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St. Johns River Water Management District
Palatka, Florida

2014

The St. Johns River Water Management District was created in 1972 by passage of the Florida Water Resources Act, which created five regional water management districts. The St. Johns District includes all or part of 18 counties in northeast and east-central Florida. Its mission is to preserve and manage the region's water resources, focusing on core missions of water supply, flood protection, water quality and natural systems protection and improvement. In its daily operations, the District conducts research, collects data, manages land, restores and protects water above and below the ground, and preserves natural areas.

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ABSTRACT

Green Cove Spring is a third-magnitude spring located on the west bank of the St. Johns River within the City of Green Cove Springs in Clay County, Florida. This spring is the northern most spring found in the St. Johns River Valley or along the Atlantic coast. Previous investigations have identified diffuse discharge in the St. Johns River, and earlier published investigations suggest the source of this spring's water is the Upper Floridan aquifer. There remains some speculation that the source of this spring's water is derived from the intermediate aquifer system based upon the dive-able depth of the spring vent and other factors. An investigation by the St. Johns River Water Management District (SJRWMD) was undertaken to determine the source of the water that discharges from this spring. Monitoring well drilling and testing did not indicate the presence of a productive intermediate aquifer system in the Green Cove Spring area. Evaluation of the lithologic and geophysical log data indicate that the top of the intermediate confining unit and the Upper Floridan aquifer have a distinct elevation change west of the spring versus east of the spring, which suggests structural deformation in those units. This deformation may have resulted in fractures in these units that have been enlarged over time by dissolution, thus providing a pathway for upward migration of Upper Floridan aquifer water. In this area, there are upward vertical head gradients that may provide recharge to permeable zones within the intermediate confining unit or surficial aquifer system. Water from this spring and six nearby monitoring wells that penetrate the Upper Floridan, intermediate, and surficial aquifers was collected for chemical analysis. Stiff and Piper tri-linear diagrams of the major chemical constituents were constructed to characterize the quality of water from each of the aquifers and spring. Strontium 87/86 ratios were used to compare the relative age date of water within the Upper Floridan aquifer and water discharge from the spring. The evaluation of current and historical water quality data collected from the spring confirms that the dominate source of discharge water from Green Cove Spring is the Upper Floridan aquifer.

INTRODUCTION

Green Cove Spring is a third-magnitude spring located on the west bank of the St. Johns River within the City of Green Cove Springs in Clay County, Florida (Figure 1). The spring water discharges from the cavern into a recreational swimming pool (Figure 2) and then discharges to the St. Johns River. The U.S. Geological Survey (USGS) measured the flow rate from the spring seven times between 1929 and 1972. The St. Johns River Water Management District (SJRWMD) measured the flow between 2000 and October 2010. Since 2010, the District continues to measure the discharge six times per year. For the period from 1929 to 2010, the mean discharge rate from the spring is 2.94 cubic feet per second (cfs) and the median discharge rate is 2.82 cfs.

Many previous investigations of Green Cove Spring indicated that water discharging from this spring originates from the Eocene Epoch Ocala limestone, which is part of the Upper Floridan aquifer (UFA). However, some of the previous investigations have suggested that permeable units within the Hawthorn Group are the source, and therefore, this spring is not connected to the UFA.

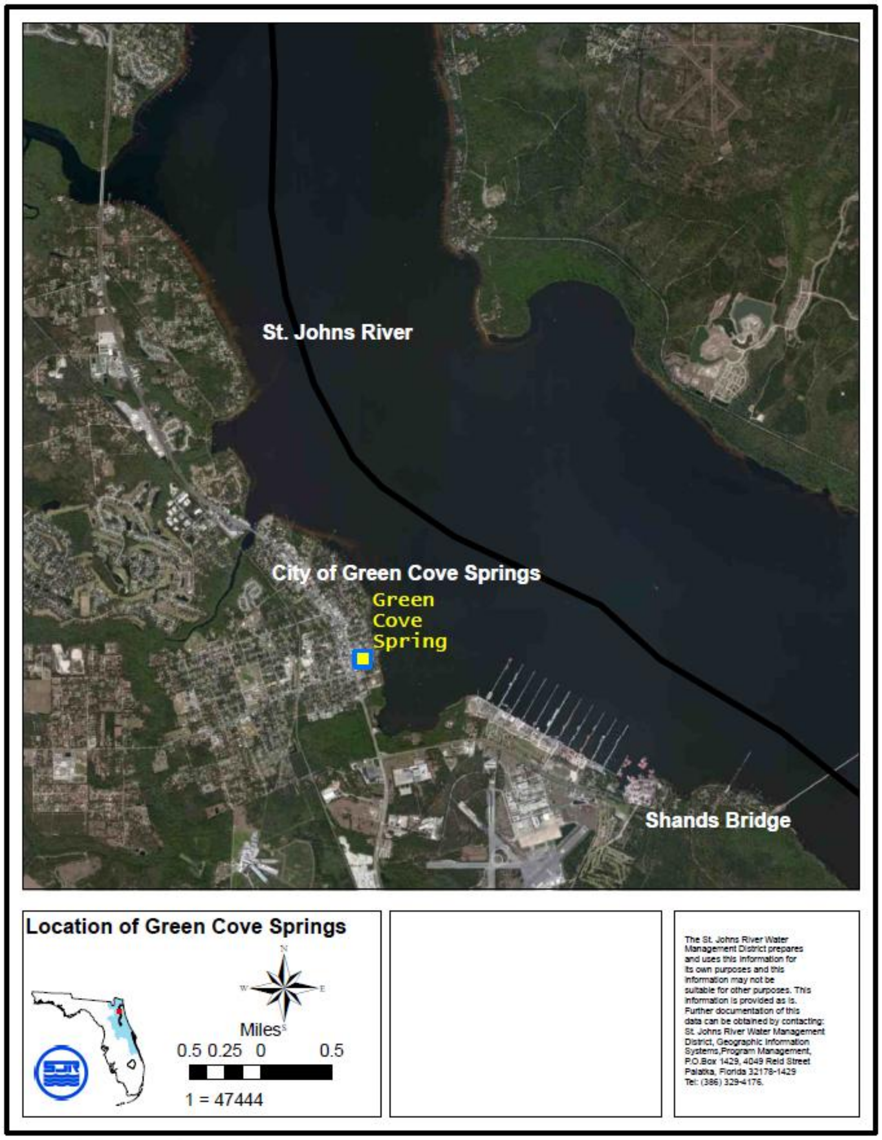

Figure 1. Location of Green Cove Spring

Figure 2. Green Cove Spring and spring run flowing to the St. Johns River

PREVIOUS INVESTIGATIONS

There have been several studies of or related to Green Cove Spring. Stringfield (1936) was originally of the opinion that this spring did not directly affect the head in the Floridan aquifer. However, Stringfield (1966) later reported that the "flow of Green Cove Spring doubtless affects the head of water in the Hawthorn in the vicinity of the spring." According to other studies, the chemical quality of the water (Ferguson et al. 1947) is similar to that from the Floridan aquifer (Black and Brown 1951). Foster (1962) reported the potential for large amounts of subsurface leakage from the Floridan aquifer (principal aquifer) to the Hawthorn Group and younger formations through wells—"Therefore, it seems likely that some of the water of the spring is from that aquifer." Additionally, he states, "the piezometric surface of the artesian water in the principal artesian aquifer in that area indicates continuous discharge from the aquifer, and the quality of the spring water is similar to that in the principal aquifer."

Fairchild (1972) reported on the shallow aquifer system in Duval County where a limestone section occurs between 112 and 140 feet (ft) below land surface (bls). Many small diameter wells in Duval and northeastern Clay counties obtain water from this portion of the shallow aquifer. Where the limestone was not present in the shallow aquifer system, water was obtained from less permeable sand and shell beds. In eastern Duval County, a coarse-grained sand unit occurs within the Hawthorn Group at a depth of 140 to 165 ft bls. Yields from these units are at least 20 gallons per minute (gpm). A cross section of the shallow and Floridan aquifer potentiometric levels in Duval County (Fairchild, 1972, p.29) illustrates that Floridan aquifer potentiometric levels are much higher than shallow aquifer water levels in the vicinity of the St. Johns River Valley. Causey and Phelps (1978) also investigated the availability of water from the shallow aquifers in Duval County. They reported the shallow rock aquifer will yield as much as 200 gpm, but most sites tested yielded between 30 and 100 gpm.

Spechler (1996) also looked at the water quality in Green Cove Spring and other springs and seeps along the northern most section of the St. Johns River. He evaluated the Strontium 87/86 (Sr87/86) isotopic ratio and concluded the spring water had been in contact with Eocene epoch carbonate rock. Through seismic reflection profiling in the St. Johns River several karst features were identified, which could account for preferential pathways for UFA source water to flow through the Miocene epoch sediments and ultimately discharge at the spring or as upward leakage within the river.

In 2006, SJRWMD performed thermal-infrared aerial surveys over the same section of the St. Johns River just south of where Green Cove Spring discharges into the river (SJRWMD, 2006). The imagery collected from that survey showed the warmer Green Cove spring water contrasting with the cooler St. Johns River water. Additionally, a similar thermal contrast observation was made in the St. Johns River at the Shands Bridge Spring just east of Green Cove Spring (Figure 3). When the temperature anomaly was ground investigated by divers on August 31, 2007, they observed clear water flowing through a wire crab trap and other debris at a depth of 28 feet below the water surface in a depression in the river (KES 2007). Spechler 1996 obtained water samples from the vent and estimated that only a small amount (1.0 cfs) of discharge was occurring and the source of water was similar in geochemical makeup as the Floridan aquifer

SDII Global Corporation (2010) suggests the discharge from Green Cove Spring is derived from the intermediate flow system based on the lack of spring discharge response to regional pumping and the physical setting (Appendix E). SDII Global Corporation (2010) also suggests "The increased sulfate concentrations coupled with the distinctive odor of hydrogen sulfide emanating from the spring strongly suggest that the water has been influenced by oxidation of sulfide minerals—a process typical of the intermediate aquifer system The enrichment in magnesium, combined with the hydrogen sulfide odor—a result of pyrite oxidation—is an excellent indicator of a flow system through the Hawthorn."

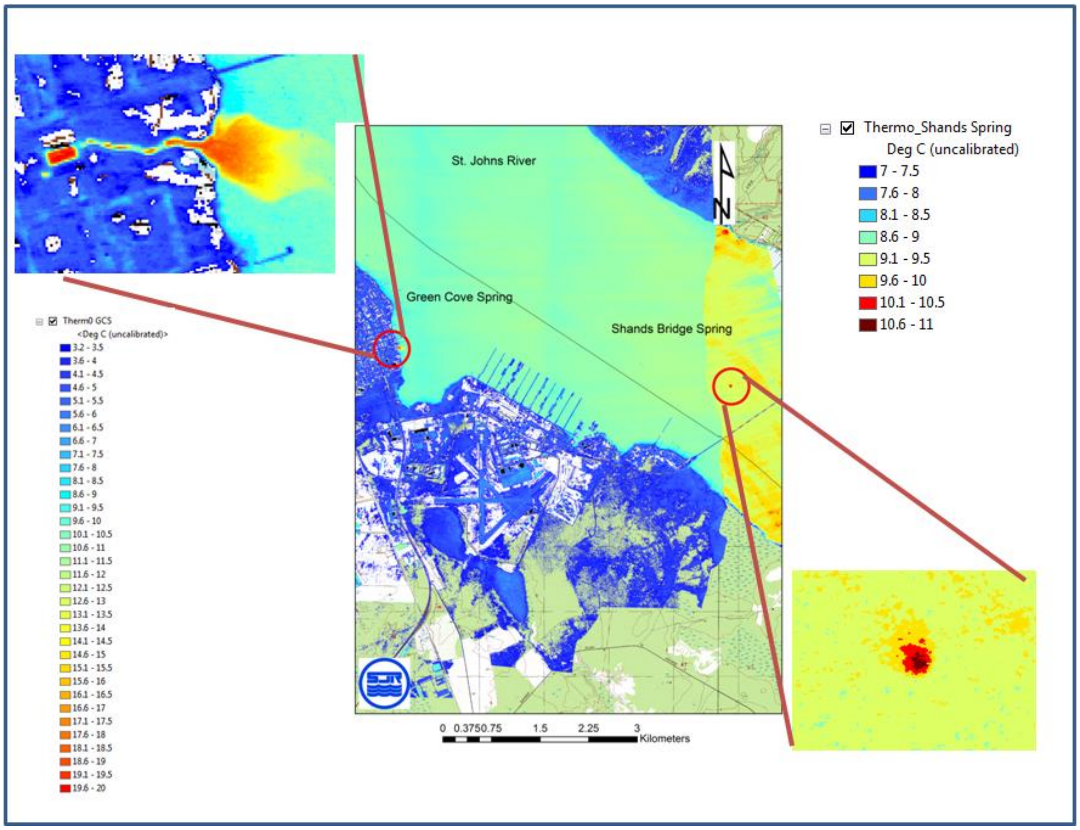

Figure 3. Thermal imagery showing Green Cove Spring and Shands Bridge Spring

METHODS

To determine the source of water discharging from Green Cove Spring, a comprehensive approach was developed. This approach was divided into several specific tasks. First, the hydrogeology of the spring and nearby area was examined by evaluating existing data and supplementing that data with new hydrogeologic data. An underwater physical survey of the spring was performed where geologic and water quality samples were collected for comparison to other published sources of geologic/lithologic data found in the area. Finally, the water quality data collected representing the various aquifers present in the area were compared to the water quality of Green Cove Spring using interpretive geochemical techniques.

Hydrogeology

Defining the hydrogeology of the spring area was accomplished by examining the existing information and the collection of new data from a test drilling, geologic sampling and geophysical logging in the area of the spring. Geophysical logs were obtained from nearby existing wells to guide the construction of the new monitoring wells. Geophysical logs such as natural gamma and various resistivity logs can be useful in identifying potential aquifers and confining units. In Florida, certain clay minerals and phosphatic material can produce high natural gamma counts per second (cps); whereas, quartz sands and clean limestone typically produce low counts. High resistivity zones often indicate a tight formation that may act as a confining unit. The quantity of phosphate in the sediments affects the magnitude of natural gamma counts. Lower sections of the Hawthorn Group sediments that contain both radioactive clays and phosphate produce very high natural gamma cps. The shape of the gamma log produced from the geophysical equipment can be considered a signature that can be correlated from one well to the next.

Four wells (C-0672, C-0673, C-0674, and C-0675) were drilled approximately 2,000 ft west of Green Cove Spring to monitor water levels and water quality in the SAS, ICU, and FAS (Figure 4). The monitoring wells for the SAS (C-0674 and C-0675) and ICU (C-0673) were completed on 21 May 2010. The FAS monitoring well (C-0672) was completed on September 6, 2012. After construction, specific capacity tests were performed on each of the four monitoring wells. Construction details for the wells are in Appendix C.

To evaluate the regional hydrogeological setting for Green Cove Spring, geophysical and lithologic well logs were used to create surface elevation grids of the major hydrostratigraphic units (Davis and Boniol 2013, GIS layers). Using these data, the relative structure and continuity of the hydrostratigraphic units, with respect to one another, can be evaluated. Cross sections prepared from this information could reveal whether a regionally persistent intermediate aquifer could be identified.

Groundwater Quality

Groundwater quality samples from the aquifers present in the area of the spring were compared to the water quality of the spring using Stiff (Stiff 1951) and Piper-trilinear (Piper 1944) diagrams of the chemical composition of each water sample source. Also, water samples were also analyzed for the Sr87/86 ratio to identifying the age of water within the Upper Floridan aquifer as compared to the water discharged from the spring.

Water samples were analyzed for major chemical constituents and isotopic composition. Strontium isotope ratio measurements are particularly important in geochronological applications. For example, variations as small as 0.00001 in 87Sr/86Sr are significant in high resolution dating of marine carbonates. (e.g. McArthur JM, Howarth RJ, Bailey TR. 2001.). The use of Sr87/86 ratio is an acceptable method for identifying the age of water in equilibrium within limestone. Comparison of the Stiff diagrams and Strontium content of water quality samples taken from the surficial, intermediate, Floridan aquifers and the spring will be used to determine the water source for the spring.

On August 24, 2010, Andreyev Engineering, Inc. sampled six wells near Green Cove Spring according to SJRWMD water sampling protocol. The wells were purged prior to sample collection. Wells C-0674, C-0675, and C-0579 were purged for three well volumes, while temperature, pH, and conductivity were measured after each well volume. Because no three of the measured variables changed by more than 10% between the second and third well volume, water samples were collected. Wells C-0673, C-0536, and RS-1 were purged for one well volume and two 3-minute intervals for temperature, pH, and conductivity. Because the temperature, pH, and conductivity did not change by more than 10% between the first and second 3-minute interval, water samples were collected. A water quality sample from the six wells and a sample from Green Cove Spring were analyzed for chemical constituents by ALS Environmental. All water quality samples were measured for calcium-total (Ca-T), magnesium-total (Mg-T), sodium-total (Na-T), potassium-total (K-T), chloride (Cl), sulfate (SO4), alkalinity, conductivity, and total dissolved solids (TDS).

On August 23, 2010, second set of water samples were collected by Karst Environmental Services, Inc. divers. The divers collected a two water samples from the deepest depth accessible by scuba divers within the Green Cove Spring vent at a depth of 98 feet bls. The water samples were brought to the surface, and the field parameters of temperature, pH, and conductivity were measured. One sample was sent to ALS Environmental Laboratory for water quality analysis. The other sample was filtered through a 0.45-micron filter into a sample bottle supplied by the University of Florida, Department of Geological Sciences, acidified to pH 2 with concentrated pure nitric acid, and delivered to the University of Florida for Sr87/86 isotope analysis.

<u>Physical Survey of Green Cove Spring</u>

During August and September 2010, divers from Karst Environmental Services, Inc., performed a subsurface survey of the spring cavern. The survey included video (Figure 7), sketches, and a plan view and cross-sectional diagrams of the cave that supplies water to the spring (Appendix A). As part of the dive a geologic sample was collected from within the cave at various depths for lithologic correlation with other available geologic data in the area.

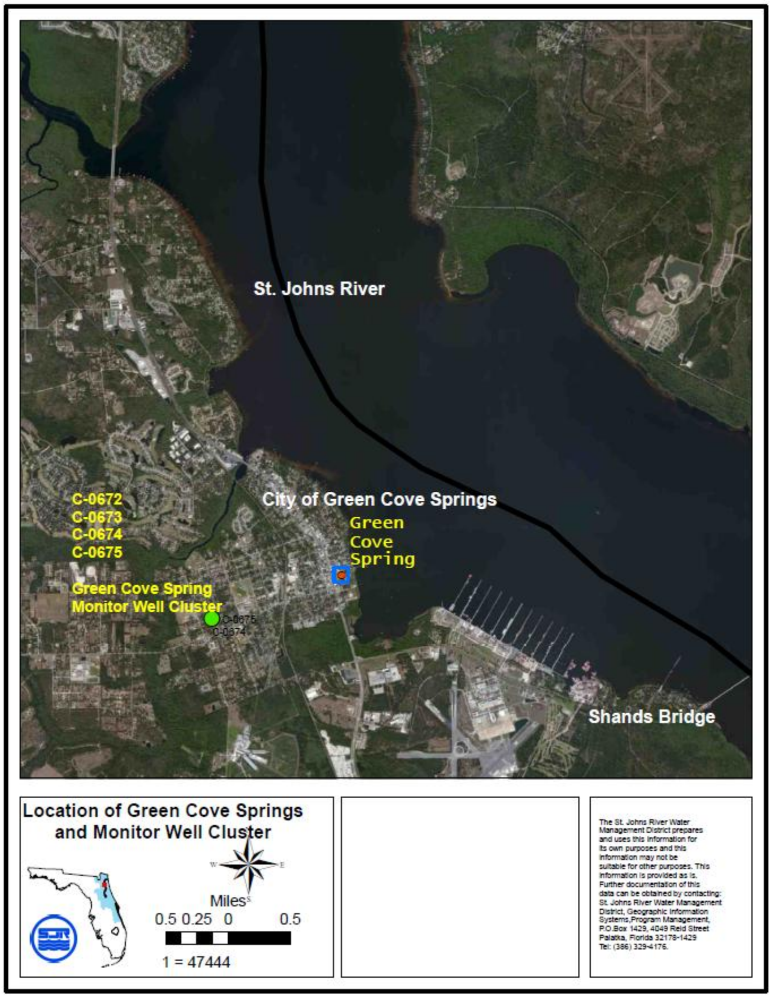

Figure 4. Location of the monitoring wells

RESULTS

Hydrogeology

Test and Monitoring Well Data

Geophysical logs and lithologic information obtained during test drilling are often used to identify a suitable water-bearing zone for purpose monitor well construction design. At the location where wells C-0673, 0674 and 0675 were constructed an initial test hole was drilled. Geologic samples were collected from 144 ft to total depth of 295 ft bls and examined to identify a zone for monitoring water levels in the ICU. The test hole was also geophysically logged. While the lower gamma counts recorded from 190 to 250 ft bls would have been indication of a good candidate for a monitoring zone, in this case, there was a high percentage of grain size fines with no indication of water production during drilling. Wet and unconsolidated material typically characteristic of sufficient permeability to produce water was not encountered. Additionally, the split spoon samples collected were relatively dry and stiff. In the field, the zone from 285 to 295 ft bls seemed sufficiently permeable based on induration, porosity, and sand percentage to be the best candidate for monitoring. During well monitor well construction phase of drilling, none of the intervals encountered required the addition of water to the borehole as would be expected if a water-producing zone was encountered. During test pumping of the finished well this zone yielded only 4 gpm.

Permeability tests were run on selected samples from well C-0673 using the ASTM D-5084 method A (Table 1). These data were not available when selecting a zone in the ICU to monitor; however, the permeability measured for the intermediate aquifer monitoring zone was orders of magnitude greater than the other intervals that were measured. The lithologic characteristics and measured permeability from the cores suggest that the SAS and ICU are not composed of material capable of storing and transmitting enough water to supply the spring.

Table 1. Permeability tests from well C-0673 using the ASTM D-5084 method A

Well	Depth Interval (feet bls)	Lithology	Permeability (cm/s)
C-0673	42–44	Clay	5.4E-08
C-0673	292–293	Dolostone	3.3E-04
C-0673	309–310	Dolostone	3.7E-09
C-0673	327–328	Sand	9.3E-07

After construction, specific capacity tests were performed on each of the four monitoring wells. The upper SAS well, C-0674, was pumped at 0.5 gpm, and no specific capacity was determined because the pumping rate could not be sustained without the water level declining below the pump intake. The lower SAS well, C-0675, was pumped at a rate of 21 gpm, which resulted in a specific capacity of 2.75 gpm/ft. The ICU well, C-0673, was pumped at a rate of 4 gpm, which resulted in a specific capacity of 0.039 gpm/ft. The rate of pumping rate was also limited in this zone due to the pump cavitating. The UFA well, C-0672, was pumped at a rate of 73 gpm, which resulted in a specific capacity of 6.3 gpm/ft. Additionally, slug tests were performed on wells C-0674 (upper SAS), C-0675 (lower SAS), and C-0673 (ICU) after construction (Table 2). The hydraulic conductivity obtained for the intermediate well was the lowest of all tests indicative of the inability of this unit to produce a significant quantity of water as also observed in the specific capacity test.

