Wakulla Spring Restoration Plan

Prepared for

The Wakulla Springs Alliance

and the Friends of Wakulla Springs

Prepared by

The Howard T. Odum

Florida Springs Institute

August 2014

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Acknowledgements

This ***Wakulla Spring Restoration Plan*** provides an update of the ***Wakulla Spring Adaptive Management Strategy*** previously published in August 2011 by the Howard T. Odum Florida Springs Institute (FSI). Information included in that earlier report was gathered under a project completed by Wetland Solutions, Inc. (WSI) for the Florida Department of Environmental Protection (FDEP) in June 2011. Due to funding cuts, the three-year contract for the ***Wakulla Spring Working Group Coordination and Restoration Planning Project*** was discontinued at the end of its first year. That budget-cutting decision led to the demise of the longest, continuously-active springs working group in Florida, the ***Wakulla Springs Basin Working Group***, originally organized in 1992 by Jim Stevenson, head of the Florida Springs Task Force when he was employed by FDEP.

Following the publication of the ***Wakulla Spring Adaptive Management Strategy*** report, some members of the ***Wakulla Springs Basin Working Group*** reorganized as the ***Wakulla Springs Alliance*** (WSA) under the existing non-profit ***Hydrogeology Consortium***, a group of scientists and advocates with deep interest in Wakulla Spring. The WSA is the principal group actively promoting the restoration and protection of Wakulla Spring. In addition to their ongoing efforts, the Florida Department of Environmental Protection (FDEP) and the Northwest Florida Water Management District (NWFWMD) have stepped up their programs to provide protection of the quantity and quality of water at Wakulla Spring. FDEP published a final Total Maximum Daily Load (TMDL) for Wakulla Spring in 2012 and is currently in the process of developing a Basin Management Action Plan (BMAP) to control nitrate pollution at the spring. The NWFWMD has started preliminary work on establishing Minimum Flows and Levels (MFLs) for several major springs and Wakulla Springs MFL is scheduled for MFL adoption in 2023. A considerable body of new information concerning Wakulla Spring collected and published by FDEP, the NWFWMD, and by local governments and volunteers has become available since August 2011.

This updated restoration plan seeks to summarize all relevant information concerning the current environmental conditions at Wakulla Spring, describe the status of the multiple threats affecting the ecology of the spring, and describe a roadmap for restoring the spring to a more pristine condition. This report was prepared by FSI with review by members of the WSA and the ***Friends of Wakulla Springs State Park*** and represents another step in a continuing journey to eventual recovery and protection of Wakulla Spring. It should not be construed to be the final word of the authors or members of the ***Wakulla Springs Alliance*** on any of these complex issues.

Partial funding for development of this comprehensive restoration plan was provided by the Wildlife Foundation of Florida, Protect Florida Springs Tag Grant PFS 1314-09.

Executive Summary

Wakulla Spring is located in Wakulla County, Florida about 14 miles south of the state capital in Tallahassee and 14 miles north of the Gulf of Mexico. Wakulla Spring has the highest measured instantaneous flow of any spring in Florida, the largest spring basin in terms of depth and volume, and is the source of the Wakulla River. Wakulla Spring is the focal point for the Edward Ball Wakulla Springs State Park. Up to 200,000 people visit Wakulla Spring each year, contributing over $9 million per year in direct economic benefits and more than 185 local jobs.

Similar to most other springs in Florida, Wakulla Spring has been impacted for over 100 years by human activities occurring in its springshed. Rising concentrations of nitrate - a key ingredient in synthetic fertilizers, invasion by hydrilla (*Hydrilla verticillata*) - a non-native plant species, a decline of native eelgrass (*Vallisneria americana*) and strap-leaved sagittaria (*Sagittaria kurtziana*), extended periods of decreased transparency due to influxes of tannic-stained water, increasing flows augmented by surface water entering swallets during and after storm events, and loss of native apple snails (*Pomacea paludosa*) and limpkins (*Aramus guarauna*) are the principal changes of concern.

The Wakulla Springs Basin Working Group was originally formed in 1992 to attempt to address growing concerns about the health and future of the spring and its ecosystem. Significant strides have been taken and are underway to lower nitrogen loading in the Wakulla Springshed. However, as documented in this report, nitrogen concentrations still exceed protective levels in Wakulla Spring and problems related to flow and reduced water transparency appear to have worsened.

In 2010 the Florida Department of Environmental Protection's (FDEP) Springs Initiative program commenced a more comprehensive restoration project at Wakulla Spring. This project included a continuation of the Working Group meetings combined with development of a preliminary comprehensive restoration plan for the spring. This project was originally intended to more formally organize stakeholder activities to address the nutrient impairment issue in advance of the anticipated Best Management Action Plan (BMAP) process and to provide an opportunity for other issues at Wakulla Spring to be discussed and addressed. Wetland Solutions, Inc. (WSI) was selected by FDEP to conduct this proposed three-year restoration plan project. Due to budgetary constraints during the spring 2011 legislative session, this project was cancelled at the end of the first year.

The original scope for the FDEP-funded project required development of a preliminary draft Restoration Plan by the end of the first year, continued refinement and finalization of the restoration plan over the remaining two years, and encouragement of stakeholder actions throughout the three-year period. WSI submitted a preliminary draft Restoration Plan to FDEP in June 2011. Due to the unexpected termination of the Wakulla Spring restoration project (and similar projects at three other springs), there was not sufficient time for WSI to review, discuss, and incorporate editorial comments. Thus, FDEP received and accepted an unedited, draft version of the Wakulla Spring Restoration Plan as the final deliverable for that project.

In an effort to revitalize the restoration process at Wakulla Spring, the Howard T. Odum Florida Springs Institute (FSI) decided to revise and update the WSI report and make it widely available on the FSI website. The updated report was issued by FSI as the Wakulla Spring Adaptive Management Strategy in August 2011 (FSI 2011) and did not reflect FDEP's views regarding the sources of impairment to Wakulla Spring. However, that document was the next iteration of an adaptive management strategy to maintain stakeholder momentum for eventual recovery and protection of Wakulla Spring.

Following the publication of the Wakulla Spring Adaptive Management Strategy in 2011, the Wakulla Springs Alliance (WSA) was organized within the existing non-profit Hydrogeology Consortium to take a more pro-active approach to protection and restoration of Wakulla Springs. The WSA is currently working on multiple fronts to raise awareness about the environmental threats facing Wakulla Spring and encouraging state and local governments and individuals to take actions needed to protect and restore the spring and the Wakulla River it feeds. This updated Wakulla Spring Restoration Plan was prepared by the Howard T. Odum Florida Springs Institute (FSI) in cooperation with the WSA to serve as a reference document and a roadmap for comprehensive spring restoration.

A review of the existing literature, studies, and available data for Wakulla Spring determined the following principal impairments:

- Nitrate-nitrogen concentrations at the spring rose from historical concentrations of less than 0.05 mg/L to over 1.1 mg/L by the early 1990s. Nitrate-nitrogen concentrations began to level off and then declined slightly during the last decade and now average about 0.79 mg/L. Wakulla River has been found by FDEP to be impaired for nitrate-nitrogen due to excessive growth of hydrilla and filamentous algae. FDEP has found that the biology of the Upper Wakulla River, which includes Wakulla Spring, is impaired due to elevated nitrate concentrations and that the primary source of the nitrate in the river is from the spring. Additionally, FDEP has concluded that successful restoration of the river will depend on achieving significant reductions in the sources of nitrate within the Wakulla Spring springshed. These findings are contained within the final TMDL report for the Upper Wakulla River posted on the FDEP web-site at: http://www.dep.state.fl.us/water/tmdl/draft_tmdl.htm
- FDEP's total maximum daily load (TMDL) analysis indicates that the concentration of nitrate will need to be lowered by at least 56% to meet the TMDL.
- The City of Tallahassee reduced nitrogen loads in the Wakulla Springshed by eliminating the use of fertilizer and removal of livestock at the Southeast Sprayfield and land application of nitrogen-containing biosolids. Following these changes, nitrate concentrations in water from the Wakulla Spring vent declined. However, nitrate concentration reductions at Wakulla Spring appear to be at least partially the result of dilution due to increasing discharge at the spring. The overall mass of nitrogen discharged at the spring vent has been about 460 tons per year during the most recent decade and the average discharge from Wakulla Spring during the most recent decade was about 85% greater than the long-term average flow recorded at the spring.

- Over the past several years the City of Tallahassee has further reduced nitrogen loads discharged to the Southeast Sprayfield by completing treatment plant upgrades to provide total nitrogen less than 3 mg/L.
- Wakulla Springs State Park has had an increasing number of "dark and green water" days over the last 25 years as measured by park staff. Between 1987 and 2003, water in the upper river at the spring vent was clear enough that glass-bottom boats could run from 17 to 75% of the time. Between 2004 and 2010 the frequency of dark water and green water days increased to the point where glass-bottom boats ran less than 15% of the time. Research has demonstrated that this tannic and chlorophyll-stained water is originating from inputs of surface water runoff into swallets that feed the Wakulla Springshed. These sources include creeks flowing from the Apalachicola National Forest to the west, Lake Munson to the north, and the Bradford chain of lakes on the south side of Tallahassee. Preliminary hydrogeologic research suggests that the increased frequency of black and green water events appears to be the result of a shift in the delicate balance of the inter-connected cave system that feeds both Wakulla Spring and Spring Creek springs.
- An updated analysis described in this report for the most recent decade found that an estimated average of 33 million gallons per day (MGD) of clear, artesian water that formerly discharged at these two springs has been removed from the water balance. This could be due to a combination of low recharge during drought conditions, groundwater pumping in the springshed, and sea level rise. These changes appear to be the cause for the increased flows and dark water days at Wakulla Spring. There is also evidence that an increase in the number of dark water days results in reduced primary productivity in the spring run, and in turn, is likely to reduce the amount of food available to all organisms in the aquatic food web.
- The upper Wakulla River at Wakulla Spring has suffered from an invasion of hydrilla and filamentous algae. Hydrilla control in Wakulla Spring and Wakulla River is dependent upon annual applications of the herbicide, Aquathol, and periodic mechanical harvesting. However, herbicide control of hydrilla can result in unintended consequences such as invertebrate mortality, depressed dissolved oxygen levels, loss of desirable submerged plant species, increased algal cover, and excessive formation of organic sediments. Other biological changes have been observed over the same period, including the extirpation of limpkins, a relatively rare bird that was formerly emblematic of Wakulla Springs State Park, and the bird's primary food – the native apple snail.

A future-scenarios visualization and a goal setting exercise was conducted by WSI with stakeholders at the March 3, 2011 Wakulla Spring Working Group meeting. After review and discussion of the various restoration goals, the stakeholders recommended the following restoration goals:

Restoration Goal # 1 – Reduce Nitrate-Nitrogen (NO_3-N)

- Meet or exceed the target nitrate-nitrogen goal of 0.35 mg/L that is noted in the draft

TMDL;
- Develop a Basin Management Plan Action Plan (BMAP) within the next five years;
- Reduce the nitrogen loading from septic tanks in the springshed; and
- Decrease fertilizer use in the springshed.

Restoration Goal # 2 – Reduce Dark Water Days

- Conduct a hydrogeologic assessment to better quantify recharge and withdrawals and their influence on the spring systems;
- Continue to promote water conservation & education;
- Continue research regarding a water budget and flow patterns;
- Enhance groundwater recharge; and
- Reduce net groundwater withdrawals.

Restoration Goal # 3 – Restore Spring Ecology

- Decrease nitrate-nitrogen concentrations in order to decrease hydrilla and filamentous algal growth;
- Increase clear water days by reducing net groundwater withdrawals, promoting water conservation & education, and continuing research regarding a water budget and flow patterns;
- Continue limited hydrilla management; and
- Increase ecological research.

This Wakulla Spring Restoration Plan provides estimates of the sources and magnitudes of the detrimental changes measured and observed at Wakulla Spring based on extensive information gathered by hundreds of individuals over the past two decades. The data and analyses included in this report are not the final word on the issues that confront Wakulla Spring and its eventual recovery. They are just a starting point, with the hope that they will be refined by the affected stakeholders with better analyses and quantification. However, there is wide-spread sentiment among the majority of the stakeholders that now is the time to initiate significant restoration actions, so Wakulla Spring can continue to progress towards recovery rather than suffer from further degradation. The City of Tallahassee's wastewater upgrade project is a significant first step in the restoration process and should result in a measurable reduction in the total load of nitrate-nitrogen discharging from Wakulla Spring during this decade. However, evidence is presented in this report that indicates that more action is needed to fully restore Wakulla Spring to its desired condition. Major obstacles to comprehensive restoration still include removal of on-site, human waste disposal systems, significant water conservation needs, and the resolution of inter-state issues between Florida and Georgia over excessive water and fertilizer uses.

With the early cancellation of FDEP's Wakulla Spring Working Group and Restoration Planning Project, a greater share of the responsibility for continuing the restoration process for Wakulla Spring falls on the shoulders of the non-governmental stakeholders, including the WSA. While FDEP plans to continue with finalization of the Upper Wakulla River BMAP and the District intends to eventually adopt MFLs for the spring and river, those stakeholders may wish to insist that their local and state officials move forward in a more timely fashion and comprehensive actions needed to fully meet the Wakulla Spring Working Group's restoration goals.

Section 1.0 Introduction

Wakulla Spring is a true natural wonder. One of the largest first-magnitude artesian springs in Florida and in the United States, Wakulla Spring has flowed for tens of thousands of years and served as a water supply for humans and wildlife throughout that time. Wakulla Spring lies within the Edward Ball Wakulla Springs State Park and has for many years been an important recreational site for local residents and a tourism destination (Figure 1-1). Wakulla Spring, Wakulla Springs Lodge, and the Edward Ball Wakulla Springs State Park continue to attract and entertain over 200,000 visitors each year.

Wakulla Spring's principal attraction has always been its vast flow of pure, clear water. The primary source of this water is the Floridan Aquifer System, which occurs in a limestone formation that holds hundreds of billions of gallons of fresh, potable water and provides the primary drinking water source for residents of Leon, Wakulla, and surrounding counties (NWFWMD 2008). In addition to the humans who are dependent upon this groundwater resource, a complex and highly productive ecosystem of wild plants and animals is also dependent on abundant fresh water from Wakulla Spring for its livelihood. The source of this water is rainfall that falls on more than 1,000 square miles in Leon, Wakulla, Gadsden, and Jefferson Counties in Florida, and parts of at least three Georgia counties (Decatur, Grady, and Thomas) just north of the Florida-Georgia border.

Unfortunately, springs throughout north and central Florida, and south Georgia, are experiencing degradation as a result of human development in their springsheds (FSTF 2000; FSI 2007). The most common documented impacts have been reductions in the flow of clear groundwater and increases in concentrations of nitrate-nitrogen. Changes in the quantity and quality of spring flows as well as a diversity of other environmental stressors have often resulted in biological changes at affected springs.

Wakulla Spring has not been immune to these impacts. Wakulla Spring has a lower average nitrate concentration than springs in other parts of Florida due largely to the fact that its springshed does not include as much intensive agricultural and urban development. However, existing nitrate-nitrogen concentrations are more than 15 times (1,400%) higher at Wakulla Spring than typical historical spring concentrations, and the Upper Wakulla River has been deemed impaired by the Florida Department of Environmental Protection (FDEP) based on elevated nitrate-nitrogen and increased growth of hydrilla (*Hydrilla verticillata*) and filamentous algae (Gilbert 2012). The Total Maximum Daily Load (TMDL) target concentration for nitrate-nitrogen for the Upper Wakulla River is 0.35 mg/L, requiring an estimated reduction of about 56% in nitrogen loads within the springshed area (Gilbert 2012).

In addition to the nitrate pollution issue facing Wakulla Spring, there is increasing evidence that the historical water balance of the spring has been significantly altered (Kulakowski 2010). While Wakulla Spring was previously known for its extreme clarity, except during high rainfall periods, this clarity has been replaced by an increasing frequency of "dark-colored" and "green" water days of low light transparency that not only reduce the aesthetic properties of the

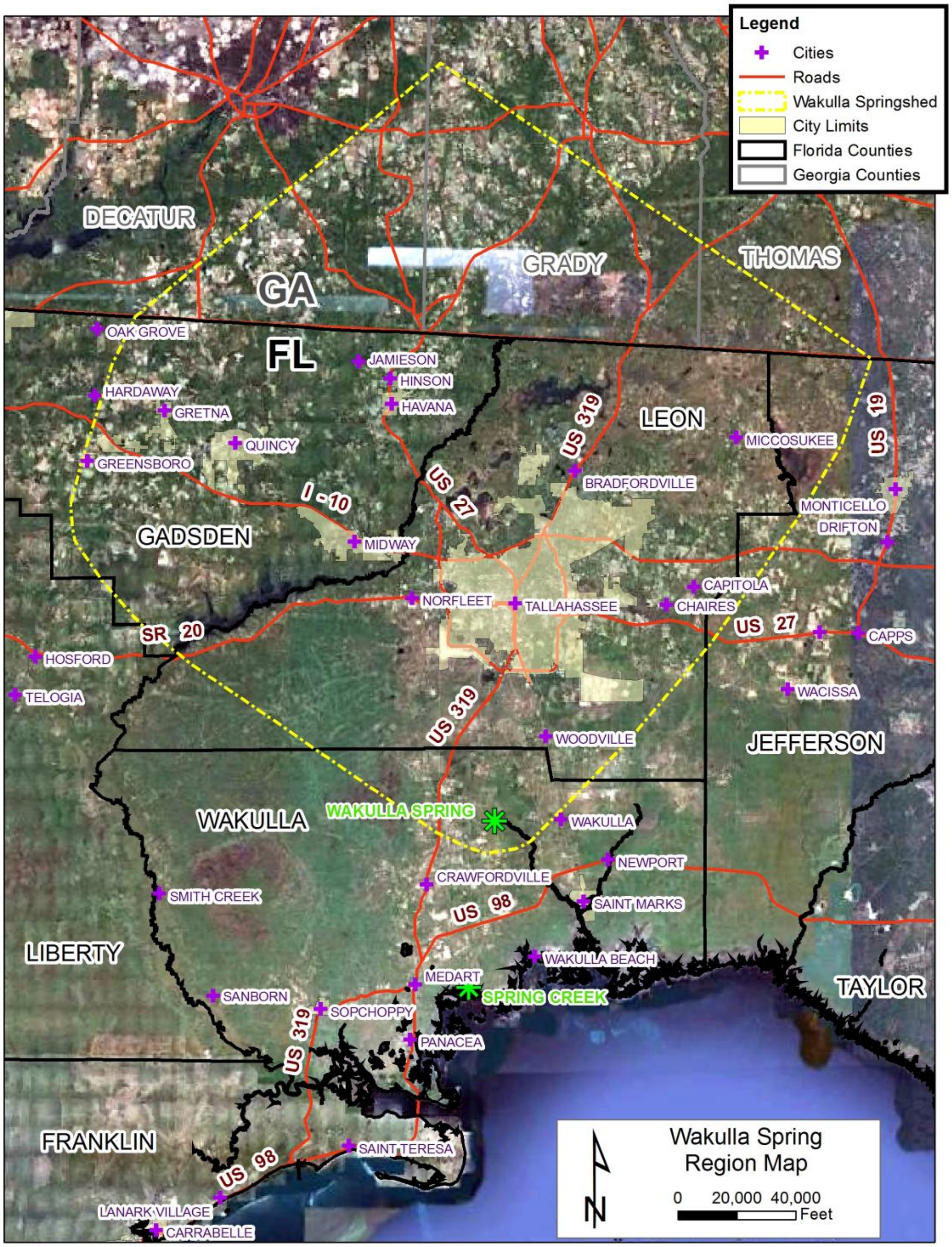


Figure 1-1. Location of Wakulla Spring South of Tallahassee in the Florida Panhandle

spring and river for nature-based tourism, but also decrease primary productivity of the plant community (due to reduced light availability for the underwater plants), thus potentially altering the entire food chain (WSI 2010). Based on existing information it appears that the increase in dark water flows at Wakulla Spring is the combined result of rising sea levels and declining clear, artesian water flows from the Floridan Aquifer (Kulakowski 2010; Davis 2011; Kincaid *et al.* 2010).

Increases in nitrate concentrations and dark water at Wakulla Spring have been reasons for concern for over 22 years. The Wakulla Spring Working Group was founded in 1992 to increase the understanding of these problems and to pursue feasible restoration solutions. While technical understanding of these issues has greatly increased and led to implementation of dozens of large and small projects at the spring and in its springshed; some conditions at the spring (especially the occurrence of dark water and changes to the submerged plant communities) have continued to worsen during this time. There is no doubt that on-going restoration and protection strategies have resulted in some benefits for the spring, however they have been unsuccessful at reversing the overall degradation experienced at Wakulla Spring. The goal of this Wakulla Spring Restoration Action Plan is to summarize detrimental changes that have occurred at Wakulla Spring and to suggest decisions and actions that should be made to achieve the desired restoration of Wakulla Spring.

1.1 List of Accomplishments

The Wakulla Spring Basin Working Group was formed in 1992 to better understand the increase in dark water days at Wakulla Spring that was severely hampering water clarity and limiting the glass bottom boat tours. Over time, the working group mission evolved to address additional water quality and water flow threats to Wakulla Spring. During its 19 years of existence, many stakeholders became involved and numerous projects and activities were implemented. Some of the most significant activities and accomplishments to restore and protect Wakulla Spring were summarized by Jim Stevenson, founder and long-time coordinator of the Wakulla Springs Basin Working Group:

Research:

- Numerous research projects have been conducted at Wakulla Spring - more research projects than for any other Florida panhandle spring.
- Dye trace studies have been implemented throughout the spring basin at many of the sinks and swallets and at the City of Tallahassee Sprayfield in order to better understand groundwater flow to Wakulla Spring.
- The Woodville Karst Plain Project (WKPP) achieved world records by mapping the extensive cave systems leading to Wakulla Spring. A portion of the cave mapping was sponsored by National Geographic.

Spring Protection Zone

- The first Spring Protection Zone ordinance in the state was passed by the Wakulla County Commission in 1994.

- Wakulla County expanded the Protection Zone in 2008 to include the entire spring basin.
- Leon County established a Wakulla Spring Protection Zone in 2008.

Land Acquisition:

- The State has acquired nearly 12,000 acres in the Wakulla Spring Basin to protect the spring. Some of the land was added to the state park for management and additional land was used to create the new Wakulla State Forest.
- Leon County acquired 132 acres along Munson Slough to protect Wakulla Spring.

Fertilizer

- Florida Department of Transportation (FDOT) stopped fertilizing road shoulders in the basin.
- The City of Tallahassee stopped fertilizing the wastewater sprayfield.
- The City of Tallahassee passed a fertilizer ordinance.
- The City of Tallahassee spent over $80 million on stormwater management.

Septic Tanks

- The State park facilities were connected to central sewer and nitrate reducing septic systems were installed.
- The Wakulla County Comprehensive Plan amendment requires use of nitrate reducing septic systems in the county.
- The City of Tallahassee, Leon County, and Wakulla County jointly funded a comprehensive septic tank study within the spring basin.

Wastewater Treatment:

- The City of Tallahassee spent about $225 million to upgrade its municipal wastewater facilities for nitrogen removal. The City also removed cattle from the sprayfield & stopped applying sewage sludge at the airport.
- Wakulla County is upgrading wastewater treatment facilities for advanced nitrogen removal.

Private and Public Activities:

- St. Joe Corporation protected vulnerable sinkholes on their lands and leased lands to hunt clubs which stopped abuse.
- FDOT redesigned a stormwater conveyance system to prevent potential contamination from draining to Wakulla Spring in the event of a chemical spill.
- Concerned citizens prevented a gas station from being built close to Wakulla Spring and got land placed in public ownership.
- The Florida Fish and Wildlife Conservation Commission (FFWCC) developed a drawdown schedule for Lake Munson on an 8-10 year cycle to oxidize sediments and improve water quality.

- The City of Tallahassee implemented the Pollution Reduction Plan in 2004 to generate funds for stormwater upgrades. Several capital improvement projects within the springshed have been completed with these funds.

Springs Ambassador:

- The first springs' ambassador position was created for Wakulla Spring with the goal to educate the local public and to survey karst windows within the spring basin.

Education:

- The TAPP (Think About Personal Pollution) water conservation and prevention program was implemented by the City of Tallahassee.
- Wakulla County implemented the LIFE (Learning in Florida's Environment) program with the middle schools.
- The Wakulla Spring Wildlife Festival is held annually.
- The Friends of Wakulla Spring have presented power point presentations to many organizations.
- WFSU Radio has provided 3 appearances of the program, "Perspectives".
- Several educational videos have been produced:

  WKPP: Beneath Wakulla Springs

  WKPP: Push for the Connection

  WKPP: Chip's Hole Exploration

  Wakulla Springs: A Watery Treasure

  Florida Crossroads: Below the Surface

- The Department of Transportation installed road signs to identify the Wakulla Spring Basin, Munson Slough drainages to Wakulla Spring, and Wakulla Spring cave systems.

Special Events:

- Wakulla Spring Karst Plain Symposium was held on October 9, 1998
- Wakulla Spring Scientific Symposium was held on May 13, 2004
- Exploring the Secrets of Wakulla Spring; (Riverspring) was held on April 20, 2004
- Walk for Wakulla Spring was held on November 13, 2004
- Solving Water Pollution Problems in the Wakulla Springshed was held on May 12-13, 2005
- Celebrate Wakulla Spring was held on November 6, 2005
- Saving Wakulla Spring was held on August 26, 2006 (sponsor: Tallahassee Democrat)
- Wakulla Watershed Coalition: The Missing Link Public Forum was held on October 2, 2007
- Expanding the Wakulla Spring Protection Zone was held on January 16, 2008
- Exploring the Secrets of Wakulla Spring was held in Tallahassee on April 2, 2008
- Wakulla Spring Restoration Workshop was held on February 25-26, 2009
- Run for Wakulla Spring (to the Capital) was held on February 16, 2010

Press:

- Tallahassee Democrat published special in-depth series on Wakulla Spring issues.
- Wakulla Spring has received frequent TV news coverage.

1.2 Planning Process

As noted above, numerous activities have already taken place or are currently underway to protect and restore the historic character of Wakulla Spring. While all of these actions are necessary and important, alone and in combination none of them to-date appear to be sufficient to achieve the ultimate success of returning Wakulla Spring to a desirable historic condition within a reasonable time frame. A more comprehensive, holistic effort is necessary to achieve fundamental restoration of many of the attributes of Wakulla Spring. An adaptive management approach that constantly evolves, monitors progress, and implements improvements is needed to focus limited resources and energy to solving the problems, large and small, that are apparent at Wakulla Spring.

In June 2010, FDEP issued a three-year contract to Wetland Solutions, Inc. (WSI) for Working Group Coordination and Restoration Plan Development for Wakulla Spring. Development of the Restoration Plan was planned to include involvement and input from the various stakeholder groups. Between July 2010 and June 2011, WSI coordinated four quarterly meetings of the Wakulla Spring Basin Working Group, ten planning meetings, and began development of the draft Wakulla Spring Restoration Plan.

The Wakulla Spring quarterly working group and planning meetings focused on the stakeholder involvement process of understanding the environmental characteristics, identifying the threats, developing future restoration scenarios, and developing restoration goals for Wakulla Spring. That process came to an unexpected end on June 30, 2011 when FDEP announced that it would not continue support of the original three-year contract awarded to WSI. Wakulla Springs was not singled out in this decision since FDEP also prematurely terminated similar contracts for Silver, Rainbow, and Ichetucknee springs at the same time.

In early August 2011, the Howard T. Odum Florida Springs Institute (FSI), a non-profit, 501(c)(3) corporation, decided to continue the momentum generated by the Wakulla Spring stakeholders and working group members for more than 18 years. The Wakulla Spring Adaptive Management Strategy (FSI 2011) was developed by FSI based largely on technical information collected and summarized by WSI in their final draft deliverable to FDEP.

This Wakulla Spring Restoration Plan builds on the work initiated by WSI, FSI, and the Wakulla Spring stakeholders and contains the following essential elements:

- A description of the environmental resources at Wakulla Spring and changes in these resources over time;
- A shared vision for the goals of restoration developed by stakeholders who attended the quarterly Wakulla Spring Working Group meetings;

- A description of the existing impairments at Wakulla Spring and the factors and forcing functions causing those impairments;
- A set of specific actions and responsibilities needed to eliminate or substantially reduce the factors resulting in impairment of Wakulla Spring; and
- A plan for assessing the progress towards restoration and updates to the strategy through adaptive management of the restoration process.

This Wakulla Spring Restoration Plan provides a flexible road map for the constantly-evolving activities that need to be completed to achieve the vision of the Wakulla Spring Alliance and all stakeholders in the former Wakulla Spring Working Group. It is hoped that the major stakeholder groups will unite and share the responsibility for reviewing progress, and continuing on the path to restoration and protection of Wakulla Spring, and will work together to coordinate implementation of the recommended management strategies.

Section 2.0 Description of the Wakulla Spring System

2.1 General

2.1.1 Location

Wakulla Spring is located in Wakulla County, Florida at latitude/longitude: 30.234161°/-84.302161°, within the Edward Ball Wakulla Springs State Park (physical address: 550 Wakulla Park Drive, Wakulla Springs, Florida 32327; phone: 850-926-0700; park website: http://www.floridastateparks.org/wakullasprings/default.cfm). Wakulla Spring is in the panhandle of Florida and is located 22 km (14 miles) south of Tallahassee (Figure 1-1 and Figure 2-1).

2.1.2 Ownership and History

One of Florida's largest springs, Wakulla Spring and the surrounding area was developed as a retreat/attraction in the 1930s by Edward Ball. In 1986 Wakulla Spring became a state park administered by FDEP and the Florida Division of Recreation and Parks (FPS), consisting of approximately 6,055 ac (detailed history is provided by Cook in FGS [1998]). Wakulla Springs State Park and Lodge are listed on the Natural Register of Historic Places and are a designated National Natural Landmark. The park facilities include the original Edward Ball Lodge and restaurant, museum, and guided river and glass-bottomed boat tours in the upper 1 mile of the river. A swimming beach area, diving platform, and two swim platforms provide in-water recreational opportunities and the spring is a popular regional swimming destination. Visitors to the park are not allowed to SCUBA dive, although research divers have extensively explored and mapped the underwater cave system connected to the spring. Private boat access is prohibited in the park-managed portion of the Wakulla River (the upper 3 miles of the spring run). Alligators, turtles, birds, and other wildlife are abundant along the spring run. Historic underwater images of the spring and spring run are available since several films were made at Wakulla Spring, including *Airport '77*, *Tarzan's Secret Treasure* and sequels of the Creature from the Black Lagoon movie - *Return of the Creature* and *Revenge of the Creature*.

2.2 Physical

Wakulla Spring is an unusual spring due to its large physical size (Figure 2-2). The circular pool is roughly 300 ft in diameter and about 100 ft in depth, with an immense vent opening of 50 ft by 82 ft at a depth of approximately 185 ft (Figure 2-3). WSI (2010) estimated the Wakulla Spring basin (from the western edge of the spring basin to the boat dock) to have a water volume of about 13.1 MG with a surface area of 3.9 ac and a calculated average depth of 10 ft.

The Wakulla Spring cave system (Figure 2-4) has been extensively explored by cave divers (Olsen 1958), including most recently the members of the Woodville Karst Plain Project (WKPP). Figure 2-4 provides a map of the Wakulla-Leon Sinks Cave System as of September

2008. This network of explored passages contains a total of 32 miles, connecting 27 named sinkholes and springs and its full extent has yet to be determined (Kincaid and Werner 2008).

