily recognizable natural features, roads, political boundaries, and major survey boundaries.

The PFA boundary shown in **Figure 9** was developed by considering GIS coverages of recharge, vulnerability, soils, conservation lands, and potential contaminant nitrogen source information. The PFA boundary delineates a region including most of the springshed for Ichetucknee Springs. This area includes high groundwater recharge/vulnerability conditions and soil conditions that tend to leach nitrogen. It also includes the sensitive Ichetucknee Trace area within the springshed over which groundwater travel to the springs occurs rapidly. In addition, the PFA also includes interconnected areas of agricultural land use, urban development, areas of OSTDS, and domestic wastewater facilities, which all have potential to contribute to nitrogen enrichment in the aquifer and springs.

The PFA is mostly in Columbia County, with a small portion in eastern Suwannee County. It includes much of the city of Lake City and a portion of the unincorporated community of Fort White. The PFA also includes a portion of Ichetucknee Springs State Park, Alligator Lake county park, and several SRWMD-managed conservation areas. Conservation land boundaries, natural features, political boundaries, roads, and survey boundaries in the area were all considered so that the PFA boundary would be readily identifiable.

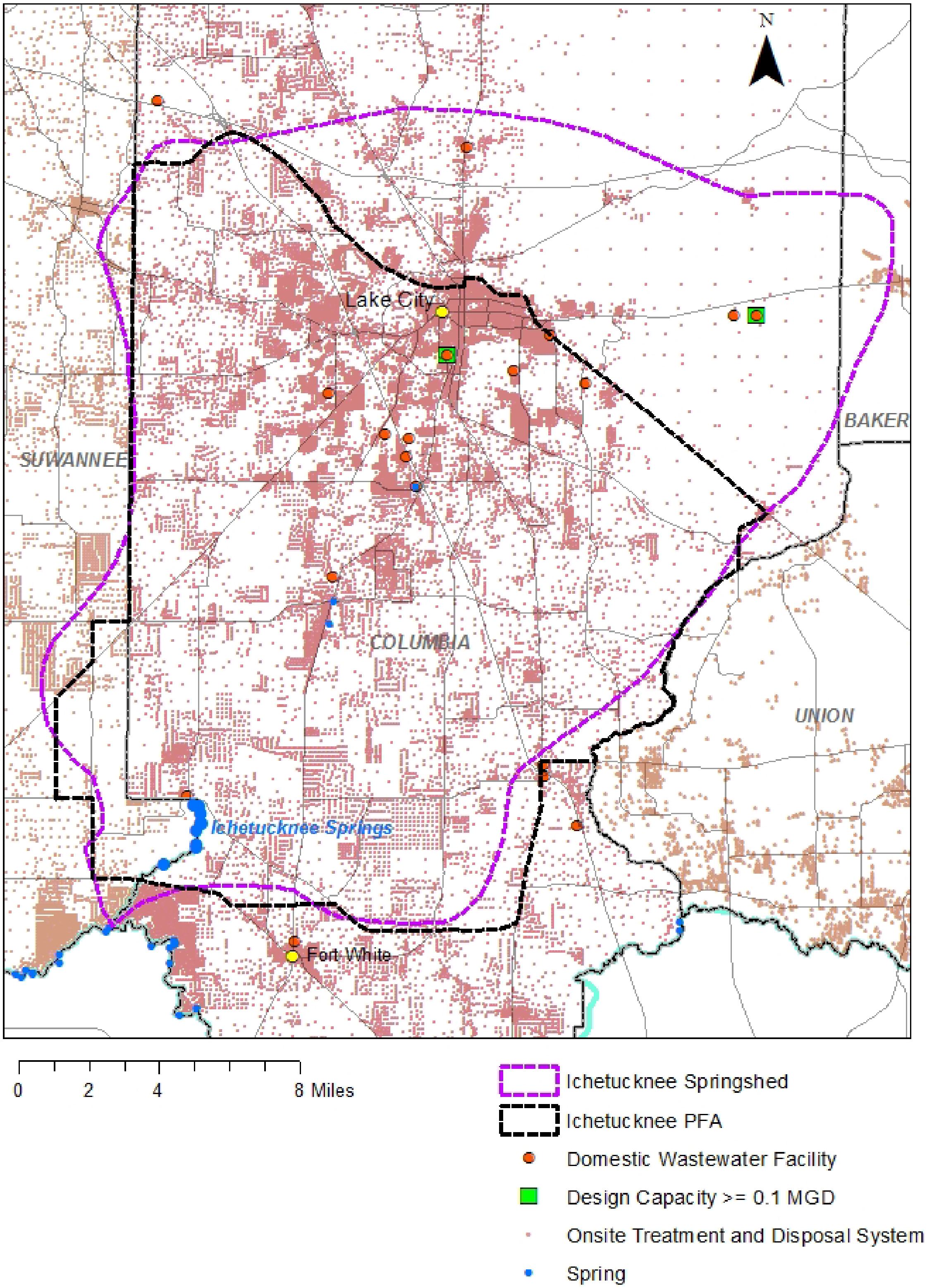

Figure 8. Onsite treatment and disposal systems, domestic wastewater treatment facilities, and priority focus area

