A CHARACTERIZATION OF JACKSON BLUE SPRING, JACKSON COUNTY, FLORIDA

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Jackson Blue is a first magnitude spring in the karst terrane of northeast Florida. Previous studies have identified inorganic fertilizer as the source of high nitrate levels in the spring. Agricultural land use and karst vulnerability make Jackson Blue a good model for conservation concerns. This work offers an aggregation of studies relating to the springshed, providing a valuable tool for planning and conservation efforts in the region. An analysis of nitrate levels and other water quality parameters within the springshed did not reveal significantly different values between agricultural and forested land use areas. Confounding factors include: high transmissivity in the aquifer, interspersed land use parcels, and fertilizer application in forested areas due to commercial pine stand activity.

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In completing this work, great appreciation and acknowledgement is due my parents and grandparents, who have always encouraged me to reach beyond that within easy grasp, and for their continued support of my educational goals. Immeasurable thanks are also extended to Michael David, without whom each day would not be the same.

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CHAPTER 1

INTRODUCTION

Jackson Blue Spring and the Vulnerability of Florida Groundwater

Water is an essential requirement for the functioning of metabolic processes in all known organisms; of those which are primarily terrestrial, fresh water is a major limiting factor of life. Roughly 30% of fresh water on earth occurs as groundwater (Gleick, 1996). In the state of Florida, underground aquifers provide nearly 100% of the state's drinking water and more than 60% of the state's fresh water usage in agriculture and industry (Servone, 2010). Increasingly, anthropogenic activities strain these invaluable groundwater supplies, via both pumping and contamination. Consumer and agricultural demands result in the removal of billions of gallons of subsurface freshwater annually: 4.3 billion gallons daily in 2005 (Marella, 2008). For many years, contamination of aquifers was not of particular concern because it was believed that the recharge was sufficiently slow as to remove pollutants through natural filtration. While there is significant residence time for some portion of aquifer waters (Katz, 2001; Katz *et al.,* 2005), recharge rates and the porosity structure of bedrock have been estimated through dye traces and additional study (Wilson and Skiles, 1988; Connair and Murray, 2002) to also reveal a much shorter timeframe. In Florida, the groundwater is highly vulnerable in many areas due to the karst terrane; the bedrock is very porous and sinkholes are a common landscape feature, providing rapid access for contaminants into the underlying Floridan Aquifer and local water table, which is in many places close to the surface. The underground rivers which make up the aquifer frequently emerge as springs, with more than 700 naturally occurring across the state; of these, 33 are designated as first magnitude springs, with discharge in excess of 100 ft^3/min.

Nitrate is known to be a common contaminant in aquifers around the world (Spalding and Exner, 1993) and previous studies have revealed causation by agricultural activities (Vowinkel and Tapper, 1995). In the predominantly agricultural Florida county of Jackson, the principal source of nutrients in Jackson Blue Spring has been identified as inorganic fertilizer (Katz, 2004). Groundwater nitrate levels in Florida have steadily increased over the past several decades (Jones *et al*., 1996; Champion and DeWitt, 2000; Means *et al*., 2003), far exceeding the natural background concentrations of less than 0.1 mg/L (Maddox *et al.*, 1992; Katz, 2004). At an average of 3.3 mg/L, Jackson Blue Spring has the second highest nitrate concentration of the first-magnitude springs in the state; this represents a more than 30-fold increase over natural background levels.

Jackson Blue Spring is a valuable site for recreation and provides a window into the condition of the Floridan aquifer from whence it flows. An examination of the springshed and a study of the influence of land use on groundwater parameters can assist in development and conservation planning in order to best protect this vulnerable resource. The present study undertakes to gather the as of yet scattered data which exists, so that it may be more easily accessed by those in positions of impactful decision-making, and to investigate the relationship between agricultural land use and compromised water quality parameters.

Problem Statement

While prior scientific research has focused on generalized karst processes and hydrogeology, Florida geology, land use-water quality relationships, various regional spring inventories and groundwater chemical studies, no single published study has synthesized these works into a focused characterization of Jackson Blue Spring in its entirety. Florida recognizes both the inherent and economic value of its more than 700 natural springs and in 2001 the Florida Springs Initiative (FSI) received funding from the state legislature to study and preserve the quality of Florida's springs. Continued funding has been approved through 2010, but many of the working groups it established early on have seen their budgets cut as the national economic climate has come under duress.

Research Purpose

The purpose of this study is to characterize Jackson Blue Spring and its associated springshed in a comprehensive manner intended to provide a valuable tool in the planning arsenal for conservation and development planning purposes. This research aims to provide such a description, with the goal of further illuminating the importance of the preservation and restoration of this essential resource. Similar projects will benefit and support the conservation and preservation of other springs and springsheds; ideally such a characterization should exist for every major spring and for groups of less significant springs by springshed as tools for land use planning in terms of sustainable development.

Research Questions

The research questions involved in this study included:

1) What information is available about the geology, hydrology, stygobytic biota, discharge and water quality, and subterranean cave exploration pertaining to Jackson Blue Spring?

2) Is there a relationship between land use in the Jackson Blue Springshed and measured water quality parameters gathered from monitoring wells in the springshed?

3) To the extent that relationships exist, how might they be explained and what mitigation measures might be implemented in the future?

Research Objectives

To address these questions, several objectives were needed:

1) Gather and synthesize broad research on Florida geology, karst processes and hydrology, discharge data, biota inventories, and exploration, to focus on Jackson Blue Spring.

2) Gather water quality data from Jackson Blue springshed monitoring wells.

3) Delineate land use categorization at monitoring well locations.

4) Run statistical analyses to determine relationships between water quality parameters and monitoring well designated land use.

CHAPTER 2

STUDY AREA

This study and characterization was conducted in Jackson County, located in the northeastern corner of the Florida panhandle, bordering Alabama to the north and Georgia to the east (Figure 1). Florida springs are viewed as important indicators for changes in regional environment, as the anthropogenic impacts on groundwater over large areas are assimilated in their discharge. Jackson County has more springs within its borders than any other county in Florida, with at least 68 springs identified (Barrios, 2009). Jackson Blue Spring was chosen as the subject of this research because it is a good bellwether for Florida springs: it is a first magnitude spring located in an area where the underlying Floridan aquifer is unconfined and therefore highly vulnerable. Jackson Blue Spring is also known to have a high nitrate level while in a region where agricultural land use percentage is high; this relationship is correlative and may be applied to other areas in the state, as agriculture is a significant industry in both Jackson County and much of Florida. Additionally, Jackson Blue Spring is the headspring for the nearly five mile long Merritt's Mill Pond, which has been well frequented for recreation by the local population and visitors alike for many generations, adding further public interest and inherent value. The following section describes Florida's geography and karst, the karst of the Florida panhandle, and the features of Jackson County and the Jackson Blue springshed.

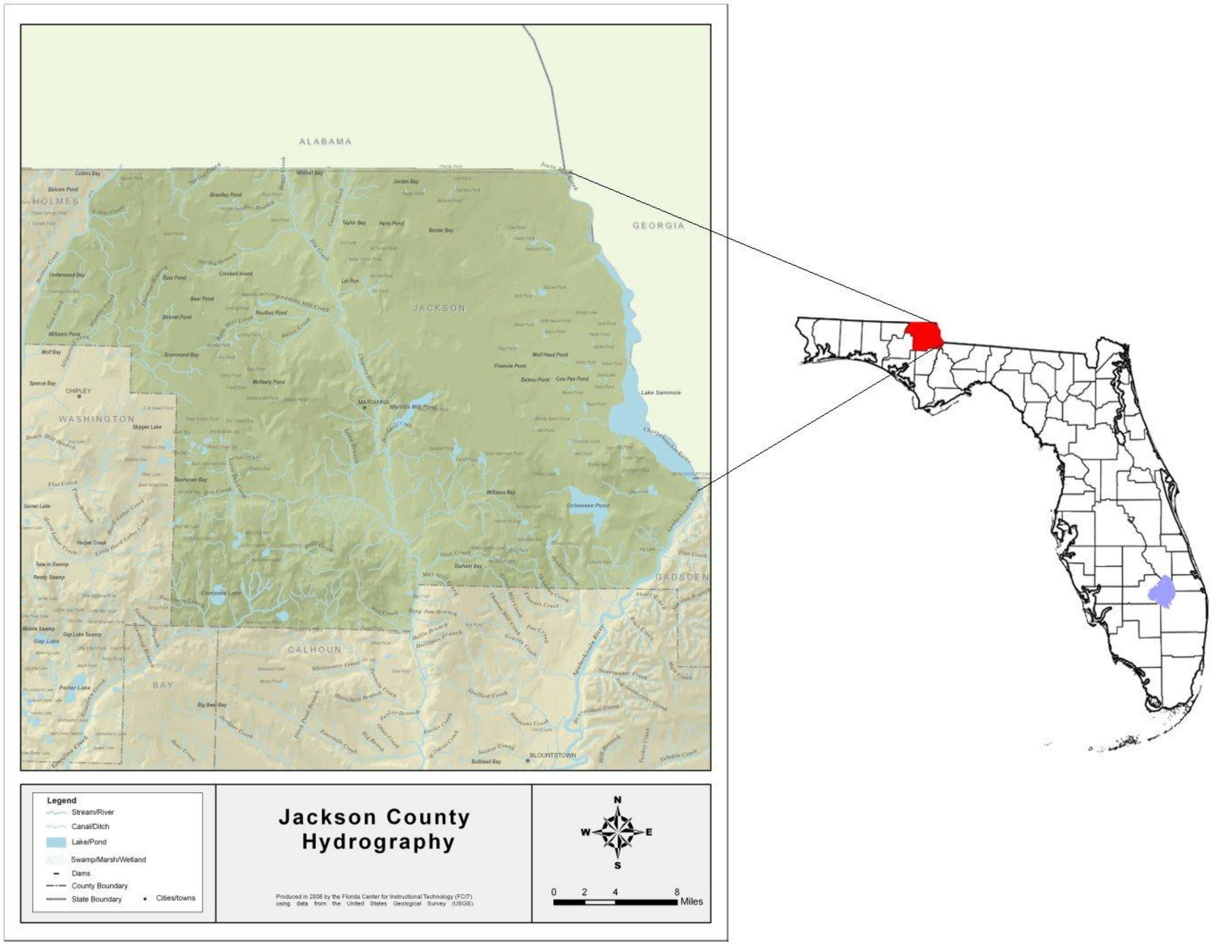

FIGURE 1. Jackson County, Florida, Geographical Location and Waterways (adapted from Florida Waterways: Jackson County, 2008. Florida Center for Instructional Technology: map #f11244).

Florida Geography and Climate

The state of Florida has a total area of 58,560 square miles, of which 4,308 (13.5%) is water area: more than 11,000 miles of rivers, streams, and waterways earn the state third position in the nation for land area covered by water. The St. Johns River is the longest river in the state at 273 miles and Lake Okeechobee is the largest lake, covering 700 square miles (it is also the second largest freshwater lake wholly within the United States). The longest land distance from north to south measures 447 miles and the widest east-west girth spans 361 miles in the panhandle. Florida has over 200 springs and ranks first in the nation with 33 first magnitude springs. The highest natural point in Florida is Britton Hill in Walton County, elevation 345 feet.

The climate of Florida is hot-humid, with abundant sunshine, large bodies of water and in excess of 50 inches annual rainfall. Average temperatures range from 55˚F (13˚C) in the winter to 90˚F (32˚C) in the summer. Although among the wettest states in the U.S., great variations in total annual precipitation may lead to floods one year, followed by droughts the next (Black, 2003). The panhandle has the most rain; the Keys the least. The winter months are typically cooler and drier. In the Florida panhandle, rainfall averages 56-70 inches annually.

Jackson County has a total area of 955 square miles, of which 39 (4%) is water area. The longest land distance from north to south measures about 30 miles, and the widest east-west girth spans some 40 miles across. Alabama forms the northern county border and Georgia the eastern, where the Chattahoochee River and Lake Seminole form the state line. In the northwest, the border with Holmes County, FL is drawn based on Holmes Creek; other borders are shared with Florida counties Washington, Bay, Calhoun, and Gadsden. The Chipola River runs south through the center of the county and Interstate 10 cuts centrally running east-west. Jackson County is home to the most springs in the state of Florida, boasting at least 68 within its boundaries. Average temperatures range from 45˚F in the winter to 88˚F in the summer, with high humidity and heat indexes. The average annual rainfall in Jackson County is 57 inches, of which an estimated 10-20 inches per year recharges the Floridan Aquifer in the outcrop areas (Wagner, 1984; Barrios, 2010). In those areas which are confined, this recharge enters the Surficial aquifer. About 60% of the annual rainfall occurs during the five month rainy season, which is typically from early December to late April; heavy rain associated with these storms causes increased dissolution of the area's limestone (Hyde *et al*., 1977).

Florida Geology and Geomorphology

Modern geological research indicates that the basement rocks of Florida make up an exotic terrane, meaning that the land mass originated separately from the rest of North America. This is a deviation from previous thinking, which, until 40 years ago, speculated the basement of the peninsula was an extension of the igneous, metamorphic, and sedimentary rocks of the Appalachian Mountains (Lane, 1994). More recent study has revealed that South Florida is underlain primarily by basalts which were formed during the Late Triassic and Early Jurassic Periods. Some of these basalts are also found deep in northern areas of the state, interlayered with Mesozoic sedimentary rocks: granite formed during the Early Cambrian period makes up most of the central region and reaches into parts of the panhandle (Lane, 1994). Most of the north and panhandle regions of the state are underlain by undifferentiated sandstones, shales, limestones, and evaporates more than 2,000m thick of the Lower Cretaceous Period (Randazzo, 1997).

Geochemical and geochronological data correlates Florida basement rocks to the basement rocks of West Africa (Lane, 1994; Smith and Lord, 1997), and paleontological analyses of Florida and Africa by Cramer (1971), Pojeta *et al.* (1976), and others indicate that the Florida Platform block was originally part of the West African continental margin near Senegal. During the Triassic breakup of Pangaea, the block rifted from the African margin (Smith and Lord, 1997) and gradually migrated to its present-day location. Further supporting evidence for this theory is provided by paleomagnetic data (Van der Voo *et al*., 1976; Opdyke *et al*., 1987), and comparisons of isotopic ages (Dallmeyer, 1987; Dallmeyer *et al*., 1987).

The Florida Peninsula as it exists today reflects approximately half of the underlying Florida Platform; the currently submerged portions extend 100 miles west of Tampa and three to five miles east of Miami. For tens of millions of years, the region has been alternately flooded by shallow seas and exposed as dry land. Marine processes have been the dominant geomorphic influence on the formation of the peninsula; erosion and deposition from ocean currents shaped the seabed while submerged, and subsequent erosional forces have affected the landform while exposed. The peninsula is at a very low elevation, averaging 100 feet with the highest point of 345 feet found in the northern panhandle region, in Walton County. Because of the low elevation, minor changes in sea level can have a significant effect on coastline locations, and the exposed area of the Florida Platform has changed dramatically throughout history (see Appendix A). As a result, a number of marine terraces have been defined in the state (Figure 2) and fossiliferous outcroppings are significant. The original source of all freshwater in Florida is precipitation (Miller, 1997). Drainage systems vary throughout the state; in the panhandle, dendritic drainage patterns dominate, indicating a uniform erosion resistance and a lack of underlying influential structural control (Schmidt, 1997). The soils are dominantly well drained to somewhat poorly drained, and have a sandy surface layer and a loamy subsoil; the natural vegetation is dominantly mixed pine and hardwood forest. Much of the region has been cleared and is used for crops and pasture (Duffee *et al*., 1979).

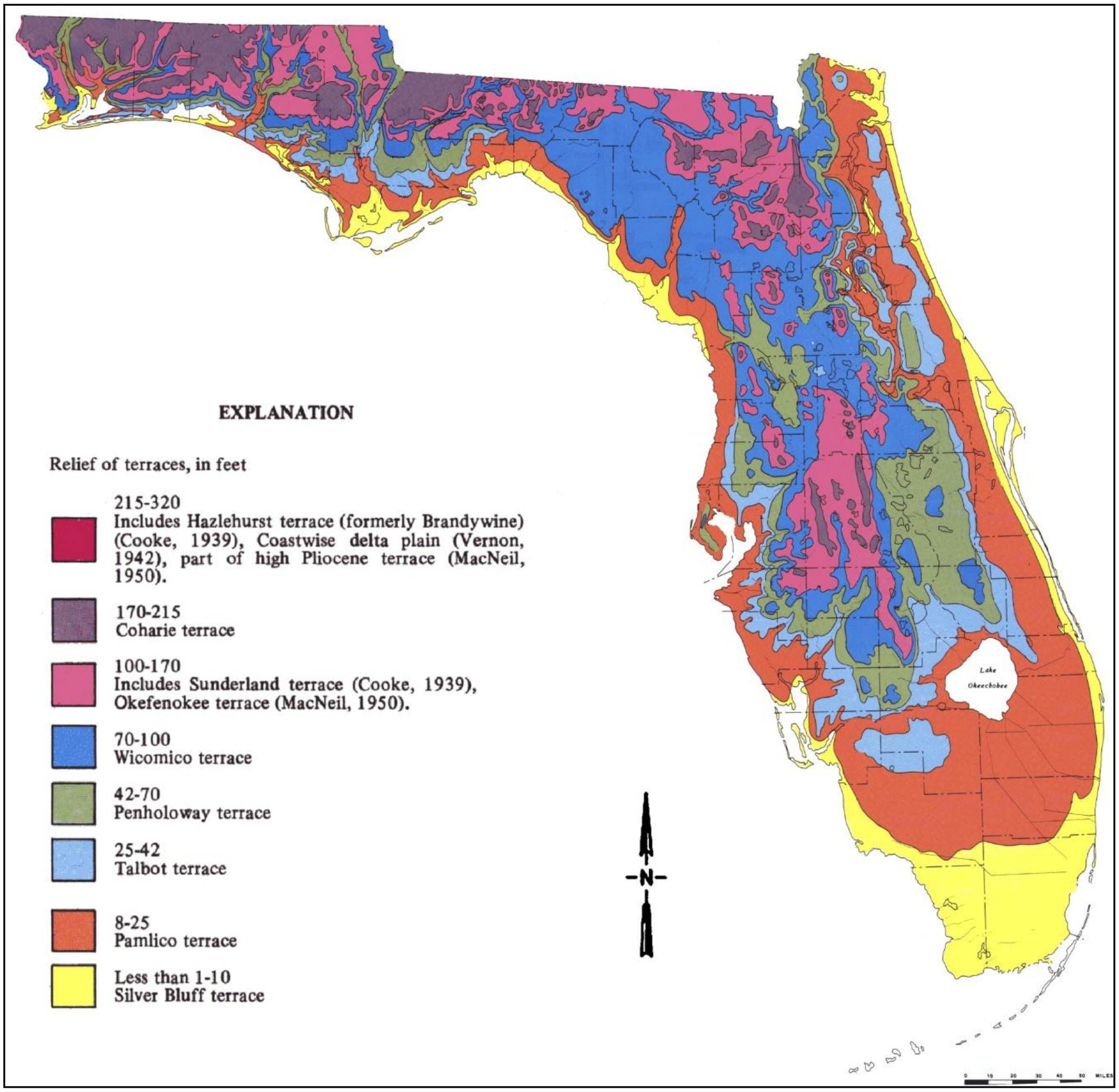

FIGURE 2. Terraces and Shorelines of Florida (adapted from Healy, 1975).

