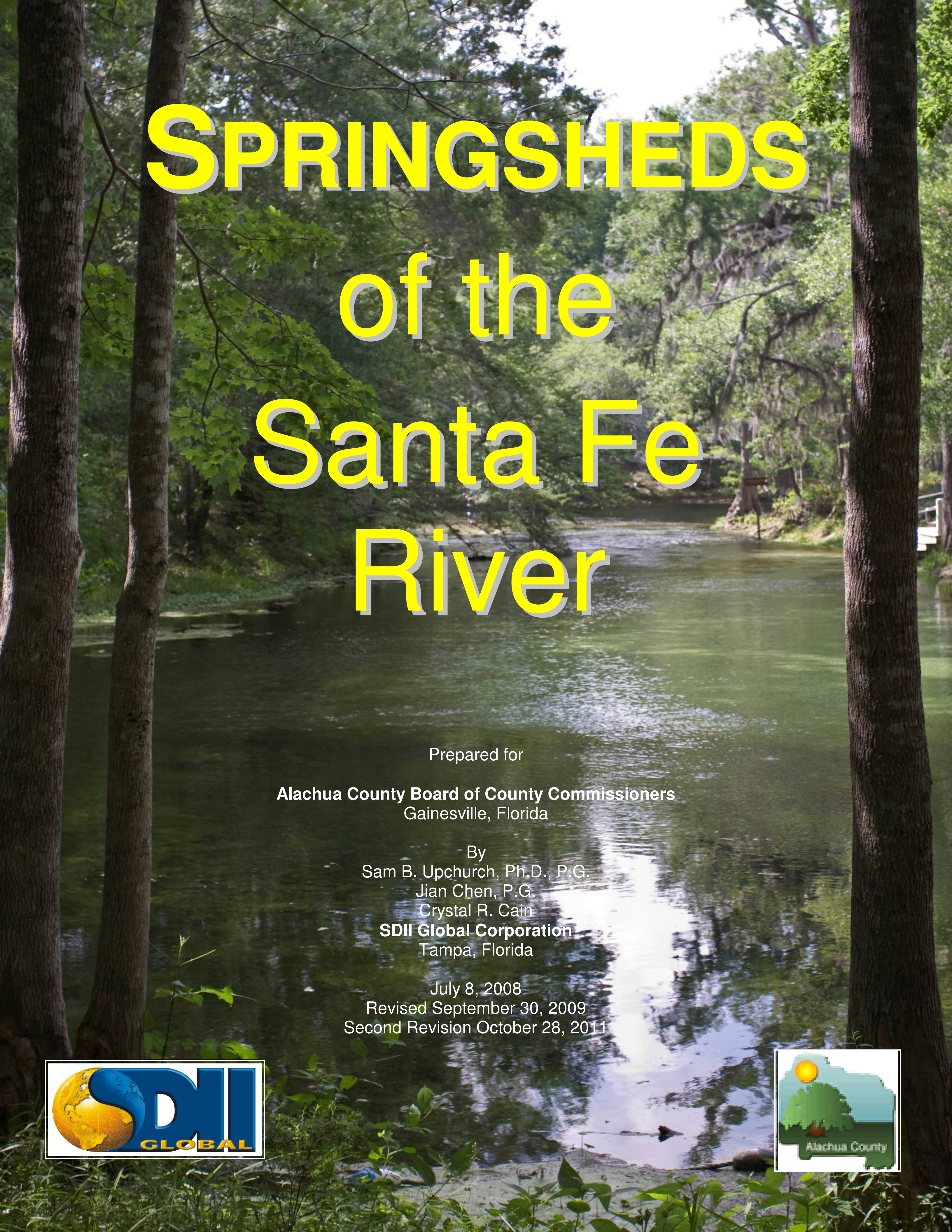

SPRINGSHEDS of the Santa Fe River

Prepared for

Alachua County Board of County Commissioners
Gainesville, Florida

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Endorsement

This report was submitted to the Alachua County Environmental Protection Department by SDII Global Corporation under Purchase Orders 071623 and 111454. All work was performed under the supervision of the undersigned.

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Cover Photograph

Poe Spring, Alachua County, Florida, in November, 2006. The view is looking downstream from the spring pool toward the Santa Fe River.

EXECUTIVE SUMMARY

Alachua County, Florida, retained SDII Global Corporation to delineate springsheds for springs on the Santa Fe River downstream from the Santa Fe River Rise in 2006. Springshed delineation was undertaken in three phases. Three major tasks were undertaken as part of Phase I. These were:

(1) Prepare a literature review to identify previous investigations that assist in understanding the extent of each extents,

(2) Delineate Santa Fe River springsheds using September 2007, regional potentials in the upper Floridan aquifer, and

(3) Use U.S. Geological Survey and Suwannee River Water Management District groundwater flow models to estimate springsheds and capture zones.

When it was determined that delineation of springsheds in the Newberry Plain area of Alachua and Gilchrist counties was problematic, Alachua County authorized Phase II, which involved adding more groundwater monitoring points and re-contouring the Floridan aquifer potentiometric surface at a higher resolution. Phase III consisted of addition of more September 2007, potentiometric data and preparing springshed maps for May 2008, potentials, as well. The results of these three phases are combined in this report.

In Phase I, springsheds consisting of clusters of springs were delineated using existing September 2007, upper Floridan aquifer potentiometric-surface data. The low density of existing monitoring wells and dominance of conduit flow to the springs limited delineation of springsheds for specific springs. The springsheds generally extend from the Cody Scarp and Waccasassa Flats to clusters of springs near the river in a manner that is generally consistent with the results of dye tracing, chemical fingerprinting, cave mapping, and other available data. The only major issues remaining from Phase I and II were (1) the "headwaters" of some springsheds extended beyond the data and (2) differentiation of the lateral boundaries that were hypothesized to separate the springsheds within the Newberry Plain. Phase III refinements of the potentiometric data allowed for delineation of the "headwater" extents of the springsheds, but separation of individual springsheds within the Newberry Plain remains problematic.

Groundwater flow modeling using the Suwannee River Water Management District's model (Schneider et al., 2008) was successful in delineating general springsheds when the model was run to steady state. This is important information because this steady-state model is utilized by the District to evaluate proposed groundwater withdrawals for permitting. In some cases, capture zones were approximated, as well. The U.S. Geological Survey (USGS) "Megamodel" (Sepúlveda, 2002) was designed to explore the flow relationships of the Intermediate and upper Floridan aquifer. Because the model sets Layer 1 as a constant head boundary, the Megamodel was not serviceable for use in characterization of springsheds or spring capture zones. It is clear that groundwater flow modeling has limitations as far as characterization of springshed capture zones based on flow times.

These limitations are a result of (1) the complex karst system, including in-river siphons and resurgences and overlapping cavern systems, and (2) inability of finite-difference models to account for conduit flow.

Geostatistical analysis of the September 2007, potentiometric data indicates that the monitoring well density of Alachua County's new monitoring network is sufficient for springshed delineation. With the expansion of the network in Phase III, the spatial extent of the network is sufficient, as well.

An upper Floridan aquifer potentiometric surface map was prepared from the September 2007 data utilizing a 1-foot contour interval and the results of the geostatistical analysis. The results of the analysis allow for higher resolution of major springsheds. In order to account for the extended spatial extent of monitoring in Phase II and III, 2-foot contour maps were prepared for September 2007, and May 2008, as well. Even with the high resolution and increased spatial extent, the springs that drain the Newberry Plain generally do not have distinctive springsheds, however. This result is consistent with cave mapping, dye tracing, and other investigations that indicate complex overlaps of spring flow systems.

In 2011, it was discovered that a data point one the May, 2008, potentiometric surface map was incorrect. The October, 2011, revision corrects this error.

The final delineations of Santa Fe River springsheds suggest that the springsheds for the some springs (Santa Fe Rise, Hornsby-Treehouse, Ichetucknee) can be discretized for management purposes. The lateral boundaries of springsheds for other springs (Poe, Blue, Ginnie, and other springs that drain the Newberry Plain) cannot be easily differentiated. Therefore, it is recommended that the Newberry Plain be treated as a single springshed with multiple springs.

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INTRODUCTION

Alachua County has been involved for several years in developing an understanding of the springsheds[1] for the springs along the Santa Fe River (Figure 1). This is partly because of concerns about rising nutrient levels discharging from many of the springs and also because of the County's awareness of the need for protection of the springs as the county develops. Because of this concern, Alachua County retained SDII Global Corporation (SDII) to delineate springsheds along the Santa Fe River, including springsheds within and adjacent to the county downstream from the Santa Fe Rise.

Project Phases

This report presents the results of delineation of springsheds along the Santa Fe River system (Figure 1). The report includes the results of three phases of investigation.

Phase I

Phase I, which was completed in 2007, included preliminary delineation of springsheds based on existing data from the year 2000. Potentiometric surface data were sparse in many areas, and springshed delineation resulted in identification of broad drainage areas with limited details of each springshed.

Also in Phase I, two groundwater flow models were utilized to investigate springsheds by inverse particle tracking. The groundwater flow model developed by the U.S. Geological Survey (USGS; Sepúlveda, 2002) was found to be unsuitable for springshed delineation because Layer 1, the surficial aquifer layer, was constructed in the model as a constant head source of water to the underlying model layers. The Suwannee River Water Management District (District) groundwater flow model (Schneider et al., 2008) was constructed as a fully three-dimensional model with many specified springs and swallets. That model was better able to identify possible springsheds, but the swallets in the model limited the predicted extents of spring recharge areas to some extent.

When Phase I was completed, it was recommended that additional upper Floridan aquifer potentiometric surface data be collected in Alachua and Gilchrist counties in order to increase the resolution of the potentiometric surface map for better delineation of springsheds in the Lower Santa Fe River system.

[1] A springshed consists of "those areas within ground- and surface-water basins that contribute to the discharge of the spring" (Copeland, 2003).

Phase II

Phase II of the study included an extensive data collection effort by Alachua County to develop the recommended, high-resolution potentiometric surface data. All totaled, Alachua County Environmental Protection Department staff obtained almost 200 data points, which included potentiometric data from wells in the Newberry Plain[2] as well as elsewhere in Alachua and Gilchrist counties and neighboring areas, stream stage data, and spring stage data. The Alachua County data were obtained over a 10-day period from September 11 through 20, 2007. The District also provided data resulting in 205 data points for the high-resolution study.

SDII utilized these data to perform a geostatistical analysis of the upper Floridan aquifer potentiometric data and develop a 1-foot contour map of the potentiometric surface for high-resolution delineation of the springsheds of the Santa Fe River system.

Phase III

A draft report was prepared and submitted to Alachua County and the Florida Department of Environmental Protection (FDEP) in 2008. The high-resolution data were found to be appropriate for springshed delineation to the extent practicable, but the ultimate extents of some of the springsheds in their "headwaters" remained unidentified. This was particularly problematic for the springsheds that extend under the Northern Highlands. Based on recommendations in the draft report, Phase III was developed to develop springshed maps that include the springshed headwaters. At the same time, Alachua County requested, and provided data for, development of a May 2008, potentiometric surface map and springshed delineation.

Data were collected by Alachua County from their monitoring network for a 10-day period in May 2008. Potentiometric data from the St. Johns River Water Management District were used to extend the potentiometric September 2007, and May 2008, potentiometric surfaces under the Northern Highlands. These maps are included as part of this report.

Scope of Work

Phase I

Three activities were undertaken as part of Phase I. These tasks are discussed individually below.

[2] The Newberry Plain is that portion of the Western Valley (White, 1970) that includes the karst terrain located along the Alachua-Gilchrist County line. It extends northward from south of the town of Newberry to the Santa Fe River and from the Cody Scarp on the east to the Waccasassa Flats/Brooksville Ridge on the west (White, 1970).

Task 1 - Literature Review: In order to assist in understanding how the springs function, investigations conducted for springs on the Santa Fe River through dye tracing, chemical fingerprinting, previous springshed delineations and other sources were reviewed and incorporated into the final report. Also, springshed investigations from other areas in Florida that assist in understanding how springsheds function in general were reviewed for the report.

Task 2 - Delineate Springshed Extents and Capture Zones Using Existing Groundwater Flow Models: Groundwater flow models can be used with limitations to delineate springsheds and spring capture zones. Since the existing models are finite difference models, they cannot account for conduit flow, an important process that affects Santa Fe River springs.

Two groundwater flow models were utilized with the intent of comparing them and delineating capture zones and springshed that encompass the results of both models. The models used were developed by the District (Schneider et al., 2008) and U.S. Geological Survey (Sepúlveda, 2002). Based on the two models, the areas that represent the estimated travel times to the springs were estimated to incorporate the areas delineated by the combined models.

Task 3 - Estimate Springsheds from Potentiometric Surface Maps: In addition to running the groundwater flow models to identify contribution areas to the springs, two preliminary potentiometric maps of the upper Floridan aquifer were developed for estimation of springshed extents. The two maps represent May and September 2000. The year 2000 was selected for initial analysis because

- The District's groundwater flow model (Schneider et al., 2008) was calibrated to conditions in 2000;
- 2000 was a dry year, so the potentiometric surface should have high relief, which should enhance ability to identify springsheds; and
- Available Floridan aquifer potentiometric data were at a maximum.

Based on these two maps, preliminary springsheds were delineated by identifying watershed divides within the groundwater system. Maps were produced to depict these springsheds and their spatial extents. Note that it was not possible to identify springsheds associated with specific springs in many cases. This is because of

- The high density of springs along the river,
- The fact that many springs share a springshed (they appear to function as large spring systems with multiple vents), and
- The relative scarcity of potentiometric data near the springs.

Where these conditions existed, the springs were treated as clusters (informal spring groups) and springsheds were delineated for the multiple springs. The spring clusters are discussed below.

Phase II

The scope of work for Phase II of this study consisted of two tasks (Tasks 4 and 5 to be consistent with Phase I terminology).

Task 4 - Potentiometric Data Collection: Task 4 included data collection for development of a high-resolution potentiometric map of the upper Floridan aquifer, as recommended upon completion of Phase I. This task was completed by the Alachua County Environmental Protection Department and the data were transferred to SDII Global Corporation for processing.

Task 5 - Geostatistical Analysis of the High-Resolution Potentiometric Data: Task 5 included geostatistical analysis of the potentiometric data. A structural analysis was conducted to develop contouring "rules" and kriging was utilized to model the potentiometric surface and prepare uncertainty maps.

Phase III

The scope of work for Phase III included addition of two more tasks.

Task 6 – Expansion of the Aerial Extent of the September 2007, Potentiometric Map: Additional data from Alachua County and the St. Johns River Water Management District were used to expand the potentiometric surface maps and revise the springshed delineations for September 2007.

Task 7 – Development of a Potentiometric Map and Springshed Delineation for May 2008 Data: Alachua County provided upper Floridan aquifer potentiometric data from their monitoring network. These data, combined with data from the Johns River Water Management District, were used to develop a high-resolution potentiometric surface map of the area for May 2008. Springsheds were delineated based on these data.

BACKGROUND HYDROGEOLOGY

It is important to understand several aspects of the regional geology before introducing the results of this study. The three most important hydrogeological concepts deal with the

- Regional physiography or landforms,
- Degree of confinement of the upper Floridan aquifer, the principal water bearing aquifer of the area and the aquifer from which the majority of springs discharge water, and
- Regional, upper Floridan aquifer potentiometric surface.

These three aspects of the system are discussed below.

Regional Physiography

The study area includes nine physiographic provinces (Figure 2). The most important of these to the behavior of the lower Santa Fe River springs are the Gulf Coastal Lowlands, Bell Ridge and the associated Waccasassa Flats, High Springs Gap and the Brooksville Ridge, Western Valley (the Newberry Plain), and the Northern Highlands (White, 1970).

The Gulf Coastal Lowlands consist of an extensive karst plain that is characterized by numerous small sinkholes and internally drained basins. The bedrock consists of the Eocene Ocala Limestone and, locally, Oligocene Suwannee Limestone (Table 1). The Santa Fe River lies within this province from just downstream from the mouth of the Ichetucknee River westward to the Suwannee River.

Bell Ridge (Figure 2) is a dune ridge that bisects Gilchrist County from north to south. The ridge is perched on a feature known as the Waccasassa Flats (Col et al., 1997). Bell Ridge and the Waccasassa Flats are underlain by sandy and clayey sediments that have significantly lower permeabilities than the surrounding limestone. As a result, Bell Ridge and the Waccasassa Flats are characterized by a perched water table and numerous swamps and wetlands. In addition, there is a potentiometric high in the upper Floridan aquifer under these physiographic features.

The High Springs Gap is a low, gap between the Brooksville Ridge and the Northern Highlands within which the Santa Fe flows. The Brooksville Ridge is a complex of weathered, sandy sediments and limestone that forms a topographic high. The Brooksville Ridge is dotted with large sinkholes and is a recharge area in many areas.

The Western Valley (Figure 2) is a low valley that trends north to south between the Brooksville Ridge and Northern Highlands. In Alachua County, the Western Valley is known as the Newberry Plain. The valley is a karst plain with sandy soils overlying limestone. Sinkholes are abundant.

Finally, the Northern Highlands (Figure 2) consist of a relatively high plateau characterized by little karst and thick sequences of low permeability, clay-rich sediments of the Miocene Hawthorn Group (Table 1). Note in Figure 2 that the Northern Highlands are also characterized by well-developed, dendritic stream systems. These streams exist because the underlying, low permeability sediments greatly retard recharge to the underlying limestone.

Table 1. Generalized lithostratigraphic column and aquifer systems in the Suwannee River Basin.

LITHOSTRATIGRAPHIC NOMENCLATURE			HYDROSTRATIGRAPHIC NOMENCLATURE
System	**Series**	**Formation/Group**	**Aquifer System**
Quaternary	Holocene Pleistocene	Undifferentiated Sand	Surficial Aquifer
Tertiary	Pliocene	Undifferentiated Sand	
	Miocene	Hawthorn Group St. Mark's Formation	Intermediate Aquifer and Confining Unit
	Oligocene	Suwannee Limestone	Upper Floridan Aquifer
	Eocene	Ocala Limestone Avon Park Limestone Oldsmar Limestone	Mid-Floridan Confining Unit
	Paleocene	Cedar Keys Formation	Lower Floridan Aquifer

The transitional boundary between the Northern Highlands and Western Valley/Gulf Coastal Lowlands (Figure 2) is known as the Cody Scarp[3] (Puri and Vernon, 1964; White, 1970; Upchurch and Lawrence, 1984; Upchurch, 2002, 2008). This Scarp is characterized by numerous streams that sink into the subsurface by way of swallets as the streams flow off the Northern Highlands. The sinkholes of the Cody Scarp are large as a result of coalescing of smaller sinks in an area where the overlying cover is relatively thick (Upchurch, 2002, 2008). The Scarp is also an area where through-flowing streams, such as the Santa Fe River, go underground via swallets or siphons, and re-emerge through resurgences, or springs. Some of the springs of the Santa Fe System are siphon-to-resurgence systems that range in size up to the well-known Santa Fe Sink/Rise system near High Springs (Butt et al., 2007). Other springs are associated with swallet-to-spring systems that originate at the swallets of the Cody Scarp. As a result, these systems are affected by activities in the surface-water drainage basins upstream from the swallets and siphons that introduce the surface water to the aquifer.

[3] Figure 2, which is based on the work of White (1970), does not show the Cody Scarp as a physiographic province, nor is it commonly treated as such. The Scarp is a 1 to 10 mile wide transition area that occupies the western margin of the Northern Highlands in Figure 2.

Degree of Confinement of the Upper Floridan Aquifer

The behavior of the upper Floridan aquifer (Table 1) is highly dependent on recharge. Where the aquifer is unconfined (Figure 3), the aquifer receives widespread recharge. In areas where the aquifer is confined, recharge is limited or insignificant. Unconfined areas of the upper Floridan aquifer are characterized by well-developed porosity and permeability as a result of initial, intergranular porosity of the limestone and fractures and karst conduits (Upchurch, 2002). Where the aquifer is well confined, the initial, intergranular, moldic, and fracture porosity exists, but the fractures and karst-related porosity is limited in extent (Upchurch, 2002; Budd and Vacher, 2004).

Within the study area, the recharge areas of the springs are limited to the unconfined or semi-confined areas depicted on Figure 3. Because there is a drainage gradient, springsheds extend into the Northern Highlands where confinement is present, but the springs do not receive significant water from these confined regions. Water-quality data from the upper Floridan aquifer strongly suggests that water in areas where the aquifer is confined under the Northern Highlands has had a long residence time and that flow is sluggish to stagnant (Lawrence and Upchurch, 1976, 1982; Upchurch and Lawrence, 1984; Upchurch, 2002; Upchurch and Champion, 2003a, b).

Figure 4 is an example of a springshed delineated by the potentiometric surface. The Ichetucknee Spring Group springshed abuts the Cody Scarp and Northern Highlands to the north and east. The Cody Scarp is at the location where the green upper Floridan aquifer potentiometric surface contour lines are close together along the upper and right-hand side of the figure. Note that the springshed is drawn to extend into the Northern Highlands. Even though there is a drainage gradient that extends under the Northern Highlands, this portion of the springshed is not part of the active recharge and flow system. For this reason and a lack of really extensive data, the Phase II springshed delineation lines in this report were terminated at the location where the Floridan becomes well confined and the flow system becomes significantly less dynamic. Phase III maps include sufficient data to extend the springsheds under the Northern Highlands.

Upper Floridan Aquifer Potentiometric Surface

Figure 5 depicts the Upper Floridan aquifer potentiometric surface as drawn by the USGS from potentiometric data from the year 2000. The contour interval is 10 feet. Note that the contour lines indicate a steep gradient under the Bell Ridge area (cf. Figure 2). The term Bell Ridge potentiometric high is used for this feature in the remainder of this report. This potentiometric high indicates that recharge is limited and that the permeability of the underlying, upper Floridan aquifer is also limited. As a result, water that was unable to recharge the aquifer runs off as streams and forms lakes and wetlands. The low permeability of the upper Floridan allows what little recharge there is to slowly drain down gradient. Springs that back up to the Bell Ridge potentiometric high receive little water from the area of the potentiometric high because of the low recharge and low permeability. They do receive recharge through small swallets around the margins of Bell Ridge and the Waccasassa Flats (Copeland et al., 2005), however.

A similar situation exists on the western margin of the Northern Highlands. While the gradient is not as steep, it is still steeper than in the Western Valley or Gulf Coastal Lowlands. The potentiometric-surface contour lines shown in Figures 4 and 5 illustrate this phenomenon and reflect low recharge and low aquifer permeability on areas where the upper Floridan is confined relative to other portions of the study area.

Finally, note in Figure 5 the large areas in the Gulf Coastal Lowlands, Western Valley, and High Springs Gap areas where the potentiometric contours lines are widely spaced. These areas are characterized by low hydraulic gradient and high aquifer permeability. These conditions result in efficient draining of the aquifer after recharge. It is within these areas that springsheds are typically best developed in Florida.

PREVIOUS WORK

The Santa Fe River has been the focus of a number of studies that provide information on springshed delineation. For example, Alachua County retained Karst Environmental (Butt et al., 2006) in 2006 to investigate hydrologic connections between Mill Creek Sink and Lee Sink, near the city of Alachua, and Poe, Hornsby and Treehouse Springs. Studies, such as these, set the stage for initial attempts at springshed delineation.

Spring Characterization

Over the last few years, the Suwannee River Water Management District undertook a series of investigations for the purpose of establishing minimum flows and levels (MFLs) for the rivers and selected springs within the District. The basis document for the MFLs for the Upper Santa Fe River, which extends upstream from the gage on the Santa Fe River at Worthington Springs, has been completed (Water Resource Associates, 2006) and the District has adopted MFLs for the basin.

The District is also working on developing MFLs for the Lower Santa Fe River (Olustee Creek and the Santa Fe River downstream from Worthington Springs) at the present time. The MFL report for the Lower Santa Fe River will include suggested MFLs for

- The Lower Santa Fe River,
- The Ichetucknee River,
- All first magnitude springs on the Lower Santa Fe and Ichetucknee Rivers, and
- All second magnitude springs that are on lands purchased by state and local governments for conservation purposes.

Therefore, MFLs will be developed for the Treehouse Spring, Hornsby Spring, Blue Hole Spring, an unnamed spring designated COL 101974, Columbia Spring, Devils Ear in the Ginnie Spring group. Siphon Creek Rise, the Ichetucknee group of springs, July Spring, Poe Spring, Rum Island Spring, and the Santa Fe Rise. The process of developing MFLs for these springs will be greatly enhanced by Alachua County's springshed delineation efforts.

In addition to the studies associated with MFL development, there have been a number of site-specific investigations dealing with major springs along the Santa Fe River. These include dye-trace studies (i.e., Karst Environmental Services, 1997; Butt, 2005) and chemical fingerprinting studies (Upchurch and Champion, 2003; Upchurch et al., 2004) associated with Ichetucknee River and springs, delineation of the Ichetucknee springshed (Upchurch and Champion, 2003), dye tracing associated with Hornsby and Poe Springs (Butt et al., 2006), and chemical fingerprinting and dye investigations associated with Ginnie Springs (Wilson and Skiles, 1988).

Kinkaid (1998) explored the sources of water in the Devil's Ear System (including July Spring) using water clarity, and ^{222}Rn, and $\delta^{18}O$ data. He concluded that as much as 62 percent of the water in the Devil's Ear system is river water, apparently related to an up-gradient swallet or siphon.

Butt et al. (2007) developed a summary of relationships of swallets and siphons in the Santa Fe River to Santa Fe basin springs. The results synthesis of cave mapping, dye tracing, and other data clearly indicate that many of the springs of the Santa Fe basin have significant surface-water sources. Those springs that are served by siphons or swallets in the river should have somewhat limited springsheds.

Upchurch et al. (2007a) investigated temporal trends in nitrate + nitrite concentrations in Suwannee River Water Management District springs. It was found that Santa Fe River springs reveal variable temporal trends of nitrate + nitrite concentrations as follows:

- Statistically significant trends with declining concentrations over time: 6 springs (i.e., Hornsby Spring and Poe Spring),

- Statistically significant trends of increasing concentrations with time: 2 springs (Ichetucknee Head Spring, Gilchrist Blue Spring), and

- Springs with no temporal trend in nitrite + nitrite either because of low sample size or lack of statistical significance: 9 springs.

Upchurch et al. (2007b) investigated the relationship of nitrate + nitrite to spring discharge. It was determined that the nitrate + nitrite concentrations are directly proportional to spring discharge. That is, nitrate concentrations are greatest when spring discharge is greatest. This relationship suggested that nitrate + nitrite concentrations reflect nitrogen leaching and flushing processes in the springsheds and that MFLs that maximize flow will not assist in reducing nitrogen flux to the Santa Fe River.

In order to investigate the nitrogen leaching/flushing process, Upchurch et al. (2007b) compared nitrate + nitrite concentrations to specific conductance in spring discharge. Springs where the two analytes were inversely correlated were found to reflect springsheds where a significant proportion of the groundwater was derived from surface-water runoff and recharge through swallets and/or siphons in the Santa Fe River. Where the two analytes were positively correlated, the springshed was dominated by diffuse recharge and longer residence times in the aquifer. Examples of runoff-dominated springsheds include Columbia Spring, Santa Fe Spring, Poe Spring, and Hornsby Spring. Examples of diffuse recharge-dominated springsheds include Gilchrist Blue Spring, Devil's Ear Spring, Ginnie Spring, Blue Hole Spring, Devil's Eye Spring, and Grassy Hole Spring. This study is of consequence because it provides insight relating to the "plumbing" of the springsheds; particularly as relates to swallet-dominated as opposed to diffuse recharge systems.

These investigations have all shown a close association between spring water quality and swallets and other recharge features associated with the nearby Cody Escarpment (Upchurch, 2002, 2007). The springsheds that correspond to these springs should reflect the sources of water, both in their physical locations and in terms of recharge basin size.