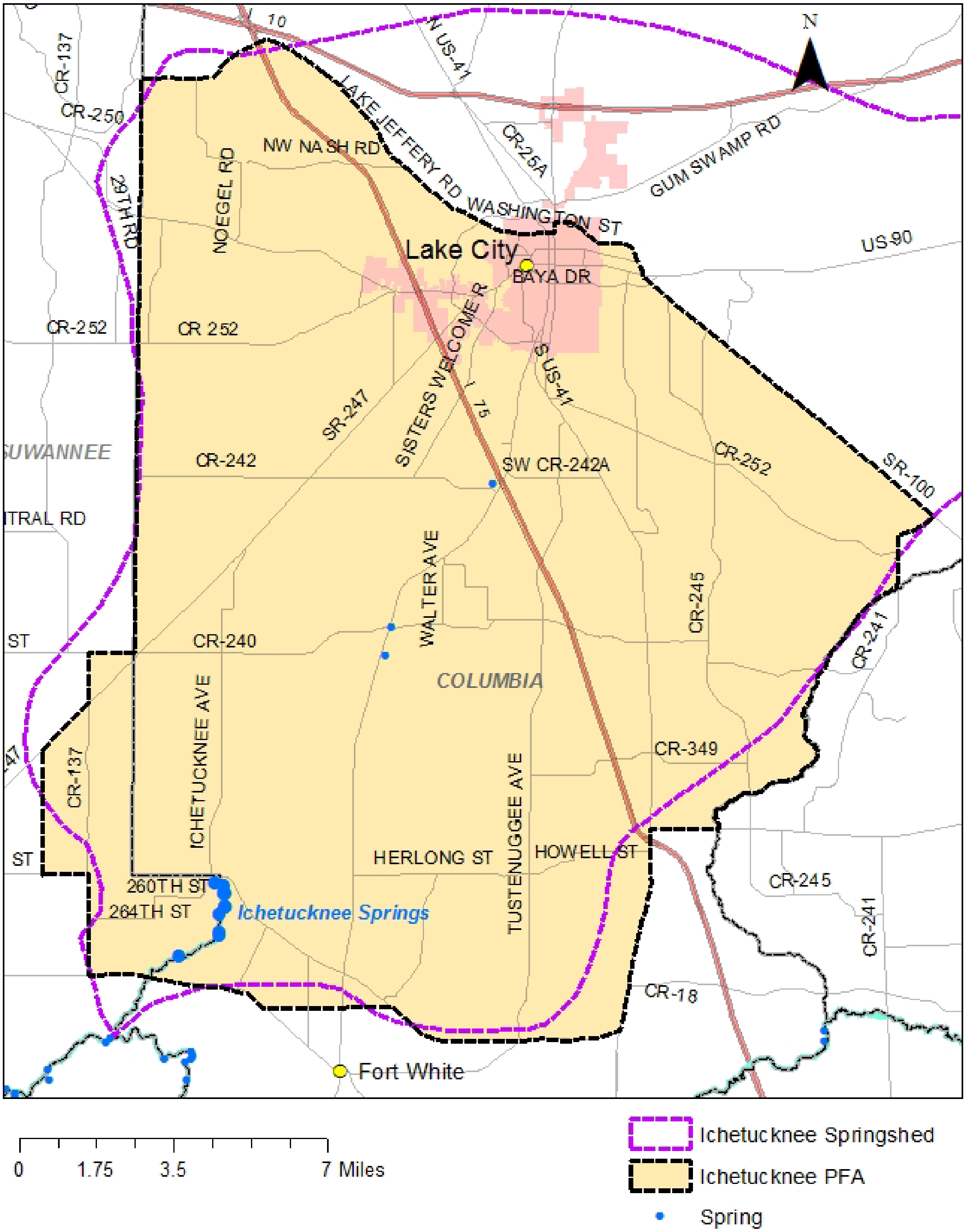

Figure 9. PFA boundary for Ichetucknee Springs

Priority Focus Areas for Devil's Spring System and Hornsby Spring

Division of Environmental Assessment and Restoration
Florida Department of Environmental Protection

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2600 Blair Stone Road
Mail Station 3575
Tallahassee, FL 32399-2400
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Additional Information

The following individuals can provide additional information about the priority focus areas for the Devil's Spring System and Hornsby Spring:

Terry Hansen, P. G.
Basin Coordinator
DEP Watershed Planning and Coordination Section
850–245–8561
terry.hansen@dep.state.fl.us

Richard Hicks, P.G.
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Introduction

Under the Florida Springs and Aquifer Protection Act, the Florida Department of Environmental Protection (DEP) is required to delineate priority focus areas (PFAs) for all Outstanding Florida Springs identified as impaired. According to the Florida Springs and Aquifer Protection Act, adopted by the Florida Legislature in 2016 (Chapter 373, Part VIII, Florida Statutes [F.S.]), *" Priority focus area' means the area or areas of a basin where the Floridan Aquifer is generally most vulnerable to pollutant inputs where there is a known connectivity between groundwater pathways and an Outstanding Florida Spring, as determined by the department in consultation with the appropriate water management districts, and delineated in a basin management action plan. . . . Using the best data available from water management districts and other credible sources, the department, in coordination with the water management districts, shall delineate priority focus areas for each Outstanding Florida Spring or group of springs that contains one or more Outstanding Florida Springs and is identified as impaired in accordance with s. 373.807. In delineating priority focus areas, the department shall consider groundwater travel time to the spring, hydrogeology, nutrient load, and any other factors that may lead to degradation of an Outstanding Florida Spring. The delineation of priority focus areas must be completed by July 1, 2018, shall use understood and identifiable boundaries such as roads or political jurisdictions for ease of implementation, and is effective upon incorporation in a basin management action plan."*

Factors to consider in establishing these geographically bounded areas include the following:

- Groundwater travel time to the spring, which could be based on empirical data from tracer studies and/or predicted travel time from modeling, if such data or studies are available.

- Hydrogeology, which includes the spring's groundwater contributing area (or springshed), the amount of confining material protecting the Floridan aquifer, the aquifer recharge characteristics, the capacity for the aquifer to transmit water, and other characteristics that help determine the aquifer vulnerability and the likelihood of adverse water quality impacts to springs.

- Nutrient load to the spring, which includes actual measured load in the water discharging from the spring as well as the potential nutrient load based on land uses in specific regions that would most probably influence water quality in the spring.

- Other factors, which include soil characteristics that are favorable for pollutant leaching to the aquifer in the springshed and the presence or absence of pollutant sources in the area.

- Identifiable boundaries, which include roads, natural boundaries, and political jurisdictions.

Delineation of the PFAs for the Devil's Spring System and Hornsby Spring is described in the following section.

Steps in Delineating the Devil's Spring System and Hornsby Spring PFAs

The PFAs for these springs were developed using geographic information system (GIS) tools, spring-specific data, and published information to help identify the portion of the springs' contributing areas that are most important from the perspectives of both water quality restoration and protection. The steps discussed below were taken to develop PFAs for review and input by stakeholders. The overlapping of mapped characteristics that express high vulnerability, high potential for pollutant mobility, and likely pollutant sources provides the best assurance that the PFAs include the areas of greatest concern for water quality restoration and protection.

Step 1. Establish the springshed for the priority spring

The estimated springshed areas used for this evaluation were developed jointly by the Suwannee River Water Management District (SRWMD) and DEP staff. Generalized springsheds developed by SDII Global in 2008 for springs of the Santa Fe River were also used in their development.[1] Information from previous work plus high resolution (250-meter grid spacing) flow paths based on more recent potentiometric surface contour maps were used to help create springshed boundaries. Potentiometric surface maps used in the analysis were developed by the U. S. Geological Survey (USGS) and the Florida Geological Survey (FGS) in cooperation with the water management districts. Flow pathways were compared for multiple dates to develop contributing areas that account for seasonal variation in potentiometric surface. In addition, results from dye traces and cave explorations documented by SRWMD were used to help define spring contributing areas. Due to the interconnected nature of springs along the middle Santa Fe River, the contributing areas for the Devil's Spring System and several other significant springs (by magnitude) were combined. This combined springshed includes an area that contributes groundwater recharge to the first magnitude Devil's Spring System (Devil's Ear, Devil's Eye and Little Devil's Springs), Ginnie Springs (second magnitude), Gilchrist Blue Spring (second magnitude), July Spring (second magnitude), Rum Island Spring (second magnitude) as well as several smaller named springs that are close by. Hornsby and Treehouse Springs also share a common springshed due to their overlapping contributing areas. These springsheds and PFAs for the Devil's Spring System and Hornsby Spring are shown in **Figure 1**.

[1] SDII Global, July 8, 2008. *Springsheds of the Santa Fe River*. Prepared for Alachua County Board of County Commissioners under purchase orders 071623 and 111454.