Table 2. Results of Slug Test Analysis

Well	Top of Interval tested (feet bls)	Bottom of Interval tested (feet bls)	Transmissivity T* (gpm/ft)	Hydraulic Conductivity K† (ft/day)	Method	Duration (hrs)
C-0674 (upper SAS)	16	26	168	2.24	Bouwer-Rice	0.33
C-0675 (lower SAS)	90	105	1710	15.23	Hvorslev	0.22
C-0673 (ICU)	285	295	66.6	0.89	Bouwer-Rice	0.62

Hydrogeologic Data Evaluation

Hydrostratigraphic units refer to laterally extensive mappable units of similar and connected hydrogeologic properties. The aquifers present in the Green Cove Spring area from top to bottom are the surficial aquifer system (SAS), the intermediate confining unit (ICU) and/or the intermediate aquifer system (IAS), and the Floridan aquifer system (FAS). This paper follows the conventions proposed by the Florida Department of Environmental Protection (Copeland et al., 2010, draft). When the unit is functioning primarily as a confining unit, it is referred to as the ICU. If there is a single aquifer within the unit, it is referred to as an IAS. Where the unit is acting as a system of aquifers and confining units, it is referred to as the ICU/IAS. Locally, the ICU may be composed of lenses of material (course grained sands, cemented shell or limestone) that can store and transmit sufficient water for a potable water supply source. However, the discontinuous nature of productive water bearing zones within the ICU difficult to map using geophysical logs or drill cuttings observation from water well construction drillers logs.

Two cross sections were prepared to illustrate and examine the configuration of the hydrostratigraphic units near Green Cove Spring (Figures 5 and 6). Figure 5 shows a west to east section beginning west of Penny Farms through the Green Cove Spring and continuing across the St. Johns River. Figure 6 shows a north to south cross section from the Fleming Island area to approximately 4 miles south of the city of Green Cove Springs   Each cross section includes a natural gamma log for a well that is on or close to the cross section line that passes near Green Cove Spring. The logs are colored to show the intervals likely to contain clay and phosphate in yellow-red and the sand and limestone in blue-green. Examination of the west to east cross section

(Figure 5) indicates that the SAS material (yellow) is thicker west of the spring than east and can provide more storage of surficial water. The gamma response in the SAS is higher than the FAS carbonates but significantly lower than the ICU and is shown as predominately green in the section. The SAS sediments are poorly cemented sands with grain size larger than silt and clay size. Though there is not a direct correlation between high gamma response and percent clay, the logs are a practical indicator of low permeable clay rich beds (high response) compared to the higher permeability sand or limestone units (lower response).

Split spoon samples from wells drilled for this project had reasonable correlation with the higher gamma response intervals. The gamma log response for sediments in the SAS, ICU, and FAS can be seen clearly in the sections as a grouping of similar high or low peaks. The sections indicate there are multiple beds in the ICU that could act as a barrier to flow unless the original bedding was disrupted by fractures or dissolution-enlarged features. The ICU and UFA have a distinct elevation change west of the spring versus east of the spring (Figure 5). This is suggestive of a structural deformation that has created fractures in the units that have enlarged over time by dissolution.

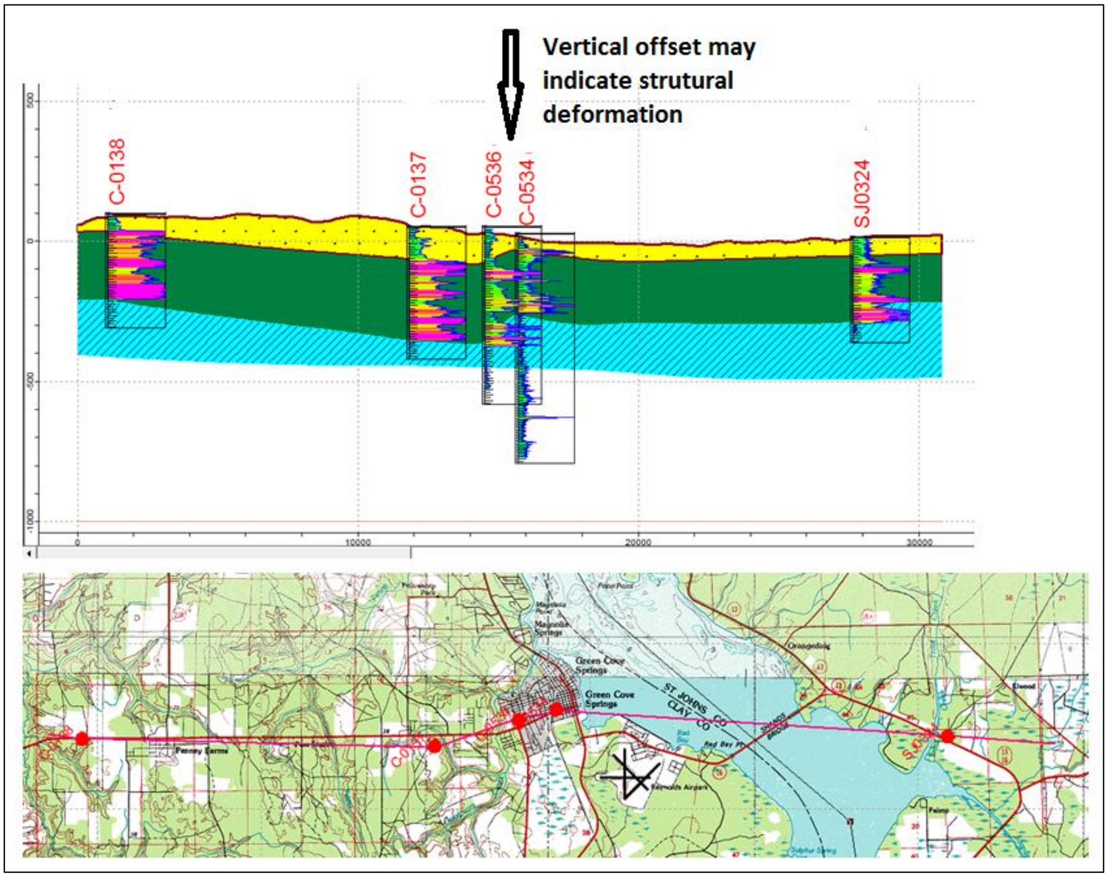

Figure 5. Hydrogeologic cross section west to east through Green Cove Springs

The north to south cross section (Figure 6) also shows a lack of structural continuity in the geologic units near the Green Cove Spring area. Based upon these two cross sections there appears to be some vertical displacement in the Hawthorn Group near Green Cove Spring (well C-0534) that could have locally fractured indurated units of the ICU allowing for pathways for FAS water to flow upward and enlarge the fracture(s) over time.

The top of the ICU (or base of the surficial aquifer) is indicated in the cross sections by the first regionally, laterally persistent high-gamma response unit. If any zones within the ICU were permeable enough to function as an aquifer capable of supplying water for Green Cove Spring discharge, its presence would be laterally and vertically extensive as traced by analysis of geophysical and lithologic logs. The laterally persistent unit of high gamma counts in the cross sections (Figures 5 and 6) indicate the top of the ICU. However, between the top of the ICU and UFA, the gamma response in the geophysical logs is highly variable vertically and along each cross section. The implications of this heterogeneity support the lack of a regionally persistent aquifer in the ICU.

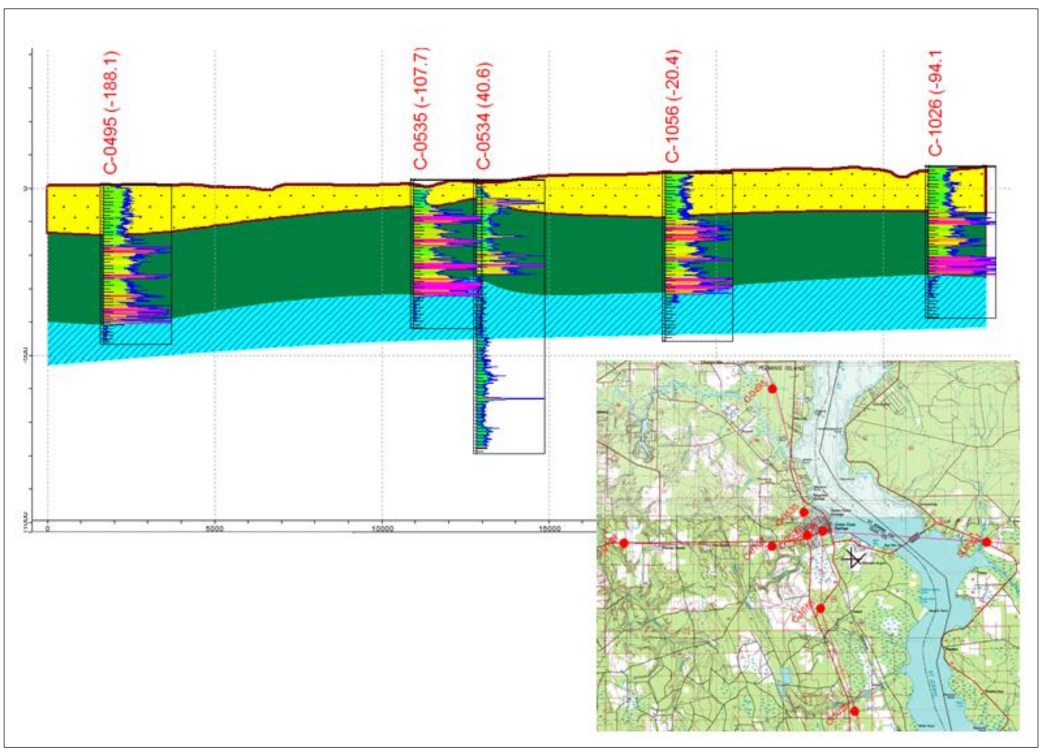

Figure 6. Hydrogeological cross section from north to south through Green Cove Spring

Green Cove Spring Subsurface Structure

During August and September 2010, divers from Karst Environmental Services, Inc., performed a subsurface survey of the spring cavern. The survey included video (Figure 7), measurements, sketches, and a plan view and cross-sectional diagrams of the cave that supplies water to the spring (Appendix A). The divers were able to reach a depth of 98 ft, where it appeared that water flowed from deeper depths within the cave system. The depth obtained during these dives was consistent with other dives done during 1987 or earlier by cave diving enthusiasts (Appendix A). At the 98-ft depth, a lithologic sample was collected and determined to be from the Miocene Hawthorn Group. The depth at which the geologic sample was taken from the spring vent and the cross section of the spring vent favorably compares to the gamma log from well C-0673 (Figure 8). By comparing the cross section and gamma log, the depth penetrated by divers was determined to be above the high gamma, low permeability zone of the ICU.

Video (Appendix B) taken during the dive provided documentation of subsurface morphology and character of the walls (Figure 7). The divers reported a single vertical fissure with only one side chamber, and did not report fractures in the walls. The smooth vertical walls and lack of obvious bedding changes were present throughout the vent. The walls were sufficiently indurated to preclude slumping or even a large amount of dissolution. This is very different from cave morphology such as that observed at Silver Springs (Munch et.al. 2007) or many Florida air-filled caves that occur due to a lack of lateral chambers. It seems quite evident that all flow has been concentrated in a narrow vertical zone. The divers reported grains that sparkled and suggested this was pyrite that can occur within the Hawthorn Group. However, the samples from the cave wall contained a large amount of quartz grains that are most likely the material reflecting light.

<u>Comparative Lithology</u>

The lithology of this area can be characterized as follows: from 0 to 31 ft is sand, from 31 to 146 ft is interbedded sand and clay, from 146 to 285 ft bls is clay, 285 to 310 ft bls is dolostone, and 310 to 330 ft bls is sand (Appendix D). Sands are medium to well indurated with grain size ranging from very fine to fine. Phosphatic clay and sand occurs at 144 ft bls and marks the top of the Hawthorn Group, which is also referred to as the ICU. This lithologic description for well C-0673 was obtained from split spoon samples taken from the depths from 0 to 251 ft bls, drill cuttings from 251 to 290 ft bls, and cores from 290 to 300 ft bls. This test hole constructed prior to conversion to a monitor well was drilled to determine if an intermediate aquifer was present and therefore well C-0673 did not penetrate the FAS.

The lithologic columnar section with the natural gamma log (appendix D) is based on descriptions from split spoon samples from well C-0673 collected at 2-ft intervals. The clean quartz sand units between 60 and 108 ft are indicated by the lowest gamma counts. The high gamma response (purple) at a depth of 144 ft bls (-96 ft NAVD88) demonstrates the effect of increased clay and phosphate content that marks the top of the Hawthorn Group. Phosphatic sand is present in all samples from a depth of 144 ft to final depth of 295ft bls. These samples have not been analyzed to determine the actual percent of clay minerals and phosphate or which minerals have the greatest effect on the gamma response. In the text description (Appendix D), the term clay is used to describe both clay mineral and clay size. The green and olive color of the sediments is typically an indication of clay minerals.

In borehole W-14476 a small percentage of phosphatic sand is reported at 73 ft below land surface; however, the Hawthorn Group is not identified until 114 ft below land surface. Borehole 2907 is similar in that small amounts of phosphatic sand are reported in the 65 to 90 ft interval. The Florida Geological Survey State Geologic

Map (Scott et al. 2001) provided a cross section through the St. Johns River. The cross section indicates that the base of the river may penetrate the upper part of the Hawthorn Group sediments, but undifferentiated Quaternary sediments are exposed at the surface. These sediments are described as being above 100 ft mean sea level and contain sediments reworked during the Pleistocene.

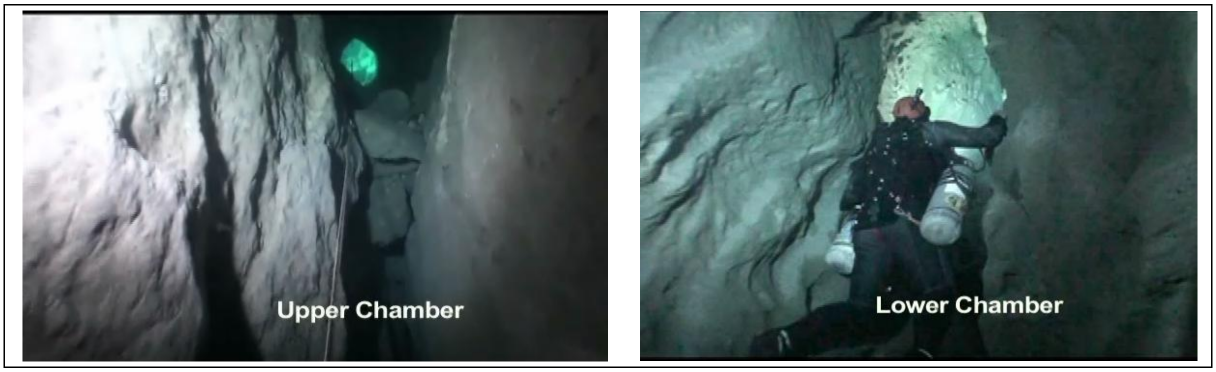

Figure 7. Screenshots from the video taken in the upper and lower chambers of Green Cove Spring (August 31, 2010)

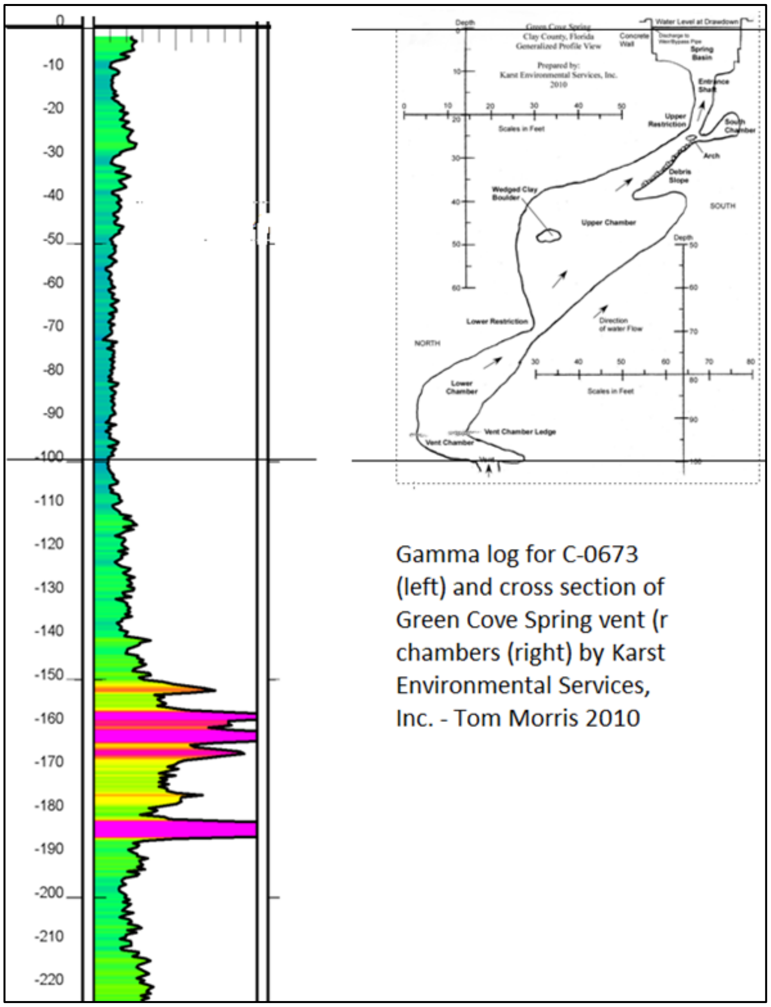

Figure 8. Comparison of well C-0673 gamma log and spring vent cross section

Samples taken from the spring wall provide insight into the depositional history of the sediments above the Hawthorn Group and explain why previous descriptions of drilling cuttings have caused variable identification for the Hawthorn Group based on the presence of phosphate pebbles. The top of the Hawthorn Group has been identified in nearby boreholes where cuttings have been described by the Florida Geological Survey. The FGS descriptions can be found at SJRWMD website *floridaswater.com* in the Hydrogeologic Information System. A review of these descriptions (Table 3) compared to recent log picks indicates a range between an elevation of -61 ft in borehole W-14476 and -170 ft NAVD88 in borehole W-2753. The lowest elevation of -170 ft seems to be anomalously deep. The photographic images shown in Figure 9 illustrate the difference between pockets of pebbles found within the walls of the spring vent and coarse-grained, sand size phosphate from a core sample within the ICU. In addition, there are clasts of limestone and shell within the pockets. Typically, phosphate grains in the Hawthorn Group were more disseminated during original deposition (Figure 9, bottom photograph) rather than concentrated in pockets. In both cases, cuttings from drilling would show phosphate grains. However, it would be difficult to distinguish if the samples collected reflect primary or reworked depositional features. The source of these grains may be related to down slope movement of upslope Miocene deposits. This reworking of the Miocene sediments would occur because of sea level transgressive and regressive events. The samples collected by divers (KES 2010) from the wall of Green Cove Spring were taken at a depth of 31 ft below pool surface. The two top photos in Figure 9 are examples of the sidewall samples. They show pockets of black phosphate pebbles suggestive of lag deposits concentrated as a result of reworked Hawthorn Group sediments. The lower photograph is a sample from well C-0673 at 290 ft showing a more typical occurrence of phosphate pebbles where grains are more evenly distributed within the matrix. The quantity of phosphate in the sediments affects the natural gamma counts as seen in the upper sections of the natural gamma logs (Appendix D) but not to the degree found in lower sections of the Hawthorn Group sediments with both radioactive clays and phosphate as seen below 144 ft.

Table 3. Differences in the elevation of the Hawthorn Group in the Green Cove Spring area

Borehole (W) or Well (C) ID	SAS Undifferentiated Sand and Clay Elevation (ft NAVD88)	ICU Hawthorn Group Elevation (ft NAVD88)	FAS Ocala Limestone Elevation (ft NAVD88)	Land Surface Elevation (ft NAVD88)	Agency -Geologist
W-14476	53	-61	-350	53	FGS*—T. Scott, B. Reik
W-2753	10	-170	-300	10	FGS—M. Shafie
W-3478	17	-88	-278	17	FGS—M. Shafie
W-10797	49	-111	-321	49	FGS—R. Hoenstine
W-522	17	-83	-393	17	FGS—B. Reik
W-2907	21	-129	-404	21	FGS—B. Reik
C-0673	48	-96	Not penetrated	48	SJRWMD†— L. Nelms
C-0536	51	-89	-373	51	SJRWMD—Gamma log—J. Davis

* FGS = Florida Geological Survey
† SJRWMD = St. Johns River Water Management District

Figure 9. Side wall samples from Green Cove Spring at a depth of 31 ft below pool elevation, and split spoon sample of ICU at 290 ft bls in well C-0673

Table 4. Location of wells sampled for water quality

Well	Location	Diameter (in.)	Casing Depth (ft bls)	Total Depth (ft bls)	Aquifer
C-0536	Green Cove Springs	10	426	605	Upper Floridan
C-0579	Bayard Point	6	320	655	Upper Floridan
C-0673	Green Cove Springs	4	285	295	Intermediate
C-0674	Green Cove Springs	4	16	26	Surficial
C-0675	Green Cove Springs	4	90	105	Surficial
RS-1	Reynolds Water Treatment Plant	6	274	657	Upper Floridan

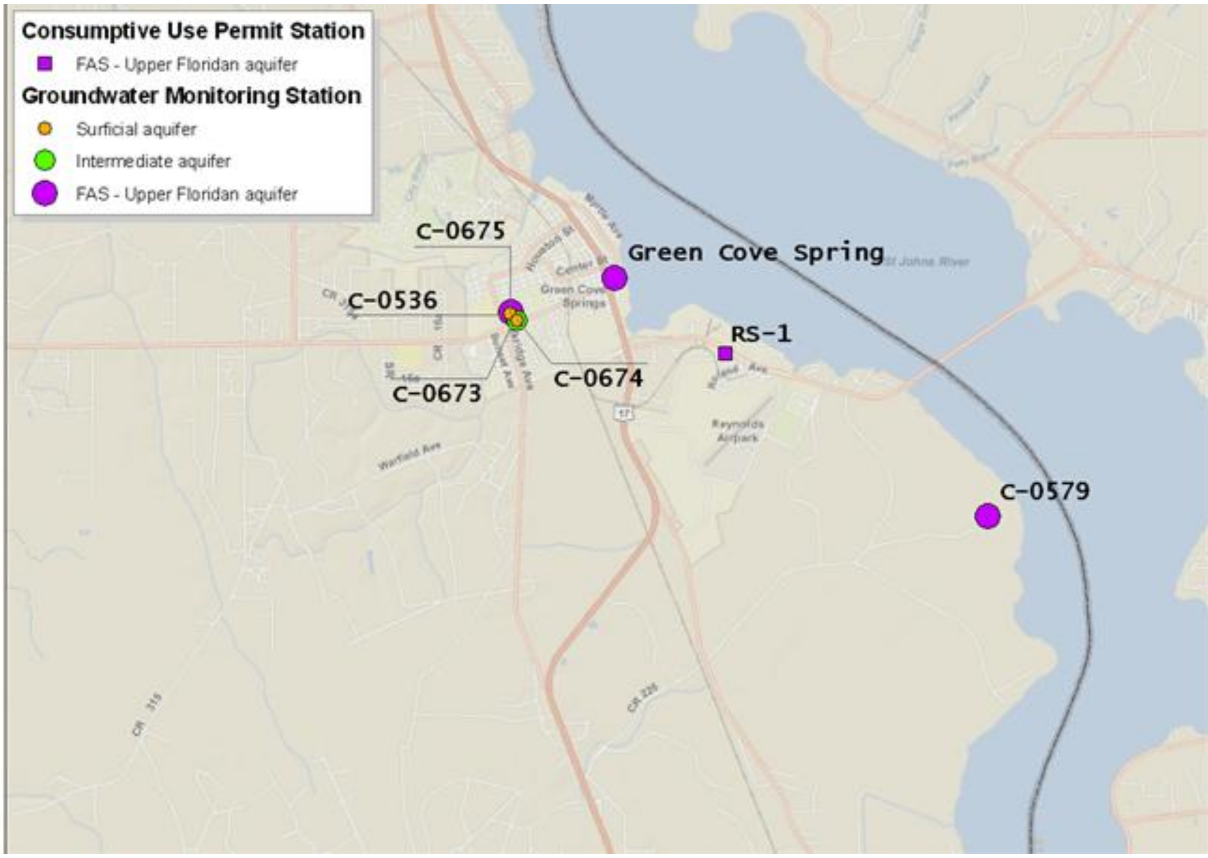

Figure 10. Consumptive use permits (CUPs) and groundwater monitoring wells sampled for water quality

Water quality

Table 5 presents the results of groundwater water quality sample analyses from the locations referenced in Table 4.