Local Hydrogeologic Setting

Jackson Blue Spring is located within the Dougherty Karst Plain District and the semi-confined state of the Floridan Aquifer across the region allows for significant local recharge; the same condition makes the aquifer particularly vulnerable to contamination resulting from land use on the surface. Figure three illustrates Jackson County geologic units: at the head of Jackson Blue Spring are Suwannee Limestone (Ts) and undifferentiated Suwannee Limestone and Marianna Limestone (Tsm) consisting of white to cream-colored, poorly to well indurated, variably fossiliferous limestones (grainstone, packstone, wackestone and mudstone) (Miller, 1986). The oldest exposed unit is found to the north: Ocala Limestone (To) exhibits white to gray, fossiliferous, moldic limestone, variable from packstone to grainstone. Younger formations offlap the Ocala Limestone in succession to the south and also progressively thicken (Wagner, 1984; Scott, 1997). The surrounding area is part of the Chattahoochee formation, which consists of dolostone with subordinate limestone, clays, and silts. The springshed within Florida to the northeast is residuum on Eocene (Tre): clay, sandy clay, fossiliferous, varies from poorly recrystallized to well recrystallized packstone to grainstone (Lane, 1994). The whole area is very fossiliferous and this can be witnessed firsthand in the subterranean cave of Jackson Blue Spring. Publications of the region are numerous and include significant work by the federal and state geological surveys. Treatments of the region include work by Matson (1913), Moore (1955), Randazzo and James (1997), and Bryan *et al.* (2008).

Precipitation across Florida exceeds runoff because the underlying limestone is so near the surface; the high porosity of the rock, overlain by permeable sands, results in speedy drainage (Miller, 1997). Karst topography generally lacks well developed rivers for this reason (Schmidt, 1997). This paradigm provides the opportunity for significant aquifer recharge and also makes the groundwater vulnerable to contamination. Also as a result, drainage density (stream length/contribution area) is low in most of the state; surface water features include extensive wetlands and lakes

(Miller, 1997). The limestone layer is honeycombed with underground rivers, and springs and sinkholes exist where these conduits reach the surface.

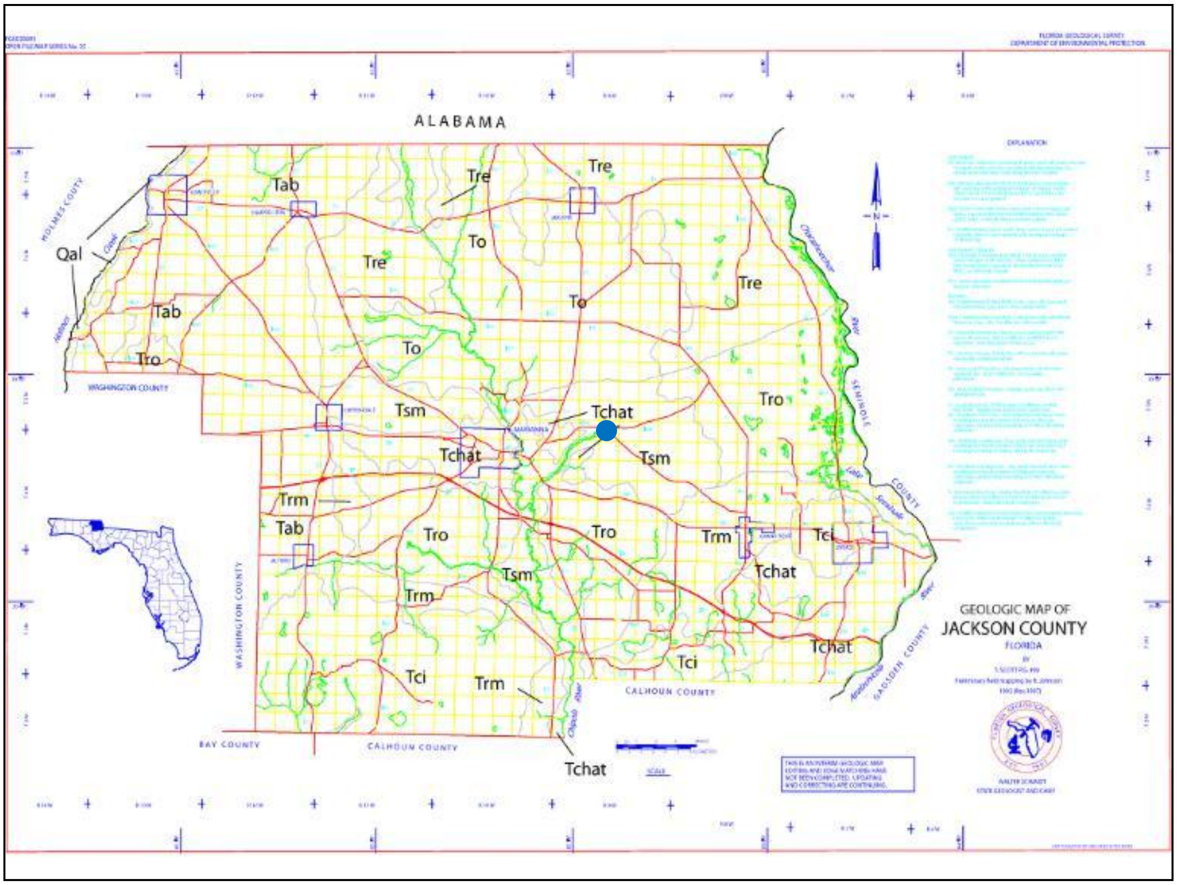

FIGURE 3. Geologic Map of Jackson County, Florida (Scott, 1997). Approximate location of Jackson Blue Spring has been added.

Florida Aquifers and Aquifer Systems

There are five principal aquifers or aquifer systems in Florida: the Surficial aquifer system, the Sand and Gravel aquifer, Biscayne aquifer system, the Intermediate aquifer system, and the Floridan aquifer (FDEP, 2011). Figure five illustrates the locations of the aquifers and aquifer systems. An aquifer system consists of two or more aquifers with sufficient hydraulic connection that groundwater flow conditions are similar and changes in one aquifer changes the other(s) (Miller, 1997). Four of Florida's aquifers crop out at the land surface or are covered by only a thin layer of soil and/or weathered rock. The fifth, the intermediate aquifer system of southwestern Florida, is completely confined; these aquifers lie between the surficial aquifer system and the Floridan aquifer system and are primarily comprised of permeable layers of sand, shell, and limestone separated by confining units (FDEP, 2011).

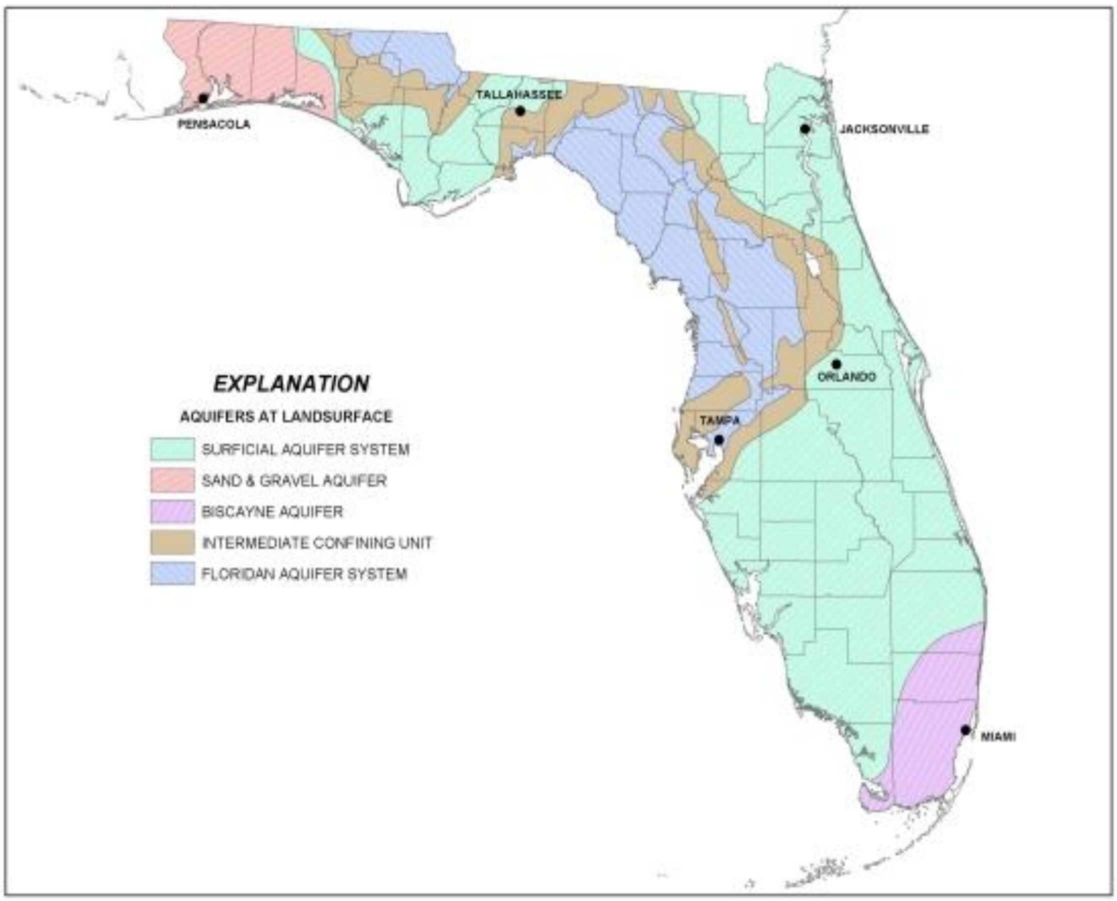

FIGURE 4. Florida’s Aquifers. The highly productive Floridan aquifer underlies the entire state and a significant area to the north; it is overlain where other aquifers are shown. The portion of the Floridan aquifer beneath the southern third of the state is nonpotable water, due largely to salt intrusion (FDEP, 2011a).

The undifferentiated Surficial aquifer system includes all aquifers that consist primarily of unconsolidated sand and clastic sediments, are unconfined and at the land surface, and are not included in the Biscayne or Sand and Gravel aquifers. These aquifers include the water table and are recharged by precipitation; temperature and flow are rapidly affected by precipitation recharge. The Sand and Gravel aquifer underlies, in whole or part, the four westernmost counties in the panhandle of Florida and supplies most water in these counties, including the city of Pensacola. In most of its 2,400 square mile area the Sand and Gravel aquifer is separated from the underlying Floridan aquifer by a confining unit; however, this layer tapers out at the northeast edge and the two aquifers are in direct hydraulic contact (Miller, 1997). The Biscayne aquifer, also a surficial aquifer, extends beneath more than 3,000 square miles of southern Florida and the Atlantic Ocean. The water demands in this region are very intense, supplying the counties of Dade, Broward, Palm Beach, and Monroe, as well as the Florida Keys. In some areas contamination has occurred from fuel spills, landfills, industrial discharge, and saltwater intrusion (FDEP, 2011a). The Intermediate aquifer system includes those aquifers in southwestern peninsular Florida which are beneath the surficial aquifer system and above the Floridan aquifer. This system is wholly confined and provides water supplies to those areas where the Floridan contains brackish water or saltwater.

The Floridan Aquifer system is among the most productive in the world and underlies all of Florida, as well as reaching into a large area of Georgia, and parts of Alabama and South Carolina. The Floridan consists of a thick sequence of Paleogene carbonate rocks (limestone and dolomite) which thicken from 250 feet in the north region to over 3,400 feet in south Florida (Miller, 1990). These rocks are of variable permeability separated by those of low permeability; a relatively impermeable cap is formed in some areas by early Neogene siliciclastic sediments, creating confined conditions where the aquifer is characterized as artesian. In areas where the overlying confining beds are absent, the system is unconfined (Lane, 1994). Many cities in the state depend on the Floridan aquifer for fresh water supplies and approximately four billion gallons per day (Bgal/d) of water was withdrawn from the Floridan aquifer system in 2000; of this amount, 90% was withdrawn from the Upper Floridan (USGS, 2005).

In most places, the Floridan aquifer system can be divided in the Upper Floridan and Lower Floridan aquifers, separated by a less permeable middle confining unit (Miller, 1986; 1990). The Lower Floridan aquifer is lesser known because much of it contains salt or brackish water. The carbonate rocks of the Floridan aquifer system are generally soluble in slightly acidic groundwater. Dissolution begins as water moves through natural pore spaces and fractures, and continues to enlarge the spaces into passageways and caverns. Where groundwater circulation is most dynamic, enlarged solution openings and other karst features readily occur; in the Floridan aquifer system this occurs most in the areas where the confining layer is absent or less than 100 feet in thickness. This is apparent in the distribution of the large springs which emerge from the Floridan aquifer system: all of the first-magnitude springs in Florida issue from the Floridan aquifer system and in areas where the confining layer is thin or absent (Rosenau *et al*., 1977; Miller, 1990), including Jackson Blue Spring.

In areas where the Floridan aquifer system contains freshwater, it is the principal source of supply; in areas where saltwater is present, the aquifer has been used as a repository for treated sewage and industrial waste delivered by injection wells. Nearly 50% of water withdrawals in 2000 were for purposes of irrigation: agriculture, livestock, and golf courses. Withdrawals providing public supply totaled 33% and 14% were for industrial uses (Figure 5).

Intense pumping in select areas has lowered the potentiometric surface of the Floridan aquifer, resulting in some reversal of groundwater flow towards the pumping stations, where they were previously moving towards the coast; the most significant case has occurred in Fort Walton Beach (located on the Gulf Coast in the western panhandle) (Miller, 1990). The cumulative effects of large quantities of groundwater withdrawals from the Floridan aquifer system have caused extensive water-level drawdowns and saltwater intrusion in other areas as well.

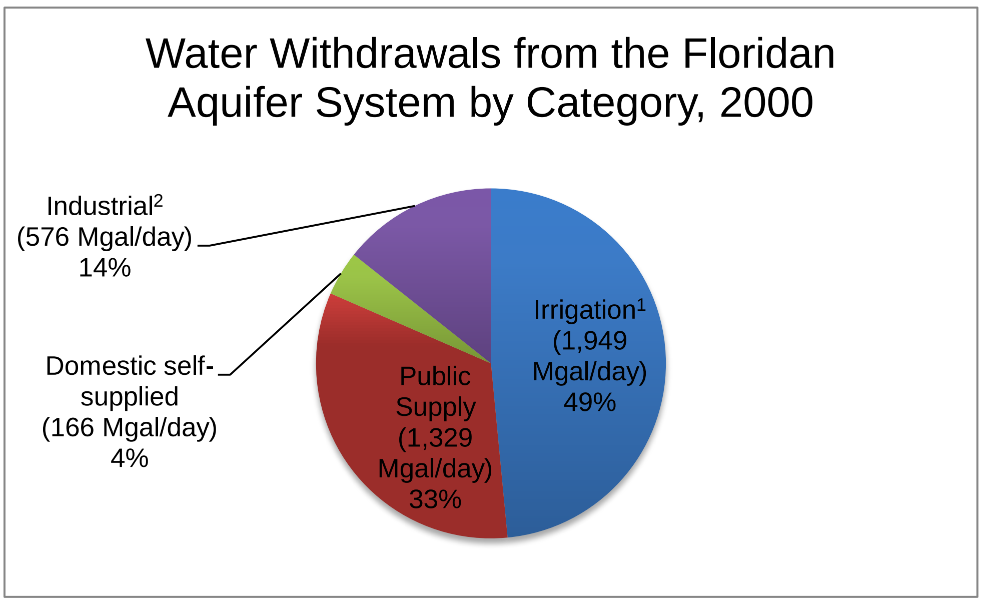

FIGURE 5. Water Withdrawals from the Floridan Aquifer System by Category, in millions of gallons per day. [1]Includes agricultural irrigation, livestock, and golf course irrigation. [2]Includes commercial, mining, and power generation (adapted from USGS, 2005).

The Floridan aquifer system underlies all of Jackson County and the confining layer is very thin or absent altogether. Jackson Blue Spring is a direct conduit from the aquifer system, combined with quick flow waters which enter the springshed locally during storm events via both sinkholes and the highly porous limestone overlain by sands. Because the confining layer is so thin, the area is particularly vulnerable to groundwater contamination from residential, commercial, and especially agricultural development and activities. This regional vulnerability is common to karst environments, with further elaboration following some background on the terrane.

Karst: Formation, Hydrology and Importance

An estimated 25% of the world's population depends on water from karst aquifers for daily use (Ford and Williams 2007). Subterranean karst aquifers have been included in the RAMSAR Wetland Classification System since 1971 (New Zealand Department of Conservation 1999), and provide habitat for underground-adapted aquatic fauna known as stygobites (Pipan 2005; Ford and Williams 2007; Pipan and Culver 2007).

Karst terrane is characterized by the process of chemical dissolution in carbonate bedrock, principally limestone ($CaCO_3$) and dolomite ($MgCaCO_3$), and is typified by features including sinkholes, subsurface drainage systems, disappearing streams, caverns and caves. Karst terrane is estimated to make up 10-20% of the earth's land area (Figure 6) (Ford & Williams, 2007) and most of Florida's.

The formation of karst landscapes in carbonate bedrock is driven by CO_2 content in the water, acquired by raindrops as they fall through the atmosphere and from the soil directly, forming a weak solution of carbonic acid ($H_2O + CO_2 = H_2CO_3$). Existing joints or fractures in the bedrock are exploited by the slightly acidic water, gradually dissolving the fractures into larger conduits and openings and forming underground drainage systems and caves.