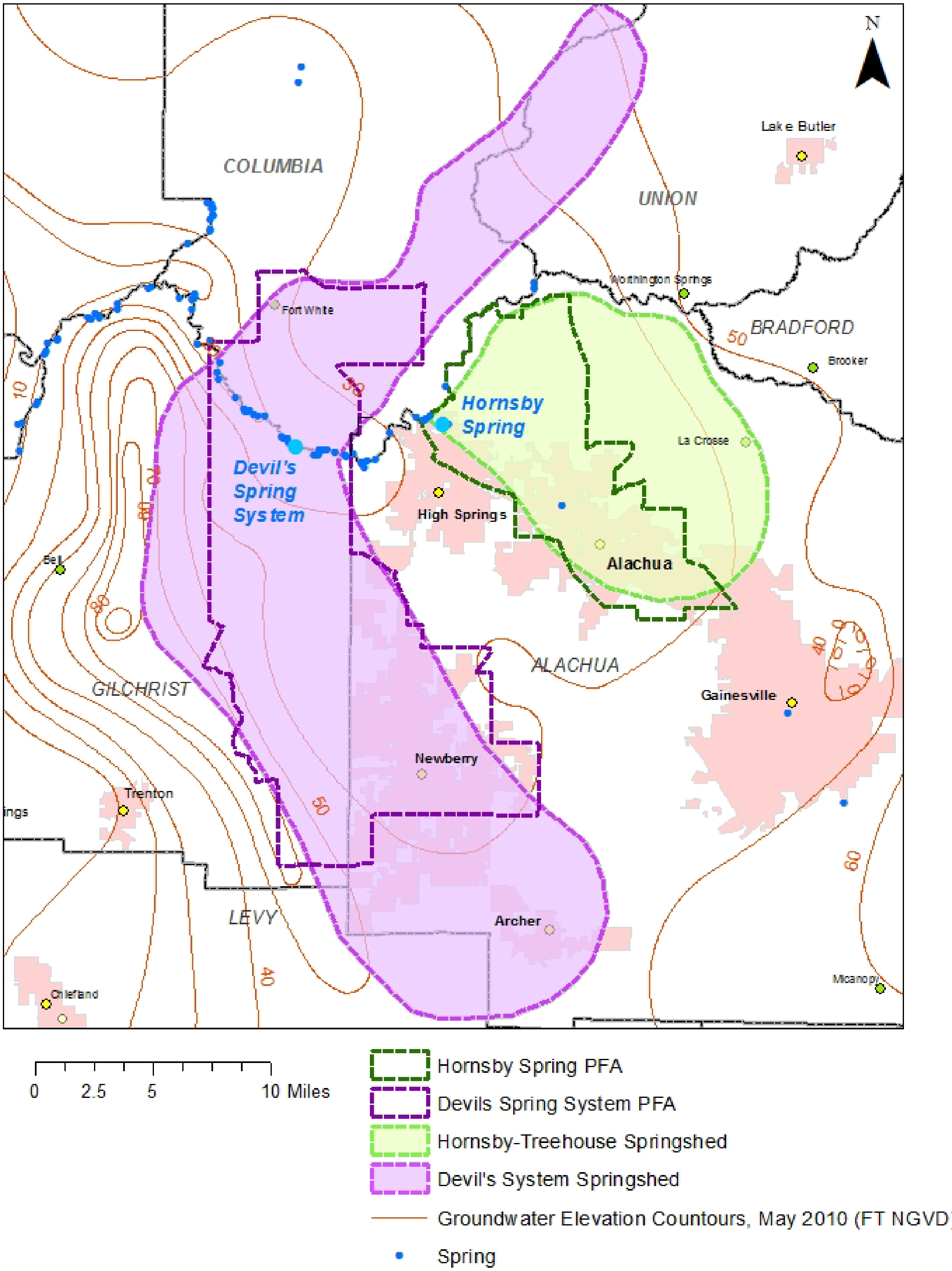

Figure 1. Devil's System and Hornsby springsheds and PFAs and groundwater elevation contours (ft-MSL)

Step 2. Identify regions in the contributing areas where the greatest recharge occurs

Several GIS coverages developed by the USGS and water management districts delineate areas of high, medium, and low recharge to the Floridan aquifer system as well as areas of aquifer discharge. The areas to be considered in the PFA delineation are the areas of highest recharge to the aquifer, which could occur as diffuse infiltration through permeable geological material as well as focused recharge to sinkholes that breach confining layers. Pollutant sources in high recharge areas have the greatest potential for causing adverse impacts to the groundwater and springs because water is impeded the least as it infiltrates to the aquifer from the surface. In high recharge areas, recharge is 10 inches per year (in/yr) or greater. The area of high recharge shown in **Figure 2** is from a GIS coverage developed for a 2002 USGS model.[2]

[2] Sepulveda, N. 2002. Simulation of Ground-Water Flow in the Intermediate and Floridan Aquifer Systems in Peninsular Florida. USGS Water Resources Investigation Report 02-4009.

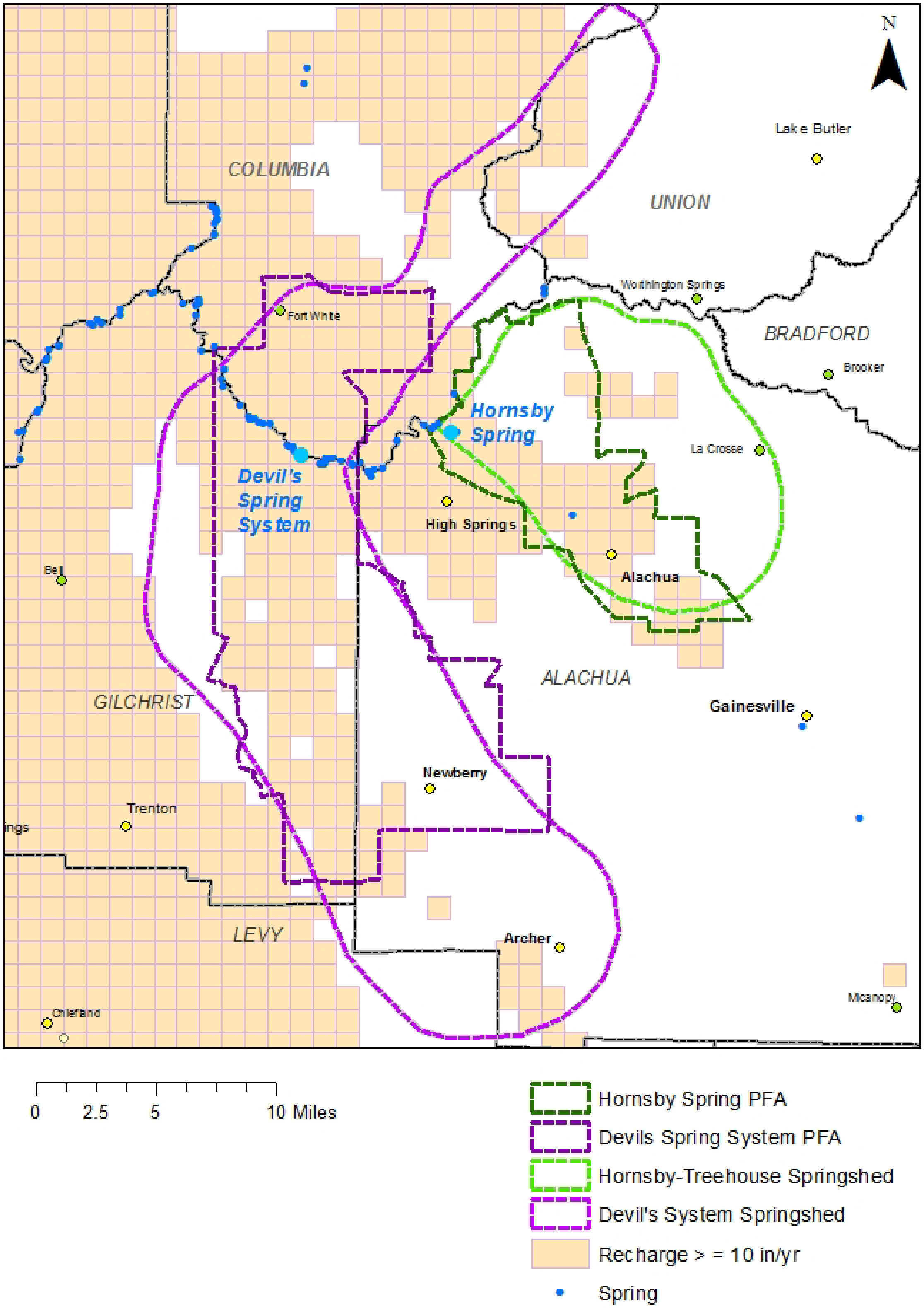

Figure 2. Areas of high recharge to the Floridan aquifer (≥10 in/yr) based on USGS 2002 methodology, springsheds and PFAs for Devil's spring system and Hornsby spring

Step 3. Identify regions in the springsheds where the Floridan aquifer is most vulnerable

The FGS developed the Florida Aquifer Vulnerability Assessment (FAVA) model to provide a spatial coverage of aquifer vulnerability ranges across an area of interest.[3] The modeling results from the statewide FAVA model, which is quite generalized, show almost the entire area covered by these two springsheds to be classified as "more vulnerable". In 2005, the FGS used the model to create a much more refined aquifer vulnerability map for Alachua County, which includes the Hornsby Spring contributing area and part of the contributing area for the Devil's Spring System.[4] The vulnerability classes for the spring contributing areas within Alachua County are shown in **Figure 3**. Often, the areas of greatest aquifer vulnerability occur where aquifer recharge is also greatest. Regions in the springsheds for the Devil's Spring System and Hornsby Spring that are mapped as "more vulnerable" correspond somewhat with areas that have highest recharge.