Springshed Delineation and Springshed Management

Springshed delineation as a management tool is just beginning in Florida. Because of the need to manage land use in order to protect water quality and flows to springs, there has been a concerted effort over the last few years to delineate springsheds and, in some cases, identify travel times of groundwater to springs. This section discusses some of these efforts.

Spring Catalogs

The first step in understanding how springs function and how to protect them is identification of the springs. This involves cataloging of springs and describing their properties.

Naming and cataloging of springs typically involves identification of any location where a significant amount of water issues from the ground. As such, some confusion has arisen as to what constitutes a spring and which springs have significant springsheds. For example, the springs of the Ichetucknee Spring Group (Ichetucknee Springs) predominantly drain groundwater from the upper Floridan aquifer. During large rainfall events and wet seasons, creeks, such as Rose and Cannon creeks, discharge to swallets and contribute to the spring discharge. In contrast, the Santa Fe Rise is a resurgence - a spring whose flow is largely surface water that has entered a cavern system in the aquifer through a siphon in a stream. Groundwater contributions to a resurgence may be minor compared to the volume of surface water that flows through the system. Copeland (2003) has discussed the different forms of springs in Florida and developed a nomenclature system for springs, which is followed in this report.

The first systematic description of Florida springs was by Ferguson et al. (1947). This report described selected springs throughout the state and presented physical descriptions of the springs, discharge data, and water quality data. No attempt was made to identify groundwater contribution areas. Ferguson et al. (1949) discussed Poe and Ichatucknee [sic] springs and noted the presence of Blue Springs, Hornsby Springs, July Spring, Lily Spring, and two small springs near High Springs.

Rosenau et al. (1977) revised the Springs of Florida by Ferguson et al. (1949) and included additional springs in the statewide catalog. Spring-specific descriptions included the current status of each spring and a summary of discharge and water-quality data. Santa Fe River springs which were discussed included Hornsby, Poe, Blue, Ginnie, and the Ichetucknee Springs Group. Springs that were identified with coordinate locations included Allen, Betty, Columbia, Darby, Devil's Eye, Jamison, Jonathan, July, Lily, Northbank, Rum Island, Wilson, and a series of small springs at High Springs.

Hornsby and Ceryak (1999) developed the most comprehensive inventory of springs on the Santa Fe. Their report includes location data, a brief discussion of the physical setting of each spring and recent flow and water quality data. In addition, an appendix summarizes much of the historical flow and water quality data for each spring and an appendix presents available cave maps. The 26 named Santa Fe River springs that are included in Hornsby and Ceryak are Betty, Blue, Columbia, Hornsby, Darby, Deer, Devil's Ear, Devil's Eye, Dogwood, Ginnie, Ichetucknee Spring Group, Jamison, July, Lily, Little Devil, Oasis, Pickard, Poe, Rum Island, Santa Fe (COL61981), Santa Fe Rise, Sawdust, Sunbeam, Trail, Twin, and Wilson springs. Thirty five unnamed springs (ALA12971, ALA930971, ALA930972, COL928972, COL93071, COL1012971, COL1012972, COL101974, COL428982, COL917971, COL928971, COL101971, COL101972, COL428981, COL101975, COL61982, GIL1012973, GIL729971, GIL107971, GIL107972, GIL1012971, GIL1012974, GIL99972, GIL99974, GIL917971, GIL928971, GIL101971, GIL1012972, GIL729972, GIL729973, GIL99971, GIL928972, SUW107971, SUW917971, and SUW17972) were also described. All together, 61 springs were identified in the Santa Fe River system. Many of these are small springs that cluster near larger, better known springs and should be considered part of a spring group (Figure 1).

Hornsby and Ceryak (1999) also identified five siphons (submerged swallets) in the river. These are important because they are sources for several of the springs, or resurgences.

Most recently, the Florida Springs Initiative has funded two, statewide springs assessments. The first (Scott et al., 2002) discussed first magnitude springs[4], including Columbia, Devil's Ear, Hornsby, Ichetucknee Springs Group, Santa Fe River Rise, Siphon Creek Rise, and Treehouse Spring on the Santa Fe River system. Flow and water-quality data, detailed location maps, and photographs were included in the report. This was a preliminary document to the 2004 revision of the Springs of Florida (Scott et al., 2004).

Scott et al.'s 2004 Springs of Florida report is an update of Bulletin 31 (revised) by Rosenau et al. (1977). It presents a discussion of springshed delineation methods and reports on the current status of Florida's major springs. As with previous reports, water quality and discharge data are summarized. The Santa Fe River springs that were included include Columbia, Devil's Ear, Blue (Gilchrist Blue), Ginnie, Hornsby, Ichetucknee Springs Group, Poe, Santa Fe River Rise, Santa Fe, Siphon Creek Rise, Sun, and Treehouse springs.

The apparent growth in the number of springs identified within the Santa Fe River system over time is a result of increased awareness of the springs and their importance, development and commercialization of some springs, statutory requirements for stewardship of springs on public lands, and the effects of springs on property values. Small (third magnitude) springs are often discovered. Many of these small springs are ephemeral and develop and wane over short periods of time, primarily as a result of major rainfall events. Other springs and siphons are located within the river, so that are not normally observable. Most of these features were first discovered during the droughts of the late 1990s and mid-2000s, when the Santa Fe River was at record low stage.

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[3] First magnitude springs have an average discharge of 100 cubic feet per second (cfs) or more (Meinzer, 1927; Copeland, 2003). One hundred cubic feet per second equals 64.6 million gallons of water per day. Second magnitude springs discharge between 10 and 100 cfs.

Springshed Delineation

Some examples of past springshed delineations include Jones and Upchurch (1993) at Lithia and Buckhorn springs in Hillsborough County, Florida; Jones and Upchurch (1994) at the Kings Bay springs in Citrus County, Florida; Jones et al. (1996) at Rainbow Springs in Marion County, Florida; Jones et al. (1997) at Homossassa, Chassahowitzka, Weeki Wachee, and Aripeka spring, Citrus and Hernando counties, Florida; Toth and Fortich (2002) at Wekiva Springs in Orange and Lake counties; Upchurch and Champion (2003) in the Ichetucknee Springs springshed in Suwannee and Columbia Counties; Barrios and Chelette (2004) at the Econfina Creek springs in Washington and Bay counties, Florida; Barrios (2005) at the Choctawatchee River springs in Holmes, Walton, and Washington counties; Upchurch and Champion (2004) at four springs (Troy, Madison Blue, Fanning, and Manatee springs) in the Suwannee River Water Management District; and Barrios (2006) at the St. Marks and Wakulla River springs in Leon and Wakulla counties.

Shoemaker et al. (2004) explored the use of groundwater flow models for identifying areas contributing to recharge to springs in north-central Florida. They present examples of the use of models for springshed delineation and time-based capture zones.

Water Resource Associates and SDII Global Corporation (2005) delineated the springsheds of Silver and Rainbow Springs for Marion County, Florida, in order to assist in development of spring protection areas. They utilized two different groundwater flow models to identify the springsheds for the two areas within which groundwater could be expected to reach the springs in 10 and 100 years. These zones were identified as Spring Protection Zones for land-use planning and management.

Finally, there is an on-going effort to identify springsheds throughout the state. The Florida Geological Survey is actively pursuing this effort and is the repository for springshed delineation maps. Greenhalgh (2003) and Greenhalgh and Baker (2005) have produced statewide maps showing general springshed areas based on potentiometric surface data as a result of the Survey's efforts.

Spring Flow Path and Travel Time Mapping

Very little has been done as far as travel time and flow path mapping at springs in Florida. Modeling, chemical fingerprinting, dye tracing, and cave diving are the primary means by which flow paths and travel times can be evaluated. Much of this work has been completed relative to springs in the Santa Fe River basin. This section discusses these three methods in the context of nearby spring systems.

Modeling - Groundwater flow models have been used for many years to identify the extent of contributing areas to a spring and to delineate areas based on travel times to the spring. The method takes advantage of particle tracking, a numerical solution available in most finite-difference flow models. Particle tracking is essentially a bookkeeping process wherein a parcel of water is numerically tacked as it moves from cell to cell in the model. Particle tracking can be run forward and backward. In the forward mode, numerical "particles" are placed in grid cells and the model is run to estimate the pathways along which the simulated parcels of water move. In the inverse mode, the particles are placed at the spring and the model is run backward to determine from whence the simulated particles were derived. The latter mode is most commonly utilized, and the model is run for specified time steps to identify where the particles would have been 2 years previously, 5 years previously, and so on, in order to obtain travel times.

The problem with using flow models to predict capture zones in karst terrains is that the models cannot account for conduit flow. Therefore, the model results may greatly under estimate the capture zones and travel times associated with cavernous flow.

Shoemaker et al. (2004) utilized this method to compare springshed extents in north central Florida. The springsheds for Rainbow and Silver springs were derived by this method (Water Resource Associates and SDII Global Corporation, 2005).

Water Resource Associates and SDII Global Corporation (2005) used two groundwater flow models to estimate the extents of areas with 10 and 100 year travel times to Silver and Rainbow springs. One model, the "Megamodel" of Sepúlveda (2002), was utilized to evaluate both springs. The St. Johns River Water Management District North-Central Model (Motz and Dogan, 2004) was also utilized for Silver Springs travel time estimates. The Suwannee River Water Management District regional groundwater flow model (Schneider et al., 2008) was used to model travel times for Rainbow Springs. The maximum extents of the 10 and 100 year travel times, as calculated by the various models, were combined to obtain a maximum estimated capture zone extent for each spring.

Geochemical Fingerprinting - While geochemical fingerprinting cannot estimate travel times, it can be used in many cases to determine the spatial extent and origin of water traveling to a spring. Jones et al. (1996) used the method successfully to determine the different domains of the Rainbow Springs springshed that were contributing water to the various spring vents within the spring group. A similar approach was utilized by Upchurch and Champion (2003) to identify source waters for the springs of the Ichetucknee Springs Group.

Chemical fingerprinting includes identification of suites of chemicals that differ from spring to spring. These suites are then matched to similar suites of analytes from groundwater in wells within the springshed.

Dye Tracing - Dye tracing involves introduction of a unique chemical to the groundwater via a well or sinkhole. Springs in the vicinity are then monitored for arrival of the tracer chemical. The time of arrival is used to estimate the travel time and concentration profile can be used to estimate the dilution and dispersion that has occurred along the flow path. Dye traces work best in conduit flow situations where dilution and dispersion are minimal and rock-water interactions are least likely to cause sorption or dilution of the dye.

Some of the most interesting dye trace experiments in Florida have taken place within the Santa Fe River watershed. These include the traces reported by Karst Environmental Services (1997) and Butt and Murphy (2003), who proved connections between swallets and sinkholes near Lake City, Florida, with the Ichetucknee Spring Group springs. Travel times in this system were found to be up to one mile per day. Similar dye trace studies by Butt et al. (2006) have demonstrated connections between Mill Creek and Lee sinks in Alachua County and Hornsby and Treehouse Springs. Butt et al. (2007) also demonstrated that one vent of Treehouse Springs is connected to a swallet in the Hornsby Spring run.

Butt (2005) has also demonstrated the utility of dye tracing to establish the connection between septic tanks within the Ichetucknee State Park to the springs, thus demonstrating a potential source of nitrate in the spring.

While dye tracing provides irrefutable evidence of a connection between springs and karst features and contaminant sources, there is no way to identify the precise route of the water from the source to the spring. Furthermore, the method deals with specific routes through the springshed. It does not allow identification of the springshed or general contribution areas.

Dye tracing is important for understanding the behavior of springsheds. The travel times of tracers through conduits are often orders of magnitude faster than through rock or soil matrix. Therefore, tracer tests provide a sobering reality check to those who utilize groundwater flow models to predict capture zones and travel times in fractured and/or karst aquifers. Where rapid conduit flow is present in a spring system there is a high probability that the true capture zones will (1) extend well outside of the model-predicted capture zones and (2) have more rapid travel times than predicted by the flow model.

<u>Cave Mapping</u> - Cave diving has made important contributions to understanding the behaviors of springsheds through the preparation of cave maps and identifying the importance of caverns to the flow systems. Orientations of caverns provide insight into potential groundwater flow directions. The summary by Butt et al. (2007) is an excellent example of the use of cave mapping to solve hydrologic problems.

Many caverns associated with the springs in the Santa Fe River system have been explored and mapped. Examples of cave maps are presented in Hornsby and Ceryak (1998). The recent report by Butt et al. (2007) summarizes the connections between swallets and resurgences in the Santa Fe River system. This report was based on diving records, dye tracing, and other lines of evidence.

Spring Protection

Based on modeling, dye tracing, and other hydrogeologic analyses, it is possible in many cases to identify locations where land use is most likely to lead to reduced water quality or flows in springs. These areas, which are often termed spring protection zones, can be identified and management strategies developed with a minimum of data.

The Florida Springs Task Force (2000) discussed the need for protection zones, and the Florida Departments of Community Affairs and Environmental Protection (2002) stressed the need for identification of spring protection areas. Springshed delineation and travel time estimates are the major first step to the process of developing protection zones.

The North Central Regional Planning Council (1978) evaluated the Ichetucknee Springshed with respect to flooding as a limitation to development. Flooding along the Ichetucknee Trace[5] was the primary concern of the study. Given the importance of the Trace to the function of the Ichetucknee Springs, this report marked an early evaluation for spring protection.

Upchurch and Champion (2002) revised the Regional Planning Council's work and attempted to identify areas where geologic hazards, such as flooding and spring contamination, might limit development or require special protection in the Ichetucknee springshed. In 2004, they attempted to delineate hypothetical spring protection areas at five, first magnitude springs, including the Ichetucknee Springs Group. Upchurch and Champion's (2004) Ichetucknee Springs delineation included Primary and Secondary Spring Protection zones and a protection zone based on the streams that empty into the swallets that have been traced to the springs.

We are aware of only three springs where spring protection zones have been identified by governmental agencies. These are protection zones for Wekiva, Silver, and Rainbow Springs. Water Resource Associates and SDII Global Corporation (2005) delineated the springsheds of Silver and Rainbow Springs for Marion County, Florida, in order to assist in development of spring protection areas by the county government. They utilized two different flow models to identify the springshed for the two springs and areas within which groundwater could be expected to reach the springs in 10 and 100 years. These zones were identified as protection zones for land-use planning and management. A different approach was taken for Wekiva Springs. The protection areas are codified in Florida Statutes (Wekiva River Protection Act, Ch. 369.301-369.324 F.S., and Wekiva Parkway and Protection Act, Ch. 369.314-369.324 F.S.). The springshed was delineated by potentiometric surface contouring and modeling was involved to identify flow paths.

[4] The Ichetucknee Trace is a low valley that connects Cannon Creek and the swallets that capture stream water near Lake City with the Ichetucknee Springs. It is thought to be an ancient stream valley and is characterized by elongated closed depressions (sinkholes) and flooding during extreme rainfall events.

METHODS

This section describes the methods utilized to delineate springsheds and capture zones for springs on the Santa Fe River.

Potentiometric Surface Development and Springshed Delineation

Initial Springshed Evaluation

In order to identify probable springsheds, a USGS 2000 potentiometric surface was initially evaluated and springsheds were drawn on the maps to identify areas that, according to the potentiometric surface data, drain toward the springs. The year 2000 was selected for evaluation because

- There was a relatively high number of wells monitored in that year,
- The Suwannee River Water Management District's ground-water flow model is calibrated to that year,
- The year was characterized by low rainfall, so groundwater basins were likely near their maximum extents and relief, and
- A state-wide potentiometric surface map had been previously prepared by the USGS (2000; Figure 5).

This evaluation was utilized to develop the methods for potentiometric surface analysis throughout the remainder of the study. Owing to the widely spaced wells used by the USGS in preparing the 2000 potentiometric surface and the complexity of the karst within the study area, it was thought that it would not be possible to delineate springsheds for each spring. Rather, the springs were separated into "clusters" within which individual springsheds could not be discerned and between which there was some evidence to allow boundaries of the combined springsheds to be identified. As it turned out, well spacing was a minor problem and the complexity of the karst is the principal reason for inability to delineate individual springsheds. As a result, use of the spring cluster concept has been utilized throughout this report.

September 2007 and May 2008 Potentiometric Surface Development

Index Period - The index periods for the Phase II and III potentiometric surface maps were September 2007, and May 2008, to coincide with District, St. Johns River Water Management District, and USGS semi-annual data collection efforts.

Data Collection - The Alachua County Environmental Protection Department (EPD) identified 185 monitoring points, the majority of which were wells in the western part of Alachua County and eastern Gilchrist County (the Newberry Plain area) and southern Columbia County. Other data points included stage data from the Santa Fe River and springs and aquifer water level data from the Suwannee River Water Management District, St. Johns River Water Management District, and the Southwest Florida Water Management District. Some of the datasets consisted of daily measurements. Daily measurements for September 2007, were averaged to obtain the single value used in the geostatistical analysis. Figures 7 through 11 depict the locations of the monitoring points and Appendix A provides coordinates ans water levels for each site.

All new monitoring points were surveyed to the National Geodetic Vertical Datum (NGVD 1929) by Alachua County EPD, and the potentiometric surface data were transferred to SDII for analysis.

In order to force the contouring algorithm to conform to the Suwannee, Santa Fe, and Ichetucknee rivers, control points in addition to the stage data on the river were obtained from the relevant USGS topographic maps.

The data were then contoured with Surfer© using the kriging option with zero nugget and a linear interpolator. The contour grid was 200 meters on a side and contour interval was set at 1 foot.

The estimated locations of springsheds were drawn on the contour maps by hand and then digitized in order to produce the springshed delineations presented below. The springsheds were identified by searching for apparent groundwater divides in the potentiometric data.

The initial attempt at development of a potentiometric map using September 2007, was limited by a need for additional data, especially in the headwaters of the springsheds. As a result, springshed delineations were limited in extent to those areas where the upper Floridan aquifer is considered to be either unconfined or semi-confined.

Phase II and III involved addition of more September 2007, data and preparation of a May 2008 potentiometric map. The resulting maps were contoured at 2-foot intervals owing to the larger study area, which extend to the groundwater divides at the headwaters of the springsheds. Figures 7 through 11 present these maps. Springsheds were delineated using apparent groundwater divides on these maps.

Geostatistical Analysis

Geostatistical analysis consists of two steps (Isaaks and Srivastava, 1989; Chilès and Delfiner, 1999). First, a *structural analysis* is performed to determine the pattern of variance with distance between all possible sample pairs. The results of this analysis assists in determining the maximum distance between samples (water-level measurements) before they are no longer correlated and beyond which contour lines can no longer be drawn. In addition, the structural analysis allows one to establish "rules" for estimating the uncertainty, in terms of standard deviations, of interpolations between correlated data points.

Once the structural analysis is completed and the "rules" of uncertainty estimation are completed, the second step, *kriging*, is initiated. Two maps are prepared as part of the kriging phase. The first is the traditional contour map showing the distribution of the property being contoured. The second map is an uncertainty map, which illustrates the areas where one cannot interpolate or extrapolate because the data points are too far apart and the magnitudes of uncertainty, in standard deviations, between correlated points are too high. This map is used to select additional monitoring locations, if needed, and to evaluate the uncertainties associated with the contour map.

Structural analysis of water level data was performed using the U.S.E.P.A. code Geo-Eas (Englund and Sparks, 1991). The kriged maps were contoured utilizing Surfer® (Golden Software, 2002).

Groundwater Flow Modeling

There are two regional groundwater flow models available for potential use in delineating the springsheds and travel times associated with groundwater leading to springs along the Santa Fe River. These are (1) a model developed by the Suwannee River Water Management District (Schneider et al., 2008) and the USGS "Megamodel" (Sepúlveda , 2002) which covers all of north Florida. These models have been successfully utilized for springshed delineation in Marion County, Florida (Water Resource Associates and SDII Global Corporation, 2006).

The Suwannee River Water Management District groundwater flow model (District model) is a fully 3-dimensional model with layers to represent the surficial aquifer, the intermediate aquifer and confining system, and the upper, middle, and lower Floridan aquifers. The model is based on a 5,000 x 5,000 foot grid and extends from south Georgia to the southern part of Marion County and the Tallahassee area to the Atlantic Ocean. Recharge is based on rainfall during the calibration period in 2000. The model is also calibrated to spring and river discharge, lake levels, and groundwater levels in over 1,000 wells throughout the area. All first and second magnitude springs and some third magnitude springs are included in the model, and known swallets and siphons are included as wells in order to balance the water budget for downstream springs.

Similarly, the USGS "Megamodel" is a 3-dimensional model with active layers to represent the intermediate aquifer and/or confining beds and the upper and lower Floridan aquifer. The uppermost layer (the surficial aquifer) uses specified heads to act as a source/sink for the flux of water to the underlying aquifers. The grid sizes are similar to the District model, and calibration is to groundwater levels and a limited number of springs. The Megamodel extends from the Atlantic Ocean to the western part of the Suwannee River Water Management District and from south Georgia to south central Florida. Few springs are included in the model.

The District model was developed in GMS©, a proprietary graphical interface coupled with the USGS's MODFLOW code. The Megamodel was developed in MODFLOW and converted by SDII to the GMS model interface.

The models were run to steady state using the particle tracking option to identify the projected springsheds. Particle tracking was also run to identify the 5, 10, 25, and 100 year capture zones.

Note that the models do not incorporate conduit flow, so they best replicate flow systems that integrate intergranular and conduit flow. As such, caverns are not identified by the models. The District model includes most of the springs of concern and some swallets, however. Also, the model grid sizes (5,000 x 5,000 feet) are large relative to the short-term capture zones of many springs. For these, one can only conclude that the short-term capture zones are within 5,000 feet of the springs.

RESULTS

Springshed Delineation

Phase I Springshed Delineation

Phase I data resulted in identification of eight springsheds. Because of the inability of the potentiometric surface data to capture small elevation differences that might indicate individual springsheds, the springs were clustered (Figure 6) to assist in defining springshed boundaries.

When the September 2007, data were initially contoured (Figure 7), there were insufficient data to complete delineation under the Northern Highlands. As a result, the springshed delineations were truncated on Figure 8 because of limitations in the data. Conceptually, the springsheds can be extended to the crests of the potentiometric surface highs under the Northern Highlands to include the potentiometric data that reflect aquifer drainage towards the Cody Scarp. Note that the groundwater in these areas under the Northern Highlands is not considered to be active springshed.

Considering the uncertainties associated with the lower resolution of the Phase I potentiometric data, the Ichetucknee Springs Group springshed (Figure 7) is consistent with the Suwannee River Water Management District's high resolution springshed delineation (Figure 4). The springshed includes Rose Creek and Cannon Creek, both of which are known to supply water to the springs through recharge to swallets.

The Sunbeam and Wilson Springs (Figure 7) consist of a cluster because of an indistinct boundary between the two springsheds. The majority of the water discharging to these springs is apparently from the north. The segment of the springshed to the south and southwest, towards the Bell Ridge potentiometric high, is not considered to be an important source of water to these springs because of the lower permeability of the aquifer strata in that area.

The springshed for the Ginnie Springs cluster of springs (Figure 7) apparently extends north and south of the river. This is consistent with the evaluations of water sources by Wilson and Skiles (1988) and Kinkaid (1998) who noted water sources from the north at springs in the Ginnie Springs cluster. The portion of the springshed nearest the crest of the Bell Ridge potentiometric high is not considered to be an important source of water to these springs because of the lower permeability of the aquifer strata in that area. The remainder of the springshed in the south portion of the springshed is thought to be a significant source of water because some of the streams flowing off of the Waccasassa Flats enter the aquifer in this area via swallets and other conduits (Copeland et al., 2005).

The apparent springshed for the Rum Island – Gilchrist Blue springs cluster apparently comes from both north and south of the river. Note that the southern part of the springshed, as initially drawn, includes most of the Western Valley (Newberry Plain). There is a general "rule of thumb" that average discharge of a spring is roughly equal to 1 $cfs/mi.^2$ of springshed

(Faulkner, 1973). If this is the case, then the portion of the Rum Island – Gilchrist Blue springshed south of the river is too large for the magnitude of the springs in this cluster. It appears that some of this water captures within the springshed is finding its way to the Ginnie Group of springs and, possible, Poe Springs. The potentiometric surface does not provide sufficient information as to this issue.

The springshed for the Hornsby-Treehouse spring cluster terminates against the Northern Highlands in Alachua and Columbia Counties and includes such swallets as Mill Creek and Lee sinks. The springshed is consistent with the dye tracing, cave diving, and other data available for these springs.

Finally, there is a narrow capture zone (Figure 7) associated with the Santa Fe River Rise. This springshed area appears small relative to the findings of Martin and Screaton (2001). They concluded that only 4% of the water discharging from the River Rise was recharges at the River Sink at low river flow. Ninety-six percent of the water discharging from the Rise was thought to be derived from other, groundwater sources. The largest source of discharging water was thought to be the Old Bellamy Cave conduit system that extends to the east. They further concluded that this eastern conduit system received little surface water, so most of the discharge was from diffuse recharge. At intermediate discharge from the Rise, about 73% of the discharge was from the River Sink and the remaining 27% was from other sources.

Phase II Springshed Delineation

Figures 8 through 11 depict the potentiometric surface maps prepared with the revised September 2007, and May 2008, data sets. The results of addition of data improved the ability to delineate certain portions of the springsheds.

Figure 8 depicts the contoured September 2007, data for the region. The groundwater basin for the Santa Fe River springs is depicted on this figure. Note that the potentiometric highs under Bell Ridge and the Northern Highlands are evident and that the Newberry Plain area is represented as a broad, low gradient area.

When the map area is reduced to the extent of the Santa Fe River groundwater basin (Figure 9), nine springsheds can be identified. These include the Ichetucknee, Sunbeam–Wilson, Ginnie, Rum Island – Gilchrist Blue, Poe, Hornsby–Treehouse, and Santa Fe Rise springsheds. In addition to the seven named springsheds, there were two that remain undifferentiated owing to the lack of distinguishing features on the potentiometric maps.

The springsheds remain similar to the original delineation (Figure 7), but they have been extended to include the headwaters under the Northern Highlands. The size of the July – Gilchrist Blue springshed remains large relative to the discharge of the springs within the cluster area.

Note also, that there is a depression in the potentiometric surface in the vicinity of Gainesville. This cone of depression is apparently related to withdrawals by the Gainesville Regional Utilities (GRU) wellfield.

Figure 10 depicts the regional potentiometric map for the May 2008, data with the apparent extent of the Santa Fe River groundwater basin. There are several problem areas in this map, including shifted potentiometric highs under Bell Ridge and a depression in the potentiometric surface in Bradford County, near Starke. These features are not accurately depicted on the map and are a result of the kriging process used to prepare the maps.

There is little change in the positions of the springshed boundaries on the May 2008, potentiometric map (Figure 11). This indicates that the springshed boundaries are relatively stable.

Springshed Evaluation

The Sunbeam – Wilson Springshed, as shown on Figures 7, 9, and 11, includes Wilson, Sunbeam, and several other small springs. The springshed well of the spring cluster is delineated on both sides of the Santa Fe River. There appear to be clear groundwater divides in all directions for the cluster, but individual springsheds cannot be differentiated within the cluster.

The study area (Figures 9 and 11) includes the springshed of the Ichetucknee River and Springs. This springshed was previously delineated by Upchurch and Champion (2003) utilizing high-resolution monitoring (Figure 4). Data were insufficient for high-resolution delineation of the Ichetucknee springshed as part of this study.