Figure 2-5 provides a closer view of the network of feeder tunnels nearest to Wakulla Spring. The highly karst nature of this region creates variable water quality conditions in the spring pool. Water clarity can vary between "air-clear", "tannin-stained", to "turbid green", as a result of groundwater recharge through swallets receiving surface runoff from wetlands and swamps. A small spring to the northwest, Sally Ward, and its own spring run braid along the northern shore of the main run (upper Wakulla River). The spring-fed McBride's Slough also discharges to the upper river, contributing to its flow. The upper 3 mile of the resulting spring run is about 330 ft wide, and ranges in depth between 3.3 ft and 10 ft, and has sandy sediments. In total, the Wakulla River travels southeast for about 9 miles before joining the St. Marks River. Wakulla Springs lodge is approximately 14 mile due south of the Florida state capital in Tallahassee and roughly the same distance from the Gulf of Mexico. As such, its springshed, underground conduits, and spring run are all integrated with the underlying Woodville Karst Plain (WKP).

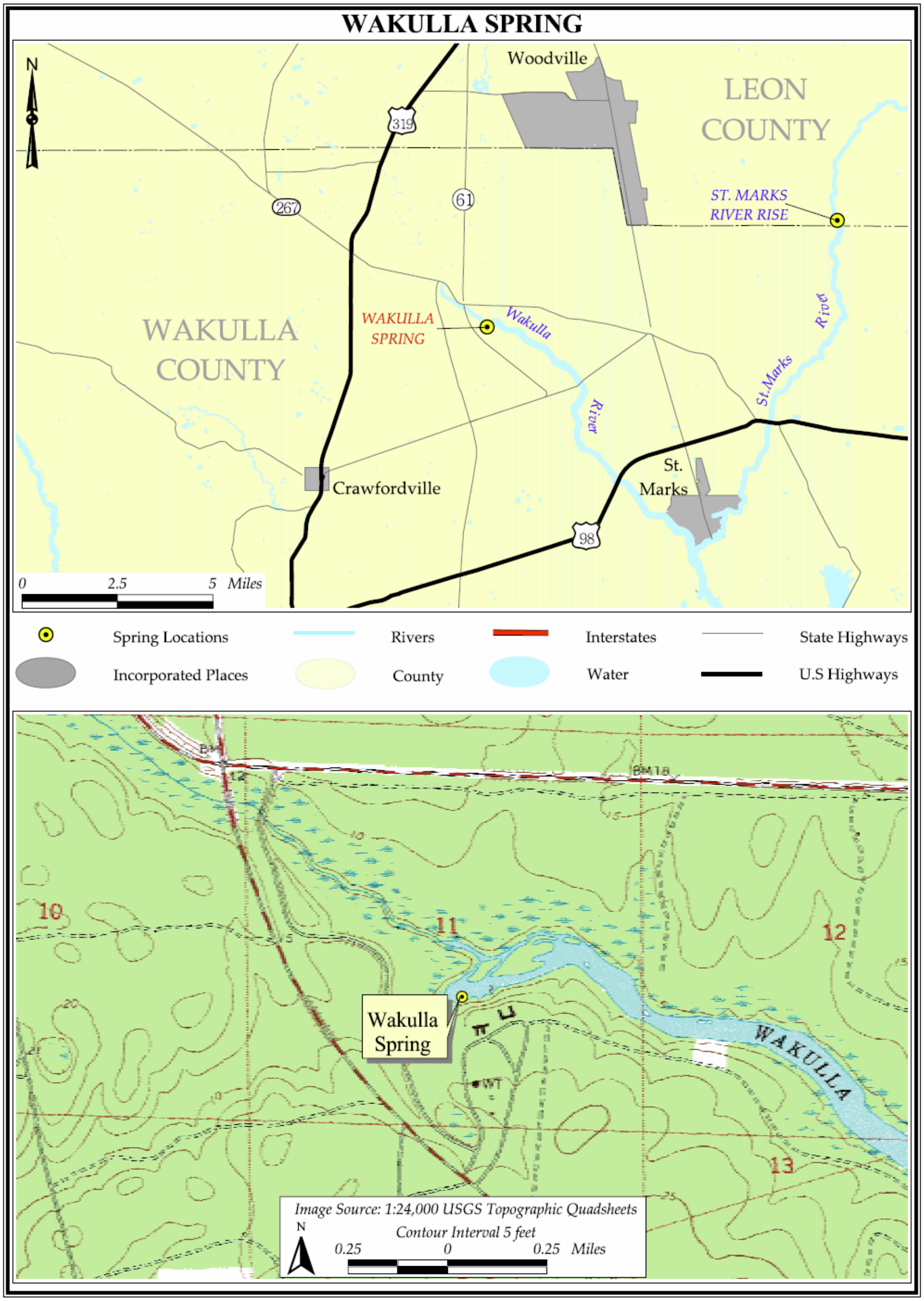


Figure 2-1. Wakulla Spring geographic location (from Scott *et al.* 2002).

Figure 2-2. Aerial photo of Wakulla Spring, the vent is left of the diving platform.

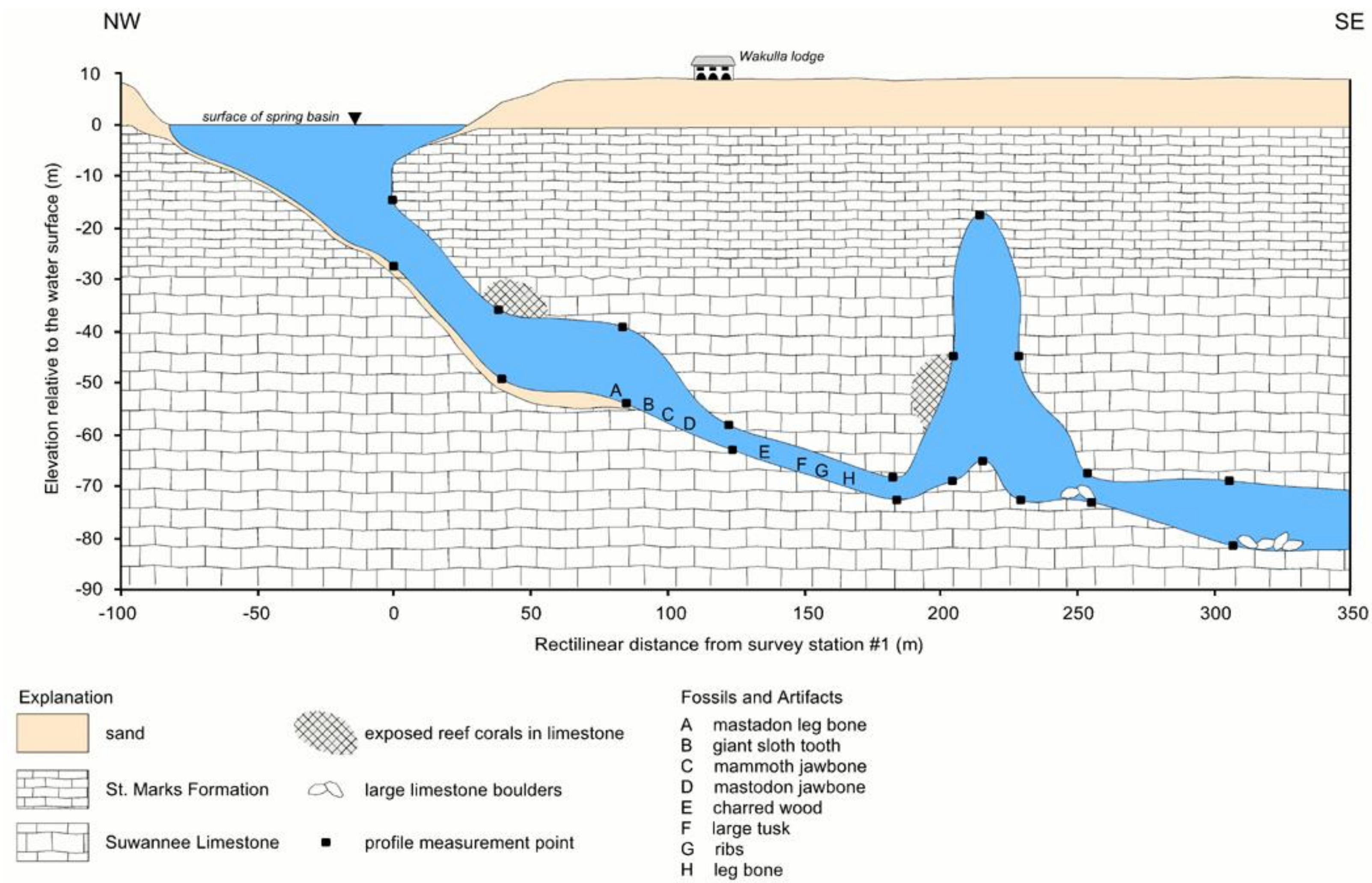


Figure 2-3. Cross-sectional view of the main vent at Wakulla Spring, locations of fossils from Olsen (1958) and depth profiles by WKKP divers (from Kincaid 1999).

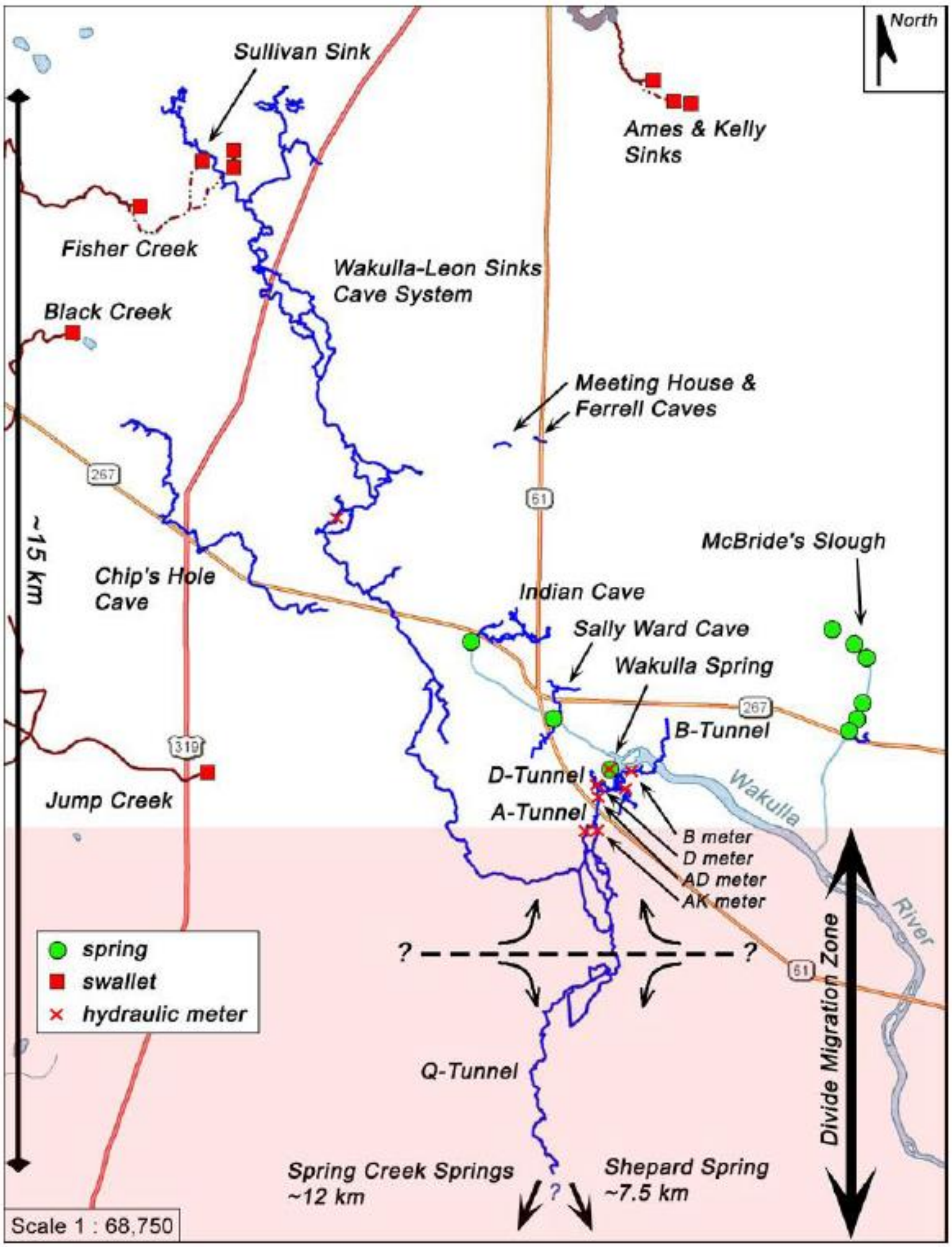


Figure 2-4. Map of the Wakulla Spring-Leon Sinks Cave System, springs, sinks, and swallets as of September 2008, including the estimated location of the zone where flow direction varies in response to changing aquifer water pressures (Kincaid and Werner 2008).

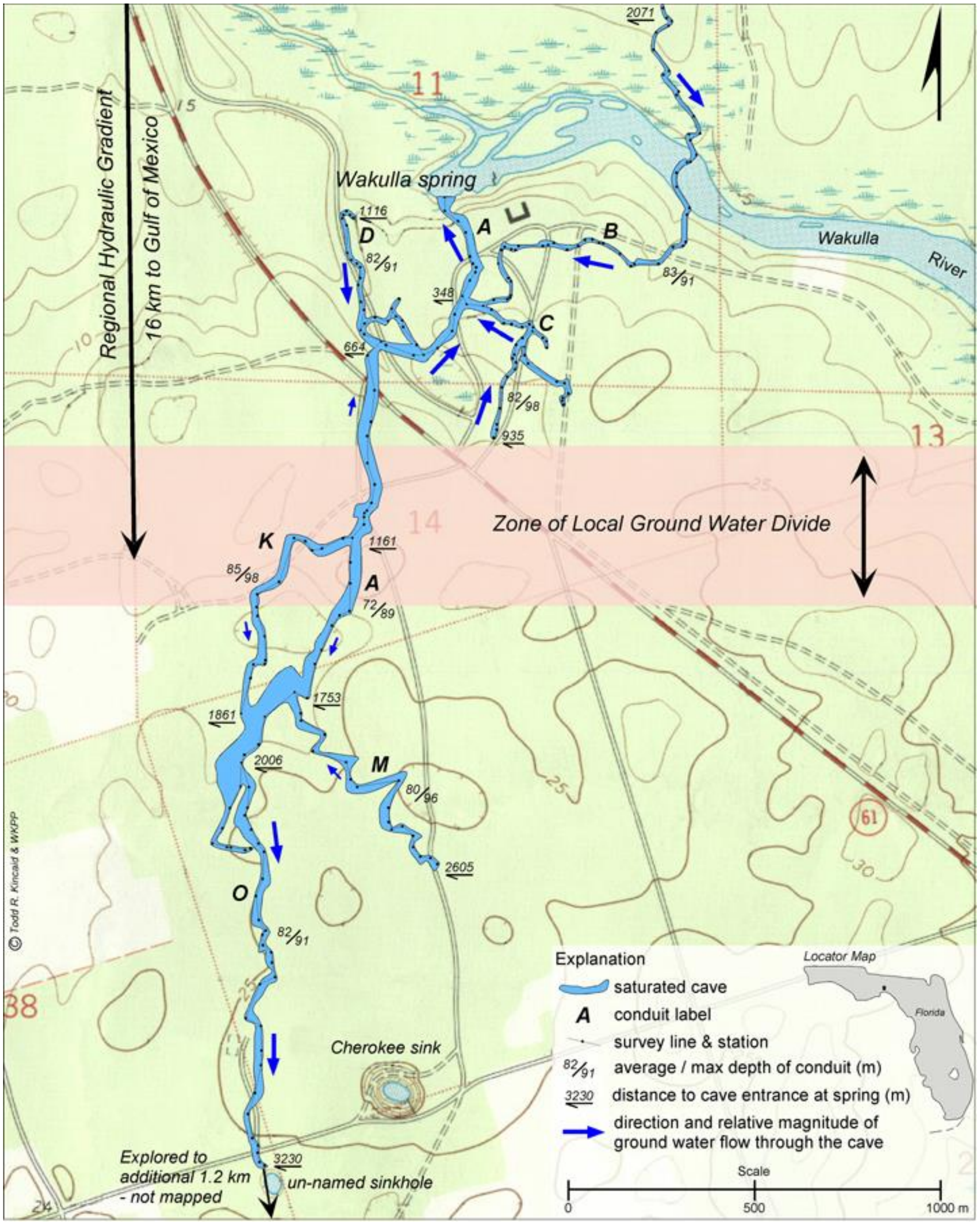


Figure 2-5. Map of Wakulla Spring cave system showing the local groundwater divide which crosses the conduit system and is marked by a broad zone of low groundwater velocities. The southern conduits typically convey groundwater toward the Gulf of Mexico while the northern conduits convey groundwater to Wakulla Spring (from Kincaid 1999).

2.3 Geology

The Wakulla Springshed region generally consists of marine sedimentary deposits including sands, clay, limestone, and dolostone of Tertiary to Quaternary age (Davis and Katz 2007). Figure 2-6 provides a generalized north-to-south hydrogeologic cross-section of these deposits. Of particular note are the remnant Miocene to Holocene deposits of clays and limestones of the Hawthorn Group overlying the northern portion of the springshed and absent from the southern portion of the springshed. Groundwater recharge rates are dependent on the presence/absence and thickness of the Hawthorn formation. Below the Cody Scarp this confining layer is generally absent and above the scarp the confining layer may or may not be perforated by sinkholes and swallets that allow recharge from surface watersheds that may include lakes and streams. The limestone formations that underlay the Wakulla Springshed include solution channels and conduits that have formed as the limestone has slowly dissolved as a result of the percolation of acidic rainfall and surface water over many thousands of years. The development of karst features like sinkholes and solution channels depends on the amount of exposure the limestone has had to this acidic water. In the WKP, the development of these features is the most advanced. In the upslope Streams region where the Floridan Aquifer is partially confined under lower-permeability soils limestone dissolution and conduit development is much less advanced.

2.3.1 Hydrogeologic Setting

Wakulla Spring is located within the WKP, a geologic feature which extends from central Wakulla County, eastward through southernmost Jefferson County and around the coastal Big Bend region to the Steinhatchee River in southwestern Taylor County (Schmidt *et al.* 1998). The WKP can be described as a very-gently-seaward-sloping, sandy, swampy sub-zone of the Ocala Karst District geomorphic province which is underlain by shallow, karstic, carbonate bedrock covered by a veneer of undifferentiated Pleistocene sands (Schmidt *et al.* 1998). Land surface elevations typically vary between 0 and 50 ft above mean sea level and sinkholes, collapse depressions, disappearing streams, and caves are common throughout the region (Schmidt *et al.* 1998). Loosely consolidated sands overlying these karstic features allow rapid infiltration of rainfall, the dominant water supply to the underlying aquifers.

Wakulla Spring is within the St. Marks River Basin, which has four hydrostratigraphic units: the surficial aquifer system, the intermediate aquifer system, the Floridan Aquifer system, and the sub-Floridan confining unit. Wakulla Spring represents a natural outflow from the Floridan Aquifer. Because of the karstic nature of this region, surface water and groundwater mixing can occur as evidenced by the variable water quality observed at Wakulla Springs. Groundwater travels south along existing potentiometric gradients (Rupert 1988) and cave conduits toward the Gulf of Mexico. Notable exceptions to this trend occur within Wakulla Spring cave (and Indian Spring cave) systems because of the well-developed conduit system. Detailed knowledge regarding the hydrogeology of this area is available in the compilation reports by Schmidt *et al.* (1998) and Chelette *et al.* (2002).

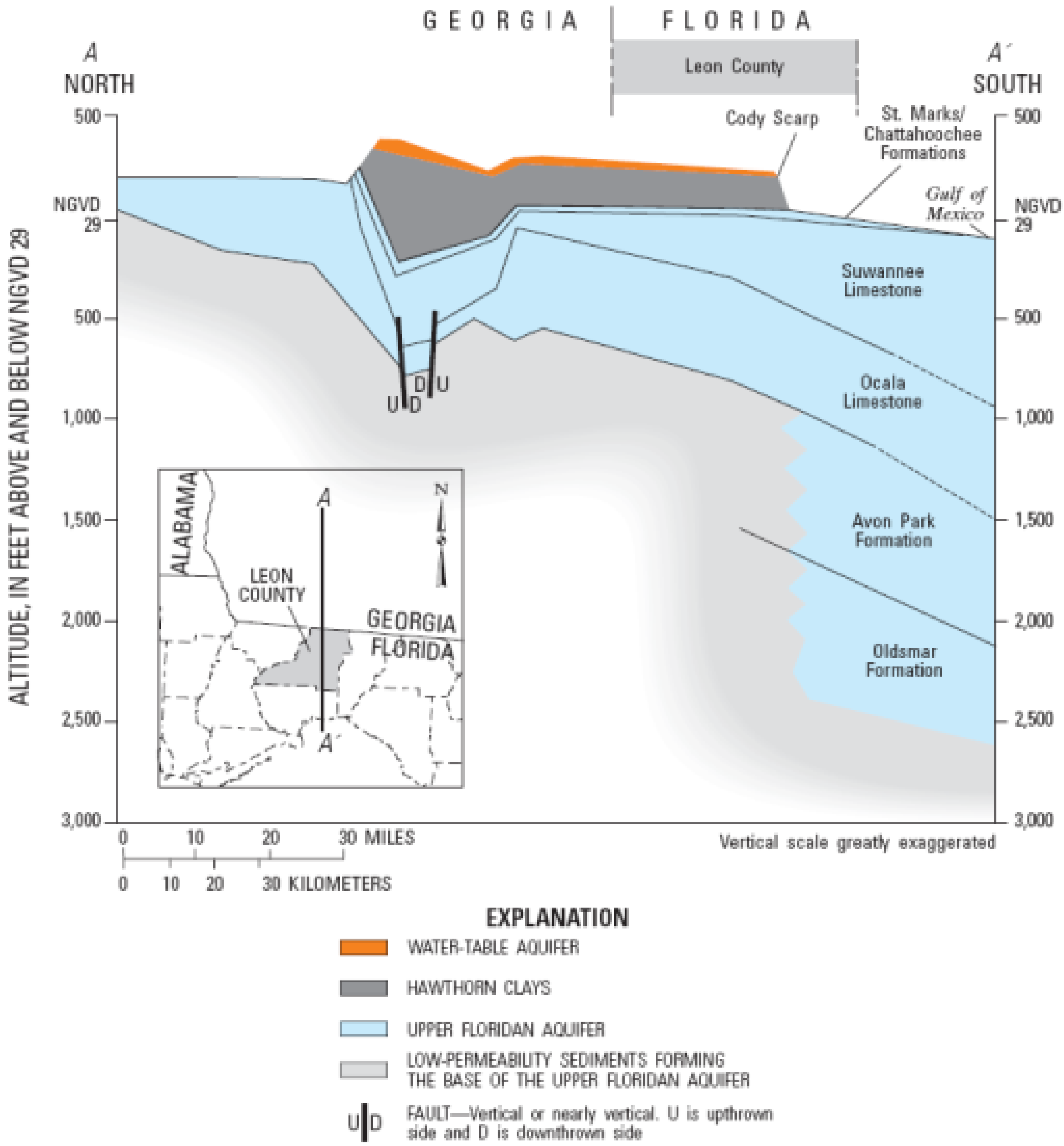


Figure 2-6. General hydrogeologic section of the water table and Upper Floridan Aquifers from south Georgia south through Leon and Wakulla Counties in Florida (Davis and Katz 2007).

Extensive physical exploration in the cave systems feeding Wakulla Spring over the past two decades has provided a fairly detailed understanding of the complex hydrogeology in this area (Kincaid *et al.* 2010). Wakulla Spring is hydraulically connected to the Spring Creek springs group, a group of 14 known springs located in a tidal marsh at the edge of the Apalachee Bay about 14 miles to the south. Until recently, both the Spring Creek Group and Wakulla Spring shared the same delineated springshed because they are hydraulically connected. Based on an analysis of extensive flow and water quality data collected at Wakulla Spring and at Springs Creek Springs, Davis (2011) has provided a theory that describes the fluctuations in groundwater flow and spring discharge that occur as a result of this interconnection. There are four general types of flow periods currently evident in this interconnected conduit/spring system:

1. During a prolonged period of low precipitation, saltwater from the Apalachee Bay estuary backflows into the Springs Creek Springs and creates a "plug" of accumulated higher-density water in the lower part of the springs' conduit system. This plug displaces groundwater flowing toward the Spring Creek vents and re-directs it toward Wakulla Spring. This appears to be evidenced by increased discharge from the Wakulla Spring vent when this "plug" is in place and the Spring Creek springs are not flowing.

2. Precipitation events that occur during these periods will generally result in black water flows from the Apalachicola National Forest into the swallets along the western edge of the Wakulla/Springs Creek Springshed (Fisher, Black, Jump, and Lost Creeks). Surface water entering the Lost Creek swallet has been linked via dye trace studies to the Spring Creek Group when the denser saline water "plug" is absent and Wakulla Spring when the plug is in place. When there is recharge from the Lost Creek swallet during drought periods, this water will preferentially flow to Wakulla Spring as long as the saltwater in the conduits downstream at Springs Creek Springs is not forced out. This condition results in an increase in the tannins in water discharging from Wakulla Spring following intermediate rainfall events.

3. If precipitation continues or is especially heavy, the surface water inflows from the swallets to the cave system eventually force the saltwater "plug" out of the conduits feeding the Springs Creek Group, resulting in a lower effective hydraulic head at Springs Creek than at Wakulla Spring. This results in the majority of the water exiting the inter-connected conduit system at Springs Creek Springs, with a resulting flow reduction at Wakulla Spring. A blend of clear and some dark water still exits Wakulla Spring but total discharge declines as the water from Lost Creek now discharges freely from the Spring Creek spring vents.

4. Following the cessation of rainy conditions, Springs Creek Springs continue to take a larger share of the flow until the hydraulic head in the springshed (potentiometric surface) declines enough so that Wakulla Spring once again becomes the preferred path for clear water discharges, and flows at Springs Creek Springs decline enough so that saltwater once again fills the conduits.

The actual set of hydraulic head conditions that tip this balance between Wakulla Spring and the Springs Creek Group are not precisely known. Factors that likely affect this delicate balance in flow between Wakulla Spring and Spring Creek Springs include the following:

- The groundwater gradient throughout the Wakulla/Spring Creek Springshed
- Hydrological factors that affect groundwater recharge and the height of the potentiometric surface, including rainfall, evapotranspiration, and groundwater pumping
- The sea level elevation in Apalachee Bay at the Spring Creek spring vents, which is affected by the tidal stage, storm tides, atmospheric pressure, and sea level rise affected by climate change, and
- The salinity in the estuary at Spring Creek, which is also affected by climate and tidal fluctuations

Within the historical record at Wakulla Spring (beginning in 1894 in a diary entry by Henry L. Beadel and four times between 1945 and 1962 in notes to Edward Ball; personal communication from Scott Savery, Florida Park Service) there have been periodic documented events of dark water reaching the spring following high rainfall events, probably indicating events qualitatively similar to those described recently by Davis. Based on anecdotal information from individuals who have visited Wakulla Spring over the past 60+ years, the occurrence of dark water days during this period has increased from occasional in the past (prior to 1950s), to frequent under more recent conditions. Quantitative data concerning dark water days affecting glass bottom boat tours has been collected by state park staff for the past 28 years (Figure 2-7). These data indicate that the frequency of dark water days has been increasing for at least the past 15 years. Over the past five years (2010-2014) the frequency of dark water days has increased to over 95% compared to about 57% during the first five years of measurement (1987-1991). The recorded increase in dark water days may be related to greater frequency and longevity of periods when the Spring Creek springs are "plugged" and water from the Lost Creek swallet is preferentially flowing to Wakulla Spring.

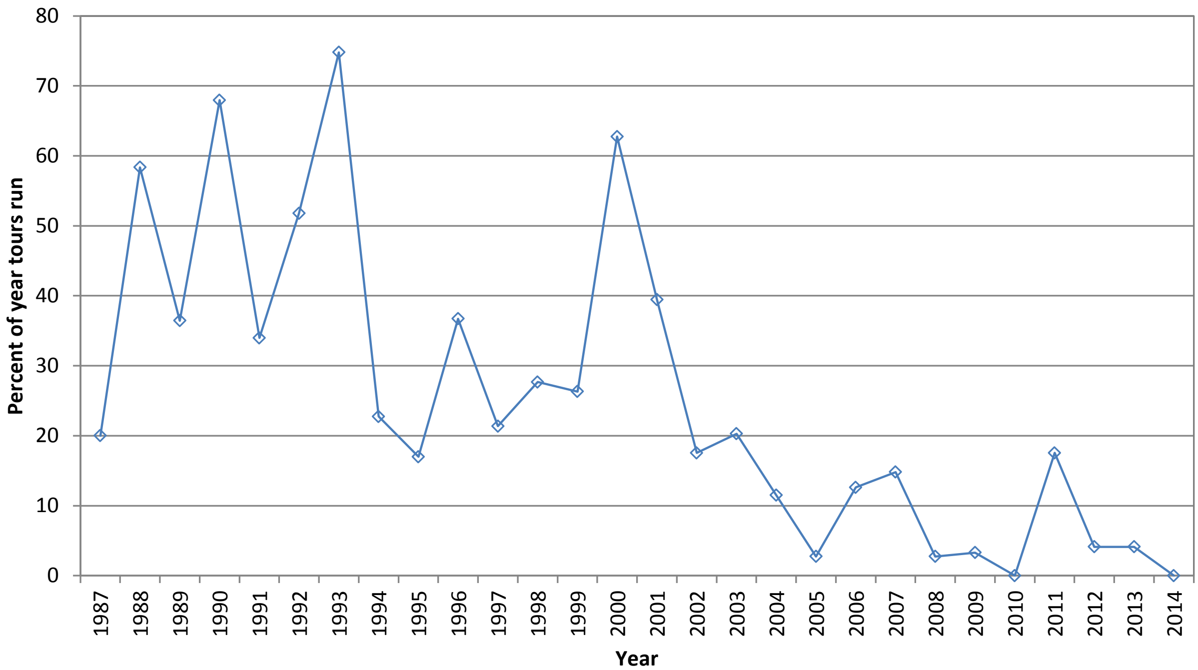


Figure 2-7. Percent of time water clarity allowed glass bottom boat use at Wakulla Springs State Park (source Florida Park Service).

2.4 Watershed Characteristics

As previously noted, the Wakulla springshed is located in the eastern Panhandle of Florida (Gadsden, Jefferson, Leon, and Wakulla Counties) and southern coastal plain of Georgia (Decatur, Grady, and Thomas Counties). Ground elevations range from sea level along the Florida coastline to a maximum elevation of about 139 feet above mean sea level in the northwest corner of Gadsden County, Florida and in the northern portion of the three Georgia counties. The Wakulla Springshed was estimated to encompass about 1,165 mi^2 by Chelette *et al.* (2002) and Barrios (no date) and they conceptually divided it into three general areas (Figure 2-8) based on the extent of confinement of the underlying Floridan Aquifer as:

- Streams region (Floridan Aquifer confined) – 770 mi^2 ; Groundwater recharge ~ 1”/year
- Lakes region (Floridan Aquifer semi-confined) – 250 mi^2; Groundwater recharge ~ 8”/year
- Karst plain region (Floridan Aquifer unconfined) – 145 mi^2; Groundwater recharge ~ 18”/year

A large portion of the Wakulla Springshed extends into the region north of the Cody Scarp, an erosional boundary feature that marks the southern edge of the Hawthorn Group, which includes lower-permeability sediments that act as a confining layer. Thus, the Streams and Lakes regions (about 1,020 mi^2) contain relatively impermeable soils associated with the

Hawthorn Group, and as a result, a significant fraction of rainfall runs off as surface flow into lakes and streams, rather than infiltrating through the soil and into the Floridan Aquifer. Most of the lakes in the Lakes region are formed in sinkholes that have breached the confining unit and the closed depressions formed by these sinkholes act as points of recharge to the underlying Floridan Aquifer.