As an additional step in helping define areas of greatest vulnerability of the aquifer, local points of recharge through sinkholes and linear karst features were mapped by using the statewide Digital Elevation Model (DEM). The DEM is based on the Light Imaging, Detection, and Ranging (LIDAR) remote sensing method. In much of the springshed, closed topographic depressions form as solution or collapse sinkholes and water flowing into these features will more rapidly reach the aquifer and erode and enlarge conduits in the limestone. These can be expressed in linear arrays across the landscape. The DEM shows that most of the springshed for the Devil's System springs is a karst plain with an average elevation of about 90 feet above sea level. This karst plain is riddled with sinkholes, many of which connect directly with the aquifer system. Much of the springshed area for Hornsby Spring is a topographic upland that has a maximum elevation of about 175 feet. Elevation slopes westward toward the vicinity of the spring, where elevation is about 45 feet. Several intermittent drainage features in the Hornsby-Treehouse springshed expressed in the DEM east and southeast of Hornsby Spring have associated subterranean conduit networks. Sink features known as "swallets" in these areas capture stream flow and provide direct conduits for surface water discharge into the aquifer. The FGS completed a project to map all known swallets in the state and produced a GIS layer that includes their locations. The DEM map (2009), closed depressions, and swallets in the region are shown in **Figure 4**. Two swallets identified in the figure, Mill Creek Sink and Lee Sink, have been linked to Hornsby Spring by a dye trace (discussed in a following section).

[3] Arthur, J. D., Wood, H. A. R., Baker, A. E., Cichon, J. R., Raines, G. L., 2007, *Development and Implementation of a Bayesian-based Aquifer Vulnerability Assessment in Florida*: Natural Resources Research, Vol. 16, No. 2., P. 93-107. Also for more information go to http://www.dep.state.fl.us/geology/programs/hydrogeology/fava.htm.
[4] Baker, A. E., Wood, A. R., Cichon, J. R., and Arthur, J. S., February 10, 2005. *Alachua County Aquifer Vulnerability Assessment*. FGS report submitted to the Alachua County Planning and Development Office.

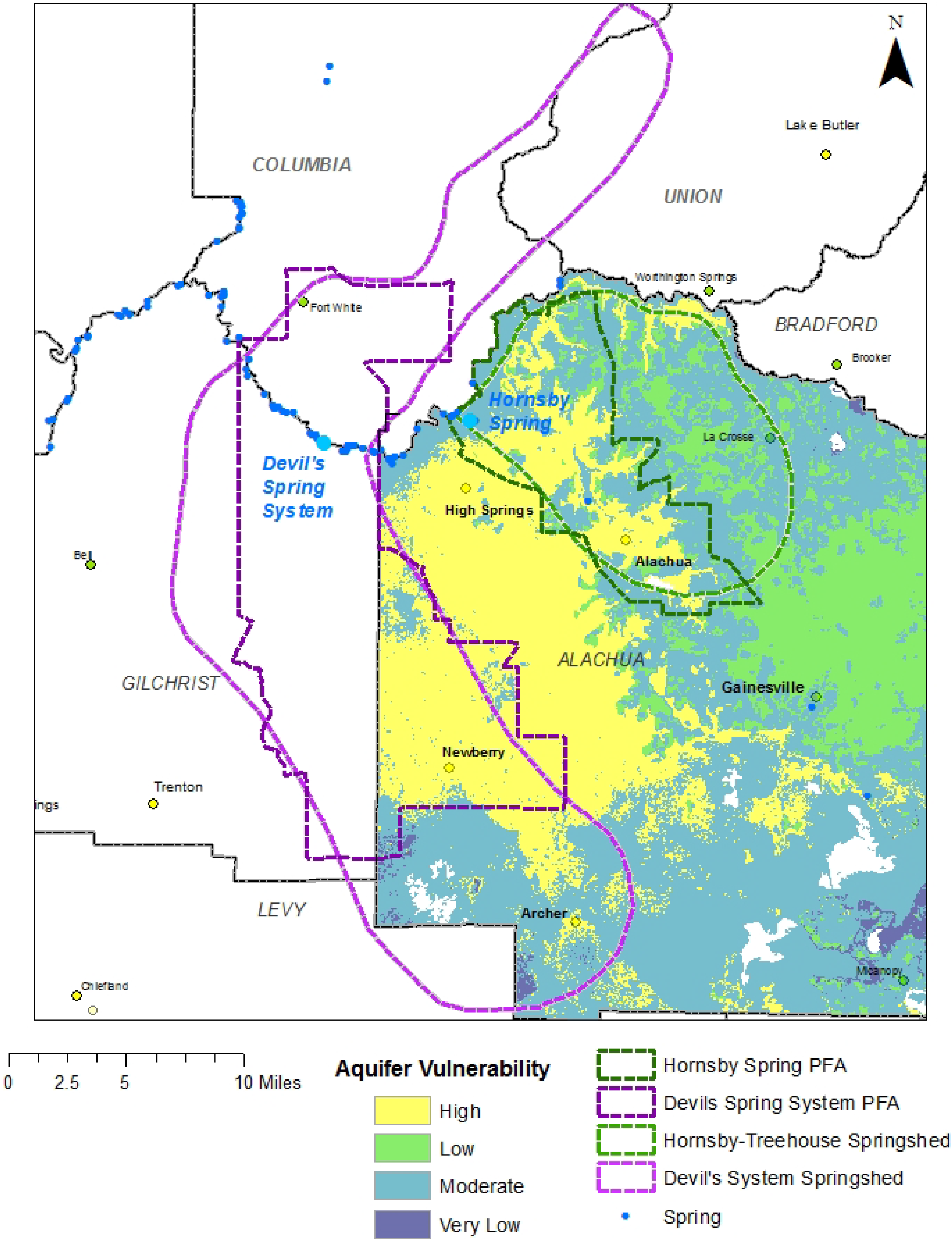

Figure 3. Floridan Aquifer Vulnerability in Alachua County portion of the springsheds