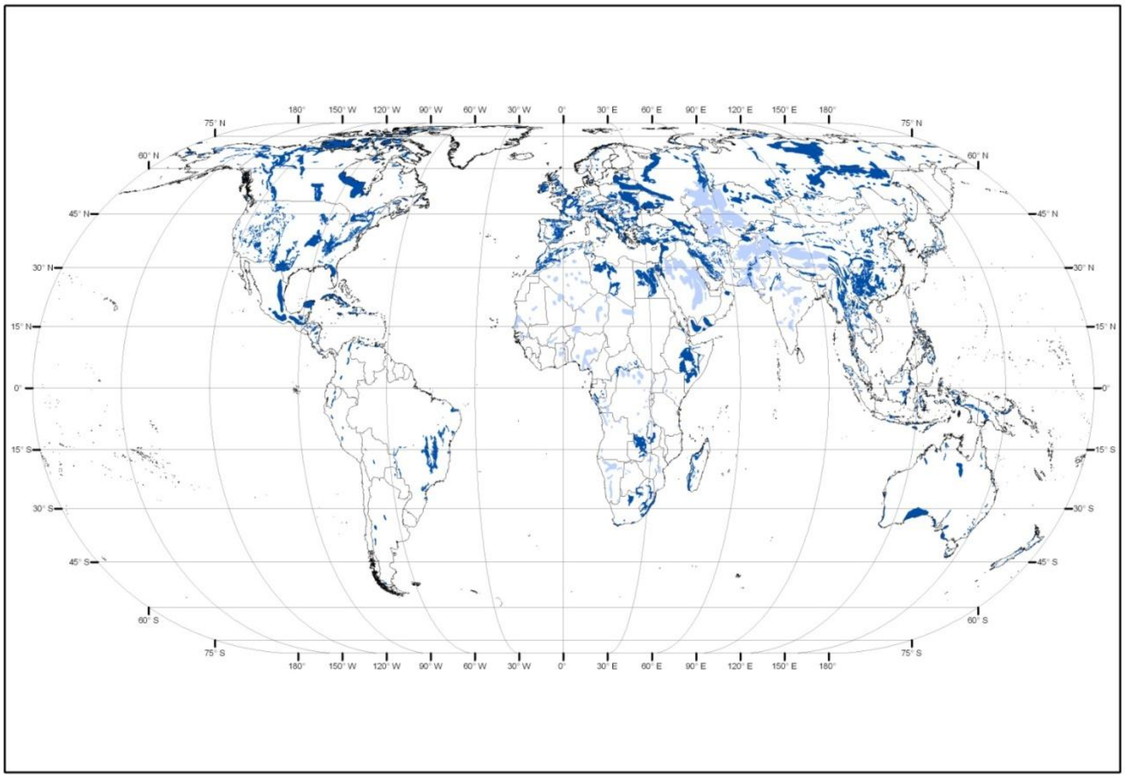

FIGURE 6. Global Distribution of Karst and Pseudo-Karst Terrane (Ford and Williams, 2007).

Carbonate karst aquifers are characterized by the open conduits which provide low resistance pathways for groundwater flow; often conduit flow has more in common with surface water than with groundwater (White, 2002). In the history of karst hydrologic study, conduits were at first ignored and assumed to have no interference with the active groundwater system; advances in cave exploration and survey, and systematic tracer studies in the 1970s and 1980s resulted in an overemphasis of the hydraulic properties of conduit systems. More realistically, karst hydrology includes conduit flow, fracture flow, matrix flow, and the coupling between all three, and this is the current concept of study regarding karst systems (White, 2002).

The time for evolution of a conduit, as is present in Jackson Blue Spring, is a complicated set of events facing numerous critical thresholds (Bosak, 2008). Three phases of speleogenesis are now generally accepted: (1) initiation: initial enlargement of a fracture to a critical size; (2) breakthrough: a fairly sudden transition to rapid dissolution, resulting in the growth of an incipient cave into a true cave, and (3) enlargement: the growth of a protoconduit/incipient cave to full conduit size (White, 1988; Palmer, 2002, Bosak; 2008).

While all landscapes are functioning systems in which the natural processes of energy, material and biota cycles are continual, karst landscapes are exceptionally complex due to their inherent porosity. The interrelated feedback that keeps other environments balanced is complicated by the direct links between surface and subsurface created by sinkholes, springs, and the general porosity of the landscape (Stokes *et al.*, 2010). In karst regions the relationship between surface and groundwater is intimately intertwined. Surface water becomes groundwater when it sinks into streambeds or sinkholes; groundwater becomes surface water when it emerges as springs into rivers or forming the headwater of streams. Because it is possible to delineate a drainage divide encircling the surface water basin based on topography, surface water is typically discussed in terms of the drainage basin; the identification of groundwater basins requires (sometimes) extensive dye tracer tests on sinking streams and cave streams, often supported by surveyed cave passage. Such delineations must be considered flexible, as changes in recharge and water table affect groundwater unlike the topographic highs identified in surface water basins. Determination of the groundwater basin, even if fluid in its boundaries, is useful in writing water budgets for karst springs (White, 2002). Karst spring discharge is often used to infer some of the physical and chemical characteristics of a karst aquifer, and springs with continuous flow throughout the year indicate that the aquifer has some potential for storage relative to the amount of water flowing through the system (Gunn, 2004; Stokes *et al.*, 2010).

The high degree of interaction between surface water and groundwater in karst aquifers renders them highly vulnerable to contamination (Lane, 1994; Mahler and Garnery, 2009). The amount of discharge waters which are 'quick flow' waters, which have moved through the system with little residence time, varies significantly between springs and temporally—ascertaining this proportion is necessary in the study of a spring because this is often the primary delivery source of concern with regard to contamination. Precipitation that moves through the system very quickly undergoes little filtration and little of any suspended pollutants can settle out; this proportion also can vary seasonally. Traditionally, determining these proportions is approached via hydrograph separation (Ashton, 1966), age dating (Katz *et al*., 2001), transfer function models (Long and Putnam, 2006), and geochemical tracers and chemical mixing models (Lakey and Krothe, 1996), sometimes in various combinations (Mahler and Garner, 2009). Mahler and Garner have also proposed using nitrate to quantify quick flow, as it is inexpensive and readily available, and their study supported a clear difference between storm- and nonstorm-flow measured nitrates.

CHAPTER 3

JACKSON BLUE SPRING

Jackson Blue Spring is located approximately five miles east of Marianna in Jackson County, Florida, and is the headspring for Merritt's Mill Pond, a roughly five mile long impoundment created by a weir at US 90 in Marianna. Eight lesser springs also feed the reservoir, which is a nationally recognized Redear Sunfish fishery as well as home to numerous other species desirable to sport fishermen. The spring pool is a highly modified swimming area encircled on three sides by concrete walls to reduce erosion, with diving boards and slides for recreation, and picnicking pavilions and restrooms on site (Figures 7 & 8). On the rest of the pond, boating is permitted and with the exception of some lakeside homes, much of the shoreline is undeveloped and in a natural state. The land surrounding Jackson Blue Spring is owned by the state and the park facilities are operated by the county under lease from the Board of Trustees (WSI, 2010).

Regional Land Use

Agriculture is the predominant land use in Jackson County, making up approximately 62% of the unincorporated area of the county, and introducing the byproducts of significant inorganic fertilizer (Katz, 2001; Barrios, 2006). Because of its importance for crop yields, high amounts of nitrogen are commonly applied to soils in agricultural production systems; when these amounts are in excess of the soil and plants' uptake needs, leaching and runoff into groundwater sources occurs. Most nitrogen leaching through agricultural soils occurs as NO_3^- when levels in the soil are high and the downward movement of water is sufficient to displace the available NO_3^-

FIGURE 7. Photograph of Merritt's Mill Pond, Jackson Blue Vent in Foreground. Taken from the north shore, looking southwesterly down the extant of the water body. The spring emerges from the cave below the diving board. Both recreational development of the spring pool and some invasive plant growth (primarily hydrilla) in the pond can be noted. (Photo: Harley Means, FDEP).

FIGURE 8. Photograph of the submerged Jackson Blue Spring Vent (adapted from WSI, 2010).

below the rooting depth of plants (Ritter and Bergstrom, 2001). Sandy soils in areas where precipitation exceeds evapotranspiration provide an environment with prime leaching conditions: Jackson County firmly meets these criteria.

The groundwater contribution area (springshed) for Jackson Blue Spring covers 109 square miles and approximates a tear-drop shape extending north to just above the Florida-Alabama state line (Chelette *et al*., 2002; Jones and Torak, 2004; Barrios, 2010) (Figure 9). This contribution area was refined in 2007 using LiDAR (Light Detection And Ranging) elevation data to increase the resolution of the Florida Aquifer surface contours to two feet (NWFWMD), revealing a somewhat different shape. Because of the variability inherent in spring basins due to changes in hydraulic head, rainfall, and aquifer use, the borders of the springshed presented here must be understood to be a snapshot, with some flexibility of borders existing in reality (Figure 10).

The Jackson Blue Spring springshed published in 2005 was analyzed using GIS and aerial photography to identify the land uses within the area. Based on this data, 50% of the basin is agricultural use (30% row crops, 12.5% other cropland, and 7.6% improved pasture land), 41% forested, 3.8% urban, 0.2% water and wetlands, and 0.2% other (Chelette *et al.*, 2002). Predominant agricultural crops are corn, peanuts and cotton.

A groundwater chemical characterization of the basin was conducted by the NWFLWMD in 2007: average water chemistry values from samples drawn in November 2006, February 2007, and June 2007 and conducted in accordance with FDEP standard operating procedures listed under DEP-SOP-002/02 (revised 6/28/2004) can be found in Table 1 (Barrios and DeFosset, 2007).

TABLE 1. Jackson Blue Spring Average Water Chemistry Values, 2006-2007.

Parameter	**2006-2007 Average**	**Parameter**	**2006-2007 Average**
Temperature (Celsius)	20.6	Kjeldahl Nitrogen (mg/L)	*U*
Conductance (uS/cm)	253	Magnesium (mg/L)	2.17
Dissolved O2 (mg/L)	8.07	Manganese (mg/L)	*U*
pH (su)	7.5	NO2NO3-N (mg/L)	3.2
Alkalinity mg/L	113	O-Phosphate-P (mg/L)	0.02
Ammonia-N (mg/L)	*U*	Organic Carbon (mg/L)	*U*
Arsenic (ug/L)	*U*	Potassium (mg/L)	0.35
Barium (ug/L)	5.8	Silica (mg/L)	6.2
Boron (ug/L)	*U*	Sodium (mg/L)	1.77
Caffeine (ug/L)	*U*	Strontium (ug/L)	35.3
Calcium (mg/L)	48.7	Sulfate (mg/L)	1.02
Chloride (mg/L)	4.2	TDS (mg/L)	147
Color (PCU)	*U*	Total-P (mg/L)	0.02
Fluoride (mg/L)	*U*	TSS (mg/L)	*U*
Iron (ug/L)	*U*	Zinc (ug/L)	*U*

U = Material was analyzed for but not detected.

FIGURE 9. Approximated Jackson Blue Spring Basin (adapted from Barrios, 2009).

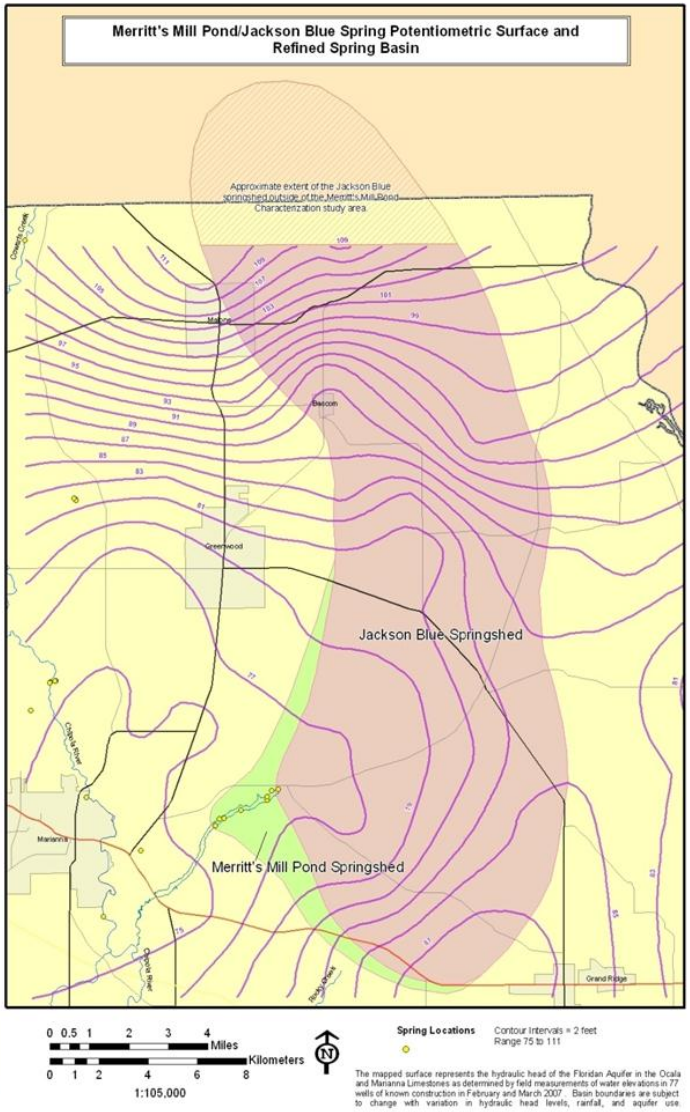

FIGURE 10. Refined JB Spring Basin Using LiDAR (Barrios, 2010).

As of the 2010 U.S. Census, the population of Jackson County numbers 49,746. Land use planning in the county is governed by Jackson County EAR-based amendments adopted in 2001 and amended as needed, most recently in 2010. Population growth is slow in the county, with over 50% of population growth due to inmate population growth; resident population growth is expected to continue at a gain of less than 100 persons per year (Jackson County, 2010).

In 1997 the Florida Legislature amended the Florida Water Resources Act (Chapter 373, F.S.) to provide direction to the state's five water management districts on regional water supply planning. Each water management district jurisdiction was divided into water supply planning regions and needs and demands assessed. Region IV included Jackson County, as well as those sharing its western border: Holmes and Washington counties. Regional water supply plans were developed for those regions identified as having, or being likely to develop, future water supply constraints: region IV was not among these in 1998, nor in the subsequent reassessment in 2006 (Northwest Florida Water Management District, 2009b). The NWFMD 2009 annual report for the region included the purchase of several tracts of land for public use, improved access to some previously state held lands, and a sewer improvement project, but no projects relating directly to Jackson Blue Spring (2009a).

Historical real-time monitoring of discharge and periodic water quality parameters dating back to 1960 was discontinued by the USGS in July 2010, due to budget cuts. Ongoing monitoring by the NWFLWMD includes quarterly spring water quality and discharge, continuous groundwater level, continuous rainfall, quarterly groundwater level measurements, and randomized ground and surface water quality at Merritt's Mill

Pond. According to data collected in July 2007 which tallied Merritt’s Mill Pond submerged springs discharge and the pond outflow, Jackson Blue Spring contributes, on average, 70% of water input to the Mill Pond (Barrios, 2010).

Hydrology

A comprehensive analysis of the hydrology of Jackson Blue Spring has not yet been conducted. Determining the hydrology of any karst environment is a complex process which requires more data than simple dye traces can provide: while this procedure can illuminate drainage divides, flow directions and flow velocities in various locations, identifying the nature of water flow and contaminant dispersion requires the identification of numerous other variables. Some of these variables include: groundwater storage, retention times, patterns of convergence and divergence, and response to wet-dry cycles in the soils (Palmer, 2010). Interaction between conduits and the adjacent fracture-matrix system plays an important role in karst hydrology; however, in conduit dominated aquifers with low bedrock porosity and conductivity, such exchange can be neglected when discussing short term flood response of the system (Jeannin, 2001; Peterson and Wicks, 2005). Understanding the hydrology of the spring is essential to accurately determining the age and mixture of the emerging waters, in order to more effectively analyze the sources of and remedies for water quality measurements of concern. Because of the high degree of interaction between surface water and groundwater in karst aquifers, vulnerability to contamination is high. Recharging surface water can deliver contaminants, including nutrients, pesticides, pathogens, petroleum hydrocarbons, and sediment (Vesper *et al*., 2001). The level of risk is dependent on what proportion of the groundwater exiting the spring is quick flow—water which has spent little residence time in the system and consequently undergone little natural filtration before exiting as spring discharge—having arrived recently from storm events and local drainage. The amount of discharge which may be quick flow waters varies temporally (Mahler and Garner, 2009).

Karst spring discharge remains reasonably stable over extended periods of time (Berndt *et al*., 1998); however, because discharge rates are driven by the rate of recharge, climatic fluctuations can have a significant effect on spring flow (FDEP, 2010). Jackson Blue Spring discharge averaged 113 cfs, 73 million gallons/day during the period of December 2004 through December 2009; Jackson County was in a severe drought condition throughout 2006-2007: the two year cumulative rainfall in this period reached a near record low of 87.94 inches. During this time the maximum discharge of 283 cfs was measured August 10-11, 2005 and the minimum of 28cfs was recorded December 17-20, 2007 (Barrios, 2010).

Jackson Blue Spring emerges from the Floridan aquifer via an extensive conduit system large enough for divers to pass: penetration has been made over 10,000 feet into the system, with over 30,000 feet total passages under survey currently (E. Sorenson, personal communication, June 25, 2011). The mouth of the cavern is about 12 feet top to bottom and averages 16 feet across, with a total cross-sectional area of some 194 square feet and beginning with a maximum depth of 20 feet. Inside the mouth of the cavern, the area opens up considerably, to more than 30 feet across in some sections, and with a variety of rock formations and evidence of old collapses littering the floor with very large boulders; these could have fallen from the ceiling at any time over thousands of years. The cavern zone ends at a penetration of approximately 250 feet, at which point the depth of the passable conduit plunges to 90 feet down a narrow fissure; this depth range is then maintained throughout the many thousands of feet of explored passages. Two major breakdown areas exist: the first is at a linear penetration of some 470 feet and the second at a linear penetration of approximately 783 feet. As with all caves, the cavern and cave at Jackson Blue Spring is active; under continuous growth and development fissures appear and sections of rock move and fall from the cave ceiling to rest on the floor. These geologic events may happen centuries apart and are often unknown, but in cases where they occur in travelled areas of the cave, cave divers can bear witness to these changes. Such a rock fall occurred during the writing of this study, taking place between July 4 and July 5, 2011. Several tons of rock fell from the ceiling at a distance of approximately 240 feet penetration from the cave entrance where the conduit is approximately 15 feet tall and 45 feet deep. The rocks that fell were in quantity great enough to fill a dump truck (M. Michaud, personal communication, July 16, 2011).

Water quality

The susceptibility of an area in Jackson County to groundwater contamination is determined primarily by the hydrogeologic and land use characteristics of the area. Where the aquifer is protected by the presence of low permeability materials, transport is limited; high permeability sediments, such as those which occur in the Florida outcrop region of Jackson County will readily transport contaminants along with rainfall which recharges the aquifer (Wagner, 1984).

Due to the very nature of karst, the area immediately surrounding a spring is a vulnerable area; because its springshed can extend for miles, the overall recharge may not be so vulnerable. In 2004 Florida Geological Survey (FGS) developed a statewide GIS model to evaluate the relative aquifer vulnerability within springsheds. The Florida Aquifer Vulnerability Assessment (FAVA; in Arthur *et al.*, 2007 and FDEP, 2010) utilizes data on depth to groundwater, differences in hydraulic head, thickness of confining units, soil permeability, and other characteristics. Figure 11 shows that application of this tool to the Jackson Blue Springshed indicates high vulnerability throughout.