The Ginnie Springshed includes Ginnie, Devil's Ear, Devil's Eye, Dogwood, and other springs. As noted by Wilson and Skiles (1988) and Kinkaid (1998) the individual springs exhibit complex inter-relationships and have variable sources of water from the river and from groundwater flow from north and south of the river. The springshed is well defined south of the river. North of the river, there is uncertainty as to the springshed boundary. There is a well-defined hydrologic divide between the Ginnie and Sunbeam-Wilson and Ichetucknee springsheds, but the eastern boundary is indistinct, largely because of lack of a well-developed groundwater divide.

The Rum Island – Gilchrist Blue Springshed is defined on the west by a locally apparent divide, but much of the boundary is drawn through areas where the potentiometric surface is broad and divides are ill-defined, if present. The boundary with the Poe Springshed is equally indistinct and a well-defined divide only exists under the Cody Scarp and the Northern Highlands. There is probably a source of water on the north side of the river, as well. The extent of the springshed north of the river cannot be estimated based on existing data. This area is designated as "undifferentiated springshed" on Figures 9 and 11.

The Poe Springshed is well-constrained in on its north side and weakly developed on the south, where it abuts the Rum Island – Gilchrist Blue springshed. Again, the lack of well-defined hydraulic divides adds uncertainty to the springshed delineation. Well developed divides exist under the Cody Scarp and Northern Highlands.

The Hornsby–Treehouse Springshed has known sources related to swallets (Butt et al., 2006) and siphons in the river (Butt et al., 2007). Based on the springshed maps (Figures 9 and 11), the springshed appears to be relatively broad in extent with moderately defined hydraulic divides to the north and south.

Finally, the Santa Fe Rise Springshed is known to be dominated by riverine water derived from the swallet (Santa Fe Sink) at O'Leno State Park (Martin and Screaton, 2001; Butt et al., 2007). The Old Bellamy Cave System is thought to derive water from the northeast, as well. The springshed appears to support these conclusions. It is relatively small and is skewed to the northeast from the Sink-Rise system, which is consistent with the orientation of the Old Bellamy Cave system.

Interpretation of the Phase II and III Springshed Delineations

Overall, the Phase II and III springshed delineations (Figures 9 and 11) have added much to the level of detail obtained in the Phase I springshed delineation (Figure 7). Apparently, discharge from the springs upstream of the Sunbeam – Wilson Springshed is dominated by source areas south of the river. These springs, however, have sources north of the river, as well. All of these springsheds have headwaters that are distributed along the Cody Scarp and/or the Bell Ridge potentiometric high. In both situations, surface water draining off the confined areas recharges the upper Floridan aquifer through swallets. In addition, there is enhanced recharge through large sinkholes (uvalas and poljes; Upchurch, 2002, 2007). It is problematic in many cases as to which spring this water migrates. Additional dye tracing may assist in identifying source-to-sink relationships.

Some general features of the overall pattern of springsheds are of importance, however. First, the lack of distinct divides between spring-specific springsheds in many cases leads to remaining uncertainty. Second, the apparent springshed areas are not necessarily proportionate to the apparent discharge from the springs associated with the springsheds. Both of these features are indicators of complex karst-conduit flow.

The well-documented instances where (1) conduits that discharge at springs on the Santa Fe cross each other in the vertical dimension and (2) adjacent springs have different sources of water (Wilson and Skiles, 1988; Kinkaid, 1998; Martin and Screaton, 2001; Butt et al., 2007; etc.) support the complexity of the karst-conduit flow systems in the Santa Fe springsheds. Therefore, given (1) the known complexity of near-field flow to the springs, (2) the presence of indistinct groundwater divides in many springsheds, and (3) the lack of proportionality of springshed areas to spring discharge, the Newberry Plain should be considered as a single springshed for management purposes. Trying to attribute specific locations in the far-field flow systems of the springsheds to specific springs may lead to management difficulties and disputes.

Geostatistical Analysis

Structural Analysis

Structural analysis of the September 2007, potentiometric surface data resulted in a semivariogram exhibiting a Gaussian curve with a nugget of 15 ft^2. The sill was determined to be 800 ft.^{2} with a range of 350,000 ft.[6] (Figure 12).

Note that the semivariance and sill are rather high, with a maximum of 800 ft.^{2}. This is because water levels are relatively variable within the unconfined portions of the study area. The data collected for the Phase II and III study were obtained over a 10-day period[7] near the end of the rainy season. Furthermore, because of the potentiometric surface highs to the east and west of the study area, de-trending the data in order to minimize the accumulation of variance with distance between points was not advantageous. Therefore, the variogram was constructed without de-trending and the accumulation of variance over great distances between data pairs is high. This results in some localized uncertainty in the potentiometric surface highs, but not in the unconfined areas of the Newberry Plain.

Kriging Results

Figure 13 illustrates a contour map of the regional, September 2007, Floridan aquifer potentiometric surface based on raw, un-kriged data. Note the potentiometric highs in eastern Alachua County and in west central Gilchrist County. The potentiometric surface high to the east lies under the Northern Highlands and to the west under the Brooksville Ridge, Waccasassa Flats, and Bell Ridge (Figure 2) where the upper Floridan is relatively confined. The large, low area in the central part of the study area is the Western Valley or Newberry Plain, where the upper Floridan aquifer is unconfined. Note also the cone of depression developed in central Alachua County. This reflects the effects of pumpage for water supply to Gainesville.

Figure 14 presents the same area using modeled potentiometric data. Note that the overall pattern of potentiometric highs and lows is similar to that shown in Figure 13. The cone of depression near Gainesville is represented by a re-entrant in the potentiometric surface.

In order to depict the potentiometric contours in the Western Valley/Newberry Plain in detail, the regional maps shown in Figures 13 and 14 were used to control the kriged maps, and new

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[5] The Gaussian curve (Figure 9) illustrates how uncertainty accumulates as the distance between pairs of data points (wells) increases in the geostatistical model. The nugget is the minimum uncertainty (semivariance) between closely spaced data points and the sill is the maximum uncertainty between data points that are correlated. The range is the distance between data points were the sill is reached by the model and where correlation of water levels ceases to exist.

[6] The data collected by Alachua County were obtained between September 11 and 20, 2007. During this period 2.2 inches of rainfall were recorded at the Gainesville airport. Rainfall from September 1 through 19 was 1.35 inches. Data from the District were obtained at various times throughout the month of September.

maps were prepared that zoom in on eastern and central Gilchrist County and central and western Alachua County (the Newberry Plain area). These maps, which utilize 1-foot contour intervals, were used to evaluate Alachua County's monitoring network and assist in drawing springshed boundaries.

Figure 15 depicts a contour map of raw, September 2007, potentiometric surface data in the Newberry Plain and surrounding areas. The potentiometric highs under Bell Ridge and the Northern Highlands are well depicted. The relatively flat potentiometric surface under the Newberry Plain is shown as a broad region with a gentle hydraulic gradient from the southeast corner of Alachua County northwest to the Santa Fe River. Note that the cone of depression at the GRU wellfield lies within the potentiometric high under the Northern Highlands.

Figure 16 presents the same area utilizing the modeled potentiometric elevations (K* values[8]) derived by kriging. As noted above, the GRU cone of depression is represented by a re-entrant rather than an internally drained area. Note also that there is a modeled depression centered on the river in northern Gilchrist County. This depression does not exist in the upper Floridan aquifer potentiometric surface. Rather, there is a potentiometric high south of the river in this area. The depression is a result of the numerical influence of potentiometric data at springs on the river.

The kriged standard deviation (K_{SD}[9]) map (Figure 17) is considered to reflect uncertainty in the contouring process. This map is used to evaluate and identify spatial gaps in data where additional data points are needed. For most of the study area the K_{SD} values are between 4 and 5 feet. This minimum K_{SD} reflects the uncertainty in aquifer potentials as distance between monitoring wells increases. The K_{SD} is as high as it is because of local variability in aquifer water levels created by local drawdown by pumpage and temporal variations in water levels over the index period (September 2007). Addition of more sampling points is unlikely to reduce this uncertainty. Based on evaluation of the K_{SD} map, the monitoring network is appropriate in the Newberry Plain area and does not need additional sampling points. The area shown in red on Figure 14 is very high uncertainty. The area represents one well data point and may reflect surveying or measurement error. The data density in the area of this data was increased as part of Phase II and III, so the uncertainty in this are has been mitigated.

Figure 18 shows another way of evaluating the kriged data points. This figure depicts residuals[10] for the Newberry Plain, upper Floridan aquifer data. Blue areas indicate that the modeled elevations under estimated the measured aquifer potentials, and yellow areas indicate where the modeled data over estimated the raw data. The yellow (over estimated) areas on the western side of the study area reflect wells on the Bell Ridge potentiometric high. Here, negative residuals indicate that the modeled results were greater than the measured.

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[7] K* is the symbol used to designate the modeled potentiometric elevation as opposed to measured.

[8] The kriged standard deviation is the square root of the semivariance values shown in Figure 9.

[9] Residuals are by calculating $Residual_X = X_{obs} - X_{calc}$ for each data point (X). Positive residuals indicate that the kriged estimates under estimate the measured data and negative residuals indicate over estimation of the data by the kriged values.

The blue area in Alachua County represents the GRU wellfield cone of depression, where the observed measurements were greater than the modeled results. Residuals are typically less than 2 feet in the Newberry Plain area. Again, these data suggest that kriging successfully modeled the upper Floridan aquifer potentiometric surface data, which indicates an appropriate monitoring network.

Modeling Capture Zones with Groundwater Flow Models

As noted above, groundwater flow models can be utilized to estimate springshed extents and identify rough travel times of groundwater to springs. The travel times and recharge-area extents (springsheds), as estimated by the groundwater flow models, are limited by the inability to incorporate conduit flow in the regional, finite difference models and by the complexity of swallet- and siphon-to-spring flow known to exist in the Santa Fe River basin.

Springshed Delineation and Capture Zones Identified by the Megamodel

Figure 19 depicts the areas identified by particle tracking using Sepúlveda's (2002) "Megamodel." The area shown in yellow represents the springsheds identified by running the model to steady-state. There are significant areas for the Ichetucknee and Sunbeam - Wilson clusters, and a very small area related to Poe and Rum Island – Gilchrist Blue springs. Otherwise, there was no regional dispersion of particles in the model. The shorter term capture zones (5, 10, 25, and 100 year particle track areas) are limited in extent and not representative of the known capture zones (see the literature and springshed delineations discussion above).

The inability of the model to depict reasonable capture zones is not surprising. Some of the reasons for this inability to document larger capture zones are

- Layer 1 in the model is set as a constant head boundary to approximate recharge to the intermediate and upper Floridan aquifers.
- The 5,000-foot grid size is too large to capture detail of flow near a spring.
- Many of the springs were not represented in the model, so particle tracking was from the cell within which the spring(s) fell. This causes uncertainty in the particle tracking results.
- The model cannot account for fracture and cavern flow, which is a major pathway for water to the Santa Fe River springs.
- Many of the springs are actually resurgences, which should have small capture zones.

Clearly, the "Megamodel" is not adequate to approximate capture zones and travel times to the springs.

Springshed Delineation and Capture Zones Identified by the District Model

Figure 20 depicts the areas identified by particle tracking using the District's model (Schneider et al., 2008). The District model has a fully active layer one (the surficial aquifer or unconfined upper Floridan aquifer, where appropriate) and included all first and second magnitude springs and many of the known siphon-resurgence systems (Butt et al., 2007) on the Santa Fe. As such, it represents a better model to approximate the springsheds than the Megamodel, but the short-term travel times are clearly under estimated.

The area shown in yellow on Figure 20 represents the springsheds identified by running the model to steady-state. There are significant springshed areas shown on the capture zone map (Figure 20). The larger springs have large, steady-state capture zones or modeled springsheds, as one would expect. Springs that do not have large capture zones include resurgences (i.e., Santa Fe Rise) and some of the smaller springs just upstream from the mouth of the Ichetucknee River (the Sunbeam – Wilson spring cluster).

The shorter term capture zones (5, 10, 25, and 100 year particle track areas) are limited in extent to the immediate vicinities of the cells within which the springs are located. These are clearly not representative of the known capture zones of these springs (see above). The inability of the model to depict reasonable capture zones is not surprising. The reasons are as discussed in the previous section and include:

- The 5,000-foot grid size is too large to capture the detail and complexity of flow near a spring;
- The model cannot account for fracture and cavern flow, which is a major pathway for water to the Santa Fe River springs;
- Many of the springs are actually resurgences, which have small capture zones; and
- The siphons in the river are, in some cases, within the same cells as the springs, so they supply water to nearby springs in the model.

Clearly, the District's model is somewhat suitable to identify rough springsheds, but it is inadequate to approximate short-term capture zones and travel times to the springs.

DISCUSSION

This section discusses the results of previous investigations and compares these findings to the results of this investigation. The springs are grouped in clusters as shown in Figures 7, 9, and 11. The order of the discussion is from the most upstream spring cluster, Santa Fe Rise, down stream to the mouth of the Santa Fe River and the Betty Spring Cluster.

Santa Fe Rise

The Santa Fe Rise is considered a first magnitude spring (Ferguson et al., 1947; Rosenau et al., 1977; Hornsby and Ceryak, 1998; Scott et al., 2002, 2004). It is a resurgence of the Santa Fe River, which goes underground through a swallet (Santa Fe Sink) in O'Leno State Park, near High Springs, Florida.

Scientists at the University of Florida have traced the water from sink to resurgence and investigated the processes that affect recharge water that enters the Santa Fe River Sink and discharge from the Santa Fe Rise. Special focus of this research has been on the mixing of river water with aquifer water underground. Some of the important findings of these investigations are discussed below.

A dye tracer test found that the River Sink is connected with Sweetwater Lake (a small lake between the Sink and Rise) and several karst windows. The tracer was not, however, detected at the Rise (Hisert, 1994). A second dye trace beginning at Sweetwater Lake was detected at the River Rise (Hisert, 1994), thus establishing the connection and demonstrating that dilution and/or dispersion may be important processes for reducing concentrations of the dye to less than detection limits. The Hisert investigation was undertaken when the river stage was moderately high (44.3 ft. above msl). Hisert (1994) also estimated that the rate of travel from Sink to Rise was 2.7 miles per day.

Dean (1999) and Martin and Dean (1999, 2001) utilized temperature measurements to show that flow rates vary with river stage. At high stage (44.3 ft. above sea level), travel time was estimated to be less than 6 hours. During low stage (34.3 ft.), the travel time was over 7 hours. At "exceptionally low stage" in 2001, the entire flow of the river was captured by a small sink upstream from the River Sink (Smith et al., 2002). After several precipitation events, during which stage rose, discharge pulses moved through the Sink/Rise system. The data obtained indicated the possibility of a complex "plumbing" system controlled by differing elevations of conduits.

Martin and Screaton (2001) used the Sink/Rise system to characterize exchange and mixing of diffuse and conduit flow water. They concluded that only 4% of the water discharging from the River Rise was contributed at the River Sink at low river flow, while 96% of the water discharging from the Rise was thought to be derived from other sources. The largest source of discharging water was thought to be a conduit system (the Old Bellamy Cave system) that had been mapped by cave divers to extend to the east. They further concluded that this eastern conduit system received little surface water inflow, and most of the discharge was from diffuse flow. At intermediate discharge from the Rise, about 73% of the discharge was from the Sink and the remaining 27% was from other sources.

The Santa Fe Sink/Rise complex is, therefore, a complex system with significant recharge at the Sink and other conduits within the main stem of the Santa Fe River during moderate to high flow conditions. During droughts, when the river is low, the discharge from the Rise is sustained by movement of water out of the aquifer matrix into the conduit system.

Butt et al. (2007) briefly described the Santa Fe Rise cave system, which is called the Old Bellamy Cave System, and concluded that the groundwater contribution came from the east, following this cavern system. This is consistent with the springshed delineations (Figures 7, 9, 11).

The springshed maps (Figures 7, 9, and 11) clearly show the potential for flow from the Santa Fe Sink area and flow from the east. The northwestern boundary of the springshed also suggests that there may be some contribution from as far away as the lower reaches of Olustee Creek.

The groundwater flow models (Figures 19 and 20) fail to delineate capture zones that are distant from the Santa Fe Rise. This is a result of the construction of the models, which indicate that the water discharging from the Rise is derived within 5,000 feet of the spring. This is, of course, not consistent with the dye tracing and other evidence that implicate the Santa Fe Sink and groundwater sources to the east and northeast.

Hornsby-Treehouse Spring Cluster

The Hornsby–Treehouse spring cluster includes Hornsby, Columbia, and ALA112971, or Treehouse, Springs, all first magnitude springs. In addition, Darby Spring, which is located near Hornsby Spring, and an unnamed spring (COL428981) are located within the cluster. Both Treehouse and Columbia Spring include surface water resurgence (Butt et al., 2007). There are several siphons within this reach of the Santa Fe River. Butt et al. (2007) have characterized the interactions of these siphons with the springs.

Butt et al. (2005) conducted dye traces from Mill Creek Sink and Lee Sink, the swallet that captures flow from Cellon Creek, in Alachua County to Hornsby Spring. They were able to demonstrate direct connections with the spring with travel times of 12-13 days from Mill Creek Sink, which is located approximately 6 miles southeast of Hornsby Spring and 28 to 31 days from Lee Sink, which is approximately 9 linear miles from the spring. The spring has a cavern system that has been explored to the east (Butt et al., 2007).

Treehouse Spring is a first magnitude spring located on the Alachua County side of the Santa Fe River. It is a double resurgence (Butt et al., 2007) associated with three siphons, two of which are located in the river and one in the Hornsby Spring Run.

Columbia Spring, a first magnitude spring on the Columbia County side of the river, is also thought to be a resurgence (Butt et al., 2007). It is associated with two siphons that are located on the east and west sides of the river, just downstream from the US 441 bridge (Butt et al., 2007).

Darby Spring, which is near the mouth of the Hornsby Spring Run, was also found to be connected to Mill Creek Sink. The travel time from the sink, which is over 6 miles from the spring was 28 to 31 days.

Therefore, two of the largest springs in this cluster (Columbia and Treehouse) are more closely associated with river flow than groundwater. Only Hornsby and Darby appear to have dominant groundwater components. The springshed maps for this spring cluster suggest a source area that extends to the east, toward Mill Creek and Lee sinks. The District groundwater flow model (Figure 20) also shows a groundwater component that flows from the east in the vicinity of Mill and Cellon Creeks.

Poe, Rum Island - Gilchrist Blue, and Ginnie Springs Clusters

The literature review failed to identify any evidence of cave mapping in the Poe Spring system. Butt et al. (2006) screened Poe Springs during the Mill Creek/Lee sink dye trace, but no dye was detected. The Phase I springshed map (Figure 7) and high resolution springshed maps (Figures 9 and 11) indicate that the extent of the springsheds is predominantly to the southeast. For example, Poe Spring is served by recharge through one or more swallets and sinkholes along the Cody Scarp. The District model (Figure 20) suggests that the source for Poe Spring may be to the south and east, toward the Cody Scarp in Alachua County.

The Rum Island – Gilchrist Blue Springshed (Figures 7, 9 and 11) is located on the north and south sides of the river has sources to the southeast and, apparently, northeast. The District model shows water flowing to both springs from the southeast.

The Ginnie Springs cluster and springshed includes springs of the Ginnie Springs Group, July Spring, Devils Ear and Devils Eye springs, and others. The springshed indicates sources of water on both north and south sides of the river. The southern part of the springshed appears to terminate on the Bell Ridge potentiometric high. The District flow model indicates springsheds for these springs are located within the Newberry Plain (Figure 20).

Dye tracing by Wilson and Skiles (1988) on the south side of the river at Ginnie Springs suggested that there is no cross over between July and Ginnie springs flow systems. The water flowing to the Ginnie system did not indicate that July was interconnected to the Ginnie flow system. Mapping of the Devil's Ear system indicated that caverns extend to the north of the river as well as under it. Dye injected in wells south of the Ginnie system migrated to the Ginnie and Devil's Eye systems, however. Based on cavern orientations and the work of Wilson and Skiles (1988), there is some suggestion that the springshed north of the river may be dominated by the Devil's Ear system, including July Spring, while flow from the south appears to go predominantly to the Ginnie system. The District groundwater flow model (Figure 20) suggests this phenomenon with the steady-state capture zones being contiguous and extending well south in the Western Valley (Newberry Plain). Note, however, that there is a minimal capture zone north of the river.

Therefore, one must conclude that the flow systems of the Poe, Rum Island–Gilchrist Blue, and Ginnie Spring springsheds are complex and cavern-dominated. Water enters the systems from north and south of the river. The sizes of the springsheds mapped by potentiometric surface data (Figure 7, 9, and 11) and the model results (Figure 20) strongly suggest that most discharge from the springs within the spring clusters is from the south, however. The data also suggest that these springsheds should be considered as one for management purposes.

Siphon Creek and the Sunbeam - Wilson Spring Cluster

Siphon Creek Spring (Figure 2) is a siphon/resurgence system (Butt et al., 2007). It could not be differentiated from the Wilson-Sunbeam cluster based on potentiometric data (Figures 7, 9, and 11) or the District flow model (Figure 20), which did not indicate a capture zone owing to the presence of siphon and resurgence in close proximity.

The springsheds within the Sunbeam–Wilson spring cluster could not be separated from each other on the basis of potentiometric data. The capture zone of the springs within the cluster is limited, which explains the low magnitude of springs in this area. It is interesting that the steady-state run of the District flow model indicated that water from near the Santa Fe Rise might contribute to these springs. This is not corroborated by any other data, however.

For the purpose of springshed delineation and management, the springsheds Siphon Creek Rise and the Sunbeam–Wilson spring cluster should be considered as one.

Ichetucknee Spring Group Cluster

The Ichetucknee Springs Group includes six named springs. The spring group is part of a state park. As a result of their importance, these springs have been extensively studied, including many studies that provide information relevant to delineation of the Ichetucknee springshed.

Lawrence and Upchurch (1976) investigated groundwater quality in the area near Lake City, the headwaters of the Ichetucknee springshed, and found that water draining from Alligator Lake, a sinkhole lake that periodically drained into the Floridan aquifer, migrated toward the springs.

Cannon Creek, Clay Hole Creek, Rose Creek, and several other small streams that flow off the Northern Highlands are known to drain to sinkholes at the foot of the Cody Scarp. Karst Environmental Services (1997) established the best evidence of connections of these swallets to the Ichetucknee Spring Group through dye tracing. Dye was injected into Rose Sink, a swallet that captures Rose Creek and that is located near Columbia City, about half way between the park and Lake City. The dye appeared in several springs, and transport rates up to approximately 1 mile per day were observed. The pattern of the dye detections appeared to indicate flow to the east of the spring, with significant dye arrivals at Mission and Blue Springs, which are located on the eastern side of the Ichetucknee River.

A second dye trace from Black and Dyal Sinks, which are located in the Clay Hole Creek sinkhole complex just southwest of Lake City, completed the connection of flow from the swallets to the Ichetucknee Spring Group. This study by Butt and Murphy (2003) first detected dye at Rose Sink, the site of injection of dye in the 1997 study. Dye was also detected at Mission, Blue Hole, and Devil's Eye Springs. Therefore, there is a clear groundwater flow system from Alligator Lake and the Clay Hole Sink complex near Lake City to the Ichetucknee Spring Group. It took from 65 to 125 days for the dye to reach the springs from the distal margin of the springshed.

Upchurch and Champion (2002) developed a preliminary springshed for the Ichetucknee Springs Group in order to consider development potential of the springshed. The map developed by Upchurch and Champion was general and conceptual in nature.

In 2003, Upchurch and Champion (2003a) assessed the source areas of the Ichetucknee Spring Group based on water-quality data. By matching groundwater quality with the quality of water discharging from the springs, they were able to show that the water that flows from the north migrates to the east and discharges at Blue Hole, Mission and other springs. There was a component of groundwater flow from the east to the southern most of the springs in the group.

Upchurch and Champion (2003b) utilized a high resolution monitoring network established by the District to identify the springshed extent. By contouring the groundwater potentials at a 1-foot interval, the springshed became evident. Figure 4 in this report is the springshed delineation developed by Upchurch and Champion.

The springshed delineated in this report is similar to the Upchurch and Champion springshed (Figure 4), although it lacks the details of the earlier study because of lower monitoring-well density. The capture zones predicted by the District groundwater flow model (Figure 20) terminates at Rose Sink and does not extend as far north as Dyal and Black sinks or the toe of the Cody Escarpment.

CONCLUSIONS AND RECOMMENDATIONS

In summary, this springshed delineation project resulted in some important findings relative to our understanding of the springs of the Santa Fe River basin. The following presents general conclusions and recommendations that derive from this study.

1. The springsheds of clusters of springs can be delineated with existing potentiometric surface data. The low density of existing monitoring wells and dominance of conduit flow to the springs limit delineation of springsheds for specific springs.
2. High-resolution monitoring yields much better springshed delineation than traditional monitoring networks, however.
3. Springsheds of most springs on the Santa Fe River cannot be individually delineated. In order to identify springsheds based on low- or high-resolution potentiometric data, the springs have to be grouped.
4. Springsheds in the Newberry Plain are broad and do not have well-defined hydrologic divides. Therefore, the springshed boundaries have associated uncertainty.
5. While potentiometric evidence was found in the high-resolution potentiometric surface data to allow for springshed boundary delineation, the springshed areas in the Newberry Plain area appear to be disproportionate to the discharge of the associated springs.
6. It is recommended that the Newberry Plain springsheds (Poe, Rum Island – Gilchrist Blue, and Ginnie) be considered as one springshed for springshed management purposes because of uncertainties in springshed delineation and the complexity of the karst and flow system in the area.
7. The springsheds of the Newberry Plain (Figures 7, 10, and 11) generally extend from the Northern Highlands or Bell Ridge potentiometric highs to the springs in a manner that is consistent with dye tracing, fingerprinting using water-quality data, cave mapping, and other available data.
8. Traditional springshed maps, including the Ichetucknee Springs Group map (Figure 4) and the results of this study (Figures 7, 9, and 11), extend the springsheds to the nearest up-gradient groundwater divide. When the divide and headwaters of the springshed extend into highly confined areas, the results may be unrealistically large springsheds. This delineation may convey an incorrect impression that the portions of the “springsheds” that lie under well-confined conditions may be vulnerable to contamination from the land surface. The Santa Fe River springsheds extend under confined areas under the Northern Highlands because of slow aquifer drainage adjacent to the Cody Scarp. While these areas of the upper Floridan aquifer are not highly vulnerable to land-use practices, the overlying streams that flow over the Highlands and feed swallets on the Scarp should be protected because of their potential contributions to the aquifer at the point of recharge.
9. Geostatistical analysis of the high-resolution monitoring data indicates that there are no statistically significant gaps in Alachua County’s monitoring network. Increasing the resolution of the network by adding more sampling points beyond the well array used

for the Phase II and III analyses would require a large and probably unnecessary network. The expanded aerial extent used in the Phase II and III maps (Figures 9 and 11) is important, however.