Water quality analyses results from the wells and Green Cove Spring were compared using Stiff (Stiff 1951) and Piper-trilinear (Piper 1944) diagrams of the chemical composition of each sample source. Based on the major ion constituents in the samples, the spring is most similar to UFA well RS-1 (Figures 11, 12, 13, 14). Similarities occur for sodium, potassium, chloride, bicarbonate, and pH between well RS-1 and Green Cove Spring. Calcium and magnesium are slightly higher in well RS-1 than in Green Cove Spring. The sulfate concentration is the major difference between the two. Sulfate is 104 milligrams per liter (mg/L) in well RS-1, but 52.7 mg/L in Green Cove Spring. It is likely that well RS-1 derives water from a deeper depth within the UFA; whereas, Green Cove Spring derives its water from the uppermost part of the UFA. The calcium and magnesium constituents also dominate water samples from wells C-0536 and C-0579, which are UFA wells. This is reflective of water derived from or in contact with a limestone geologic environment as also illustrated in the Stiff diagram for Green Cove Spring (Figure 11).

The water quality in the permeable ICU does not compare well with that of the spring except for alkalinity and TDS (Table 5). The potassium concentration of 22.1 mg/L measured for the sample collected on August 24, 2010, from ICU well C-0673 was high, but this may be caused by the presence of phosphate. This sample's 9.67 pH was high in comparison to other samples collected. The average potassium concentration and average pH for three samples collected on February 18, May 17, and August 31, 2011, was 7.6 mg/L of potassium and a pH of 8.67. The difference between the results for the August 24, 2010, and August 31, 2011, samplings is represented graphically in Figure 11. All other water quality variables for the sample derived from the ICU well C-0673 are different from those for Green Cove Spring. For example, sodium and potassium are much higher in ICU permeable zone well C-0673 than in Green Cove Spring (Table 5). Calcium, magnesium, and sulfate are also much lower in well C-0673 than in Green Cove Spring.

Water quality results from SAS wells C-0674 and C-0675 are also different from Green Cove Spring (Table 5). Chloride and sulfate concentrations are higher in water from well C-0674 than in Green Cove Spring. Bicarbonate is much lower in water from well C-0674 than in Green Cove Spring. Calcium, magnesium, and potassium are also lower in water from well C-0674 than in Green Cove Spring. Sodium in water from well C-0674 is about twice the concentration as that in Green Cove Spring. Sulfate in water from well C-0675 is much lower than concentrations in Green Cove Spring. Magnesium concentration is also much lower in water from well C-0675 than in water in Green Cove Spring. Calcium, sodium, and bicarbonate concentrations are higher in water from well C-0675 than in water in Green Cove Spring.

When comparing the shape of the Stiff diagrams based on the concentration of water quality constituents of the SAS, ICU permeable zone, and UFA, Green Cove Spring is most similar to that of UFA well RS-1 (Figure 10). The water collected from ICU permeable zone well C-0673 is rich in sodium and depleted in calcium, magnesium, and sulfate compared to Green Cove Spring. The water collected from SAS well C-0674 is depleted in calcium and bicarbonate compared to Green Cove Spring. The water collected from SAS well C-0675 is depleted in magnesium and sulfate relative to Green Cove Spring.

The bicarbonate ion was adjusted to electrical neutrality for the water quality analyses used to graphically represent the water chemistry for the wells and Green Cove Spring in the Piper-trilinear diagram (Figure 14). The graphical results indicate the water chemistry is different at each sampling location. Although the water chemistry at UFA well RS-1 is predominantly a calcium sulfate, it compares most similarly to the calcium-magnesium bicarbonate water chemistry at Green Cove Spring. The water chemistry of ICU permeable zone well C-0673 is a sodium bicarbonate (August 24, 2010, and August 31, 2011, samplings), which is distinctly different from the water chemistry exhibited at the UFA and SAS aquifer wells and Green Cove Spring.

Table 5. Water quality for Green Cove Spring and wells (concentrations in mg/L, alkalinity in mg/L as $CaCO_3$; conductivity in microsiemens per cm

Sample Location	Ca-T (mg/L)	Mg-T (mg/L)	Na-T (mg/L)	K-T (mg/L)	Cl (mg/L)	SO_4 (mg/L)	Alkalinity (mg/L)	HCO_3 (mg/L)	Total Dissolved Solids	pH	Temp (°C)	Field Cond	Lab Cond
C-0536/UFA	20.0	10.6	3.7	1.3	4.3		81.7	99.7	96	8.72	23.3	164	176
C-0579/UFA	63.0	46.6	7.0	3.6	8.2	251.0	79.2	96.6	495	8.00	24.6	599	638
C-0673/ICU	5.2	5.3	36.1	22.1	7.3	17.0	88.5	108.0	168	9.67	23.7	240	249
C-0674/SAS	16.5	10.7	10.1	0.9	13.7	72.2	3.6	4.4	141	4.78	24.0	200	217
C-0675/SAS	41.2	3.5	8.5	2.0	6.2	0.8	117	142.7	180	8.70	22.8	227	234
RS-1/UFA	42.9	21.6	5.6	1.7	6.8	104	80.8	98.6	262	7.97	26.6	201	383
Green Cove Spring	29.2	15.2	4.9	1.4	5.5	52.7	81.7	99.7	174	8.00	24.4	295	268

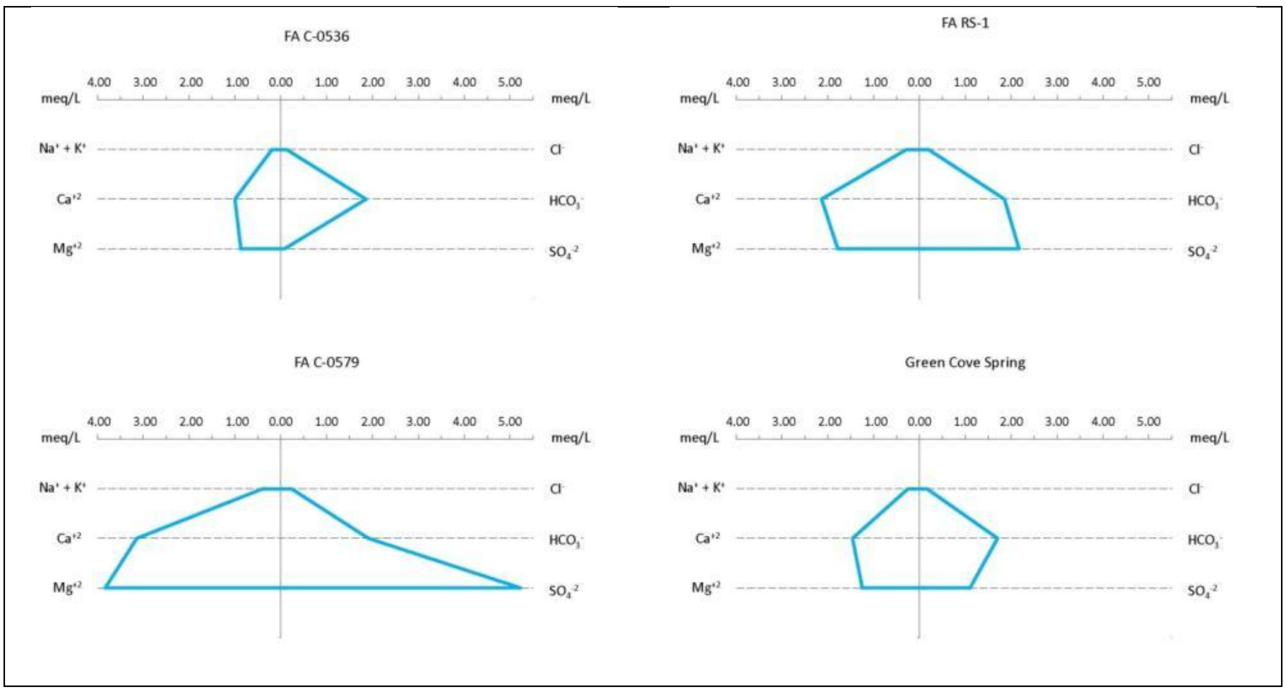

Figure 11. Stiff diagrams for Upper Floridan aquifer (UFA) monitoring wells C-0536 and C-0579, production well RS-1, and Green Cove Spring

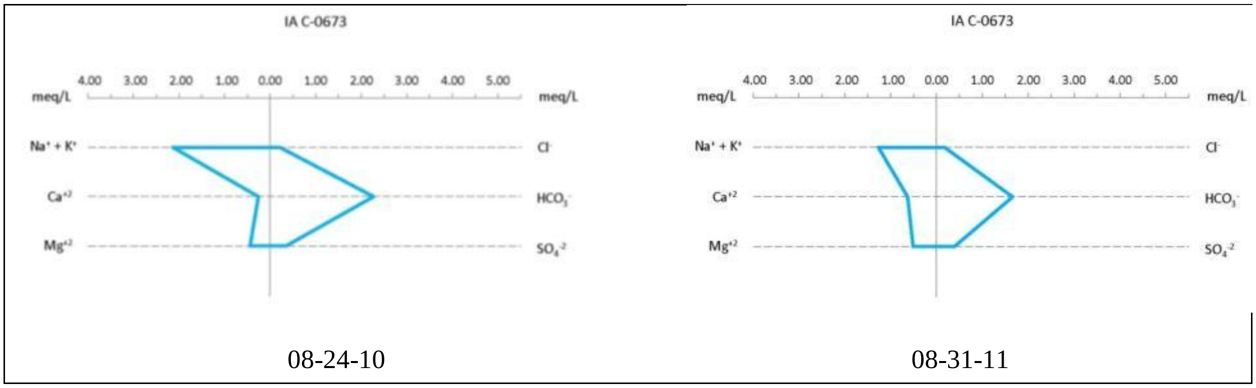

Figure 12. Stiff diagrams for Intermediate Confining Unit (ICU) permeable zone monitoring well C-0673 on August 24, 2010, and August 31, 2011

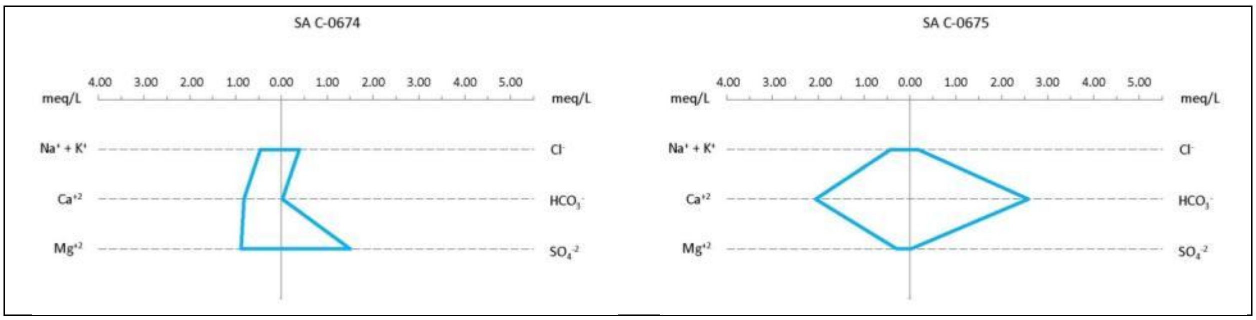

Figure 13. Stiff diagrams for Surficial Aquifer system (SAS) monitoring wells C-0674 and C-0675

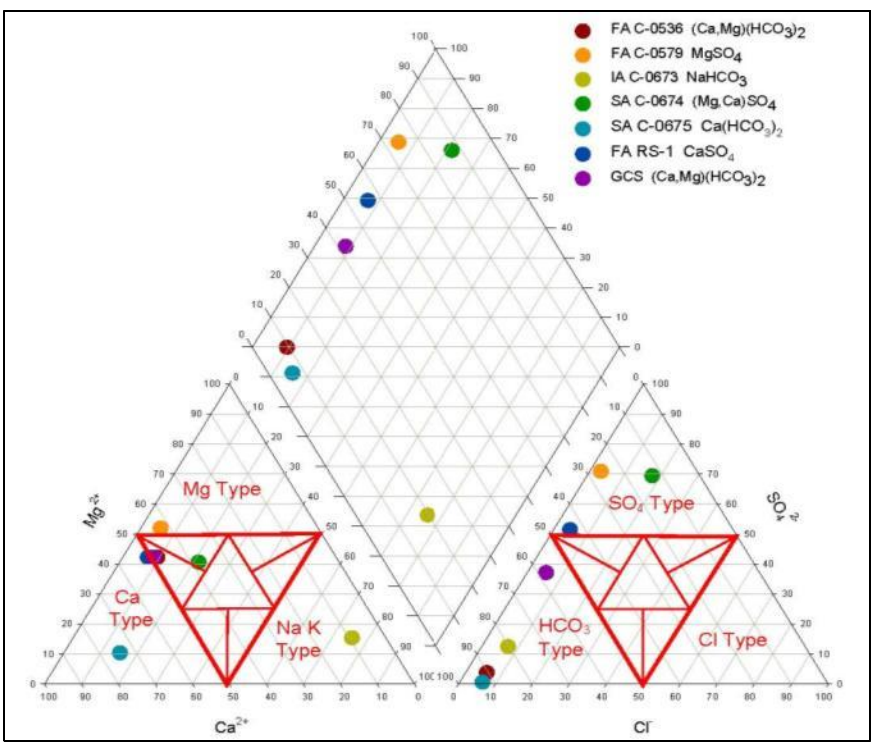

Figure 14. Piper-trilinear diagram for Floridan (UFA), intermediate (ICU), and surficial aquifer (SAS) wells and Green Cove Spring

Strontium87/86 (Sr87/86) Ratio

Strontium-87 (Sr87) is a radiogenic isotope of strontium produced by the radioactive decay of rocks rich in Rubidium-87. Sr87 is normally reported as a ratio of Sr87 to strontium-86 (Sr86)—Sr87/86. This ratio is a good hydrologic cycle tracer because strontium obtains its isotopic ratio by dissolution of or exchange with strontium-bearing minerals along a flow path of groundwater. The Sr87/86 ratio is an acceptable method of identifying the age of water is in equilibrium within limestone. During the Tertiary period, the Sr87/86 values of marine carbonates were very distinctive. The Sr87/86 value increases as the age of carbonate sediments decreases. Limestones in the FAS from the Paleocene epoch have Sr87/86 values between 0.7076 and 0.70775. Limestones from the Eocene epoch have Sr87/86 values between 0.70775 and 0.7079. Limestones from the Oligocene epoch have Sr87/86 values between 0.7079 and 0.7083, and limestones from the Miocene epoch have Sr87/86 values above 0.7083. For comparison, present-day seawater has a Sr87/86 value of 0.70925 (Kendall et al. 1995). The FAS consists of Eocene and Paleocene epoch limestones.

Analysis of the water sample taken from Green Cove Spring resulted in a Sr87/86 ratio of 0.707820 (Table 6). This value is equivalent to Eocene epoch limestone and suggests that Green Cove Spring is discharging from the UFA. Spechler (1996) and Toth (2003) reached a similar conclusion. The Sr87/86 for the intermediate aquifer derived from well C-0673 had a value of 0.708610 (Table 6). Comparing this value to the metrics of Kendall et al. (1995), the water quality is most representative of source water that is in contact with Miocene epoch Hawthorn Group sediments.

Table 6. Strontium 87/86 (Sr87/86) ratio for Green Cove Spring and six well samples (data relative to National Bureau of Standards 987 reference for Sr87/86 = 0.71024)

Well / Spring	Aquifer	Sr87/86	Error
Green Cove Spring	Upper Floridan	0.707820	0.000018
RS-1	Upper Floridan	0.707833	0.000008
C-0536	Upper Floridan	0.707883	0.000016
C-0579	Upper Floridan	0.707886	0.000010
C-0673	Intermediate	0.708610	0.000012
C-0674	Surficial	0.708089	0.000013
C-0675	Surficial	0.708741	0.000020

The Sr87/86 values in Table 6 increase as the age of the aquifer decreases except for the sample from well C-0674, which is an SAS well that is only 26 ft deep. There are two possible explanations for the anomalously low Sr87/86 values for the SAS well. The low value is likely the result of UFA water moving upward through the intermediate and then laterally into the more permeable SAS. This process would have been ongoing since the spring vent was originally formed, and as it has enlarged over time, it allowed more water to flow. The other explanation for the low value is the possibility that the water brought on site for drilling infiltrated the SAS during construction. The value of 0.708089 reported in well C-0674 is less than the range for the Miocene reported by Spechler (1996) and more likely an Oligocene epoch source.

DISCUSSION

Based on the data evaluation presented in this paper, a conceptual model of groundwater flow to the spring dominated by the UFA is presented in Figure 15. Rainfall enters the system through the sand ridges to the west of Green Cove Spring and migrates down gradient to the east toward the spring. There are discontinuous clay lenses within the ICU that may retard flow locally. The sediments that comprise the ICU may contain local lenses or pockets of water. However, there is no evidence of a regional intermediate aquifer flow system that would provide a sufficient magnitude of water supply to the spring. SAS material has a higher percentage of sand as an overall component and is more permeable than samples obtained from the ICU that tend to have higher clay content. Water chemistry at the spring is more comparable to that in the FAS. The low Sr87/86 value in well C-0674 could be explained by the mixing of UFA water as it flows through the ICU into the SAS. Lower permeable zones at the top of the ICU retard the downward leakage from the SAS allowing more SAS waters to flow toward the spring and surface water bodies at lower elevations. Mixing of UFA water with SAS water may occur since the upward gradient of the UFA would minimize surficial water from entering the vents. However, it is not clear how far away from the spring this may occur. Water levels in wells monitoring a permeable zone in the ICU (well C-0673) and UFA (well C-0672) indicate a much higher head for the UFA at the spring, which would tend to reduce mixing of ICU water with the upward flowing UFA water in the vents due to the pressure difference.

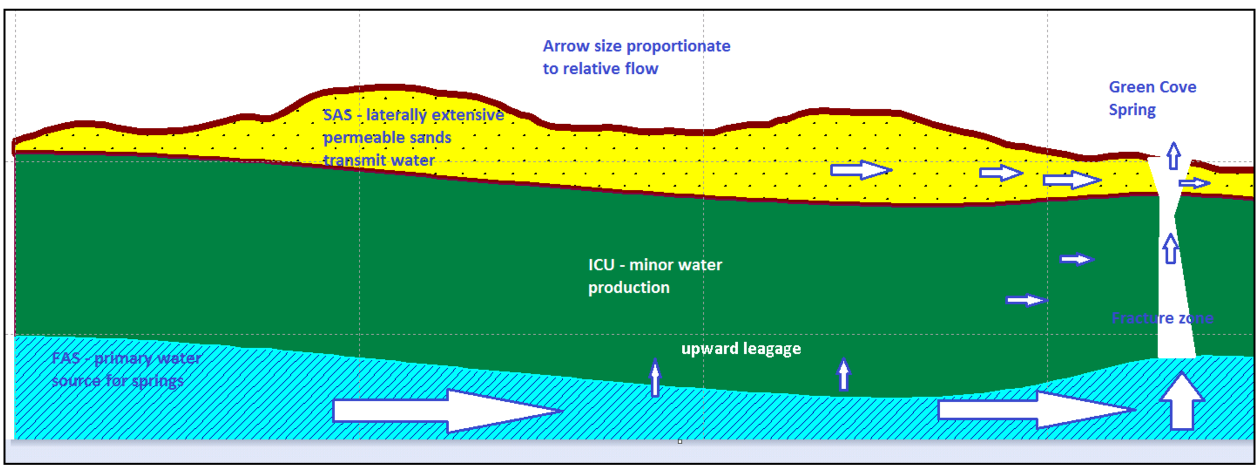

Figure 15. Conceptual model of groundwater flow system at Green Cove Spring

The presence of individual aquifers within the ICU has not been mapped in the Green Cove Spring area, and geologic data collected during monitoring well drilling does not indicate a productive IAS. Breaches in the ICU such as vertical dissolution-enlarged fractures are present at Green Cove Spring and provide a pathway for upward migration of UFA water, which may actually provide recharge to permeable zones within the ICU or SAS.

A review of nearby wells that are included on consumptive use permits (CUP) and for which well construction information is available indicates that most wells penetrate the UFA and a few withdraw only from the SAS. The ICU/IAS is used very little, if at all, for production in the area. Of the 1,428 CUP wells, only 24 are reported to use the ICU as a water source (Figure 16). This is a strong indication that the ICU functions primarily as a confining unit and is further supported by Causey and Phelps (1968), which indicates that yields from the shallow aquifers in Duval County range between 30 and 100 gpm. These yields are significantly lower than the measured discharge at Green Cove Spring.

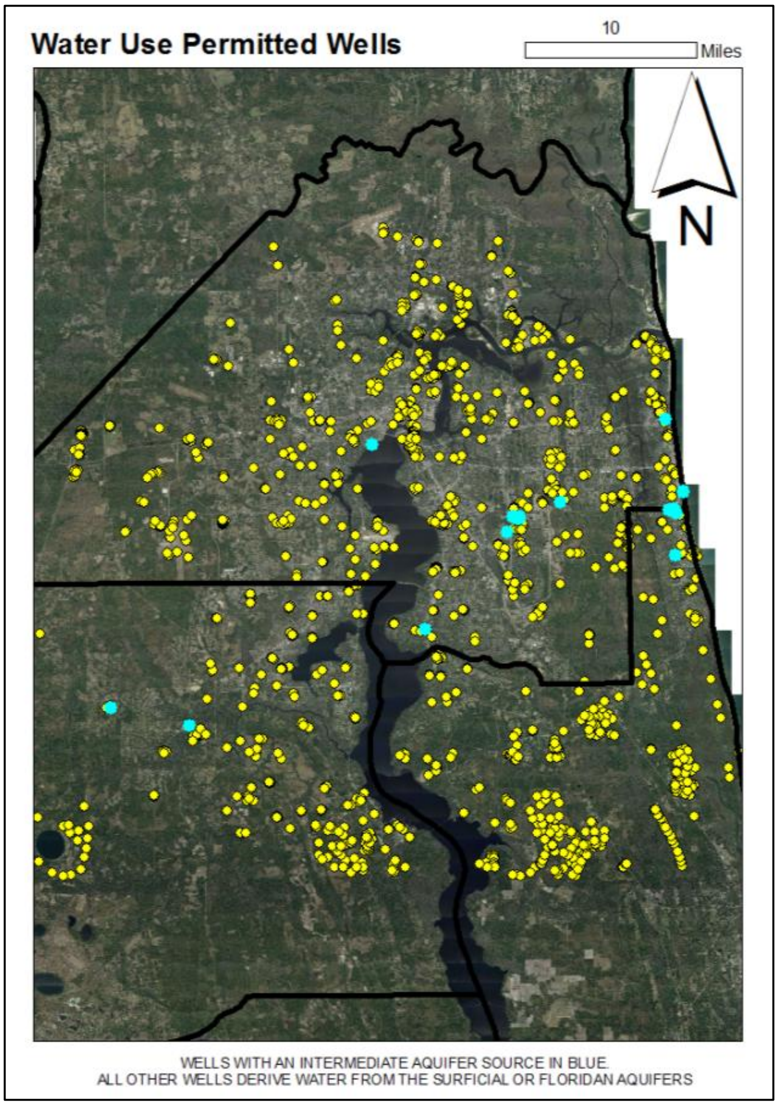

Figure 16. Wells included on consumptive use permits issued by the St. Johns River Water Management District—wells that withdraw water from an intermediate aquifer are highlighted in blue

Continuous water level measurements are only available for the SAS and ICU/IAS wells at the monitoring site nearest Green Cove Spring. However, there is a single water level measurement of 30.66 ft for UFA well C-0672 taken after final construction on September 6, 2012 (NAVD88, Appendix C, as-built diagrams). This measurement can be used to illustrate the potentiometric head relationship between aquifers. When this single water level measurement taken from UFA well C-0672 is compared to the water level records from the other monitoring wells (Figure 17), the magnitude of the head difference between zones indicates the hydraulic connection between aquifers is poor. By comparison the nearby Bayard Point UFA well (C-0579) has water level fluctuations that respond quite differently than the Green Cove Springs SAS and ICU permeable zone wells (C-O673, C-0674, C-0675). At the Green Cove monitoring well site, there is an upward gradient from the ICU permeable zone well to the lower SAS well, a downward gradient from the upper SAS to the IAS well, and an upward gradient from the UFA to the ICU and lower SAS wells.