The surface watersheds in the vicinity of Wakulla Spring are illustrated in Figure 2-9. The Ochlockonee River watershed extends about 50 miles into South Georgia. Much of the surface water runoff in the springshed that is captured by the Ochlockonee River eventually leaves the springshed without significantly recharging the underlying groundwater. However, a portion of the rain water entering creeks, streams, and lakes in the semi-confined land areas north of the Cody Scarp, and the area on the west side of Wakulla County that is underlain by the Torreya Formation, eventually reaches the underlying Floridan Aquifer through sinkholes in some lakes such as Lafayette, Jackson, Iamonia, and Miccosukee, and a number of swallets such as Fisher, Black, and Jump Creeks (Loper *et al.* 2005). A closer view of the locations of surface streams and the underlying groundwater potentiometric surface that delineates the Wakulla Springshed is provided in Figure 2-10. This figure illustrates how a number of streams and lakes in the springshed are not connected with surface channels, but are essentially closed internally-drained basins that recharge the underlying Floridan Aquifer.

2.5 Springshed Characteristics

2.5.1 Aerial Extent

The springshed for Wakulla Spring, developed by Florida Geological Survey (Figure 2-11), is approximately 1,569 square miles, and includes portions of four Florida counties (Gadsden, Jefferson, Leon, and Wakulla – 1,157 mi^2 or 73.7%) and portions of three south Georgia counties (Decatur, Grady, and Thomas – 412 mi^2 or 26.3%). There is considerable variability in the estimation of the absolute area of any springshed due to the density of wells used to map the groundwater potentiometric surface and the normal year-to-year variation in hydrologic conditions. To illustrate, Figure 2-11 also presents the Wakulla Spring springshed developed by FSI using May 2010 groundwater potentiometric surface data. This springshed is approximately 2,859 mi^2 and includes much of the same area in Florida as the FGS springshed (Gadsden, Jefferson, Leon, and Wakulla – 1,100 mi^2 or 38.5%), however extends further north into Georgia (Decatur, Grady, Thomas, Brooks, Mitchell, Colquitt, and Worth – 1,759 mi^2 or 61.5%). The FGS springshed delineation is used throughout this report to characterize the water and nitrogen mass balances at Wakulla Spring. But it should be kept in mind that comprehensive restoration at Wakulla Spring may require significant land use changes in a large region of south Georgia.

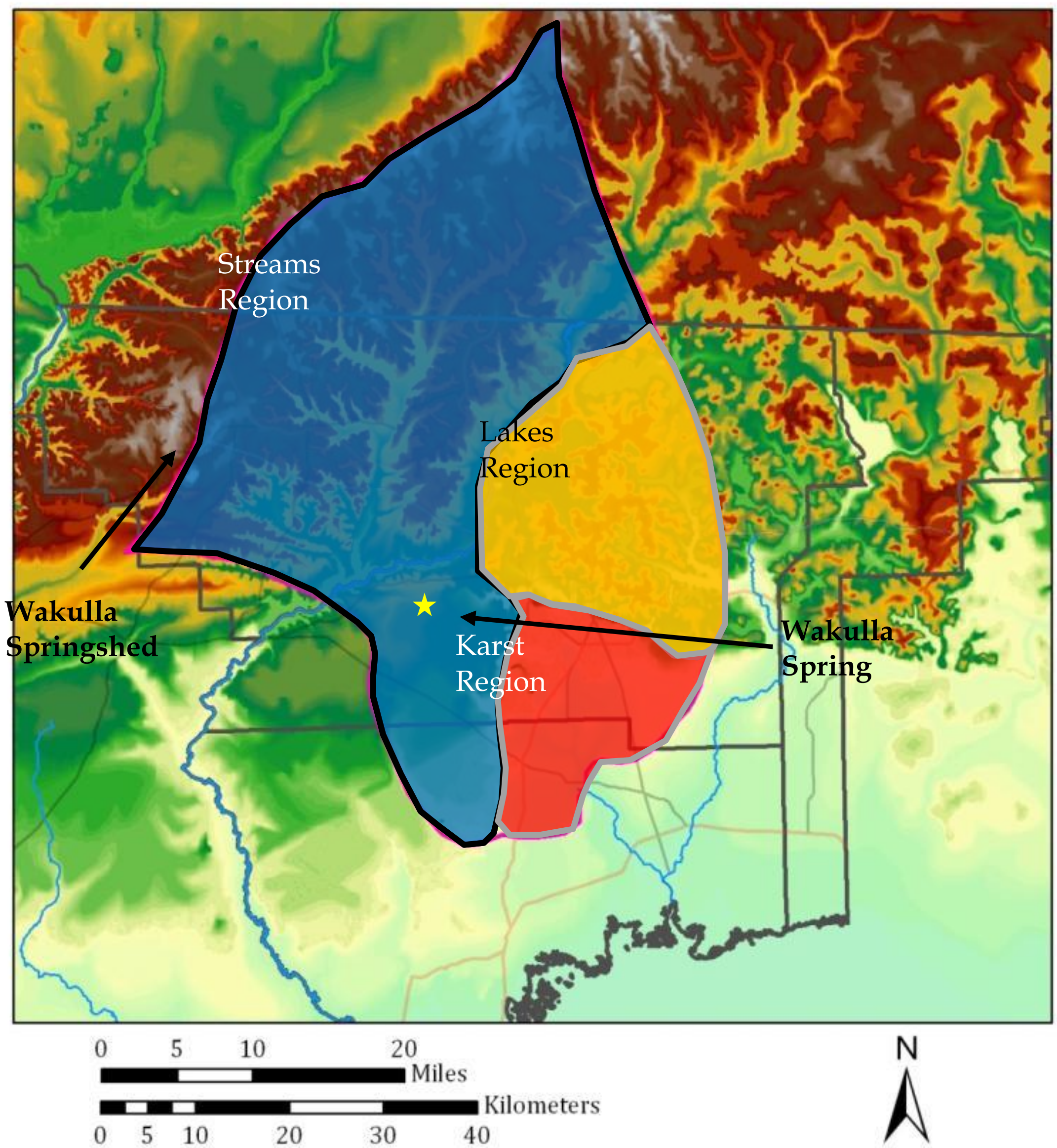


Figure 2-8. Conceptual diagram of the Wakulla Springshed with three areas of differing recharge potential highlighted: the Streams Region with low infiltration (about 1 inch/year), the Lakes Region with higher groundwater recharge (about 8 inches/year), and the Karst Plain Region with lowest confinement between the ground surface and the Floridan Aquifer (recharge about 18 inches/year). Adapted from Kris Barrios, NWFWMD "Hydrology 101" Power Point presentation (no date).

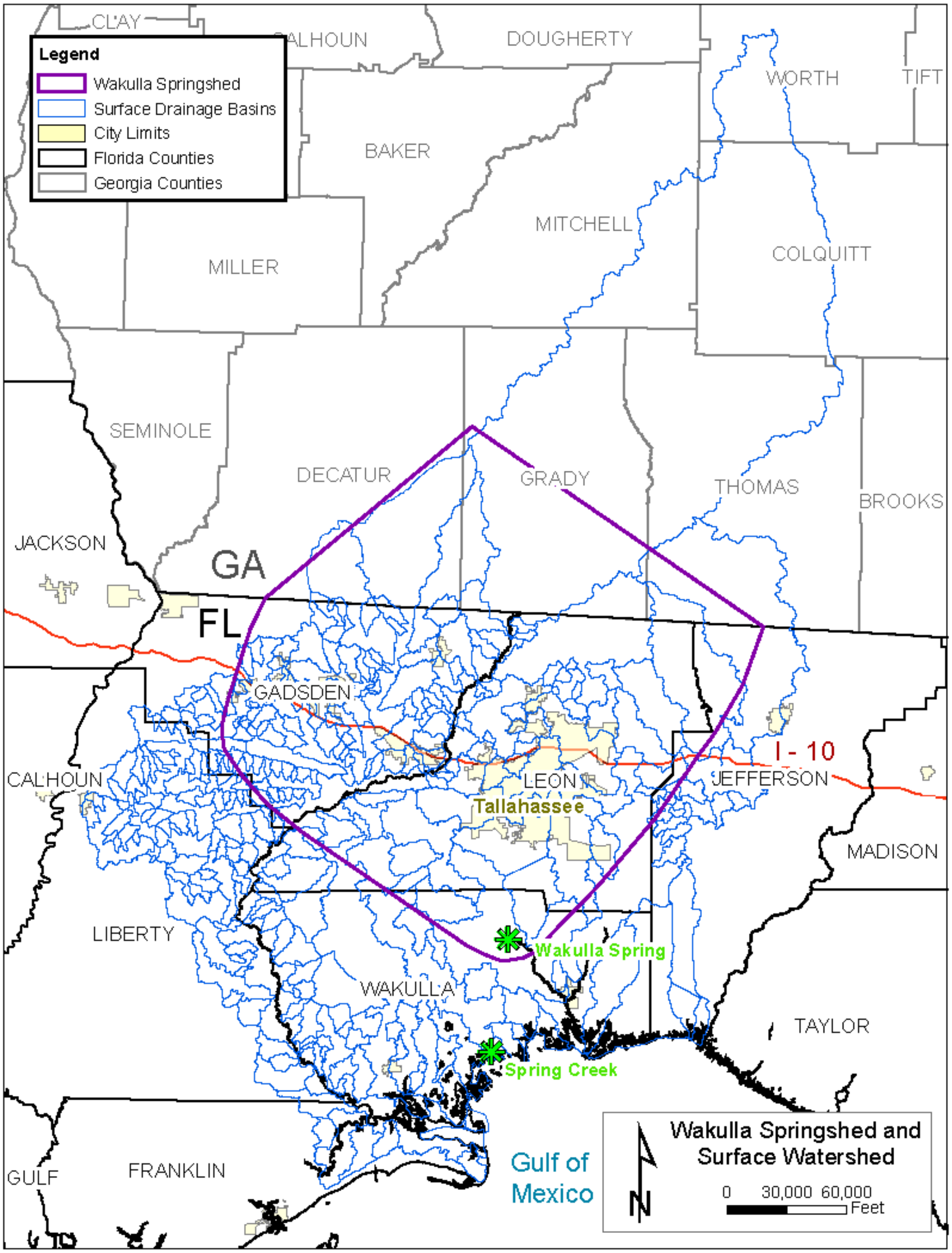


Figure 2-9. Surface watersheds outlined by blue lines, intersecting the Wakulla Spring springshed in south Georgia and north Florida.

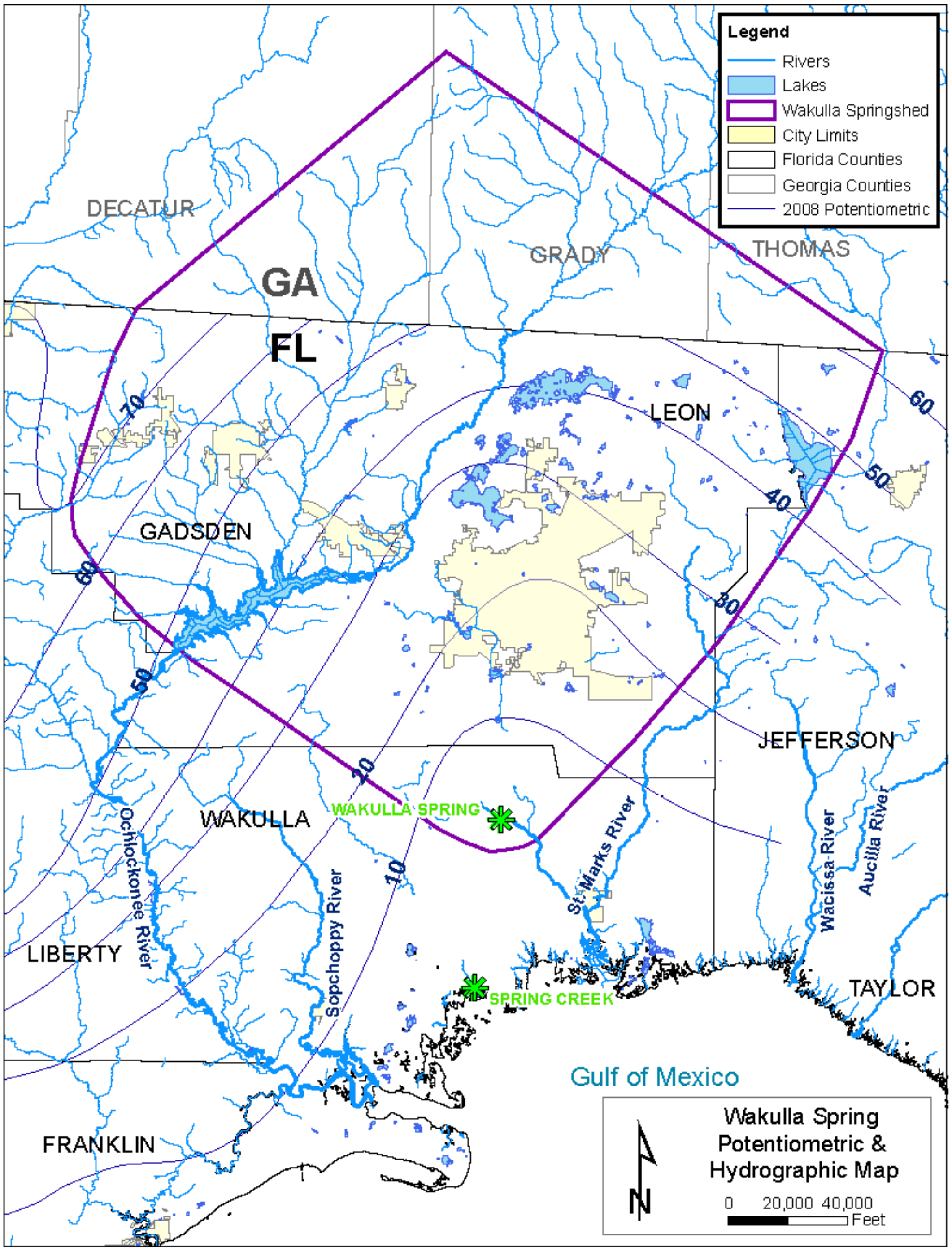


Figure 2-10. Surface and subsurface hydrographic features in the vicinity of the Wakulla Spring springshed. The estimated 2008 potentiometric isopleths are included.

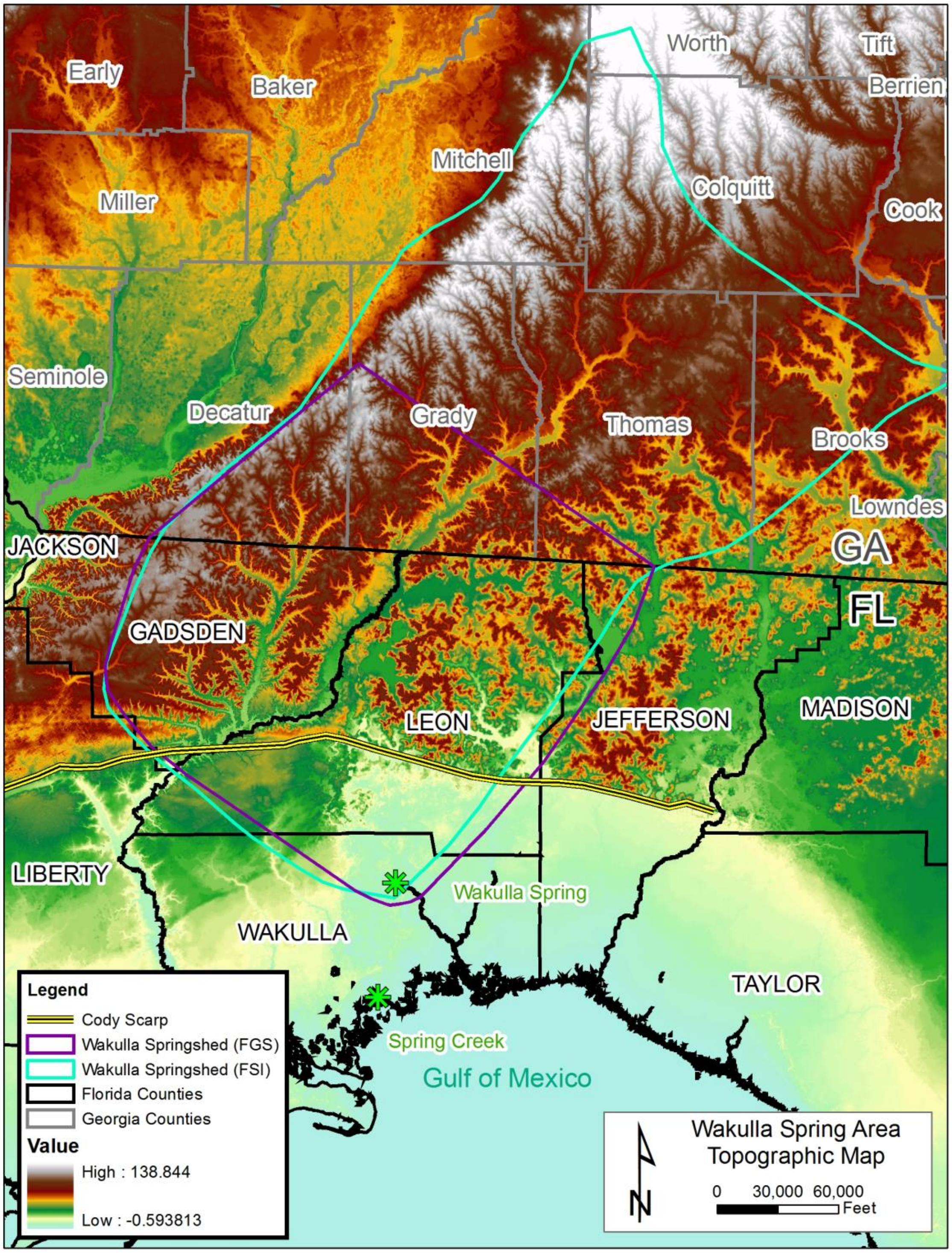


Figure 2-11. Topographic landform map of the Wakulla Springshed (springshed delineations from the Florida Geological Survey [FGS] and the Florida Springs Institute [FSI]).

2.5.2 Groundwater Flow Paths and Travel Times

A number of groundwater flow tracer studies have been conducted in the vicinity of Wakulla Spring (Hazlette-Kincaid 2007; Kincaid *et al.* 2012). Figure 2-12 illustrates a summary of what has been learned from these studies (Kincaid *et al.* 2012). Groundwater recharging the Floridan aquifer north of Wakulla Spring travels to the south and southwest towards the springs as well as Indian and Sally Ward springs. Average measured groundwater flow rates from the City of Tallahassee Tram Road Sprayfield site to these springs was in the range from 671 to 977 feet per day. These are very high rates for groundwater flow and confirm the presence of large natural conduits in the limestone formations that feed these springs.

2.5.3 Springshed Land Use

Figure 2-12 illustrates land uses within the portion of the springshed located within Florida and Georgia in 2006-2008. Slightly different land use categories were used in the Georgia and Florida mapping efforts. Table 2-1 provides a summary of the principal land uses within the entire springshed and subdivides those categories by state and county. The dominant land uses in the Wakulla springshed include forestry (43%), followed by wetlands (21%), agriculture (about 19%), and urban/commercial (about 14%).

2.5.4 Aquifer Vulnerability

All groundwater and aquifer systems are susceptible to some extent to contamination from surface sources of pollution. An aquifer vulnerability assessment provides a data-based method of estimating that susceptibility to groundwater contamination. The Florida Geological Survey has prepared a state-wide assessment of vulnerability for the Floridan aquifer (Arthur *et al.* 2005). Figure 2-13 provides the FGS aquifer vulnerability assessment for the Wakulla Springshed. Table 2-2 provides estimates of the areas in each county and in the whole springshed in each category of vulnerability. In addition, certain counties, including Leon and Wakulla counties have also had a more detailed evaluation of aquifer vulnerability (AGI 2007; AGI 2009).

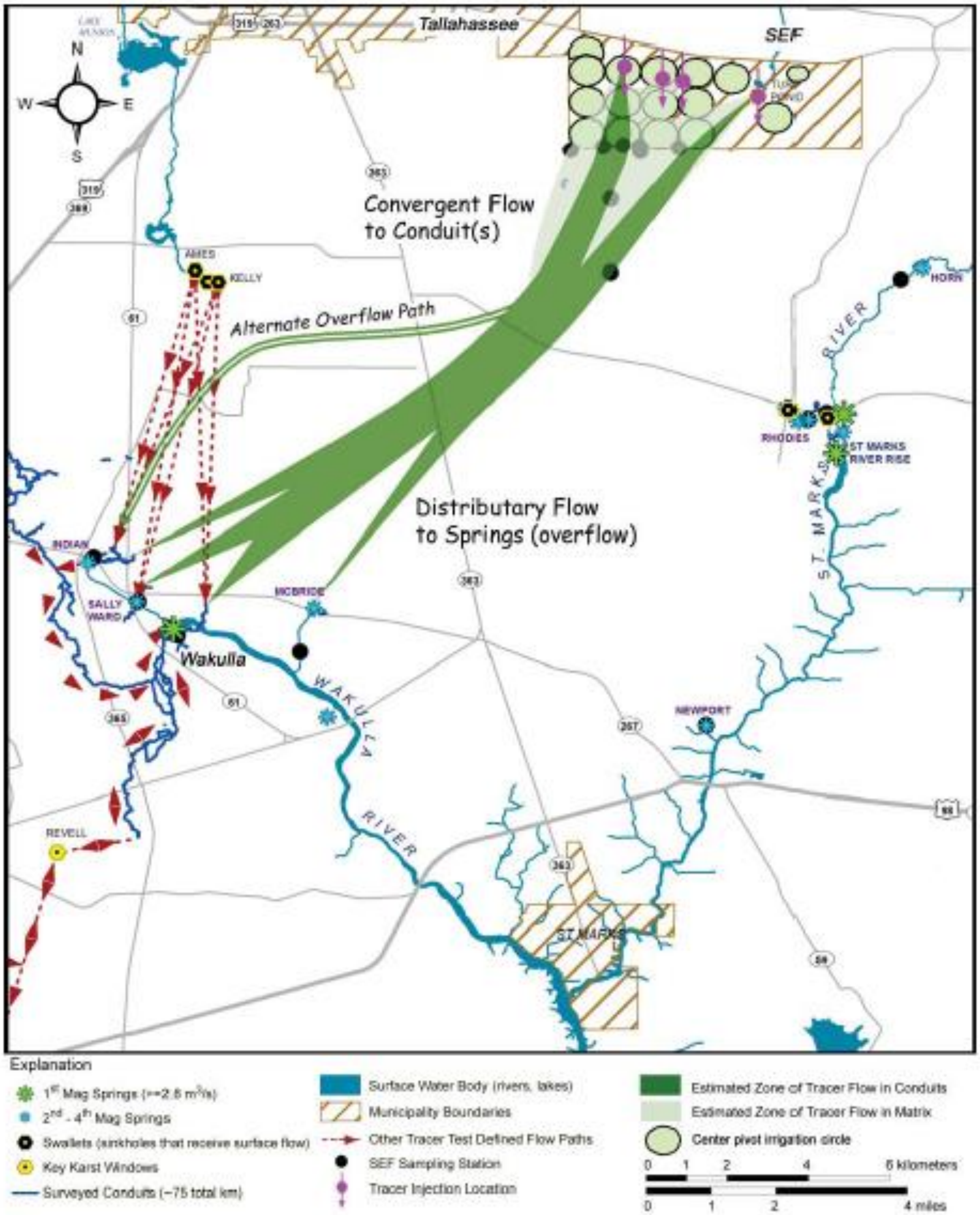


Figure 2-12. Probable conduit flow zones within the Wakulla Springshed as identified by tracer-defined groundwater flow pathways (Kincaid 2012).

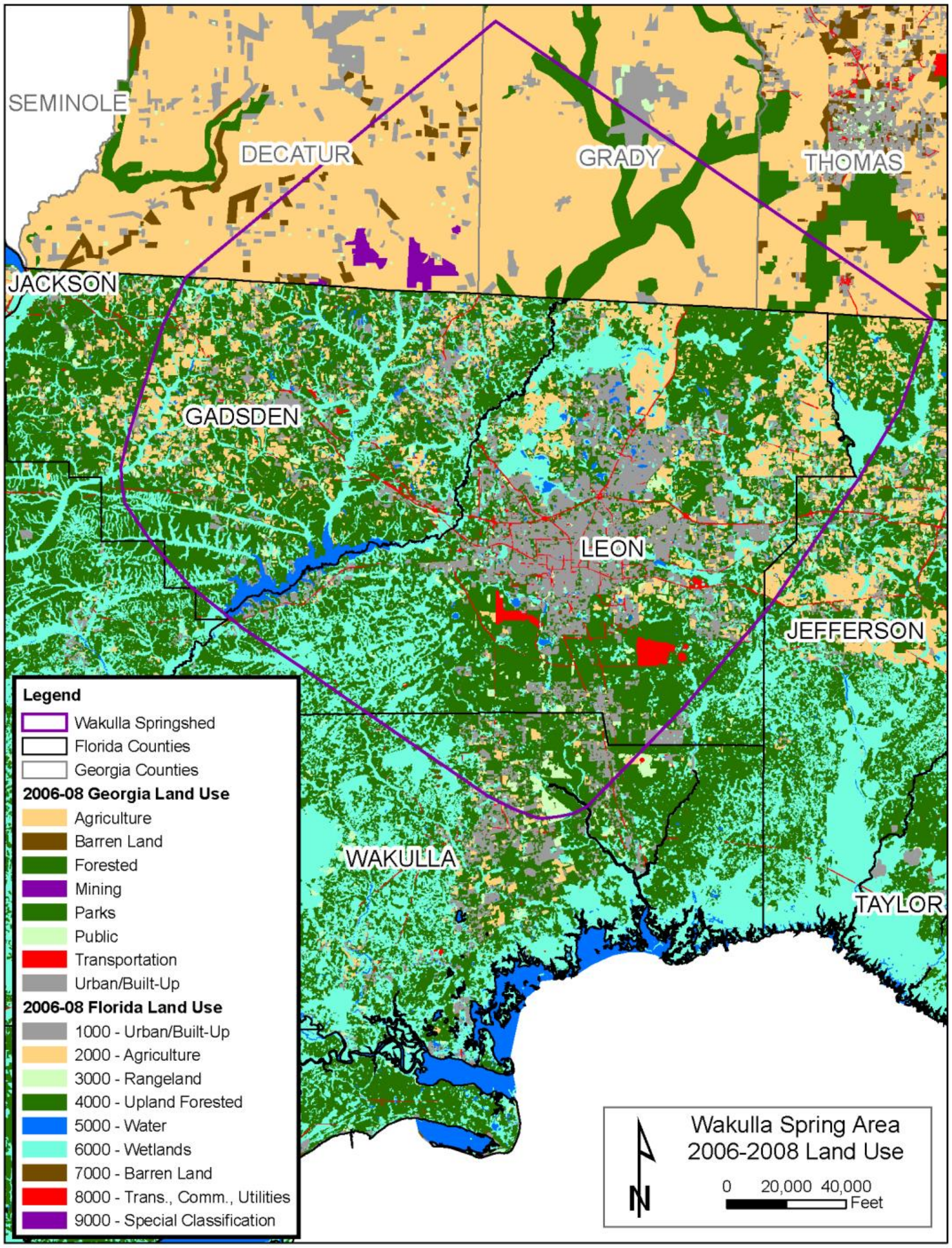


Figure 2-12. Land use map for the Wakulla Spring recharge area (based on FGS springshed delineation and land use data for 2006-2008).

Florida land uses are based on the Florida Land Use and Cover Classification System (LUCCS) and reflect both land use and dominant land cover types. Georgia land use categories were less detailed and assumptions concerning their similarity to Florida FLUCCS codes were made in preparation of this map.

Table 2-1. Estimated land use (acres) in the Wakulla Springshed (FGS springshed has a total area of about 1,569 mi²) for the 2006-2008 period. Florida data are from the NWFWMD. Georgia data are from Jeff Hamilton (personal communication, Southwest Georgia Regional Commission).

Land Use	Florida	Georgia[1,2,3,4]	Total	% of Area
Urban/Built-Up	109,465	13,999	123,464	12%
Agriculture	83,186	104,962	188,147	19%
Rangeland	16,072	369	16,441	2%
Upland Forested	350,806	78,345	429,151	43%
Water	15,632	0	15,632	2%
Wetlands	151,550	56,480	208,030	21%
Barren Land	1,059	4,469	5,528	1%
Trans., Comm., Utilities	12,396	89	12,485	1%
Special Classification	0	5,134	5,134	1%
Total	740,166	263,846	1,004,012	100%

[1] Assumed Georgia Agriculture is 30% upland forested, 20% wetlands, and 50% agriculture.

[2] Assumed Georgia Public is rangeland.

[3] Assumed Georgia Parks is 50% forested and 50% wetlands.

[4] Assumed Georgia Mining is a Special Classification.