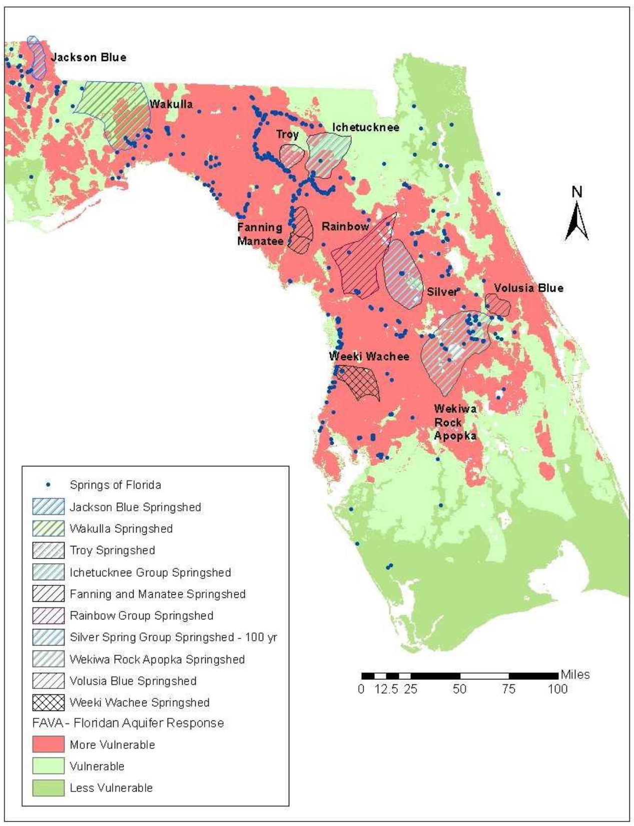

FIGURE 11. Aquifer Vulnerability in Spring Areas (FDEP, 2010).

Known water quality problems in the basin include arsenic (from cattle vats, cemeteries, and natural deposits), ethylene dibromide (EDB; a crop parasite fumigant no longer in use), and nitrate: a soluble nutrient product of waste treatment and fertilizer (Barrios, 2009).

The vulnerability of karst aquifers and in particular, Jackson Blue Spring waters, becomes principally meaningful when applied to concerns about water quality parameters and the effects of contamination levels on human and ecosystem health. The contamination of groundwater from nitrate and nutrients is a major problem globally and these problems are generally the result of any one of, or a combination of the following factors: anthropogenic activities, lack of management, and overdevelopment of water resources (Murgulet and Tick, 2009). The deterioration of water quality in areas dominated by agriculture and heavy fertilizer application is commonly a result of elevated nitrogen, phosphorous, and suspended solids. Numerous studies indicate that rural land uses, especially agricultural practices, can cause nitrate contamination of underlying groundwater (Bouwer 1978; Driscoll 1986; Vowinkel and Tapper 1995). In places where fertilizers are applied to the land surface there is an increased potential for groundwater contamination due to the direct downward infiltration of nitrate to the aquifer system (Murgulet and Tick, 2009). In the ammonium-N (NH_4-N) form, nitrogen is fairly immobile in soil. However, under most conditions NH_3-N is converted to NO_3-N, which can readily move with soil water (Sharpley *et al.*, 1987). Thus, the mobile form of nitrate (NO_3^-) is the most evident manifestation of the problem with applications of fertilizer in areas of karst terrane. Nitrate is the most widespread contaminant in Florida impacting groundwater quality (FDEP, 2008) and elevated nitrate levels have been implicated as a cause of negative impacts on the flora and fauna of Florida’s springs (Stevenson, 2000; Scott *et al*., 2002).

Concerns about phosphorous, also a significant fertilizer additive, have been investigated and found not to require attention at this time. Overall, phosphorous additions in fertilizer tend to be a lesser problem primarily because it undergoes rapid fixation by surface soil material. Typically, the Redfield ratio for N:P indicates which nutrient is the limiting factor in terms of phytoplankton biomass; this ratio of 16:1 is usually expressed in atomic units and represents approximately 7:1 by weight (Redfield *et al*., 1963; Duarte, 1992). Samples taken by Wetland Solutions Inc. (WSI) in 2008-2009 (2010) revealed that N:P ratios at the Jackson Blue Springhead were 411 (atomic) and 186 (weight), with a mean TN:TP (weight) of 170. These values far exceed the Redfield ratio, and would seem to indicate that phosphorous is indeed the limiting factor for biomass growth at Jackson Blue, explaining why elevated nitrate levels have not resulted in eutrophication in the spring pool to date. However, the WSI study further investigated this data and reports that the relationship between total phosphorous concentrations and GPP, while positive, was not significant. In phytoplankton-dominated systems, phosphorous concentrations are commonly positively correlated to aquatic ecosystem productivity: this assumption cannot be made in spring systems which are dominated by submersed aquatic vegetation and the report concluded that phosphorous is not limiting productivity in this environment (WSI, 2010).

Major concerns regarding elevated nitrate levels in groundwater and surface water systems include health risks to humans through drinking water (methemoglobinemia and potential carcinogenic effects) and degradation of local ecosystems (both as a result of excessive plant and algal growth leading to eutrophication and due to invasive species outcompeting native plants) (Murgulet and

Tick, 2009). Acceptable limits of NO_3-N concentration of 10 and 100 mg/L have been established for human and livestock consumption, respectively (USEPA, 1996). Specific standards for concentration limits for nuisance levels of algal growth have only recently been published by the United States Environmental Protection Agency (USEPA) and the Florida Department of Environmental Protection (FDEP), and are still under further review and study. The protective numeric nutrient criteria for streams in the bioregion have been calculated as 1.7 mg/L for TN and 113 µg/L for TP (FDEP, 2009).

Nitrate nitrogen (NO_3^--N) levels in Jackson Blue Spring have been measured between 3.0-3.5 mg L^{-1} in the decade 2001-2010 (NWFMD). While these levels do not reach or exceed regulatory maximum contaminant limits (MCLs) for human consumption, they are many times higher than historic levels, pointing to anthropogenic causes in a highly vulnerable region. These levels also do exceed appreciably the protective numeric nutrient criteria developed by the USEPA and FDEP; concern for the health of the ecosystem and biodiversity downstream is considerable. High levels of nitrogen can lower the quality of natural habitat by increasing invasive vegetation and lowering the available oxygen levels for fish and other aquatic life. Invasive vegetation also can lower recreational value, by clogging waterways and changing the aquatic habitat which harbors desirable fish populations. Hundreds of thousands of dollars are spent every year by the State of Florida to clean up nutrient-impacted water bodies like Merritt's Mill Pond (Barrios, 2009). For these reasons, concurrent with high vulnerability to contamination, nitrate-nitrogen is the water quality parameter of greatest concern at Jackson Blue Spring.

A springs ecosystem study funded by the Florida Fish and Wildlife Conservation Commission included inventories at Jackson Blue Spring pool and provided 2008-2009 data on some basic parameters (Table 2). These parameters are similar to measurements taken in 2001 by Florida Geological Survey (Scott *et al.*, 2002). Gross primary productivity reflects the total amount of organic carbon fixed by photosynthesis within the local ecosystem which is available to meet the respiratory requirements of the plants, microbes, invertebrates, and vertebrates living in the community; the magnitude of this measurement is an indicator of the overall ability of a natural ecosystem to support life. Community respiration is an independent estimate of the size and function of the biological community; essentially the metabolic rate of the system (WSI, 2010).

TABLE 2. Jackson Blue Spring Ecosystem Parameters (2008) measured at the spring pool (adapted from WSI, 2010).

Spring Pool Volume (m^3)	Discharge (m^3/s)	Cond (µS/cm)	DO (mg/L)	pH (SU)	NO_x-N (mg/L)	PO_4 (mg/L)
4,081	3.42	262	6.8	7.55	3.32	0.02

Max Horiz Secchi (m)	Gross Primary Productivity ($gO_2/m^2/d$)	Net Primary Productivity ($gO_2/m^2/d$)	Community Respiration ($gO_2/m^2/d$)	Photosynthetic Efficiency (%)
64	2.88	-0.16	3.04	1.3

A significant study by B.G. Katz in 2004 analyzed multiple isotopic and other chemical tracers in water samples from 12 large Florida springs to assess sources and timescales of nitrate contamination: the age of waters emerging from Jackson Blue Spring was estimated to be between nine and 17 years, with favor toward the higher end. The nitrate was identified as primarily inorganic in origin, indicating fertilizers as the most likely source of the elevated concentration. Transit time was estimated based on the piston flow model, which assumes that after a tracer is isolated from the atmosphere (at the time of groundwater recharge) it becomes incorporated in the water and moves with the mean velocity of the groundwater (Katz, 2004). The transit time and subsequent age of water reflects the relatively slow movement of solutes through small pores in the aquifer matrix: dye-tracer studies have demonstrated very quick movement of solutes through conduit systems to springs, on the order of days to weeks (Wilson and Skiles, 1988; Otz and Azzolina, 2007). These seemingly contradictory statements are a reflection of the mixture inherent in spring discharge: a portion of the waters emerge from deep in the aquifer, having undergone significant residence time, and a portion of the waters are born of quick flow from recent recharge to the system.

The percentage of deep versus quick flow water varies by site, temporally, and relative to storm cycles, and can be estimated in a number of ways, including: hydrograph separation (Ashton, 1996), geochemical tracers, and chemical mixing models (Lakey and Krothe, 1996). Mahler and Garner have proposed using nitrate to quantify quick flow in karst aquifers based on the typical dilution of nitrate levels in response to storms in many systems (2009); a time series plot of rated Blue Spring discharge and nitrate concentration reveals no correlation (Figure 12), therefore, this method would likely not be fruitful at this site.

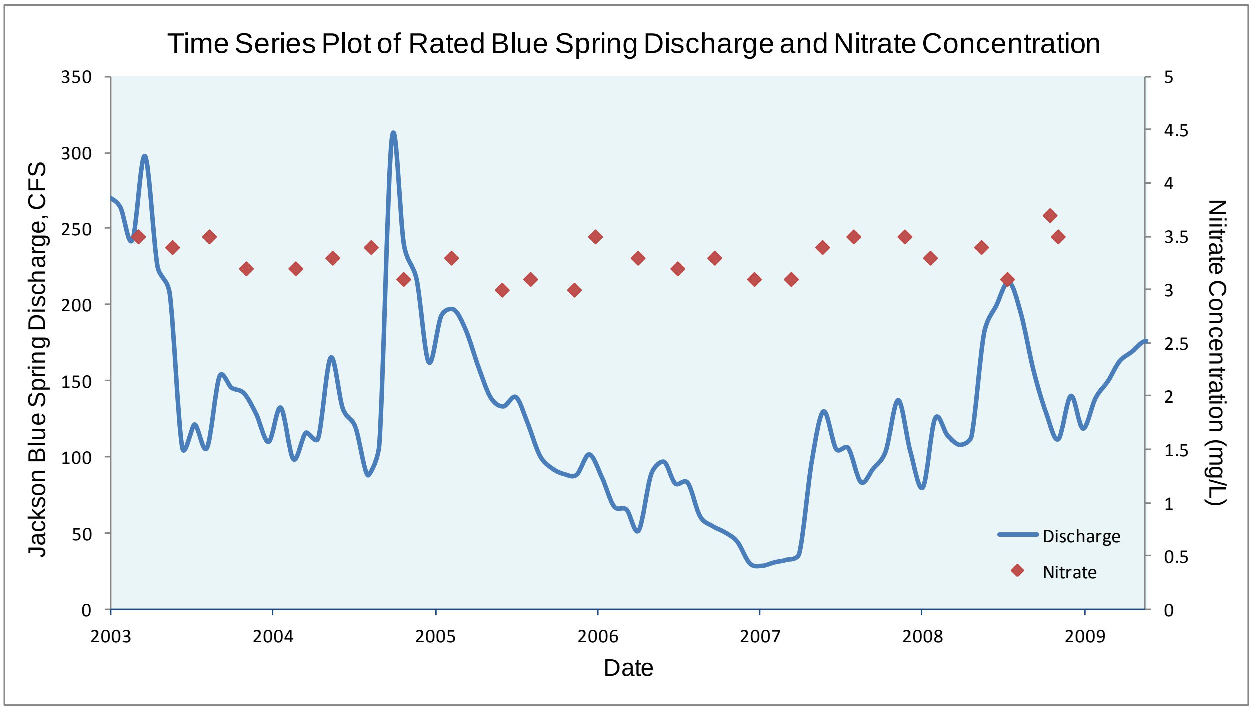

FIGURE 12. Time Series Plot Reflecting Jackson Blue Spring Discharge and Concurrent Measured Nitrate Concentrations (data from USGS).

The lack of correlation between spring discharge and nitrate concentration may indicate that Jackson Blue Spring does not experience the typical trend of lowered nitrate levels during times of high discharge. Typically, during storm flow the concentration of nitrates and other water soluble contaminants undergoes dilution by storm water. In many cases, a measureable peak also occurs in what is called a storm pulse, as a result of contaminant runoff (Vesper *et al.,* 2001). The apparent trend at Jackson Blue Spring may be explained by an interesting balance between higher levels of contamination concurrent with increased discharge: because the area is highly vulnerable to speedy recharge, along with significant agricultural activity, the dilution which usually lowers nitrate levels following storm events may, in fact, be washing with it an equivalent level of increased nitrate from the land surface. As this explanation is speculative, further study is indicated to determine a more definitive accounting of why this trend is observed. A study of storm events and nitrate concentrations at the spring would inform this issue greatly, as the nitrate concentrations recorded have not been frequent enough, nor intentionally timed with storm events to provide a definitive answer. The results of such a study would also further illuminate the proportion of quick flow present at Jackson Blue.

The difficulty in ascertaining an accurate estimate of the age of waters emerging from the aquifer at springheads is directly related to the complexity of karst system and how robustly it is understood. Typically, the application of CFCs, SF6, and $3H/3He_{trit}$ for groundwater dating has been used in groundwater flow systems that are relatively well characterized and utilizing water samples collected from narrow depth intervals (Katz, 2004). Interpreting the groundwater age based on isotropic and chemical tracers involves a high degree of uncertainty; uncertainty which is amplified by models which may be a poor fit. Without a thorough understanding of the complex karst system under study, this uncertainty is best approached by considering multiple possible groundwater flow scenarios which might influence tracer concentrations in spring water. Even so, flow models may not approach the groundwater mixing scenarios present in complex karst systems, significantly affecting the estimated outcomes.

Jackson County fertilizer application levels dropped precipitously in the mid-1990s from a combination of community awareness of the nutrient contamination problem and the realization by farmers that using more fertilizer than plants could uptake is a financial and resource waste which does not result in higher output. Application of N fertilizer and irrigation water to meet but not exceed crop requirements is known to be important to reducing the NO_3^- leaching from irrigated sandy soils (Gehl, *et al*., 2005). This positive behavior change would not result in an immediately measureable reduction in nitrate levels in springshed sampling because of the likelihood of a system already contaminated from previous years of recharge and the residence time of at least some proportion of those waters (Figure 13). Given Katz's (2004) average age estimation of 17 years, some reduction in nitrate levels should be expected around 2016; the measurements over the next decade will be indicative of both the accuracy of the age estimates and also the effectiveness of reducing fertilizer application in combating nitrogen pollution.

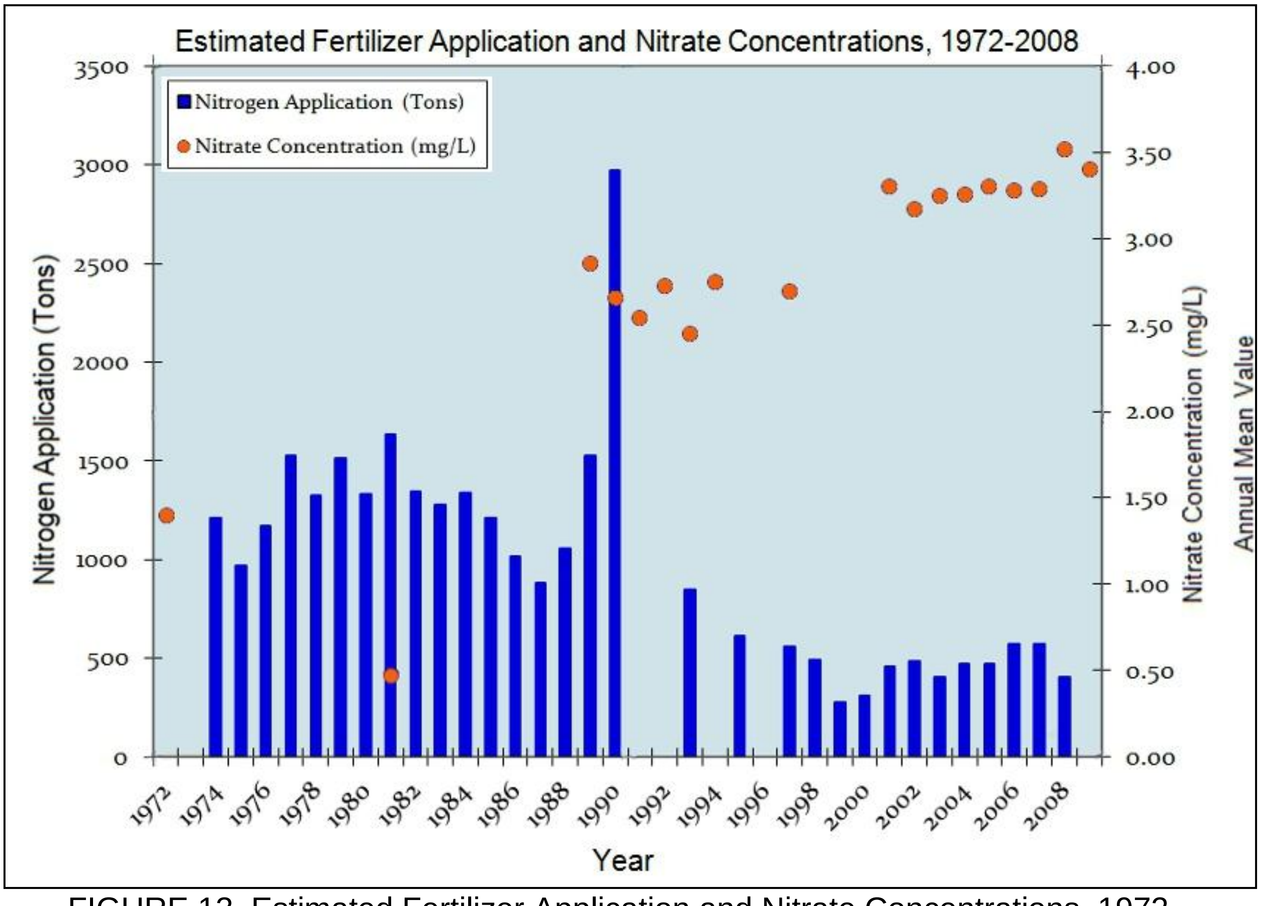

FIGURE 13. Estimated Fertilizer Application and Nitrate Concentrations, 1972-2008. Calculated from fertilizer usage in Jackson County, Florida with concurrent annual mean nitrate concentrations measured at Jackson Blue Spring (adapted from Barrios, 2010).