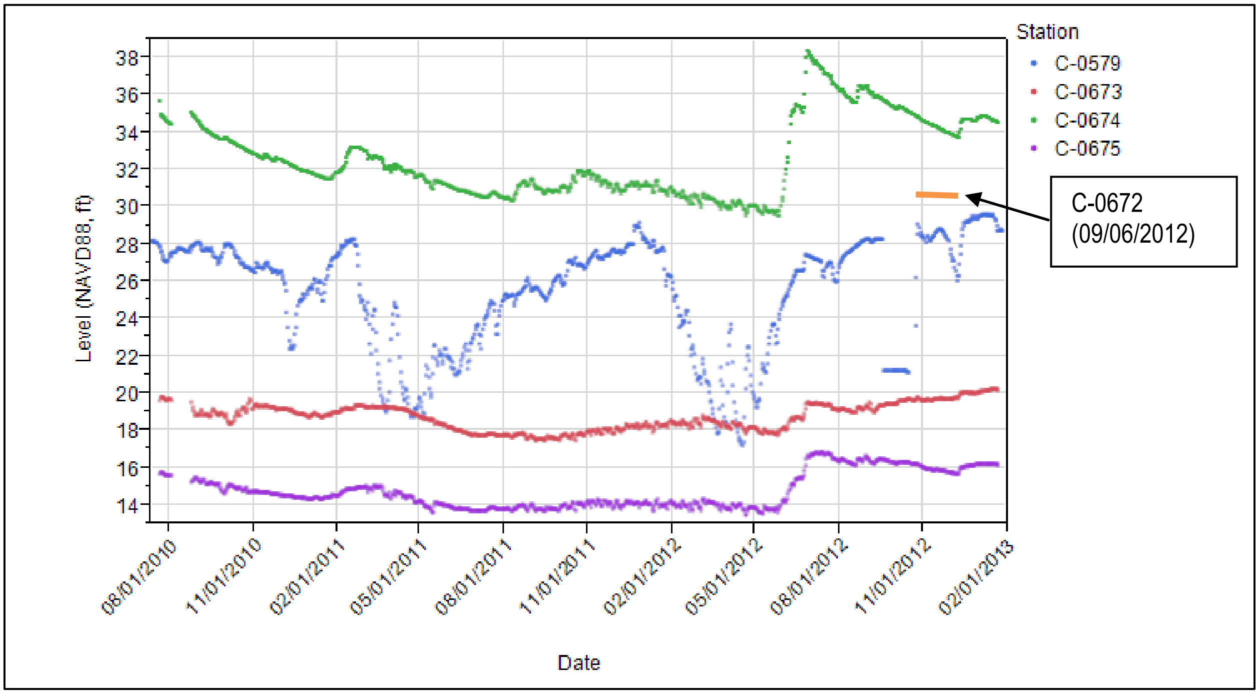

Figure 17. Hydrographs for wells with water level recorders and single measurement for recently drilled FAS monitoring well C-0672

CONCLUSIONS

Previous investigations (Spechler 1996; Toth 2003) indicate the source of water discharging from Green Cove Spring is predominately from the UFA. While SDII Global Corporation (2010) suggests the source is derived from the IAS, it is a reasonable assumption that UFA water must travel through and is in contact with the Miocene sediments before discharging from Green Cove Spring. Observations from exploratory diving also provide reasonable evidence that flow is manifested through karst features at depths similar to those observed by Spechler (1996).

Analysis of the hydrogeological data in the near vicinity of the spring provides little indication that the sediments of the ICU could provide significant quantities of water to supply the measured discharge from the spring. Permeability analysis was performed for four split spoon samples obtained from well C-0673 all indicated a low vertical permeability with values ranging from a high of 3.3E-04 to a low of 3.7E-09. Such low values are also indications of poor production zones. Specific capacity and slug tests of the completed wells likewise suggest low production from the permeable zone of the ICU and only slightly higher production from the SAS. Lithology from the nearby well cluster monitoring site indicate the sediments above 140 ft are dominated by sand with interbedded clay. Below 140 ft, an increase in clay percent decreases permeability as evidenced by the permeameter tests. This lessens the possibility that the water source for the spring is derived from a regionally extensive permeable zone within the ICU.

Although the spring vent is within the sediments above the ICU and is void of wall fissures or sidewall crevices that could be a source of water discharge. The divers could not access the cavity at the bottom of the spring vent where water was observed flowing up from the deeper zones. Cavity morphology is consistent with dissolution of an enlarged vertical fracture. The sidewall samples taken from the spring vent are sufficiently indurated enough to be brittle which could allow for fracturing to form within that unit under stress. Elevation of the top of the UFA indicates an abrupt change near the spring that suggests some form of structural deformation has occurred.

Water levels obtained from the monitoring well sites near Green Cove Spring indicate an upward hydraulic pressure gradient from the UFA to the ICU. This being the case, if the ICU sediments were sufficiently permeable, UFA water would be more likely to flow into the ICU rather than ICU water flowing into the vents. If a sufficiently large quantity of water had been flowing through sediments above the UFA over time, additional lateral conduits would be present, which is not the case.

Analysis of the groundwater and spring water quality data collected, as illustrated by Stiff diagrams, indicates similar water quality between Green Cove Spring and the UFA. The interpretation of the Sr87/86 ratio value of the water sampled from Green Cove Spring is equivalent with the Sr87/86 value of water in contact with Eocene-age limestone of the UFA. Additionally, the Sr87/86 value of the spring water is consistent with UFA water taken from observation wells in this same locality. The evaluation of current and historical water quality data collected from the spring confirms the dominate source of discharge water from Green Cove Spring is the UFA. Breaches in the ICU, likely in the form of vertical dissolution enlarged fracture(s), are present at Green Cove Spring and provide a pathway for upward migration of UFA water that provides water to recharge permeable zones within the ICU or SAS.

RECOMMENDATIONS

Additional work could be performed to add further weight to the evidence supporting the conclusions presented in this document. The following additional work is suggested:

- Perform additional drilling and testing to determine if limestone units of sufficient permeability are found in the Hawthorn Group within closer proximity to Green Cove Spring. Because such units of limestone within the Miocene sediments are not regionally persistent throughout northeast Florida, interconnected lenses of this unit may exist, but could not be identified from the work performed for this study.

- Perform a dye trace test. This could involve injecting one type of dye into UFA well C-0536 and a different type of dye into ICU well C-0673 to measure the travel time between the injection sites and the spring. It could also involve dye injection deep into the spring vent with monitoring in nearby SAS wells to assess mixing of UFA and SAS waters. This could provide additional insight into the previously described anomalous Sr87/86 ratio.
- Perform a detailed land-based seismic reflection or DC resistivity survey, which may help confirm the extent of deformation and possibly identify lateral conduits that connect to the spring vent.
- Perform age dating of the sandy sediments above 144 ft, which may confirm the upper limit of Miocene sediments and possibly provide additional insight into the Strontium isotope analysis interpretations.
- After a sufficient continuous record is available for all the wells at the monitoring site near Green Cove Spring, the water level data should be reviewed to confirm that the head relationships remain similar to information presented in this paper.

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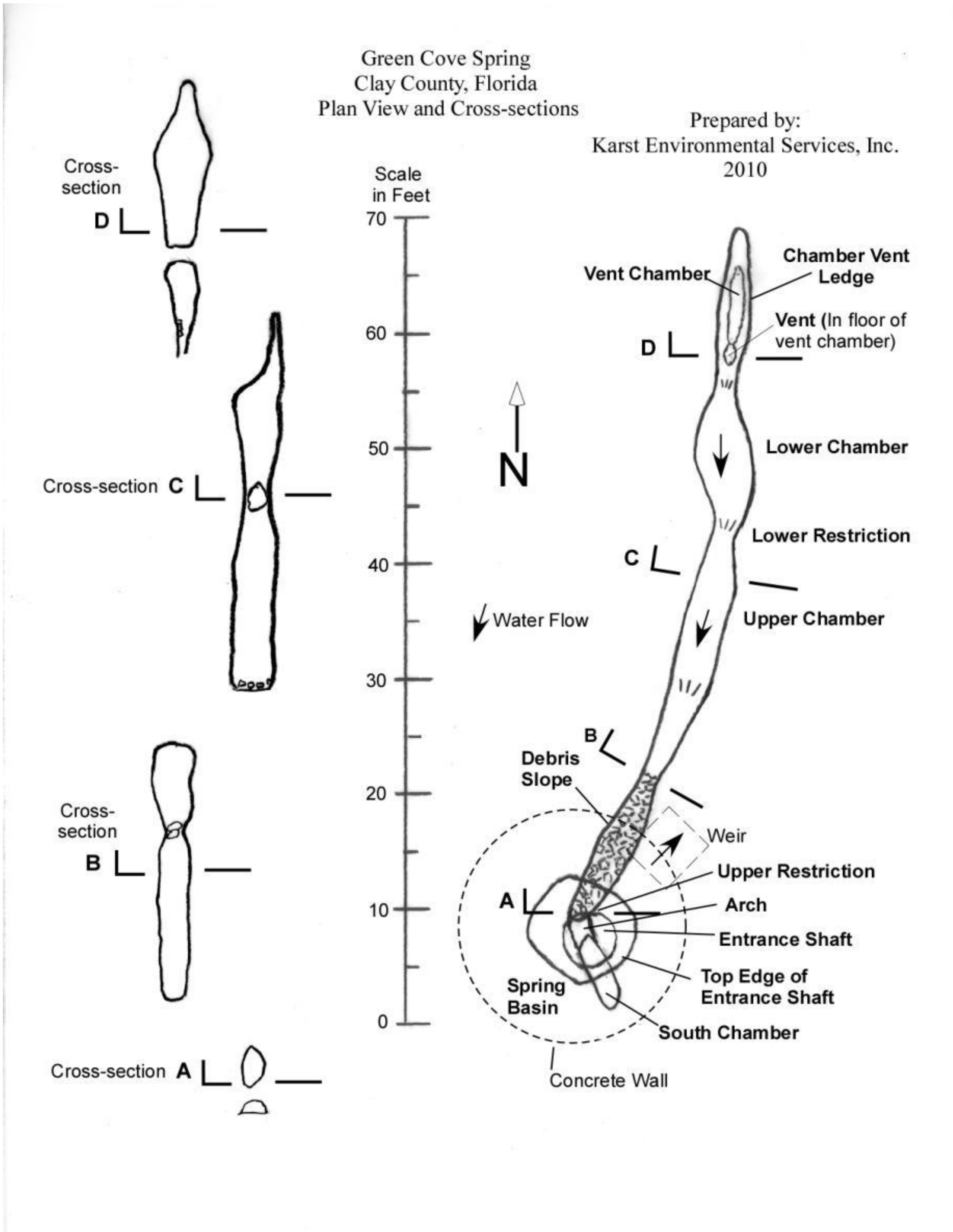
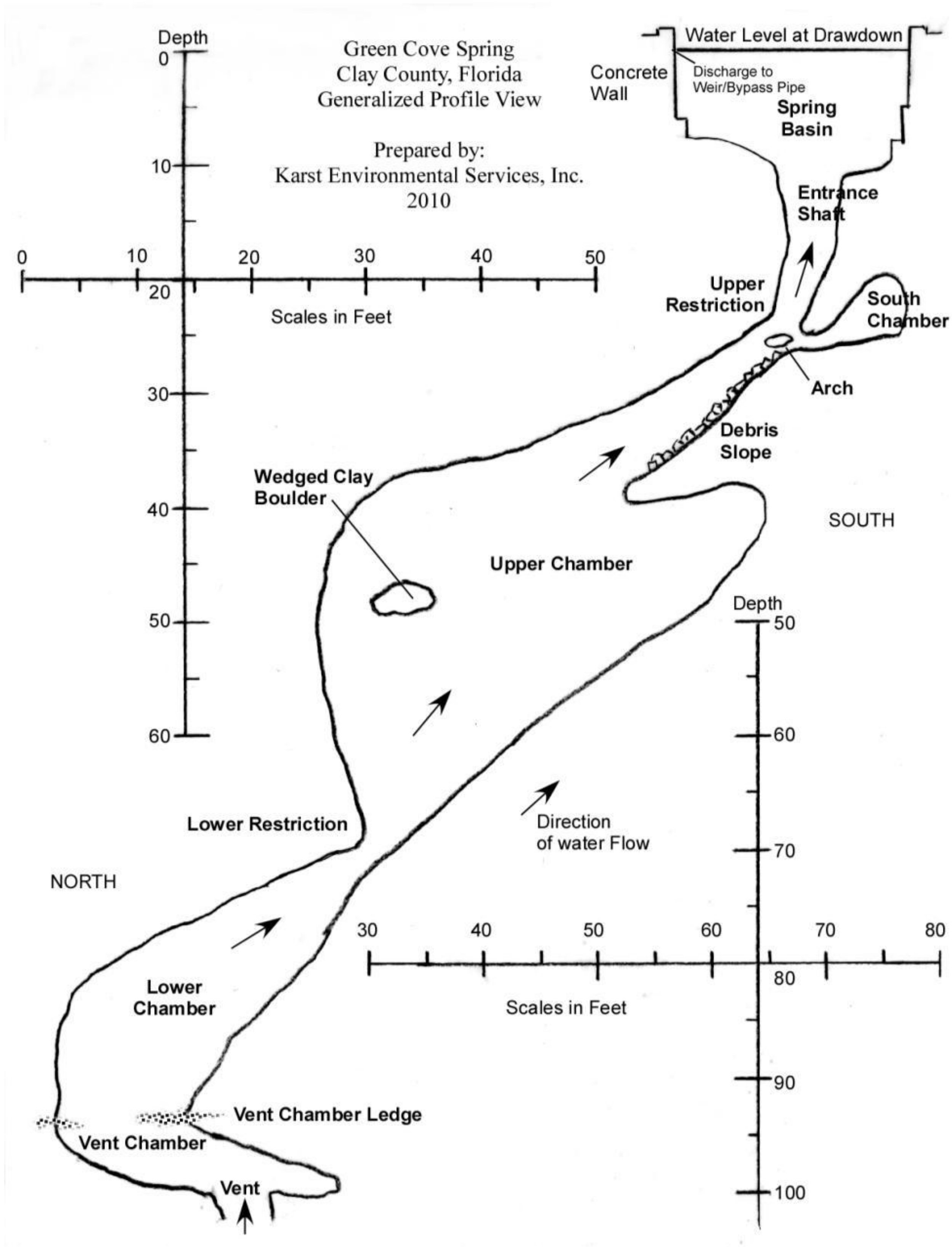
APPENDIX A

Sketches and Measurements of Green Cove Spring Vent, Karst Environmental Services, Inc.




Green Cove Spring
Clay County, Florida
Generalized Profile View
Prepared by:
Karst Environmental Services, Inc.
2010
Depth
Scales in Feet
Water Level at Drawdown
Concrete Wall
Discharge to Weir/Bypass Pipe
Spring Basin
Entrance Shaft
Upper Restriction
South Chamber
Arch
Debris Slope
Wedged Clay Boulder
Upper Chamber
SOUTH
NORTH
Lower Restriction
Direction of water Flow
Lower Chamber
Vent Chamber Ledge
Vent Chamber
Vent

Discussion of Subterranean Conditions at Green Cove Springs, Clay County, Florida

Prepared By Tom Morris, Karst Environmental Services, Inc.

The following information has been prepared by Tom Morris, based on his experiences from two dives he made into Green Cove Springs in Clay County, Florida during 1987, and the recollections of fellow divers.

During the mid-1980s members of the Green Cove Springs City Council were concerned that a large cavern with the potential for catastrophic collapse might be located beneath the City Hall building. Divers are not normally allowed in the spring, and little information existed at that time, so they asked Wes Skiles, Woody Jasper, Lamar Hires and Tom Morris to dive into the spring and assess the risk of collapse. The divers made verbal reports to the city council, but no written reports were created; the only information in print is a few newspaper articles reporting on the dive.

The following description is based on the two dives made into the spring in February of 1987. The description is taken from memory, based on discussions between Tom Morris and Wes Skiles and Woody Jasper, and represents a consensus of their recollections of those dives.

The spring discharges vertically from a funnel-shaped vent into a concrete pool about twelve feet in diameter. A shallow sluice carries the discharge to a nearby swimming pool, but the flow can be directed to bypass the pool. The sluice is covered with colorless sulfur-oxidizing bacteria and is very slippery. The water has a noticeable odor of hydrogen sulfide. Good photographs of the basin and vent can be viewed online at: *http//sjr.state.fl.us/springs/clay/green_cove.html* (Springs of the SJRWMD), and *http//underwaterflorida.homestead.com/greencovesprings.html.*

The spring entrance, a few feet below the water surface, is almost as large as the walled pool, but tapers irregularly down to a three foot diameter vertical restriction at about thirty feet deep. The water in the pool seems to always be very clear, and it is easy to make out features down to just below the restriction. The walls of the funnel shaped vent have been described in Springs of Florida, Bulletin 31 (1977) and at the SJRWMD internet site cited above as being composed of soft marl. However, the recollection of the divers is that the vent surfaces are composed of hard gray clay.

About four feet below the restriction there is a slight offset in the vertical development of the cavern, and a short horizontal passage, about six feet long by three feet wide, forms a floor. This is where objects that people have thrown into the spring, such as coins and bottles, come to rest. The floor is visible from the surface through the restriction.

From this point the recollection of the divers and the account reported in Bulletin 31 (1971) differ somewhat. Bulletin 31, pages 92-94, reports that "*the 2-ft opening then opens into a cavern 25 feet wide trending in a northeast direction toward the St. Johns River. The roof of the cave descends to a depth of 50 feet and the bottom of the cavern falls to 150 feet. Some of the flow in this cavern is toward the St. Johns River and it is possible that the spring does discharge water into the river bed*."

The divers recall that, beyond the flat section below the restriction, the cavern continues as a vertical fissure for 35 or 40 feet in an easterly direction, and is no wider than about 6 feet at its widest point. The floor of the fissure descends steeply (about 60 degrees) to a depth of about 100 feet, where the fissure narrows. Water discharges vigorously from a several vertical vents along the bottom of the fissure, which is too narrow for divers to enter.

There was no evidence that any of the flow in the cavern was towards the St. Johns River, as quoted above from Bulletin 31, or that any cavern passages went in that direction. All the water appeared to be discharging up through the restriction and into the concrete pool.

The walls of the fissure were composed of greenish-gray clay typically associated with Miocene Hawthorn Group sediments. There were small grains in the clay surface that sparkled under the influence of the diver's lights and were thought to be pyrite.

The Florida Geological Survey, *Report of Investigations No 35,* Water Resources of Alachua, Bradford, Clay, and Union Counties, Florida (1964) shows that the top of the Ocala Group carbonates lies about 280 feet below sea level at Green Cove Springs, and is overlain by over 200 feet of Hawthorn Group sediments and possibly 20 feet of Choctawhatchee Formation sediments. These Miocene sediments are generally characterized by thick clays and sandy clays with a range of colors including green and gray, along with relatively thin layers of sand, limestone and dolomite. This matches what was observed in the cavern and strongly suggests that the cavern of Green Cove Springs is located within Miocene sediments, which make up the secondary aquifer in the eastern part of Clay County.

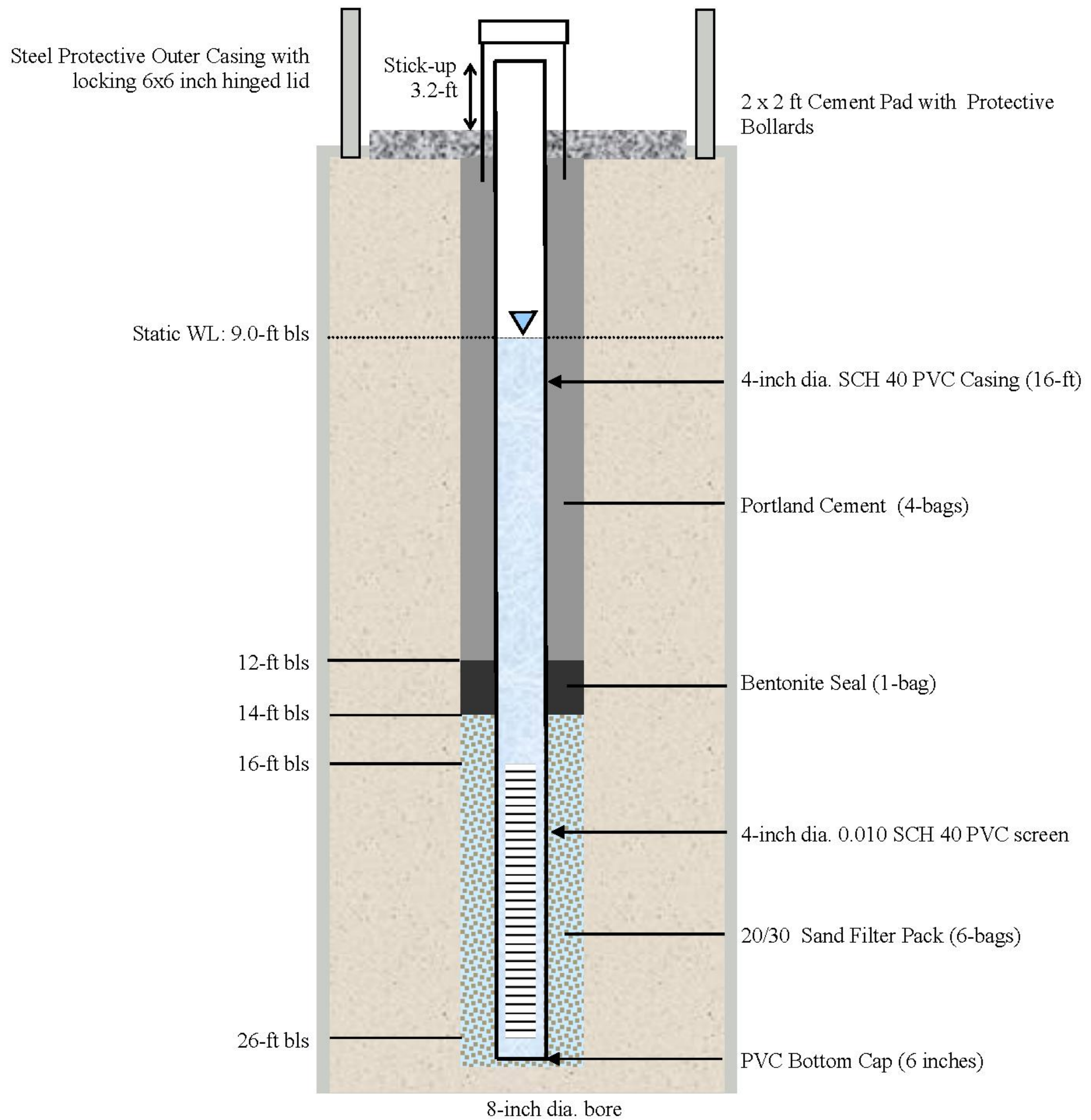
APPENDIX B

Divers' Video of Green Cove Spring, Karst Environmental Services Inc.

Video available on request through the District's Scientific Reference Center or by ordering online at *floridaswater.com/technicalreports/ppapers.html*.