Table 2-2. Estimated Floridan aquifer vulnerability (acres) in the Florida portion of the Wakulla Springshed area (Arthur *et al.* 2005)

County	FAV Class	Acres
Gadsden	Less Vulnerable	82
	Vulnerable	237,664
	More Vulnerable	12,619
Jefferson	Vulnerable	4,250
	More Vulnerable	32,995
Leon	Vulnerable	166,745
	More Vulnerable	220,728
Liberty	Vulnerable	296
	More Vulnerable	10
Wakulla	Vulnerable	2,916
	More Vulnerable	41,152
Total	Less Vulnerable	82
	Vulnerable	411,870
	More Vulnerable	307,504

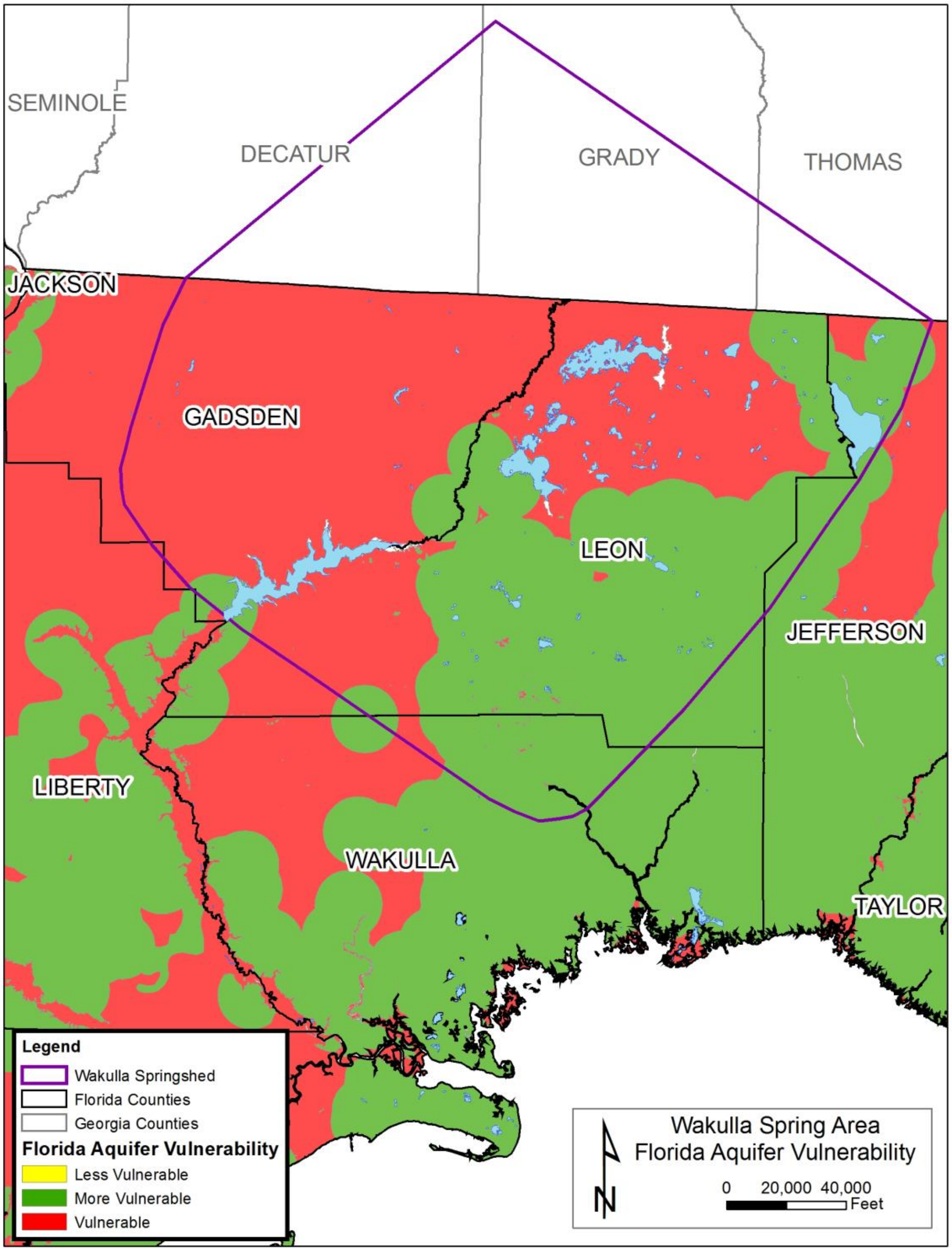


Figure 2-13. Floridan aquifer vulnerability map for the Florida portion of the Wakulla Springshed area (Arthur *et al.* 2005)

2.5.5 Population

The City of Tallahassee, suburbanized Leon County, and developed portions of Wakulla County overlie the Wakulla Spring springshed and groundwater capture zone. The 2010 US Census recorded an estimated 471,246 people residing in the seven counties that encompass the Wakulla springshed (Table 2-3). Based on the fraction of each county that is in the delineated Wakulla springshed, the estimated human population in the springshed in 2010 was 303,685, with 7.4% in the Georgia portion and 92.6% in Florida. About 40% of the Wakulla Springshed is in Leon County, Florida, with 25.6% in Gadsden County, Florida, 13.9% in Grady County, Georgia, and smaller percentages in the remaining four counties. About 89% of Leon County is in the Wakulla Springshed.

Table 2-3. Estimated land area and population within the Wakulla Springshed

State	County	County Area (ac)	July 2010 County Population[1]	Area Springshed (ac)	2010 Estimated Springshed Population[2]	% Springshed in County	% County in Springshed
Florida	Leon	449,196	268,185	401,671	239,811	40.0%	89.4%
	Gadsden	338,169	47,776	256,700	36,266	25.6%	75.9%
	Jefferson	391,451	14,019	37,272	1,335	3.71%	9.52%
	Wakulla	390,648	33,314	44,115	3,762	4.39%	11.3%
	Liberty	539,754	7,401	306	4	0.03%	0.06%
	Total	**2,109,218**	**370,695**	**740,253**	**281,178**	**73.7%**	**--**
Georgia	Decatur	398,815	28,777	99,209	7,159	9.9%	24.9%
	Grady	294,553	25,560	139,826	12,133	13.9%	47.5%
	Thomas	353,400	46,214	24,584	3,215	2.45%	6.96%
	Total	**1,046,768**	**100,551**	**263,711**	**22,507**	**26.3%**	**--**
Springshed	**Total**	**3,155,986**	**471,246**	**1,003,964**	**303,685**	**100.0%**	**--**

[1] Population estimate for July 2010 from US Census Bureau

[2] Springshed population estimate based on % of county in springshed

2.5.6 Water Use

2.5.6.1 Groundwater Withdrawals

Groundwater is the principal source of supply for most withdrawals in the Wakulla Springshed (Chelette *et al*. 2002; Davis and Katz 2007; NWFWMD 2008). Table 2-4 summarizes the estimated groundwater withdrawals in the Florida portion of the Wakulla Springshed by decade starting in the 1960's. Total estimated groundwater withdrawals increased from about 14 MGD for the period from 1965-1970 to about 42 MGD for the period from 1990-2010. The dominant groundwater uses are public and domestic supply (Figure 2-14). The City of Tallahassee is the single largest groundwater user with a total of 28 water-supply wells (Davis and Katz 2007). The most recent data indicate that total combined withdrawals in the Florida portion of the springshed were about 43 MGD in 2010 (Marella 2014).

Table 2-4 summarizes the estimated groundwater withdrawals in the Georgia portion of the Wakulla Springshed for 2005 (USGS 2009). Total estimated groundwater withdrawals were about 14 MGD, with agricultural irrigation being the dominant groundwater use (10.5 MGD or 76%). The estimated total current (Florida 2010; Georgia 2005) groundwater withdrawal in the combined Georgia/Florida Wakulla Springshed is about 57 MGD (88 cfs).

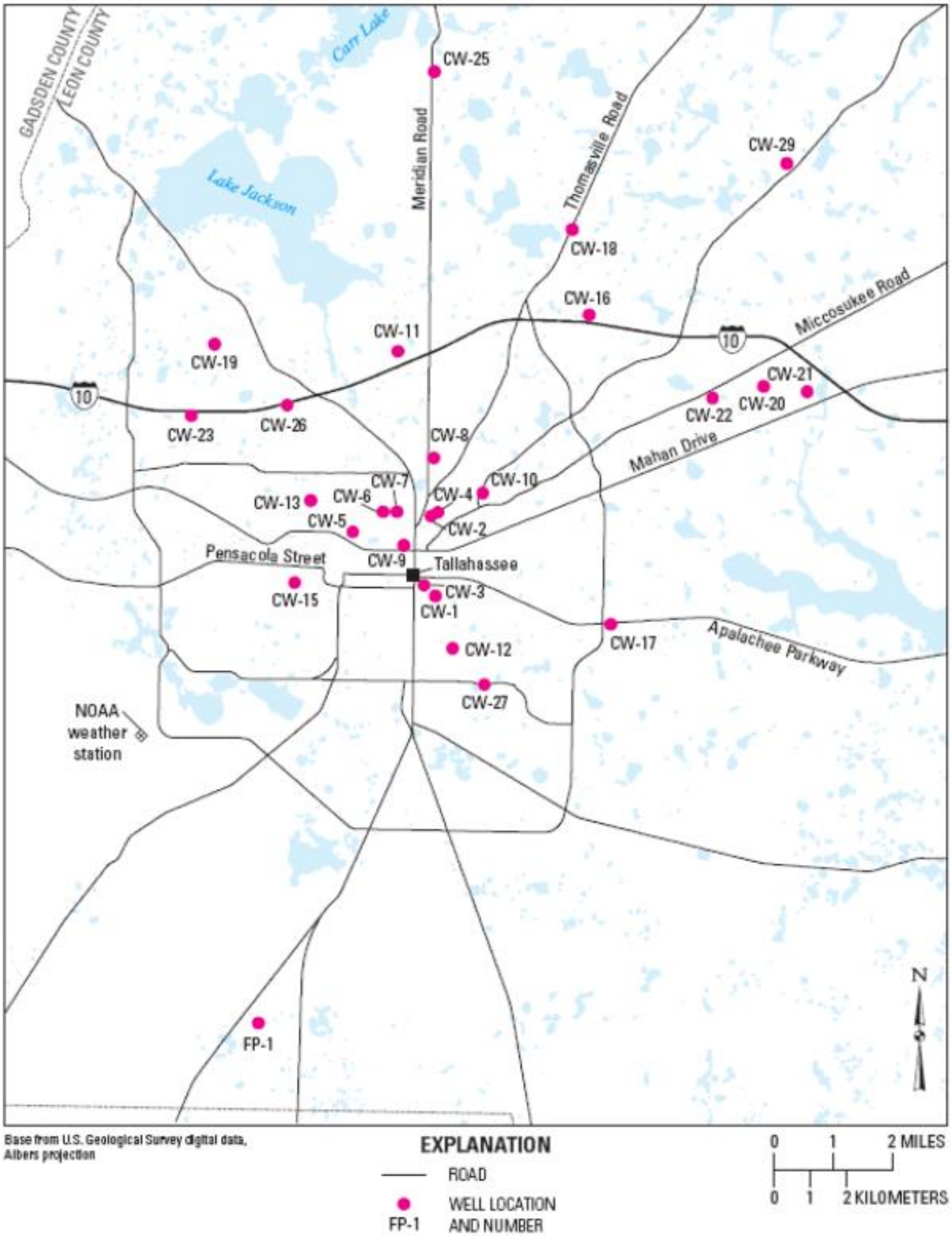


Figure 2-14. Map showing the location of the City of Tallahassee's public water supply wells (from Davis and Katz 2007).

Table 2-4. Estimated groundwater withdrawals within the Florida portion of the Wakulla Springshed

			Estimated Groundwater Withdrawals (MGD)					
State	**County**	**Category**	**1965-1970**	**1971-80**	**1981-90**	**1990-2000**	**2005**	**2010**
Florida	**Leon**	Public Supply	9.44	15.01	21.42	26.31	---	27.19
		Domestic	2.07	3.23	4.54	4.06	---	3.25
		Commercial, Industrial, Mining	0.00	0.94	0.26	0.16	---	0.01
		Agricultural	0.09	1.00	1.44	0.96	---	0.34
		Recreational	0.00	0.00	1.56	1.13	---	0.64
		Power Generation	0.00	2.16	3.75	2.41	---	1.52
		Total	**11.61**	**22.34**	**32.98**	**35.01**	**---**	**32.96**
	Gadsden	Public Supply	0.53	0.83	1.48	1.89	---	3.37
		Domestic	1.43	1.69	1.63	1.60	---	0.98
		Commercial, Industrial, Mining	0.11	0.08	1.56	0.74	---	0.46
		Agricultural	0.49	0.18	2.12	1.79	---	3.80
		Recreational	0.00	0.00	0.09	0.10	---	0.00
		Power Generation	0.00	0.00	0.00	0.00	---	0.00
		Total	**2.57**	**2.78**	**6.89**	**6.12**	**---**	**8.62**
	Jefferson	Public Supply	0.03	0.04	0.06	0.07	---	0.08
		Domestic	0.05	0.06	0.11	0.10	---	0.08
		Commercial, Industrial, Mining	0.01	0.00	0.00	0.02	---	0.02
		Agricultural	0.03	0.10	0.70	0.71	---	0.51
		Recreational	0.00	0.00	0.01	0.03	---	0.02
		Power Generation	0.00	0.00	0.00	0.00	---	0.00
		Total	**0.12**	**0.21**	**0.88**	**0.92**	**---**	**0.70**
	Wakulla	Public Supply	0.01	0.04	0.08	0.15	---	0.27
		Domestic	0.04	0.06	0.08	0.14	---	0.17
		Commercial, Industrial, Mining	0.04	0.09	0.08	0.07	---	0.13
		Agricultural	0.00	0.00	0.01	0.04	---	0.03
		Recreational	0.00	0.00	0.00	0.02	---	0.02
		Power Generation	0.02	0.03	0.02	0.02	---	0.00
		Total	**0.11**	**0.22**	**0.26**	**0.44**	**---**	**0.62**
	Total	Public Supply	10.02	15.92	23.04	28.41	---	30.92
		Domestic	3.59	5.04	6.36	5.90	---	4.48
		Commercial, Industrial, Mining	0.16	1.11	1.91	0.99	---	0.62
		Agricultural	0.61	1.29	4.26	3.50	---	4.68
		Recreational	0.00	0.00	1.66	1.28	---	0.68
		Power Generation	0.02	2.19	3.76	2.42	---	1.52
		Total	**14.41**	**25.56**	**41.00**	**42.50**	**---**	**42.90**
Georgia	**Decatur**	Public Supply	---	---	---	---	0.71	---
		Domestic & Commercial	---	---	---	---	0.36	---
		Industrial & Mining	---	---	---	---	0.15	---
		Irrigation	---	---	---	---	8.65	---
		Livestock	---	---	---	---	0.04	---
		Thermoeletric	---	---	---	---	0.00	---
		Total	**---**	**---**	**---**	**---**	**9.92**	**---**
	Grady	Public Supply	---	---	---	---	0.88	---
		Domestic & Commercial	---	---	---	---	0.41	---
		Industrial & Mining	---	---	---	---	0.17	---
		Irrigation	---	---	---	---	1.32	---
		Livestock	---	---	---	---	0.02	---
		Thermoeletric	---	---	---	---	0.00	---
		Total	**---**	**---**	**---**	**---**	**2.79**	**---**
	Thomas	Public Supply	---	---	---	---	0.39	---
		Domestic & Commercial	---	---	---	---	0.06	---
		Industrial & Mining	---	---	---	---	0.21	---
		Irrigation	---	---	---	---	0.54	---
		Livestock	---	---	---	---	0.01	---
		Thermoeletric	---	---	---	---	0.00	---
		Total	**---**	**---**	**---**	**---**	**1.20**	**---**
	Total	Public Supply	---	---	---	---	1.98	---
		Domestic & Commercial	---	---	---	---	0.83	---
		Industrial & Mining	---	---	---	---	0.52	---
		Irrigation	---	---	---	---	10.51	---
		Livestock	---	---	---	---	0.07	---
		Thermoeletric	---	---	---	---	0.00	---
		Total	**---**	**---**	**---**	**---**	**13.91**	**---**

[1] USGS water use data by county prorated for the fraction of each county in the Wakulla Springshed

2.5.6.2 Net Water Consumption

A fraction of the water withdrawn by wells from the Floridan Aquifer in the Wakulla Springshed is returned to the aquifer upgradient of Wakulla Spring and subsequently is part of the spring's discharge. The fraction of this water that is not returned to the Floridan Aquifer is referred to in this report as the "net consumption". This net consumption is the difference between the total amount of groundwater withdrawn and the amount that recharges the Floridan Aquifer. Several factors affect the net consumption of groundwater in the Wakulla Springshed. These factors include the following:

- Due to the presence of confining layers in the soil profile, deep groundwater withdrawn from the aquifer in the Streams region (northern, confined) portion of the springshed has no way to effectively return to the aquifer. Recharge of rainfall and surface water to the deep groundwater in this region is minimal (about 1" per year) and most water that soaks into the surface of the ground finds its way to surface streams and wetlands that ultimately drain out of the springshed to the Ochlockonee River drainage. The net consumption of groundwater pumped from the Floridan Aquifer in this area is assumed to be between 80 and 100 percent.

- Deep groundwater withdrawn from the Floridan Aquifer in the Lakes Region of the Wakulla Springshed is only partially returned to the deep aquifer through swallets and disappearing (sinkhole-drained) lakes (estimated 8" recharge per year). The City of Tallahassee's effluent disposal sprayfield (Tram Road Southeast Farm) is located below the Cody Scarp in the Karst Region (which allows recharge at a greater rate estimated as 18" per year). The rest of the pumped water that infiltrates into the soil likely travels to the shallow surficial aquifer and then discharges into creeks, streams, and rivers that flow out of the springshed (Davis and Katz 2007). Due to the relatively low natural permeability of the Hawthorn clays in this area, there is greater opportunity for land applied waters (residential, golf course, and agricultural irrigation and effluent disposal sites) to evaporate before some of the water infiltrates. The net consumption of groundwater pumped from the Floridan Aquifer in this area is assumed to be between 50 and 70 percent.

- Deep groundwater withdrawn from the karst areas below the Cody Scarp is more likely to directly recharge the aquifer in the springshed than waters utilized in the previous two geographical areas (estimated as 18" per year). Most of the water applied to the ground in these areas will infiltrate through the sandy surface layers and into the underlying limestone aquifer. However, a significant portion of the water pumped to the surface for human uses in this area is lost by evapotranspiration. Therefore, the net consumption of groundwater pumped from the Floridan Aquifer in this area is assumed to be between 30 and 50 percent.

Different groundwater uses have inherently different net consumption fractions. These net consumption fractions have been estimated in a series of reports published by the US Geological Survey detailing Florida water withdrawals and use (Marella 1988, 1992, 1999, 2004, 2009). For example, standard spray or flood agricultural irrigation consumes an estimated 62 to

70% of the water applied. Lawn and golf course irrigation has an estimated average net consumption fraction of about 70 to 80%. Domestic in-house uses consume an estimated 28% of the water withdrawn. Commercial and industrial uses are assumed to have an average net consumption rate of about 20%.

Using these estimates with the general groundwater recharge potential of the Wakulla Springshed, Table 2-5 provides estimates of the net consumption of groundwater withdrawn from the Wakulla Springshed. Estimated net consumption of groundwater within the Florida portion of the Wakulla Springshed has increased from about 4.3 MGD (6.6 cfs) in the period from 1965-1970 to about 13.9 MGD (21.4 cfs) during 2010. The overall average estimated net consumption for the Florida portion of the springshed is about 32% of the total water withdrawn from the aquifer. Estimated net consumption of groundwater within the Georgia portion of the Wakulla Springshed was 8.1 MGD (12.5 cfs) during 2005, or about 58% of the total water withdrawn from the aquifer. Based on these data and assumptions, an estimated average 22 MGD (34 cfs) [Florida 2010; Georgia 2005] of Floridan Aquifer water is currently being removed from the sources of groundwater inflow to Wakulla Spring.

Table 2-5. Estimated groundwater net consumption within the Florida and Georgia portions of the Wakulla Springshed

		Estimated Net Consumptive Water Use in the Springshed (MGD)					
State	**County**	**1965-1970**	**1971-80**	**1981-90**	**1990-2000**	**2005**	**2010**
Florida	Leon	3.29	6.15	9.80	10.24	--	9.38
	Gadsden	0.91	0.85	2.70	2.42	--	3.90
	Jefferson	0.04	0.10	0.53	0.55	--	0.41
	Wakulla	0.03	0.05	0.07	0.14	--	0.18
	Liberty	--	--	--	--	--	--
	Total	**4.26**	**7.15**	**13.09**	**13.36**	--	**13.86**
Georgia	Decatur	--	--	--	--	6.24	--
	Grady	--	--	--	--	1.30	--
	Thomas	--	--	--	--	0.54	--
	Total	--	--	--	--	**8.08**	--

Use Type	Percent Consumed[1]
Public Supply	28%
Domestic	28%
Commercial, Industrial, Mining	20%
Agricultural	68%
Recreational	77%
Power Generation	8%

[1] Average values from USGS (Marella 1988, 1992, 1999, 2004, and 2009)

Section 3.0 Hydrology

3.1 Introduction

Chelette *et al.* (2002) prepared an estimated "water balance" for Wakulla Spring based on average conditions and a variety of assumptions (Figure 3-1). Detailed assumptions concerning the size of the recharge area, the nature of the aquifer, and groundwater flow paths are discussed in the original reference. Based on those assumptions the summary of inflows and outflows for the modeled area north of the Cody Scarp includes:

- Inflows (sum = 300 cfs [194 MGD])
  - Groundwater inflows from Georgia – 45 cfs (29 MGD)
  - Groundwater inflows from Gadsden County to the west – 36 cfs (23 MGD)
  - Direct recharge – 219 cfs (141 MGD)
  - Leakage from streams – 0.3 cfs (0.2 MGD)
- Outflows (sum = 254 cfs [164 MGD])
  - Groundwater outflows to the east – 53 cfs (34 MGD)
  - Groundwater flows to the south towards Wakulla Spring – 201 cfs (130 MGD)

The estimated outflows from the northern area of recharge summarized above were used as the estimated inflows to the southern modeled area. A summary of estimated inflows and outflows for this southern area includes:

- Inflows (sum = 395 cfs [255 MGD])
  - Groundwater inflow from the north – 201 cfs (130 MGD)
  - Groundwater inflow from the western portion of Leon County – 7 cfs (4.5 MGD)
  - Leakage from streams – 9 cfs (6 MGD)
  - Direct recharge – 178 cfs (115 MGD)
- Outflows (394 cfs [255 MGD]) to the south (assumed to Wakulla Spring)

3.2 Precipitation and Evapotranspiration

Figure 3-2 presents a summary of the historical precipitation records for four weather stations within the Wakulla springshed. The median annual rainfall in this area for the period-of-record from 1968 to 2010 was 62.2 in/yr. Based on an estimated springshed area of 1,569 square miles, the estimated median annual rain input to the Wakulla Springshed is about 4,650 MGD (7,200 cfs).

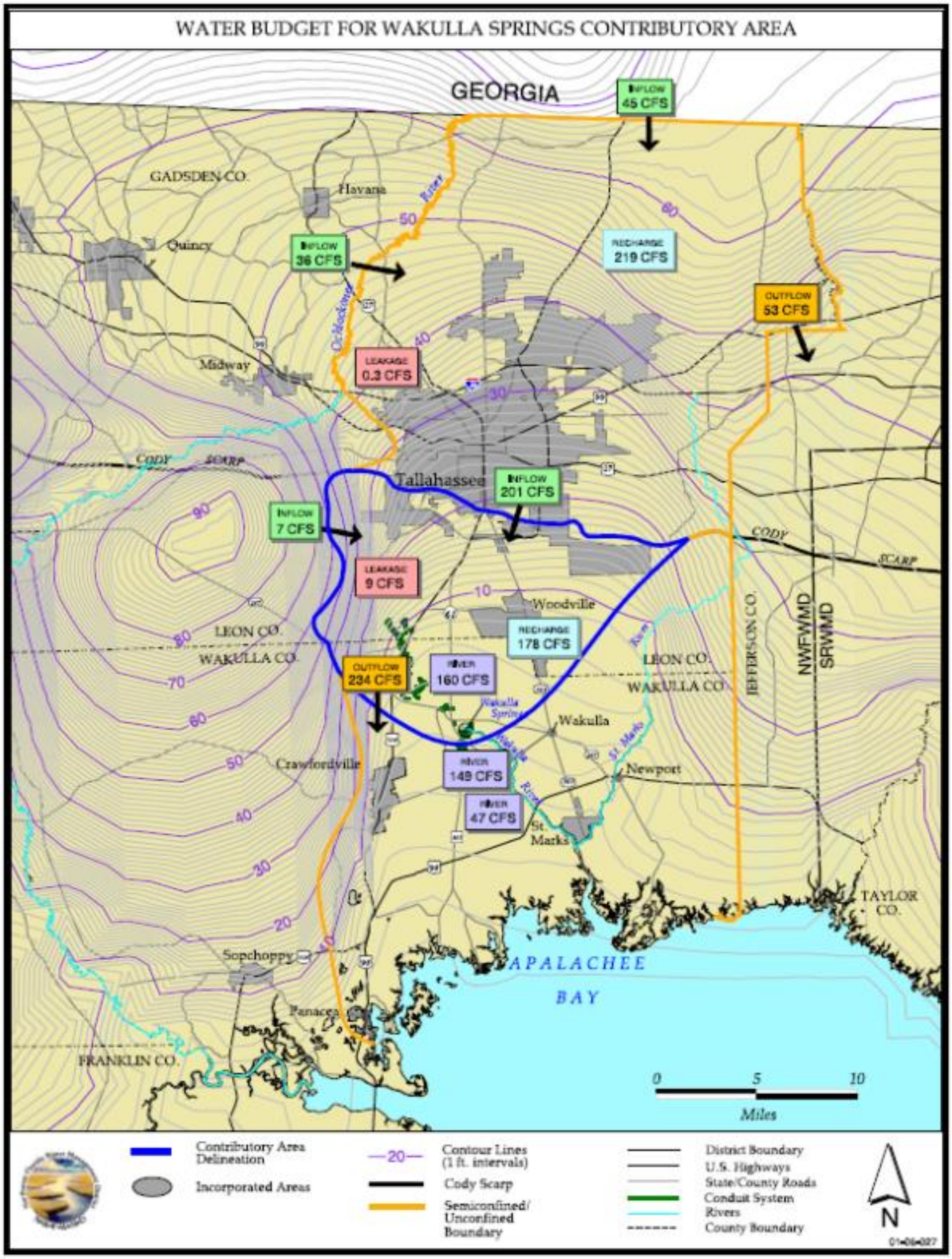


Figure 3-1. Estimated water budget for Wakulla Spring (from Chelette *et al.* 2002).

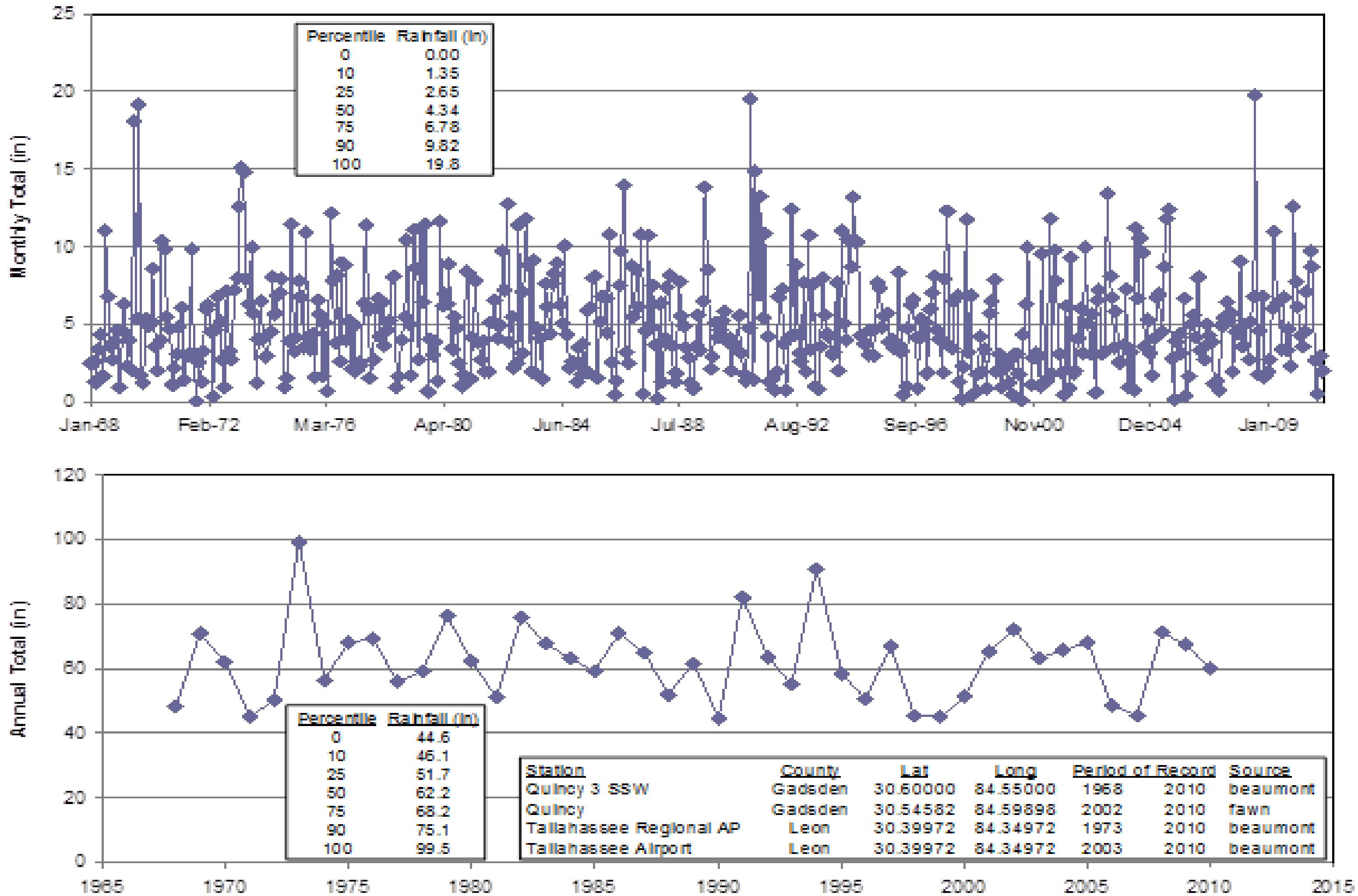


Figure 3-2. Average monthly and annual rainfall totals in Leon and Gadsden Counties, Florida (1968-2010) source: http://beaumont.tamu.edu/CLIMATICDATA/WeatherMapSelection.

3.3 Evapotranspiration

Evapotranspiration or ET (the sum of evaporation and transpiration) is second only to rainfall in importance for constructing water budgets for Florida (Knowles 1996). Evapotranspiration for this portion of Florida can be estimated as about 42 in/yr or about 3,120 MGD (4,825 cfs), for an estimated net precipitation in the springshed of about 20 in/yr or about 1,530 MGD (2,375 cfs).

3.4 Groundwater Recharge

Bush and Johnson (1988) have estimated recharge for the entire Floridan aquifer that extends from South Carolina, through the Coastal Plain of Georgia, under all of the Florida peninsula, and into coastal Alabama and Mississippi. A digitized version of their map was used to estimate the typical average recharge to the Floridan aquifer in the Wakulla springshed. Annual average (area weighted) recharge within the springshed was estimated to be 10.2 inches/year (Table 3-1). This is equivalent to a recharge estimate of about 760 MGD (1,160 cfs) over the entire Wakulla Springshed.