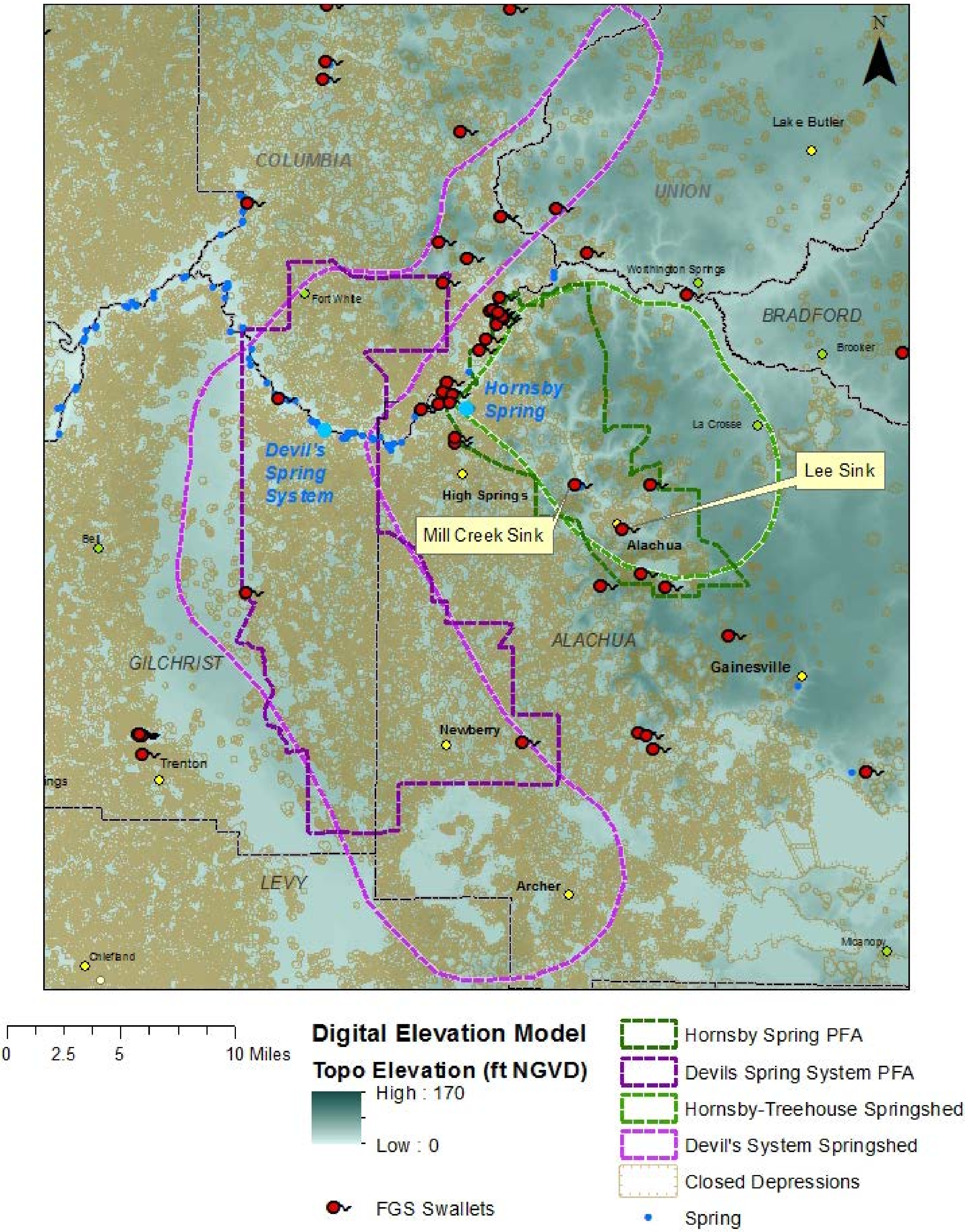

Figure 4. Digital elevation model, closed depressions and swallets in springsheds

Step 4. Consider nitrogen load

Nitrate-nitrogen is the major nutrient of concern in Florida's spring systems due to its pervasive nature in groundwater, its mobility, and its availability for uptake by aquatic flora when it is discharged from springs. High concentrations of nitrate in the spring water contributes to excessive growth of algae in the Santa Fe River. The source of flow from most springs in Florida is groundwater from the Floridan aquifer system. This groundwater comes mainly from local precipitation that recharges the aquifer in the springshed area. The nitrate originates from atmospheric deposition and anthropogenic sources in the springsheds.

Recent mean nitrate concentrations in Devil's Eye Spring and Hornsby Spring were 1.9 milligrams per liter (mg/L, based on 6/2017 DEP data) and 0.49 mg/L (based on SRWMD 2016 data), respectively. The recent average nitrate concentrations in Devil's Eye and Hornsby Spring are 5.4 and 1.3 times greater, respectively, than Florida's numeric nitrate criterion for spring vents and the nitrate concentration-based Total Maximum Daily Load for the Santa Fe River system (both set at 0.35 mg/L). The load of nitrogen from these springs depends on concentration and flow. While discharge is not routinely measured in these springs, there is some data available from which load estimates can be made. In 2006, DEP measured discharge in the Devil's Complex on two dates and the average discharge was 138 cubic feet per section (cfs). Discharge from Hornsby Spring has been highly variable over the years ranging from 0 to greater than 300 cfs over the measurement period with data. On a date in 2015, discharge in Hornsby Spring was greater than 80 cfs, based on historical SRWMD hydrologic data. Assuming the recent nitrate concentrations and available discharge data for the springs, the estimated loads of nitrogen (as nitrate) from the Devil's Spring System and Hornsby Spring were 1,418 and 215 pounds per day, respectively. The potential annual nitrogen load from the Devil's System could be greater than 500,000 pounds per year. Due to the intermittent flow from Hornsby Spring and the low frequency of discharge measurements in the historical record, it is not possible to estimate its annual load.

Step 5. Consider groundwater travel time in creating the PFA boundaries

To the extent possible, PFAs should include parts of contributing areas that have demonstrated or anticipated short travel times to the springs. Springs occur in areas of karst terrain where surface and subsurface erosion of the limestone can result in the development of complex networks of solution channels and conduits in the aquifer material. In these areas, groundwater can move rapidly from points where the water enters the aquifer to the spring vents. In some Outstanding Florida Spring areas, dye traces have been conducted by researchers to measure the travel times and information from these studies can be incorporated into the PFA development. In some other areas, models have been used to estimate travel times and define protection zones and can also be used to help define PFAs. In the absence of modeled or demonstrated travel times, best professional judgement of groundwater professionals experienced in the spring area may be considered.

There are no past dye traces or published groundwater transport models that could be used in refining the PFA for the Devil's Spring System, although many of the spring caves in this area have been mapped by cave divers. The Devil's System and July Spring have an extensive network of caves extending northward and up river along the Santa River that includes over an area that extends several hundred yards wide by more than a mile in length.[5] Cave divers have also mapped several tunnels extending from Hornsby spring for distances up to a mile. In the Hornsby springshed, a 2005 dye trace study identified connections between Hornsby Spring and two swallets, Mill Creek Sink and Lee Sink, which are 6 and 8.5 miles southeast of the spring, respectively.[6] Based on distance and arrival time (less than 13 days), groundwater travel time from these sinks to Hornsby Spring was between 1,400 and 2,400 feet per day.

Step 6. Identify regions in the contributing area where soil conditions are most favorable for the leaching of nitrogen from surface sources

Nitrogen is the target nutrient for spring restoration. Research has shown that the removal of nitrogen in the soil zone through denitrification and its tendency to leach is related to soil drainage class.[7] Denitrification is lowest and nitrogen leaching is highest in areas with soils that are excessively drained, somewhat excessively drained, or well drained. Leaching may occur in areas with moderately well-drained soils and is least likely to occur in soils that are poorly drained, somewhat poorly drained, or very poorly drained because of their greater potential for denitrification.

The portions of the spring contributing areas where soil conditions are more favorable for nitrogen leaching can be mapped using the U.S. Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS) Soil Survey Geographic (SSURGO) Database for Florida.[8] Mapped areas of excessively to well-drained soils often occur in areas where aquifer recharge is highest and vulnerability is greatest. **Figure 5** shows the soils that have high and moderate potential for nitrogen leaching. Areas of highest leaching include soils in the excessively drained, somewhat excessively drained, and well-drained SSURGO drainage classes. Areas of moderate leaching potential are those with moderately well drained soils.

Step 7. Identify regions in the contributing area to exclude or include based on land use and potential pollutant sources

Conservation lands, wetlands, and undeveloped open lands protected from development may be excluded from the PFA if there is no expectation that they would include pollutant sources affecting springs in the foreseeable future and are under protection. However some state-owned lands such as state parks may include wastewater treatment sites that could exist as potential

[5] Kinkaid, T. R., August 25, 2007. *Karst Hydrology of Florida's Santa Fe River Basin*, SEGS Field Trip Guidebook 47.

[6] Butt, P. L., Boyes, S., and Morris, T. L. June 7, 2006. *Mill Creek and Lee Sinks Dye Trace Alachua County Florida, July-December, 2005*. Karst Environmental Services report prepared for Alachua County Environmental Protection Division.

[7] Otis, R.J. 2007. *Estimates of nitrogen loadings to groundwater from onsite wastewater treatment systems in the Wekiva Study Area, Task 2 report, Wekiva onsite nitrogen contribution study.* Prepared by Otis Environmental Consultants for FDOH.