10. Groundwater flow modeling with the District's model was successful in delineating general springsheds when the model was run to steady state. This is important because the steady-state model was developed for utilization by the District to evaluate proposed groundwater withdrawals for permitting.
11. While the District model includes both springs and siphons and swallets, capture zone delineation of springs with significant surface-water contributions was generally not as desired. This is because of the inability of the model to account for conduit flow and, in part, the grid cell size of the model.
12. The steady-state capture zones of springs with significant groundwater flow components were generally well defined and in general agreement with the springshed delineations.
13. Short-term travel-time or capture zones were generally not identified by the groundwater flow model. This is because of the dominance of conduit flow near the springs and the large (5,000 x 5,000 ft.) model grid size.
14. The USGS Megamodel was designed to explore the flow relationships of the Intermediate and Floridan aquifer. Layer 1, which includes the surficial aquifer, was set up as a constant head boundary in the model and few of the springs in the Santa Fe River system were included in the model. The model grid size has the same limitation as the District model. The model was not serviceable for use in characterization of springsheds or capture zones.
15. It is clear that groundwater flow modeling has limitations as far as characterization of springshed flow times in the very complex Santa Fe Basin. The inability of the models to incorporate the effects of conduit flow is especially important at the scale of the springsheds. This inability resulted in predicted springsheds based on steady-state flow that are often smaller than predicted by dye tracing, groundwater potentials, and other means.
16. The siphon to resurgence relationships of many of the springs were generally adequately characterized by the District model, which includes major siphons and all first and second magnitude springs as well as important third magnitude springs. If there are springsheds associated with the resurgences, they are not revealed by the model, however.
17. Several recommendations are clear from this investigation. The un-prioritized recommendations follow.
    - The springsheds of the Newberry Plain (Ginnie, Rum Island – Gilchrist Blue, and Poe) should be considered as one springshed for management purposes. This is because the individual springsheds are difficult to differentiate and the known conduit systems are complex.
    - Additional dye tracing in the vicinity of Poe, Rum Island – Gilchrist Blue, Ginnie Springs, and perhaps the Ichetucknee Springs Group would be useful for

understanding local patterns of flow to these Santa Fe River springs.

- Groundwater chemical fingerprinting, such as was done at Ichetucknee Springs, would also be useful in understanding flow through the Western Valley to the springs on the Santa Fe River and sources of water for specific springs or spring groups.
- The monitoring network developed by Alachua County and existing networks by Coca-Cola/Danone at High Springs, the District, St. Johns River Water Management District, and the USGS should be maintained to understand flow dynamics to the springs and assist in springs protection and management.
- It is recommended that a transient, sub-regional, groundwater flow model be considered for the Santa Fe River watershed. This would allow for a smaller grid size, incorporation of temporal variation in spring behavior, and potential for incorporation of some conduit flow in the model. Optimally, an integrated, surface water/groundwater model could be used to better understand and manage the effects of growth in the Alachua, Columbia, and Gilchrist county areas as well as the floods and droughts that affect the region.

REFERENCES CITED

Barrios, K., 2005. Choctawatchee River Springs Inventory, Holmes, Walton, and Washington Counties, FL. Northwest Florida Water Management District, Water Resources Special Report 05-02, 20 p.

Barrios, K., 2006. St. Marks and Wakulla River Springs Inventory, Leon and Wakulla Counties, FL. Northwest Florida Water Management District, Water Resources Special Report 06-03, 29 p.

Barrios, K., and A. Chelette, 2004. Econfina Creek Spring Inventory - Washington and Bay Counties, Florida. Northwest Florida Water Management District, Water Resources Special Report 04-02, 43 p.

Budd, D.A., and H.L. Vacher, 2004. Matrix Permeability of the Confined Floridan Aquifer, Florida, USA. Hydrogeology Journal, 12:531-549.

Butt, P.L., 2005. Dye Trace: Potential Infrastructure Impact to Ichetucknee Springs State Park. Contract report prepared for the Florida Department of Environmental Protection by Karst Environmental Services, High Springs, FL, 82 p.

Butt, P.L., and G. J. Murphy, 2003. Dyal and Black Sinks Dye Trace, Columbia County, Florida, May-September 2003. Contract report prepared by Karst Environmental Services, Inc., for the Florida Department of Environmental Protection, Florida Springs Task Force, 132 p. [Publication available at http://www.dep.state.fl.us/springs/reports/index.htm]

Butt, P.L., S. Boyes, and T.L. Morris, 2006. Mill Creek and Lee Sinks Dye Trace, Alachua County, Florida, July-December, 2005. Report submitted to the Alachua County Environmental Protection Department by Karst Environmental Services, Inc., 71 p.

Butt, P.L., T.L. Morris, and W.C. Skiles, 2007. Swallet/Resurgence Relationships on the Lower Santa Fe River, Florida. Contract report prepared by Karst Environmental Services for Water Resource Associates, Tampa, Florida, 27 p.

Clark, W.E., R.H. Musgrove, C.G. Menke, and J.W. Cagle, Jr., 1963. Water-resources data for Alachua, Bradford, Clay, and Union Counties, Florida. U.S. Geological Survey Open-File Report 63-17, 162 p.

Chilès, J-P., and P. Delfiner, 1999. Geostatistics: Modeling Spatial Uncertainty. New York, John Wiley & Sons, 720 p.

Col, N., F. Rupert, and G. Horvath, 1997. Reappraisal of the Geology and Hydrogeology of Gilchrist County, Florida, with Emphasis on the Wacassassa Flats. Florida Geological Survey, Report of Investigations No. 99, 76 p.

Copeland, R. (compiler), 2003. Florida Spring Classification System and Spring Glossary. Florida Geological Survey, Special Publication No. 52, 17 p. [Publication available at http://www.dep.state.fl.us/geology/publications/ index.htm]

Copeland, R., T. Scott, R. Ceryak, S. Upchurch, J. King, G.H. Means, B. Katz, T. Mirti, B. Kaufman, and W. Zwanka, 2005. Geomorphic Influence of Scarps in the Suwannee River Basin. Southeastern Geological Society, Field Trip Guidebook 44, 56 p.

Englund, E., and A. Sparks, 1991. Geo-Eas 1.2.1 User's Guide. U.S. Environmental Protection Agency, Environmental Monitoring Systems Laboratory, Las Vegas, Nevada, EPA/600/8-91/006, 186 p. [Publication available at http://www.epa.gov/ada/download/models/geoeas.pdf]

Faulkner, G.L., 1973. Geohydrology of the Cross-Florida Barge Canal Area with Special Reference to the Ocala Vicinity. U.S. Geological Survey, Water-Resources Investigations Report 1-73, 116 p. [Publication available at http://fl.water.usgs.gov/Orlando/legacy/legacy.htm]

Ferguson, G.E., C.W. Lingham, S.K. Love, and R.O. Vernon, 1947. Springs of Florida. Florida Geological Survey, Geological Bulletin No. 31, 196 p.

Florida Departments of Community Affairs and Environmental Protection, 2002. Protecting Florida's Springs: Land Use Planning Strategies and Best Management Practices. Tallahassee, Division of Community Planning, Florida Department of Community Affairs, 124 p. [Publication available at http://www.dca.state.fl.us/fdcp/DCP/publications]

Florida Springs Task Force, 2000. Florida♣s Springs: Strategies for Protection & Restoration. Report prepared for the Florida Department of Environmental Protection, Tallahassee, FL. 58 p. [Publication available at http://www.dep.state.fl.us/springs/reports/index.htm]

Golden Software, Inc., 2002. Surfer. Golden Software, Inc., Golden, Colorado, Version 8.01.

Gordon, S.L. and J.B. Martin, 1997, Chemical and isotopic variation in water discharging from karst springs: Evidence for surface and ground water mixing in the Ichetucknee River ground water basin, Florida. SE Section, Geological Society of America, Abstracts with Program.

Gordon, S.L. and J.B. Martin, 1997, Seasonal variability of surface and ground water mixing in an unconfined karst aquifer, examples from the Ichetucknee River ground water Basin, Florida, Geological society of America Annual Meeting, Abstracts with Program.

Greenhalgh, T., 2003. Florida♣s First Magnitude Springsheds. Florida Geological Survey Poster 12.

Greenhalgh, T.H., and A.E. Baker, 2005. Florida Springs Protection Areas. Florida Geological Survey Open File Map Series No. 95.

Hisert, R.A., 1994, A Multiple Tracer Approach to Determine the Ground Water and Surface Water Relationships in the Western Santa Fe River, Columbia County, Florida: Unpublished Ph.D. Dissertation, Department of Geology, University of Florida, Gainesville, FL 32601.

Hornsby, D.. P. Batchelder, T. Mirti, R. Ceryak, and W. Zwanka, 2003. WARN Water Monitoring Atlas. Suwannee River Water Management County, WR-02/03-01.

Hornsby, D., and R. Ceryak, 1998. Springs of the Suwannee River Basin in Florida. Suwannee River Water Management District, WR99-02, 183 p.

Isaaks, E.H., and R.M. Srivastava, 1989. Appled Geostatistics. Oxford, Oxford University Press, 592 p.

Jones, G.W., and S.B. Upchurch, 1993. Origin of nutrients in ground-water discharging from

Lithia and Buckhorn Springs. Brooksville, FL, Southwest Florida Water Management District, 209 p.

Jones, G.W., and S.B. Upchurch, 1994. Origin of Nutrients in Ground Water Discharging from the Kings Bay Springs. Brooksville, Southwest Florida Water Management District, 133 p.

Jones, G.W., S.B. Upchurch, and K.M. Champion, 1996. Origin of nitrate in ground water discharging from Rainbow Springs, Marion County, Florida. Brooksville, Southwest Florida Water Management District, 155 p.

Jones, G.W., S.B. Upchurch, K.M. Champion, and D.J. Dewitt, 1997. Water quality and hydrology of the Homossassa, Chassahowitzka, Weeki Wachee, and Aripeka Spring complexes, Citrus and Hernando counties, Florida: Origin of increasing nitrate concentrations. Brooksville, Southwest Florida Water Management District, 166 p.

Karst Environmental Services, 1997. Ichetucknee Springs Water Quality Working Group Cooperative Dye Trace: Rose Creek Swallet-Ichetucknee Springs Group. Unpublished manuscript produced for the Ichetucknee Springs Working Group and the Suwannee River Water Management District.

Kinkaid, T.R., 1998. River water intrusion to the unconfined Floridan aquifer. Environmental & Engineering Geoscience, 4:361-374.

Lawrence, F.W., and S.B. Upchurch, 1976. Identification of geochemical patterns in ground water by numerical analysis. In E.A. Zaleem (ed.), Advances in Ground water Hydrology, America Water Resources Association, p. 199-214.

Lawrence, F.W., and S.B. Upchurch, 1982. Identification of recharge areas using geochemical factor analysis. Ground Water, 20:680-687.

McDonald, M.G., and A.W. Harbaugh, 1988. A Modular Three-Dimensional Fine-Difference Ground-Water Flow Model. U.S. Geological Survey, Techniques of Water-Resources Investigations of the United States Geological Survey, Book 6, Chapter A1.

Martin, J.B., and E.J. Screaton, 2001, Exchange of Matrix and Conduit Water with Examples from the Floridan Aquifer, in U.S. Geological Survey Karst Interest Group Proceedings, St. Petersburg, Florida, Water-Resources Investigations Report 01-4011, p. 38-44.

Martin, J.B., and R.W. Dean, 1999. Temperature as a Natural Tracer of Short Residence Times for Groundwater in Karst Aquifers. In A.N. Palmer, M.V. Palmer, and I.D. Sasowsky (eds.), Karst modeling. Karst Waters Institute Special Publication 5, pp. 236-242.

Martin, J.B., and R.W. Dean, 2001. Exchange of Water Between Conduits and Matrix in the Floridan Aquifer. Chemical Geology, 179:145-165.

Martin, J.B., and S.L. Gordon, 1997, Rapid Chemical variations in spring discharge: Evidence for surface and ground water mixing and reactions in the Floridan aquifer, Geological society of America Annual Meeting, Abstracts with Program.

Martin, J.B., and S.L. Gordon, 2000. Surface and Ground Water Mixing, Flow Paths, and Temporal Variations in Chemical Compositions of Karst Springs. In I.D. Sasoksky and

C.M. Wicks (eds.), Groundwater Flow and Contaminant Transport in Carbonate Aquifers, London, Taylor & Francis Publishers, pp. 65-92.

Martin, J.M., 2003. Quantification of the matrix Hydraulic Conductivity in the Santa Fe River Sink/Rise System with Implications for the Exchange of Water Between the Matrix and Conduits. Unpublished Master's Thesis, University of Florida, 80 p.

Martin, J.M., E.J. Screaton, and J.B. Martin, 2006. Monitoring Well Responses to karst Conduit Head Fluctuations: Implications for Fluid Exchange and Matrix Transmissivity in the Floridan Aquifer. In R.S. Harmon, and C. Wicks (eds), Perspectives on Karst Geomorphology, Hydrology, and Geochemistry - A Tribute Volume to Derek C. Ford and William B. White. Geological Society of America Special Paper 404, pp. 209-217.

Meinzer, O.E., 1927. Large Springs in the Unites States. U.S. Geological Survey Water-Supply Paper 557, 94 p.

Motz, L.H., and A. Dogan, 2004. North-Central Florida Active Water-Table Regional Ground water Model. Contract report prepared by the Department of Civil and Coastal Engineering, University of Florida for the St. Johns River Water Management District, 141 p.

North Central Florida Regional Planning Council, 1978. Assessment of Development Potential ▪ Ichetucknee River Headwaters Area. Study prepared for the Columbia County Board of County Commissioners for use in the County Comprehensive Plan, Appendix A.

Puri, H.S., and R.O. Vernon, 1964. Summary of the Geology of Florida and a Guidebook to the Classic Exposures. Florida Geological Survey Special Publication No. 5 (Revised), 312 p., plus plates.

Rosenau, J.C., G.L. Faulkner, C.W. Hendry, Jr., and R.W. Hull, 1977. Springs of Florida. Florida Geological Survey Bulletin No. 31 (Revised), 461 p.

Schneider, J.C., S.B. Upchurch, J. Chen, and C. Cain, 2008. Simulation of Groundwater Flow in North Florida and South-Central Georgia: A Three-Dimensional Model of Groundwater Flow in the Surficial, Intermediate, and Floridan Aquifer Systems. Suwannee River Water Management District, Live Oak, Florida, 98 p.

Scott, T.M.,G.H. Means, R.C. Means, and R.P. Meegan, 2002. First Magnitude Springs of Florida. Florida Geological Survey Open File Report No. 85, 138 p.

Scott, T.M., G.H Means, R.P. Meegan, R.C. Means, S.B. Upchurch, R.E. Copeland, J. Jones, T. Roberts, and A. Willet, 2004. Springs of Florida. Florida Geological Survey, Bulletin No. 66, 377 p., plus CD ROM.

Screaton, E., J.B. Martin, B. Ginn, and L. Smith, 2004. Conduit Properties and Karstification in the Unconfined Floridan Aquifer. Ground Water, 42:338-346.

Sepúlveda, N., 2002. Simulation of Ground-Water flow in the Intermediate and Floridan Aquifer Systems in Peninsular Florida. U.S. Geological Survey, Water-Resources Investigations Report 2002-4009, 130 p.

Sepúlveda, N., B.G. Katz, and G.L. Mahon 2006. Potentiometric Surface of the Upper Floridan Aquifer in the Ichetucknee Springshed and Vicinity, Northern Florida, September 2003.

U.S. Geological Survey, Open-File Report 2006-1031, 1 p.

Shoemaker, W.B., A.M. O'Reilly, N. Sepúlveda, S.A. Williams, L.H. Motz, and Q. Sun, 2004. Comparison of Estimated Areas Contributing Recharge to Selected Springs in North-Central Florida by Using Multiple Ground-Water Flow Models. U.S. Geological Survey, Open-File Report 03-448, 38 p. [This publication is available at http://fl.water.usgs.gov/Pubs_products/online.html]

Smith, L.A., 2004. Using Radon-222 as a Tracer of Mixing Between Surface and Ground Water in the Santa Fe River Sink/Rise System. Unpublished Master's Thesis, University of Florida, 63 p.

Smith, L.A., J.B. Martin, and E.J. Screaton, 2002. Surface Water Control of Gradients in the Floridan Aquifer: Observations from the Santa Fe River Sink-Rise System. In J.B. Martin, C.M. Wicks, and I.D. Sasowsky (eds.), Hydrogeology and Biology of Post-Paleozoic Aquifers, Karst Waters Institute Special Publication 7, pp. 44-48.

Sprouse, B.E., 2004. Chemical and Isotopic Evidence for Exchange of Water Between Conduit and Matrix in a Karst Aquifer: An Example from the Santa Fe River Sink/Rise System. Unpublished Master's Thesis, University of Florida, 84 p.

Strong, W.A., 2004. Temporal Water Chemistry Trends Within Individual Springs and Within a Population of Florida Springs. Unpublished Master's Thesis, University of Florida, 54 p.

Suwannee River Water Management District, 1982. Hydrogeologic Overview. Suwannee River Water Management District. SRWMD Technical Report 82-3. 19 p.

Toth, D.J., and C. Fortich, 2002. Nitrate Concentrations in the Wekiva Groundwater Basin with Emphasis on Wekiwa Springs. St. Johns River Water Management Disrict, Technical Publication SJ2002-2, 84 p.

Upchurch, S.B., 2002. Hydrogeochemistry of a karst escarpment. In J.B. Martin, C.M. Wicks, and I.D. Sasowsky (eds.), Hydrogeology and Biology of Post-Paleozoic Carbonate Aquifers. Charles Town, WV, Karst Waters Institute, Special Publication 7, pp. 73-75.

Upchurch, S.B., 2007. An Introduction to the Cody Escarpment, North-Central Florida. Live Oak, Florida, Suwannee River Water Management District, 16 p.

Upchurch, S.B., and F.W. Lawrence, 1984. Impact of ground-water chemistry on sinkhole development along a retreating scarp. In B.F. Beck (ed.), Sinkholes: Their Geology, Engineering & Environmental Impact. Rotterdam, A.A. Balkema, pp. 23-28.

Upchurch, S.B., and K.M. Champion, 2002. Development Potential of the Ichetucknee Springshed, Florida. Tallahassee, Florida Department of Environmental Protection, Division of State Lands.

Upchurch, S.B., and K.M. Champion, 2003a. Delineation of Spring-Water Source Areas in the Ichetucknee Springshed. Tallahassee, Florida Department of Environmental Protection, Division of State Lands.

Upchurch, S.B., and K.M. Champion, 2003b. Geostatistical Analysis of Water-Level and Water-Quality Data for the Ichetucknee Springshed. Live Oak, Florida, Suwannee River Water Management District.

Upchurch, S.B., and K.M. Champion, 2004. Delineation of Spring Protection Areas at Five, First-Magnitude Springs in North-Central Florida. Live Oak, Florida, Suwannee River Water Management County, 24 p.

Upchurch, S.B., and F.W. Lawrence, 1984. Impact of ground-water chemistry on sinkhole development along a retreating scarp. In B.F. Beck (ed.), Sinkholes: Their Geology, Engineering & Environmental Impact. Rotterdam, A.A. Balkema, pp. 23-28.

Upchurch, S.B., D. Hornsby, R. Ceryak, and W. Zwanka, 2001. A Strategy for the Characterization of First Magnitude Springs. Live Oak, Florida, Suwannee River Water Management County, WR01/02-01, 86 p.

Upchurch, S.B., J. Chen, and C.R. Cain, 2007a. Trends of Nitrate Concentrations in Waters of the Suwannee River Water Management District, 2007. Live Oak, Florida, Suwannee River Water Management District, 39p. (Report available from the District at http://www.srwmd.state.fl.us/resources)

Upchurch, S.B., J. Chen, and C.R. Cain, 2007b. Relationships of Nitrate to Flow in Springs of the Suwannee River Water Management District, 2007. Live Oak, Florida, Suwannee River Water Management District, in final peer review, 38p. (Report available from the District at http://www.srwmd.state.fl.us)

Upchurch, S., K. Champion, J. Schneider, D. Hornsby, and R. Ceryak, 2004. Identifying water-quality domains near Ichetucknee Springs, Columbia County, Florida (extended abs.). In B.G. Katz and E. Raabe, Suwannee River Basin and Estuary Integrated Science Workshop: September 22-24, 2004, U.S. Geological Survey Open-File Report 2004-1330, p. 24.

Water Resource Associates, Inc., 2006. MFL Development for the Upper Santa Fe River. Draft Technical Report, submitted to the Suwannee River Water Management District, Live Oak, Florida (available on-line at http://www.srwmd.state.fl.us/resources).

Water Resource Associates and SDII Global Corporation, 2005. Strategies and Recommendations for Protecting Silver and Rainbow Springs. Marion County, Florida Springs Protection Program, 130 p. (This publication is available at http://www.marioncountywaterstudy.com)

White, W.A., 1970. The Geomorphology of the Florida Peninsula. Florida Department of Natural Resources, Bureau of Geology, Geological Bulletin 51, 164 p.

Wilson, W.L., and W. C. Skiles, 1988. Aquifer characterization by quantitative dye tracing at Ginnie Spring, northern Florida. Proceedings, Second Conference on Environmental Problems in Karst Terranes and Their Solutions, Association of Ground Water Scientists and Engineers, pp. 121-141.

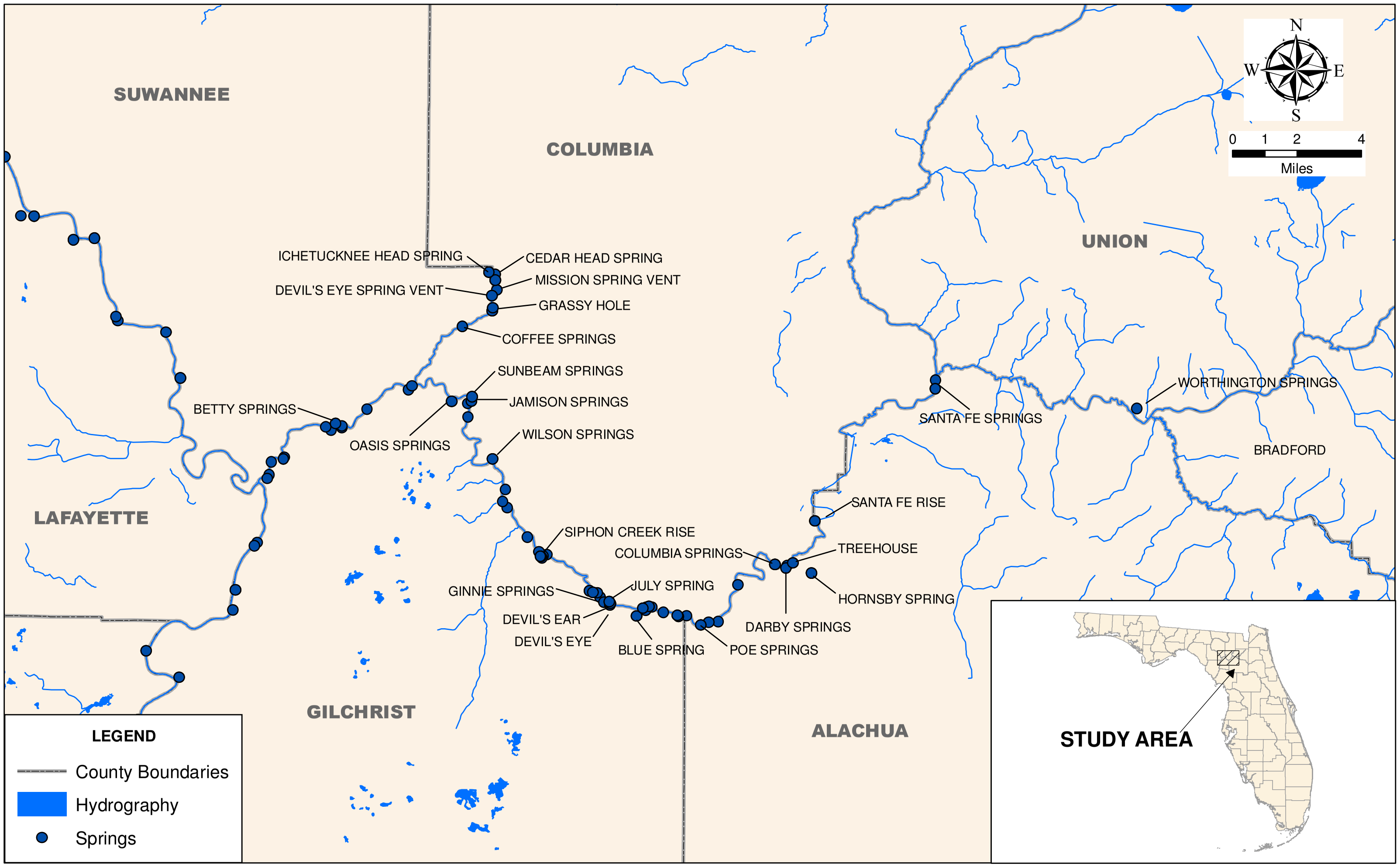

Figure 1 - Study area showing the springs along the Suwannee and Santa Fe Rivers of Florida.

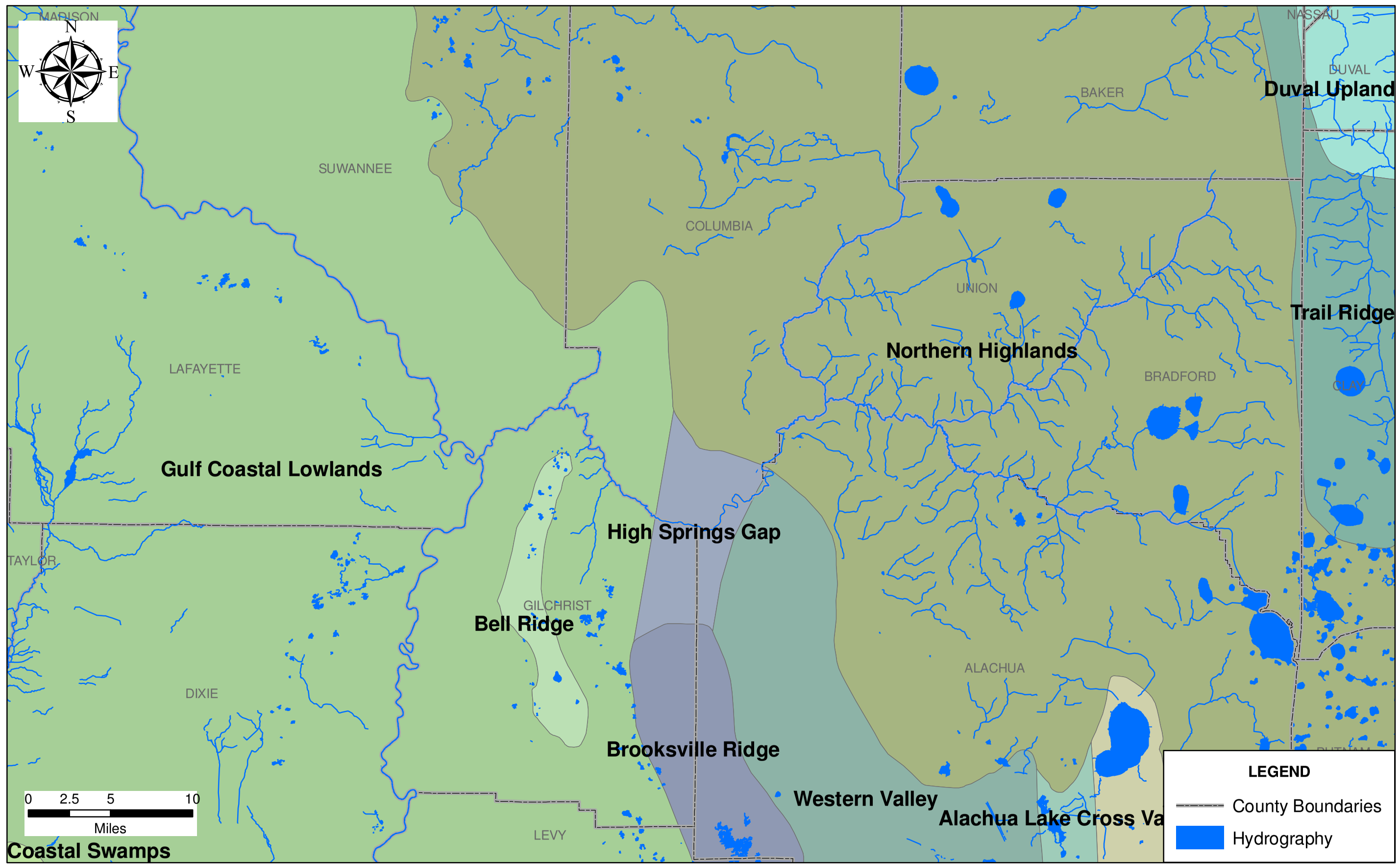

Figure 2 - Physiographic provinces within the study area. From White (1970). Note that the Cody Scarp is the transitional boundary between the Northern Highlands and the Western Valley (Newberry Plain).