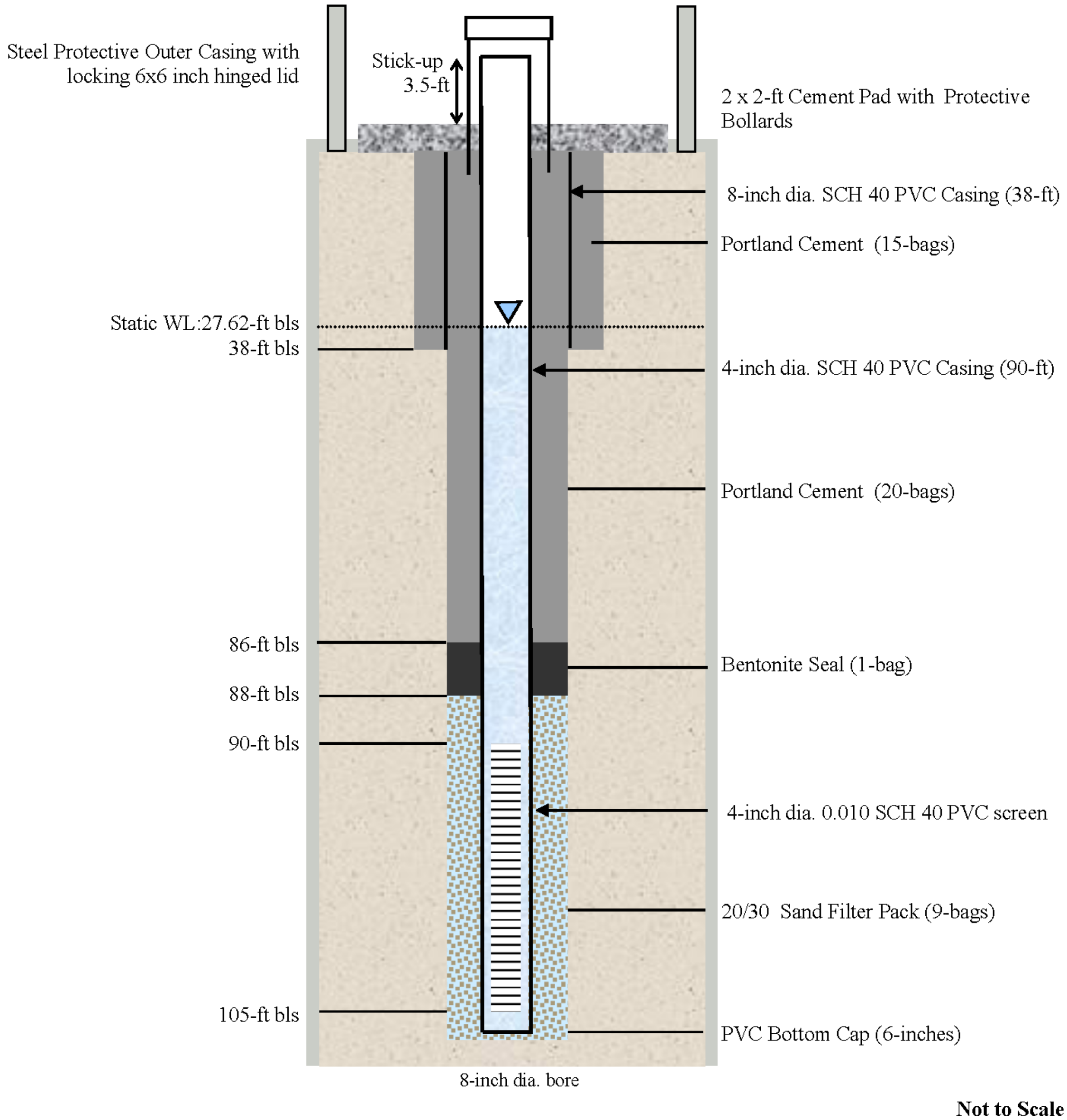
APPENDIX C

As Built Well Construction Diagrams for Wells C-0672, 0673, 0674, 0675

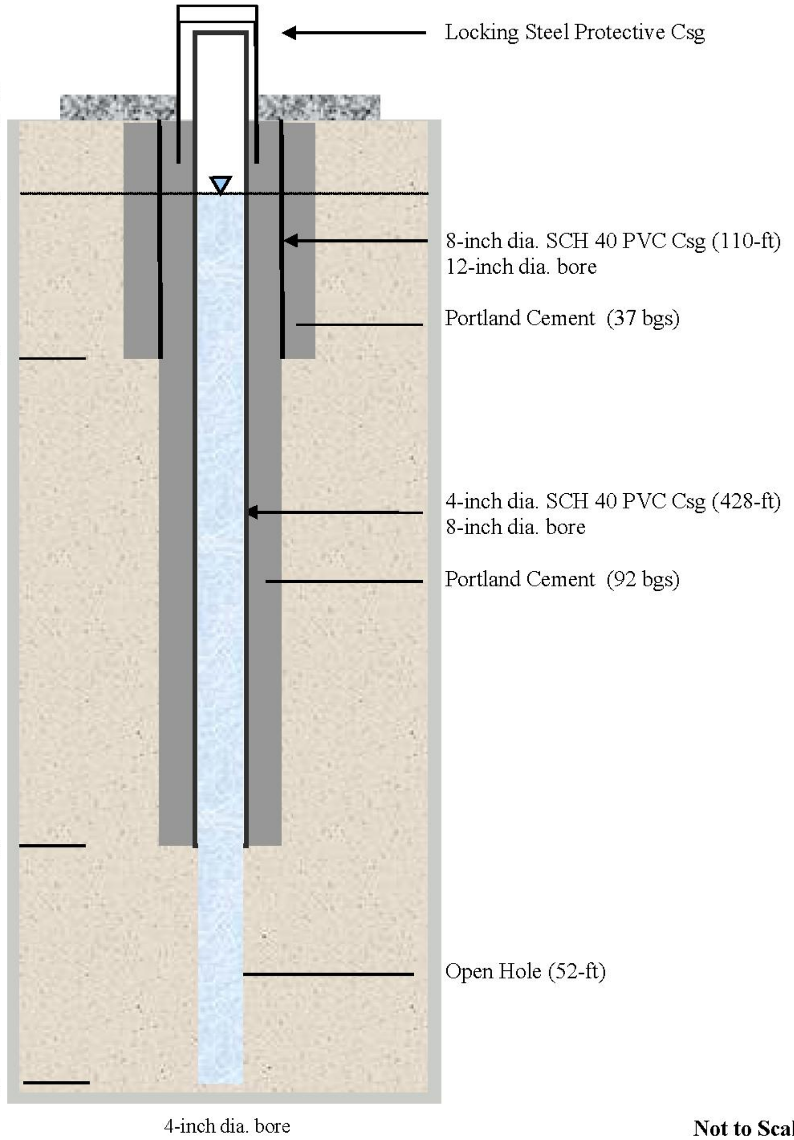


Not to Scale

Site:	Green Cove Springs	**SJRWMD**
Drilled:	Mud Rotary	
Developed:	Moyno Pump	
Rate:	0.5 gpm	
Pumping GWL:	Draws down to TD-ft bls	
Specific Capacity:	Not recorded- gpm/ft	
Lat/Long:	295914/814139 WGS 84	**Figure. Monitor Well C-0674**
UTM x/y:	432935/3317684 WGS 84	
Driller:	Huss Drilling	
Well Completed:	May 21, 2010	



Site:	Green Cove Springs	**SJRWMD**
Drilled:	Mud Rotary	
Developed:	Air and Submersible	
Rate:	21.0-gpm	
Pumping GWL:	35.25-ft bls	
Specific Capacity:	2.75- gpm/ft	
Lat/Long:	295914/814139 WGS 84	**Figure. Monitor Well C-0675**
UTM x/y:	432935/3317684 WGS 84	
Driller:	Huss Drilling, Inc.	
Well Completed:	May 21, 2010	

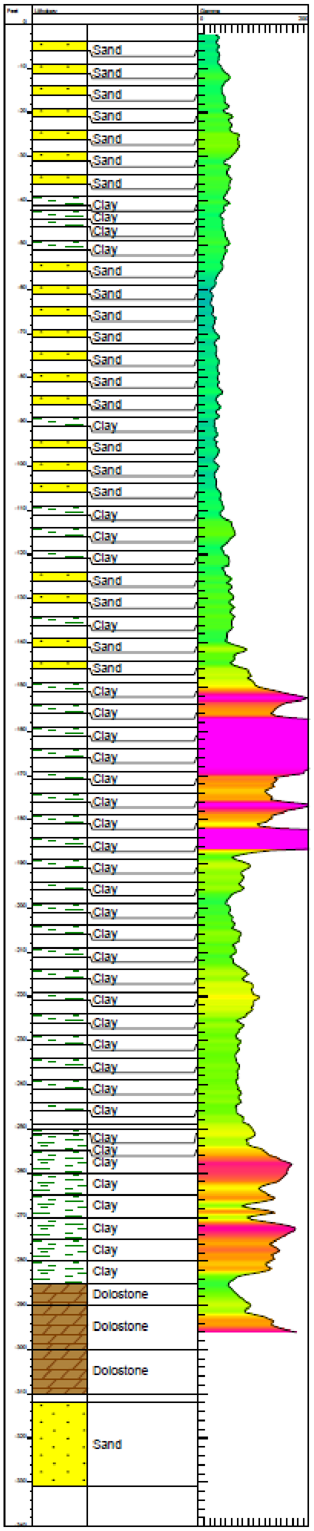


Not to Scale

Site:	Green Cove Springs	**Field Water Quality**	
Drilled:	Mud Rotary	**Date Sampled:**	September 6, 2012
Developed:	Air and Submersible	**Specific Conductivity:**	193.6 us/cm
Rate:	73 gpm	**Temperature:**	24.1 °C
Pumping GWL:	29.0 ft bls	**Chlorides:**	Not Recorded
Specific Capacity:	6.3 gpm/ft	**pH:**	Not Recorded
Lat/Long:	295917.5/814142.7/ NAD 83	SJRWMD	
Driller:	Huss Drilling, Inc.		
Well Completed:	September 6, 2012	**Figure. Monitor Well C-0672**	

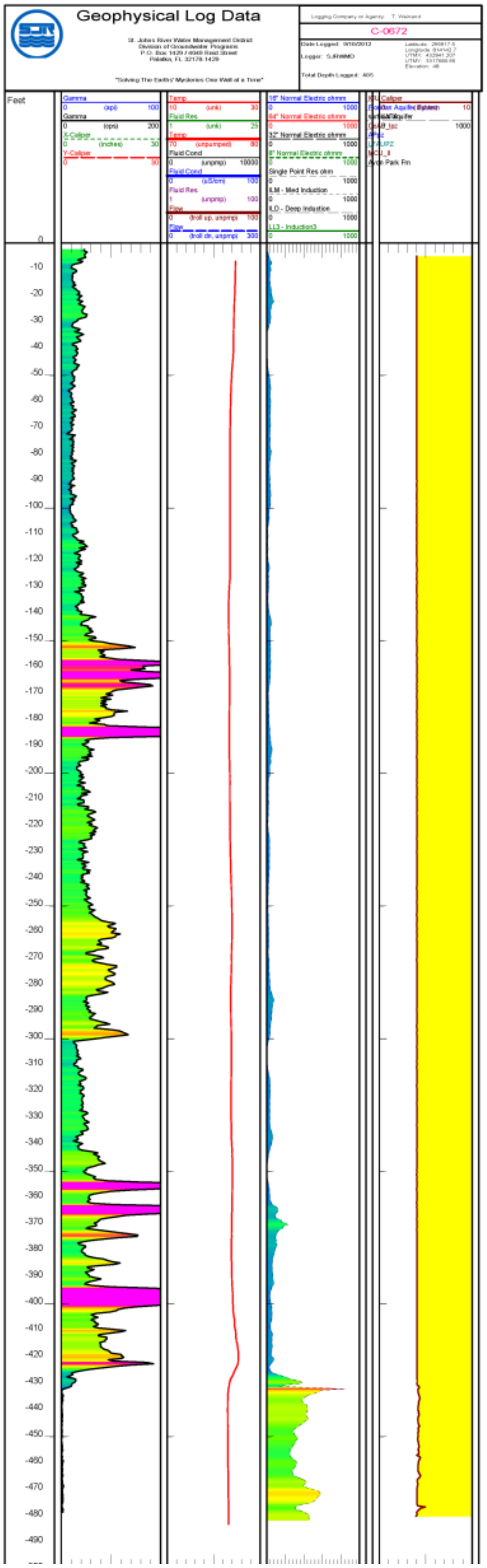
APPENDIX D

Lithologic Descriptions and Geophysical Logs of Selected Boreholes in the Area of Green Cove Springs



Natural Gamma log and lithologic columnar section of well C-0673

Geophysical logs of C-0672



Station Id: 406451 Report

Well Number :31723208 Station Name:C-0673

County Name :Clay Location: T.6S R.26E S.38

Latitude :29D 59M 17S Longitude: 81D 41M 42S

UTM (x,y): 432933.262,3317695.989 Elevation (DEM): 888

Owner/Driller: Greencove Springs_Bonaventure Ave_IAS Originator Elevation:null

Owner: null

Driller: HUSS DRILLING, INC.

Total Depth: 320 Originator Elevation:null

Total Depth: 320 Originator Elevation:

Sample Interval From: 4 Sample Interval To:320

No. of Samples:61 Worked By: L NELMS

Litho Strata Details :

Depth Strata Code Strata Details
----
0 090UDSS Undifferentiated Sand, Clay, and Shell (Formation/Unit) -->Pliestocene (Series) -->Quaternary (System) -
->Cenozoic (Erathem)

144 122HTRN Hawthorn Gp. (Group) -->Oligocene-Miocene (Series) -->Tertiary (System) -->Cenozoic (Erathem)

Litho Data Details :

Top Interval Bottom Interval Litho Data Description
----
4 6 Rock Type :Sand;tan To cream
Porosity :Intergranular
Sand Properties:GRAIN SIZE: Very Fine
Cement:
Accessory Minerals :
Sediment Structures:
Other Features :

Sample Type :Split Spoon

9 11 Rock Type :Sand;tan To cream
Porosity :Intergranular
Sand Properties:GRAIN SIZE: Very Fine
Cement:
Accessory Minerals :
Sediment Structures:
Other Features :
Sample Type :Split Spoon

14 16 Rock Type :Sand;dark reddish brown_10R 3/4_17
Porosity :Intergranular
Sand Properties:GRAIN SIZE: Fine
Cement:Clay Matrix
Accessory Minerals :
Sediment Structures:
Other Features :
Sample Type :Split Spoon

19 21 Rock Type :Sand;white_N9_76 To cream
Porosity :Intergranular
Sand Properties:GRAIN SIZE: Very Fine
Cement:
Accessory Minerals :
Sediment Structures:
Other Features :
Sample Type :Split Spoon

24 26 Rock Type :Sand;medium gray_N5_80
Porosity :Intergranular
Sand Properties:GRAIN SIZE: Fine
Cement:
Accessory Minerals :
Sediment Structures:
Other Features :
Sample Type :Split Spoon

29 31 Rock Type :Sand;olive gray_5Y 3/2_39
Porosity :Intergranular
Sand Properties:GRAIN SIZE: Fine
Cement:Clay Matrix
Accessory Minerals :
Sediment Structures:
Other Features :
Sample Type :Split Spoon

34 36 Rock Type :Sand;olive gray_5Y 3/2_39 To dark reddish brown_10R 3/4_17
Porosity :Intergranular
Sand Properties:GRAIN SIZE: Very Fine
Cement:
Accessory Minerals :
Sediment Structures:
Other Features :

Sample Type :Split Spoon

39 41 Rock Type :Clay;dark greenish gray_5GY 4/1_92
Porosity :Low Permeability
Cement:Clay Matrix
Accessory Minerals :
Sediment Structures:
Other Features :
Sample Type :Split Spoon

42 44 Rock Type :Clay;dark greenish gray_5GY 4/1_92
Porosity :Low Permeability
Cement:Clay Matrix
Accessory Minerals :
Sediment Structures:
Other Features :
Sample Type :Shelby

44 46 Rock Type :Clay;dark greenish gray_5GY 4/1_92
Porosity :Low Permeability
Cement:Clay Matrix
Accessory Minerals :
Sediment Structures:
Other Features :
Sample Type :Split Spoon

49 51 Rock Type :Clay;dark greenish gray_5GY 4/1_92
Porosity :Low Permeability
Sand Properties:GRAIN SIZE: Very Fine
Cement:Clay Matrix
Accessory Minerals :
Sediment Structures:
Other Features :
Sample Type :Split Spoon

54 56 Rock Type :Sand;dark reddish brown_10R 3/4_17
Porosity :Intergranular
Sand Properties:GRAIN SIZE: Fine
Cement:
Accessory Minerals :
Sediment Structures:
Other Features :
Sample Type :Split Spoon

59 61 Rock Type :Sand;olive gray_5Y 3/2_39
Porosity :Intergranular
Sand Properties:GRAIN SIZE: Fine
Cement:
Accessory Minerals :
Sediment Structures:
Other Features :
Sample Type :Split Spoon

64 66 Rock Type :Sand;white_N9_76 To dark reddish brown_10R 3/4_17

Porosity :Intergranular
Sand Properties:GRAIN SIZE: Fine
Cement:
Accessory Minerals :
Sediment Structures:
Other Features :
Sample Type :Split Spoon

69 71 Rock Type :Sand;grayish yellow green_5GY 7/2_51 To tan
Porosity :Intergranular
Sand Properties:GRAIN SIZE: Fine
Cement:
Accessory Minerals :
Sediment Structures:
Other Features :
Sample Type :Split Spoon

74 76 Rock Type :Sand;tan
Porosity :Intergranular
Sand Properties:GRAIN SIZE: Fine
Cement:Clay Matrix
Accessory Minerals :
Sediment Structures:
Other Features :
Sample Type :Split Spoon

79 81 Rock Type :Sand;tan
Porosity :Intergranular
Sand Properties:GRAIN SIZE: Fine
Cement:
Accessory Minerals :
Sediment Structures:
Other Features :
Sample Type :Split Spoon

84 86 Rock Type :Sand;tan
Porosity :Intergranular
Sand Properties:GRAIN SIZE: Fine
Cement:
Accessory Minerals :
Sediment Structures:
Other Features :
Sample Type :Split Spoon

89 91 Rock Type :Clay;olive gray_5Y 3/2_39
Porosity :Low Permeability
Cement:Clay Matrix
Accessory Minerals :
Sediment Structures:
Other Features :
Sample Type :Split Spoon

94 96 Rock Type :Sand;cream To white_N9_76
Porosity :Intergranular

Sand Properties:GRAIN SIZE: Fine
Cement:
Accessory Minerals :
Sediment Structures:
Other Features :
Sample Type :Split Spoon

99 101 Rock Type :Sand;tan To dark reddish brown_10R 3/4_17
Porosity :Intergranular
Sand Properties:GRAIN SIZE: Fine
Cement:
Accessory Minerals :
Sediment Structures:
Other Features :
Sample Type :Split Spoon

104 106 Rock Type :Sand;dark reddish brown_10R 3/4_17 To medium gray_N5_80
Porosity :Intergranular
Sand Properties:GRAIN SIZE: Fine
Cement:Clay Matrix
Accessory Minerals :Shell
Sediment Structures:
Other Features :
Sample Type :Split Spoon

109 111 Rock Type :Clay;olive gray_5Y 3/2_39
Porosity :Low Permeability
Cement:Clay Matrix
Accessory Minerals :
Sediment Structures:
Other Features :
Sample Type :Split Spoon

114 116 Rock Type :Clay;olive gray_5Y 3/2_39
Porosity :Low Permeability
Cement:Clay Matrix
Accessory Minerals :Shell
Sediment Structures:
Other Features :
Sample Type :Split Spoon

119 121 Rock Type :Clay;bluish green
Porosity :Low Permeability
Cement:Clay Matrix
Accessory Minerals :Shell, Quartz Sand
Sediment Structures:
Other Features :
Sample Type :Split Spoon

124 126 Rock Type :Sand;grayish yellow green_5GY 7/2_51 To tan
Porosity :Intergranular
Cement:Clay Matrix
Accessory Minerals :Shell
Sediment Structures:

Other Features :
Sample Type :Split Spoon

129 131 Rock Type :Sand;grayish yellow green_5GY 7/2_51 To tan
Porosity :Intergranular
Cement:Clay Matrix
Accessory Minerals :
Sediment Structures:
Other Features :
Sample Type :Split Spoon

134 136 Rock Type :Clay;brilliant green_5G 6/6_64
Porosity :Low Permeability
Cement:Clay Matrix
Accessory Minerals :Quartz Sand
Sediment Structures:
Other Features :
Sample Type :Split Spoon

139 141 Rock Type :Sand;tan To grayish yellow green_5GY 7/2_51
Porosity :Intergranular
Cement:Clay Matrix
Accessory Minerals :Shell
Sediment Structures:
Other Features :
Sample Type :Split Spoon

144 146 Rock Type :Sand;white_N9_76 To tan
Porosity :Intergranular
Cement:Clay Matrix
Accessory Minerals :, Phosphatic Sand
Sediment Structures:
Other Features :
Sample Type :Split Spoon

149 151 Rock Type :Clay;olive gray_5Y 3/2_39
Porosity :Low Permeability
Cement:Clay Matrix
Accessory Minerals :Quartz Sand
Sediment Structures:
Other Features :
Sample Type :Split Spoon

154 156 Rock Type :Clay;light greenish blue
Porosity :Low Permeability
Cement:Clay Matrix
Accessory Minerals :, Phosphatic Sand
Sediment Structures:
Other Features :
Sample Type :Split Spoon

159 161 Rock Type :Clay;light greenish blue
Porosity :Low Permeability
Cement:Clay Matrix

Accessory Minerals :, Phosphatic Sand
Sediment Structures:
Other Features :
Sample Type :Split Spoon

164 166 Rock Type :Clay;olive gray_5Y 3/2_39
Porosity :Low Permeability
Cement:Clay Matrix
Accessory Minerals :, Phosphatic Sand
Sediment Structures:
Other Features :
Sample Type :Split Spoon

169 171 Rock Type :Clay;grayish yellow green_5GY 7/2_51
Porosity :Low Permeability
Cement:Clay Matrix
Accessory Minerals :, Phosphatic Sand
Sediment Structures:
Other Features :
Sample Type :Split Spoon

174 176 Rock Type :Clay;grayish yellow green_5GY 7/2_51
Porosity :Low Permeability
Cement:Clay Matrix
Accessory Minerals :
Sediment Structures:
Other Features :
Sample Type :Split Spoon

179 181 Rock Type :Clay;olive gray_5Y 3/2_39
Porosity :Low Permeability
Cement:Clay Matrix
Accessory Minerals :, Phosphatic Sand
Sediment Structures:
Other Features :
Sample Type :Split Spoon

184 186 Rock Type :Clay;olive gray_5Y 3/2_39
Porosity :Low Permeability
Cement:Clay Matrix
Accessory Minerals :, Phosphatic Sand
Sediment Structures:
Other Features :
Sample Type :Split Spoon

189 191 Rock Type :Clay;light greenish blue
Porosity :Low Permeability
Cement:Clay Matrix
Accessory Minerals :Quartz Sand, Phosphatic Sand
Sediment Structures:
Other Features :
Sample Type :Split Spoon

194 196 Rock Type :Clay;grayish yellow green_5GY 7/2_51

Porosity :Low Permeability
Cement:Clay Matrix
Accessory Minerals :Quartz Sand, Phosphatic Sand
Sediment Structures:
Other Features :
Sample Type :Split Spoon

199 201 Rock Type :Clay;grayish yellow green_5GY 7/2_51
Porosity :Low Permeability
Cement:Clay Matrix
Accessory Minerals :Quartz Sand, Phosphatic Sand
Sediment Structures:
Other Features :
Sample Type :Split Spoon

204 206 Rock Type :Clay;
Porosity :Low Permeability
Cement:Clay Matrix
Accessory Minerals :, Phosphatic Sand
Sediment Structures:
Other Features :
Sample Type :Split Spoon