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

[8] The SSURGO Database is a digital soil survey developed by the National Cooperative Soil Survey. The dataset includes georeferenced digital map data and computerized attribute data. Metadata are available online.

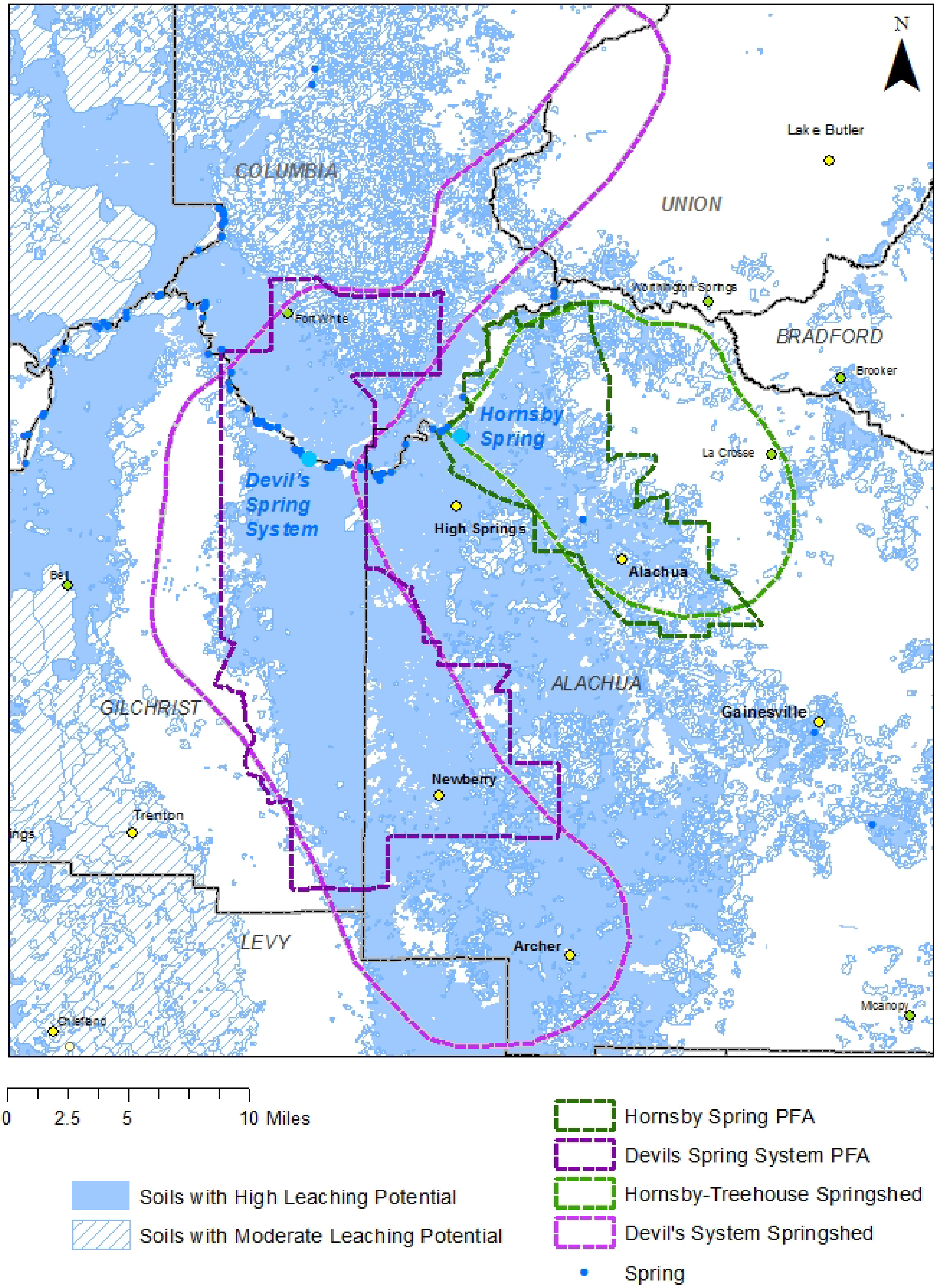

Figure 5. Areas with potential high and moderate nitrogen leaching in soils

pollutant sources. Several state-owned conservation lands and conservation easements occur along the Santa Fe River within these springsheds. Oleno and River Rise State Parks adjoin the springshed of Hornsby Spring and a future state park at Gilchrist Blue Spring will be in the Devil's System springshed. Several other state, federal and local conservation lands also occur in the springsheds. None of boundaries of these conservation lands was used in creation of PFA boundaries. **Figure 6** shows conservation lands from the Florida Natural Areas Inventory Conservation Lands (FNAI Managed Areas) GIS layer.

The PFA delineation also includes the consideration of areas with significant potential for nitrogen leaching to groundwater based on the sources of nitrogen that occur there. These potential sources could include septic systems (also known as onsite treatment and disposal systems or OSTDS), urban fertilizer, wastewater facilities, known contaminated sites, and agricultural sources such as fertilizer or animal waste. These sources occur in urban and agricultural land use areas. Approximately 12 % of the Devil's System contributing area is in urban land uses and about 27 % is in agricultural land use. Approximately 12 % pf the Hornsby springshed is in urban and 34 % is in agriculture. **Figure 7** shows mapped urban and agricultural lands (based on the 2013-2014 SRWMD land use–land cover GIS coverage). Significant urban and agricultural lands close to the springs and/or in high recharge/vulnerable soils areas were included in the PFAs.

Higher density areas of OSTDS close to the springs and/or in high recharge/vulnerable soils areas were also included in the PFAs. **Figure 8** shows the locations of OSTDS in the springsheds, based on GIS coverage developed as part of the FDOH Florida Water Management Inventory Project. This project provided information on known and estimated OSTDS location but did not provide information on system size or load to groundwater.

Existing domestic wastewater facilities, including those with design flows greater than or equal to 0.1 million gallons per day (mgd), are also shown in **Figure 8** because they also have the potential to contribute nitrogen to groundwater. Domestic wastewater facility information for the springsheds was obtained from the DEP Wastewater Facility Regulation (WAFR) Database. This database may not include data from recently permitted facilities.

Also shown in **Figure 8** is the Copeland Facility site, which is the former location of a sausage plant that has a well-documented nitrate contamination issue.