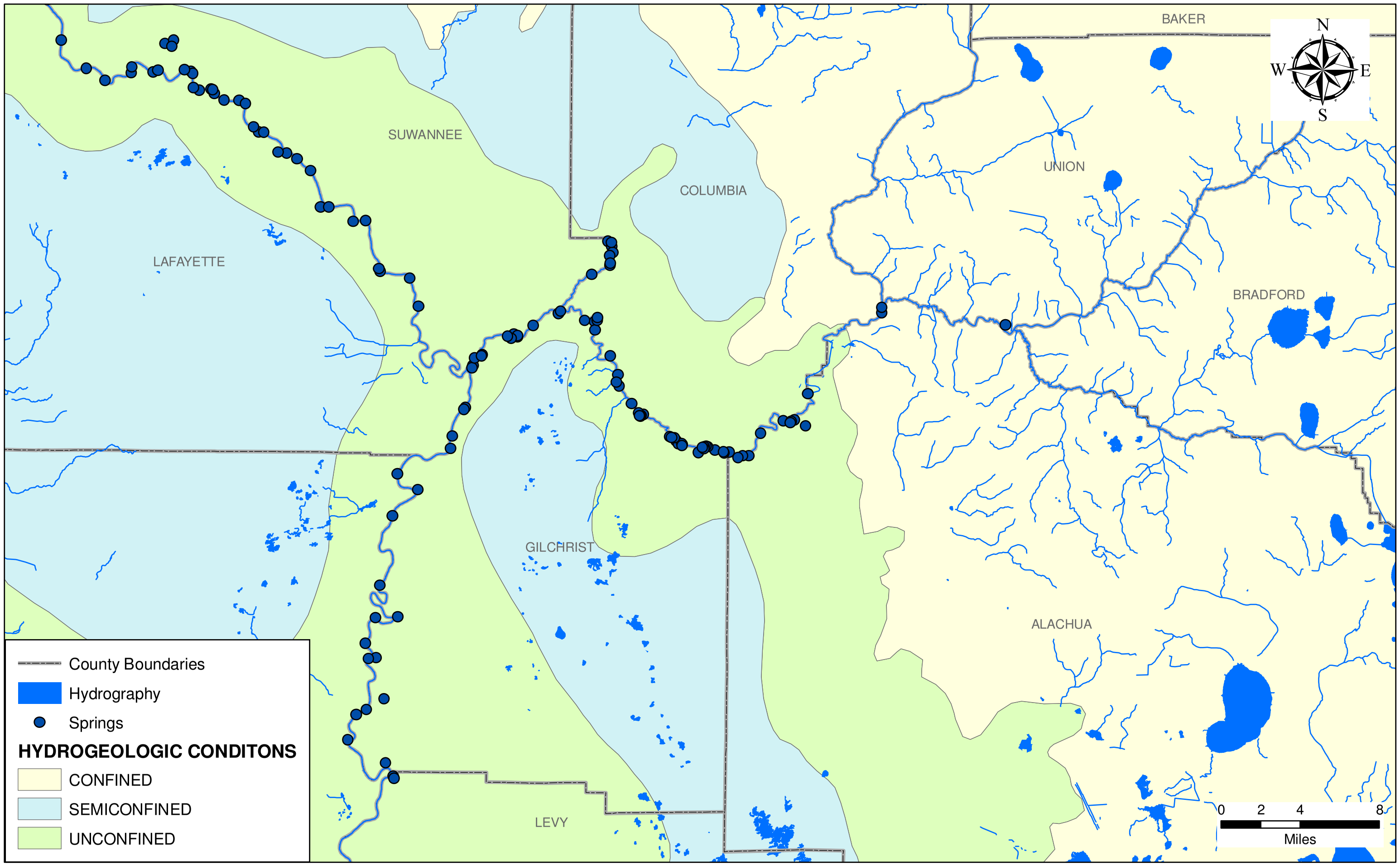

Figure 3 - Confinement of the Floridan aquifer within the study area. Data from the Suwannee River Water Management District (1980).

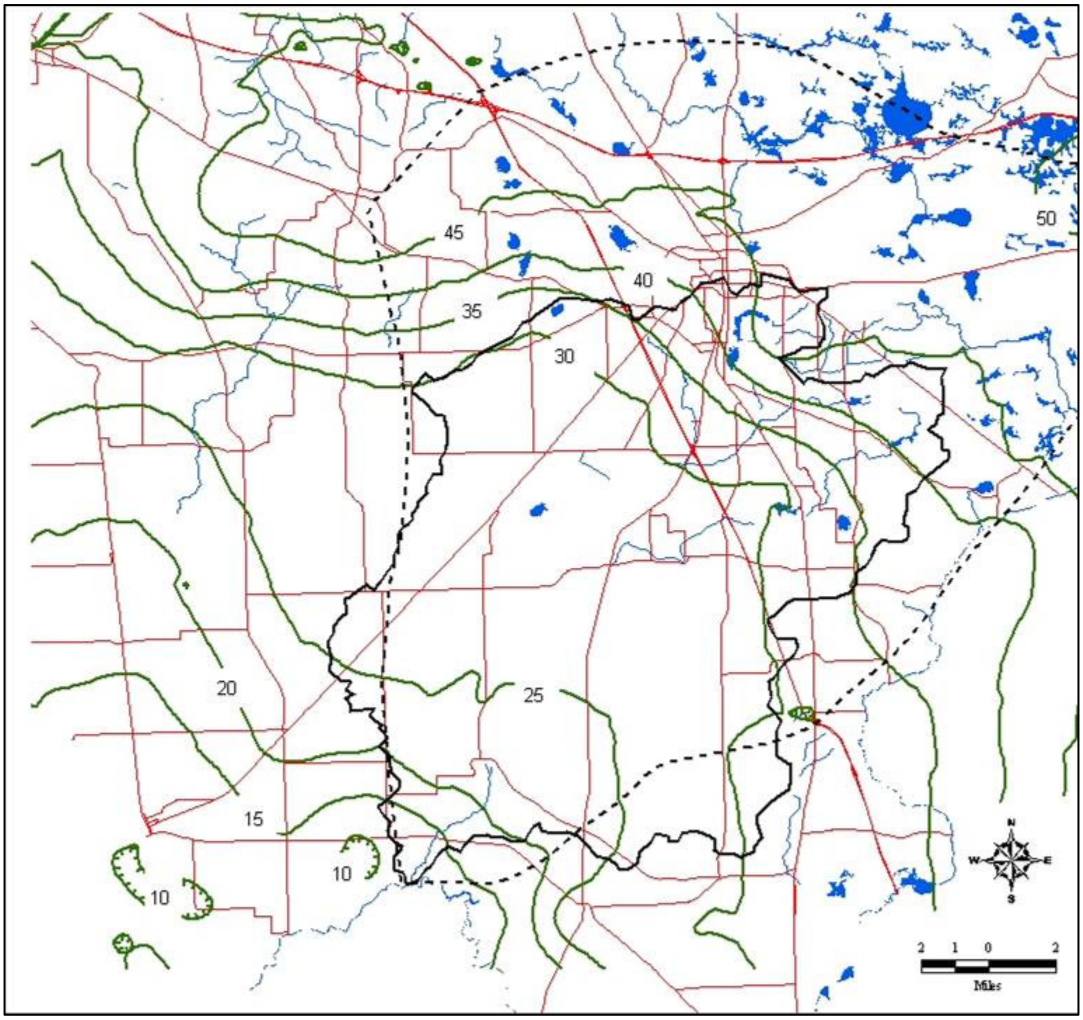

Figure 4 - Springshed delineation of the Ichetucknee Springs Group (dashed line) with upper Floridan aquifer potentiometric surface contours (green lines). From Upchurch and Champion (2003).

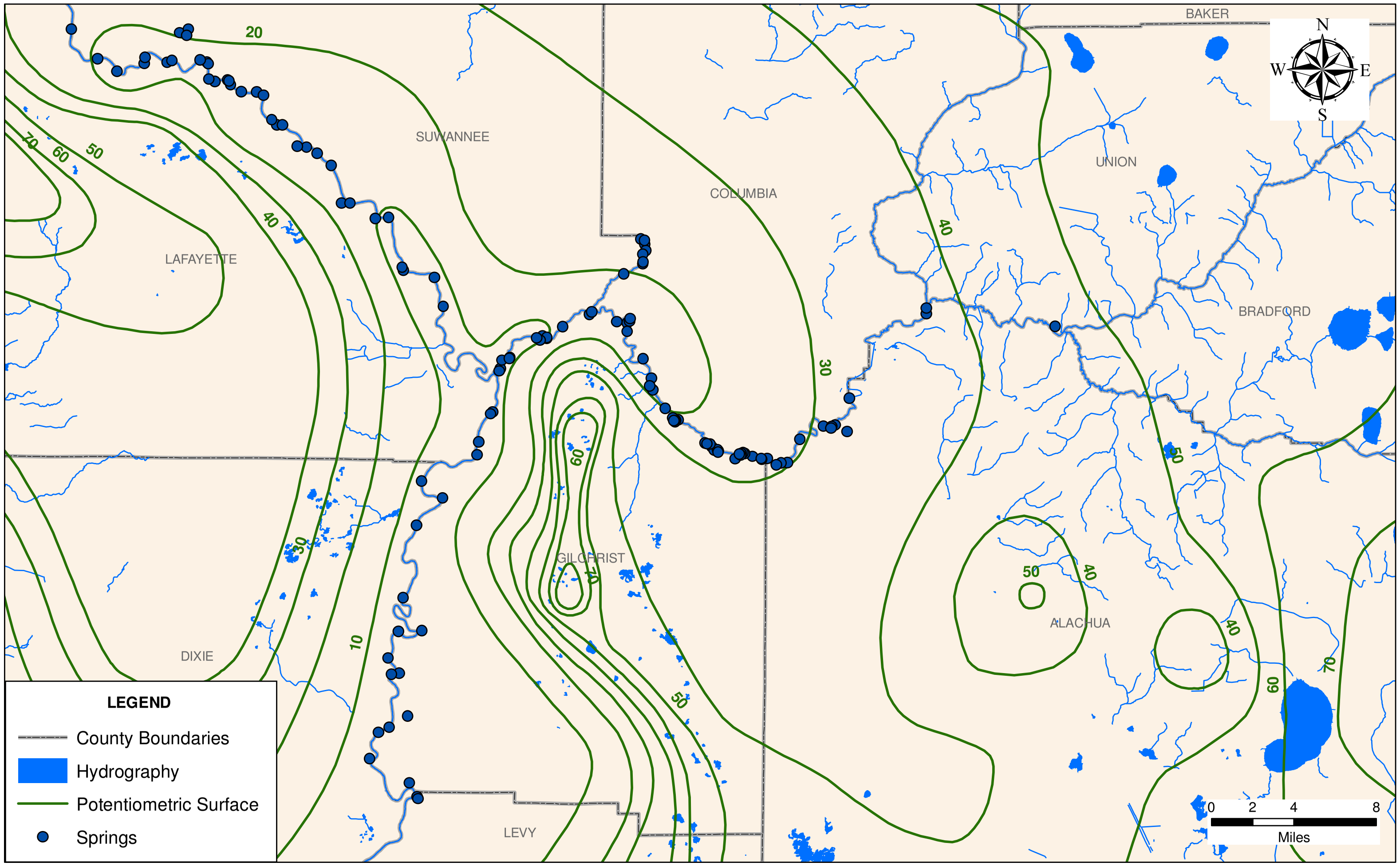

Figure 5 - Potentiometric surface of the upper Floridan aquifer in 2000. Data from the USGS.

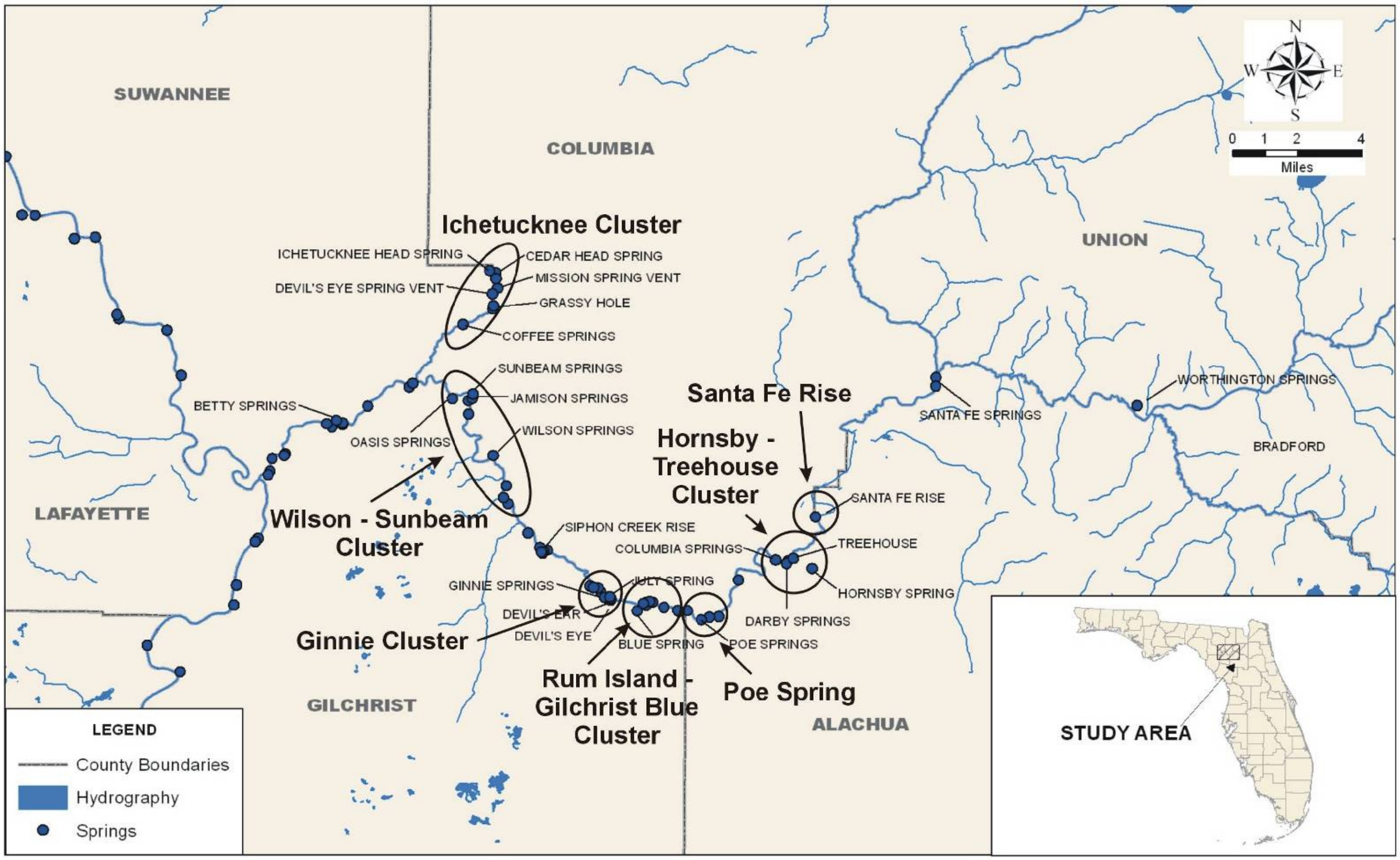

Figure 6 – Springs of the Santa Fe River showing the "spring clusters" for which springsheds were delineated.

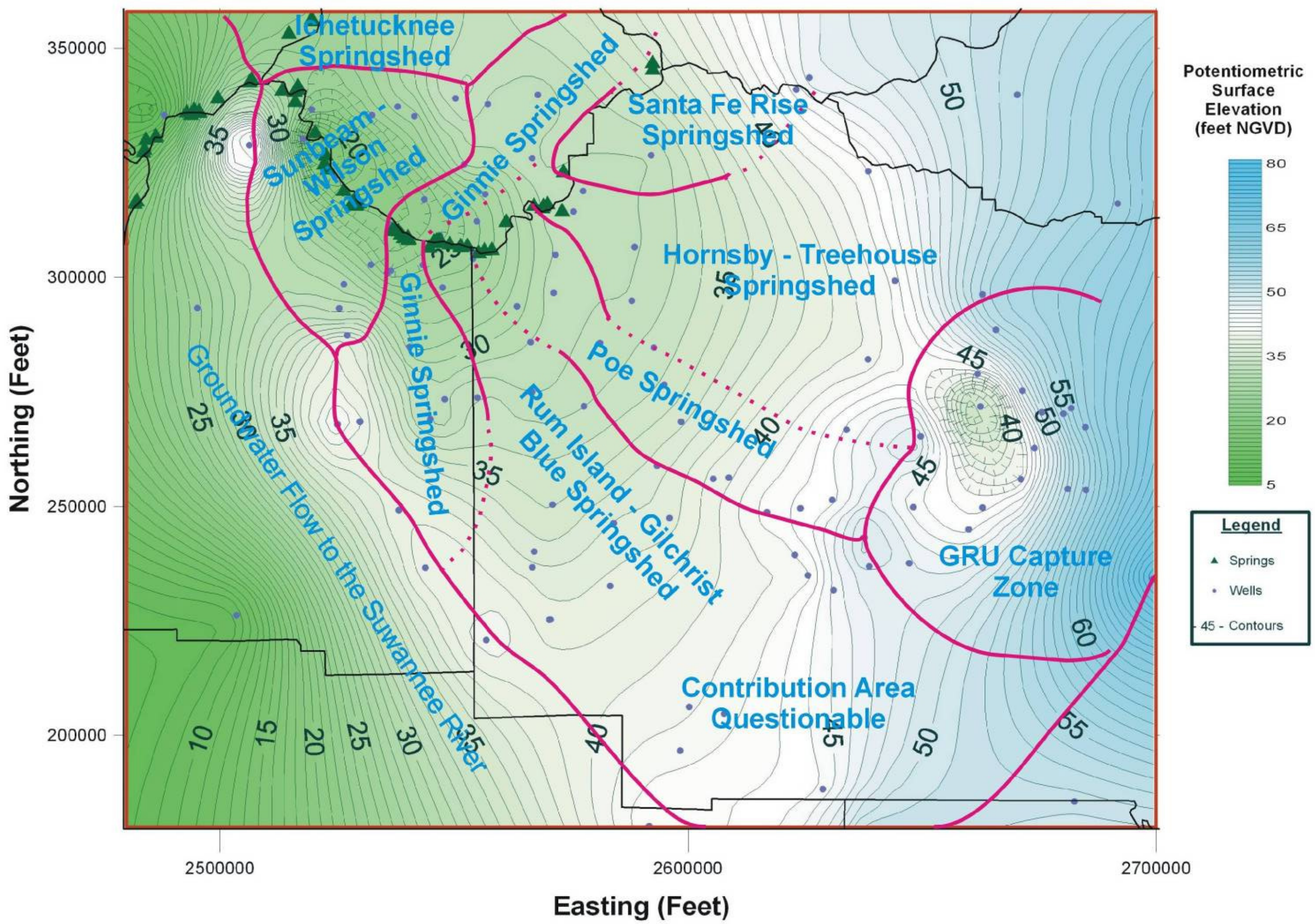

Figure 7 – Springsheds in the vicinity of the Newberry Plain delineated through high-resolution potentiometric surface data from September, 2007.

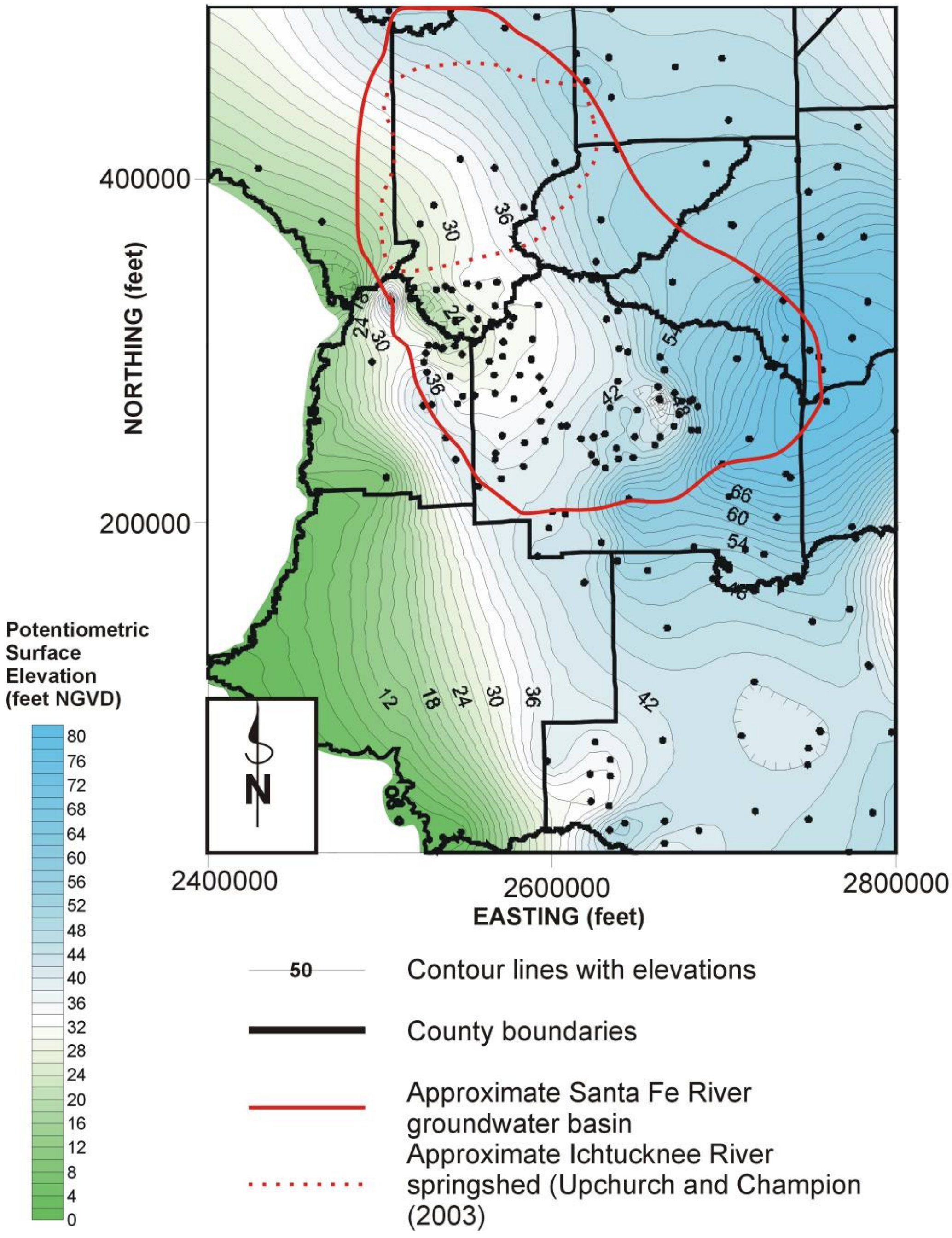

Figure 8 – Potentiometric surface map of September, 2007, data for the upper Floridan aquifer in the vicinity of the Santa Fe River basin. The approximate position of the Santa Fe and Ichetucknee groundwater basins are shown.

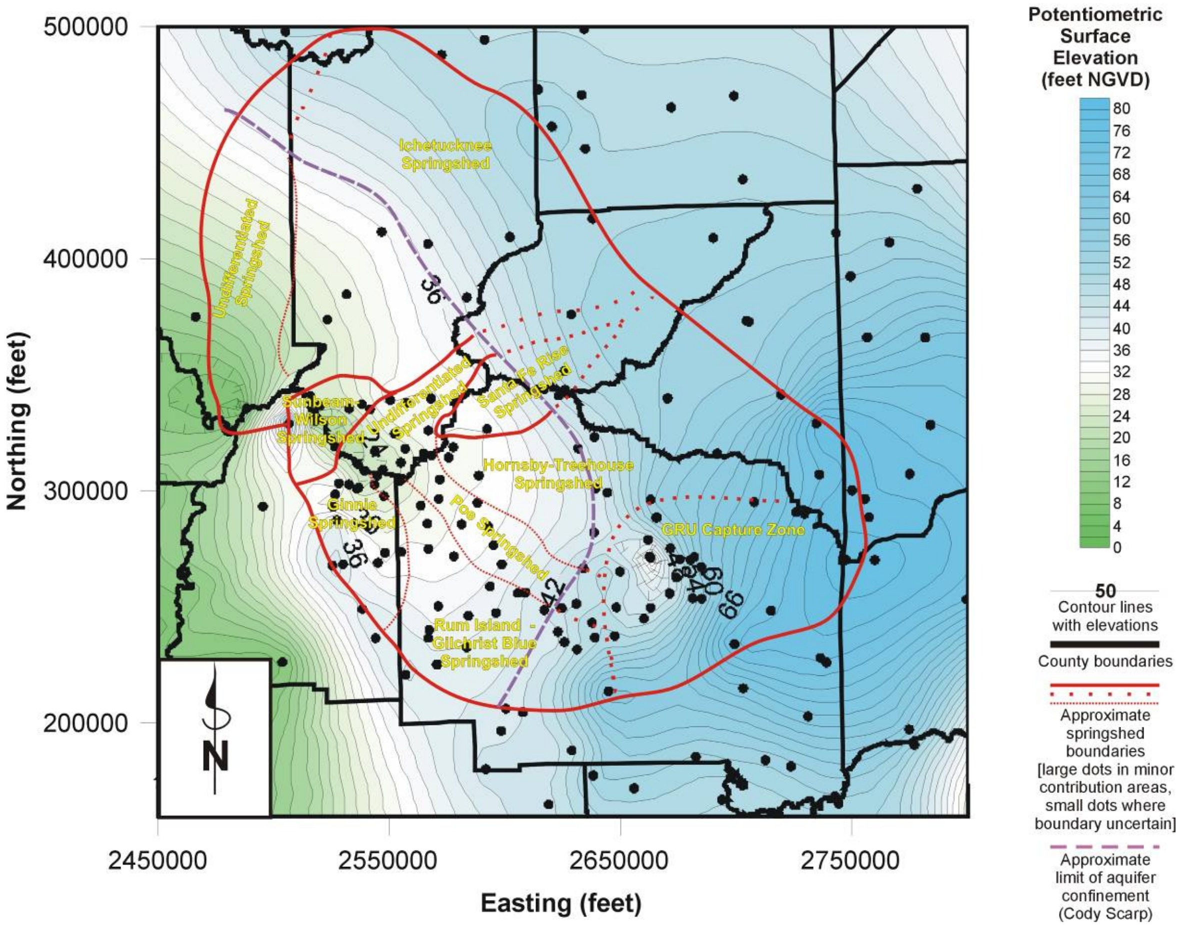

Figure 9 – Delineation of the springsheds of the Santa Fe River using the September, 2007, upper Floridan aquifer potentiometric data.