In areas where agricultural lands are animal based, rather than cropland, nitrate levels in nearby wells have been found to exceed regulatory MCLs, primarily as a result of unlined wastewater lagoons and areas of intensive animal use (Andrews, 1994). This is not the case in Jackson County, as most agriculture land use is cropland, but important to keep in mind for land use planning purposes.

Biota

Stygobites are organisms which are aquatic obligate cave dwellers, living their entire lives in underwater caves. The more general term of troglobite includes aquatic, amphibian, and terrestrial obligate cave dwelling organisms. Inventories of stygobites have been conducted in some Florida submerged caves, such as Peacock, Rose, and Jug Hole springs (K. Jessop, Personal Communication, December 30, 2010) but no formal inventory has been taken in the Jackson Blue Spring cave. A number of regional obligate cave fauna catalogs have been created, some of which include North Florida in their counts (Woodruff, 1993; Franz and Morris, 1994; Culver *et al*., 2000, 2003), and an ecosystem-level study of Florida springs in 2010 (WSI) included Jackson Blue Spring pool in a inventory of vegetation and organisms of all kinds observed as a measure of spring ecosystem health (Appendix B). Personal observation by this author has verified the presence of *Procambarus pallidus* (crayfish), inside the spring cave. Amphipods and isopods have not been observed, although their occurrence is expected; this may be due to the high flow of the main passageways and their presence should be investigated in side tunnels with lower velocity flow. Informal observations by divers over the last ten years have noted an increase of trogloxene fishes becoming troglophiles; this is likely due to a trend of reduced discharge (partly due to the severe drought in 2006-2007), combined with increased diver traffic (fish which normally frequent only the cavern zone may follow the lights of divers as they travel into the cave). The occurrence of non-native species in cave environments often results in the decimation of troglobites; without a prior inventory to compare, it cannot be known, but this is a likely contributory factor to low numbers of observed species. A formal study of Jackson Blue Spring stygobites would be a valuable addition to the knowledge base.

CHAPTER 4

METHODOLOGY

Summary of Methodology

The first goal of this research was to aggregate the previously published works relating to Jackson Blue Spring, in order to facilitate continued study and further understanding of the dynamics of the local hydrogeology, ecosystem, and anthropogenic pressures on the spring. The second goal was to determine whether there is a relationship between land use in the Jackson Blue springshed and measured water quality parameters gathered from monitoring wells in the springshed. To address this research question, water samples from 18 monitoring stations within the Jackson Blue springshed were analyzed and parameters were compared on the basis of the wells' locations in areas of land use designated as agricultural or forested. The water quality data from each monitoring well was drawn from a previous study conducted by Barrios and DeFosset (2005) which sampled 29 monitoring wells in and around the Jackson Blue Spring basin within a three week period in October 2004. All wells sampled possessed an open hole or screened interval entirely within the Floridan Aquifer and those wells with in-place plumbing functioned such that the sample withdrawal site was located before any filtration equipment. Well construction data are provided in Appendix C.

Water Sampling

Water chemistry data were obtained from Northwest Florida Water Management District records. According to Barrios and DeFosset (2005), water quality sampling was conducted in accordance with FDEP standard operating procedures listed under DEP-

SOP-002/02 (revised 6/28/2004). Lab samples and equipment blanks were submitted to the FDEP Central Chemistry Lab for analysis. In their study, related parameters were grouped into five separate "components" and the wells were grouped into seven "distribution clusters," based on their hydrogeologic similarities. Their chemical characterization was based on this combined factor approach. In this study, the water quality parameters for each well were individually analyzed to determine whether a relationship exists between negative water quality measures and land use.

TABLE 3. Water Quality Parameters Considered in this Study

Analysis	**Reported Unit**
pH	su
Temperature	˚C
Alkalinity, Total (as $CaCO_3$)	mg/L
Specific Conductance	μS/cm
Total Dissolved Solids	mg/L
Chloride, Total	mg/L
Turbidity	mg/L
Dissolved Oxygen	mg/L
Magnesium	mg/L
Orthophosphate, Dissolved (as P)	mg/L
Sodium	mg/L
Potassium	mg/L
Sulfate	mg/L
Total Nitrogren (NO_2+NO_3)	mg/L

Summary definitions and expected results of these parameters are presented below:

pH**:** The variable pH is an indicator of the potential for acid-base reactions in water. The pH of aquifer water is a result of past chemical reaction and a measure of the potential for reactions. pH is defined as the negative log of the activity of the hydrogen ion in a solution. Values range between 0 and 14. A low pH (below 7) represents acidic conditions, and a high pH (above 7) represents alkaline conditions. A pH of 7 indicates the water is near neutral conditions. As raindrops form they incorporate dissolved carbon dioxide, forming weak carbonic acid. The resulting rain has a low pH, typically around 5.5. In Florida, as rainwater passes through soil layers it incorporates organic acids and the acidity increases. When acidic water enters a limestone aquifer, the acids react with calcium carbonate in the limestone and dissolution occurs. Generally, most spring water falls within a pH range of 7 to 8. No significant difference in pH is expected between agricultural and forested land use areas.

Alkalinity: The alkalinity of spring water is affected primarily by the presence of bicarbonate, hydroxide and carbon dioxide; alkalinity is produced by the reaction of CO_2 in the atmosphere or the soil zone, the dissolution of calcite, and the oxidation of organic materials by microorganisms. Bicarbonate is the dominant anion in natural waters and is the dominant constituent of alkalinity, which is expressed in mg/L $CaCO_3$. Highly alkaline waters are usually associated with high pH, dissolved solids and hardness which, when combined, may be detrimental to the aquatic environment. While dissolved solids are expected to be elevated in agricultural versus forested areas sampled, pH and alkalinity are not expected to be significantly different relative to land use.

Temperature (˚C): Geologic material is characteristically a good insulator and tends to buffer changes in temperature, resulting in little variation and a tendency to reflect the average annual air temperature. In Florida, this temperature can range from 20˚C to 24˚C. Temperature plays a role in chemical and biological activity within the aquifer and can aid in determining residence time of the water in the aquifer. No significant difference in temperature is expected between agricultural and forested land use areas.

Specific Conductance: Conductance is a measure of the ability to conduct electricity; this is a function of the amount and type of ions in the water. Conductance typically has a strong positive correlation with TDS and chloride concentrations. It is expressed in microSiemens per centimeter at 25˚C. When water is used for irrigation, some of the water evaporates or is consumed by plants, concentrating the original amount of dissolved solids; the dissolved solids concentration and the specific conductance in the remaining water is increased. As a result, conductance may be expected to be elevated in agricultural versus forested land use areas.

Total Dissolved Solids (TDS): Total dissolved solids is a measure of the dissolved chemical constituents, primarily ions, in spring water. Concentrations in Florida's spring water vary widely. Since most of Florida's spring water issues from carbonate aquifers, the total dissolved solid concentrations are fairly high. Measurements of total dissolved solids can be expected to be higher in samples from agricultural areas relative to forested areas.

Chloride (Cl^-): Chloride is added to the atmosphere by way of marine aerosols from the ocean. In most Florida springs, chloride is introduced to the spring system via rainfall. Chloride is chemically conservative and reacts very little with spring water; the occurrence of chloride is therefore useful for identifying seawater intrusion. Elevated chloride levels can be the result of anthropogenic activities, but is not closely associated with agricultural additives, and is therefore not expected to be measured at significantly different levels in these areas as compared to forested regions.

Turbidity: Turbidity is a measure of the colloidal suspension of tiny particles and precipitates in spring water; high turbidity water impedes the penetration of light and can be harmful to aquatic life in open water. Because these samples are drawn exclusively from monitoring wells and not from open or running water, higher turbidity is not expected in agricultural land use areas as compared to forested areas.

Dissolved Oxygen (DO): A dissolved oxygen value of less than 5.0mg/L is considered impaired in a surface water body, where the standard relates to supporting aquatic life; groundwater typically has lower levels of DO because of its lack of contact with the atmosphere. Oxygen enters the water by diffusion, aeration, or as a byproduct of photosynthesis; the longer groundwater remains in the aquifer, the lower the DO concentration becomes. A significant difference in DO levels between samples drawn from agricultural and forested wells is not expected. Measurements near the 5.0 mg/L touchstone may indicate very short residence time, pointing to aquifer vulnerability to contaminants.

Magnesium (Mg^{2+}): Magnesium is dissolved from the magnesium-rich clays in the Hawthorn Group and dolomite in the Floridan aquifer. It is an important dietary mineral for all organisms excepting insects and as a central atom of the chlorophyll molecule, is also a requirement for plant photosynthesis. It also causes water to be hard and contributes to scale-forming properties of water; the biggest environmental concern regarding magnesium levels is related to human use of water softeners. Magnesium levels are not expected to differ significantly between agricultural and forested land use areas.

Orthophosphate, Dissolved (PO_4^{3-}): Phosphorous occurs naturally in rocks and other mineral deposits and is gradually released during the natural process of weathering. The Hawthorn Group geological unit is the most important source of phosphate in local spring water. Other sources include organic and inorganic fertilizers, animal waste, human waste effluent and industrial waste. The orthophosphate ion is soluble in acidic waters, but insoluble in alkaline aquifers, such as occur in the Floridan aquifer. Phosphorous is one of the key elements necessary for growth of plants and animals and in aquatic environments is often the growth limiting factor. Excess phosphate can lead to eutrophication and reduction in biodiversity. Because phosphorous undergoes rapid fixation in the soil, despite its presence in agricultural additives, levels are not expected to be significantly different in agricultural versus forested areas.

Sodium (Na^+): The primary sources of sodium in Florida's aquifer systems are the mixing of fresh with seawater along the coast, the weathering of sodium-rich minerals, and marine aerosols. As Jackson County is not coastal, sodium levels are influenced by minor amounts of sodium-rich minerals occurring in the Floridan aquifer and any differences in levels between land use areas are not expected to be significant and should be accountable to variations in the presence of these minerals.

Potassium (K^+): Potassium occurs in trace amounts in Florida's spring water and is derived primarily from seawater. Therefore, it occurs in higher concentration along the coast as compared to inland areas. The weathering of mica, feldspar and clay minerals can contribute potassium to spring water. Because potassium is an essential nutrient, it is a component of fertilizers and, if applied in excess, could be expected to be measured at higher levels in samples drawn from agricultural land use areas as compared to forested areas.

Sulfate (SO_4^{2-}): Sulfate is commonly found in aquifer waters in Florida. Inland the two most common sources are the dissolution of gypsum and anhydrite (naturally occurring rock types within Florida's aquifer systems) and use as a soil amendment to acidify soils; thus its presence is associated with agricultural activities. Disposal and industrial waste activities also release sulfate to groundwater. Sulfate-rich spring water can be potentially toxic to plants. In higher concentrations it affects the taste of drinking water. Due to its association with agricultural activities, sulfate is expected in higher levels in wells from these areas as compared with those in forested areas.

Total Nitrogen (NO_3^- + NO_2^- reported as N): Nitrogen compounds occur in groundwater as a result of specific anthropogenic activities such as inorganic fertilizer use, human waste, and animal waste. Nitrate and nitrite are both found in spring water in Florida; nitrate contamination has become a problem. Being a nutrient, nitrate encourages algal and aquatic plant growth in spring water, which may lead to eutrophication of the spring and the associated water body. Nitrite, which is much less of a problem, can originate from sewage and other organic waste products. As discussed at length earlier, nitrate is the major byproduct of inorganic fertilizer application and in the highly porous karst environment is very likely to percolate into the groundwater. Recall that the federal maximum contaminant limit (MCL) for NO_3^- as nitrogen is 10mg/L (USEPA). Samples were collected in October 2004 (detailed dates are furnished in Table 5). Significantly higher levels of nitrate are expected to be measured in areas of agricultural land use as compared to areas which are forested.

Land Use

The 18 monitoring sites chosen for this study were those which clearly fell within the boundaries of the springshed and were plainly within the land use designations of interest. With the exception of the Jackson Blue Spring vent, all stations were monitoring wells. Those excluded from this study were either outside the springshed boundaries or the well footprint was in a land use designation which was mixed or of another category, such as barren land. In some cases, well footprints were actually in areas designated as “built-up,” but were accepted as within the greater land use of the surrounding area; in these cases, the built-up area was deemed very small and was the result of some farm buildings or yards and not significantly developed commercial property or high residential density. Land use designations were identified on the basis of delineation using photographic interpretation and a GIS file containing the Jackson County Property Appraiser parcel data according to the Level I categorization recognized by the USGS. The delineation of these land uses was conducted by NWFWMD staff as part of a 2005 study comparing changes in land use from 1994 to 2004. The six categories of land use defined in the spring basin were as follows:

1. Built-up Land – This includes commercial property, residential property, churches and associated adjacent land such as parking lots and yards.
2. Agricultural Land – Land used for production of food or commercial/industrial material including row crops, center pivots, and pasture.
3. Barren Land – Includes borrow pits and cleared areas with no discernable future use.

4. Forest Land – Any area not associated with a higher impact land use with a tree canopy cover greater than 10%.

5. Wetland – Forested or unforested wetlands delineated by the National Wetlands Inventory.

6. Water – Any area with visible standing water.

The percentage of each land use category within the springshed is displayed in Table 4. A map of the springshed showing land use delineation is provided in Figure 14.

TABLE 4. 2004 Jackson Blue Springshed Land Use. Total acreage and percentage of Jackson Blue Spring contribution area land use by category. Based on the springshed delineated in 2001. Designations determined by county land parcel data and aerial photography (adapted from Barrios and DeFosset, 2007).

2004 Jackson Blue Springshed Land Use		
Land Use	Acres	Percent
Agricultural Land	33,938	49.49
Barren Land	198	0.29
Built-up Land	3,794	5.53
Forest Land	28,765	41.95
Water	215	0.31
Wetland	1,663	2.43
Total	68573	100

ArcGIS was used to compile the geospatial data, and to record and map well locations, well depths, and hydrogeological information collected from fieldwork. Land use coverage was created from digital data acquired from previous studies undertaken by Barrios and DeFosset with assist from NWFWMD staff (1994, 2005, 2007). This coverage was mapped in ArcGIS and the projection was converted to UTM for appropriate mapping agreement; a spatial join was performed to bring well location data onto a polygonal land use coverage. Well location land use designation was performed visually on an individual basis. From this determination, the 18 stations analyzed in the study were selected (Figure 15).

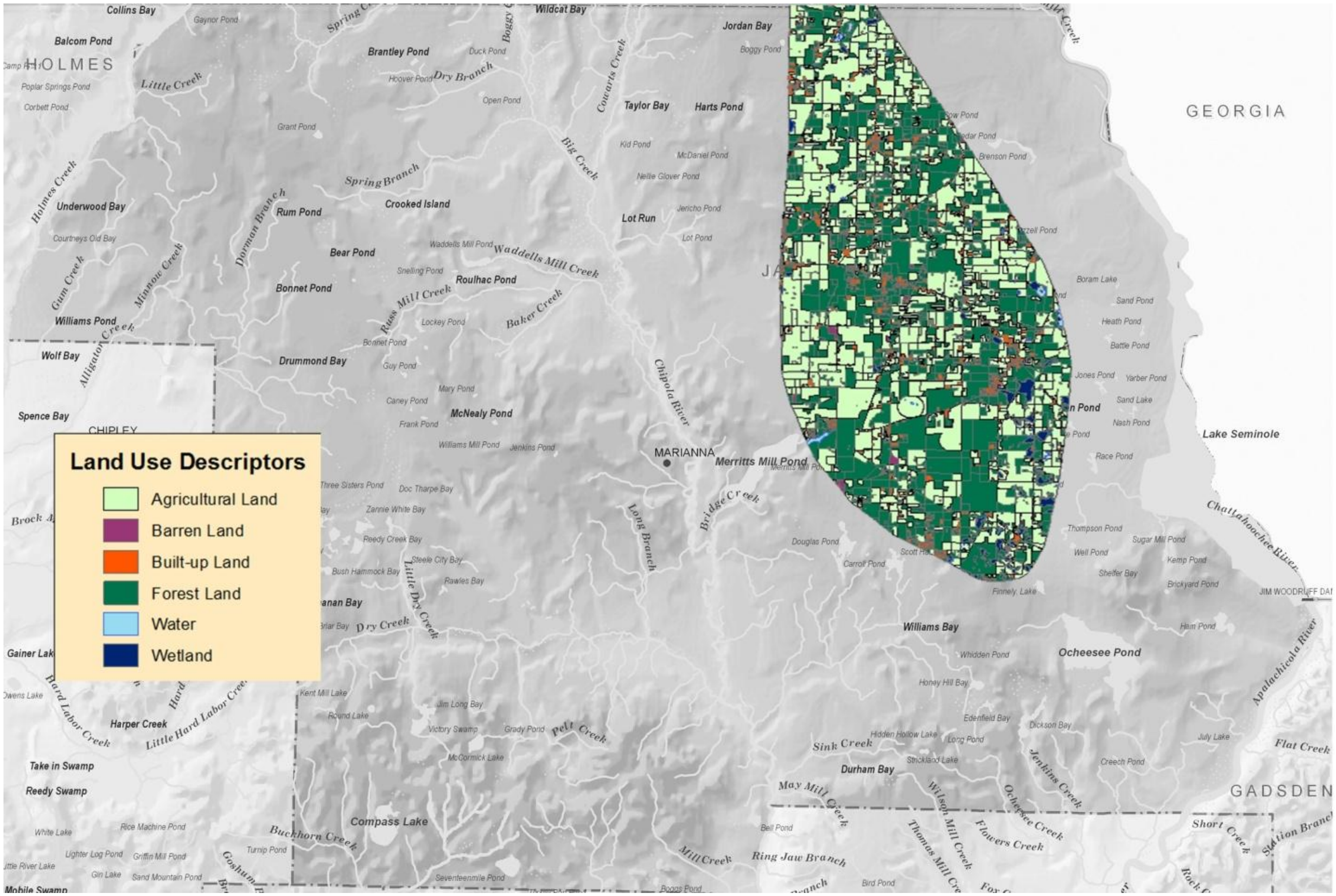

FIGURE 14. Jackson Blue Spring Contribution Area with Demarcation of Land Use Designations (after Barrios & DeFosset, 2007).