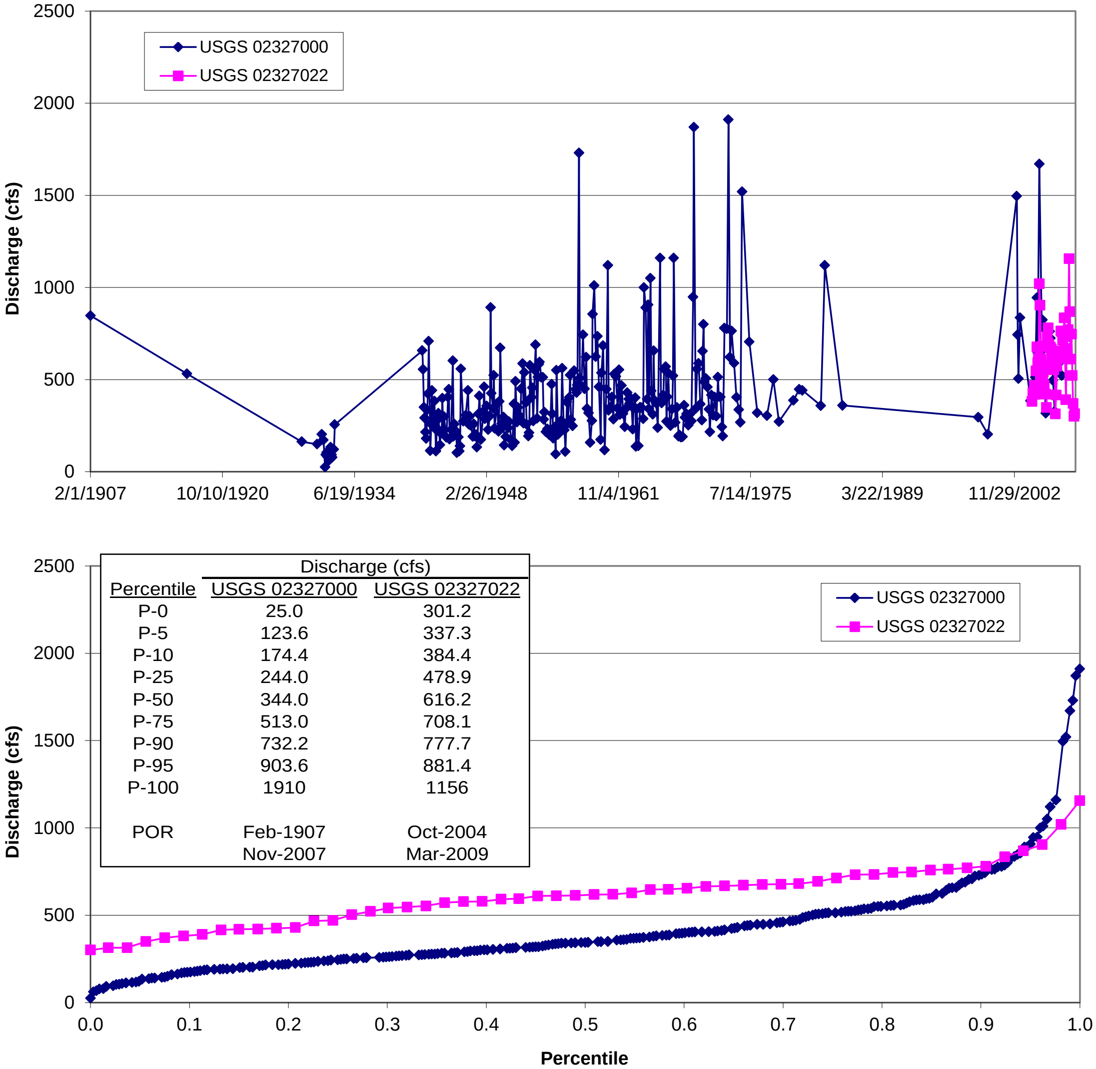
Table 3-1. Estimated recharge within the Wakulla Springshed (from Bush and Johnson 1988)

Recharge (in/yr)	Avg. Recharge (in/yr)	Area (mi^2)	Avg Recharge x Area	Area Weighted Recharge (in/yr)
0 to 1	0.5	85.3	42.7	---
1 to 5	3.0	424.8	1,274	---
5 to 10	7.5	327.0	2,453	---
10 to 15	12.5	124.8	1,560	---
15 to 20	17.5	607.1	10,624	---
Total	---	1,569	15,954	10.2

3.5 Spring Discharge

Wakulla Spring has the largest known range of discharge measurements among Florida springs (Scott *et al.* 2002). Historical discharge data reported by Rosenau *et al.* (1977), ranged from 25.2 cfs (16 MGD) on June 18, 1931 to 1,910 cfs (1,234 MGD) on April 11, 1973; with an average discharge of 390 cfs (252 MGD) for the period from 1970 to 1974. The US Geological Survey (USGS) has historically reported discharge immediately below the Wakulla Spring basin at Station # 0237000 (Figure 3-3). The USGS also has a discharge and stage station (# 02327022) further downstream (about 1 mile) from the spring vent at the CR 365 bridge. Daily records for discharge in the Wakulla River at this station after October 2004 include flows from Sally Ward and McBride Slough. Figure 3-5 illustrates the variability of discharge and stage in this spring system which is highly responsive to rainfall events in the springshed. Some of the variability in this spring's discharge has also been attributed to tidal influence (USGS 2007).

Of particular note for the discharge measurements at Wakulla Spring and downstream in the Wakulla River is a marked increase in median and average flows during the past 30 years (Figure 3-3 and Figure 3-4). WSI (2010) reported that the average flow at Wakulla Spring was 84% higher in the decade from 2000-2009 than during the entire 100+ year period-of-record. Figure 3-6 indicates that discharge in the Wakulla River at the CR 365 bridge consistently increased from about 550 to nearly 700 cfs during the period between 2004 and 2009. The observed increase in Wakulla Spring discharge is not typical of other springs in Florida during this same period and cannot be tied to an increase in precipitation in the Wakulla Spring recharge area. As described above, Davis (2011) has documented a delicate balance in the flows between Wakulla Spring and Springs Creek Springs that is affected by multiple factors, possibly including changes in sea level and an increase in net groundwater withdrawals in the combined springshed of these two inter-connected large springs.



	Discharge (cfs)	
Percentile	USGS 02327000	USGS 02327022
P-0	25.0	301.2
P-5	123.6	337.3
P-10	174.4	384.4
P-25	244.0	478.9
P-50	344.0	616.2
P-75	513.0	708.1
P-90	732.2	777.7
P-95	903.6	881.4
P-100	1910	1156
POR	Feb-1907 Nov-2007	Oct-2004 Mar-2009

Figure 3-3. Monthly average discharge time series and frequency curve for the Wakulla River (U.S. Geological Survey data).

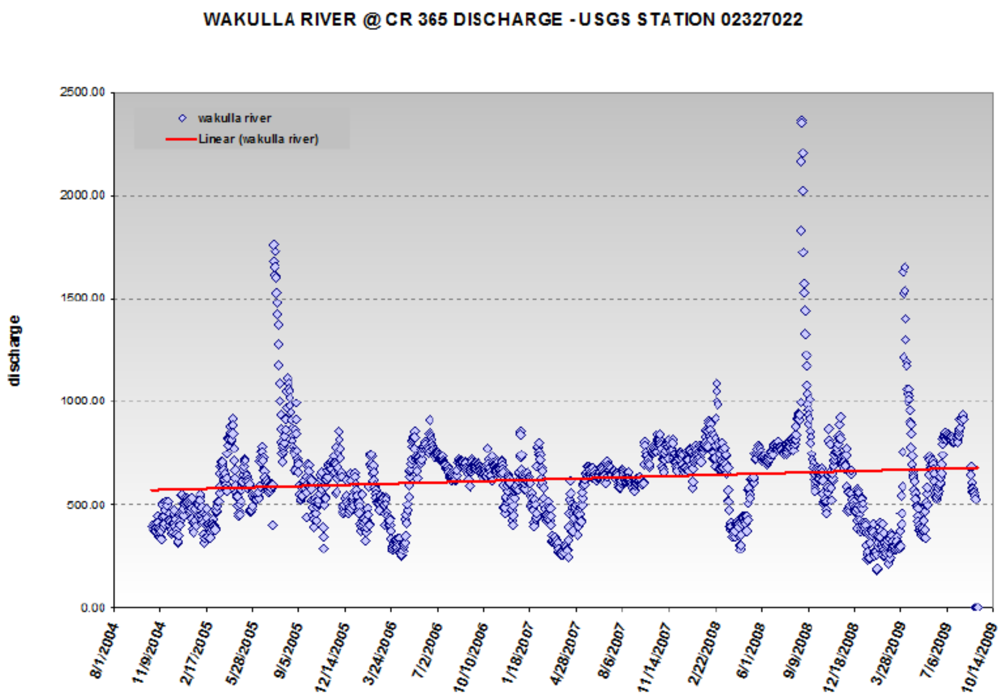


Figure 3-4. Recent discharge trend at Wakulla River at SR 365 station (Maddox 2013).

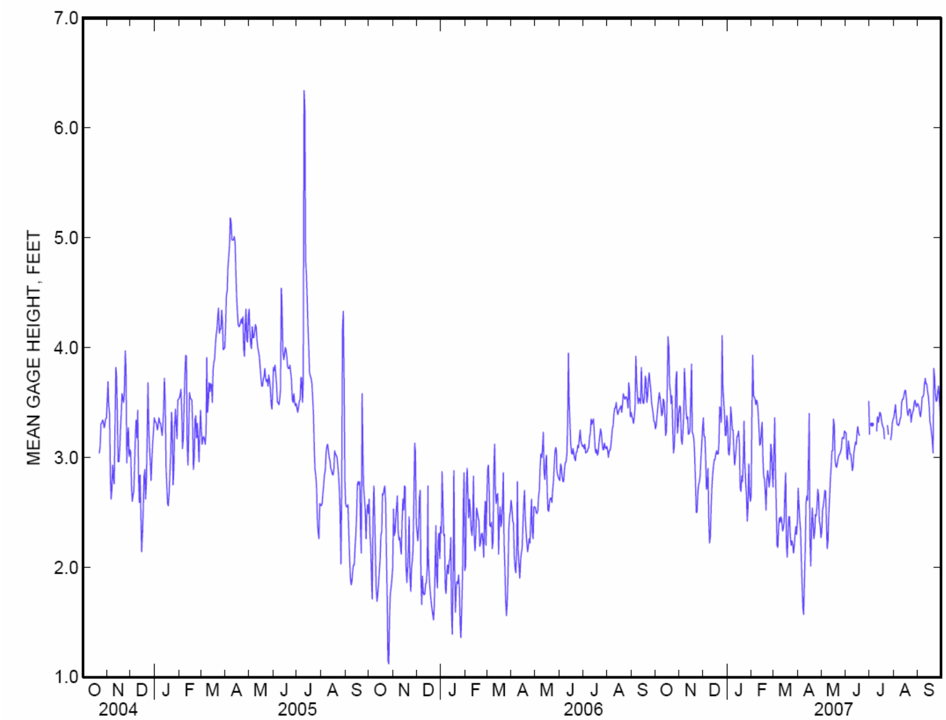


Figure 3-5. Wakulla River water stage time series (from USGS 2007).

3.6 Relationship between Groundwater Levels and Spring Discharge

Groundwater levels and discharge at Wakulla Springs are inextricably linked. Groundwater levels within the springshed directly contribute to discharge at the spring vents on the river. Figure 3-6 shows the relationship between Wakulla River discharge (#02327022) and groundwater levels from the USGS Crawfordville well (#300740084293001). The Wakulla River stations is downstream (about 3 miles) from the spring vent at the CR 365 bridge, while the USGS well is approximately 13.5 miles southwest from Wakulla Spring. These data illustrate the variability of discharge and groundwater levels in this spring system which is highly responsive to rainfall events in the springshed.

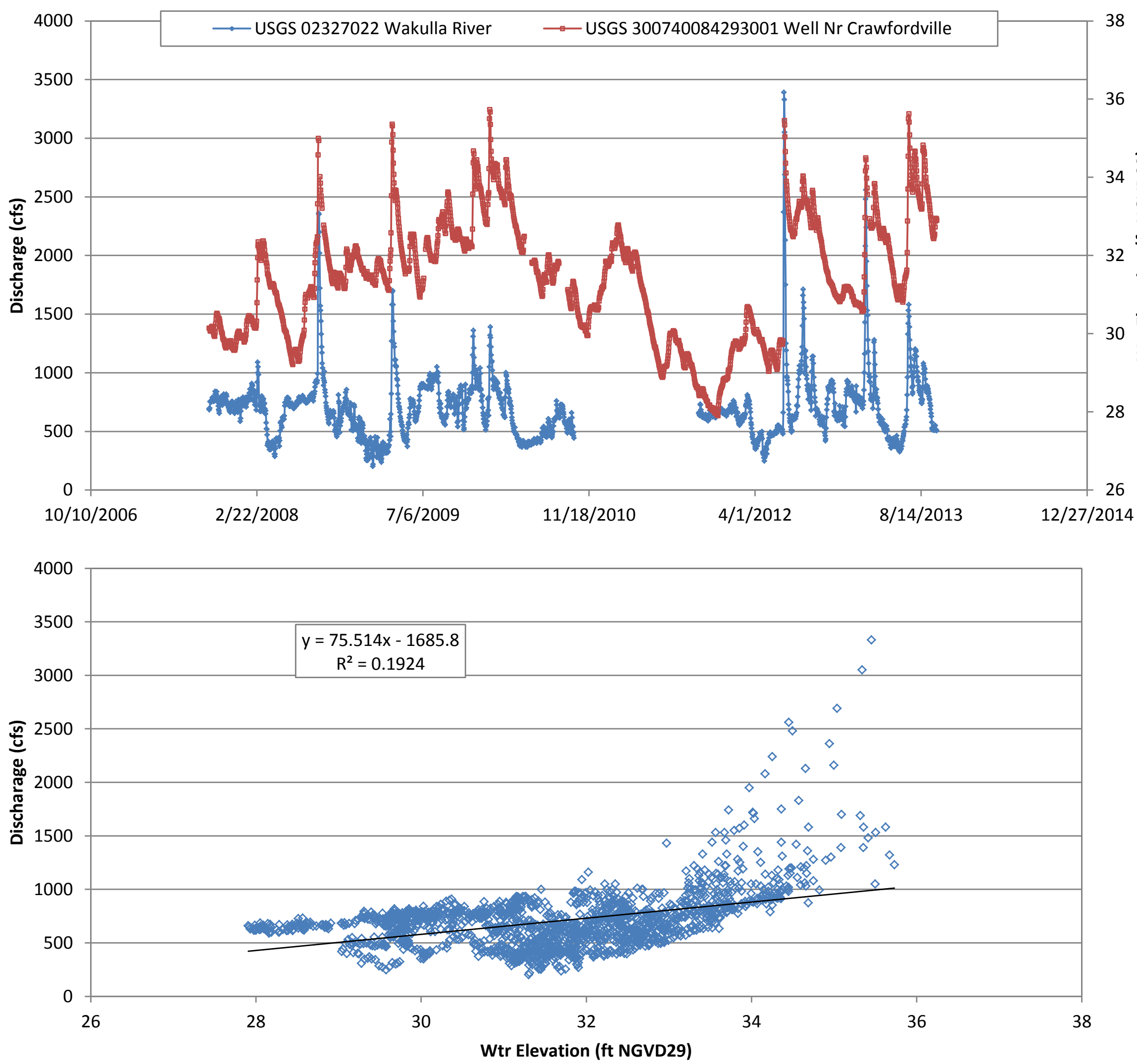


Figure 3-6. Relationship between daily average Wakulla River discharge (SR 365) and area groundwater levels (source USGS)

3.7 Inter-Basin Groundwater Transfers

Springsheds are defined based on potentiometric surfaces in the Floridan Aquifer. As water levels change, boundaries can move for areas contributing to springs. In some cases large withdrawals, or significant changes in rainfall and ET have resulted in springshed boundaries shifting between adjacent Water Management Districts. This has occurred near the Suwannee River in North Florida where areas formerly part of the SRWMD have shifted and are now contributing to the SJRWMD (Grubbs and Crandall 2007).

Knight (2014) provided an estimated water balance for the Florida springs that receive groundwater inflows from the Floridan aquifer. The estimated overall spring water balance indicates that total average recharge to the Floridan aquifer pre-development was about 13.925 billion gallons per day, resulting in an estimated total spring discharge of about 12.29 BGD and about 11.234 BGD through North Florida's springs (Bush and Johnson 1988; Knight 2014). Current average springflow in Florida's 1,000+ springs during the most recent decade (2000-2009) was estimated as 7.153 BGD, for an estimated 36% reduction (Knight 2014). In the Northwest Florida Water Management District the estimated springflow decline was about 16% since the 1930s. Bush and Johnson (1988) reported an average recharge of about 8.79 BGD for the portion of the Floridan aquifer in Florida. These numbers indicate that pre-development, between about 1.7 and 2.444 BGD was entering Florida's springs from groundwater recharge in southern Georgia and Alabama. Under current (2009) conditions it is estimated that the amount of imported groundwater from north of the state line has been significantly reduced.

3.17 Estimated Wakulla Spring Water Balance

As estimated above in the precipitation section, the total net precipitation in the larger Wakulla Springshed delineated by the FGS is about 1,530 MGD (2,375 cfs) or an average of 20" per year. If this larger springshed area is allocated to the three basic land use types described by Barrios (no date) above in Figure 2-8, then the total average annual recharge in the springshed is approximately 344 MGD (532 cfs). This is larger than the estimate by Barrios (no date) and Chelette *et al.* (2002) due to the larger estimated springshed (1,569 mi^2 vs. 1,165 mi^2) and because Chelette *et al.* (2002) prepared their water balance for a period with lower than average precipitation. This is less than one half of the recharge estimate presented above based on data from Bush and Johnston (1988). All of these estimates of groundwater flow to Wakulla Spring are higher than the historical median Wakulla Spring flow, but similar to more recent rising flow rates (see Figure 3-7).

The estimated net consumption of groundwater in the Wakulla Springshed (33 MGD) is about 13% of the average estimated groundwater flow and recharge to Wakulla Spring (255 MGD) estimated by Chelette *et al.* (2002) and 10 percent of the revised inflow estimate. Chelette *et al.* (2002) and Kulakowski (2010) noted significant reductions (up to 16 feet) in groundwater levels measured at the Lake Jackson Floridan Aquifer Monitoring Well and in northern Leon County beginning in the late 1990s. They recorded the lowest levels measured in the Floridan Aquifer for the entire 35 year period-of-record. Additional detailed trend analyses need to be performed for groundwater level data from Floridan wells in Leon County to determine if the net consumption of water estimated above is resulting in significant and continuing declines in the levels in the Floridan Aquifer.

The estimated reduction in average artesian groundwater levels and flow from the north to south is potentially a significant fraction of the total flow feeding Wakulla Spring (Kincaid *et al.* 2010). Chelette *et al.* (2002) noted that small increases in the hydraulic head level of the Floridan Aquifer result in significant increases in discharge at Wakulla Spring. Conversely, small declines in the potentiometric surface in the Floridan Aquifer near the spring are expected to result in significant flow declines. Depending on the delicacy of the “balanced” nature of the factors affecting flows to Wakulla Spring and Springs Creek Springs, this estimated change might provide a partial explanation for increased flows of dark water at Wakulla Spring (Kincaid *et al.* 2010).

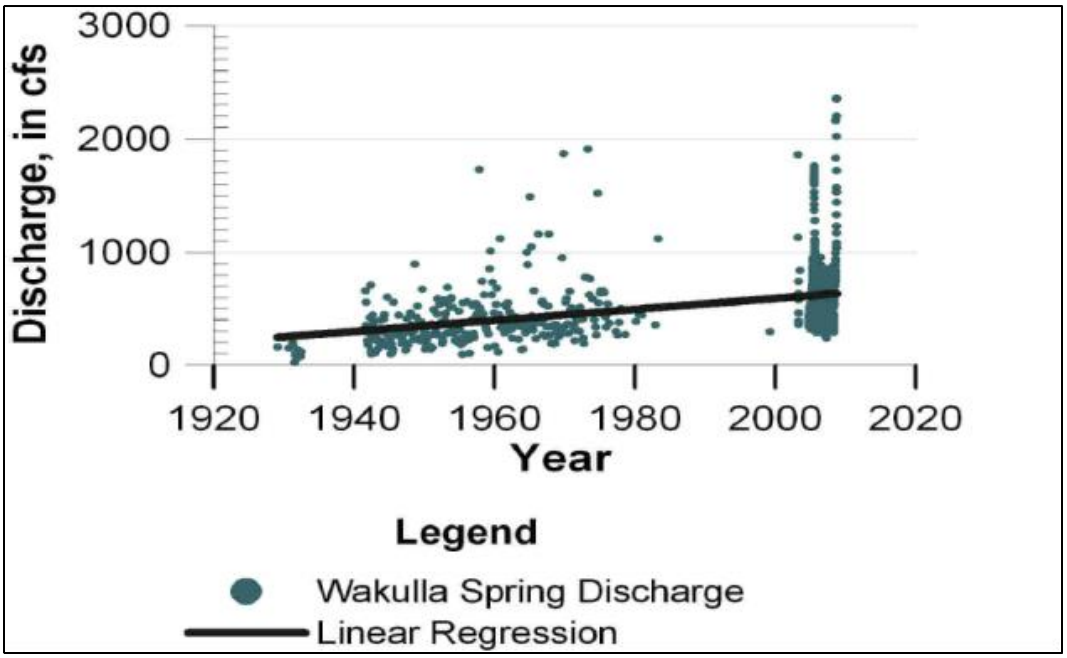


Figure 3-7. Wakulla Spring discharge data for the period-of-record with a linear trend analysis (from Davis 2011).

Due to the inter-connected nature of the limestone “plumbing” that feeds both Wakulla Spring and Springs Creek Springs, there is considerable room for variation for flows at both springs based on the selection of the artificial boundaries used for determining the overall water budget for the area (Kincaid and Meyer 2010). Kincaid *et al.* (2010) have estimated a combined average flow to the two springs of about 400 MGD (619 cfs). As detailed below in a later section, the recent (2004-2009) median discharge at Wakulla spring is about 398 MGD (616 cfs) while Spring Creek Springs are apparently flowing intermittently. Using the recently measured spring flow and the estimate of net groundwater consumption of 22 MGD (34 cfs), the groundwater recharge estimate is 420 MGD (650 cfs), a compromise between the values estimated earlier. The independently estimated inflows and outflows for the current Wakulla Spring water budget are summarized in Figure 3-8.

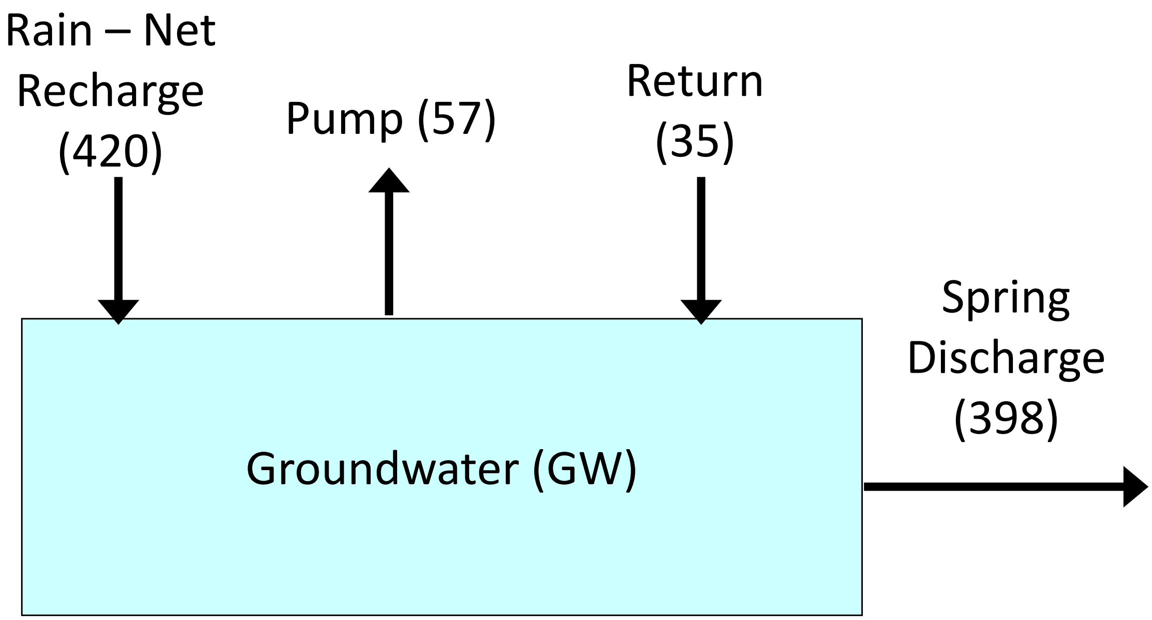


Figure 3-8. Wakulla Spring estimated water balance in million gallons per day. These inputs and outputs include the entire Georgia-Florida springshed and have been independently estimated.

Section 4.0 Water Quality

4.1 General

Water quality data for Wakulla Spring were summarized from STORET (USGS and FDEP data) for the period-of-record from February 1907 to May 2008. Among water chemistry parameters, the numbers of samples collected ranged from 1 to 537 records, with most samples collected from the spring basin area. These data are summarized in Table 4-1 with statistics for the available water quality parameters, as well as decadal averages (if available), and the period-of-record (POR) dates. Wakulla Spring (main vent) POR averages for several key parameters (with number of samples) are:

- Water temperature – 20.7 °C (n = 149)
- Dissolved oxygen – 2.07 mg/L (n = 131)
- pH – 7.51 SU (n = 146)
- Specific conductance – 308 µS/cm (n = 248)
- Turbidity – 0.44 NTU (n = 132)
- Color – 4.16 CPU (n= 108)
- Chlorophyll *a* – 1.63 ug/L (n = 12)
- Total chloride – 8.43 mg/L (n = 204)
- Sulfate – 10.5 mg/L (n = 197)
- Nitrate+nitrite nitrogen – 0.759 mg/L (n = 175)
- Total nitrogen – 0.750 mg/L (n = 365)
- Total phosphorus – 0.03 mg/L (n = 537)

The water temperature at Wakulla Spring averaged about 20.7 ^{o}C. Dissolved oxygen is low in the spring, averaging 2.07 mg/L and 34.5 percent of saturation. The water is slightly basic with a pH of 7.51 s.u. Specific conductance averaged 308 µS/cm with a range from 211 to 430 µS/cm. Average turbidity is low at 0.44 NTU with an observed range from 0 to 6 NTU. Chlorophyll *a* in the vicinity of the spring vent averaged 1.63 ug/L with a range from 1.0 to 5.3 ug/L. Average color is also relatively low at 4.16 CPU but ranges from 0 to 40 CPU, indicating inputs of tannic surface waters. Total chloride averaged 8.43 mg/L and sulfate averaged 10.5 mg/L.

Based on data from EPA's STORET database, the long-term average nitrate+nitrite nitrogen (NO_x-N) concentration in Wakulla Spring is 0.76 mg/L with a range of reported values from 0.06 to 9.8 mg/L. However, Wakulla Spring has experienced a significant increase in nitrate concentrations over the entire period-of-record. Gilbert (2010) reports nitrate concentrations less than 0.05 mg/L between 1956 and 1973. Nitrate concentrations at Wakulla Spring increased significantly from the mid-1970s to the early 1990s and have decreased slightly since then (Figure 4-2, Chelette *et al.* 2002). Based on data from 1971 through 1977, the median nitrate concentration was 0.26 mg-N/L (n=22), while data from 1989 through 2000, had a median nitrate concentration of 0.89 mg-N/L (n=26), and concentrations appear to have peaked in the late 1980s to early 1990s (Chelette *et al.* 2002; Gilbert 2012).

The concentrations of total and ortho-phosphorus at Wakulla Spring have averaged 0.03 to 0.033 mg/L over the period-of-record. These values are fairly typical of unaltered Floridan Aquifer water and have been consistently low throughout the past 60 years.

Figure 4-1 presents a time series of average daily water temperature and specific conductance collected by the NWFWMD at Wakulla Spring near the boat dock. Based on data from 1999 through 2010, average daily water temperatures ranged from 19.1 °C to 21.7 °C with a median of 20.5 °C. Average daily specific conductance ranged from 247 uS/cm to 557 uS/cm with a median of 317 uS/cm over the same time period. It appears that specific conductance in Wakulla Spring has increased slightly over the period of record, particularly since 2007.

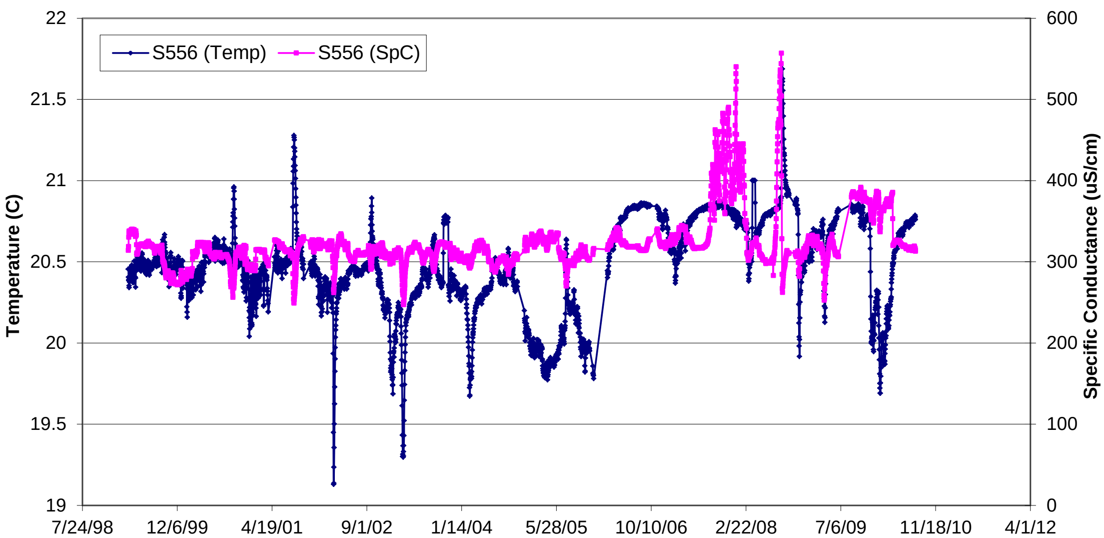


Figure 4-1. Wakulla Spring average daily temperature and specific conductance time series (source NWFWMD).