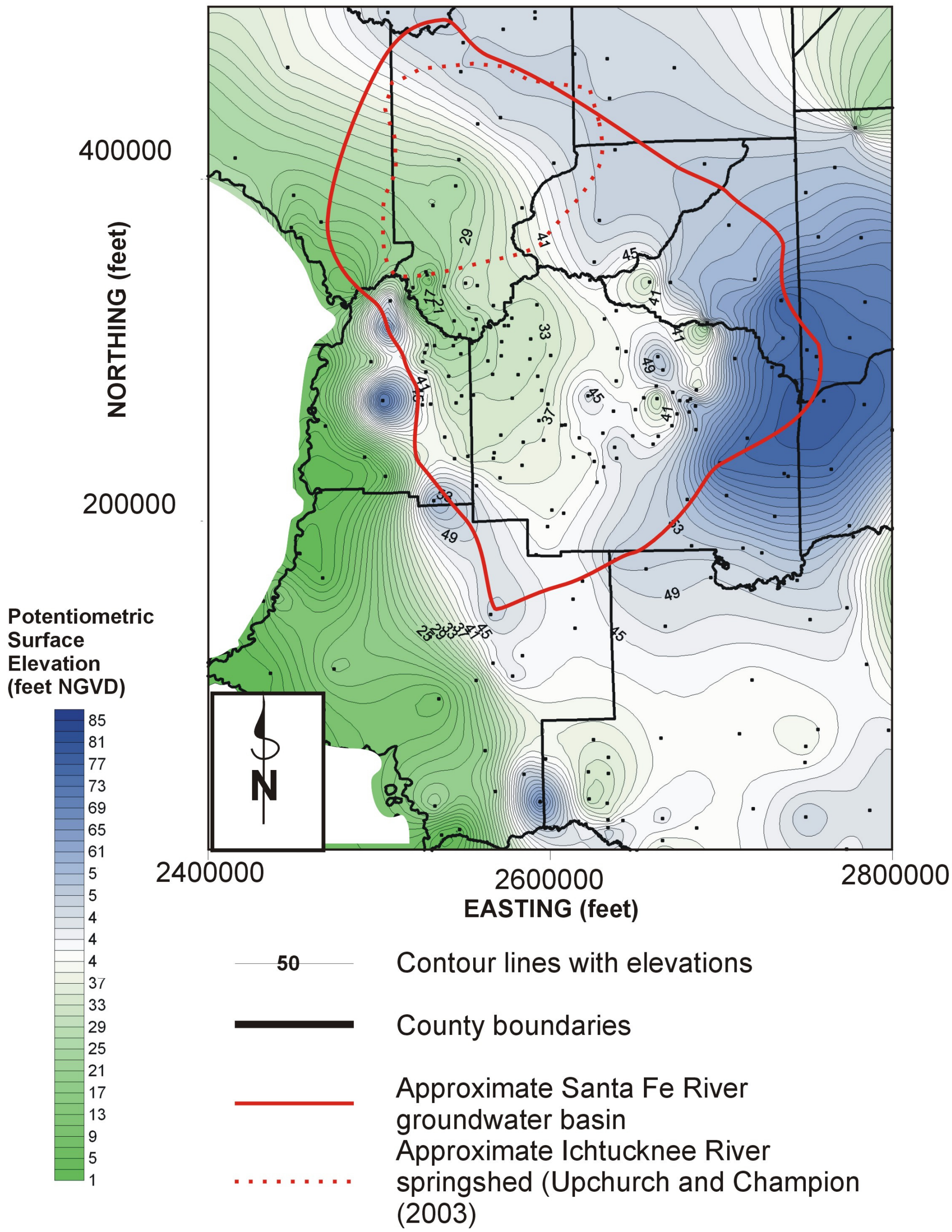

Figure 10 - Potentiometric surface map of May, 2008, data for the upper Floridan aquifer in the vicinity of the Santa Fe River basin. The approximate position of the Santa Fe and Ichetucknee groundwater basins are shown.

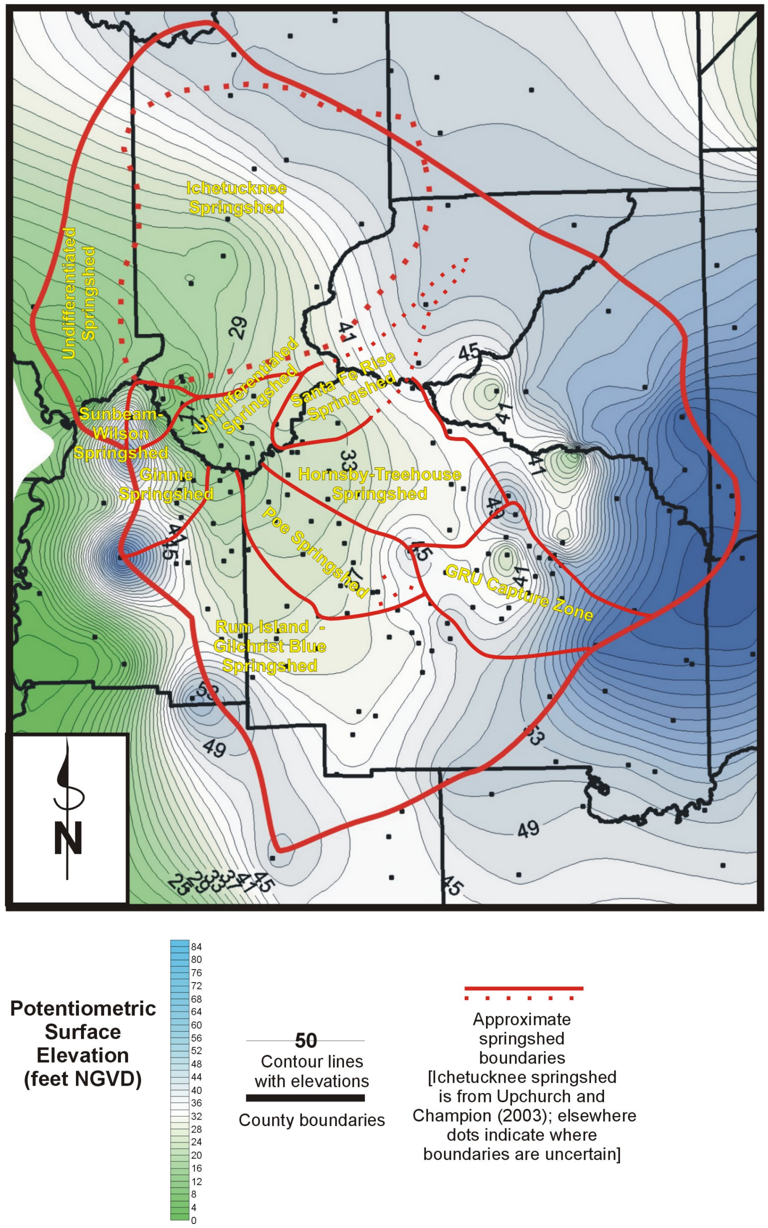

Figure 11 - Delineation of the springsheds of the Santa Fe River using the May, 2008, upper Floridan aquifer potentiometric data.

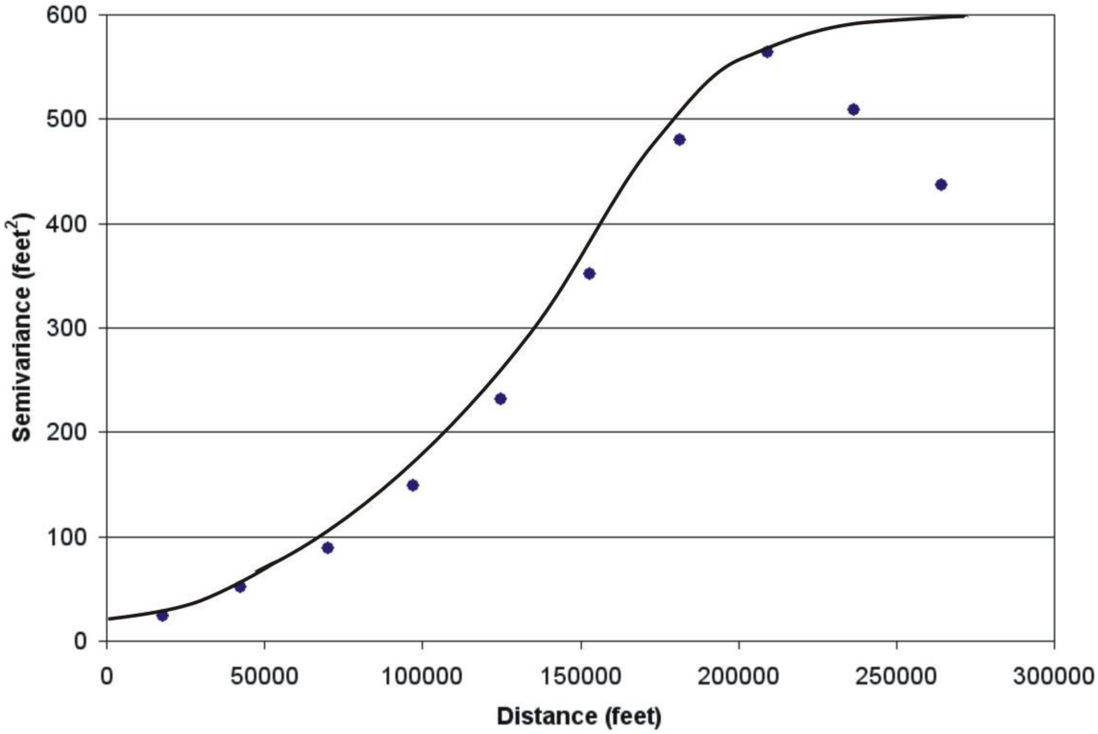

Figure 12 – Semivariogram illustrating the results of the structural analysis of the September, 2007, Floridan aquifer potentiometric surface data.

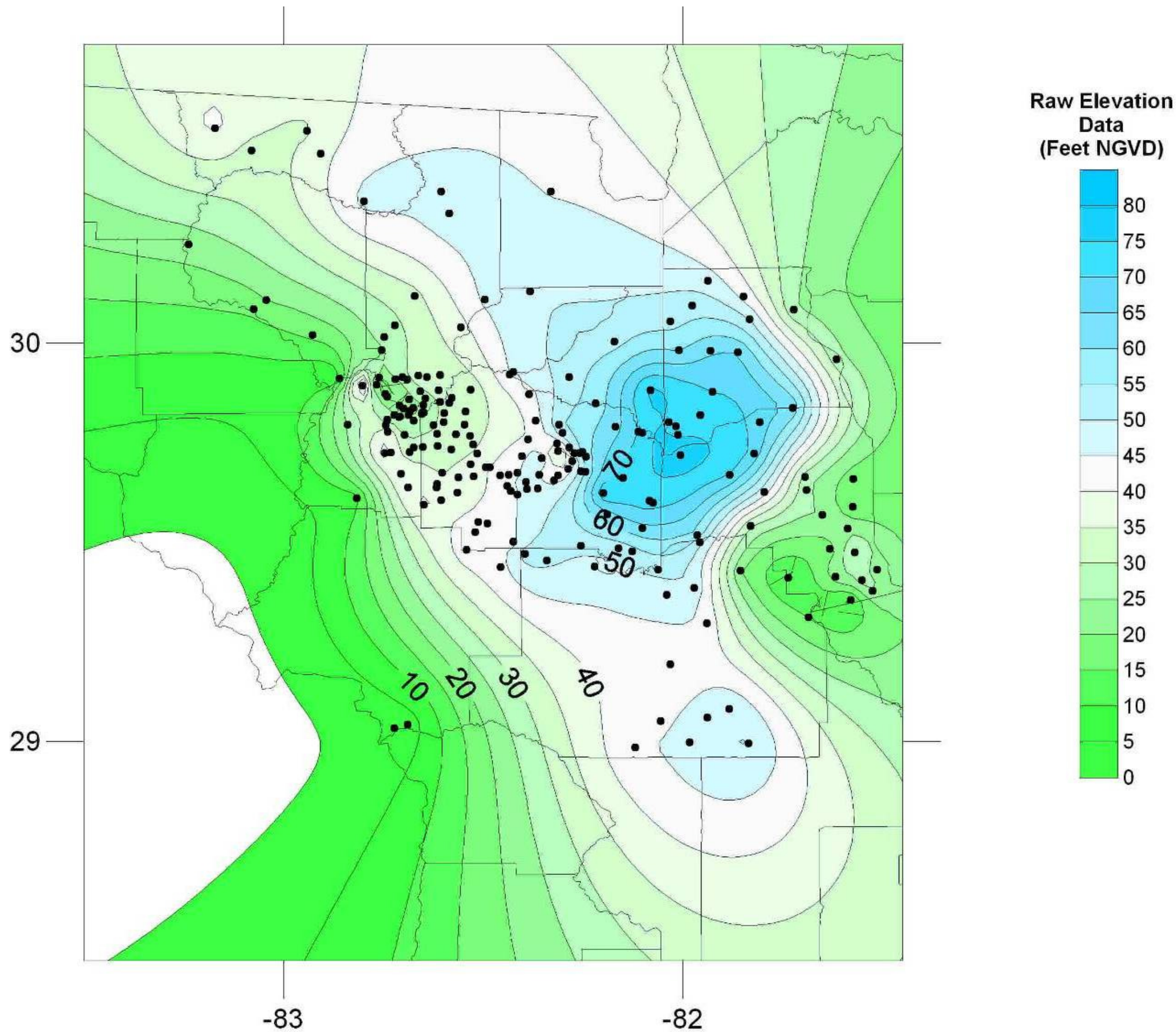

Figure 13 – Contoured regional, raw potentiometric surface data.

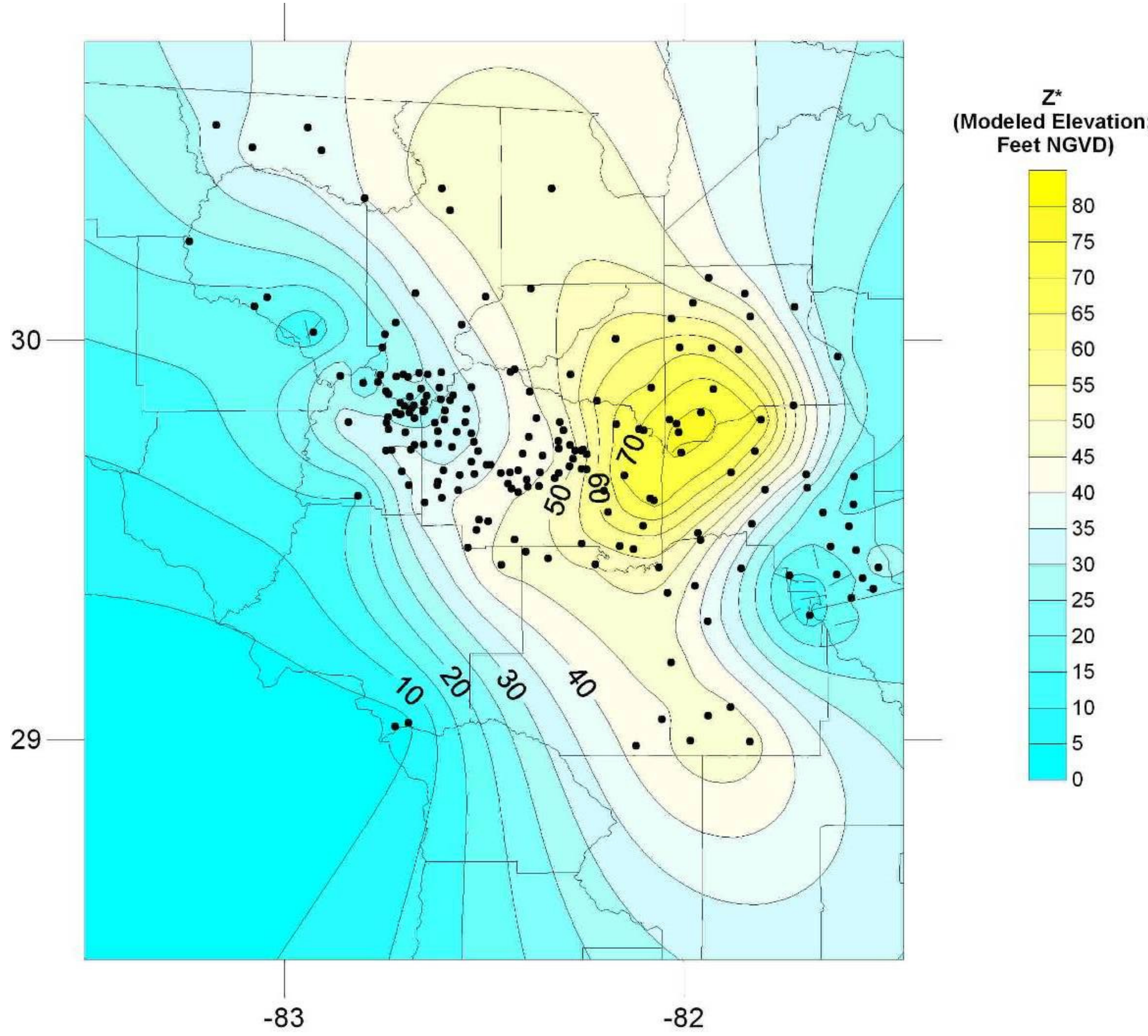

Figure 14 – Kriged regional Floridan aquifer potentiometric data (Z* output).

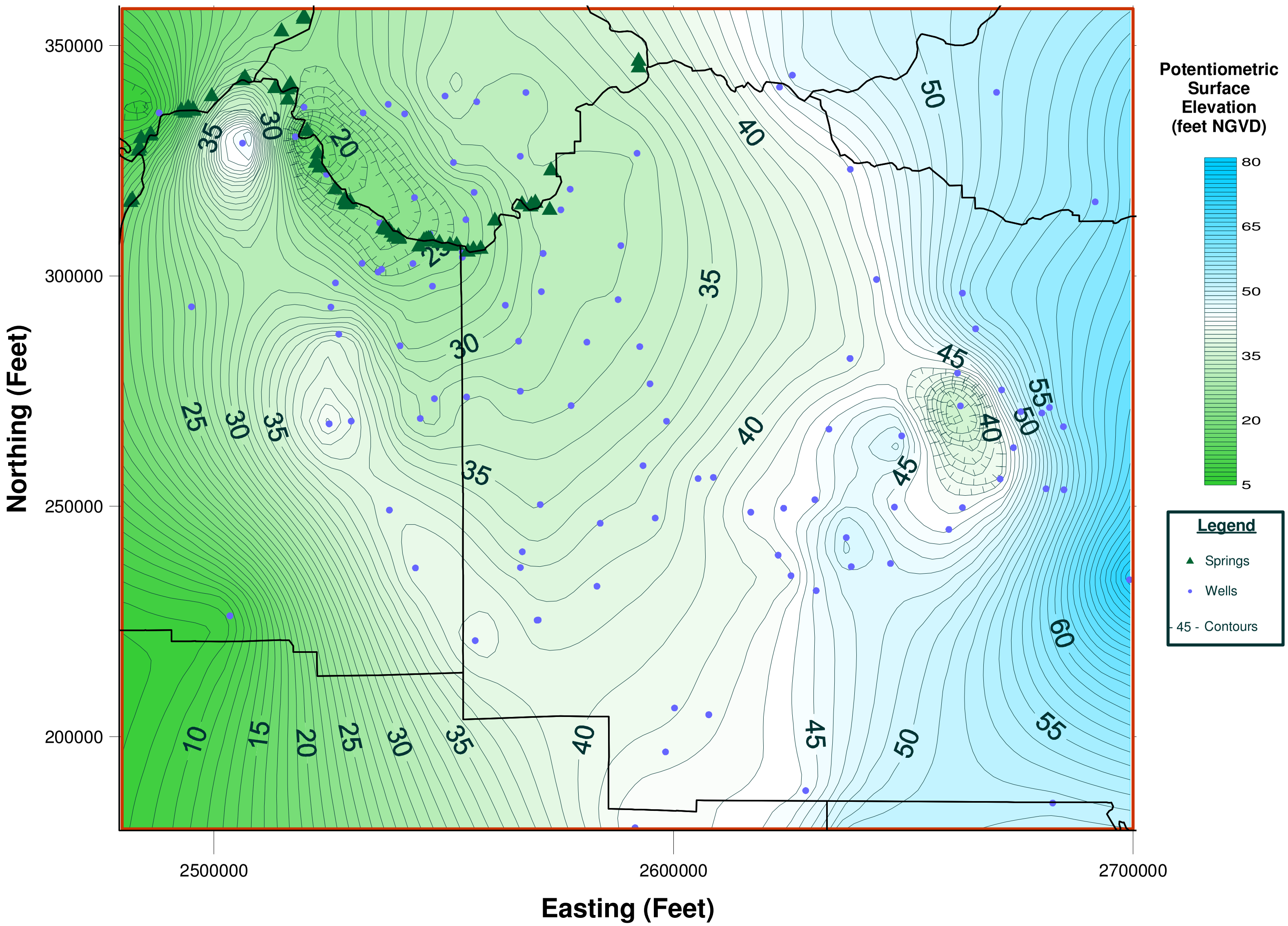

Figure 15 – One-foot contour map of raw potentiometric surface data in the Newberry Plain vicinity. Springs and monitoring wells are depicted on the map.

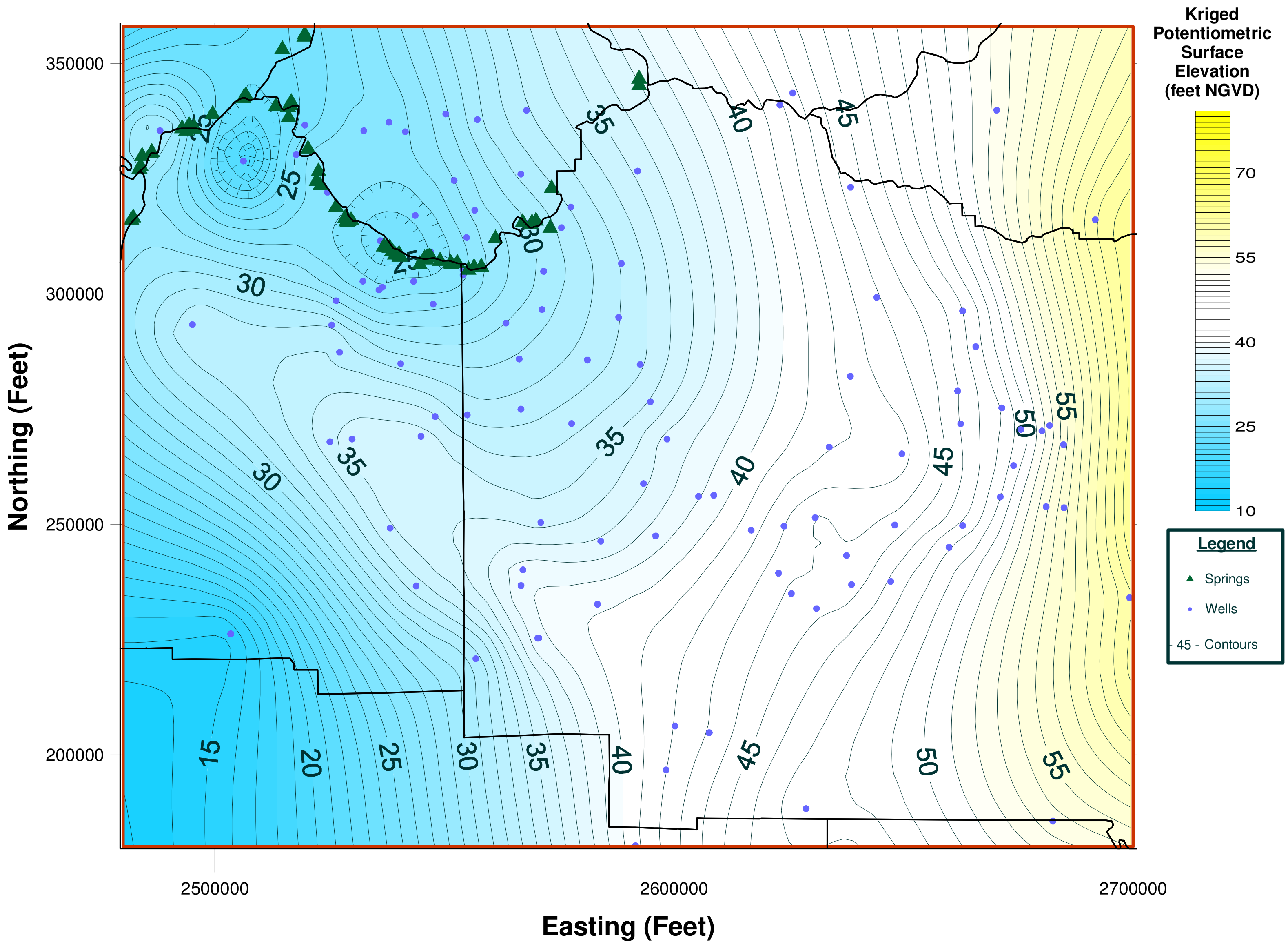

Figure 16 – Kriged potentiometric surface data (Z*) in the Newberry Plain vicinity.

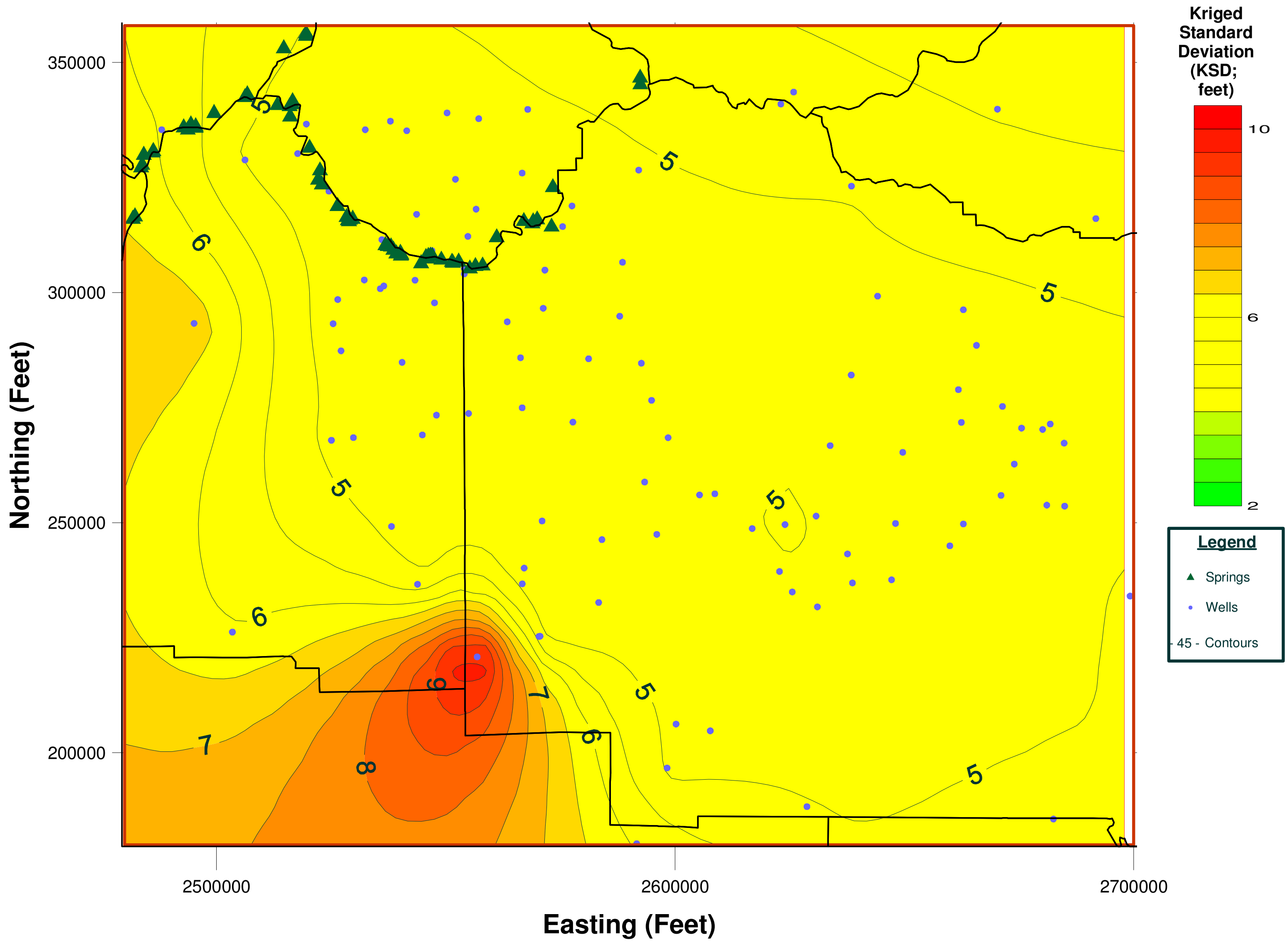

Figure 17 – Uncertainty map showing the kriged standard deviation (K_{SD}) of groundwater levels in the Newberry Plain vicinity.