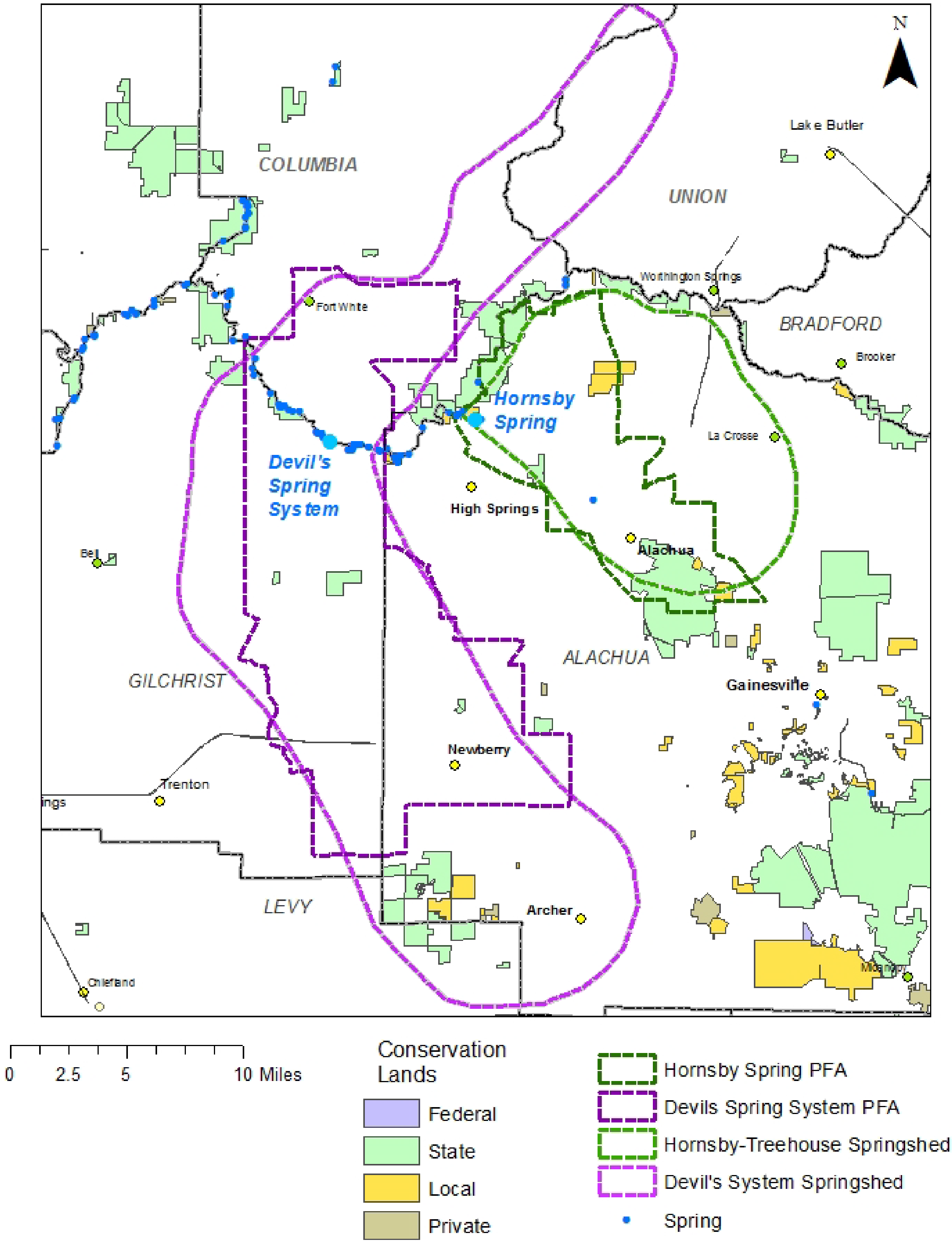

Figure 6. Conservation lands and PFAs

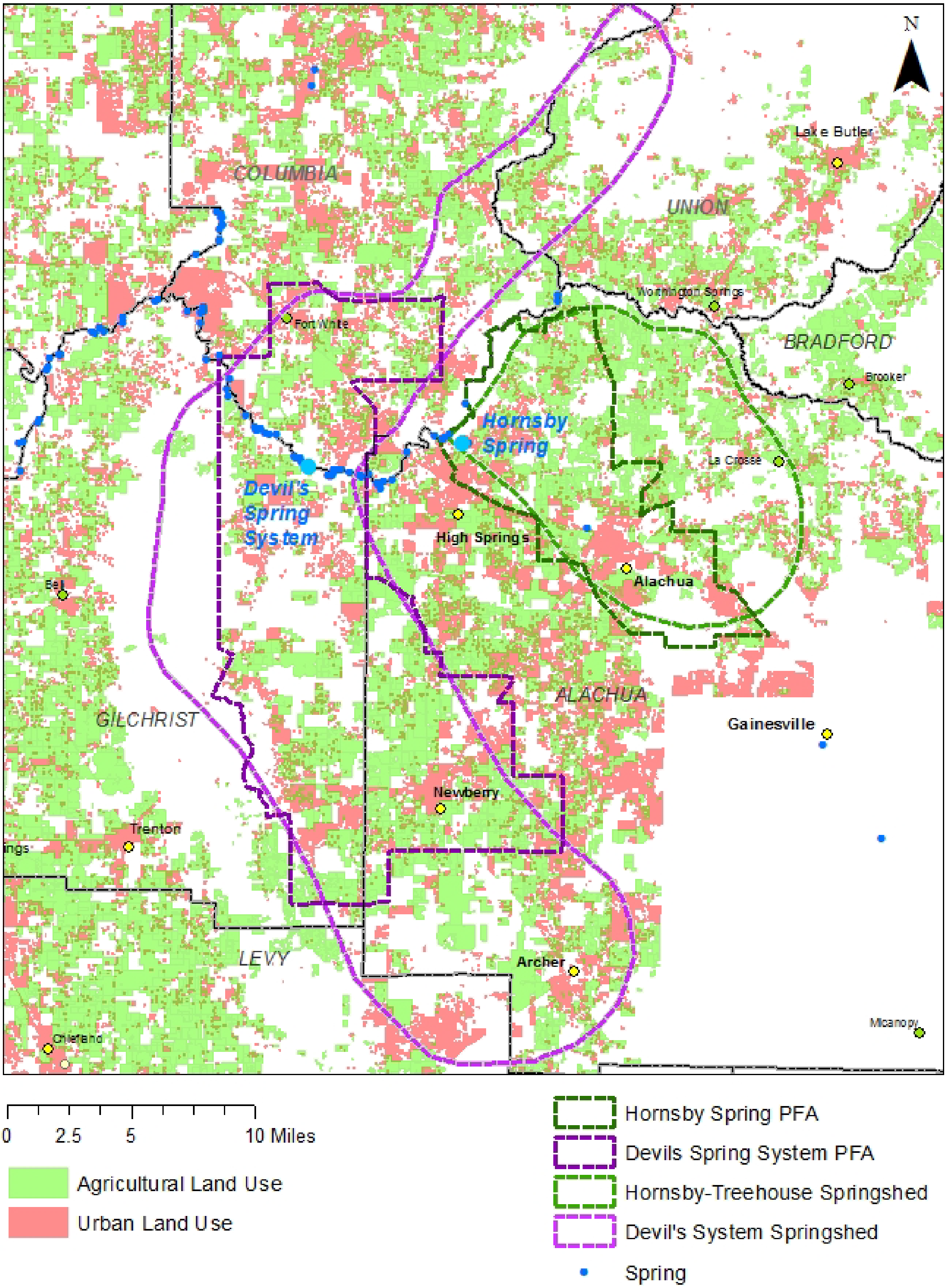

Figure 7. Urban and agricultural land use areas and PFA

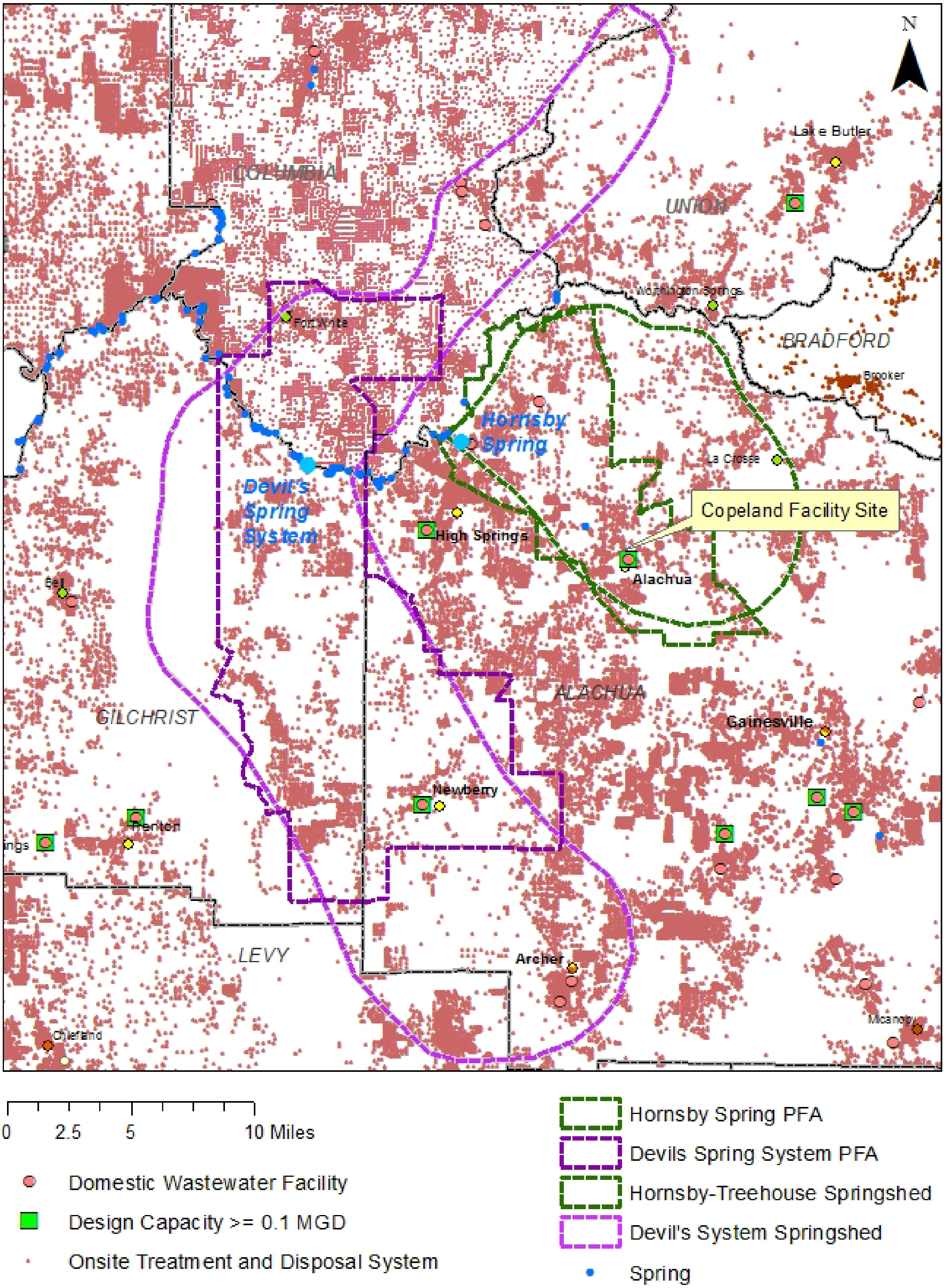

Figure 8. OSTDS, domestic WWTFs, and PFAs

Step 8. Create PFA boundaries that correspond with understood and identifiable geographic, hydrologic, and political features

For stakeholders to implement restoration and protection actions, the PFA boundaries must be clearly defined and associated with features and boundaries easily recognizable on a map, including geographic, hydrologic, and political features. The PFAs for Devil's Spring System and Hornsby Spring were developed based on roadways, major survey boundaries and political boundaries.

PFA Boundaries for Devil's Spring System and Hornsby Spring

The PFA boundaries shown in **Figure 9** were developed by reviewing GIS coverages of recharge, vulnerability, soils, conservation lands, and potential contaminant nitrogen sources.

The PFA for the Devil's System includes an area of high recharge with soils that have a high potential for nitrogen leaching. The area includes a significant amount of agricultural land use; higher concentrations of OSTDS in the Newberry