209 211 Rock Type :Clay;dark greenish gray_5GY 4/1_92
Porosity :Low Permeability
Sand Properties:GRAIN SIZE: Fine RANGE:Very Fine To Medium ROUNDNESS :Sub-Rounded; Medium SPHERICITY
Cement:Clay Matrix
Accessory Minerals :Quartz Sand-5%, Phosphatic Sand-2%
Sediment Structures:
Other Features :
Sample Type :Split Spoon

214 216 Rock Type :Clay;dark greenish gray_5GY 4/1_92
Porosity :Low Permeability
Sand Properties:GRAIN SIZE: Fine RANGE:Very Fine To Medium ROUNDNESS :Sub-Rounded; Medium SPHERICITY
Cement:Clay Matrix
Accessory Minerals :Quartz Sand-5%, Phosphatic Sand-2%
Sediment Structures:
Other Features :
Sample Type :Split Spoon

219 221 Rock Type :Clay;dark greenish gray_5GY 4/1_92
Porosity :Low Permeability
Sand Properties:GRAIN SIZE: Fine RANGE:Very Fine To Medium ROUNDNESS :Sub-Rounded; Medium SPHERICITY
Cement:Clay Matrix
Accessory Minerals :Quartz Sand-5%, Phosphatic Sand-2%
Sediment Structures:
Other Features :
Sample Type :Split Spoon

224 226 Rock Type :Clay;dark greenish gray_5GY 4/1_92

Porosity :Low Permeability
Cement:Clay Matrix
Accessory Minerals :Quartz Sand, Phosphatic Sand
Sediment Structures:
Other Features :
Sample Type :Split Spoon

199 201 Rock Type :Clay;grayish yellow green_5GY 7/2_51
Porosity :Low Permeability
Cement:Clay Matrix
Accessory Minerals :Quartz Sand, Phosphatic Sand
Sediment Structures:
Other Features :
Sample Type :Split Spoon

204 206 Rock Type :Clay;
Porosity :Low Permeability
Cement:Clay Matrix
Accessory Minerals :, Phosphatic Sand
Sediment Structures:
Other Features :
Sample Type :Split Spoon

209 211 Rock Type :Clay;dark greenish gray_5GY 4/1_92
Porosity :Low Permeability
Sand Properties:GRAIN SIZE: Fine RANGE:Very Fine To Medium ROUNDNESS :Sub-Rounded; Medium SPHERICITY
Cement:Clay Matrix
Accessory Minerals :Quartz Sand-5%, Phosphatic Sand-2%
Sediment Structures:
Other Features :
Sample Type :Split Spoon

214 216 Rock Type :Clay;dark greenish gray_5GY 4/1_92
Porosity :Low Permeability
Sand Properties:GRAIN SIZE: Fine RANGE:Very Fine To Medium ROUNDNESS :Sub-Rounded; Medium SPHERICITY
Cement:Clay Matrix
Accessory Minerals :Quartz Sand-5%, Phosphatic Sand-2%
Sediment Structures:
Other Features :
Sample Type :Split Spoon

219 221 Rock Type :Clay;dark greenish gray_5GY 4/1_92
Porosity :Low Permeability
Sand Properties:GRAIN SIZE: Fine RANGE:Very Fine To Medium ROUNDNESS :Sub-Rounded; Medium SPHERICITY
Cement:Clay Matrix
Accessory Minerals :Quartz Sand-5%, Phosphatic Sand-2%
Sediment Structures:
Other Features :
Sample Type :Split Spoon

224 226 Rock Type :Clay;dark greenish gray_5GY 4/1_92

Porosity :Low Permeability
Sand Properties:GRAIN SIZE: Fine RANGE:Very Fine To Medium ROUNDNESS :Sub-Rounded; Medium SPHERICITY
Cement:Clay Matrix
Accessory Minerals :Quartz Sand-15%, Phosphatic Sand-5%
Sediment Structures:
Other Features :
Sample Type :Split Spoon

229 231 Rock Type :Clay;olive gray_5Y 3/2_39
Porosity :Low Permeability
Cement:Clay Matrix
Accessory Minerals :Quartz Sand-5%, Phosphatic Sand-2%
Sediment Structures:
Other Features :
Sample Type :Split Spoon

234 236 Rock Type :Clay;olive gray_5Y 3/2_39
Porosity :Low Permeability
Cement:Clay Matrix
Accessory Minerals :Quartz Sand, Phosphatic Sand
Sediment Structures:
Other Features :
Sample Type :Split Spoon

239 241 Rock Type :Clay;olive gray_5Y 3/2_39
Porosity :Low Permeability
Cement:Clay Matrix
Accessory Minerals :, Phosphatic Sand
Sediment Structures:
Other Features :
Sample Type :Split Spoon

244 246 Rock Type :Clay;olive gray_5Y 3/2_39
Porosity :Low Permeability
Cement:Clay Matrix
Accessory Minerals :, Phosphatic Sand
Sediment Structures:
Other Features :
Sample Type :Split Spoon

249 251 Rock Type :Clay;dusky green_5G 3/2_62
Porosity :Low Permeability
Cement:Clay Matrix
Accessory Minerals :Quartz Sand, Phosphatic Sand
Sediment Structures:
Other Features :
Sample Type :Split Spoon

250 255 Rock Type :Clay;dusky green_5G 3/2_62
Porosity :Low Permeability
Cement:Clay Matrix
Accessory Minerals :Quartz Sand, Phosphatic Sand
Sediment Structures:

Other Features :
Sample Type :Cuttings

255 260 Rock Type :Clay;dusky green_5G 3/2_62
Porosity :Low Permeability
Cement:Clay Matrix
Accessory Minerals :Quartz Sand, Phosphatic Sand
Sediment Structures:
Other Features :
Sample Type :Cuttings

260 265 Rock Type :Clay;olive gray_5Y 3/2_39
Porosity :Low Permeability
Cement:Clay Matrix
Accessory Minerals :Quartz Sand, Phosphatic Sand
Sediment Structures:
Other Features :
Sample Type :Cuttings

265 270 Rock Type :Clay;olive gray_5Y 3/2_39 To light greenish blue
Porosity :Low Permeability
Cement:Clay Matrix
Accessory Minerals :Quartz Sand, Phosphatic Sand
Sediment Structures:
Other Features :
Sample Type :Cuttings

270 275 Rock Type :Clay;olive gray_5Y 3/2_39
Porosity :Low Permeability
Cement:Clay Matrix
Accessory Minerals :, Phosphatic Sand
Sediment Structures:
Other Features :
Sample Type :Cuttings

275 280 Rock Type :Clay;olive gray_5Y 3/2_39
Porosity :Low Permeability
Cement:Clay Matrix
Accessory Minerals :Quartz Sand, Phosphatic Sand
Sediment Structures:
Other Features :
Sample Type :Cuttings

280 285 Rock Type :Clay;olive gray_5Y 3/2_39
Porosity :Low Permeability
Cement:Clay Matrix
Accessory Minerals :Quartz Sand, Phosphatic Sand
Sediment Structures:
Other Features :
Sample Type :Cuttings

285 290 Rock Type :Dolostone;white_N9_76 To dark reddish brown_10R 3/4_17
Porosity :Intergranular,Intragranular
Cement:Clay Matrix

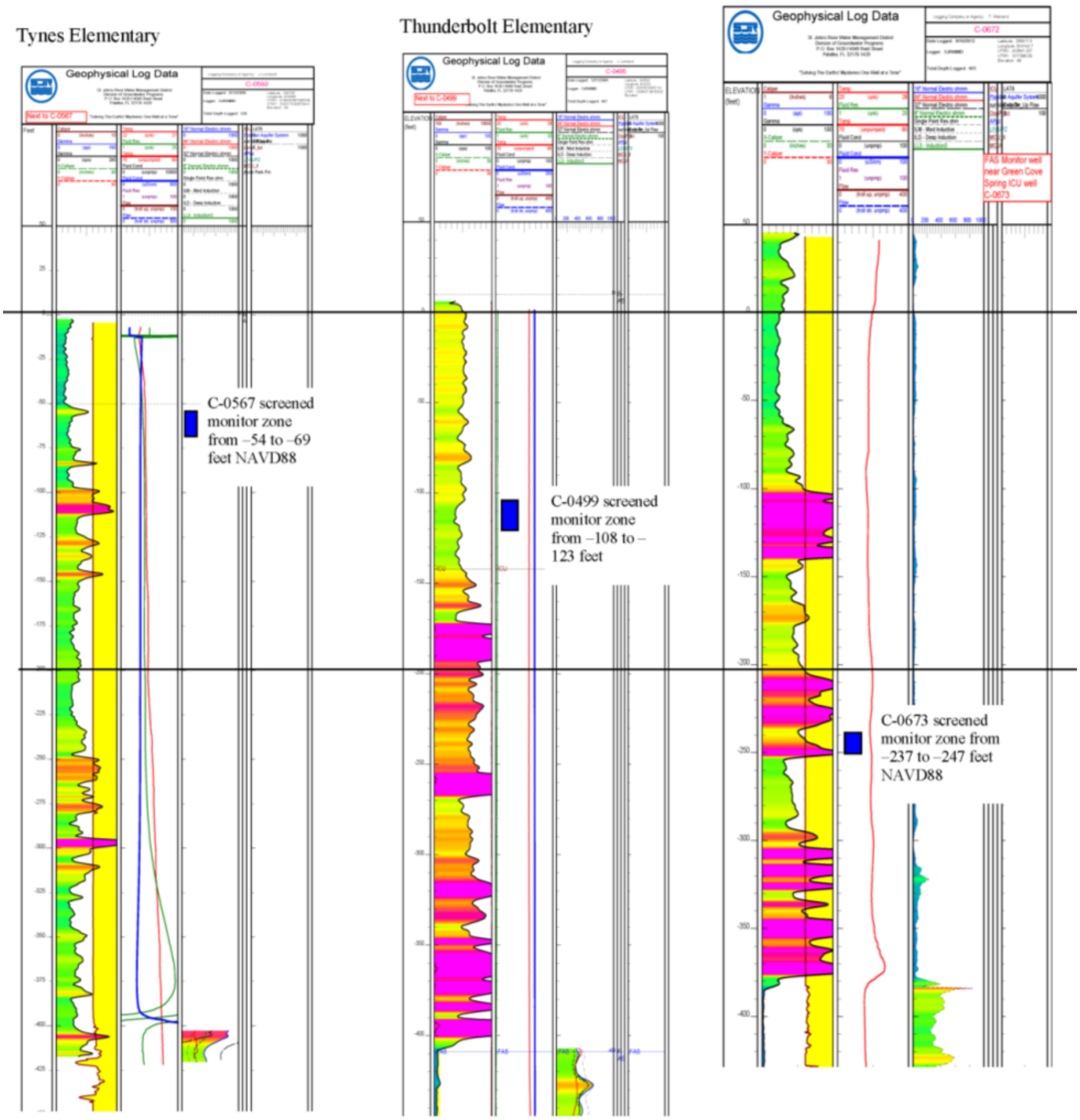
Accessory Minerals :, Phosphatic Sand
Fossils:Sharks Teeth
General Fossils :Sharks Teeth
Sediment Structures:
Other Features :Dolomitic
Sample Type :Cuttings

290 300 Rock Type :Dolostone;tan To grayish yellow green_5GY 7/2_51
Porosity :Intergranular,Intragranular
Sand Properties:GRAIN SIZE: Medium RANGE:Fine To Coarse ROUNDNESS :Sub-Rounded; Medium SPHERICITY
Cement:Clay Matrix
Accessory Minerals :Quartz Sand, Phosphatic Sand, Mica
Fossils:Sharks Teeth
General Fossils :Sharks Teeth
Sediment Structures:, Bedded, Brecciated
Other Features :
Sample Type :Core

300 310 Rock Type :Dolostone;medium gray_N5_80 To olive gray_5Y 3/2_39
Porosity :Intergranular,Intragranular
Sand Properties:GRAIN SIZE: Medium RANGE:Fine To Coarse ROUNDNESS :Sub-Rounded; Medium SPHERICITY
Cement:Clay Matrix
Accessory Minerals :Quartz Sand, Phosphatic Sand, Mica
Sediment Structures:, Bedded, Brecciated
Other Features :
Sample Type :Core

312 331 Rock Type :Sand;medium gray_N5_80 To olive gray_5Y 3/2_39
Porosity :Intergranular,Intragranular
Sand Properties:GRAIN SIZE: Medium RANGE:Fine To Coarse ROUNDNESS :Sub-Rounded; Medium SPHERICITY
Cement:Clay Matrix
Accessory Minerals :Quartz Sand, Phosphatic Sand, Mica
Sediment Structures:, Bedded, Brecciated
Other Features :
Sample Type :Core

Appendix D1—Geophysical logs from monitor wells at Thunderbolt Elementary School, Tynes Elementary School, and Green Cove Springs



APPENDIX E

Report by SDII prepared for Water Resources Associates, Inc. (SDII Global Corporation 2010)

SOURCES OF WATER FROM SPRINGS OF CONCERN IN CLAY, PUTNAM, AND MARION COUNTIES, FLORIDA

Prepared for

Water Resource Associates, Inc.

by

SDII Global Corporation
4509 George Road
Tampa, FL 33634

November 17, 2009
Revised
January 15, 2010

Endorsement

This report was submitted to Water Resource Associates by SDII Global Corporation. All original work contained in this report was performed under the supervision of the undersigned.

SDII Global Corporation

Sam B. Upchurch, Ph.D., P.G.
Vice President and Senior Principal Geologist
Florida Registration No. 4

1/19/10
Date

SDII Global Corporation Project Number
3020073

Cover Photograph

W.W. Gay Spring #2, Clay County, Florida, in August, 2009. The view is looking towards a small seep into north side of the spring pool.

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SOURCES OF WATER FROM SPRINGS OF CONCERN IN CLAY, PUTNAM, AND MARION COUNTIES, FLORIDA

Sam B. Upchurch, Ph.D., P.G.
Thomas M. Scott, Ph.D., P.G.
SDII Global Corporation

INTRODUCTION

Springs have been identified as being of concern relative to JEA CUP No. 2-031-88271-11 consumptive use permit application. Groundwater flow modeling by CDM identified these springs as being of concern because modeling suggested that groundwater withdrawals requested by JEA might affect spring discharge. The purpose of this report is to evaluate the hydrostratigraphic provenance of water discharging from these springs in order to determine if there should be concern for the effects of pumpage from the upper Floridan aquifer on spring discharge.

The groundwater flow model places these springs in Layer 2, which represents the upper Floridan aquifer. The intermediate aquifer system or confining unit (intermediate aquifer; Southeastern Geological Society, 1986) is not represented in the model as an active layer. Rather, it is treated as a leakance array separating the surficial aquifer (Layer 1) from the upper Floridan. If the springs originate from the surficial or intermediate aquifer systems, then concerns for the effects of Floridan aquifer pumpage can be ameliorated.

Clay County has few springs due to its geologic setting. Four named springs, Green Cove, Wadesboro, W. W. Gay, and Shands Bridge, an underwater spring, are known. The springs are located along the western shore of, or within, the St. Johns River (Figure 1). A few other, smaller springs have been reported within the county but the Florida Geological Survey found them to be minor seeps issuing from the surficial aquifer system (Scott et al., 2004).

Putnam County also has few springs, and only one, Whitewater Spring (Figure 2), was identified by groundwater flow modeling to be of concern.

Northern Marion County has a series of small springs along Orange Creek, the county boundary, and the Oklawaha River. Three springs (Orange, Camp Seminole, and Marion Blue; Figure 2), were represented in the model as potential springs of concern.

This report describes each of these named springs, including analysis and discussion of the aquifer systems within which each is contained, where data allow. Owing to a lack of suitable data, no effort has been made to delineate springsheds (Scott et al., 2004) or detail the specifics of the spring flow systems.

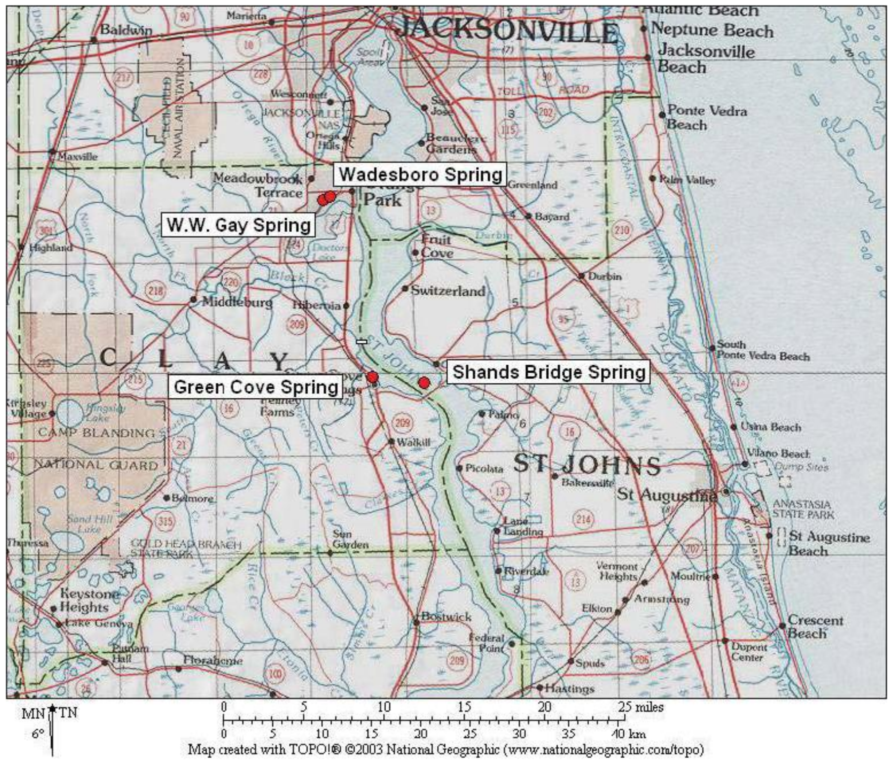

Figure 1. Location of springs of interest in Clay County.

All the springs of interest have relatively small magnitudes.[1] Green Cove Spring is the largest of the springs with a mean flow rate of approximately 3.05 cubic feet per second (cfs) or 1.97 million gallons of water per day (mgd) (St. Johns River Water Management District [SJRWMD], 2009a). As such, it is considered a 3rd magnitude[9] spring. Orange Spring is considered a 3rd magnitude spring based on a 6.4 cfs measurement, as is Marion Blue Spring (median of 2 measurements is ~7 cfs). Whitewater Spring is a low 3rd magnitude spring with 1.4 cfs discharge. Shands Bridge Spring is also estimated to be a 3rd magnitude spring discharging approximately 1 cfs (0.646 mgd; Spechler, 1996). Wadesboro Spring is a 4th magnitude spring with discharge between 0.88 and 1.16 cfs (0.569 and 0.750 mgd), and an average discharge of approximately 0.98 cfs (0.63 mgd). Camp Seminole Spring is a 4th magnitude spring with 0.8 cfs discharge. W. W. Gay Springs, which consists of two small springs, is a 4th magnitude spring that has a discharge of 0.14 cfs (0.09 mgd).

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[9] Spring magnitude refers to the long-term average, or median, discharge of the spring. First magnitude refers to average discharge that is greater than 100 cubic feet per second (cfs), 2nd magnitude springs have flows that range from 10 to 100 cfs, 3rd magnitude refers flows of 1 to 10 cfs, average flow from a 4th magnitude ranges from 0.1 to 1 cfs, and so on (Meinzer, 1927; Copeland, 2003).

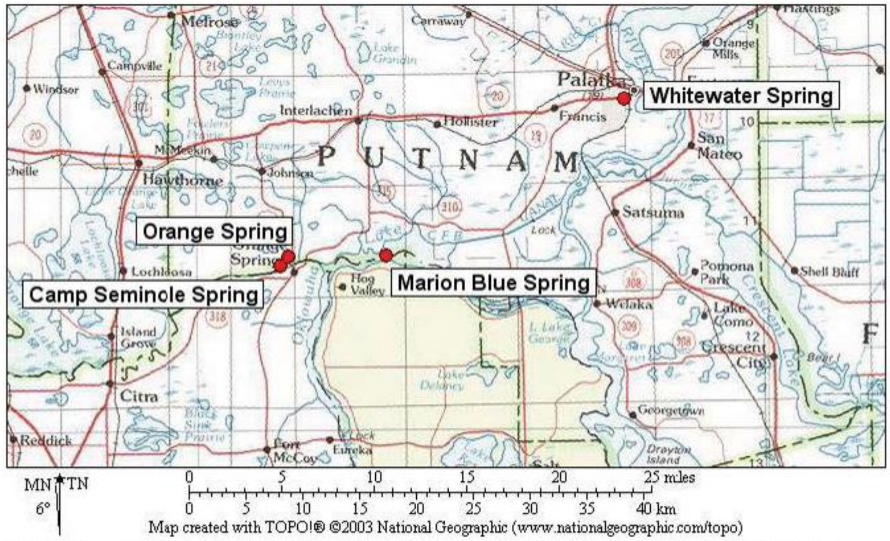

Figure 2. Small springs of interest within the simulated Floridan aquifer drawdown area.

PHYSIOGRAPHIC AND GEOLOGIC FRAMEWORK

All four Clay County springs discharge either within the floodplain of the St. Johns River or, in the case of Shands Bridge Spring, under the river. The "upland" springs have short spring runs to the river or its embayments (Figure 1).

The springs occur on the flank of the Duval Upland in the Eastern Valley (White, 1970). To the west of the springs, the land surface slowly increases in elevation as part of the Eastern Valley. The Duval Uplands and Trail Ridge form highlands west of the springs, near the Clay County Line (Figure 3).

The Jacksonville Basin, a sub-basin of the Southeast Georgia Embayment, dominates the geologic framework of northeastern Florida (Scott, 1988). Just south of the Jacksonville Basin is the St. Johns Platform, a coast-parallel subsurface high (Scott, 1988). Clay County lies west of the northern end of the St Johns Platform and on the southern flank of the Jacksonville Basin.

The springs in Marion County occur along the flanks of the St. Johns Platform within the Central Valley of White (1970). Whitewater Spring is located in a similar geologic setting in the Palatka Hill area of White (1970).

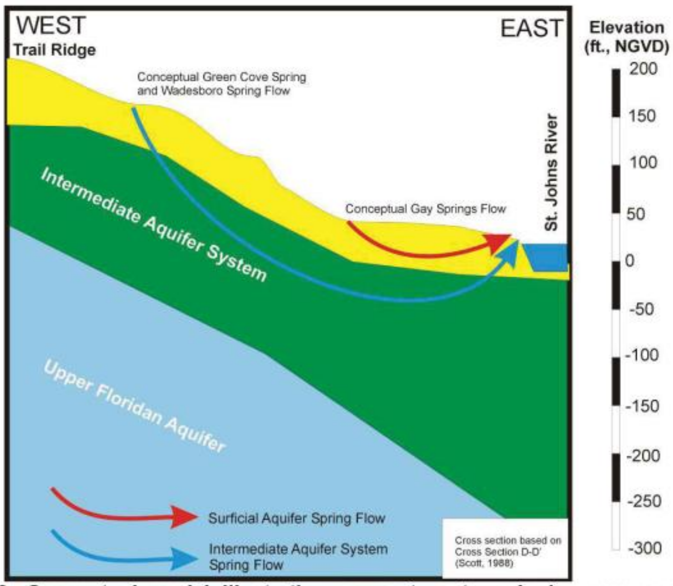

Figure 3. Conceptual model illustrating an east-west geologic cross section of Clay County with the principal aquifer systems. Horizontal dimensions are not to scale. Horizontal flow within the "Intermediate Aquifer System" is through permeable sand and carbonate strata within the clay-rich hydrostratigraphic unit.

HYDROGEOLOGIC FRAMEWORK

The Floridan aquifer system underlies all of Florida and portions of South Carolina, Georgia and Alabama (Miller, 1986). The Floridan aquifer system consists of carbonate sediments (limestone and dolostone) ranging in age from Paleocene (approximately 60 million years ago [mya]) to Miocene (approximately 20 mya). The uppermost water-producing units of the upper Floridan aquifer system in the area are is the Upper Eocene Ocala Limestone and/or Oligocene Suwannee Limestone.