Table 4-1. Wakulla Spring water quality data for the period-of-record (data from EPA STORET and other public sources)

				Decade											POR Statistics					Period of Record	
PARAMETER GROUP	PARAMETER	UNITS	STATION	1900	1910	1920	1930	1940	1950	1960	1970	1980	1990	2000	Average	Min	Max	StDev	N		
BACTERIOLOGICAL	EColi	#/100ml	Main Boil											27.8	27.8	1.00	190	65.8	8	9/27/2001	11/20/2006
			Spring Run											16.2	16.2	1.00	38.0	12.6	9	11/29/2000	8/23/2006
	Enterococci	#/100ml	Main Boil											2.08	2.08	1.00	18.0	2.47	74	9/27/2001	12/5/2006
			Spring Run											77.1	77.1	1.00	410	113	24	2/28/2000	9/28/2004
	FC	#/100ml	Main Boil											3.75	3.75	1.00	203	19.6	107	9/27/2001	5/27/2008
			Spring Run											124	124	2.00	1,600	256	42	2/28/2000	12/6/2006
	TC	#/100ml	Main Boil											33.8	33.8	1.00	1,800	182	109	9/27/2001	5/27/2008
			Spring Run											367	367	23.0	3,300	633	44	2/28/2000	12/6/2006
BIOLOGICAL	Chl-a corr	µg/L	Main Boil											1.63	1.63	1.00	5.30	1.31	12	4/10/2006	11/28/2006
			Spring Run											1.74	1.74	0.850	6.40	1.33	21	9/28/2004	12/6/2006
	Pheo-a	µg/L	Main Boil											3.68	3.68	1.00	23.0	6.22	12	4/10/2006	11/28/2006
			Spring Run											3.47	3.47	0.850	17.0	3.75	21	9/28/2004	12/6/2006
DISSOLVED OXYGEN	DO	%	Main Boil							53.0	28.6			34.0	34.5	16.0	73.0	18.4	15	6/1/1967	7/13/2006
	DO	mg/L	Main Boil							4.63	2.53	1.30	1.77	1.98	2.07	0.590	6.20	0.879	131	6/1/1967	5/27/2008
			Spring Run											6.25	6.25	2.43	11.4	2.16	45	2/28/2000	12/6/2006
FLOW	Flow	cfs	Main Boil						282	294	386			385	349	188	800	151	13	5/12/1954	8/2/2004
			Spring Run											614	614	182	2,360	214	1621	10/22/2004	3/30/2009
	Flow-Inst	cfs	Main Boil	847	532	163	117	309	393	454	514	519	296	741.82	429	25.0	1,910	305	324	2/1/1907	11/19/2007
	Velocity	ft/s	Spring Run											0.690	0.690	0.220	1.41	0.206	1595	10/22/2004	3/30/2009
GENERAL INORGANIC	Alk	mg/L as CaCO3	Main Boil						121	121	121			137	131	1.00	153	18.1	80	5/12/1954	5/27/2008
			Spring Run											132	132	130	140	3.66	20	4/10/2006	12/6/2006
	Cl-T	mg/L	Main Boil						3.00	6.25	5.85	5.40	8.03	8.91	8.43	0.020	45.0	3.79	204	5/12/1954	5/27/2008
			Spring Run											9.53	9.53	7.40	13.0	2.07	20	4/10/2006	12/6/2006
	CO2	mg/L	Main Boil						9.40	5.53	5.79	5.90			5.88	1.10	30.0	5.46	28	5/12/1954	2/11/1985
	F-D	mg/L	Main Boil						0.200	0.275	0.278	0.200	0.170	0.145	0.199	0.100	0.700	0.096	57	5/12/1954	5/27/2008
	F-T	mg/L	Main Boil											0.141	0.141	0.100	0.160	0.011	41	9/27/2001	5/27/2008
	Hardness	mg/L as CaCO3	Main Boil						140	133	132	140	147	142	135	120	150	7.75	36	5/12/1954	7/13/2006
	Si-D	mg/L	Main Boil						12.0	12.0	10.6	12.0	11.3	10.7	11.0	8.20	13.0	0.881	32	5/12/1954	7/13/2006
	SO4	mg/L	Main Boil						22.0	9.65	10.1	9.40	9.67	10.5	10.5	0.060	22.0	1.70	197	5/12/1954	5/27/2008
			Spring Run											11.2	11.2	9.60	13.0	0.972	20	4/10/2006	12/6/2006
GENERAL ORGANIC	DOC	mg/L	Main Boil										0.133	1.30	0.863	0.100	3.70	1.19	8	7/31/1997	7/13/2006
	TOC	mg/L	Main Boil								4.90			0.954	1.59	0.00	33.0	3.51	125	5/4/1970	5/27/2008
			Spring Run											0.849	0.849	0.110	4.00	0.793	26	2/28/2000	12/6/2006

Table 4-1. Wakulla Spring water quality data for the period-of-record (data from EPA STORET and other public sources)

				Decade											POR Statistics						
PARAMETER GROUP	PARAMETER	UNITS	STATION	1900	1910	1920	1930	1940	1950	1960	1970	1980	1990	2000	Average	Min	Max	StDev	N	Period of Record	
METAL	Ag-T	µg/L	Main Boil									1.00		0.080	0.157	0.080	1.00	0.266	12	2/11/1985	11/28/2006
	Al-D	µg/L	Main Boil								74.5				74.5	9.00	140	92.6	2	9/2/1970	1/16/1975
	Al-T	µg/L	Main Boil								100			11.2	21.8	0.00	200	38.6	42	5/4/1970	4/25/2005
	As-D	µg/L	Main Boil								2.44	1.00			2.30	0.00	10.0	3.09	10	5/4/1970	2/11/1985
	As-T	µg/L	Main Boil								3.63			3.87	3.84	0.00	22.0	3.25	58	4/25/1972	11/28/2006
	Ba-T	µg/L	Main Boil									100		9.91	12.2	8.20	100	14.4	39	2/11/1985	4/25/2005
	Ca-D	mg/L	Main Boil						39.0	37.5	37.9	39.0	42.3	44.1	41.8	32.0	50.9	3.65	78	5/12/1954	5/27/2008
	Ca-T	mg/L	Main Boil											44.5	44.5	0.160	62.0	4.30	166	9/27/2001	5/27/2008
			Spring Run											44.2	44.2	41.0	49.0	2.28	20	4/10/2006	12/6/2006
	Cd-D	µg/L	Main Boil								0.00				0.00	0.00	0.00	0.00	2	4/28/1971	1/16/1975
	Cd-T	µg/L	Main Boil								1.33	1.00		0.397	0.461	0.00	2.00	0.387	53	4/25/1972	11/28/2006
	Co-D	µg/L	Main Boil								0.00				0.00	0.00	0.00		1	4/28/1971	1/16/1975
	Co-T	µg/L	Main Boil								0.00			1.48	1.40	0.00	2.00	0.697	39	4/25/1972	4/25/2005
	Cr-T	µg/L	Main Boil								3.00	1.00		1.56	1.66	0.00	10.0	1.32	54	5/4/1970	11/28/2006
	Cu-D	µg/L	Main Boil								10.7				10.7	0.00	40.0	15.0	6	5/4/1970	4/28/1977
	Cu-T	µg/L	Main Boil								5.50	1.00		2.76	2.93	0.00	20.0	2.84	54	4/25/1972	11/28/2006
	Fe-D	µg/L	Main Boil						40.0	5.00	29.4				25.5	0.00	210	43.5	22	5/12/1954	4/28/1977
	Fe-T	µg/L	Main Boil						40.0		53.3			20.9	26.1	2.50	260	42.6	60	5/12/1954	11/28/2006
	Hg-D	µg/L	Main Boil								0.500				0.500	0.500	0.500		1	1/16/1975	1/16/1975
	Hg-T	µg/L	Main Boil								0.350	0.200			0.336	0.00	0.500	0.234	11	4/28/1971	2/11/1985
	K-D	mg/L	Main Boil							0.400	0.533	0.600	0.567	0.667	0.598	0.300	1.11	0.143	58	5/19/1966	5/27/2008
	K-T	mg/L	Main Boil											0.605	0.605	0.050	1.19	0.102	166	9/27/2001	5/27/2008
			Spring Run											0.619	0.619	0.520	0.770	0.080	20	4/10/2006	12/6/2006
	Mg-D	mg/L	Main Boil						9.40	9.23	9.03	9.20	9.50	10.2	9.76	7.60	12.0	0.918	78	5/12/1954	5/27/2008
	Mg-T	mg/L	Main Boil											10.2	10.2	0.020	13.9	1.12	166	9/27/2001	5/27/2008
			Spring Run											9.61	9.61	9.00	11.0	0.454	20	4/10/2006	12/6/2006
	Mn-D	µg/L	Main Boil							0.00	8.00				7.06	0.00	20.0	5.88	17	6/1/1967	4/28/1977
	Mn-T	µg/L	Main Boil								14.3			0.710	2.73	0.200	40.0	6.40	47	4/25/1972	4/25/2005
	Mo-D	µg/L	Main Boil								1.00				1.00	1.00	1.00		1	1/16/1975	1/16/1975
	Mo-T	µg/L	Main Boil								1.00				1.00	1.00	1.00		1	6/27/1973	6/27/1973
	NA-D	mg/L	Main Boil						6.00	3.60	4.03	3.60	5.97	6.39	5.49	3.40	23.0	2.95	80	5/12/1954	5/27/2008
	NA-T	%	Main Boil							5.67	6.19	5.00	8.00	7.40	6.45	5.00	9.00	0.971	33	5/19/1966	7/13/2006
	NA-T	mg/L	Main Boil											7.44	7.44	4.94	21.2	4.41	25	2/28/2007	5/27/2008
	Ni-T	µg/L	Main Boil											1.38	1.38	0.180	3.00	0.750	49	6/27/1973	11/28/2006
	Pb-D	µg/L	Main Boil								1.50				1.50	0.00	2.00	1.00	4	5/4/1970	4/28/1977
	Pb-T	µg/L	Main Boil									1.00		2.37	2.35	0.025	5.50	2.16	50	4/25/1972	11/28/2006
	SAR	ratio	Main Boil						0.200	0.100	0.168	0.100	0.200	0.200	0.167	0.100	0.200	0.048	36	5/12/1954	7/13/2006
	Se-D	µg/L	Main Boil									1.00			1.00	1.00	1.00		1	2/11/1985	2/11/1985
	Se-T	µg/L	Main Boil											6.30	6.30	1.75	22.0	3.36	38	9/27/2001	4/25/2005
	SR-D	µg/L	Main Boil							45.0	107	110	86.0		99.3	0.00	160	43.7	19	6/1/1967	10/8/1997
	SR-T	µg/L	Main Boil											95.2	95.2	83.8	109	6.36	40	9/27/2001	4/25/2005
	V-D	µg/L	Main Boil								3.00				3.00	3.00	3.00		1	1/16/1975	1/16/1975
	Zn-D	µg/L	Main Boil								48.2				48.2	20.0	230	61.1	11	5/4/1970	4/28/1977
	Zn-T	µg/L	Main Boil								15.0			4.67	5.45	0.00	20.0	4.56	53	4/25/1972	11/28/2006

Table 4-1. Wakulla Spring water quality data for the period-of-record (data from EPA STORET and other public sources)

				Decade											POR Statistics					Period of Record	
PARAMETER GROUP	PARAMETER	UNITS	STATION	1900	1910	1920	1930	1940	1950	1960	1970	1980	1990	2000	Average	Min	Max	StDev	N		
NITROGEN	NH4-N	mg/L	Main Boil								0.020	0.020		0.009	0.010	0.00	0.120	0.010	170	9/21/1971	5/27/2008
			Spring Run											0.012	0.012	0.005	0.038	0.006	24	2/28/2000	9/28/2004
	NO2-N	mg/L	Main Boil								0.007	0.010			0.007	0.00	0.020	0.005	19	3/16/1972	2/11/1985
	NO3-N	mg/L	Main Boil								0.259				0.259	0.100	0.330	0.055	18	3/16/1972	4/28/1977
	NOx-N	mg/L	Main Boil								0.283	0.550		0.786	0.759	0.058	9.80	0.719	175	8/28/1974	5/27/2008
			Spring Run											1.33	1.33	0.067	33.0	4.78	46	2/28/2000	12/6/2006
	NOx-N-D	mg/L	Main Boil								0.321		0.837	0.717	0.716	0.321	1.10	0.218	34	6/26/1974	5/27/2008
	OrgN	mg/L	Main Boil								0.149	0.080			0.146	0.00	0.550	0.171	22	5/4/1970	2/11/1985
	TKN	mg/L	Main Boil								0.030	0.100		0.073	0.071	0.010	0.760	0.066	144	8/28/1974	5/27/2008
			Spring Run											0.097	0.097	0.060	0.340	0.055	44	2/28/2000	12/6/2006
	TKN-D	mg/L	Main Boil								0.030		0.200	0.069	0.079	0.030	0.200	0.062	34	6/26/1974	5/27/2008
	TN	mg/L	Main Boil								0.328	0.650	0.814	0.750	0.750	0.00	0,001	0.181	365	5/9/1974	2/27/2006
OXYGEN DEMAND	BOD5	mg/L	Main Boil								0.360			3.29	1.77	0.00	13.0	2.86	29	5/4/1970	11/28/2006
			Spring Run											2.29	2.29	2.00	7.70	1.27	20	4/10/2006	12/6/2006
	COD	mg/L	Main Boil								6.50				6.50	0.00	15.0	5.66	8	4/25/1973	1/16/1975
PESTICIDE	Diazinon-D	µg/L	Main Boil											0.500	0.500	0.500	0.500		1	10/22/2001	10/22/2001
PHOSPHORUS	OrthoP	mg/L	Main Boil						0.030		0.047	0.030	0.033	0.029	0.033	0.012	0.060	0.009	111	5/12/1954	5/27/2008
			Spring Run											0.026	0.026	0.011	0.038	0.006	24	2/28/2000	1/31/2002
	PO4-T	mg/L as PO4	Main Boil							0.070	0.141		0.102	0.094	0.112	0.010	0.190	0.050	17	5/19/1966	7/13/2006
	TDP	mg/L	Main Boil								0.056			0.030	0.032	0.025	0.070	0.008	44	12/21/1973	5/27/2008
	TP	mg/L	Main Boil								0.077	0.050	0.029	0.029	0.030	0.00	0.400	0.018	537	4/25/1972	5/27/2008
			Spring Run											0.033	0.033	0.002	0.093	0.013	46	2/28/2000	12/6/2006
PHYSICAL	Color	CPU	Main Boil							1.25	6.88	5.00		3.75	4.16	0.00	40.0	6.19	108	5/19/1966	12/5/2006
			Spring Run											5.48	5.48	5.00	15.0	2.18	21	9/28/2004	12/6/2006
	Depth	m	Main Boil											39.2	39.2	0.00	92.1	39.5	21	9/27/2001	12/5/2006
			Spring Run											1.29	1.29	0.480	2.25	0.490	19	9/28/2004	12/6/2006
	pH	SU	Main Boil						7.40	7.65	7.73	7.65	7.23	7.46	7.51	6.48	8.30	0.247	146	5/12/1954	5/27/2008
			Spring Run											7.67	7.67	6.30	8.43	0.474	46	2/28/2000	12/6/2006
	Secchi	ft	Main Boil										11.5	10.8	11.0	5.00	20.0	5.19	65	10/29/1996	9/28/2005
	Secchi	m	Main Boil											1.91	1.91	0.00	21.3	5.10	26	7/21/2002	5/27/2008
			Spring Run											0.827	0.827	0.480	1.00	0.300	3	9/28/2004	4/10/2006
	SpCond	umhos/cm	Main Boil						272	266	268	268	275	315	308	211	430	25.7	248	5/12/1954	5/27/2008
			Spring Run											304	304	242	338	18.8	46	2/28/2000	12/6/2006
	Stage	ft	Main Boil		2.95	2.44	2.13	2.73	2.21	2.46	2.18			0.00	2.25	0.00	5.32	0.948	303	2/13/1917	11/29/2007
			Spring Run											3.11	3.11	1.12	6.37	0.685	1598	10/22/2004	3/30/2009
	Turb	NTU	Main Boil								1.57			0.225	0.440	0.00	6.20	0.835	132	9/2/1970	5/27/2008
			Spring Run											0.299	0.299	0.00	0.990	0.217	45	2/28/2000	12/6/2006
SOLID	TDS	mg/L	Main Boil						165	153	155	150	174	174	169	5.00	232	19.2	162	5/12/1954	5/27/2008
			Spring Run											167	167	138	203	12.6	44	2/28/2000	12/6/2006
	TSS	mg/L	Main Boil											3.51	3.51	2.00	23.0	2.16	111	9/27/2001	5/27/2008
			Spring Run											4.95	4.95	4.00	5.00	0.218	21	2/28/2000	12/6/2006
TEMPERATURE	Air Temp	C	Main Boil											25.5	25.5	21.0	30.0	6.36	2	11/3/2005	7/13/2006
	Wtr Temp	C	Main Boil						22.0	22.4	21.0	18.5	21.6	20.6	20.7	16.4	24.0	1.26	149	5/12/1954	5/27/2008
			Spring Run											20.9	20.9	14.2	23.6	1.38	46	2/28/2000	12/6/2006

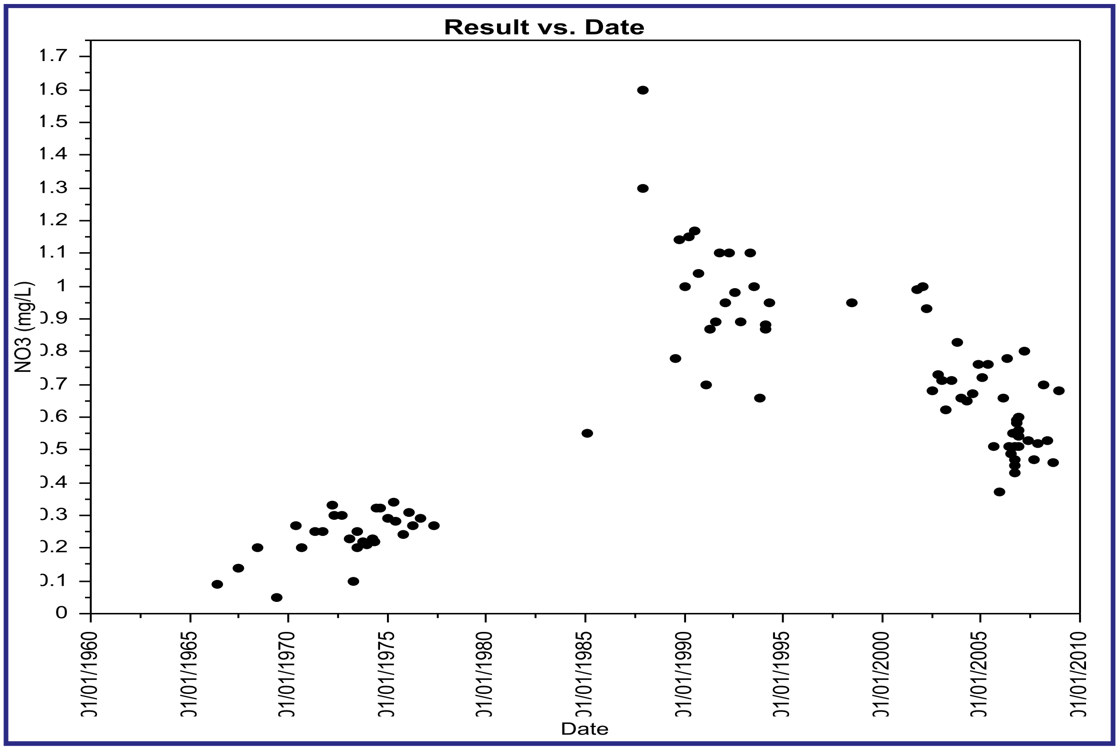


Figure 4-2. Wakulla Spring nitrate-nitrogen concentration time series (from Gilbert 2012).

Wetland Solutions, Inc. (WSI 2010) conducted a whole-ecosystem study of Wakulla Spring and the upper 1 km (0.6 mile) of the Wakulla River between August 2008 and April 2009 (Figure 4-3). During site reconnaissance at Wakulla Spring on August 18, 2008, WSI measured water quality field parameters between 8:30 and 10:00 from above the Wakulla Spring vent downstream to the 1.61 km (1.0 mi) station (Figure 4-4). Temperature over the main boil was about 21 ° C and gradually rose with distance downstream in the spring run (Figure 4-4). Temperatures observed in the lower run of Sally Ward spring were about half a degree (C) higher suggesting a longer travel path from the spring vent. Specific conductance was stable around 510 µS/cm along the spring run, with the exception of the Sally Ward run which had values of about 320 µS/cm (Figure 4-4). Dissolved oxygen concentrations from the main vent were about 1.25 mg/L (15% saturated) and rose with distance downstream to a maximum observed 2.5 mg/L at the 1.61 km station (28% saturated, Figure 4-4). Increased dissolved oxygen concentrations were measured at the confluence of the Sally Ward spring run. Field measured pH from the spring vent was about 7 standard units, rising to 7.5 by about 1 mile downstream (Figure 4-4). Downstream increases in dissolved oxygen and pH likely are in part due to aquatic plant metabolism; while lower pH values from the Sally Ward confluence suggested groundwater inputs.

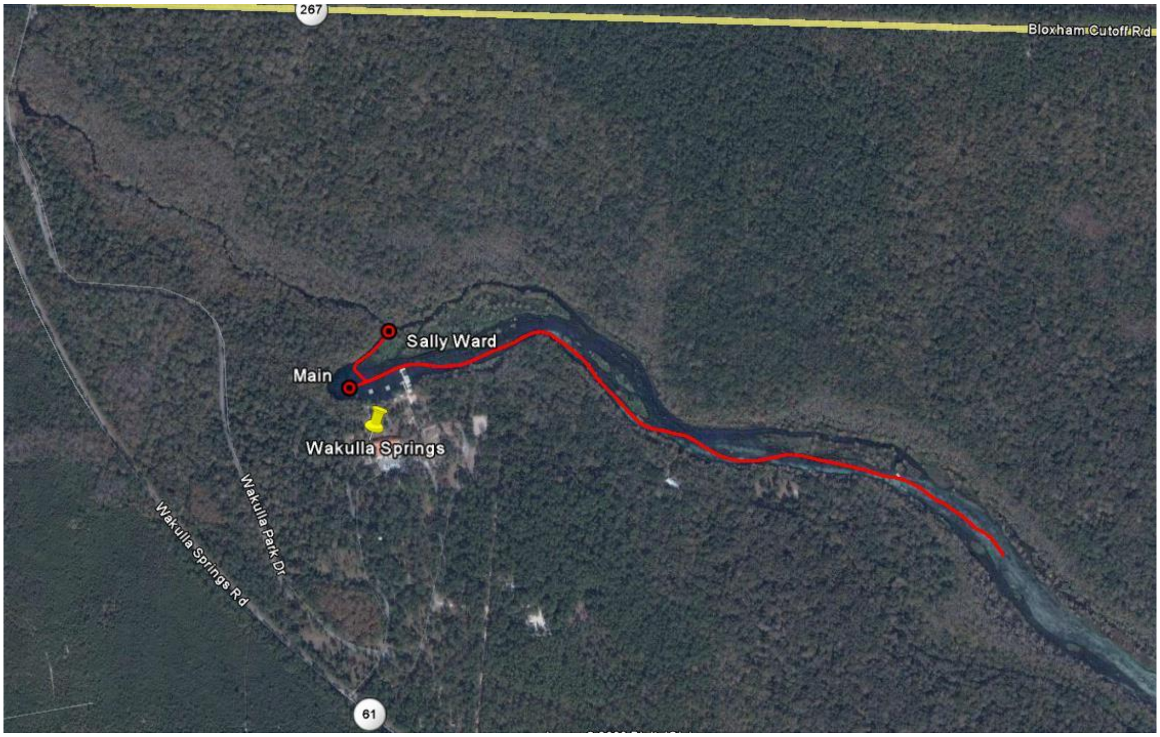


Figure 4-3. Image of Wakulla Springs with red icons and path indicating WSI's reconnaissance sampling locations on August 18, 2008.

4.2 Water Clarity

Water clarity in Wakulla Spring varies greatly in response to inputs of tannin-stained and high chlorophyll surface waters entering swallets in the springshed (Kulakowski 2010; Gilbert 2012). During periods of low rainfall, water clarity may increase, but during periods of greater rainfall and runoff, water clarity declines precipitously due to the influx of dissolved tannic acids (humate substances) and phytoplankton in the spring's source water. During a dark-water period in April 2009, WSI (2010) reported a Secchi disk reading of only 2.8 m in the Wakulla Spring pool. Typical spring pool horizontal Secchi disk readings ranged from 60 to over 100 m in springs not affected by tannic and green water inputs (WSI 2010).

Based on repeated observations over the past ten years, the source water at Wakulla Spring has been observed to change from clear, to green, to brown, to green and back to clear (Robert Thompson, personal communication). The green hue is reported to be a relatively recent phenomenon with historic water clarity impacts due only to the input of tannic waters.

The frequency and duration of tannic and now green water events at Wakulla Spring has increased during the past few decades and has severely hampered the ability of the state park to operate the glass bottom boat tours (Scott Savery, FDEP personal communication). Glass bottom boats are not run when the Secchi depth is less than about 23 m (75 ft.).

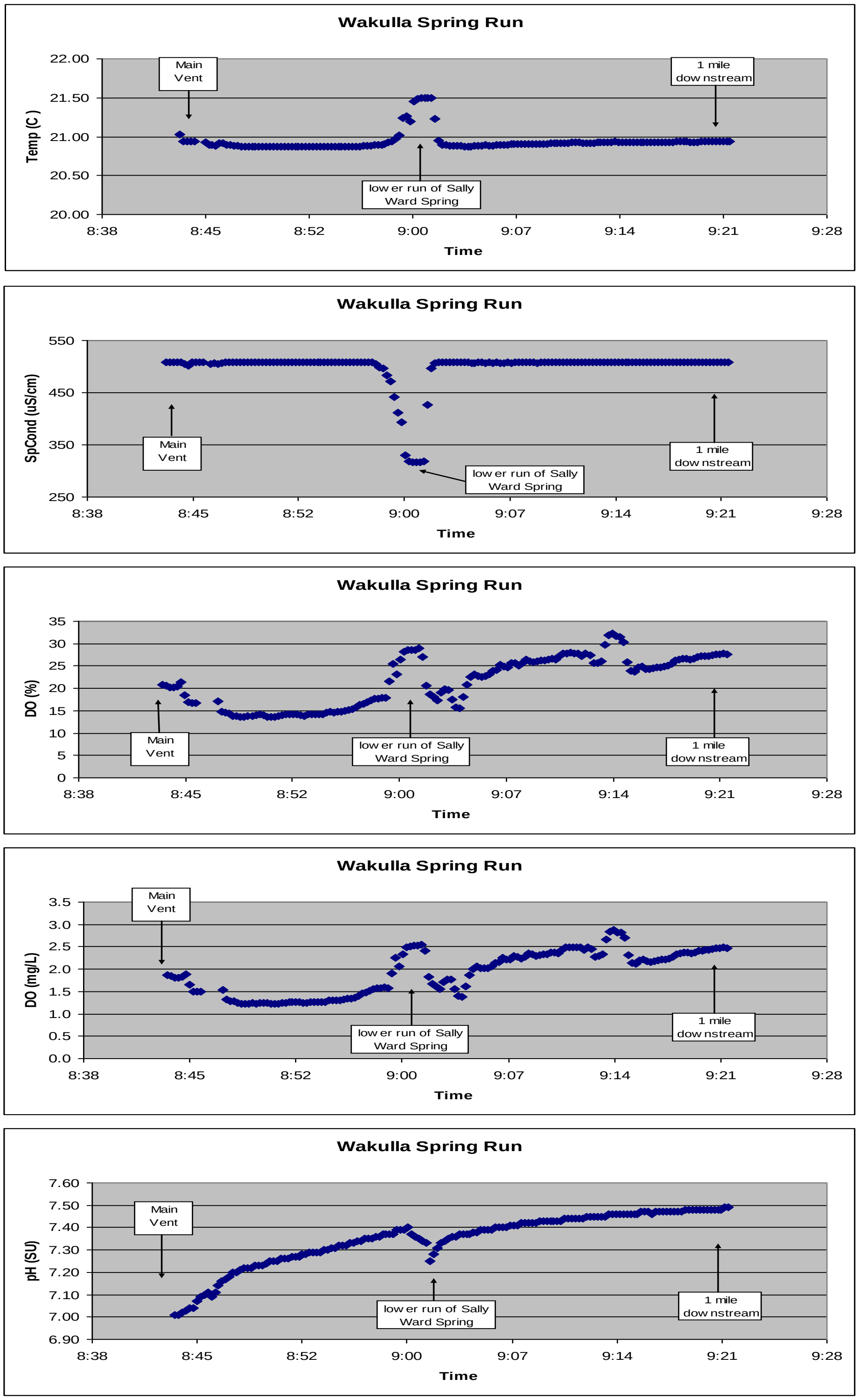


Figure 4-4. Field parameters measured by Wetland Solutions, Inc. at Wakulla Spring on August 18, 2008.

4.3 Nitrate-Nitrogen

Nutrients have been implicated as a source of impairment in numerous water bodies as part of the TMDL process conducted by the FDEP. TMDLs for nutrients have found impairment by nitrate-nitrogen in many spring-based ecosystems including: Silver Springs, the Suwannee and Santa Fe Rivers, the Wekiva River and Rock Springs Run, the Little Wekiva River, Kings Bay springs, and the Upper Wakulla River. The TMDLs are developed to document impairment and the probable sources that contribute to this impairment. The TMDL document is then used to develop a Basin Management Action Plan (BMAP) that can be used to begin corrective actions to meet the TMDL. For the Upper Wakulla River the TMDL implicated nitrate-nitrogen as the source of impairment and established an average monthly target concentration of 0.35 mg/L with a daily maximum of 0.53 mg/L. To meet the TMDL a 56.2% load reduction was recommended (Gilbert 2012).

To better understand the contributions of nitrate-nitrogen several nitrogen mass balances have been developed for Wakulla Springs with varying amounts of overlap. The first nitrogen mass balance was estimated by Chelette *et al.* (2002), a second mass balance was developed by FSI (2011), and the most recent nitrogen mass balance was completed by Eller *et al.* (2013). In their analysis Chelette *et al.* (2002) estimated a total load to the springshed, but did not estimate how much of each contribution reached the spring vent. Each mass balance was developed using slightly different study areas with only the FSI (2011) estimate including any of the Wakulla springshed lying in Georgia (although some portions of the mass balance did not have data available outside of Florida). The most recent mass balance (Eller *et al.* (2013)) represents the most complete nitrogen mass balance to date, except for the exclusion of the Georgia contributions to the springshed.

Each mass balance is discussed in more detail in the subsequent sections with loading broken down by contributing source. Figure 4-5 provides a generalized diagram of the nitrogen cycle in a typical mixed land use environment. The largest external sources of nitrogen in the Wakulla Springshed are atmospheric inputs through rainfall and dryfall (particulates such as ash from forest fires and incinerators), agriculture and livestock contributions, and the use of man-made, nitrogen-containing fertilizers.

4.3.1 Atmospheric

Based on the analysis by Chelette *et al.* (2002), FSI (2011), and by Eller and Katz (2013), atmospheric deposition (wet and dry) contributes a significant nitrogen load to the Wakulla Springshed second only to wastewater treatment facilities (WWTFs). The total atmospheric load to the Wakulla Springshed was estimated based on an areal loading rate and the estimated area lying within the contributing springshed. The annual average total atmospheric load estimate by Chelette et al. (2002) was 256 tons-TN/yr, 6,800 tons-TN/yr by FSI (2011), and 1,058 tons-TN/yr by Eller and Katz (2013).

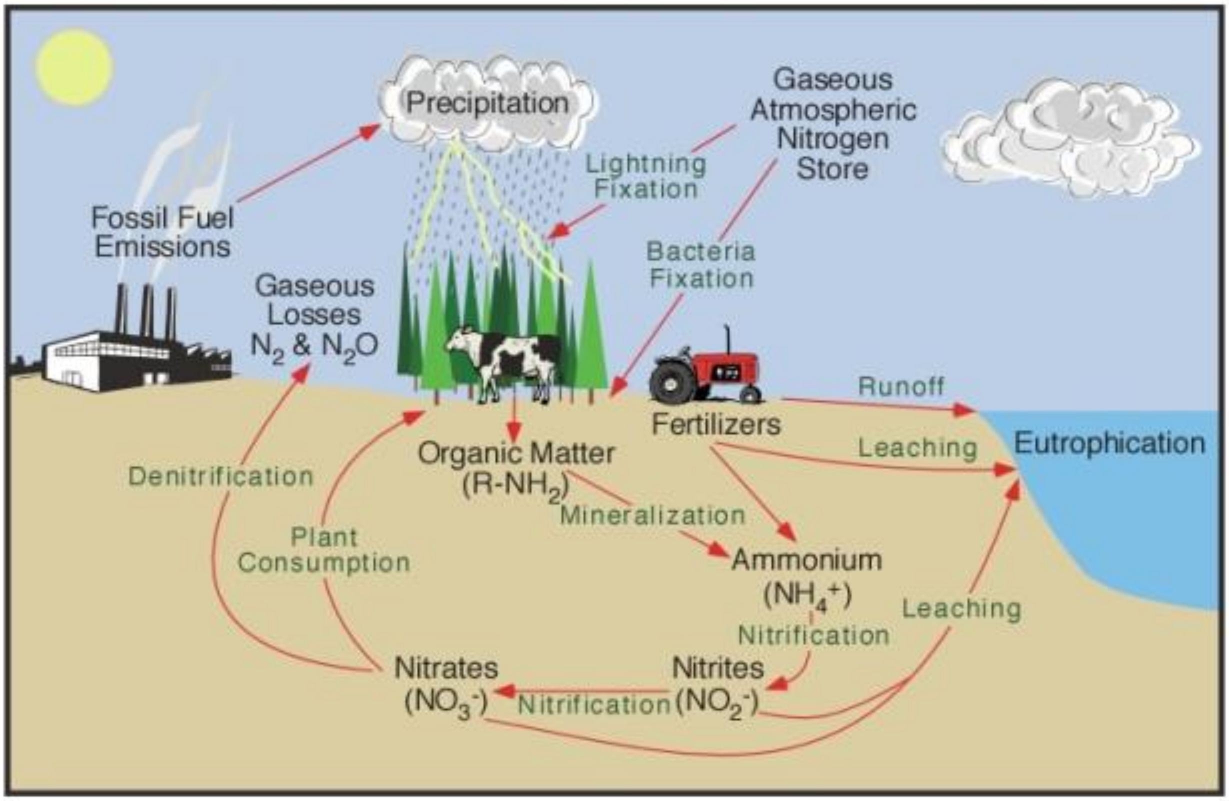


Figure 4-5. Typical nitrogen cycle in a mixed agricultural/urban landscape.

One reason for these differences is the springshed area considered in the three analyses. Eller and Katz (2013) only consider the nitrogen loads on the Florida portion of the Wakulla springshed (about 848,000 acres) while FSI (2011) evaluated the entire springshed into Georgia with a combined area of at least 1,004,160 acres.