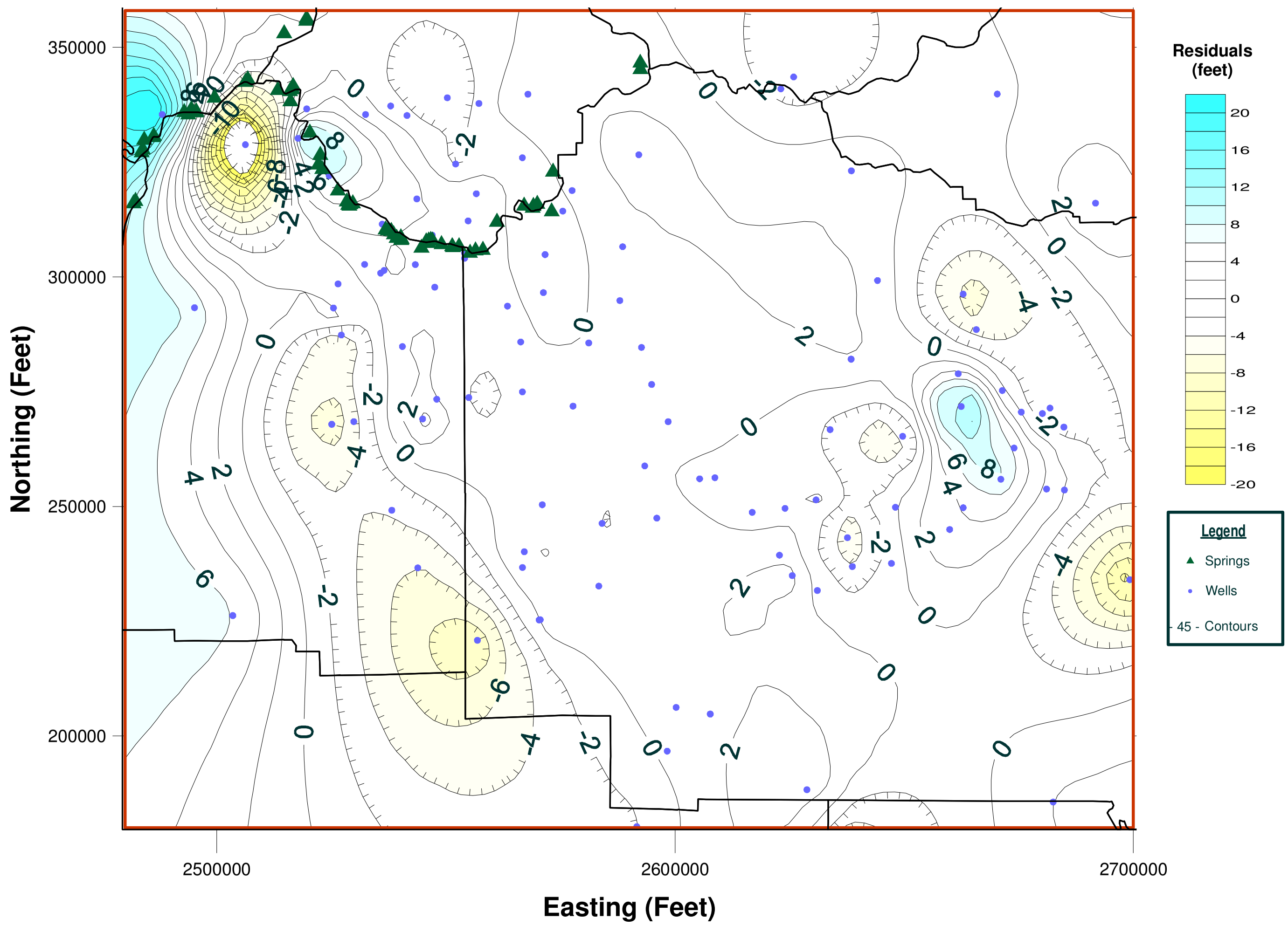

Figure 18 – Residuals from raw and kriged potentiometric data in the Newberry Plain vicinity.

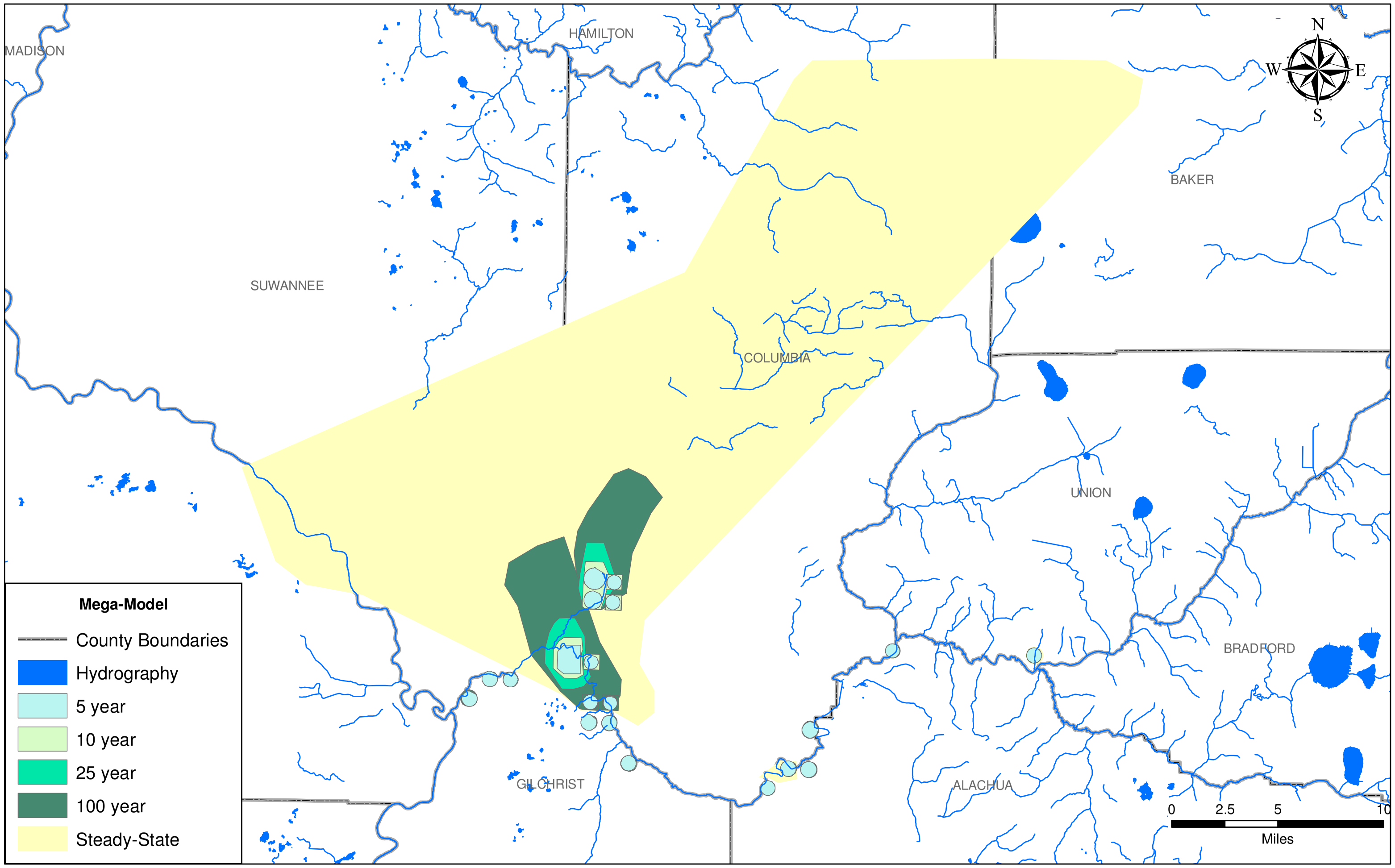

Figure 19 - Travel times for groundwater to springs of the Santa Fe River. Travel times were estimated by particle tracking utilizing the USGS Megamodel (Sepúlveda, 2002)

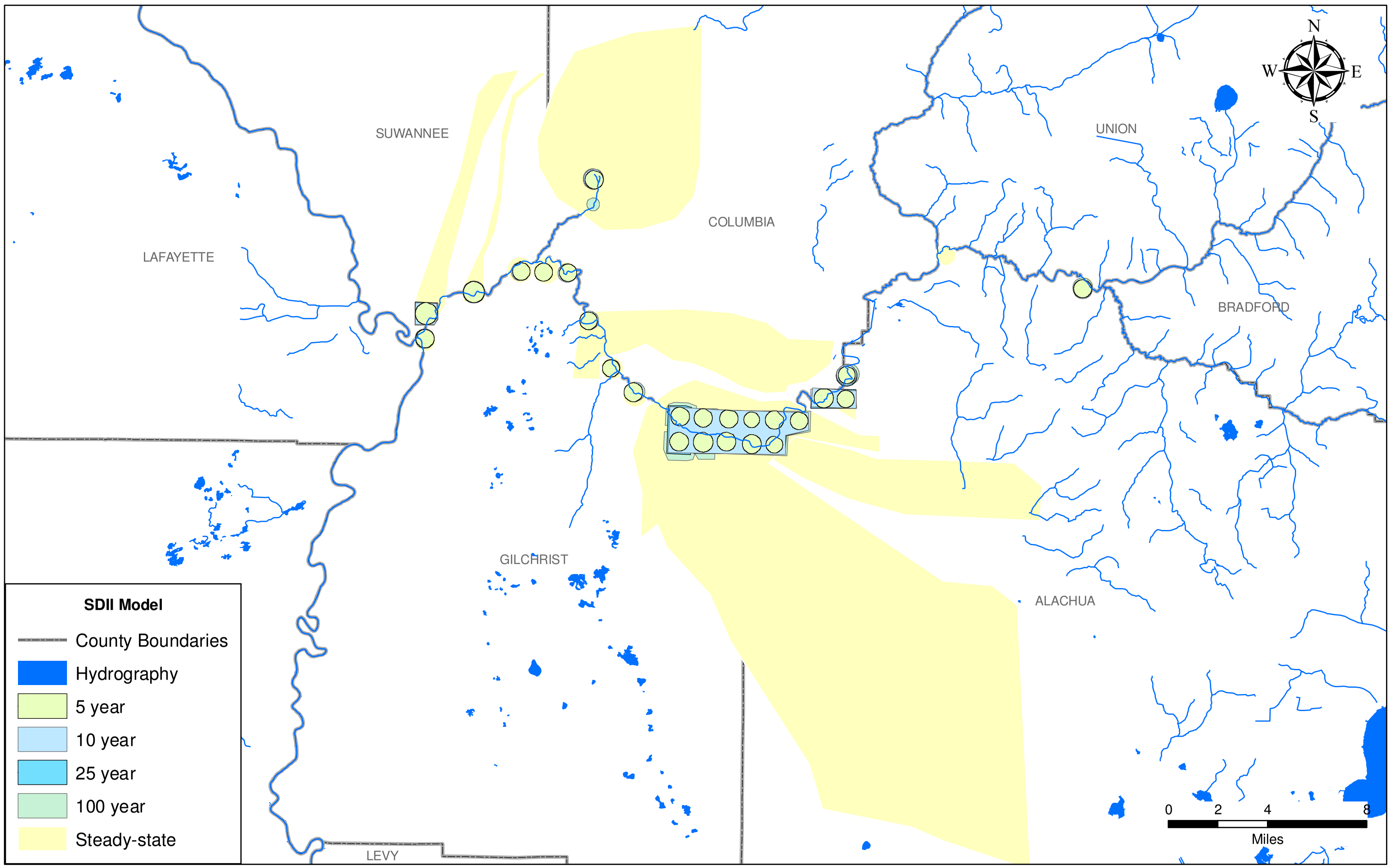

Figure 20 - Travel times for groundwater to springs of the Santa Fe River. Travel times were estimated by particle tracking utilizing the Suwannee River Water Management District model (Schneider and Upchurch, 2006)

Appendix A – List of monitoring points utilized for the high-resolution springshed delineations.

Sample ID	Lat	Long	Sept 2007 Water Surface Elevation (ft. NGVD)
(City of) Astor Park 8" UFA.	29.150000	-81.572220	31.60
10" UFA Artesian off SR46A nr Sorrento	28.824720	-81.496940	32.87
A-0002 CITY OF HIGH SPRINGS UFA	29.824440	-82.598060	31.45
A-0053 CELLON 2" UFA NR LACROSSE	29.810830	-82.385280	41.08
A-0068 USGS UFA CE-1A NR NEWBERRY	29.605560	-82.605560	38.16
A-0071 HAWTHORNE TOWER UFA	29.599090	-82.075650	71.50
A-0135 ROD REESE UFA NR KEYSTONE HEIGHTS	29.777780	-82.112500	68.73
A-0420 LYBASS AT PHIFER	29.570450	-82.373060	63.05
A-0693 ALACHUA CO FAIRGROUNDS UFA	29.684720	-82.287500	40.63
A-0704 ALACHUA CO F-1 UFA	29.774720	-82.303610	52.97
A-0706 ALACHUA CO F-3 UFA	29.727500	-82.312500	29.58
A-0708 ALACHUA CTY F-5 UFA	29.661940	-82.149720	71.32
A-0711 VISA #1	29.688610	-82.484440	39.78
A-0712 ALACHUA CO VISA #2 UFA	29.674440	-82.414720	43.39
A-0713 ALACHUA CO VISA #3 UFA	29.669720	-82.434440	43.41
A-0725 UFA LK LOCHLOOSA CR 325	29.477220	-82.126940	53.08
Alexander Springs Creek 4" UFA, OcalaNF FSR552B boat ramp	29.045560	-81.507220	13.51
B-0001 SANTA FE SWAMP (SRWMD) 4" UFA	29.821840	-82.079710	71.65
B-0007 LOUIS HILL FIRETWR (JOHN FOLKS-DOF) 4"UFA	30.106990	-82.049970	50.60
B-0010 RAIFORD-18 UFA 2102	30.005560	-82.175000	52.96
B-0011 USGS-17 4" UFA, HIGHWAY 100 NR STARKE	29.882500	-82.082500	76.78
B-0012 GRAHAM-19 USGS UFA	29.848610	-82.218890	56.47
BA0009 USGS UFA NR TAYLOR	30.438890	-82.293060	44.14
BA0011 USGS UFA NR SANDERSON	30.259720	-82.272220	46.96

BA0015 OCEAN POND UFA (SRM #-031908001)	30.239720	-82.436390	52.86
BA0018 ONF UFA #5 (BA0025)	30.380830	-82.330280	44.70
BA0019 MANNING 6" UFA	30.172810	-82.175830	49.66
BA0054 MACCLENNY FIRETOWER UFA	30.271670	-82.185830	47.02
BA0057 EDDY FIRETOWER UFA	30.543060	-82.343060	42.75
BA0096 OLUSTEE ST MONUMENT 4" UFA	30.212780	-82.391390	47.99
BUTLER FOURMAN 4" UFA NR LAKE BUTLER	29.950280	-82.425000	47.07
C-0009 COUNTYLINE 4" UFA NR MELROSE	29.720280	-82.046110	77.53
C-0120 KEYSTONE HTS UFA	29.801940	-82.035830	75.04
C-0123 SUNGARDEN TWR OCALA 4" UFA	29.837870	-81.725950	63.79
C-0128 PENNEY FARMS TOWER 4" UFA	29.980830	-81.931390	63.96
C-0442 CHESTER MOODY 6" UFA	29.791110	-82.019170	74.08
C-0453 GOLD HEAD 6" UFA	29.820040	-81.956680	72.86
C-0495 THUNDERBOLT ELEMENTARY	30.083540	-81.723130	26.16
C-0579 JP HALL 6" UFA, BAYARD POINT	29.959170	-81.615560	27.09
C-0583 YELLOW WATER CREEK 6" UFA	30.157220	-81.937780	47.46
C-0592 TYNES ELEMENTARY	30.117700	-81.848400	43.63
C-0599 CANVASBACK RD NR MIDDLEBURG	30.094320	-81.977370	52.83
C-0607 SR 16 BLACK CREEK	29.977750	-81.863190	64.77
C-1011 SR21/CR315C 6" UFA, CAMP BLANDING	29.877220	-81.926940	70.00
C-1014 CAMP BLANDING@SR 16	29.983060	-82.010830	59.32
C-1017 CAMP BLANDING NORTH PERIMETER 6" UFA	30.055000	-82.031670	54.12
C-1026 BAYARD WELL NR WALKILL	29.872780	-81.659720	42.31
C-1056 MONITOR WELL AT WALKILL	29.940280	-81.685830	43.25
C-1063 LAKE ASBURY NR MIDDLEBURG	30.060280	-81.834170	50.13
Camp McQuarrie (4-H Club Found.) 6" UFA off SR40, OcalaNF	29.153060	-81.600560	43.48
CE 12	29.127500	-82.415830	33.74
CE 24 DRAKE RANCH	28.992500	-82.323610	36.05
CE 75	29.040830	-82.418890	49.27
Central Baptist Youth Camp 4" UFA off CR42	29.014440	-81.453330	39.57

CHURCH OF GOD OF PROPHECY	28.757780	-81.883890	63.68
DICK SURRENCY WELL	29.623060	-82.200280	74.15
DOF-BUREAU OF PROPERTY ASSISTANCE 4" UFA, STARKE	29.917220	-82.129720	55.94
DR. PHILLIPS & SONS, INC. UFA NR MASCOTTE	28.591670	-81.862500	84.76
FIRE TWR UFA CE73 AT DUNNELLON	29.051670	-82.391110	49.10
HERSHEL KYPER SOUTH OF ROMEO	29.182220	-82.442220	36.58
JEFFERSON SMURFIT CORP 4" UFA, STARKE	29.915280	-82.285000	52.80
JOHN FOLKS-DOF-LACROSSE TOWER UFA	29.858330	-82.408330	40.93
KEEN RANCH WELL ASTATULA	28.711390	-81.673890	56.95
L. Knowles 4" UFA, 30845 CR 435, Mt. Plymouth	28.799170	-81.535280	42.74
L-0040 Alexander Springs 4" UFA	29.113060	-81.572500	37.30
L-0043 LAKE YALE GROVES	28.745830	-81.772500	62.66
L-0051 SAND MINE UFA	28.378060	-81.744170	113.32
L-0052 JOHNS LK 4" UFA	28.524440	-81.679720	78.67
L-0057 EVA 6" UFA AT EVA;(DEEP)	28.379170	-81.823890	108.31
L-0062 MASCOTTE UFA NR MASCOTTE	28.534440	-81.913610	98.23
L-0066 ALEXANDER SPGS UFA NR ASTOR	29.080830	-81.578890	15.61
L-0095 GROVELAND TWR UFA	28.689440	-81.895560	77.82
L-0199 TURNPIKE	28.565280	-81.688060	70.31
L-0340 JUNIPER HUNT CLUB UFA SUPPLY	29.246670	-81.637780	1.12
L-0373 J. EICHELBURGER UFA	28.882500	-81.728330	53.36
L-0380 Austin Groves 8" UFA, Umatilla	28.917780	-81.683060	48.16
L-0390 PAUL SHOKLY UFA 858-133-01	28.974170	-81.553890	38.30
L-0407 Camp Ocala 6" UFA, Lake Sellars, OcalaNF	29.109170	-81.631110	38.97
L-0441 USFS SOUTH OF ASTOR	29.112780	-81.527780	15.89
L-0455 ASTOR 6" UFA	29.167220	-81.551670	16.42
L-0555 GREEN SWAMP TEST	28.388330	-81.911110	100.96
L-0600 WOLF SINK 6" UFA LCWA	28.790280	-81.605280	43.88
L-0620 CABBAGE HAMMOCK UFA	28.899170	-81.791110	53.10
L-0658 CITY OF MONTVERDE	28.602220	-81.675000	70.33

L-0902 PALATLAKAHA DAM PROPERTY	28.743670	-81.873200	67.44
LCFD STAT 109	28.505280	-81.765830	88.35
LOWER WEKIVA RIVER STATE PRESERVE 2" UFA #1 (NORTH) ARTESIAN	28.915000	-81.403330	25.86
LOWER WEKIVA RIVER STATE PRESERVE 4" UFA ARTESIAN	28.969440	-81.394720	18.81
M-0021 LAKE GEORGE UFA NR SALT SPRINGS	29.313610	-81.687220	14.69
M-0024 USGS UFA CE84 NR SALT SPRINGS	29.366670	-81.850000	23.66
M-0025 Gores Landing CE54 6" UFA nr Ocala	29.294440	-81.938890	43.31
M-0026 CE47 6" UFA nr Silver Springs	29.191670	-82.030560	41.19
M-0031 USGS OB WELL CE36 AT PEDRO	28.983330	-82.122220	44.53
M-0037 USGS CE37 4" UFA nr Ocala	29.138890	-82.055560	42.27
M-0038 USGS UFA CE79 NR SILVER SPRINGS	29.165260	-82.053500	40.01
M-0041 CE33 4" UFA nr Ocala	29.066670	-82.152780	42.90
M-0044 REDWATER LK UFA NR LYNNE	29.188060	-81.901390	46.06
M-0052 FORT MCCOY FIRE TOWER UFA	29.368060	-82.041390	47.28
M-0059 ROMP 120 NR COTTON PLANT	29.183060	-82.318890	41.73
M-0061 LOOKOUT TOWER BOMBING RANGE UFA	29.107780	-81.714720	45.28
M-0062 KOA UFA SR 42 W OF ALTOONA	28.991670	-81.719170	48.18
M-0321 CE31 Golden Flake UFA, Ocala	29.187500	-82.174720	41.95
M-0367 Huff UFA, McIntosh	29.439440	-82.221670	48.06
M-0410 USGS 6" UFA, SW c/o FSR88/31, OcalaNF	29.471390	-81.810000	19.57
M-0419 MARION CTY SHERIFF UFA US 301	29.273610	-82.149720	41.83
M-0441 G&M RANCH NR ORANGE SPRINGS	29.499720	-81.958610	51.30
M-0443 CITRA RANCH NR ISLAND GROVE	29.431940	-82.063060	51.30
M-0445 (prev. M-0380) TIGER DEN NR OCKLAWAHA	29.060000	-81.939170	46.91
M-0463 Ft. McCoy Elementary School 6" UFA	29.386110	-81.972780	49.17
M-0465 Belleview Elementary School 6" UFA	29.051670	-82.056390	44.38
M-0467 Lake Weir Middle School 6" UFA	28.998060	-81.983610	45.89
M-0471 FOREST RD 75 WELL	29.428610	-81.856390	20.21
MAHAFFEY UFA	29.455000	-82.340560	50.90
OBSERVATION WELL CE74 NR OCALA	29.037500	-82.256670	41.50

OLENO TOWER-JOHN FOLKS-DOF 2" UFA NR FT. WHITE	29.920280	-82.608060	31.41
PITMAN WORKCENTER UFA - USFS	29.012220	-81.641110	42.97
Ponderosa Club CE30A 2" UFA Artesian (M-0316) nr Lisk Point	29.291110	-81.651390	13.55
QW OBS WELL CE13 NR RAINBOW SPGS	29.079720	-82.419170	34.88
QW UFA CE22 NR DUNNELLON	29.053330	-82.318330	45.12
RAIFORD UFA #166	30.104170	-82.218060	50.72
RAINBOW SPG WELL NR DUNNELLON	29.087220	-82.451940	30.72
ROMP 101 UFA NR BAY LK	28.454720	-81.925280	94.93
ROSE CREEK TOWER-JOHN FOLKS-DOF 4" UFA NR LK CITY	30.103330	-82.608610	37.52
SCE 116 RAINBOW ACRES	29.131110	-82.453060	33.60
SCE 118 LAKE TROPICANA RANCHETTE	29.153610	-82.415560	35.20
SCE 158 LITTLE LAKE BONABLE WELL	29.152780	-82.530560	40.48
SJRWMD C-0003 DAVID WOOD 4" UFA NR LAKE CITY	30.039440	-82.556390	38.36
SMITH BROTHERS NR RALEIGH	29.471110	-82.395830	52.25
South Pine Lakes 4" UFA, SR 44	28.927500	-81.441390	32.59
SR 316 WEST OF FAIRFIELD	29.362780	-82.306940	46.97
SRWMD B-0003 (ONF 7A)	30.283890	-82.453890	48.53
SRWMD B-0004 (ONF 8A)	30.276390	-82.394440	47.03
SRWMD BA0005 (B-2) UFA (ONF 5A)	30.354170	-82.389440	45.83
SRWMD C-0001 (ONF 3A) 4" UFA	30.343610	-82.526390	45.72
SRWMD C-0002 CROFT UFA LULU COMM CTR 4" UFA	30.109720	-82.496670	45.91
U-0001 OLUSTEE-1 UFA 72221	30.129720	-82.382780	49.49
U-0004 LULU-1 UFA	30.016940	-82.414440	49.64
USGS UFA CE23 NR DUNNELLON	29.018330	-82.319440	39.53
V-0818 OSTEEN RANCH	28.811110	-81.199170	16.23
	28.985560	-82.119999	44.54
	28.994754	-81.835882	50.32
	28.998055	-81.983611	46.00
	29.033330	-82.723056	2.22
	29.041670	-82.690278	1.89

	29.051666	-82.055833	44.33
	29.059958	-81.939269	46.97
	29.082147	-81.884138	49.34
	29.193308	-82.032247	41.22
	29.296416	-81.940794	43.42
	29.311833	-81.685725	14.80
	29.355556	-81.580824	8.00
	29.355556	-81.580824	11.13
	29.368060	-82.041390	47.28
	29.378619	-81.526011	25.52
	29.386110	-81.972780	49.17
	29.405222	-81.552458	27.47
	29.410694	-81.736683	9.92
	29.413513	-81.618302	23.00
	29.428610	-81.856390	20.21
	29.431940	-82.063060	51.30
	29.431944	-81.513888	21.78
	29.437500	-82.457220	43.15
	29.439444	-82.221667	48.06
	29.455000	-82.340560	50.90
	29.471110	-82.395830	52.25
	29.474455	-81.569547	30.06
	29.477220	-82.126940	53.08
	29.480660	-82.541710	43.19
	29.483125	-81.632608	17.45
	29.485150	-82.161510	52.41
	29.490760	-82.255870	51.42
	29.499720	-81.958610	51.30
	29.500970	-82.424610	43.69
	29.517772	-81.965099	58.39

	29.525560	-82.520000	41.52
	29.535224	-81.587848	24.18
	29.535739	-82.102233	63.85
	29.540779	-81.830823	29.88
	29.547300	-82.489960	41.65
	29.547306	-82.489972	41.71
	29.551670	-82.513340	40.75
	29.568644	-81.652055	25.18
	29.570560	-82.189720	63.05
	29.589856	-81.575781	15.39
	29.593860	-82.648960	41.00
	29.599090	-82.075650	71.50
	29.604870	-82.084010	72.80
	29.605434	-82.606389	38.20
	29.605560	-82.605560	38.16
	29.610940	-82.816610	8.06
	29.610944	-82.816611	7.98
	29.620180	-82.414960	45.67
	29.623056	-82.200278	74.15
	29.625110	-82.564990	38.34
	29.625591	-81.796936	47.24
	29.629380	-82.432010	41.55
	29.631850	-81.691388	26.87
	29.634110	-82.390610	48.00
	29.635550	-82.363710	47.13
	29.637039	-82.617183	37.38
	29.637799	-82.689082	40.13
	29.641740	-82.440540	41.63
	29.646434	-82.615729	36.16
	29.651490	-82.393650	50.68