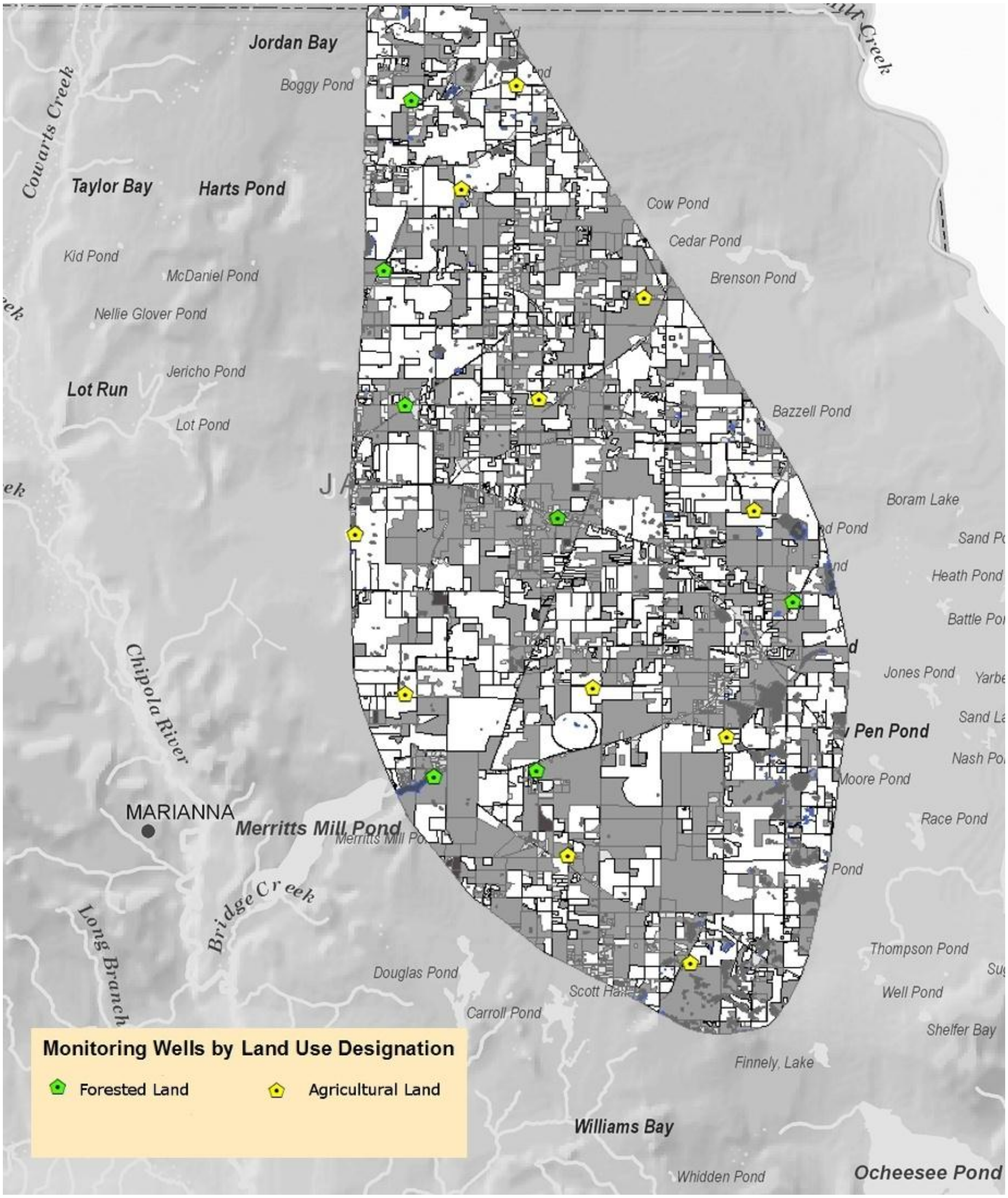

FIGURE 15. Jackson Blue Spring Basin Map Showing Locations of the 18 Monitoring Stations Analyzed. The station names and locations are included in Table 5. Well construction data are specified in Appendix C.

Statistical Analyses

A statistical software package, SAS, was used to evaluate and compare water quality and land use data. A significance level of 0.05 was used for statistical tests. Parametric and nonparametric statistics were used where appropriate, as some of the water chemistry parameter distributions are normally distributed and some of the distributions differ significantly from a normal distribution. The data for alkalinity, conductance, total dissolved solids, turbidity, dissolved oxygen, magnesium, orthophosphate (dissolved), potassium, and sulfate were found to be significantly different from an expected normal distribution; therefore, nonparametric analysis was conducted. pH, temperature, total chloride, sodium, and total nitrogen presented with normal distributions and were analyzed accordingly.

CHAPTER 5

RESULTS

This study required the comparative analysis of water quality data from each of the two land uses which predominate in the Jackson Blue Spring basin: agricultural and forested. The raw data water quality parameters collected with station names and collection dates is presented in Table 5.

As expected, pH (Figure 16) and temperature (Figure 17) measurements are not significantly different between the groups under comparison (Independent t test, $t=0.61$, $p=0.5501$; $t=1.35$, $p=0.1964$, respectively). Spring and groundwater pH levels are generally consistent across Florida, determined largely by the pH of rainwater, combined with the influence of limestone dissolution; because the hydrogeology of the basin is fairly uniform and has a greater influence on pH than does land use factors, a significant difference between groups was not anticipated. Similarly, temperatures are fairly stable in the region, typically varying by only 4˚C as groundwater is well buffered by geologic material; in the absence of a land use with the potential to exert a major influence on temperature (such as the injection or release of waste effluent from industry), significant variation is not predicted.

Alkalinity levels are significantly different (Mann Whitney U, $z=2.0388$, $p=0.0415$) between the samples drawn from wells in areas of agricultural and forested land uses (Figure 18). There was no indication from the geologic distribution of wells or the potential influences of land use which led to an anticipation of this statistically significant difference. This result is also surprising in the light of pH results which did not reveal significance (Figure 16).

TABLE 5. Raw Data from 18 Monitoring Stations. Water quality data collected between October 6 and October 20, 2004 from selected monitoring stations within the Jackson Blue Spring contribution area (springshed). Collection stations (wells, with the exception of the Jackson Blue Spring vent) are separated by the land use designation at the site: agricultural or forested. Water quality sampling was conducted in accordance with FDEP standard operating procedures listed under DEP-SOP-002/02 (revised 6/28/2004). Lab samples and equipment blanks were submitted to the FDEP Central Chemistry Lab for analysis (adapted from Barrios and DeFosset, 2005).

Station Name	Date	Latitude	Longitude	pH	Temp	Cond	DO	Turb	Alk	Cl	Mg	TN	PO_4	K	SO_4	TDS
Agricultural																
BALDWIN	10/7	30.86290	-85.05270	7.60	21.71	151	9.12	1.68	64	2.5	0.61	2.400	0.012	0.24	1.20	91
DITTY MON\JC-3\JK30	10/21	30.97907	-85.11769	7.16	20.79	220	7.14	0.94	91	4.0	0.70	3.600	0.013	0.40	0.83	154
DIXON	10/7	30.89339	-85.11145	7.31	20.85	257	8.31	2.33	107	4.5	1.00	4.600	0.016	0.24	0.71	163
MERCER	10/6	30.80105	-85.06008	7.39	21.14	177	9.38	1.91	65	4.9	0.72	4.200	0.021	0.32	0.33	120
MURPHY	10/20	30.81275	-85.14807	7.66	21.29	139	8.95	0.90	50	3.3	0.44	4.600	0.015	0.17	0.39	113
OLDS	10/20	30.92115	-85.08285	7.47	20.76	162	8.67	0.41	69	3.1	0.62	2.000	0.009	0.25	0.29	101
R.D. BENNET CATTLE	10/14	30.85668	-85.16168	7.02	21.09	444	8.32	0.06	211	6.5	1.10	4.300	0.029	0.45	0.64	257
R. MATTHEWS	10/21	30.81445	-85.09692	7.47	20.93	212	7.84	0.36	87	3.9	0.98	3.700	0.024	0.36	1.00	149
ROWELL	10/6	30.73916	-85.07013	7.54	20.29	192	7.62	0.84	96	2.7	9.60	0.180	0.010	0.22	0.99	102
WILLIAM MERCHANT	10/6	30.76859	-85.10353	7.33	20.96	246	6.93	0.47	113	3.5	6.80	1.900	0.013	0.22	1.80	133
WOOD	10/21	30.95100	-85.13272	7.41	20.96	246	8.12	8.54	100	5.1	1.00	0.013	0.012	0.56	0.76	166
Forested																
320067701	10/14	30.89176	-85.14809	7.20	20.86	230	8.53	2.29	104	3.0	0.69	2.200	0.011	0.15	0.43	127
ADAMS	10/19	30.97507	-85.14627	7.41	20.83	223	8.65	2.42	96	3.5	0.68	3.000	0.012	0.25	0.43	127
CALHOUN	10/13	30.79189	-85.11202	7.26	20.62	274	8.13	0.00	131	3.4	2.00	1.800	0.017	0.19	1.10	143
DAVIS	10/14	30.83800	-85.04203	7.54	21.47	234	1.35	210.00	108	2.3	1.80	0.120	0.021	0.18	10.00	130
JACKSON BLUE SPRING	10/21	30.79033	-85.14018	7.42	20.49	251	7.16	0.29	109	4.2	2.10	3.400	0.021	0.31	1.20	144
PETTIS	10/13	30.92868	-85.15395	7.38	20.60	288	9.26	0.00	112	6.2	1.30	6.600	0.015	0.54	1.00	192
WALKER	10/13	30.86101	-85.10646	7.22	20.35	270	9.38	0.00	126	3.3	1.30	2.400	0.012	0.21	0.54	153

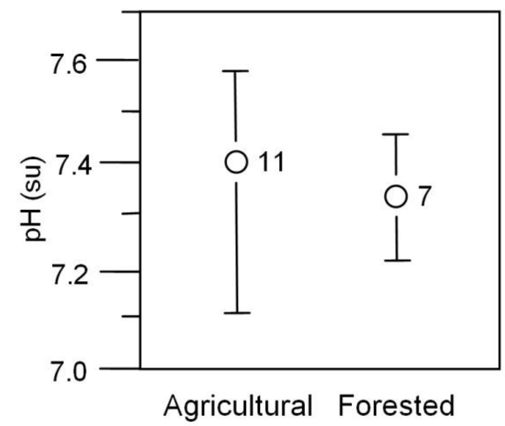

FIGURE 16. Statistical Summary of Measured pH Levels by Land Use. Groundwater pH levels measured in agricultural and forested monitoring stations within the Jackson Blue springshed do not differ significantly. Mean (o) and ± one standard deviation (brackets) are given.

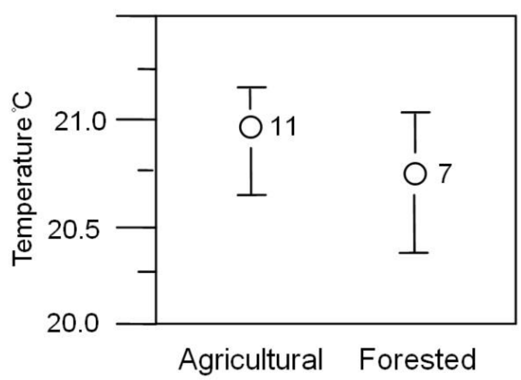

FIGURE 17. Statistical Summary of Measured Temperatures by Land Use. Groundwater temperatures measured in agricultural and forested monitoring stations within the Jackson Blue springshed do not differ significantly. Mean (o) and ± one standard deviation (brackets) are given.

Specific conductance measurements were expected to be higher in agricultural well samples as compared to forested wells; to the contrary, significance is noted in the data (Mann Whitney U, z=1.9029, p=0.0285), but reveals higher conductivity in water samples from wells located in forested land use areas (Figure 19). Specific conductance is a reflection of the amount and type of ions in the groundwater; because the concentration of such ions can be expected to increase when water undergoes

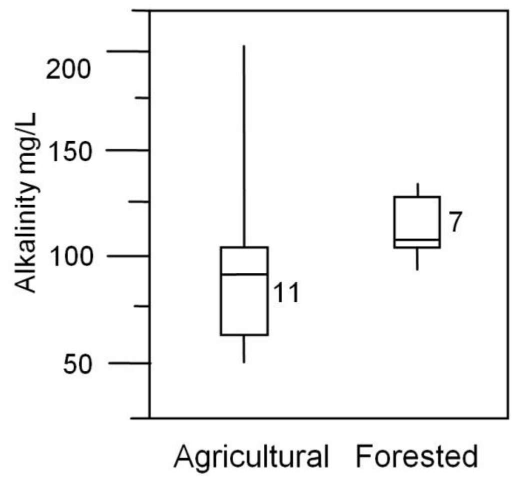

FIGURE 18. Statistical Summary of Measured Alkalinity Levels by Land Use. Groundwater alkalinity measured in agricultural and forested monitoring stations within the Jackson Blue springshed differ significantly. Mean (o) and ± one standard deviation (brackets) are given.

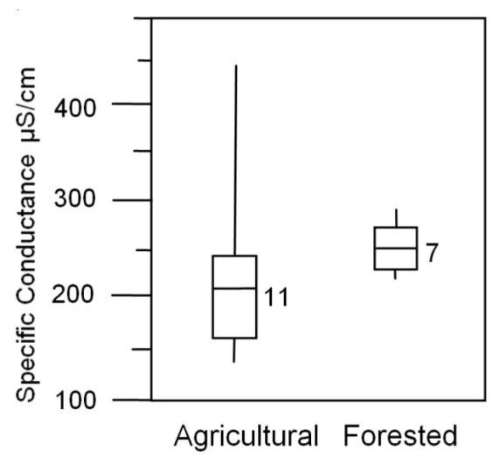

FIGURE 19. Statistical Summary of Measured Specific Conductance Levels by Land Use. Groundwater Specific Conductance measured in agricultural and forested monitoring stations within the Jackson Blue springshed differ significantly. Minimum, maximum, 1st quartile, median, and 3rd quartile are given.

evaporation (such as during the irrigation process on agricultural tracts), it is reasonable to predict that measured specific conductance may be elevated in these areas relative to forested regions. The opposite finding was not predicted. Observation of Figure 19 demonstrates the broad range of values measured in agricultural samples; while significance was gained, the extent of variation tempers the weight of this finding.

Additionally, this parameter is typically correlated with TDS and chloride concentrations, indicating that those results should be considered in evaluating this outcome (Figures 20 and 21).

Measurements of total dissolved solids indicated no significant difference between samples from wells in agricultural and forested locations (Mann Whitney U, z=0.4531, p=0.3253). TDS levels in agricultural parcels were anticipated to significantly exceed levels in forested areas; while no significance is attained, examination of Figure 20 reveals that while the highest value was measured in an agricultural sample, the overall difference present appears to favor higher levels in the forested areas. This outcome is aligned with results of specific conductance monitoring; however, it is important to note that these trends are not statistically significant.

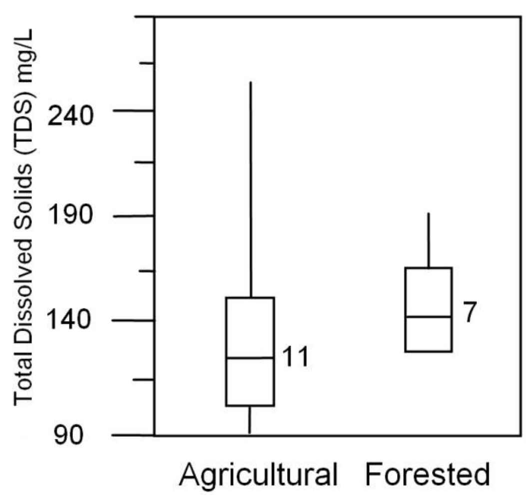

FIGURE 20. Statistical Summary of Measured TDS Levels by Land Use. Groundwater TDS measured in agricultural and forested monitoring stations within the Jackson Blue springshed do not differ significantly. Minimum, maximum, 1st quartile, median, and 3rd quartile are given.

Total chloride levels in wells located in agricultural land use designations are not significantly higher (Independent t test, t=0.51, p=0.6139) than levels measured from wells on land designated as forested (Figure 21).

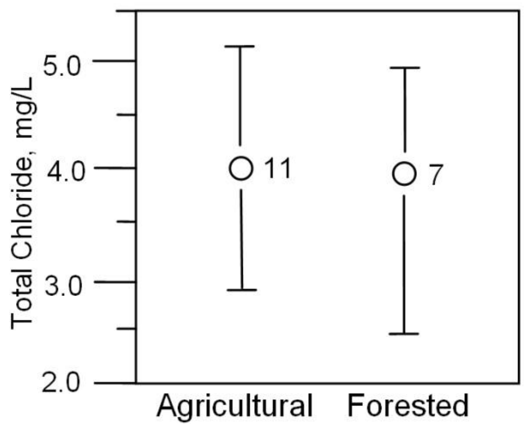

FIGURE 21. Statistical Summary of Measured Total Chloride Levels by Land Use. Groundwater total chloride levels measured in agricultural and forested monitoring stations within the Jackson Blue springshed do not differ significantly. Mean (o) and ± one standard deviation (brackets) are given.

Including all samples, turbidity measurements in wells located in agricultural land use designations are not significantly different than levels measured from wells on land designated as forested (Mann Whitney U, z=-0.6353, p=0.5252). The median turbidity value for agricultural wells is 0.9 mg/L (n=11, min=0.06, Q1=0.41, Q3=1.91, max=8.54) and the median turbidity value for forested wells is 0.29 mg/L (n=7, min=0.0, Q1=0.0, Q3=2.42, max=210). However, one sample was significantly out of range relative to all other samples: this is a reading of 210 mg/L from the Davis well, in the forested group. All other values are in the range 0-8.54 mg/L. With the exclusion of this datum, turbidity measurements in the two land use groups still are not significantly different (Mann Whitney U, z=-1.2594, p=0.2079). In this case, the median turbidity value for forested wells is 0.145 mg/L (n=6, min=0.0, Q1=0.0, Q3=2.29, max=2.42). A statistical summary of the latter is expressed in Figure 22.

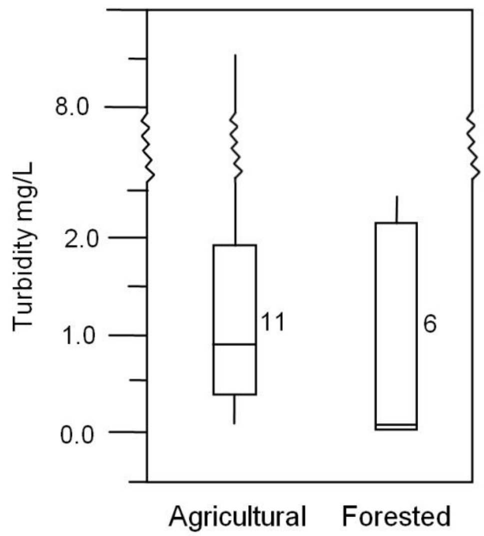

FIGURE 22. Statistical Summary of Measured Turbidity Levels by Land Use. Groundwater turbidity measured in agricultural and forested monitoring stations within the Jackson Blue springshed do not differ significantly. Minimum, maximum, 1st quartile, median, and 3rd quartile are given.