FSI (2011) estimated that only a small fraction of this load as remaining within the springshed with the remainder running off or being removed by biologic processes. FSI (2011) estimated that pre-development only 51 tons-TN/yr reached the spring vent. Under existing developed conditions with increased imperviousness and less biological removal it was estimated that 116 tons-TN/yr of atmospheric nitrogen currently reach the spring vent. This estimated increase in nitrogen load alone was expected to raise the ambient total nitrogen concentration at Wakulla Spring from about 0.15 mg/L to about 0.34 mg/L and nitrate-nitrogen from about 0.05 to about 0.11 mg/L (FSI 2011).

In the study by Eller *et al.* (2013), both wet and dry deposition values were obtained for sites within the vicinity of the springshed. Additionally the Wakulla Springshed was fractionated based on the underlying recharge capacity as shown in Figure 4-6. An attenuation rate of 90% was estimated for atmospheric inputs for an estimated total input of 49 tons-TN/yr reaching the Floridan Aquifer System.

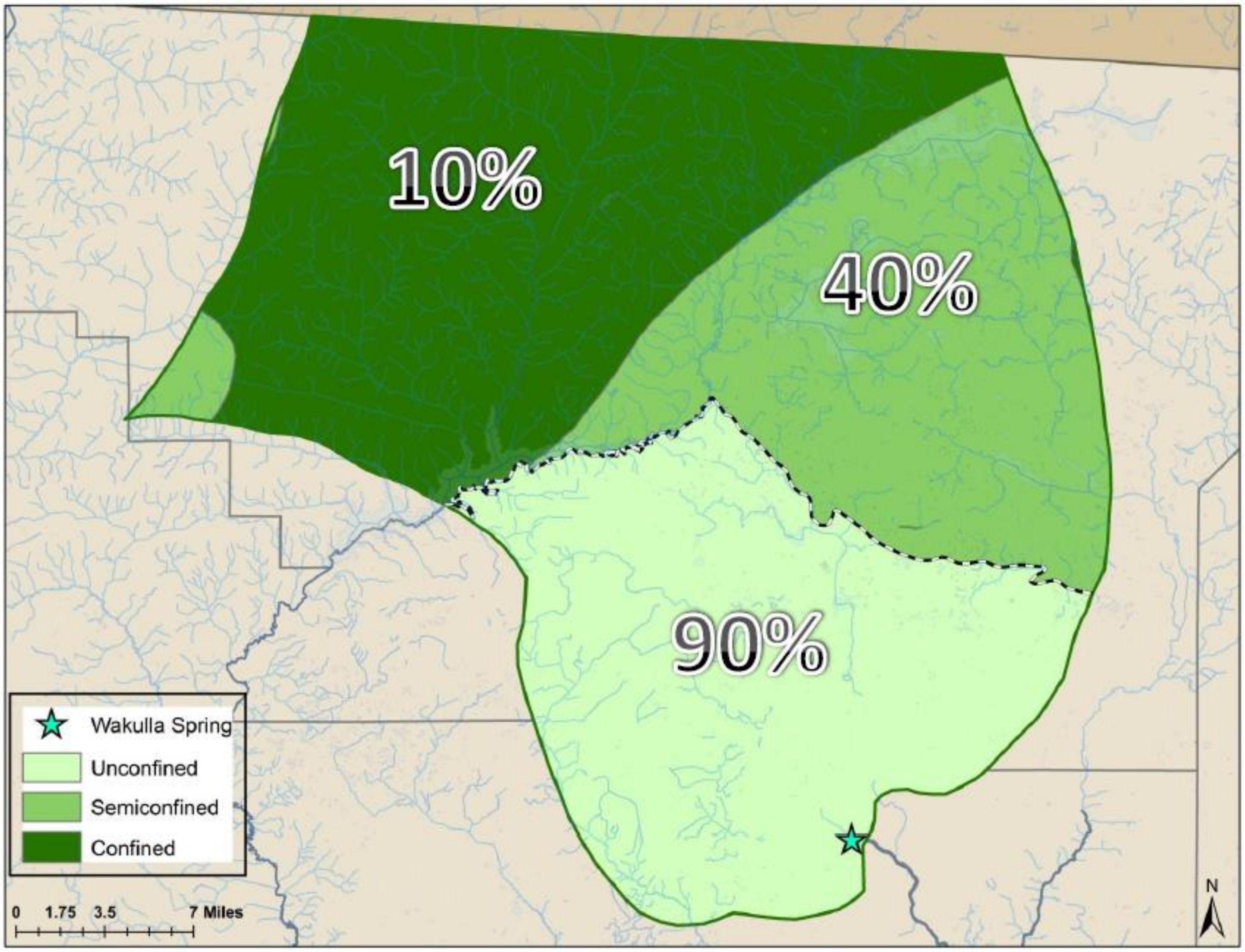


Figure 4-6. Confinement of the Floridan Aquifer within the project limits of the Eller and Katz (2013) study with estimated recharge percentages (Eller and Katz 2013)

4.3.2 Fertilizer

Chelette *et al.* (2002) developed an estimate of the fertilizer inputs to the springshed based on two data sources: the Florida Department of Agriculture and Consumer Services (FDACS) fertilizer sales and the Tallahassee Southeast Farm Sprayfield fertilizer use. Wakulla County was estimated by determining the percentage of the county within the springshed and weighting the FDACS 1990-99 fertilizer sales by the portion of the county within the springshed. Fertilizer inputs for Leon County were estimated based only on the Tallahassee Southeast Farm Sprayfield use. The average total fertilizer use was estimated as 66 tons-TN/yr.

The FSI (2011) mass balance used total fertilizer sales for Florida by county from the FDACS for the period from 1997 through 2010. Similar data were not available for the South Georgia counties in the springshed. The simplifying assumption was made by FSI that all of the fertilizer sold in these four counties is used in the county and that it is evenly distributed across the county. The approximate fertilizer load of total nitrogen (TN) for the springshed was about 1,500 tons-TN/yr assuming that the Georgia counties applied the same rate of fertilizer per land area. It was estimated that only 33% of the fertilizer was used in areas that were likely to recharge and that the remaining 510 tons-TN/yr was reduced by about 75% through plant uptake and denitrification. This resulted in an estimated total TN load from fertilizer entering the Floridan Aquifer feeding Wakulla Spring of 128 tons-TN/yr. The contribution of this nitrogen load to the nitrate concentration in the Floridan Aquifer using this set of assumptions was about 0.33 mg/L.

Eller and Katz (2013) estimated the fertilizer inputs for both agriculture and urban land uses. This was determined based on fertilizer sales and the calculation of the percentage of nitrogen in the fertilizer sold. This was then used with an estimate of total farm and total non-farm (residential) fertilizer application to calculate total nitrogen applied. Land use for the portion of the springshed in Florida was used to develop an estimate of the total land area being fertilized. This calculation resulted in an estimate of 867 tons-TN/yr fertilizer applied with 71% for agricultural purposes. Following and assumed attenuation of 70% for farm fertilizer and 80% for urban fertilizer, and various recharge factors for the confined and unconfined areas, Eller and Katz (2013) estimated that the total nitrogen reaching the Floridan Aquifer from fertilizer use was 47 tons-TN/yr.

4.3.3 Municipal Wastewater and On-Site Disposal Systems

A total of 51 permitted active wastewater treatment and disposal systems were identified by Chelette *et al.* (2002) in Leon and Wakulla Counties. The largest facilities in terms of flow, nitrogen loading, and disposal area belong to the City of Tallahassee (Chelette *et al.* 2002; Carollo Engineers 2008). The City has two wastewater treatment facilities: the Thomas P. Smith Water Reclamation Facility and the Lake Bradford Road Wastewater Treatment Facility with a combined treatment capacity of 31 MGD (48 cfs). Treated effluent from these facilities is disposed of via irrigation at the Southwest Sprayfield located at TPS and the Southeast Farm located along Tram Road. These two sprayfields have a combined permitted capacity of 31.4 MGD (48 cfs). The City can also treat and discharge up to 1.2 MGD (1.9 cfs) of reclaimed water at the Tram Road Reuse Facility.

Chelette *et al.* (2002) estimated a total nitrogen load of about 396 tons-TN/yr from the disposal of wastewater effluent and 143 tons-TN/yr from the disposal of biosolids to the land surface in the portion of the Wakulla Springshed that they evaluated. The total nitrogen load from on-site sewage disposal systems (septic tanks) estimated for the springshed by Chelette *et al.* (2002) was about 62 tons-TN/yr.

The City of Tallahassee recently quantified their average total nitrogen application rates (Oskowis 2010). Actual total nitrogen application rates were 345 tons-TN/yr in 2007, 269 tons-TN/yr in 2008, and 215 tons-TN/yr in 2009, illustrating the declining nitrogen loads resulting from the cessation of fertilization and biosolids disposal (FSI 2011). The average of these values or about 280 tons-TN/yr was used by FSI (2011).

The nitrogen applied to the City of Tallahassee Tram Road Southeast Farm (and formerly biosolids application areas) is partially removed by the crop (hay) and some nitrate may be lost to the atmosphere by denitrification in areas of the site that are saturated long enough to harbor denitrifying bacteria. Katz *et al.* 2009 quantified the changes in the concentration of applied total and nitrate-nitrogen between the Southeast Sprayfield and Wakulla Spring. Their study indicated that the concentration of total nitrogen was reduced by about 70 to 75 percent between the point of land application (about 16 mg/L) and the downgradient monitoring wells (about 5 mg/L). Based on chloride and boron concentrations (relatively inert tracers) about 44 percent of this reduction was due to dilution (no nitrogen mass load reduction) and the remainder was due to other processes (actual nitrogen load reduction, possibly via plant uptake and denitrification). No additional mass reduction was noted between the monitoring wells at the sprayfield and Wakulla Spring; however, dilution further reduced nitrogen concentrations to about 1 mg/L at the spring. Based on these estimates FSI (2011) assumed that about 58% [=1 - (.56*.75)] of the land applied nitrogen reaches the underlying Floridan Aquifer on a mass basis. This is equivalent to about 162 tons-TN/yr. FSI (2011) estimated that approximately 40 percent of the septic tank load described by Chelette *et al.* (2002) reached the Floridan Aquifer, or about 25 tons-TN/yr.

In the most recent nitrogen mass balance by Eller and Katz (2013), total WWTF loading with the City of Tallahassee WWTF upgrades in place was estimated as 81 tons-TN/yr with about 30% or 24 tons-TN/yr reaching the Floridan Aquifer system. The Eller and Katz (2013) estimate for septic tank nitrogen loading is much higher than previous estimates at 678 tons-TN/yr with about 28.4% or 193 tons-TN/yr reaching the Floridan aquifer.

4.3.4 Other Nitrogen Sources

Data from Chelette *et al.* (2002) were also used to roughly quantify the nitrogen contributions in the springshed from sinking streams and livestock. The average total nitrogen load from sinking streams in the springshed was estimated to be 36 tons-TN/yr. The total nitrogen load estimated from livestock was 15 tons-TN/yr.

For the FSI (2011) study, it was estimated that 30 percent of the TN in the sinking streams ends up in the underlying groundwater, about 11 tons-TN/yr. It was estimated that 80 percent of the livestock derived TN is likely lost through plant uptake and denitrification, resulting in an average estimated groundwater load from this source of about 3 tons-TN/yr. FSI (2011) estimated that the average total TN entering the groundwater in the Wakulla Springshed from these additional sources is about 14 tons-TN/yr.

Eller and Katz (2013) also included TN loads for sinking streams and livestock. Sinking stream contributions to the Floridan Aquifer System were estimated based on flow and nutrient concentrations for applicable streams to yield a total contribution of 40 tons-TN/yr. Livestock contributions were calculated based on the Census of Agriculture values for cows and horses and daily TN loading rates of 0.219 and 0.124 kg-TN/day/animal, respectively. This yielded an estimated average total nitrogen contribution to the Floridan aquifer of 27 tons-TN/yr.

4.3.5 Estimated Nitrogen Budget

Table 4-2 compares the three Wakulla Spring nitrogen mass balances described above. Based on the data presented above and the stated assumptions for the three evaluations, the combined total of the annual average estimated nitrogen loads to the groundwater in the Wakulla Springshed for the most recent decade ranges between 292 and 590 tons-TN/yr. These estimates indicate that nitrogen inputs from existing wastewater treatment and disposal practices are no longer the largest nitrogen source to the spring. Septic tanks appear to be contributing the highest fraction of the remaining nitrogen load, with fertilizers (both urban and agricultural), livestock wastes, and sinking streams as additional significant sources of groundwater pollution.

Figure 4-7 provides a decadal summary of documented flows, nitrate N concentrations, and estimated nitrate N loads at Wakulla Spring over the past five decades. These actual data indicate that the nitrate load in the groundwater exiting the spring vent increased from about 50 tons/yr in the 1960s to about 470 tons/yr during the most recent decade, with a peak load of about 670 tons/yr in the 1980s. Recent declines in N concentrations and mass loads over the past two decades have been in part due to dilution due to higher inflows of lower N surface water to Wakulla Spring. Figure 4-8 provides a summary of the estimated nitrogen mass balance described in this report. Assuming the measured nitrogen load at Wakulla Spring since 2000 (about 470 tons/yr) is typical of the period of the estimated inputs, this balance has an estimated error of about 20%.

Table 4-2. Comparison of three estimated total nitrogen source loads in tons per year within the Wakulla springshed and to the Floridan Aquifer System feeding Wakulla Spring. First column is total load to ground surface while second column is the estimated load to the groundwater feeding Wakulla Spring.

Nitrogen Source	Chelette et al. (2002)		FSI (2011)		Eller and Katz (2013)	
Atmospheric Deposition	256	77	6,800	116	1059	49
WWTFs	540	162	280	162	81	24
Septic Tanks	62	18	312	125	678	193
Farm Fertilizer	66	20	1,500	128	618	29
Urban Fertilizer					249	17
Livestock	36	11	173	35	374	27
Sinking Streams	15	5	79	24	56	40
Total	975	292	9,144	590	3,116	381

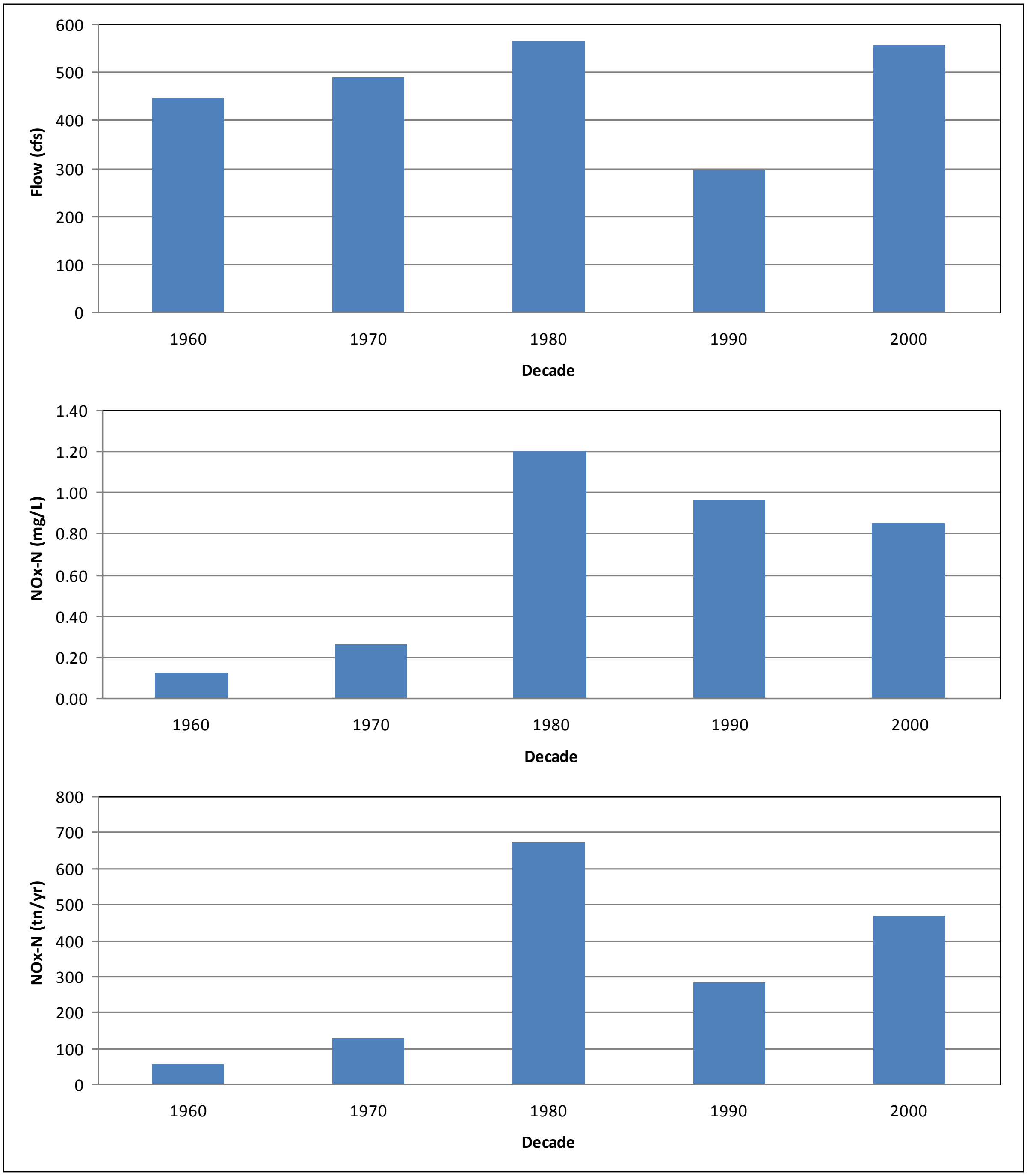


Figure 4-7. Wakulla Springs average discharge, nitrate-nitrogen concentrations, and nitrate-nitrogen loads by decade since 1960.

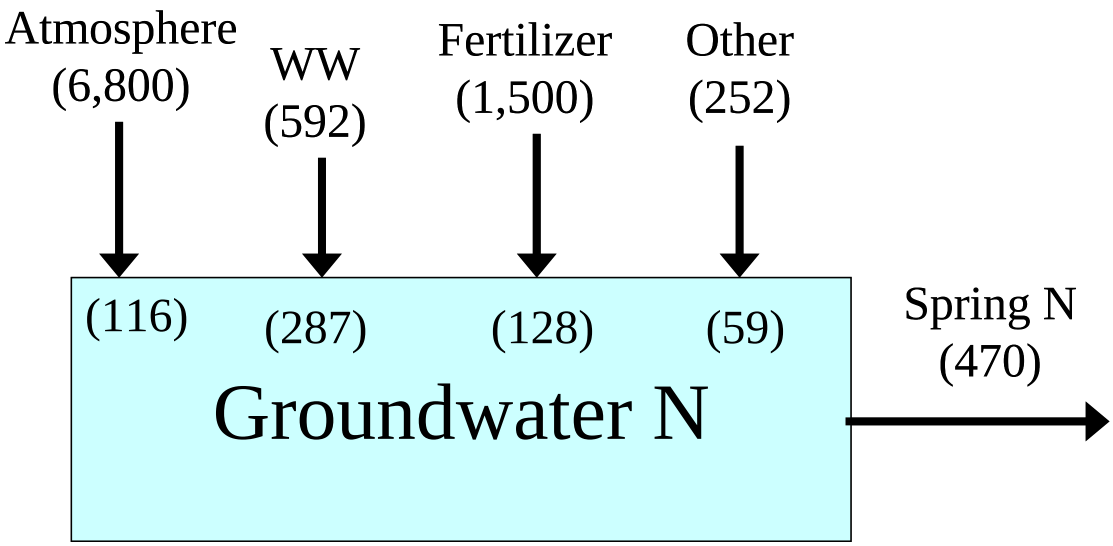


Figure 4-8. Wakulla Spring estimated total nitrogen balance in tons per year (from FSI 2011). These inputs and outputs include the entire Georgia-Florida springshed and have been independently estimated. The approximate error between the estimated inputs and the estimated outputs at Wakulla spring is about 20%.

Section 5.0 Biology

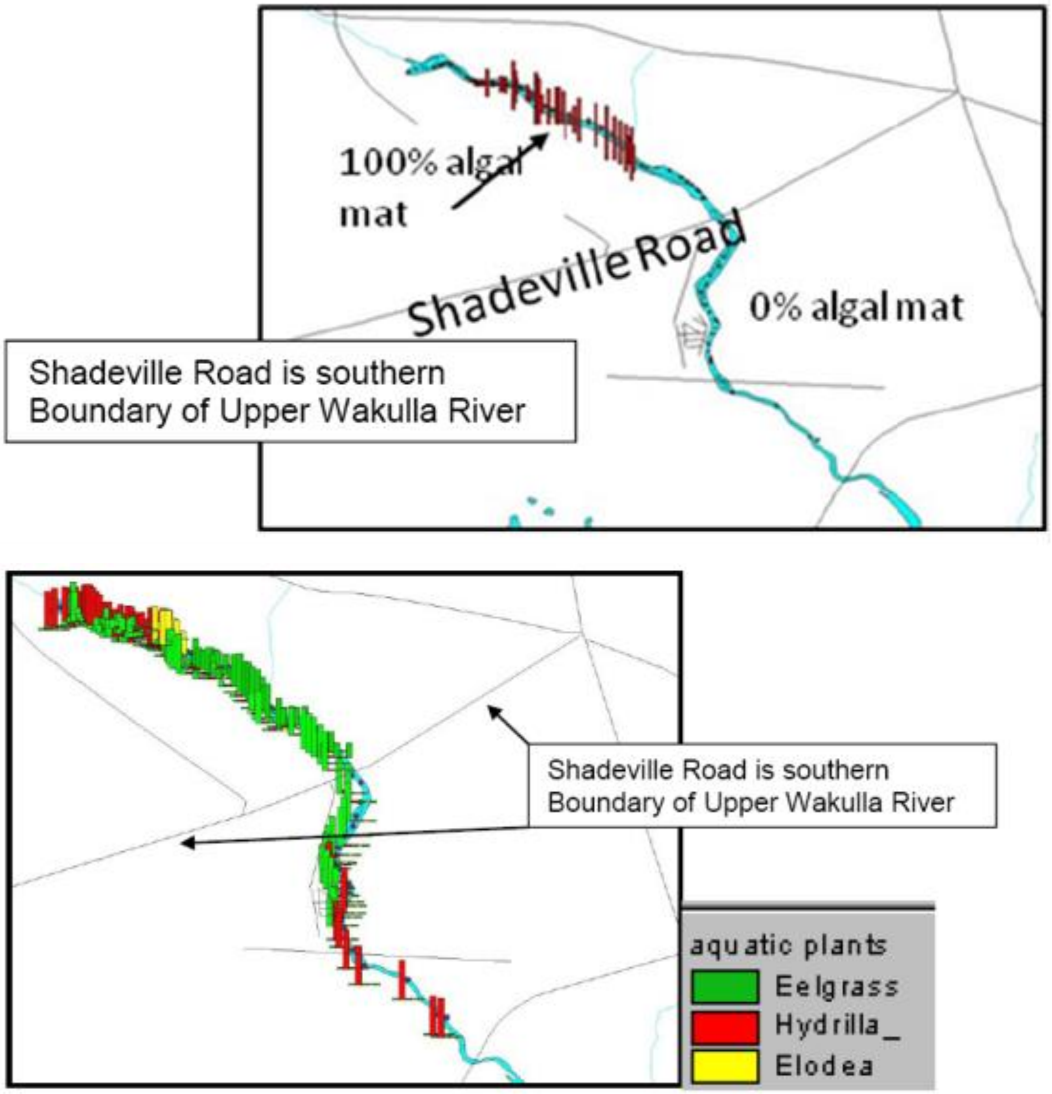
5.1 Vegetation

Increasing algal mats in the Wakulla River were first quantified in 2001 (Gilbert 2012). Figure 5-1 illustrates the occurrence of areas of 100% coverage by filamentous benthic algae using a semi-quantitative, kayak-based, photographic method (Healthy Aquatic Plant Survey, Joe Hand, FDEP, personal communication). Figure 5-1 also illustrates Hand's vegetation cover estimates for native submerged aquatic species including eelgrass (*Vallisneria americana)*, coontail (*Ceratophyllum demersum),* southern naiad *(Najas guadalupensis)*, muskgrass (*Chara* sp.), elodea (*Elodea* sp.), and hydrilla. An apparent relationship between these plant community changes and nitrate-nitrogen was described by Gilbert (2010). Hydrilla and algal mats were generally most prevalent in areas of elevated nitrate concentrations.

As part of a multi-spring macroalgae study, the pool area of Wakulla Spring was sampled during April 8 and October 1, 2003 (Stevenson *et al.* 2007). During the April sampling event, macroalgae coverage was 40.7% with an average thickness of 5 in, while in October the macroalgae coverage was 50.6% with an average thickness of 3.5 in. The average percent cover by species for both sampling events was 40.7% *Vaucheria* sp., 8.7% *Spirogyra* sp., 7.4% *Hydrodictyon* sp., 3.1% *Cladophora glomerata*, 1.9% diatoms, and 1.3% *Rhizoclonium heiroglyphicum* (Stevenson *et al*. 2007).

Submersed aquatic vascular plants were also surveyed by Stevenson *et al.* (2007) during these two sampling events. In April 2003, coverage of these plants was 51.9%, while in October 2003 coverage was 70.4%. Average percent occurrence for both sampling events was 56% hydrilla, 10.5% strap-leaf sagittaria (*Sagittaria kurziana*), and 0.5% southern naiad.

During a reconnaissance trip on August 18, 2008, WSI reported coverage of submersed aquatic vegetation as approximately 50% in the Wakulla Spring run. The most common plants observed were hydrilla and eelgrass, while beds of strap leaved sagittaria, Illinois pondweed (*Potamogeton illinoensis*), and southern naiad were also noted. Several types of filamentous algae (greens and blue-greens) were observed, commonly entangled with rooted and emergent plant material. During a sampling event in April 2009, WSI (2010) reported the coverage of submerged aquatic vegetation, including benthic algae, to be about 35% in the spring pool and 85% in the spring run.



	Mile	Sta	NO_3 (mg/L)	TKN (mg/L)	TP (mg/)	TN (mg/L)
Springhead	0.0	100	0.970	0.060	0.030	1.030
Turnaround	1.0	129	0.510	0.220	0.034	0.730
Upper Bridge	3.2	73	0.240	0.190	0.028	0.430
Above Mysterious Waters	3.9	82	0.230	0.180	0.026	0.410
Below Mysterious Waters	4.9	93	0.170	0.170	0.022	0.340
Lower Bridge	5.9	96	0.110	0.150	0.017	0.260
Salt Spring	5.9	97	0.004	0.180	0.030	0.184

Figure 5-1. Summary of Healthy Aquatic Plant Survey and water quality data conducted by Joe Hand in May and June 2001 in the upper and middle Wakulla River (from Gilbert 2012)

Hydrilla is conspicuously present in the upper Wakulla River, and although observed in 1983 during surveys by FDEP, it was not until the early 1990's that hydrilla abundance had become problematic (Figure 5-2). Aquatic plants in the Wakulla River have been managed by the state through a variety of herbicide applications and mechanical harvesting methods. Gilbert (2010) cited Joe Hand's report that hydrilla coverage declined from 50% in May 2001 to 9% in May 2003 due to herbicide applications. Hand noted that the cover of eelgrass also decreased from 50% to 30% during this period of herbicide use. During the 2006-2007 and 2007-2008 fiscal period, 75 acres of aquatic plants (predominantly hydrilla) were treated with herbicides (FDEP 2007).

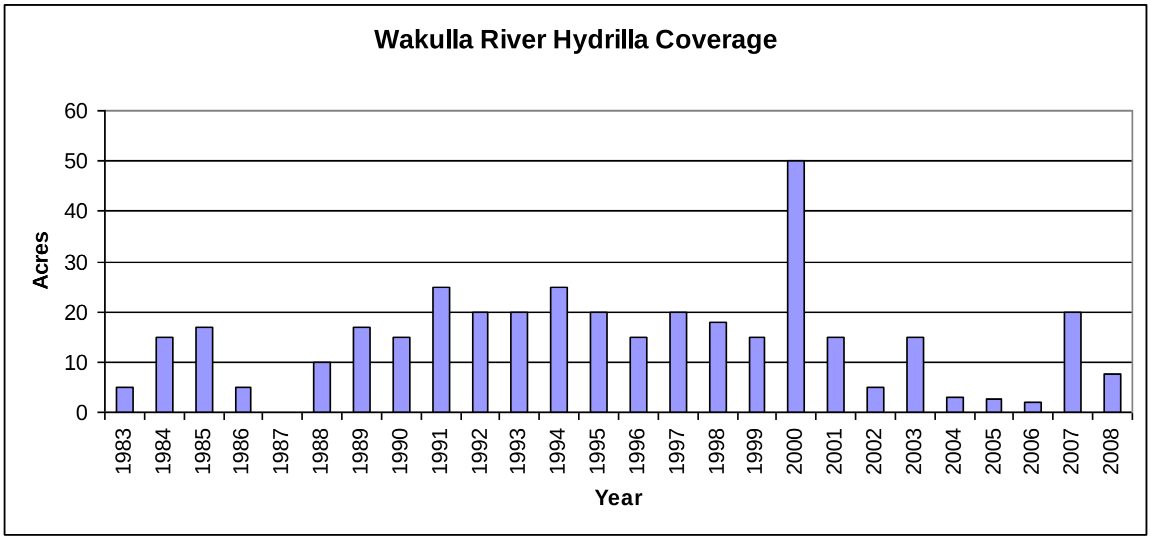


Figure 5-2. Wakulla River hydrilla abundance by year (from FDEP 2007).

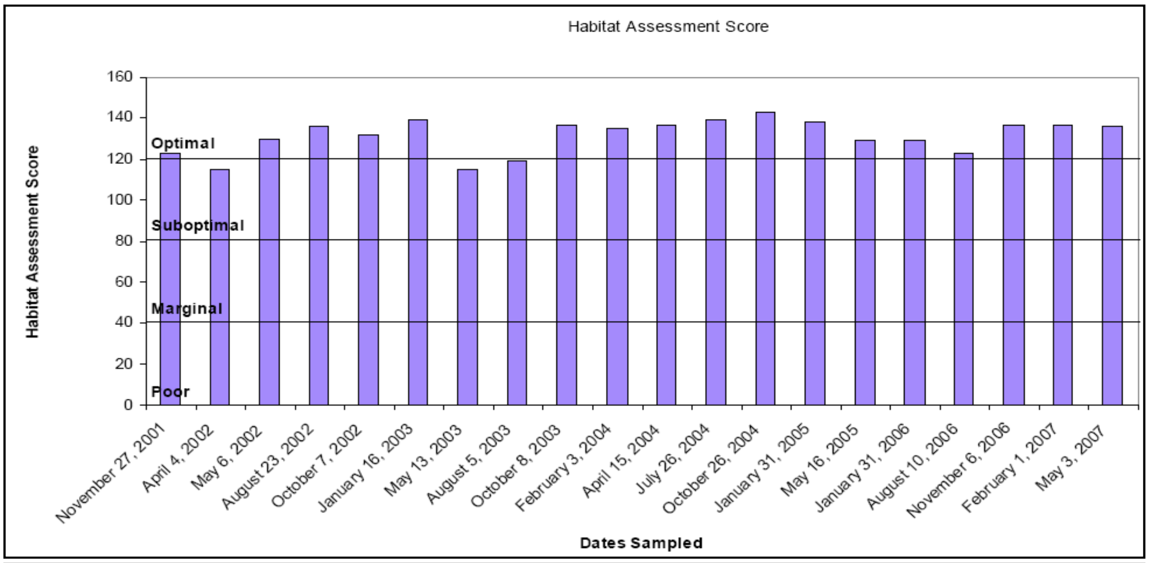
5.2 Macroinvertebrates

The Wakulla River was monitored up to four times a year from 2000 through 2007 as part of FDEP's EcoSummary sampling (FDEP 2008). The monitoring site was a 100 m stretch located in the spring run, approximately 2 miles downstream of the headspring. Results of the monitoring indicated that the habitat assessment rating was usually in the optimal range, the total number of invertebrate taxa ranged from 11 to 28, and the total number of sensitive taxa ranged from one to three (Figure 5-3 and Figure 5-4). The stream condition index (SCI) was re-calibrated in June 2004. Prior to 2004, an SCI greater than 21 indicated healthy conditions, while after the 2004 recalibration, an SCI greater than 34 indicated healthy conditions. Over the period-of-record, only four out of 27 (or 15%) SCI scores indicated a healthy invertebrate community in the Wakulla River (Figure 5-3 and Figure 5-4).