	29.655200	-82.323290	43.50
	29.659166	-81.574266	17.13
	29.661940	-82.149720	71.32
	29.662660	-82.562020	37.26
	29.664158	-81.694275	27.08
	29.665210	-82.524320	37.44
	29.667680	-82.458750	42.77
	29.668090	-82.313720	43.32
	29.669150	-82.360280	44.07
	29.669710	-82.436160	43.41
	29.669938	-81.882963	70.22
	29.672575	-82.706315	38.93
	29.674410	-82.602863	34.75
	29.674440	-82.414720	43.39
	29.677550	-82.243950	54.94
	29.678340	-82.256200	53.17
	29.684720	-82.287500	40.63
	29.688330	-82.494450	39.61
	29.688840	-82.483960	39.78
	29.696609	-82.532017	36.50
	29.703260	-82.277960	43.02
	29.711560	-82.354410	49.52
	29.715190	-82.243460	57.74
	29.716390	-82.404170	44.38
	29.719150	-82.006841	77.28
	29.722777	-81.822500	68.44
	29.722867	-82.515371	35.74
	29.723600	-82.258040	54.41
	29.724630	-82.746660	42.53
	29.724639	-82.746667	42.50

	29.724660	-82.272520	50.30
	29.726023	-82.731505	40.24
	29.726770	-82.252740	56.14
	29.726969	-82.684135	30.66
	29.728780	-82.313760	29.58
	29.733154	-82.580598	32.98
	29.737840	-82.285310	48.08
	29.738654	-82.674237	31.72
	29.739342	-82.652147	33.66
	29.742238	-82.615253	31.74
	29.745340	-82.526290	34.05
	29.748390	-82.315360	41.68
	29.758330	-82.388810	40.13
	29.758334	-82.388806	40.16
	29.767654	-82.532851	33.37
	29.769850	-82.013369	74.47
	29.770534	-82.697253	28.75
	29.770853	-82.569079	32.42
	29.772138	-82.615829	31.07
	29.774630	-82.302360	52.97
	29.775420	-82.101490	73.79
	29.777780	-82.112500	68.73
	29.777994	-82.739101	39.60
	29.790560	-82.169440	63.37
	29.791669	-82.018611	73.95
	29.793726	-82.624549	29.43
	29.794266	-82.744250	28.94
	29.795707	-82.839835	25.44
	29.795930	-82.547170	32.07
	29.796060	-82.310920	53.92

	29.801461	-82.599667	31.65
	29.801819	-81.807847	66.78
	29.802241	-82.035675	74.84
	29.805160	-82.369690	42.28
	29.805775	-82.674349	26.80
	29.808665	-82.740833	31.01
	29.814727	-82.711465	24.98
	29.816333	-82.709017	23.29
	29.819483	-82.687483	24.98
	29.820083	-81.956944	72.74
	29.820092	-82.722367	25.27
	29.821861	-82.735611	34.21
	29.822743	-82.653549	25.72
	29.824240	-82.598090	31.33
	29.824243	-82.598083	31.35
	29.825530	-82.648990	25.83
	29.825904	-82.653490	25.67
	29.828140	-82.544610	31.75
	29.829950	-82.683050	24.01
	29.836033	-82.700300	22.47
	29.836938	-82.675511	23.62
	29.837855	-81.725983	63.93
	29.844056	-82.709855	21.92
	29.845162	-82.650661	25.95
	29.848950	-82.218620	56.74
	29.850090	-82.585400	31.78
	29.852980	-82.608580	31.23
	29.858840	-82.685712	22.37
	29.861348	-82.644716	26.55
	29.862300	-82.578730	31.69

	29.864960	-82.740170	20.98
	29.871180	-82.386240	42.77
	29.873511	-82.745763	17.24
	29.877500	-81.926944	69.87
	29.879380	-82.658589	30.37
	29.882400	-82.082130	76.78
	29.882467	-82.612610	32.22
	29.883050	-82.532430	31.95
	29.892910	-82.803160	53.95
	29.896241	-82.766855	13.98
	29.908853	-82.691546	27.27
	29.909845	-82.720090	25.60
	29.911720	-82.860160	6.27
	29.913778	-82.760562	22.80
	29.914715	-82.702708	27.67
	29.915394	-82.641904	31.43
	29.915460	-82.284820	52.80
	29.919130	-82.663605	34.26
	29.920440	-82.608050	31.41
	29.921000	-82.433800	44.26
	29.928010	-82.424820	46.80
	29.959172	-81.615616	27.27
	29.977986	-81.863010	64.93
	29.981000	-81.931083	64.11
	29.982670	-82.755140	23.91
	29.982777	-82.010555	59.35
	30.003910	-82.171670	52.82
	30.015550	-82.748110	27.07
	30.021194	-82.928306	16.39
	30.039140	-82.556530	38.36

	30.045120	-82.721390	28.96
	30.055333	-82.031444	53.09
	30.060518	-81.834070	50.01
	30.083777	-81.722944	25.57
	30.085187	-83.075250	16.07
	30.094555	-81.977222	52.63
	30.108139	-83.044056	20.18
	30.109817	-82.496583	45.97
	30.117916	-81.848333	43.41
	30.118278	-82.671917	33.48
	30.129770	-82.383050	49.50
	30.157208	-81.937747	47.45
	30.248694	-83.238278	22.41
	30.326389	-82.585750	47.53
	30.356889	-82.799361	46.50
	30.380526	-82.606222	45.85
	30.381000	-82.330778	44.66
	30.475914	-82.908000	38.44
	30.483389	-83.080194	33.18
	30.533444	-82.942167	34.20
	30.539945	-83.171389	41.01

Sample_ID	Latitude	Longitude	May 2008 Water Surface Elevation (ft., NGVD)
+011316001	30.483388	-83.030194	37.01
+021035003	30.536666	-83.294722	49.95
+021125001	30.539945	-83.171379	45.16
+021211001	30.586506	-83.096219	38.52

+021432001	30.533444	-82.942166	42.03
+030524001	30.645194	-83.779750	48.47
+030727001	30.636722	-83.606722	68.39
-010527002	30.369722	-83.806944	47.70
-010920002	30.385037	-83.443858	82.00
-011534001	30.356888	-82.799361	50.22
-012003001	30.441000	-82.291194	47.89
-012029001	30.381000	-82.330777	48.18
-020433001	30.271424	-83.927195	27.23
-020731002	30.263411	-83.661040	60.57
-020828001	30.289212	-83.536204	84.63
-021335001	30.270305	-82.986027	37.54
-021608001	30.325833	-82.738611	51.05
-021624001	30.305876	-82.660660	50.84
-021711003	30.326388	-82.585750	50.53
-021805001	30.343538	-82.526396	49.00
-021902001	30.353305	-82.393055	49.31
-021930001	30.284638	-82.454777	51.44
-021934001	30.276444	-82.394555	50.11
-030730001	30.195925	-83.669928	36.27
-030833001	30.186986	-83.527793	84.08
-031105006	30.032027	-83.238286	27.19
-031108005	30.244722	-83.249722	23.09
-031232001	30.176070	-83.146038	24.14
-031601003	30.259583	-82.665638	50.85
-031734011	30.184416	-82.593527	49.41
-031923004	30.212833	-82.391305	50.89
-032012001	30.259972	-82.270416	50.06
-040407001	30.146835	-83.969019	0.26
-040504002	30.170555	-83.823333	15.96

-040736005	30.094161	-83.571847	30.46
-041112005	30.151208	-83.169516	25.41
-041223004	30.126102	-83.085268	23.85
-041329001	30.108138	-83.044055	21.75
-041625001	30.118277	-82.671916	31.44
-041705001	30.175155	-82.636161	43.96
-041827002	30.109817	-82.496586	47.34
-041923001	30.129777	-82.383055	52.18
-050615002	30.040958	-83.717446	7.74
-050701001	30.079711	-83.571886	29.86
-051208001	30.068223	-83.137972	29.04
-051311001	30.065111	-82.978388	19.33
-051331003	29.999252	-83.057599	35.34
-051335005	30.013396	-82.983354	14.53
-051428004	30.021194	-82.928305	19.47
-051621002	30.045121	-82.721395	27.48
-051819001	30.039146	-82.556530	38.30
-061301007	29.996453	-82.966233	11.38
-061527009	29.933333	-82.793888	8.66
-061629001	29.938873	-82.736132	19.69
-061734001	29.920444	-82.608055	31.89
-061920001	29.950180	-82.425194	47.97
-071401003	29.911388	-82.860277	7.96
-071528001	29.849067	-82.808427	64.10
-071628001	29.848611	-82.715277	21.14
-071635003	29.828611	-82.682777	24.35
-071702003	29.914166	-82.580000	33.58
-071728005	29.852777	-82.608611	31.57
-071927008	29.858166	-82.408250	40.58
-072104008	29.918611	-82.202222	30.77

-072215001	29.882404	-82.082137	77.96
-081132001	29.741199	-83.241199	34.22
-081313005	29.782127	-82.968971	17.53
-081409010	29.791111	-82.924444	6.49
-081806005	29.828141	-82.544613	31.89
-091420001	29.692948	-82.925318	6.02
-091504001	29.732888	-82.819333	77.49
-091607001	29.724638	-82.746666	42.14
-101210001	29.624948	-83.104748	30.38
-101312009	29.624444	-82.973888	3.28
-101429001	29.587500	-82.935555	2.65
-101506003	29.642297	-82.854716	6.78
-101516017	29.610944	-82.816611	8.48
-101601002	29.641145	-82.663830	34.61
-101634001	29.570232	-82.697062	59.35
-101812013	29.636944	-82.469722	39.73
-111326002	29.489166	-82.976944	1.94
-111326004	29.488660	-82.975238	2.07
-111326007	29.488611	-82.981111	2.28
-111811001	29.547305	-82.489961	41.51
-121330002	29.413265	-83.043989	5.18
-121332005	29.398333	-83.022500	2.20
-121420001	29.418333	-82.934166	2.68
-121508005	29.448870	-82.832357	18.04
-131433001	29.302407	-82.915624	17.84
-131617001	29.351655	-82.738734	25.08
-131732001	29.307785	-82.623960	44.37
-141305001	29.296555	-83.032472	2.52
-141707004	29.281011	-82.655578	24.10
-151317001	29.181305	-83.021472	2.87

A-0002 CITY OF HIGH SPRINGS UFA	29.824440	-82.598060	31.69
A-0053 CELLON 2" UFA NR LACROSSE	29.810830	-82.385280	40.58
A-0056 GRU-DEERHAVEN UFA NR GAINESVILLE	29.758330	-82.388890	39.19
A-0068 USGS UFA CE-1A NR NEWBERRY	29.605560	-82.605560	37.74
A-0071 HAWTHORNE TOWER UFA	29.599090	-82.075650	72.75
A-0420 LYBASS AT PHIFER	29.570560	-82.189720	65.06
A-0693 ALACHUA CO FAIRGROUNDS UFA	29.684720	-82.287500	42.55
A-0725 UFA LK LOCHLOOSA CR 325	29.477220	-82.126940	54.11
Alcorn	29.667680	-82.458750	43.00
Alexander	29.820092	-82.722367	25.04
Alford	29.919130	-82.663605	34.61
Asbell	29.480660	-82.541710	43.49
B-0001 SANTA FE SWAMP (SRWMD) 4" UFA	29.821840	-82.079710	72.78
B-0007 LOUIS HILL FIRETWR (JOHN FOLKS-DOF) 4"UFA	30.106990	-82.049970	53.86
B-0010 RAIFORD-18 UFA 2102	30.005560	-82.175000	55.35
B-0012 GRAHAM-19 USGS UFA	29.848610	-82.218890	58.51
Batey	29.525890	-82.520110	41.39
Bickmeyer	29.603690	-82.082620	73.82
Bliss	29.805160	-82.369690	41.50
Blue House	28.994754	-81.835882	50.15
Blue Springs Staff Gauge	29.829950	-82.683050	24.30
Brady	29.908853	-82.691546	27.51
Broadway	29.871180	-82.386240	42.75
Brown	29.909845	-82.720090	25.65
BULLOCK-HUBER 4" UFA NR WILLISTON	29.319440	-82.569720	42.80
Butt	29.844056	-82.709855	22.03
C-0009 COUNTYLINE 4" UFA NR MELROSE	29.720280	-82.046110	78.78
C-0120 KEYSTONE HTS UFA	29.801940	-82.035830	75.73
C-0123 SUNGARDEN TWR OCALA 4" UFA	29.837870	-81.725950	65.11
C-0128 PENNEY FARMS TOWER 4" UFA	29.980830	-81.931390	65.68

C-0442 CHESTER MOODY 6" UFA	29.791110	-82.019170	75.09
C-0453 GOLD HEAD 6" UFA	29.820040	-81.956680	74.02
C-0495 THUNDERBOLT ELEMENTARY	30.083540	-81.723130	21.56
C-0579 JP HALL 6" UFA, BAYARD POINT	29.959170	-81.615560	23.79
C-0583 YELLOW WATER CREEK 6" UFA	30.157220	-81.937780	49.97
C-0592 TYNES ELEMENTARY	30.117700	-81.848400	44.12
C-0599 CANVASBACK RD NR MIDDLEBURG	30.094320	-81.977370	54.96
C-0607 SR 16 BLACK CREEK	29.977750	-81.863190	66.45
C-1011 SR21/CR315C 6" UFA, CAMP BLANDING	29.877220	-81.926940	71.27
C-1014 CAMP BLANDING@SR 16	29.983060	-82.010830	61.24
C-1017 CAMP BLANDING NORTH PERIMETER 6" UFA	30.055000	-82.031670	56.35
C-1026 BAYARD WELL NR WALKILL	29.872780	-81.659720	39.99
C-1056 MONITOR WELL AT WALKILL	29.940280	-81.685830	43.29
C-1063 LAKE ASBURY NR MIDDLEBURG	30.060280	-81.834170	51.39
Camp Kulaqua (River Ranch Well)	29.850090	-82.585400	31.96
CB Hines	29.672575	-82.706315	38.69
CE 12	29.127500	-82.415830	34.25
CE 24 DRAKE RANCH	28.992500	-82.323610	36.59
CE 75	29.040830	-82.418890	50.51
Church of God by Faith (G-13)	29.678500	-82.256280	54.33
City of Waldo (G-34)	29.790630	-82.169460	65.00
Clark	29.722867	-82.515371	35.51
Copeland Park (G-5)	29.677690	-82.243970	56.15
Crapo (Hetzel)	29.490760	-82.255870	52.25
DEP-SAN FELASCO HAMMOCK UFA	29.735280	-82.441100	48.50
DEVILS DEN SINK CE-08 NR WILLISTON	29.408330	-82.475000	43.58
DICK SURRENCY WELL	29.623060	-82.200280	74.26
DIXIE LIME 4" UFA, LEBANON STATION	29.167780	-82.641390	20.92
DOF-BUREAU OF PROPERTY ASSISTANCE 4" UFA, STARKE	29.917220	-82.129720	58.14
Dollar General	29.767654	-82.532851	33.51

DOT FL-15	29.724660	-82.272520	51.48
DOT FL-28	29.703260	-82.277960	44.17
Douglas	29.913778	-82.760562	23.45
Erna Nixon Pk	28.087611	-80.655277	30.47
Fahning (Taylor)	29.485150	-82.161510	53.31
FHP Station (G-26)	29.711460	-82.354480	42.93
FIRE TWR UFA CE73 AT DUNNELLON	29.051670	-82.391110	51.32
Fleming	29.861348	-82.644716	26.67
Fruitland Wells	29.483125	-81.632608	17.24
Ft. Clinch SP	30.702993	-81.454417	-8.10
Garrett	29.669150	-82.360280	44.64
Gilchrist Co. NE Recycling Center	29.777994	-82.739101	39.65
Gilchrist NE	29.808660	-82.740830	31.23
Gilchrist SE	29.637790	-82.689080	38.75
Ginnie Springs	29.836210	-82.700280	22.25
GOETHE ROAD 2" UFA, LCR 320	29.101390	-82.623890	27.14
Gorenberg	29.629380	-82.432010	40.80
Greg and Cindy Jones	29.770853	-82.569079	32.46
Gresham	29.665210	-82.524320	37.13
Grimes (Wilkes)	29.726770	-82.252740	57.62
Hall-Manship	29.879380	-82.658589	30.61
HERSHEL KYPER SOUTH OF ROMEO	29.182220	-82.442220	37.15
High Springs Sprayfield	29.793720	-82.624540	29.47
Hines	29.662660	-82.562020	36.87
Hodge	29.726969	-82.684135	30.71
Hodson	29.858840	-82.685712	23.37
Hogle	29.688650	-82.490410	39.24
Holliman	29.595870	-82.427570	43.01
Hornsby Springs	29.850140	-82.593150	32.16
JEFFERSON SMURFIT CORP 4" UFA, STARKE	29.915280	-82.285000	54.65

JIFFY (141620) CITY OF GULF HAMMOCK 4" UFA	29.252220	-82.724720	9.46
Joan Pocklington	29.883050	-82.532430	32.08
Jones	29.593860	-82.648960	40.57
Julie Pocklington	29.733154	-82.580598	32.99
July	29.915394	-82.641904	31.87
Karst Environmental	29.814727	-82.711465	25.19
Lander	29.801461	-82.599667	31.85
LeClaire	29.795707	-82.839835	25.73
Lk Adair	28.559671	-81.393021	41.33
Lk Geneva Wells	29.769850	-82.013369	75.68
Lk Grandin Wells	29.669938	-81.882963	70.56
Lk Norris Wells	28.922719	-81.569926	41.33
Lochloosa Well	29.535739	-82.102233	64.85
Loncala North	29.805770	-82.674340	26.85
Loncala Office	29.772138	-82.615829	31.19
Loncala Ranch	29.739342	-82.652147	33.71
Loncala South	29.738650	-82.674230	31.62
M-0013 Moss Bluff 8" UFA	29.081944	-81.884444	49.51
M-0021 LAKE GEORGE UFA NR SALT SPRINGS	29.313610	-81.687220	14.39
M-0024 USGS UFA CE84 NR SALT SPRINGS	29.366670	-81.850000	24.48
M-0025 Gores Landing CE54 6" UFA nr Ocala	29.294444	-81.938889	43.47
M-0026 CE47 6" UFA nr Silver Springs	29.191667	-82.030556	40.88
M-0031 USGS OB WELL CE36 AT PEDRO	28.983330	-82.122220	44.78
M-0037 USGS CE37 4" UFA nr Ocala	29.138889	-82.055556	42.12
M-0038 USGS UFA CE79 NR SILVER SPRINGS	29.165260	-82.053500	39.78
M-0041 CE33 4" UFA nr Ocala	29.066667	-82.152778	43.26
M-0044 REDWATER LK UFA NR LYNNE	29.188060	-81.901390	46.60
M-0052 FORT MCCOY FIRE TOWER UFA	29.368060	-82.041390	47.76
M-0059 ROMP 120 NR COTTON PLANT	29.183060	-82.318890	42.23
M-0061 LOOKOUT TOWER BOMBING RANGE UFA	29.107780	-81.714720	44.62

M-0062 KOA UFA SR 42 W OF ALTOONA	28.991670	-81.719170	47.36
M-0321 CE31 Golden Flake UFA, Ocala	29.187500	-82.174720	42.07
M-0367 Huff UFA, McIntosh	29.439444	-82.221667	48.91
M-0410 USGS 6" UFA, SW c/o FSR88/31, OcalaNF	29.471390	-81.810000	19.16
M-0413 OCALA 4" SAS	29.297500	-81.695280	16.18
M-0419 MARION CTY SHERIFF UFA US 301	29.273610	-82.149720	41.85
M-0441 G&M RANCH NR ORANGE SPRINGS	29.499720	-81.958610	51.53
M-0443 CITRA RANCH NR ISLAND GROVE	29.431940	-82.063060	52.09
M-0463 Ft. McCoy Elementary School 6" UFA	29.386110	-81.972780	48.83
M-0465 Belleview Elementary School 6" UFA	29.051670	-82.056390	44.71
M-0467 Lake Weir Middle School 6" UFA	28.998060	-81.983610	46.18
M-0471 FOREST RD 75 WELL	29.428610	-81.856390	19.88
MAHAFFEY UFA	29.455000	-82.340560	51.03
Main	29.845162	-82.650661	26.15
Majors	29.641740	-82.440540	41.13
Marvin Jones Rd	29.413513	-81.618302	21.72
Mcalhaney	29.882467	-82.612610	33.62
McDilda	29.646434	-82.615729	35.74
McGurn Investments (HRS,G-06)	29.668150	-82.313550	43.87
Mill Creek Sink	29.801030	-82.508770	33.50
Milne	29.862170	-82.578740	32.09
Murphy Is	29.568644	-81.652055	24.26
MW 1-F	29.774460	-82.302350	54.33
MW 2-F	29.748430	-82.315430	44.41
MW 3-F	29.728770	-82.313820	28.35
MW 5-F	29.661940	-82.149720	74.74
MW F-6F	29.730000	-82.339000	41.43
MW FL-13	29.723600	-82.258040	55.84
NE-2D (G-24)	29.715200	-82.243480	59.27
Newberry Cemetary	29.637039	-82.617183	36.91

Newmans	29.737920	-82.285230	49.17
Niles Rd Wells	29.405222	-81.552458	26.55
OBSERVATION WELL CE74 NR OCALA	29.037500	-82.256670	42.12
Olson	29.775390	-82.101520	74.91
P-0076 A J ROBERTS UFA	29.715280	-81.543060	15.20
P-0123 DHQ UFA	29.664170	-81.694170	23.72
P-0132 GREENWAY NR RODMAN	29.541110	-81.831390	29.31
P-0166 CAMP KATERI WELL NR ORANGE SPRINGS, FL	29.517500	-81.965280	58.42
P-0172 93913411 10S27E04 PUTNAM 29 UFA	29.659170	-81.575000	13.84
P-0246 THUNDERBIRD AIRPARK (COL SAULS)	29.473330	-81.570830	29.22
P-0270 FRUITLAND HANDYWAY 6" UFA	29.426970	-81.643140	15.28
P-0382 GEORGE MAIN FERNERY 6" UFA	29.520280	-81.617500	29.62
P-0396 Welaka Fish Hatchery 6" UFA Artesian, Fruitland	29.441110	-81.648610	10.94
P-0410 Union Camp 4" UFA #9	29.371670	-81.558610	23.26
P-0421 DRAYTON ISLAND 4" UFA ARTESIAN	29.381670	-81.639170	9.48
P-0427 UFA NR FRONTIER D H NR SALT SPRINGS	29.409720	-81.736940	12.07
P-0464 COWPEN LK UFA DRAINAGE	29.609170	-81.996110	74.34
P-0472 JOHNSONS FIELD UFA NR WELAKA	29.473330	-81.742500	6.78
P-0474 SAN MATEO TOWER UFA	29.598330	-81.573890	13.85
P-0510 HOLLISTER WORKCTR UFA	29.625830	-81.796670	46.47
P-0736 MIDDLE RD UFA	29.356670	-81.581110	6.68
P-0817 UFA NR LK BROWARD	29.535000	-81.588060	23.42
P-0822 FLORIDA ROCK GRANDIN UFA	29.711940	-81.933060	76.32
P-0891 E H MILLER SCHOOL UFA	29.631940	-81.691390	25.39
P-2037 LAKE STELLA AT CRESCENT CITY	29.435280	-81.514170	20.44
P-4083 ETONIA MANNING TRACT	29.804440	-81.806110	67.95
P-4086 ETONIA EAST V ROAD	29.722500	-81.822500	69.26
Paynes Pr Buffalo	29.565494	-82.262248	56.09
Poe Springs	29.825660	-82.648850	26.03
Poe Springs Lodge	29.825904	-82.653490	25.97

Poe Springs Production	29.822743	-82.653549	26.05
Ponderosa Club CE30A 2" UFA Artesian (M-0316) nr Lisk Point	29.291110	-81.651390	13.75
Pratt	29.770534	-82.697253	28.99
PUGH (Kerr)	29.796020	-82.547280	32.21
PW8	29.674410	-82.602860	34.34
QW OBS WELL CE13 NR RAINBOW SPGS	29.079720	-82.419170	35.16
QW UFA CE22 NR DUNNELLON	29.053330	-82.318330	46.23
R. Taylor	29.821861	-82.735611	33.94
RAIFORD UFA #166	30.104170	-82.218060	53.28
RAINBOW SPG WELL NR DUNNELLON	29.087220	-82.451940	30.68
Raulerson	29.794266	-82.744250	28.97
Rauseo	29.892910	-82.803160	51.97
Red Shirt Farms	30.481130	-81.823994	36.52
ROBINSON 4" UFA, SR 337 AND LCR 158	29.286670	-82.588330	47.24
ROMP 124 D 8" UFA NR YANKEETOWN	29.033330	-82.723060	2.48
ROMP 125 D 6" UFA, CRACKERTOWN	29.041670	-82.690280	2.82
ROMP 134 6" UFA NR WILLISTON	29.437500	-82.457220	43.17
San Mateo	29.589856	-81.575781	13.74
SCE 116 RAINBOW ACRES	29.131110	-82.453060	33.98
SCE 118 LAKE TROPICANA RANCHETTE	29.153610	-82.415560	35.74
SCE 158 LITTLE LAKE BONABLE WELL	29.152780	-82.530560	41.28
Silver Pd Wells	29.378619	-81.526011	24.59
Smith	29.836938	-82.675511	23.85
SMITH BROTHERS NR RALEIGH	29.471110	-82.395830	52.15
SR 316 WEST OF FAIRFIELD	29.362780	-82.306940	47.60
SR19 & 40	29.168846	-81.641967	35.52
Stahmer	29.651490	-82.393650	50.31
Stavely	29.726023	-82.731505	40.07
Stevenson	29.873511	-82.745763	16.89
Sulek	29.914715	-82.702708	27.70

Swan Lk Well	29.719150	-82.006841	78.56
T & J RANCH 4" UFA, SR 336	29.084170	-82.541940	68.91
TIDEWATER 12" UFA #1	29.128610	-82.570560	51.84
Tiger Den	29.059958	-81.939269	47.05
Tipton	29.552670	-82.511020	40.44
Tosohatchee Reserve	28.497951	-80.998063	31.26
TREEO Center	29.620180	-82.414960	45.78
Truluck	29.625110	-82.564990	37.93
U-0004 LULU-1 UFA	30.016940	-82.414440	51.60
United Methodist Church	29.655200	-82.323290	44.02
USGS 6" UFA, ROSEWOOD	29.237220	-82.935830	9.78
USGS UFA CE14 NR DUNNELLON	29.053330	-82.418900	36.96
USGS UFA CE23 NR DUNNELLON	29.018330	-82.319440	40.23
VISA #1	29.688840	-82.483960	39.77
VISA #2	29.674440	-82.414720	43.66
VISA #3	29.669710	-82.436160	43.73
VISA #4	29.634110	-82.390610	46.87
Waters (G-17)	29.796050	-82.310950	54.91
WEEMS 6" UFA NR BRONSON	29.386110	-82.626940	50.25
Weiss	29.896241	-82.766855	13.84
Willis	29.920910	-82.433740	44.75
WILLISTON AIRPORT 6" UFA	29.361940	-82.472780	43.09
Wood	29.696609	-82.532017	36.25
WUFT Transmission Tower (G-30)	29.709780	-82.394830	43.91
Yates	29.745340	-82.526290	34.27