The top of the Floridan aquifer system ranges from 50 feet below mean sea level (msl) in the southwestern-most portion of Clay County to below –400 feet msl in the northeastern area (Scott and Hajishafie, 1980). In the area where the Clay County springs occur, the top of the Floridan aquifer system is approximately -300 to –350 feet msl. The top of the Floridan aquifer is approximately 0 to + 50 feet in north central Marion County, and -50 feet msl near Palatka in Putnam County.

The Floridan aquifer system is overlain by the intermediate aquifer system or confining unit (Figure 3).[10] In this portion of the state, the Miocene Hawthorn Group comprises the

[10] As suggested in Figure 2, the intermediate aquifer system or confining unit should be termed the intermediate aquifer system in Clay County because this hydrostratigraphic unit contains "one or more low to moderate-yielding aquifers … interlayered with relatively impermeable confining beds" (Southeastern Geological Society, 1986, p. 5). Given the focus of this report on springs, the term intermediate aquifer is utilized in this report.

intermediate aquifer system (Miller, 1986). The Hawthorn Group is composed of interbedded and intermixed carbonate (predominantly dolostone) and siliciclastic (sand, silt and clay) sediments. It is very important to recognize the water-bearing characteristics of the Hawthorn Group. Overall, the vertical permeability of the Hawthorn Group is low and it functions as confining unit for the Floridan aquifer system. However, localized water-bearing units occur, as is observed at Green Cove Spring and Wadesboro Spring. The strata that are capable of supplying water to wells and the springs reflect permeable zones within the Hawthorn Group that have relatively high horizontal permeabilities and constitute local to sub-regional aquifers. For lithologic logs that include examples of the higher permeability strata in the Hawthorn Group in Clay County, see Appendix B.

The Hawthorn in the area of the Clay County springs ranges from approximately 200 feet to 300 feet in thickness (Scott, 1988; Figure 3). The top of the Hawthorn Group is approximately at sea level and the elevation of the St. Johns River, which is a few feet above sea level in the vicinity of the springs (Scott, 1988). In northern Marion County, the Hawthorn Group is approximately 50 to 100 feet thick, and in the Palatka area it is approximately 100 feet (Scott, 1988) in thickness.

The surficial aquifer system overlies the intermediate aquifer system. In northeastern Florida, the Pliocene Cypresshead Formation and undifferentiated Quaternary sediments comprise the surficial aquifer system (Scott, et al., 2001). The Cypresshead Formation is composed of unconsolidated to poorly consolidated, fine to very coarse-grained sand and clayey sand. Quartz pebbles and discontinuous clay beds are also present in the formation. The undifferentiated Quaternary sediments consist of fine to coarse unconsolidated, fossiliferous to non-fossiliferous sand and clayey sand. The surficial aquifer system ranges from less than ten feet thick near the St. Johns River to more than 50 feet thick in the western portion of the area.

GREEN COVE SPRING

Setting

Green Cove Spring occurs in a City park along a shallow slope descending eastward toward the St. Johns River (Figure 4). The park is a former location of a spa and casino (Figure 5). Today, a bathhouse and swimming pool lie adjacent to the enclosed spring bowl.

The vent area has been highly modified with a circular, 15-foot wide, concrete structure surrounded by a brick walkway, an overflow that drains to the adjacent swimming pool, and a discharge by-pass pipe to allow for pool maintenance. The spring bowl measures 28 feet deep (Scott et al., 2004) and issues from a small (approximately two feet in diameter) cavern opening with the cavern floor dropping to a depth of 150 feet below land surface (SJRWMD, 2009a). Some of the flow in the cavern has been reported to be toward the St Johns River (Rosenau et al., 1977) but the current understanding is that all of the flow discharges up through a vertical fissure and into the concrete pool (Morris, 2009).

The spring flow discharges into the adjacent public swimming pool by way of a shallow, paved weir. Discharge from the pool is directly to the spring run where the water ultimately discharges into the St. Johns River.

Figure 4. Location of Green Cove Spring in the City of Green Cove Springs, Florida.

Figure 5. Green Cove Spring, the enclosed circular feature in the left middle, and casino in 1929. Photograph by Herman Gunter courtesy of the Florida State Library and Archives.

The area where the spring occurs is mapped as undifferentiated Quaternary (1.8 mya to the present) sediments with Holocene sediments along the St. Johns River (Scott et al., 2001). The undifferentiated Quaternary sediments lie on the Hawthorn Group sediments. Rock is exposed in the spring pool (Figure 6). The St. Johns River Water Management District (SJRWMD, 2009a) website refers to the exposed rock as "soft marl." The appearance of the rock is more like a poorly indurated carbonate (dolostone?). The sediment exposed in the spring pool is the upper Coosawhatchie Formation of the Hawthorn Group (Scott, 1988). The rock may be part of the Charlton Member of the Coosawhatchie Formation but samples have not been taken and analyzed. The upper Coosawhatchie Formation varies from a poorly indurated, dolomitic, clayey quartz sand to a poorly to moderately indurated sandy, clayey dolostone, both with variable but generally minor concentrations of phosphate (Scott, 1988).

Spring Conditions

Water discharging from the spring is clear and is utilized, untreated, in the public swimming pool. There is a distinct odor of hydrogen sulfide emanating from the spring. Long, white to light gray, filamentous bacteria mats (Figure 6b) develop on the walls of the spring vent. These appear to be sulfur-obligate bacteria. The City brushes the walls of the vent from time-to-time in order to control bacterial development.

Figure 6a. The Green Cove Spring pool showing exposure of Hawthorn Group sediments (photo by S. Upchurch, 4-30-2009).

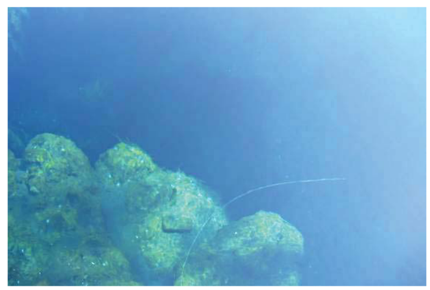

Figure 6b. Rocks of the Hawthorn Group with long, light gray filaments of sulfur bacteria (photo by S. Upchurch, 8-11-2009),

The spring run also contains mats of light gray bacteria, which are presumed to be the same bacterial colonies. Other than mowing and trash removal, the spring run is not cleaned.

Water Sources

There are ample data to evaluate the origin of the flow system that supplies Green Cove Spring. Two approaches were utilized to determine the aquifer system(s) supplying water to the spring. There were (1) comparisons of water levels in nearby aquifer monitoring wells to flows from the spring and (2) chemical fingerprinting of spring and aquifer water.

Monitoring Data

Discharge at Green Cove Spring was measured by the U.S. Geological Survey 7 times from 1929 to 1972. The SJRWMD measured discharge 21 times from 2000 to 2005, and currently measures discharge four times per year.

According to the SJRWMD (2009a) water quality at Green Cove Spring was sampled by the U.S. Geological Survey 7 times from 1956 to 1989. The SJRWMD sampled Green Cove Spring 20 times from 2000 to 2005, and currently samples the spring four times per year. Summary statistics of the water quality data for selected variables are shown in Table 1.

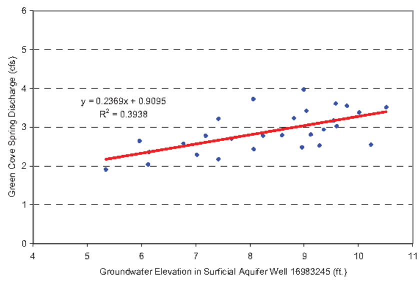

Figure 7. Relationship of discharge from Green Cove Spring to water levels in SJRWMD's surficial aquifer system monitoring well 16493245.

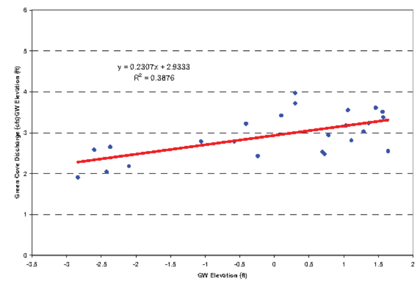

Figure 8. Relationship of discharge from Green Cove Spring to water levels in SJRWMD's surficial aquifer system monitoring well 16533255.

Discharge

According to the SJRWMD (2009a), the difference between the minimum and maximum discharge is 3.8 cfs over the period of record. The maximum measured discharge of 5.4 cfs occurred in February 1929; the minimum discharge of 1.6 cfs occurred in March 2000. The mean and median discharges for the period from 1929 to 2005 are 3.05 cfs

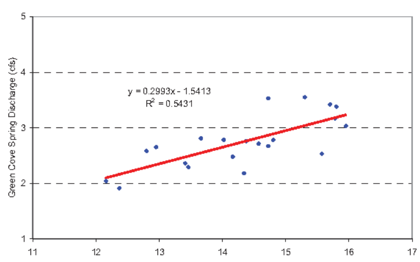

Figure 9. Relationship of discharge from Green Cove Spring to water levels in SJRWMD's intermediate aquifer system monitoring well 8274211.

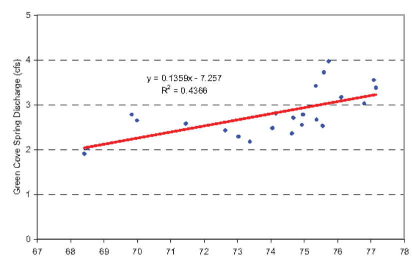

Figure 10. Relationship of discharge from Green Cove Spring to water levels in SJRWMD's intermediate aquifer system monitoring well 11600022.

and 2.86 cfs, respectively. The discharge data indicate that the spring is a low 3rd magnitude spring.

Flow-Discharge Relationships

Discharge from the spring was compared to water level measurements from wells monitored by the SJRWMD in order to determine if the discharge responds best to levels in the surficial, intermediate, or upper Floridan aquifer systems.

Figures 7 and 8 illustrate the relationships of discharge from Green Cove Springs to water levels in two surficial aquifer system monitoring wells. In both cases, there is a statistically significant (α = 0.05), positive correlation[11] between water levels in the surficial aquifer system data and spring discharge. The coefficient of determination (R^2) is a measure of the goodness of fit. The R^2 values are 0.38 to 0.39, respectively, which indicates that the linear regressions account for about 38% of the variability of the spring discharge about the regression line.

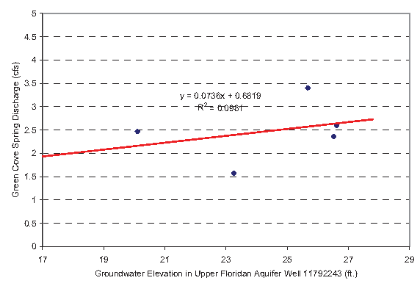

Figure 11. Relationship of discharge from Green Cove Spring to water levels in SJRWMD's upper Floridan aquifer system monitoring well 11792243.

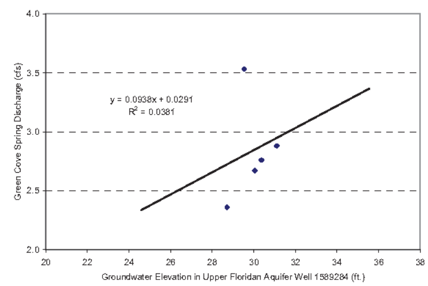

Figure 12. Relationship of discharge from Green Cove Spring to water levels in SJRWMD's upper Floridan aquifer system monitoring well 1589284.

Figures 10 and 11 illustrate the relationships of discharge from Green Cove Springs to water levels in the intermediate aquifer system as measured in two SJRWMD wells in the general vicinity. Again, the relationships are statistically significant (α = 0.01) and the coefficients of determination are considerably stronger than for the relationships with the surficial aquifer system. The R^2 values in the data shown in Figure 9 and 10 suggest that 44 to 54% of the data variability can be accounted for by a linear relationship.

Finally, a similar analysis of the relationships of spring discharge to upper Floridan aquifer system water levels was attempted. Synoptic data for spring discharge and aquifer levels are limited for wells within a reasonable distance of the spring. Therefore, sample size limits the utility of the data to account for spring flows.

Figures 11 and 12 illustrate the relationships of spring discharge to upper Floridan aquifer system levels. With sample sizes of 5 each, the linear regressions are not statistically significant (α = 0.05) and the R^2 values indicate little ability to reproduce spring discharge from aquifer levels.

[11] The Pearson product-moment correlation coefficient coupled with a least-squares linear regression was used to test the significance of all linear regressions.

The analysis of relationships between spring discharge and aquifer levels indicates a stronger and more significant relationship with intermediate aquifer system levels. There is also a significant, but weaker, relationship with the surficial aquifer system. One cannot establish such a relationship with water levels in the upper Floridan aquifer system, however.

Pumpage-Discharge Relationships

In addition to examining relationships of head and spring discharge, an analysis of Green Cove Spring discharge to permitted withdrawals from public supply wells in the area of the spring (Figure 13). In this analysis, pumpage from St. Johns County Utilities, Clay County Utilities, and the City of Green Cove Springs plus the total withdrawals show an upward trend in withdrawals with time from 1998 through 2008 (Figure 13).[12]

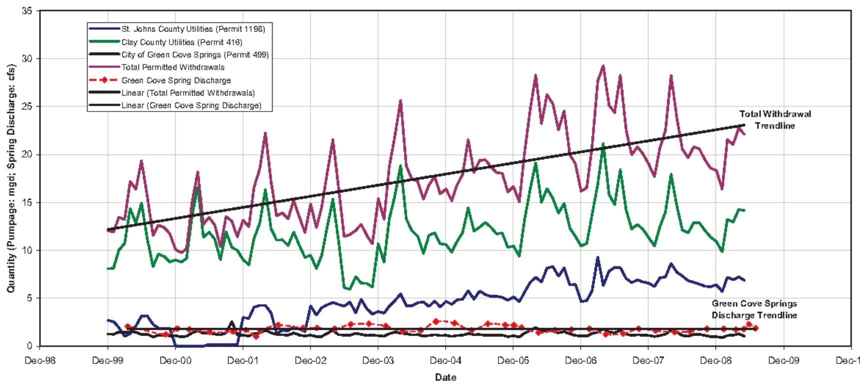

Figure 13. Comparison of Green Cove Spring discharge to pumpage from area utilities.

Discharge from Green Cove Spring does not show a trend in discharge with time while cumulative and individual pumpage from the utilities show significant trends (Figure 13). Clearly, the increased withdrawals from the upper Floridan aquifer have had no effect on spring discharge. In other words, the spring is not affected by nearby Floridan aquifer withdrawals.

Water Quality and Chemical Fingerprinting

The odor of hydrogen sulfide emanating from the spring is a strong clue that water quality in spring water is affected by the pyrite (FeS_2) – rich Hawthorn Group sediments (Upchurch, 1992a, b).

Table 1 presents water quality data for Green Cove Spring as tabulated by the SJRWMD (2009a). Note that, relative to dissolved calcium, concentrations of dissolved magnesium are elevated. Similarly, fluoride concentrations are elevated. This bulk water quality is also indicative of interaction with the Hawthorn Group sediments, which are the dominant sources of fluoride, magnesium, and other constituents in the upper

[12] JEA withdrawal rates are not shown for clarity. They are larger than the local withdrawals but positioned a greater distance from the spring.

Floridan aquifer system in north Florida (Lawrence and Upchurch, 1976, 1982; Upchurch, 1992a, b).

Table 1. Chemical quality of water discharging from Green Cove Spring as tabulated by the SJRWMD (2009a).

Analyte	Min.	Mean	Median	Max.	Count	Period of Record
Water temperature (deg. C)	23.5	24.7	24.6	25.5	23	1960-2005
Specific conductance (field; µmhos/cm @ 25°C)	238	288	291	317	19	2000-2005
pH (field)	7.2	7.86	7.89	8.49	26	1956-2005
Discharge (cfs)	1.60	3.05	2.86	5.40	28	1929-2005
Calcium (dissolved; mg/L)	27.8	29	29	30	8	1956-2001
Magnesium (dissolved; mg/L)	15.0	15.5	15.5	16.0	8	1956-2001
Sodium (dissolved; mg/L)	4.1	4.4	4.4	4.9	8	1956-2001
Potassium (dissolved; mg/L)	1.2	1.4	1.4	1.6	8	1956-2001
Chloride (mg/L)	4.8	6.1	6.0	8.7	26	1956-2005
Sulfate (mg/L)	46.2	53.4	53.8	58.0	26	1956-2005
Fluoride (dissolved; mg/L)	0.30	0.37	0.40	0.40	6	1956-1989
Nitrate + nitrite (mg/L)	0.01	0.02	0.02	0.04	3	2001-2004
Orthophosphate (mg/L)	0.00	0.01	0.01	0.03	5	1972-2004
Alkalinity (total; mg/L as $CaCO_3$)	79.0	80.1	82.0	86.5	25	1956-2005

Frazee and McClaugherty (1979) were successful in characterizing sources of groundwater in coastal areas of northeast Florida using chemical fingerprinting methods. Specifically, they utilized Stiff (1951) diagrams, which allow for pattern analysis of water with similar chemical facies characteristics. A similar analysis was attempted for the Green Cove Spring data utilizing District water quality data from the springs and regional aquifer system water-quality data from the Florida Department of Environmental Protection's Generalized Water Information System [GWIS] database (Florida Department of Environmental Protection, 2000).

Note the different scales of the Stiff diagrams. Maximum ionic concentrations (ionic strengths) in the surficial aquifer system and Green Cove Spring waters are less than 2 meq/L (milliequivalents per liter). The intermediate and Floridan aquifer systems contain higher ionic strengths (the scale on the diagrams is set to 3 to 4 meq/L maxima).

Spechler (1996) used a Piper diagram (Piper, 1944) to compare one water-quality sample from Green Cove Springs to waters discharging from other springs along the St. Johns River. No regional aquifer water samples were included in the analysis. Based on this comparison, Spechler (1996) concluded that the water discharging from Green Cove Spring was derived from the Floridan aquifer system.

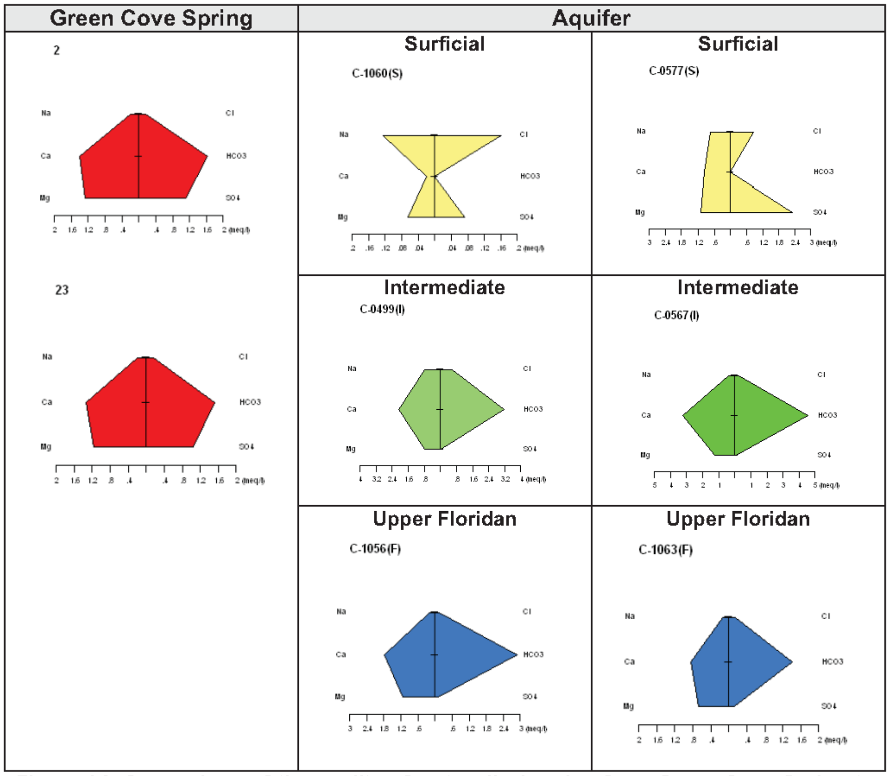

Figure 14. Comparison of the quality of water discharging from Green Cove Spring to sample water from wells in the three aquifer systems of Clay County, Florida. Data are from the SJRWMD.[13]

Figure 15 presents a Piper diagram wherein water-quality data from Green Cove Spring can be compared to regional aquifer water quality. Note that the Green Cove Spring data indicate that the water has a cation ratio pattern similar to upper Floridan and intermediate aquifer system water, but that the sulfate concentrations was significantly elevated relative to the upper Floridan and intermediate aquifer systems. The increased sulfate concentrations coupled with the distinctive odor of hydrogen sulfide emanating from the spring strongly suggest that the water has been influenced by oxidation of sulfide minerals, a process typical of the intermediate aquifer system (Upchurch, 1992a).

[13] Labels (23, C-1063, etc.) on each Stiff diagram are sample location designations from the St. Johns River Water Management District (2009) and the Florida Department of Environmental Protection (2000) databases

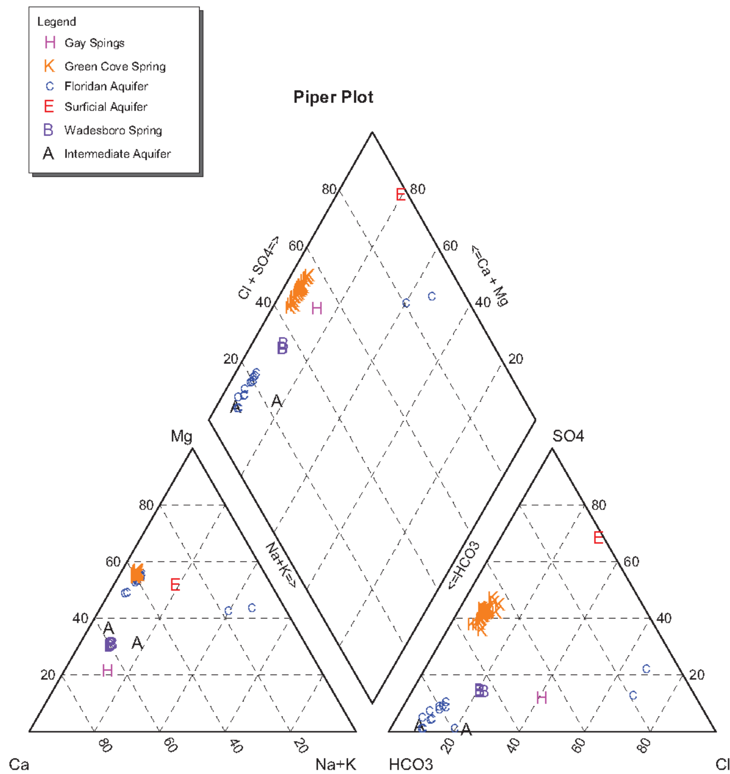

Figure 15. Piper diagram comparing water quality of waters discharging from the Clay County springs to aquifer water quality.

Based on the Piper and Stiff diagrams, comparisons of the water discharging from Green Cove Spring with water samples from the three aquifer systems in Clay County suggests that the water discharging from the spring is derived from the intermediate aquifer system, probably with some surficial aquifer system influx. Ionic strength of the Green Cove Spring water is low compared to intermediate and Floridan water, especially near discharge areas where there has been maximum opportunity for interaction with the carbonate-rock aquifers. The low ionic strength suggests short travel time and reduced interaction with aquifer materials. In other words, the Green Cove Spring springshed is small and residence time of water within the groundwater system is limited.