Measured dissolved oxygen levels at agricultural and forest locations do not indicate any significant difference under comparison (Mann Whitney U, z=0.2265, p=0.8208). The median DO for agricultural wells is 8.31 mg/L (n=11, $\bar{\chi}$=8.22, *SD*=0.791) and the median DO for forested wells is 8.53 mg/L (n=7, $\bar{\chi}$=7.49, *SD*=2.809). Because the sample taken from Davis well in the forested group is significantly out of range relative to the other samples, analysis was also run with the exclusion of this datum; as a result, a normal distribution is attained, but no change in statistical significance is noted (Independent t test, t= -0.074, p=0.4702). The median DO for forest wells in the absence of this datum is 8.6 mg/L (n=6, $\bar{\chi}$=8.51, *SD*=0.813) (Figure 23). Overall, the measured levels are substantially higher than the values expected.

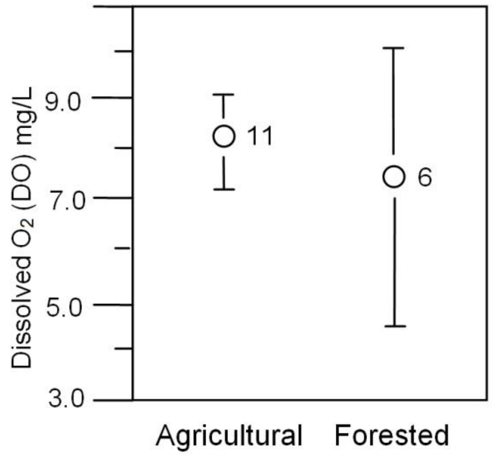

FIGURE 23. Statistical Summary of Measured DO Levels by Land Use. Groundwater DO levels measured in agricultural and forested monitoring stations within the Jackson Blue springshed do not differ significantly. Mean (o) and ± one standard deviation (brackets) are given.

Magnesium levels are not significantly different (Mann Whitney U, $z=1.0879$, $p=0.2766$) between samples from wells in agricultural and forested locations (Figure 24). As magnesium levels in the region are primarily influenced by the greater geologic influences of the region, significant variation between land use samples was not predicted. The Hawthorn Group formation and the presence of dolomite in the Floridan aquifer present a greater effect than the potential from anthropogenic activities in the Jackson Blue basin.

Measured orthophosphate (dissolved) does not indicate any significant difference (Mann Whitney U, $z=0.0457$, $p=0.4818$) between the land use areas of interest (Figure 25). While anthropogenic sources can include fertilizers and human or industrial waste, these effects are reduced by rapid soil fixation. Akin to magnesium, phosphate as dissolved orthophosphate is released gradually from the natural process of weathering. The dominant influence in the region is the Hawthorn Group geological unit.

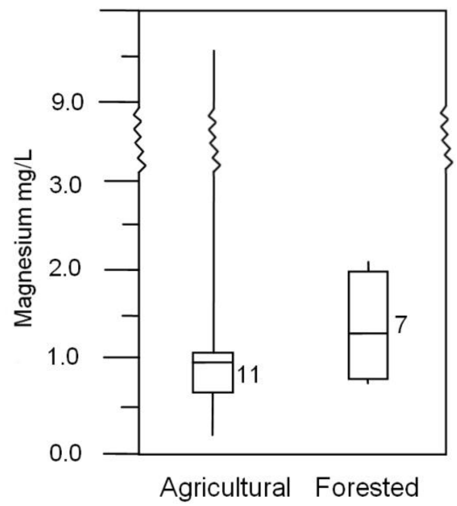

FIGURE 24. Statistical Summary of Measured Magnesium Levels by Land Use. Magnesium measured in agricultural and forested monitoring stations within the Jackson Blue springshed do not differ significantly. Minimum, maximum, 1st quartile, median, 3rd quartile are given.

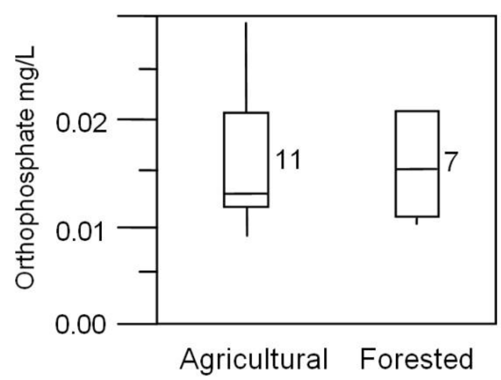

FIGURE 25. Statistical Summary of Measured Orthophosphate Levels by Land Use. Orthophosphate, dissolved, measured in agricultural and forested monitoring stations within the Jackson Blue springshed do not differ significantly. Minimum, maximum, 1st quartile, median, 3rd quartile are given.

As expected, sodium levels measured at both agricultural and forested land use wells do not reveal any significant difference (Independent t test, t= 0.18, p=0.8629) (Figure 26). The inland nature of the study area precluded the influence of seawater intrusion on groundwater sampled.

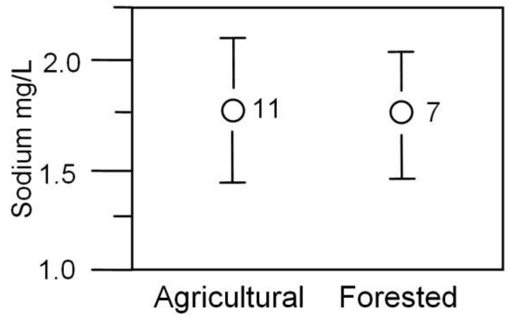

FIGURE 26. Statistical Summary of Measured Sodium Levels by Land Use. Sodium levels measured in agricultural and forested monitoring stations within the Jackson Blue springshed do not differ significantly. Mean (o) and ± one standard deviation (brackets) are given.

Potassium values measured at wells in both agricultural and forested land use areas are not significantly different (Mann Whitney U, z=-1.2245, p=0.2207). Elevated K^+ levels are primarily associated with seawater mixing, but may also be derived from inorganic fertilizer application. While the results are not significant, observation of Figure 27 gives the impression of a trend towards higher K^+ levels in the agricultural group: this influence may be reasonably attributed to the anthropogenic activity of fertilizer application, as saltwater intrusion cannot be responsible.

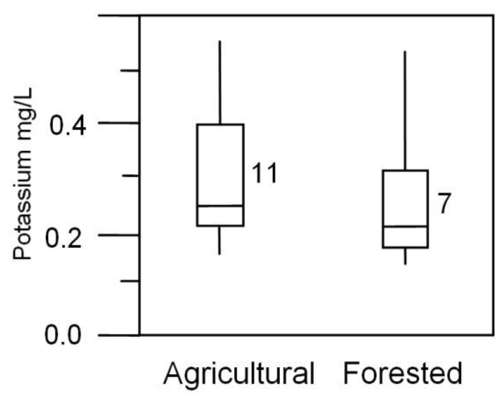

FIGURE 27. Statistical Summary of Measured Potassium Levels by Land Use. Groundwater potassium levels measured in agricultural and forested monitoring stations within the Jackson Blue springshed do not differ significantly. Minimum, maximum, 1st quartile, median, 3rd quartile are given.

Sulfate levels are not significantly different between agricultural and forested areas (Mann Whitney U, z=0.7257, p=0.2340). The median SO_4^{2-} value for agricultural wells is 0.76 mg/L (n=11, $\overline{\chi}$=0.81, *SD*=0.438) and the median SO_4^{2-} value for forested wells is 1.0 mg/L (n=7, min=0.43, Q1=0.43, Q3=1.2, max=10.0). As with the turbidity parameter, the value from the Davis well was significantly out of range relative to all other samples: a reading of 10 mg/L was recorded, while a range of 0.29 to 1.2 mg/L encompassed all other values. The exclusion of this datum resulted in normal distributions within the two groups, but does not change the original findings of no significant difference (Independent t test, t=0.14, p=0.8901) in sulfate values between the land use designations (Figure 28).

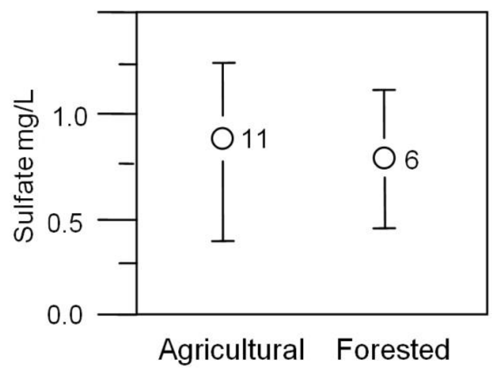

FIGURE 28. Statistical Summary of Measured Sulfate Levels by Land Use. Groundwater sulfate levels measured in agricultural and forested monitoring stations within the Jackson Blue springshed do not differ significantly. Mean (o) and ± one standard deviation (brackets) are given.

Total nitrogen (NO_3^-+NO_2^-) was the variable most expected to present a significant difference between the two land uses under investigation: agricultural and forested. However, no significant difference is indicated (Independent t test, t=0.09, p=0.9329) (Figure 29). Because of the high percentage of agricultural activity in Jackson County and the pursuant application of inorganic fertilizer across broad tracts of land in the Jackson Blue Spring basin, it was anticipated that groundwater nitrate measurements would far exceed background levels of less than 0.1 mg/L. Sampling at the spring vent over the last decade has revealed levels on the rise; the average nitrate level in recent years is 3.5 mg/L. This data revealed means of 2.8 mg/L across all samples. No samples exceeded the MCL of 10 mg/L for human drinking water consumption. However, these levels do exceed the protective numeric criteria for streams in the bioregion as defined by the EPA and FDEP: recall this value has been calculated as 1.7mg/L total nitrogen. The hypothesis that higher total nitrogen levels will be measured from wells in agricultural land use parcels than in samples from forested areas was not supported. Several explanations for this result are further explored in the following discussion.

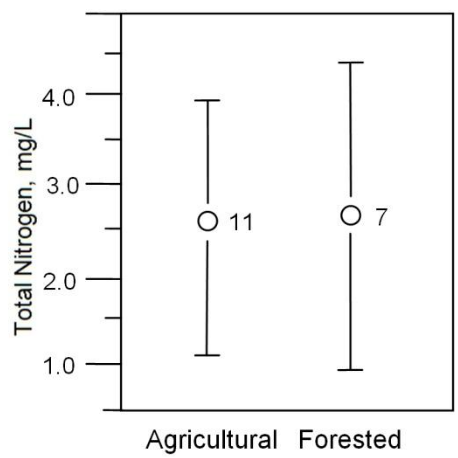

FIGURE 29. Statistical Summary of Measured Total Nitrogen Levels by Land Use. Groundwater total nitrogen (NO_3^-+NO_2^-) levels measured in agricultural and forested monitoring stations within the Jackson Blue springshed do not differ significantly. Mean (o) and ± one standard deviation (brackets) are given.

CHAPTER 6

DISCUSSION

The presence of nitrate-nitrite in groundwater above natural concentrations is associated with anthropogenic sources such as septic tanks, wastewater treatment, and fertilizers. Previous studies have identified the primary source of nitrogen in the Jackson Blue Spring basin as originating from the application of inorganic fertilizer across this county where agriculture is the predominant land use. Trends in increased nitrate-N concentrations were consistent with increased fertilizer usage, but a concurrent lowering of concentrations has not been seen with a reduction of fertilizer application; spring water responses have been delayed because average residence times are in excess of a decade (Katz *et al.,* 2001). The identification of agricultural activities as the source of nitrate-N in the basin leads to the expectation that these levels may be found in the highest concentrations in the areas closest to these activities; however, this relationship was not found to be significant.

It is unclear why some of the parameters measured at Davis well (forested) were substantially out of range. The particular well in question is one of those which sits on a small plot of land which is designated as “built-up” within a larger forested area, and also is not isolated from agricultural parcels; however, the outlying values were very far removed from values measured at all other monitoring stations. The outlying data associated with this monitoring station were measurements of DO (low), turbidity (high), and SO_4^{2-} (high). The DO reading was not abnormally low relative to expected data readings (1.35 mg/L), but was substantially out of range relative to all other recorded values. It can reasonably be concluded that these outliers were errors in either data collection or data recording. Repeated samples could support this conclusion.

Also unclear is why the dissolved oxygen values were measured at such high levels across all samples. The measured range of 6.93 - 9.38 mg/L is extremely high for groundwater DO measurements. These levels reflect healthy levels for flowing, open water ecosystems, but surprising levels for groundwater samples. These higher than expected levels can be accounted for by two possible explanations: an error in sampling methodology which resulted in aeration of samples, or a very high proportion of recently recharged waters. While the latter could be possible, it seems unlikely in light of the consistency of the readings across the springshed measured values. The more probable explanation is the first: per DEP SOP 001/01 (Revised 3/31/2008), “groundwater samples must be measured *in situ* with a downhole probe or in a flow-through container. Do not measure bailed or pumped samples in an intermediate container containing static sample.” While these samples were measured in the field, the probes used at that time required the movement of the probe in the sample, which by default could introduce aeration capable of altering the results improperly. Future samples should be executed according to the updated SOP.

Alkalinity and specific conductance measures unexpectedly revealed significant differences between agricultural and forested samples, with the higher values reported in the forested group in both cases. Higher alkalinity indicates a greater buffering capacity, and is therefore generally a positive attribute; however, there is no indication that such a difference should be noted in forested areas as compared to agricultural regions, and the statistics just barely achieve numerical significance. In combination, this finding is of little consequence. As TDS and total Cl^- concentrations were not found to differ significantly between the two land use groups, the specific conductance finding holds little weight: typically these parameters are positively correlated and it would be reasonable to expect all three parameters to exhibit significance if the finding were due to a causative factor.

Overall, a greater number of samples would add to the robustness of these results. Only 18 sample sites, with one-time sample draws, is not an ideal experimental design. While the number of sample sites available is limited by the quantity of monitoring stations within the delineated springshed, the number and frequency of samples taken is not. A repeat of this study would best be performed with at least four samples annually (quarterly) and over several years. Analysis of an extended pool of data would better illuminate real statistical trends in the basin.

There are three primary explanations for the lack of significance found in the nitrate levels sampled from wells in agricultural or forested land us designations: first, the two major land use categories are well distributed in the basin with little clustering or spatial trends. Second, transmissivity in the aquifer is high in this region allowing for the homogenization of water quality at the local scale. Third, many of the parcels designated as forested land use are commercial pine stands, which may receive direct applications of fertilizer as well.

The regional karst terrane and concomitant vulnerability of the underlying Floridan aquifer, combined with a high proportion of agricultural land use, make the Jackson Blue Spring basin an ideal location for the examination of relationships between agricultural land use and water quality measures, particularly nitrate-N.

However, the distribution of agricultural land use parcels amongst forested and other designations creates a noteworthy flaw in the determination of a statistical relationship between these factors. If significance does exist, it will be more likely to reveal itself in an area where the land use parcels are less scattered and in larger continuous tracts.

High transmissivity in the aquifer will be present in most karst regions, and may be a factor which will consistently confound results. This issue is best addressed by the same approach discussed above, where contiguous tracts of single land use will reduce the mixing at least to some extent, allowing water parameter measures to better reflect their origins.

The final obstacle in a useful comparison between water quality related to areas utilized for agricultural activities and those which are forested is found in the very definition of forested. For this study to produce data which reflects water quality effects of the application of inorganic fertilizers to agricultural lands, the land under comparison must be without this application. As much of the land designated as forested in this area is not virgin forest, nor replanted natural forests, but rather commercial pine stands, the assumption that these areas do not receive application of fertilizer is invalid and certainly a confounding factor.

CHAPTER 7

CONCLUSIONS AND RECOMMENDATIONS

Jackson Blue Spring and groundwater in its contribution area have some of the highest measured nitrate levels in the state of Florida. As a direct window into the Floridan aquifer which is relied upon heavily for the freshwater needs of individuals and commercial activities by much of the state, this is an early alarm bell of great concern. Karst aquifer systems are highly complex and also highly vulnerable to contamination from surface activities, making them both a challenging and important subject of study.

The objectives of this research included the synthesis of broad research on Florida geology, karst processes and hydrology, discharge data, biota inventories, and exploration focusing on Jackson Blue Spring. Water quality data from Jackson Blue springshed monitoring wells and the land use categorization at these stations was delineated. Statistical analyses were conducted with regard to relationships between water quality parameters and monitoring well designated land use. A thorough background of data and publications has been aggregated here, developing a focused characterization of Jackson Blue Spring with the goal of providing a valuable tool in the planning arsenal for conservation and development planning purposes. Concurrent with synthesizing previously conducted studies, this research has illuminated some areas in which further study is needed.

The significant confounding factor of high aquifer transmissivity may be surmounted by conducting a similar study with water quality data retrieved from the vadose zone: water not yet below the water table would be more likely to reflect the influences of the local area without the mixing inherent in the aquifer. Such a study might better illuminate differences between the impacts of agricultural and forested land use.

The development of a nitrogen (N) mass-balance budget for the Jackson Blue Spring basin, such as Katz and others (2009) developed for the Ichetucknee Springs basin, would well serve continued future planning and protection efforts in the region. That budget included direct measurements of N species in rainfall, groundwater, and spring waters, along with estimates of N loading from fertilizers, septic tanks, animal wastes, and the land application of treated municipal wastewater and residual solids. At the time of this writing, a nutrient transport study in the basin is being conducted by the USGS (personal communication, C. Crandall, February 18, 2010); as it is still underway, specifics regarding the nature of the study could not be released. Whether it fulfills the need for a nitrogen (N) mass-balance budget is not known, but its results will be a benefit to further understanding of the problem and its sources, regardless.

Over the next two decades, if trends in fertilizer use continue to decline or remain at the same level, it can be expected that measured groundwater nitrate levels should decrease, based on the estimated age of the basin waters and associated lag time. A failure to see this decrease might be explained by excessive inorganic fertilizer application further north in the contribution area (outside of Jackson County, where usage is known to have decreased), or perhaps by other nitrogen contributions entirely. This will require further investigation.