area, in the Fort White area and along the Santa Fe River; and the City of Newberry wastewater treatment site. This PFA adjoins the Ichetucknee Springs PFA to the north and includes part of the city of Newberry, a portion of the town of Fort White and unincorporated areas Gilchrist, Alachua and Columbia Counties. The boundaries of this PFA follow roadways, a portion of the Gilchrist-Alachua county line, and known survey boundaries.

The PFA for Hornsby Spring includes an area where the Floridan aquifer was identified as "most vulnerable" based on the FAVA model, as well as an area of high recharge and higher leaching soils. The area also includes the contributing areas of two swallets known to have connection to the spring as demonstrated by dye traces. The area includes agricultural and urban land uses, concentrated areas of OSTDS, and the City of Alachua's domestic wastewater treatment site. The Hornsby Spring PFA is bounded on the north by the Columbia-Alachua county line and on the east, west and south by roadways. It includes portions of the cities of High Springs and Alachua and is located entirely in Alachua County.

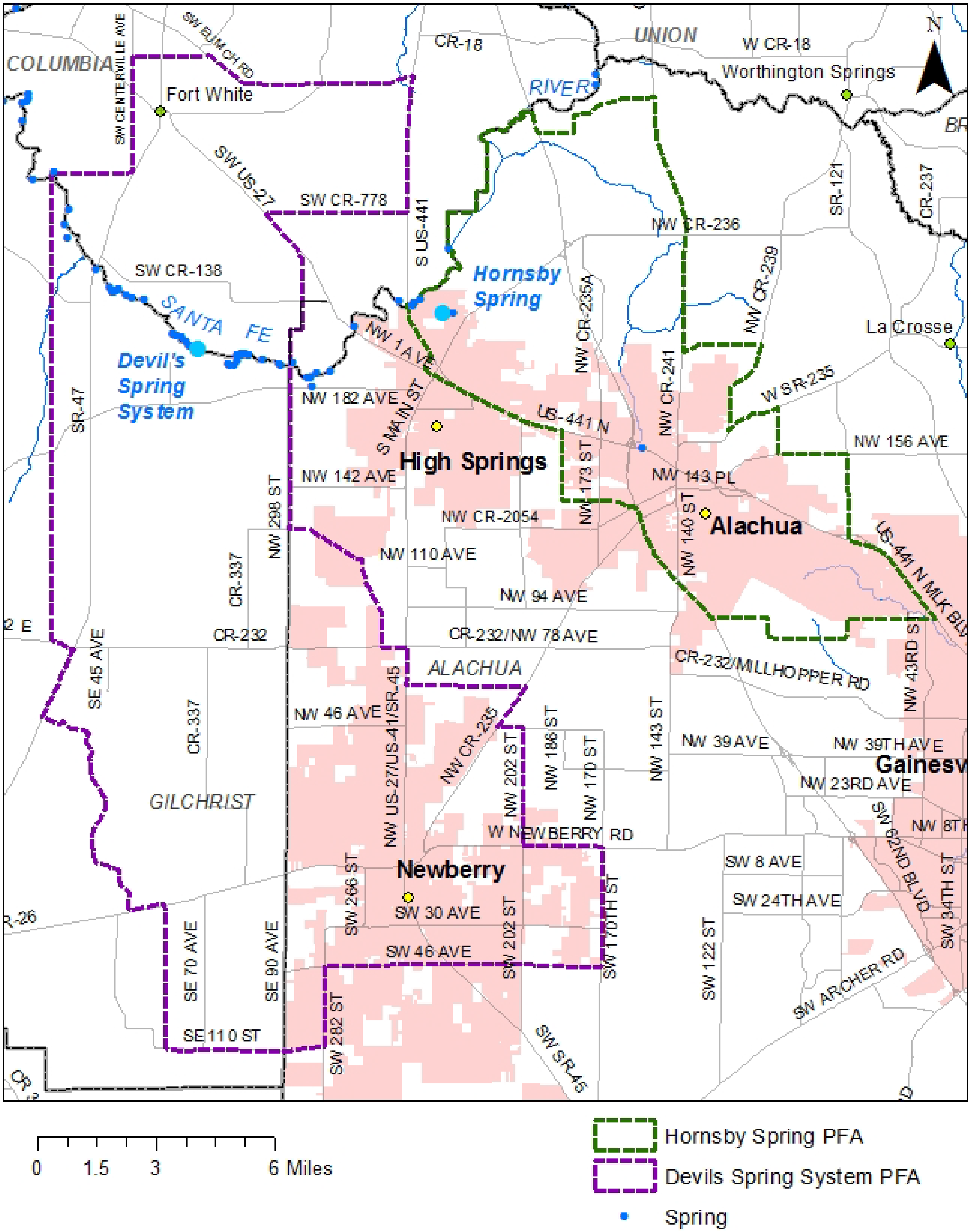

Figure 9. PFA boundaries for Devil's Spring System and Hornsby Spring