Enrichment of the Green Cove Spring water with respect to magnesium (Figures 14 and 15) also indicates an intermediate aquifer system origin. The Hawthorn Group is a predominant source of magnesium in Florida (Lawrence and Upchurch, 1976, 1982;

Upchurch, 1992a, b) owing to ion-exchange reactions with magnesium-rich clay and, to some extent, dissolution of dolostone in the Hawthorn strata. The enrichment in magnesium, combined with the hydrogen sulfide odor – a result of pyrite oxidation – is an excellent indicator of a flow system through the Hawthorn.

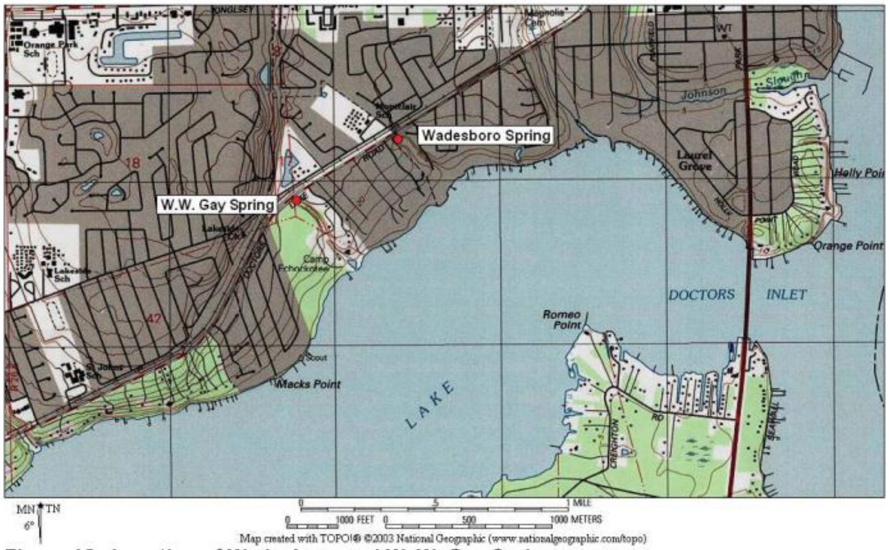

Figure 16. Location of Wadesboro and W. W. Gay Springs.

WADESBORO SPRING

Setting

Wadesboro Spring is located on the northwest side of Doctors Lake on private property (Figure 16). The spring is at the head of a wooded ravine that is a tributary to Doctors Lake, an embayment of the St. Johns River (Rosenau et al., 1977). The spring vent area has been substantially modified by concrete and wood enclosures. The spring issues from two small, closely spaced vents in exposed rock (Figure 17).

The area where the spring occurs is mapped as undifferentiated Quaternary sediments with Holocene sediments along the St. Johns River (Scott et al., 2001). The undifferentiated Quaternary sediments lie on the Hawthorn Group sediments. Rock is exposed in the spring pool (Figure 17). The SJRWMD website refers to the exposure as Hawthorn Group sediments. The appearance of the rock is that of a poorly to moderately indurated carbonate rock (dolostone?).

The sediment exposed in the spring pool is the upper Coosawhatchie Formation of the Hawthorn Group (Scott, 1988). The rock may also be part of the Charlton Member of the Coosawhatchie Formation, but samples have not been taken and analyzed. The upper Coosawhatchie Formation varies from a poorly indurated, dolomitic, clayey quartz sand to a poorly to moderately indurated sandy, clayey dolostone both with variable but generally minor concentrations of phosphate (Scott, 1988).

Figure 15. Wadesboro Spring (photo by S. Upchurch, 8-11-2009).

Monitoring Data

According to SJRWMD (2009a), discharge at Wadesboro Spring was measured by the U.S. Geological Survey in 1972 and 1993. The District has measured discharge 14 times from 2000 to 2005.

Water quality at Wadesboro Spring was sampled by the U.S. Geological Survey in 1960, 1972, and 1993. The District sampled Wadesboro Spring in 2000, 2001, and 2002 (SJRWMD, 2009a).

Discharge

The difference between the minimum and maximum discharges is 0.28 cubic feet per second (cfs) over the period. The maximum measured discharge of 1.16 cfs occurred in February 2004; the minimum discharge of 0.88 cfs occurred in May 2002. The mean and median discharges for the period are 0.98 cfs and 0.96 cfs, respectively. The spring is, therefore, a high fourth magnitude spring.

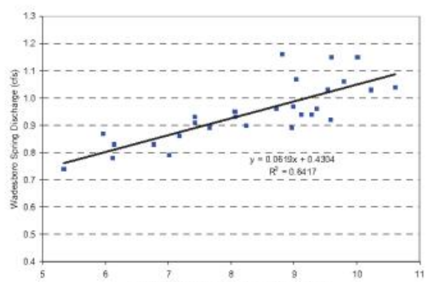

Figure 18. Relationship of discharge from Wadesboro Spring to water levels in the surficial aquifer system at well 116493245.

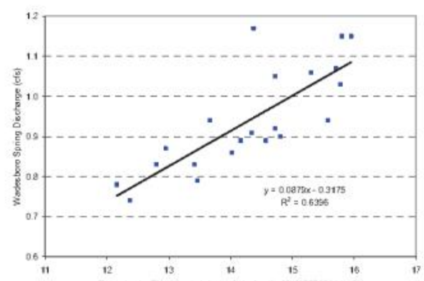

Figure 19. Relationship of discharge from Wadesboro Spring to water levels in the intermediate aquifer system at well 8274211.

Flow-Discharge Relationships

As was done with Green Cove Spring, the measured discharge from Wadesboro Spring was compared to water levels from wells completed in the three aquifer systems found in Clay County. Figures 18 and 19 illustrate the relationships of Wadesboro Spring discharge to water levels in the surficial and intermediate aquifer systems. Discharge is positively correlated to water levels in both aquifer systems, and the correlations are statistically significant ($\alpha = 0.05$).

Table 2. Chemical quality of water discharging from Wadesboro Spring as tabulated by the SJRWMD (2009a).

Analyte	Min.	Mean	Median	Max.	Count	Period of Record
Water temperature (deg. C)	21.5	22.3	22.3	22.8	5	1960-2001
Specific conductance (field; µmhos/cm @ 25°C)	354	356	356	357	2	2001-2002
pH (field)	6.5	7.4	7.4	8.0	5	1960-2002
Discharge (cfs)	0.88	0.98	0.96	1.16	16	1972-2005
Calcium (dissolved; mg/L)	32.0	39.7	42.0	46.4	5	1960-2001
Magnesium (dissolved; mg/L)	3.8	7.1	8.1	8.9	5	1960-2001
Sodium (dissolved; mg/L)	4.7	7.9	9.1	10.2	5	1960-2001
Potassium (dissolved; mg/L)	0.2	0.8	1.0	1.1	5	1960-2001
Chloride (mg/L)	7.0	14.3	17.1	19.0	6	1960-2005
Sulfate (mg/L)	6.4	17.1	20.8	22.1	6	1960-2002
Fluoride (dissolved; mg/L)	0.30	0.37	0.40	0.40	6	1956-1989
Nitrate + nitrite (mg/L)	0.02	0.02	0.02	0.02	1	2002
Orthophosphate (mg/L)	0.13	0.13	0.13	0.14	2	2001-2002
Alkalinity (total; mg/L as $CaCO_3$)	83.0	109.0	121.5	129.0	5	1960-2002

Comparison of spring discharge with water levels in the upper Floridan aquifer system is problematic owing to a general lack of synchroneity of the data. Figure 18 illustrates such a relationship. In this case, there were only four sampling events where the data were synchronous. These data result in a linear relationship with a correlation coefficient of 0.7539 with 2 degrees of freedom. This correlation is not statistically significant owing to the small sample size (n = 4).

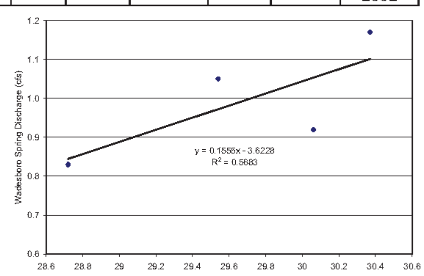

Figure 20. Relationship of discharge from Wadesboro Spring to water levels in the upper Floridan aquifer system at well 15891284-UF.

Water Quality and Chemical Fingerprinting

Table 2 summarizes the quality of water discharging from Wadesboro Spring. Note the moderately elevated sulfate and orthophosphate concentrations. These analytes

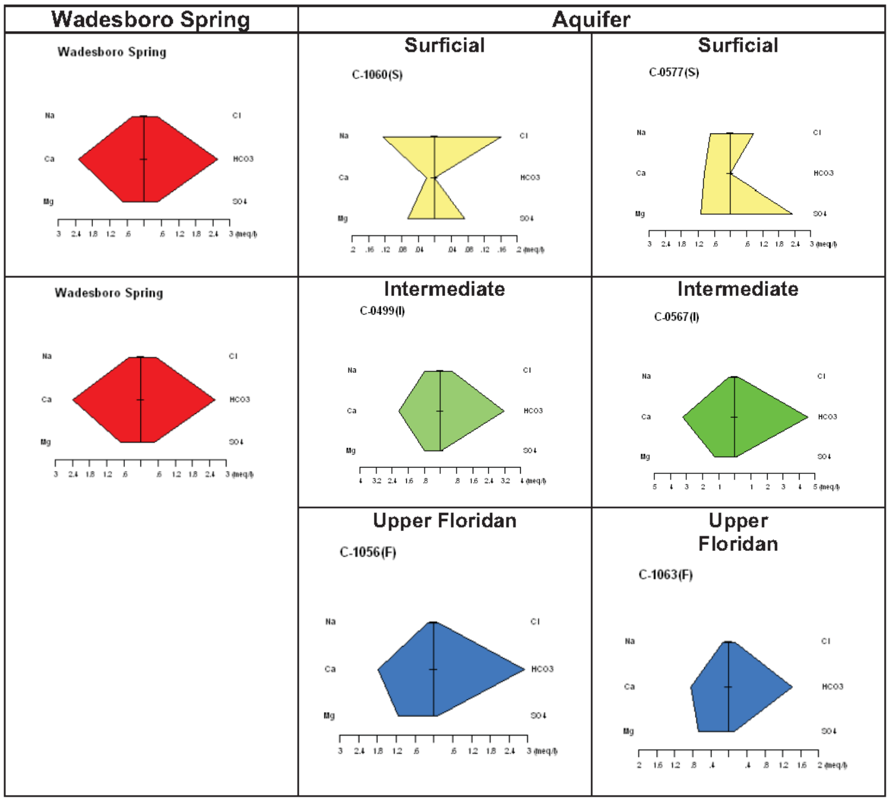

Figure 21. Comparison of the quality of water discharging from Wadesboro Spring to sample water from wells in the three aquifer systems of Clay County, Florida. Data are from the SJRWMD.[4]

suggest that the Hawthorn Group (intermediate aquifer system) has a strong influence on water quality. Magnesium concentrations appear low relative to calcium (Figure 13), however. The Piper diagram (Figure 15) also indicates elevated sulfate relative to the upper Floridan aquifer system

Stiff diagrams were used to chemically fingerprint water from Wadesboro Spring and compare the chemical patterns to water from the three aquifer systems found in Clay County. The Wadesboro spring water (Figure 21) most closely matches the water quality in the Clay County intermediate aquifer system wells. The low ionic strength, Na-Cl aerosol signature is masked by the higher ionic strength, Ca-Mg-HCO_3 pattern. Although the Wadesboro Spring Stiff diagrams appear similar to the Floridan aquifer system water, the upper Floridan aquifer system water samples have somewhat lower ionic strengths.

The Piper diagram comparison (Figure 15) indicates that Wadesboro Spring closely matches intermediate aquifer system water in terms of cation ratios, and both the intermediate and upper Floridan aquifer systems in terms of anion proportions.

Table 3. Chemical quality of water discharging from W. W. Gay Springs as tabulated by the SJRWMD (2009a).

Analyte	Min.	Period
Water temperature (deg. C)	22.5	2000
Specific conductance (field; µmhos/cm @ 25°C)	344	2000
pH (field)	7.06	2000
Discharge (cfs)	0.14	1993
Calcium (dissolved; mg/L)	49.4	2000
Magnesium (dissolved; mg/L)	6.0	2000
Sodium (dissolved; mg/L)	13.2	2000
Potassium (dissolved; mg/L)	n.a.	
Chloride (mg/L)	37.8	2000
Sulfate (mg/L)	19.8	2000
Fluoride (dissolved; mg/L)	0.12	2000
Nitrate + nitrite (mg/L)	n.a.	
Orthophosphate (mg/L)	0.06	2000
Alkalinity (total; mg/L as $CaCO_3$)	118.3	2000

n.a. = not analyzed

Therefore, the chemical data (low ionic strength, Ca-Mg-HCO_3 ratios and proportions) suggest that the water discharging from Wadesboro Spring is derived from a carbonate-rich stratum (limestone or dolostone) in the intermediate aquifer system.

W.W. GAY SPRINGS

Setting

W. W. Gay Springs (also known as Camp Echockotee Springs) is located in Camp Echockotee Boy Scout reservation on the northwestern shore of Doctors Lake (Figure 16). Two springs, W. W. Gay Spring #1 (Figure 22) and W. W. Gay Spring #2 (Figure 23), occur in a heavily wooded ravine where they are separated by approximately 100 feet.

Figure 22. Structure surrounding W. W. Gay Spring #1.

Figure 23. Spring boil at W. W. Gay Spring #2.

Spring #1 has been heavily modified by the construction of a wooden platform that surrounds the spring (Figure 22). Discharge from the spring was through a pipe system that penetrates the circular enclosure. Discharge is to a small spring run/slough that discharges to Doctors Inlet. On August 11, 2009, this spring was not flowing, apparently because of sediment blockage, and the outflow pipe had been disassembled. The camp manager indicated that flow from spring #2 increased when flow from spring #1 was blocked. It appeared that flow in spring #1 could be restored by removal of the sediment and re-constructing the outfall system.

Spring #2 consists of two sand boils (Figure 23) and a small seep (Scott et al., 2004; see also the image on the cover of this report). Other seeps drain from the ravine slopes along the spring run. The springs and seeps emanate from the surficial aquifer system (SJRWMD, 2009a).

The area around W. W. Gay Springs is mapped as undifferentiated Quaternary sediments with Holocene sediments along the St. Johns River (Scott et al., 2001). These sediments consist of quartz sand and are quite permeable. It appears from examining exposures at Green Cove Spring and Wadesboro Spring that the undifferentiated

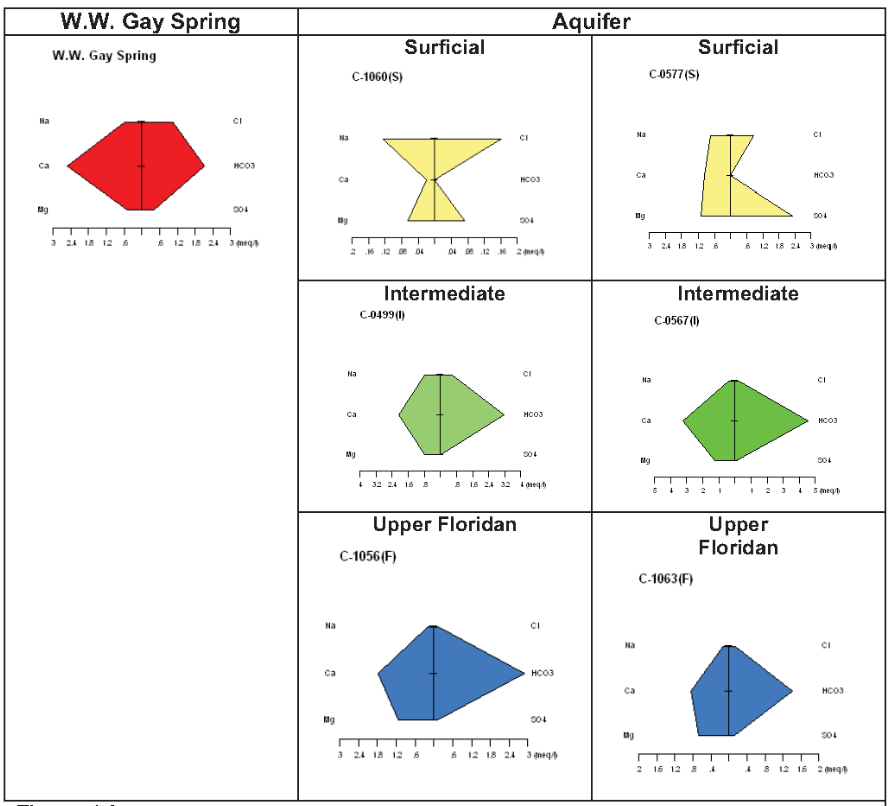

Figure 24. Comparison of the quality of water discharging from W. W. Gay Springs to sample water from wells in the three aquifer systems of Clay County, Florida. Data are from the SJRWMD.[4]

sediments overlie shallow Hawthorn Group sediments. However, there was no evidence of exposures of the Hawthorn in, or near, the W. W. Gay Springs. The hydraulic conductivity contrast between the permeable, surficial sands and the lower permeability Hawthorn Group sediments forces the water to the surface in low-lying areas.

Monitoring Data

Discharge from W. W. Gay Spring was measured in 1993 by the U.S. Geological Survey. Water quality was sampled by the SJRWMD in 2000.

Discharge

The 1993 discharge measurement indicated that the combined flow of the two springs was 0.14 cfs (0.09 mgd). Therefore, the W. W. Gay Springs constitute a 5^{th} magnitude spring group, based on one sample.

Flow-Discharge Relationships

With only one discharge measurement, it is not possible to compare the discharge relationships of the springs with the nearby aquifers.

Water Quality

Table 3 illustrates the water quality data from the District's 2000 sampling event. Note that the water shows elevated calcium and alkalinity relative to typical surficial aquifer system water derived from sand aquifers (Upchurch, 1994a, and b). This is most likely either a result of contact with limestone or shell within the surficial aquifer (Phelps, 1994) or irrigation with Floridan aquifer system water in the nearby residential areas.

Both the Piper (Figure 15) and Stiff (Figure 24) diagrams of W. W. Gay Springs water are suggestive of the flux of Floridan aquifer system water into the surficial aquifer system. Note that the Stiff diagram for W. W. Gay Springs shows the typical diamond shape of $Ca\text{-}HCO_3$ water, but that there seems to be some enrichment of Na and Cl.

SHANDS BRIDGE SPRING

Spechler (1996) investigated the possibility of springs and sinkholes in the St. Johns River along a reach from Jacksonville to Green Cove Springs. One spring was located near the Shands Bridge, offshore from Green Cove Springs (Figures 1 and 25). The occurrence of this spring is discussed below for completeness. Other than evaluation of the stratigraphy of the strata near the spring, no attempt has been made to determine the source(s) of water emanating from the spring.

Based on the occurrence of Hawthorn Group sediments exposed in Green Cove Spring and Wadesboro Spring, the St. Johns River is cut into the top of the Hawthorn Group sediments in this area. Holocene (11,500 years ago to present) sediments cover the river bottom. The spring issues from a shallow depression in the river bottom under approximately 30 feet of water (Spechler, 1996). When Spechler characterized the spring, the vent had a significant amount of debris accumulated around it making it difficult to accurately describe the spring and take water samples. One water sample was recovered and analyzed. Spechler (1996) opined that the source of the Shands Bridge Spring flow was from the Florida aquifer system.

Figure 25. Location of the Shands Bridge Spring (Spechler, 1996).

Comparison of the plotted position of the Shands Bridge Spring data point on Spechler's (1996, Figure 11) Piper diagram with the data presented in Figure 13 shows that Spechler's analysis most closely plots with surficial aquifer system water rather than Floridan or intermediate aquifer system water. Gary Maddox (Florida Department of Environmental Protection, pers. comm., 2009) questions the analysis based on the sampling method and possible contamination from river water. The comparison utilizing Piper diagrams supports the Maddox opinion.

Discharge from Shands Bridge Spring was estimated at 1 cfs (0.646 mgd). No further investigations have occurred.

Part of the Spechler (1996) investigation was to locate karst features in the river using seismic techniques. Locating karst features is important in determining possible flow from the Floridan aquifer system into the river or reduction of spring flow due to groundwater withdrawal. Spechler (1996) reported that some karst features were present in the river bed. Dr. Thomas L. Dobecki, SDII Global Corporation's Senior Principal Geophysicist, examined published examples of Spechler's seismic lines. His interpretation of the seismic data is that the data are not good and the features identified are probably not real. Using this interpretation and the known thickness of the Hawthorn Group in the area, the existence of any direct hydraulic connection from the surface with the Floridan aquifer system at the Shands Bridge Spring is doubtful.

MARION BLUE SPRING

Marion Blue Spring (Figure 2) is located on the banks of the Oklawaha River in Marion County. The spring has been flooded by the Rodman Reservoir and is accessible by boat. A faint boil is reported to be visible (SJRWMD, 2009b).

According to the St. Johns River Water Management District (2009b), discharge has been measured twice (Oct. 1937 and May 1999). Discharge was 10.6 and 5 cfs, respectively, so the spring is 3rd magnitude. No water quality data are available.

Given the location of the spring near the top of a thick section of Hawthorn Group sediments, it is apparent that this spring drains a permeable zone in the intermediate aquifer system. This spring is in a geologic setting similar to Orange and Camp Seminole springs, which are clearly intermediate aquifer system springs.

CAMP SEMINOLE SPRINGS

Camp Seminole Spring is located on private property (a Girl Scout camp) and drains to nearby Orange Creek (Figure 2). It is a 4th magnitude spring with a measured discharge of 0.79 cfs in May 1999. Water quality data provided by the St. Johns River Water Management District (2009b) are incomplete, but ortho-phosphate and fluoride concentrations are suggestive of the intermediate aquifer system (Lawrence and Upchurch, 1982; Upchurch, 1992a).

ORANGE SPRING

Orange Spring is also a 3rd magnitude spring on the banks of Orange Creek (Figure 2). A bottled water plant withdraws water from the spring, which has an average discharge of 6.4 cfs (22 measurements). The cavern of the spring is in Hawthorn Group sediments (SJRWMD, 2009b) and water quality data show ortho-phosphate and fluoride concentrations that are consistent with the intermediate aquifer system.

WHITEWATER SPRING

Whitewater Spring is located in Ravine Gardens State Park near Palatka, Putnam County. The spring consists of a series of seeps and artesian wells (SJRWMD, 2009c). Discharge was measured by the St. Johns River Water Management District (2009c) at 1.4 cfs. There are no water quality data. The St. Johns River Water Management District has determined that the spring is a surficial aquifer spring (SJRWMD, 2009c).

SUMMARY

The correlations of spring discharge with aquifer water levels and the chemical fingerprinting strongly indicate that Green Cove Spring and Wadesboro Spring discharge water derived from the intermediate aquifer system, which consists of permeable sand- and carbonate-rich strata within the generally clay-rich Hawthorn Group.[14] Water discharging from the W. W. Gay Springs is derived from the surficial aquifer system, but it has a chemical signature that appears related to either a basal limestone unit of the

[14] These strata are illustrated and discussed in Appendix B.

surficial aquifer or the Floridan aquifer system owing to irrigation with Floridan water within the springshed.

Shands Bridge Spring is unlikely to be discharging Floridan aquifer system water because of the great thickness of Hawthorn Group sediments that overlie the Floridan aquifer system. It is more likely that the Shands Bridge Spring is an intermediate aquifer system spring that is affected by mixing with surface water.

Orange, Marion Blue, and Camp Seminole springs have not been well studied, but their geologic settings and groundwater quality data show clear provenance in the intermediate aquifer system. Whitewater Spring is also poorly known, but its discharge clearly originates from the surficial aquifer system.

All of the springs characterized in this report are unlikely to be affected by groundwater withdrawals from the upper Floridan aquifer system because the water discharging from the springs neither emanates from the Floridan nor do their discharge patterns correlate with Floridan aquifer system water levels. This lack of correlation is due to the thickness of the Hawthorn Group sediments that make up the intermediate aquifer system and confining unit. Therefore, there is a low probability that groundwater withdrawals from the Floridan aquifer system will have a direct affect on the discharge of these springs.

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