Today it is widely known that over-fertilization is a common farming practice that wastes financial and nutrient resources and leads to environmental pollution. The Florida Department of Environmental Protection (FDEP) conducts considerable outreach to homeowners with an internet presence regarding lawn fertilizer use and water conservation. For farmers, some simple methods can contribute to reducing nutrient losses: soil conservation, irrigation and fertilizer management, and soil testing. Conservation tilling and mulching are highly recommended; the application of N fertilizer and irrigation water to meet but not exceed crop requirements is important to reducing the NO_3^- leaching from irrigated sandy soils. An area where there may be room for improved outreach and data collection is in the commercial forestry industry: it is safe to say that the Jackson Blue Spring basin receives the application of fertilizer across most of its soil, as most land parcels which are not used for agricultural activities are commercial pine stands. Land managers of these parcels may be less informed about the negative impacts of excess fertilizer application and because of the long-term nature of their crop, they may be less aware of the best management practices in terms of effective quantity: what amounts of fertilizer can be utilized by the pine stands to accelerate and benefit growth without wasteful and environmentally damaging leaching?

A formal study of stygobitic inhabitants of the cave has not been conducted, and would contribute to the knowledge base. This will require trained cave diving biologists to identify, tally, and record sightings, over numerous dives and years. An important aspect of this inventory will be the documentation of species known to previously be trogloxenes, which now frequent the cave zone as troglophiles.

Another valuable contribution which can only be conducted by trained cave divers is an inventory of the fossil record inside the cave inside Jackson Blue; because of the conduits formed in the rock by constantly moving water, great expanses of fossiliferous walls are exposed deep beneath the earth's surface. This provides a unique opportunity to catalog this geological history without further excavation.

A major area of potential for better understanding the Jackson Blue springshed at large involves the hydrology of the springshed, the spring run, and the spring itself. This will be a large undertaking and is best divided into several smaller projects. A dye tracer study including a broad area in the basin may shed significant light on the groundwater movement but will require the installation of many sensors and repeated visits to multiple monitoring stations over the course of an indeterminate time period. A shorter term and also informative work would be a determination of the hydraulic gradient in Merritt's Mill Pond, including the JB spring pool.

Perhaps the most valuable future study will provide more information on the proportions of discharging spring water which is quick flow and that which is groundwater of longer residence. Building upon the studies conducted by Katz and others, quantifying the character and mixture of Jackson Blue will be an involved undertaking which would provide knowledge essential for better analysis of the spring: accurately attributing causative factors behind negative water quality profiles and the promotion of land use behaviors which have positive effects would be well served by this data.

Florida is a good model for water resource protection and awareness: the economic benefits of its many recreational and commercial water resources are not lost on the governmental agencies and individuals who are in positions of decision-making power. It is fortunate that the beauty and recreational enjoyment of the state's many springs help to bring the water quality of these precious resources into the public eye, as that same source provides nearly all of the state's drinking water. The combination of these factors, along with significant anthropogenic activities including agriculture and the vulnerability to contamination that is inherent in the karst terrane, make the state a good bellwether for issues in other karst regions around the globe. North and central Florida is also an international epicenter for cave divers, as so many of the spring vents open into passable water-filled conduits beneath the surface; as such, a unique opportunity exists, to retrieve invaluable first-hand data regarding water quality, hydrogeology, biota, fossil records, and unknown additional future benefits.

Many of Florida's first and second magnitude springs are under county, state, or federal management (Scott *et al.,* 2002). Although obstacles exist, the conservation of springs through public ownership should aim to increase to include the remainder of Florida's springs and to as much of the recharge zones as possible, to include the springsheds and watersheds. Public ownership can be helpful in reducing nutrient and contaminant loading in these sensitive areas through careful land management. The challenges are significant, as the protection of these areas must be balanced with human uses; it is neither reasonable nor desirable in most cases to close the springs and their vicinities to all recreation or other land uses. Wise management requires a combination of use restrictions, careful development around recreational spring locales to reduce erosion and other human impact, public education, and intensive monitoring and guidelines relating to land use and development in the most vulnerable areas of springsheds (sinkholes and major recharge zones). Cautious deliberation regarding reasonable human uses and human carrying capacities is necessary to protect and preserve the water quality upon which residents depend upon so heavily, as well as the essential ecological functions of these sensitive habitats.

Jackson Blue Spring is representative of the vulnerability of Florida springs as a first magnitude spring in a region of considerable agricultural activity with high inorganic fertilizer application. This study aimed to provide a comprehensive characterization of the spring and associated springshed based on the information currently available. There is a great deal of information that can be added to this knowledge base through additional study and it is the author's hope that a revision may be possible in just a few short years with updates of this nature. A similar document should exist for every first magnitude spring and groups of lesser springs; it is through the assimilation of works that the most comprehensive understanding can be reached, providing informative tools to those in decision-making capacities to make the most significant difference in the protection of this precious resource.

APPENDIX A

FLORIDA PLATFORM GEOLOGICAL AND SEA LEVEL PROGRESSION

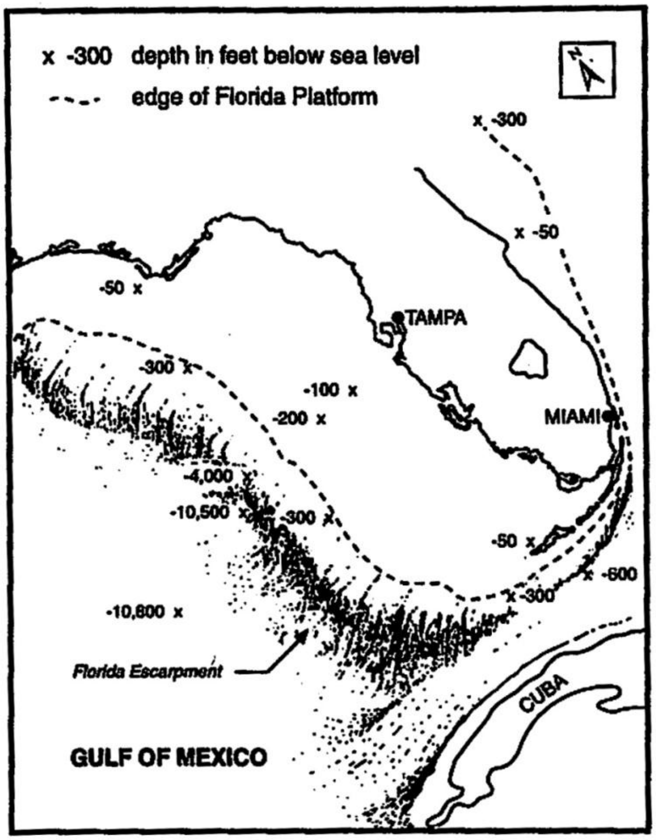

FIGURE A1. Oblique View of the Florida Platform and Florida Escarpment (Lane, 1986).

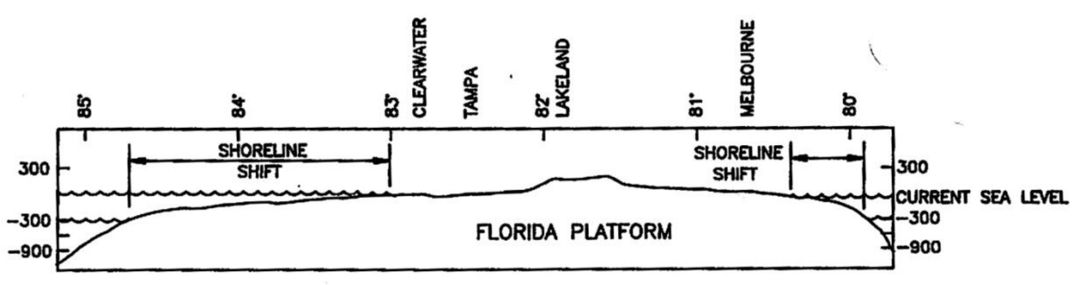

FIGURE A2. Profile Across Florida Platform Showing Shoreline-Shift Effect of Sea-level Rise over the Last 20,000 Years (Schmidt, 1997).

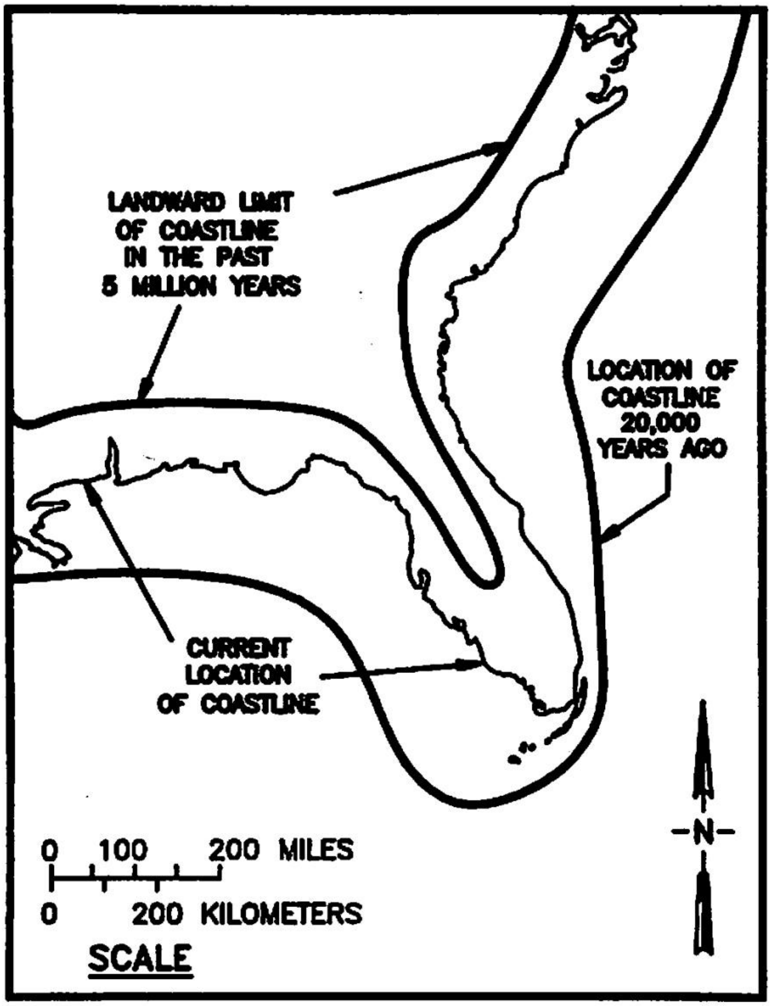

FIGURE A3. Ancient Florida Coastlines: sea level has risen dramatically since the end of the last ice age, about 20,000 years ago (Schmidt, 1997).

APPENDIX B

BIOTA INVENTORY OF JACKSON BLUE SPRING POOL AND RUN

Table B1. Data collected by Wetland Solutions, Inc. personnel in the following manner: Aquatic insects were characterized based on collections made of adults as they emerged from the water. Insect emergence was measured through the use of floating pyramidal traps, each with a sampling area of 0.25 m^2. A total of ten traps were deployed at locations along the periphery of the spring pool and run. At each location the substrate and water depth was noted. Traps were deployed and the jars containing the emergent insects collected at 24 hour intervals for a total of three collections. Insect identifications were made to the lowest practical taxonomy with the aid of FDEP staff (WSI. 2010).

Insects observed at Jackson Blue Spring Pool and/or Run			
Order	**Family**	**Tribe** (if known)	**Lowest Practical Taxonomy**
Diptera	Chironomidae		Chironomidae
Diptera	Chironomidae		*Cricotopus sp.*
Diptera	Chironomidae	Chironomini	*Apedilum elachistus*
Diptera	Chironomidae	Chironomini	*Beardius truncates*
Diptera	Chironomidae	Chironomini	*Chironomus sp.*
Diptera	Chironomidae	Chironomini	*Cladopelma collator*
Diptera	Chironomidae	Chironomini	*Cryptochironomus sp.*
Diptera	Chironomidae	Chironomini	*Parachironomus potamogeti*
Diptera	Chironomidae	Chironomini	*Polypedilum halterale*
Diptera	Chironomidae	Chironomini	*Polypedilum scalaenum*
Diptera	Chironomidae	Pentaneurini	*Ablabesmyia mallochi*
Diptera	Chironomidae	Pseudochironomini	*Pseudochironomus richardsoni*
Trichoptera	Hydroptilidae		Hydroptilidae

TABLE B2. Macrofauna Observed at Jackson Blue Spring Pool/Run. Data collected by Wetland Solutions, Inc. personnel in the following manner: While on site, the observed macrofauna (mammals, birds, reptiles, and amphibians) were identified to the lowest possible taxonomic level and their numbers quantified. Aquatic turtles were also counted during fish surveys (WSI 2010).

Macrofauna observed at Jackson Blue Spring Pool and/or Run	
Birds	
Ardea alba	Great Egret
Ardea herodias	Great Blue Heron
Baeolophus bicolor	Tufted Titmouse
Bombycilla cedrorum	Cedar Waxwing
Buteo jamaicensis	Red-tailed Hawk
Buteo lineatus	Red-shouldered Hawk
Butorides virescens	Green Heron
Cathartes aura	Turkey Vulture
Colaptes auratus	Northern Flicker
Coragyps atratus	American Black Vulture
Corvus ossifragus	Fish Crow
Cyanocitta cristata	Blue Jay
Dendoica coronata	Yellow-rumped Warbler
Dryocopus pileatus	Pileated Woodpecker
Fulica americana	American Coot
Larus delawarensis	Ring-billed Gull
Megaceryle alcyon	Belted Kingfisher
Melanerpes carolius	Red-bellied Woodpecker
Phalacrocorax auritus	Double-crested Cormorant
Podilymbus podiceps	Pied-billed Grebe
Poecile carolinensis	Carolina Chickadee
Polioptila caerulea	Blue-gray Gnatcatcher
Sayornis phoebe	Eastern Phoebe
Strix varia	Barred Owl
Thryothorus ludovicianus	Carolina Wren
Tudus migratorius	American Robin

TABLE B2. (continues)

TABLE B2 (continued)

<u>Macrofauna observed at Jackson Blue Spring Pool and/or Run</u>	
Amphibian	
None	
Crustacean	
Procambarus spiculifer	crayfish
Mammal	
Lontra canadensis	North American river otter
Procyon lotor	raccoon
Reptile	
Pseudemys floridana floridana	Florida cooter
Sternotherus minor minor	loggerhead musk turtle

TABLE B3. Fish Observed at Jackson Blue Spring Pool/Run. Data collected by Wetland Solutions, Inc. personnel in the following manner: Multiple daily surveys of fish communities were made by two people using snorkel and/or SCUBA gear. Observers noted the species (or lowest practical taxonomy) of all observed fish, and these observations were called out to a data recorder, who followed along in a boat. Following each survey, observers estimated the total length (average and range) by fish species. Fish density was calculated by dividing the average number of individuals counted by the area sampled. Biomass of fish species was estimated using published length-weight relationships and average species total lengths and numbers (WSI, 2010).

<u>Fish observed at Jackson Blue Spring Pool and/or Run</u>	
Ctenopharyngodon idella	grass carp
Gambusia holbrooki	eastern mosquitofish
Lepomis gulosus	warmouth
Lepomis macrochirus	bluegill
Lepomis microlophus	redear sunfish
Lepomis punctatus	spotted sunfish
Micropterus salmoides	largemouth bass
Notropis cummingsae	dusky shiner
<u>Fish density in pool (0.41 ha) 2,663 #/ha; biomass 287.4 kg/ha</u>	

TABLE B4. Vegetation Observed at Jackson Blue Spring Pool/Run. Data collected by Wetland Solutions, Inc. personnel in the following manner: Aquatic vegetative cover was documented for each segment at multiple sampling points (typically between 50 and 100 points). Observed plants were identified to species or lowest possible taxonomy. No quantitative plant biomass samples were collected due to concerns of destructive sampling (WSI 2010).

Vegetation observed at Jackson Blue Spring Pool and/or Run	
Emergent/Floating Species	
Alternanthera philoxeroides	alligator weed
Carez sp.	caric sedge
Cladium jamaicense	saw grass
Hydrocotyle sp.	pennywort
Kosteletzkya virginica	salt marsh mallow
Lemna sp.	duckweed
Pontederia cordata	pickerelweed
Typha sp.	cattail
Wolffia sp.	water-meal
Riparian Species	
Carya sp.	hickory
Juniperus silicicola	southern red cedar
Persea palustris	swamp bay
Quercus sp.	Oak
Taxodium distichum	bald cypress
Submersed Aquatic Species	
Ceratophyllum demersum	coontail
Chara sp.	muskgrass
Najas guadalupensis	southern naiad
Spriogyra sp.	filamentous green algae
Vallisneria Americana	tape grass

APPENDIX C

MONITORING WELL LOCATION AND CONSTRUCTION DATA

Appendix C. Well Location and Construction Data for the 18 monitoring stations included in this study (adapted from Barrios and DeFosset, 2005).

Well Name	Date Collected		Latitude	Longitude	Location Datum	Elevation (ft)	Elevation Datum	Depth of Well (ft)	Depth of Casing (ft)	Diameter (in)
Agricultural										
BALDWIN	10/7/2004	15:49	30.86290332	-85.05269845	WG384	122	NGVD29	130	60	4
DITTY MON\JC-3\JK30	10/21/2004	12:40	30.97906667	-85.11769444	WG384	154	NGVD29	123	83	4
DIXON	10/7/2004	13:05	30.89339210	-85.11144505	WG384	132	NGVD29	95	63	4
MERCER	10/6/2004	14:44	30.80104524	-85.06007916	WG384	130	NGVD29	135	84	4
MURPHY	10/20/2004	17:02	30.81275000	-85.14806667	WG384	118	NGVD29	100	63	4
OLDS	10/20/2004	12:26	30.92115000	-85.08285000	WG384	135	NGVD29	100	73	4
R.D. BENNET CATTLE	10/14/2004	12:27	30.85668333	-85.16168333	WG384	115	NGVD29	126	84	4
R. MATTHEWS	10/21/2004	16:01	30.81445000	-85.09691667	WG384	118	NGVD29	110	80	4
ROWELL	10/6/2004	12:37	30.73915847	-85.07013387	WG384	150	NGVD29	140	105	4
WILLIAM MERCHANT	10/6/2004	13:38	30.76859101	-85.10352743	WG384	110	NGVD29	89	60	4
WOOD	10/21/2004	14:06	30.95100000	-85.13271667	WG384	155	NGVD29	70	68	4
Forested										
WORLD/320067701	10/14/2004	10:54	30.89175532	-85.14808607	WG384		NGVD29			
ADAMS	10/19/2004	12:55	30.97506667	-85.14626667	WG384	151	NGVD29	122	74	4
CALHOUN	10/13/2004	15:36	30.79189255	-85.11202416	WG384	115	NGVD29	150	60	4
DAVIS	10/14/2004	16:29	30.83800278	-85.04202500	WG384	115	NGVD29	150	88	4
JACKSON BLUE SPRING	10/21/2004	18:46	30.79033333	-85.14017500	WG384	77	NGVD29	spring		
PETTIS	10/13/2004	13:07	30.92867711	-85.15395173	WG384	140	NGVD29	125	93	4
WALKER	10/13/2004	14:14	30.86101174	-85.10646025	WG384	125	NGVD29	132	95	4

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