Crustaceans were monitored at Wakulla Spring on May 17-18, 2002 by staff from the Florida Museum of Natural History (Franz 2002). In the main spring and run, freshwater shrimp (*Palaemonetes paludosus*), amphipods (*Hyalella* sp.), and the crayfish (*Procambarus paeninsulanus*) were collected. Franz (2002) lists *Procambarus kilbyi*, *P. paeninsulanus*, *P. rogersi*, *P. orcinus*, *P. spiculifer*, and *Cambarellus schmitti* as recorded crawfish species for Wakulla County.

WSI (2010) sampled emerging aquatic insects using pyramid emergence traps in April 2010. A total of 14 midge species, three species of caddisflies, and one aquatic beetle species were collected with these traps. Average insect emergence rates measured in the vicinity of the head spring were 19 insects/m²/d and 23 insects/m²/d in the spring run. This emergence rate is equivalent to an estimated 1.5 million aquatic insects emerging per day in the upper 500 m (0.3 miles) of the spring ecosystem.

Concerns over invertebrate mortality due to aquatic herbicide applications have arisen at Wakulla Spring. In 2005, a study was conducted by FDEP to examine the survival of caged crayfish during herbicide (Aquathol) treatment. Survival of crayfish did not appear to be diminished by herbicide treatments, although the corresponding reduction in spring run dissolved oxygen levels was noted as a possible stressor (FDEP 2005).



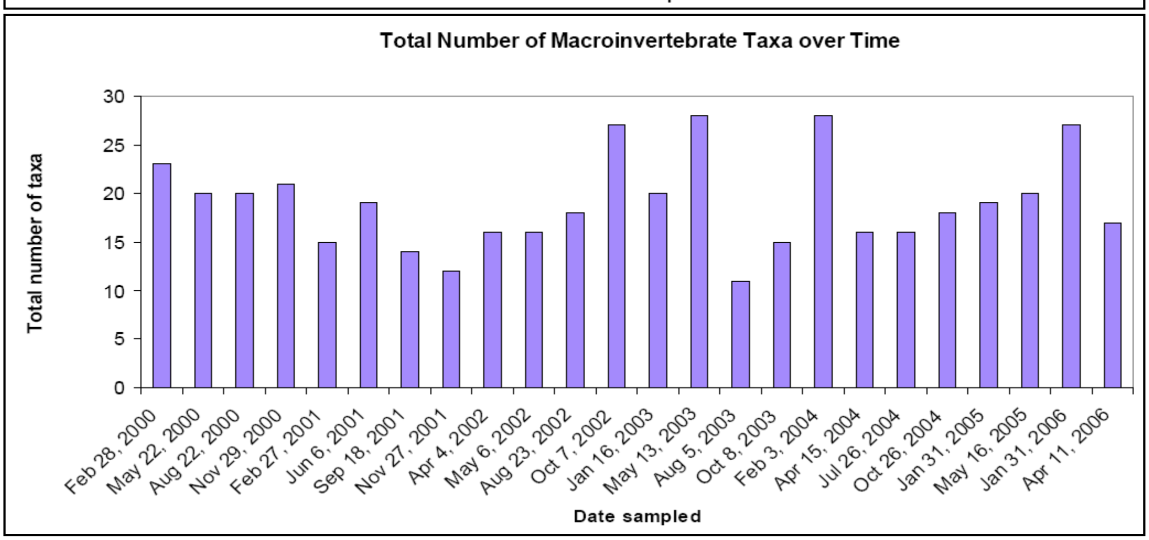


Figure 5-3. Time series of habitat assessment and total number of aquatic macroinvertebrate taxa for Wakulla Spring (from FDEP 2008).

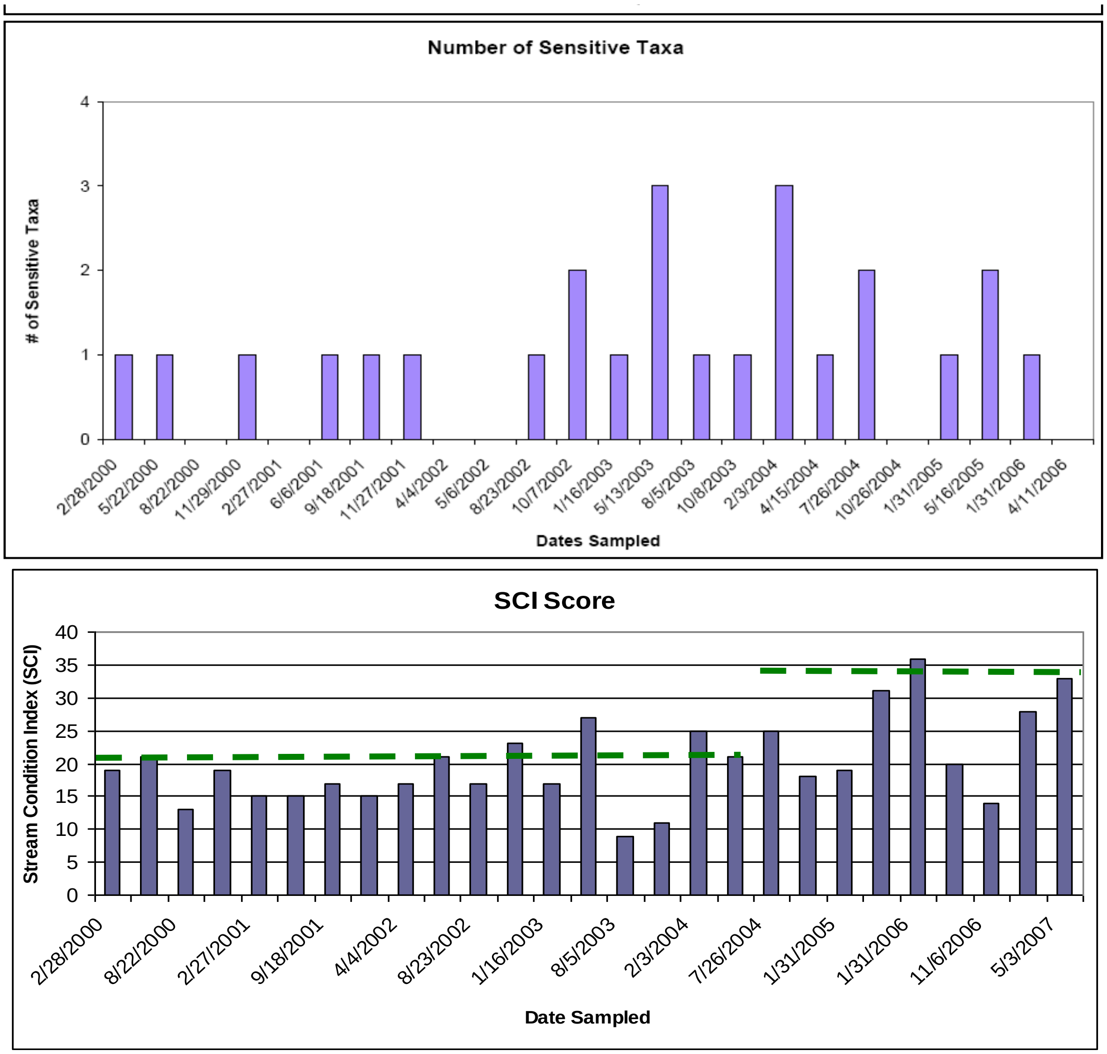


Figure 5-4. Time series of number of sensitive aquatic macroinvertebrate taxa and stream condition index (SCI) values for Wakulla Spring (from FDEP 2008).

5.3 Macrofauna

5.3.1 Fish

Fish have been surveyed at Wakulla Spring by Walsh and Williams (2003) who also conducted a review of the Florida Museum of Natural History (FLMNH) fish collections. Based on their review of museum data, a total of 43 species of 31 genera and 20 families of fishes had been collected from the headspring, river, and McBride Slough. Utilizing electrofishing techniques, Walsh and Williams (2003) collected 23 species of 21 genera and 13 families from areas near the main spring pool downstream to the vicinity of the mouth of McBride Slough. The relative abundance of fish surveyed by Walsh and Williams were dominated by redeye chub (*Notropis harperi*; 28.1%), spotted sunfish (*Lepomis punctatus*; 17.2%), and coastal shiner (*Notropis petersoni*;

15.9%). A list of fish species for Wakulla Spring is provided in Table 5-1 (from Walsh and Williams 2003).

WSI scientists observed and recorded fish from a boat on August 18, 2008. The fish observed by WSI included striped mullet (*Mugil cephalus*), lake chub sucker (*Erimyzon sucetta*), largemouth bass (*Micropterus salmoides*), Florida gar (*Lepisosteus platyrhincus*), long nosed gar (*Lepisosteus osseus*), bowfin (*Amia calva*), and several species of sunfish (*Lepomis* spp.). Several river turtles and alligators were observed as well; alligators ranged from 3 to 8 feet in length.

5.3.2 Reptiles

Figure 5-5 presents a summary of the average number of alligator and turtle species observed during Wakulla tour route surveys conducted from September 1992 to May 2014 (from Scott Savery, Florida Park Service). The tour route survey was conducted monthly through October 2012 and increased to weekly since November 2012. The American alligator has shown a steady decline since 2001, with an average of 32 observed per monitoring event from 1992 to 2001 to an average of 14 per event from 2012 to present. The average number of observed Florida cooter turtles has remained relativity stable with an average of 18 observed per event over the period of record. The Florida softshell turtle was observed infrequently with an average of less than 1 per monitoring event.

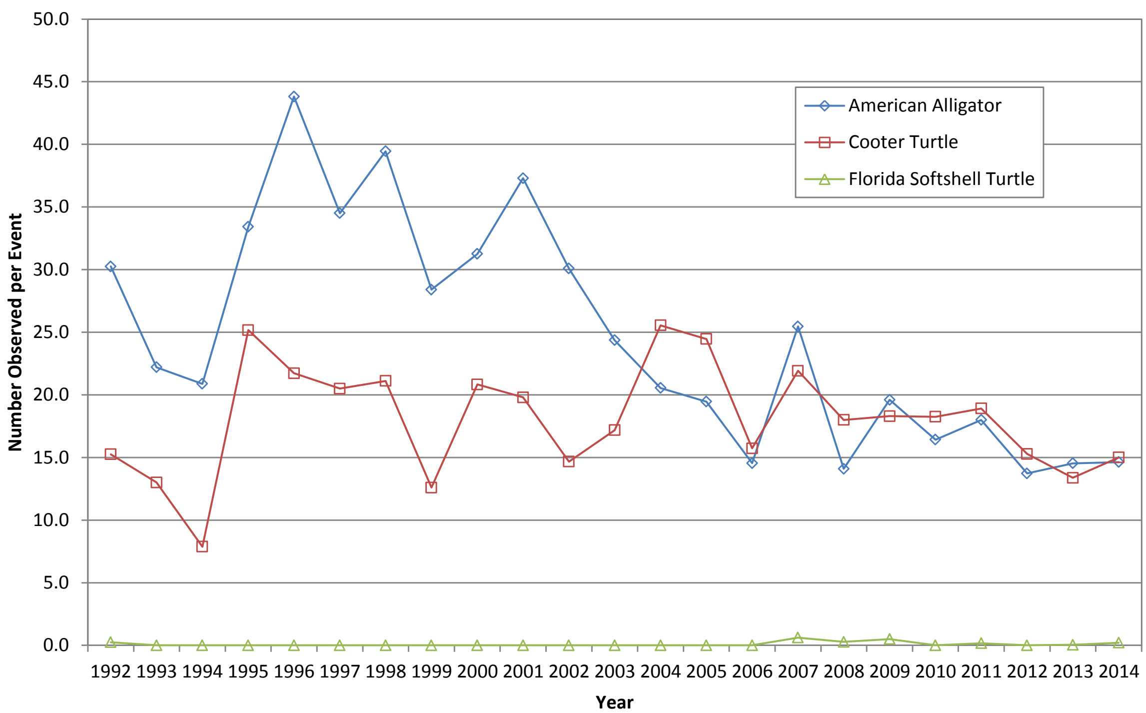


Figure 5-5. Time series of alligator and turtle species observed during the Wakulla tour route survey

Table 5-1. Listing of fishes collected in Wakulla Springs (USGS; number of specimens and relative abundance), and material in the FLMNH ichthyologic collection from the spring proper and adjacent reaches (e.g., McBride Slough) of the Wakulla River (% = total percentage of each taxon for all specimens in FLMNH collection for both spring and adjacent reaches combined, from Walsh and Williams 2003).

Family	Species	USGS		FLMNH		
		N	Relative Abundance (%)	Spring	Adjacent	%
Lepisosteidae	*Lepisosteus osseus*	9	0.9	3	---	0.05
	Lepisosteus platyrhincus	4	0.4	---	---	---
Amiidae	*Amia calva*	6	0.6	---	---	---
Anguillidae	*Anguilla rostrata*	8	0.8	9	---	0.15
Cyprinidae	*Notropis cummingsae*	---		355	---	5.84
	Notropis harperi	273	28.1	841	72	15.01
	Notropis petersoni	154	15.9	436	36	7.76
	Opsopoeodus emiliae	---	---	82	---	1.35
	Pteronotropis hypselopterus	1	0.1	252	51	4.98
Catostomidae	*Erimyzon sucetta*	39	4.0	17	1	0.30
	Minytrema melanops	3	0.3	6	---	0.10
Ictaluridae	*Ameiurus catus*	---	---	1	---	0.02
	Noturus gyrinus	---	---	24	2	0.43
	Noturus leptacanthus	---	---	10	---	0.16
Esocidae	*Esox americanus*	---	---	11	4	0.25
	Esox niger	---	---	2	---	0.03
Aphredoderidae	*Aphredoderus sayanus*	18	1.9	69	3	1.18
Mugilidae	*Mugil cephalus*	3	0.3	---	---	---
Atherinopsidae	*Labidesthes sicculus*	4	0.4	195	---	3.21
Belonidae	*Strongylura timucu*	---	---	1	---	0.02
Fundulidae	*Fundulus confluentus*	---	---	28	---	0.46
	Fundulus escambiae	---	---	---	1	0.02
	Fundulus grandis	---	---	1	---	0.02
	Fundulus seminolis	43	4.4	426	---	7.00
	Lucania goodei	78	8.0	734	27	12.51
	Lucania parva	---	---	67	---	1.10
Poeciliidae	*Gambusia holbrooki*	61	6.3	524	22	8.98
	Heterandria formosa	43	4.4	142	32	2.86
	Poecilia latipinna	7	0.7	145	---	2.38
Syngnathidae	*Syngnathus scovelli*	---	---	1	---	0.02
Centrarchidae	*Lepomis auritus*	2	0.2	143	---	2.35
	Lepomis gulosus	---	---	3	---	0.05
	Lepomis marginatus	---	---	5	---	0.08
	Lepomis microlophus	---	---	4	---	0.07
	Lepomis punctatus	167	17.2	188	---	3.09
	Micropterus notius	5	0.5	---	---	---
	Micropterus salmoides	35	3.6	44	1	0.74
Percidae	*Percina nigrofasciata*	---	---	47	---	0.77
Gerreidae	*Eucinostomus argenteus*	---	---	72	---	1.18
Sparidae	*Lagodon rhomboides*	---	---	21	---	0.35
Sciaenidae	*Bairdiella chrysoura*	---	---	8	---	0.13
	Leiostomus xanthurus	---	---	6	---	0.10
Elassomatidae	*Elassoma okefenokee*	5	0.5	500	9	8.37
	Elassoma zonatum	---	---	5	4	0.15
Gobiidae	*Gobiosoma bosc*	---	---	4	---	0.07
	Microgobius gulosus	---	---	1	---	0.02
Achiridae	*Trinectes maculatus*	3	0.3	384	---	6.31
	Total number of species	**23**		**42**	**14**	
	Total number of specimens	**971**		**5817**	**265**	

5.3.3 Birds

Wakulla Springs State Park has been surveyed as part of the Audubon Christmas bird count since 1947. Twenty aquatic bird species have been documented through this survey, with the five most commonly observed species being American widgeon (48.7%), American coot (16.2%), lesser scaup (9.6%), white ibis (5.4%), and common moorhen (4.1%). Figure 5-6 shows the average number of birds by species for the period-of-record. A number of long-term trends for individual bird species are evident in the Christmas count data. Annual counts of a number of aquatic birds have increased during the 60+ year period, including anhinga, little blue heron, green heron, white ibis, common moorhen, and hooded merganser (Figure 5-7). Numbers for several aquatic bird species have remained relatively constant, including pied-billed grebe, double-crested cormorant, great blue heron, tricolored heron, great egret, yellow-crowned night-heron, wood duck, lesser scaup, and bald eagle.

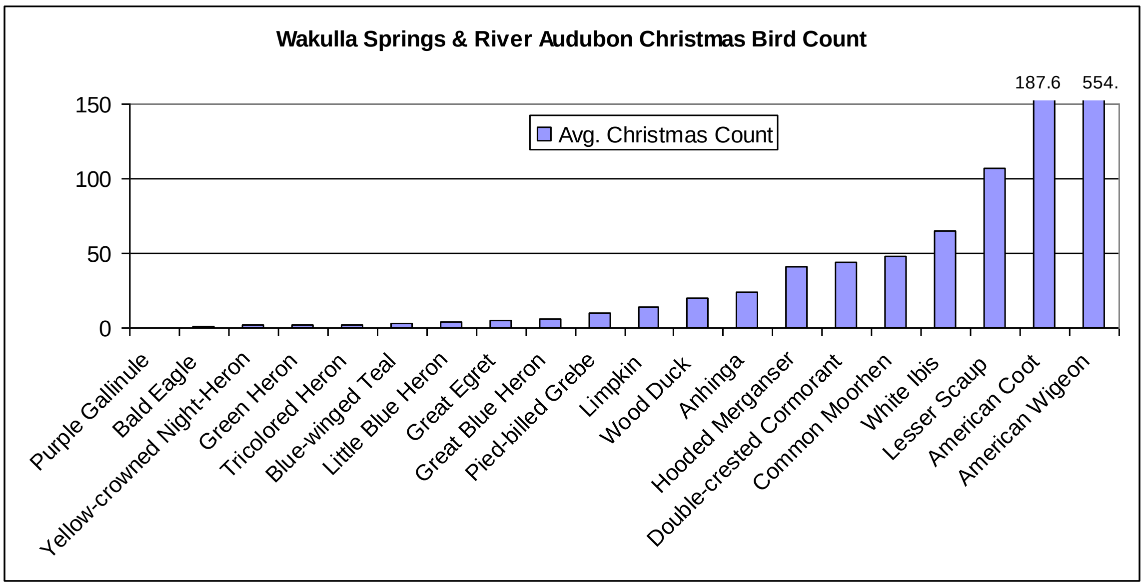
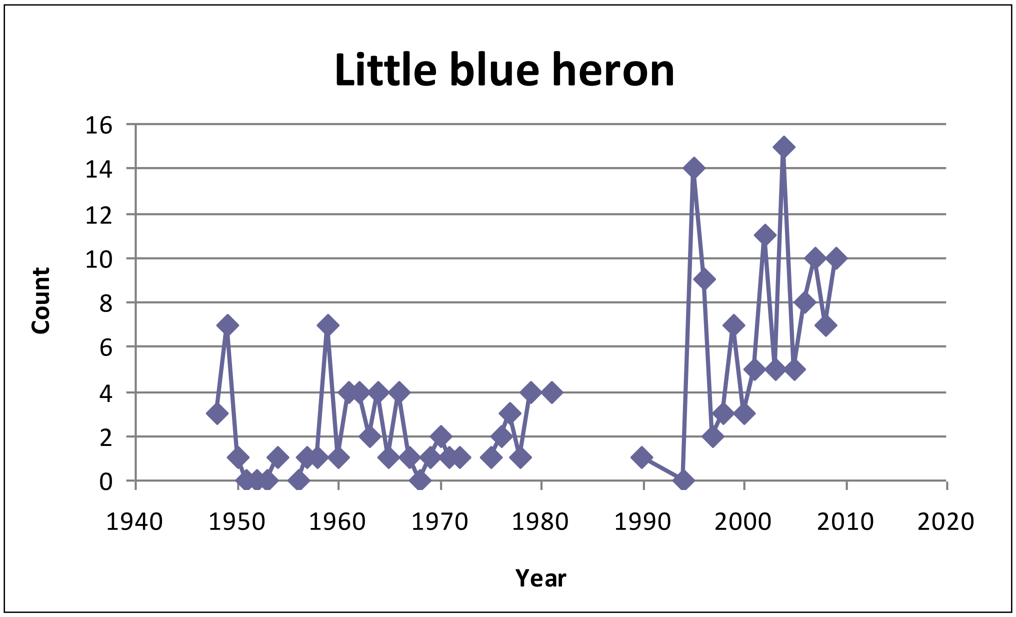


Figure 5-6. Wakulla Springs Audubon Christmas bird count data (average number by species for 1948-2009).

A few notable bird species have displayed a boom or bust population trend as noted by the Audubon Christmas bird count data. For example the American widgeon, a migratory waterfowl, increased from very low counts in 1940s through the 1960s, to high counts from 500 to over 2,000 individuals from the 1970s through the early 2000s, and have declined back to zero over the most recent decade (Figure 5-8**)**. Limpkins increased precipitously at Wakulla Spring beginning in 1969 to over 70 individuals in 1971 and then gradually declined to previous numbers (fewer than 10) by 2000 when the population suddenly collapsed (Figure 5-8). The limpkin, a relatively uncommon wading bird whose preferred prey is apple snails, has been considered by some to be a sensitive indicator of spring health (Cerulean 2004). Limpkins have not been recorded on Christmas bird counts at Wakulla Spring since about 2001.



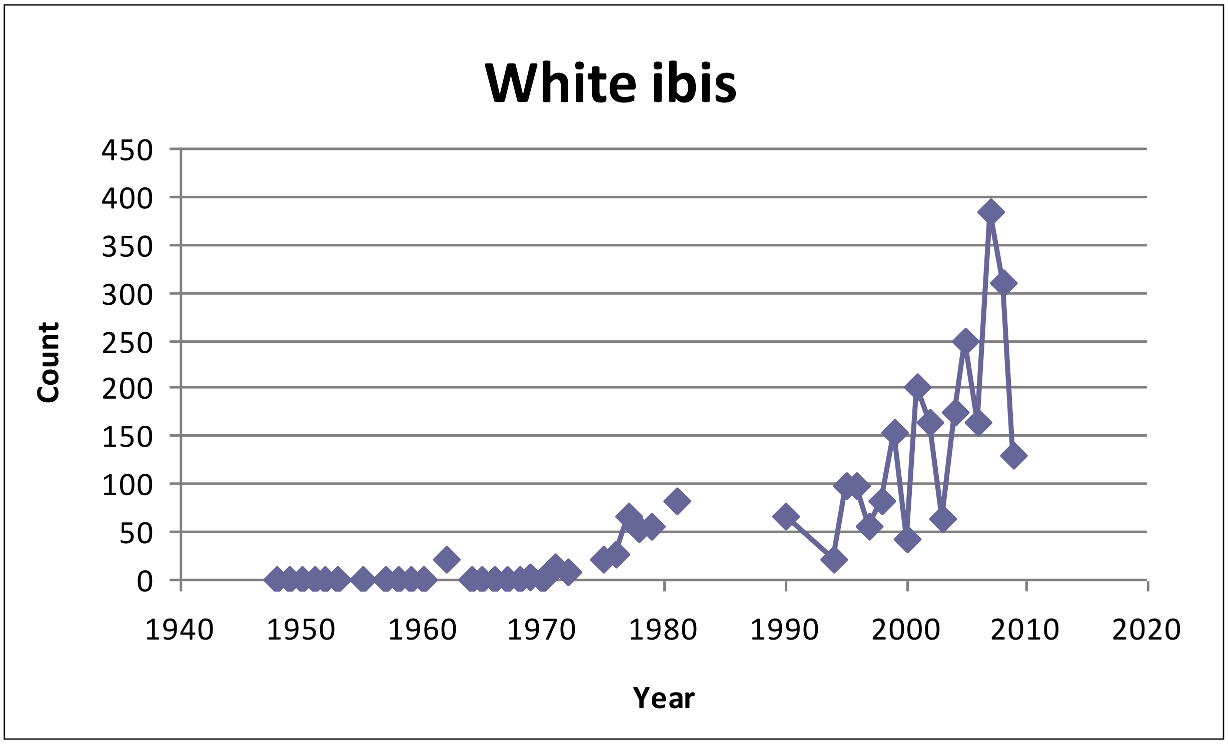
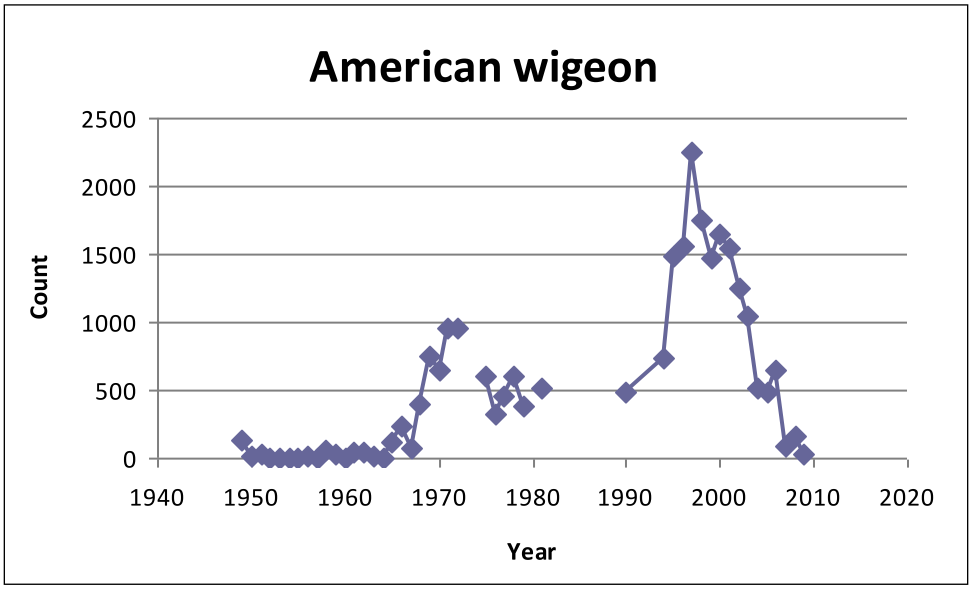


Figure 5-7. Representative bird species that have shown increased numbers at Wakulla Springs based on Audubon Christmas bird count data (number of individuals recorded for 1948-2009).



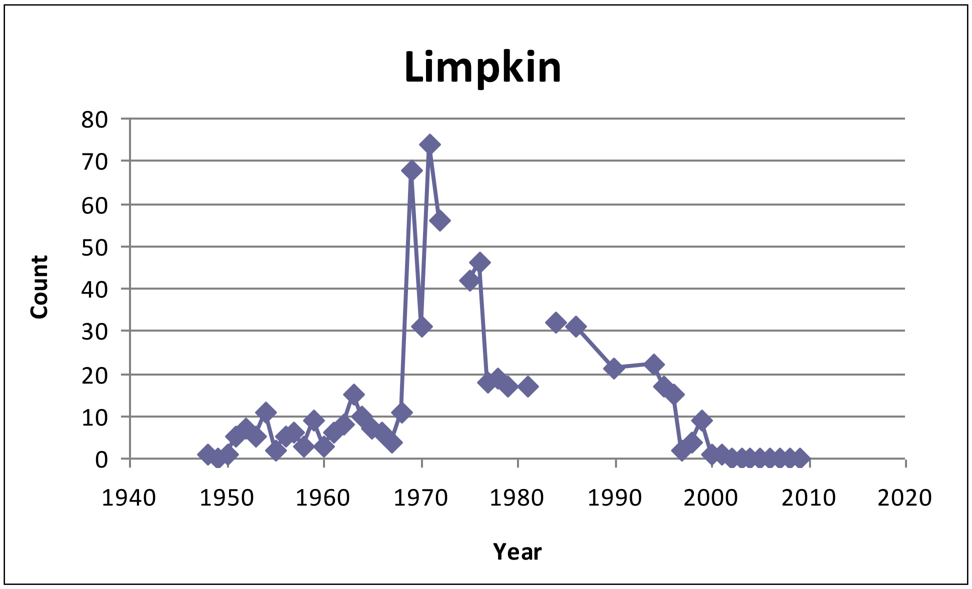


Figure 5-8. Representative bird species that have shown declining numbers at Wakulla Springs based on Audubon Christmas bird count data (number of individuals recorded for 1948-2009).

5.3.4 Manatees

Manatees are known to utilize Wakulla Spring in relatively low numbers (Figure 5-9). The current known high manatee count at the spring is 46, documented during the winter of 2012-2013 (Scott Savery, FDEP, personal communication). FDEP records indicate that 12 manatees utilized the spring during the 2007 to 2008 winter period. Wakulla Spring is considered a secondary warm-water site by the Florida manatee recovery team and does not appear to have accessibility issues despite some relatively shallow areas in the spring run (Taylor 2006).

Figure 5-9. Two Florida manatees (*Trichechus manatus latirostrus*) relaxing in the pool of Wakulla Spring (photo by S.K. Notestein, 04/14/09)

5.4 Ecosystem Functions

Aquatic ecosystem metabolism studies were pioneered by H.T. Odum (1956, 1957) and others (Odum, Galindo, *et al.* 1953) utilizing Silver Springs as a natural study system. Preliminary research in Silver Springs began in 1953, and a progress report by Odum *et al.* (1953) describes the initial results from his measurements of community metabolism. Odum found springs to be ideal experimental units because of temporal consistency; allowing exploration of community ecology, trophic status, and food webs.

Odum's (1956) publication of Primary Production in Flowing Waters described the upstream-downstream DO change method for measuring community metabolism as well as the ecological implications these measurements facilitate, *i.e.*, determination of gross primary productivity (GPP), community-wide respiration (CR), GPP/CR ratios, and heterotrophic versus autotrophic states from a variety of lotic systems. Odum's (1956) results demonstrated that higher productivity can be achieved in flowing waters compared to static or stagnant aquatic ecosystems, and that autotrophic and heterotrophic states exist in a gradient, and that primary production and community respiration can be used to characterize whole ecological communities.

WSI (2010) reported a comparison of ecosystem indices for twelve Florida springs, including Wakulla Spring. Whole ecosystem metabolism (gross primary productivity, community respiration, and net primary productivity) was estimated using upstream-downstream changes in dissolved oxygen (corrected for atmospheric oxygen diffusion) in the Wakulla Spring basin (vent to boat dock) and in the Wakulla River from the boat dock down to the 1 km station (Figure 5-10). Ecosystem metabolism was measured at Wakulla Spring from March 17 through April 16, 2009. A continuous series of upstream and downstream dissolved oxygen during this period, showing the predicable daily rhythm in response to photosynthesis and respiration is presented in Figure 5-11. Following the period of high rainfall, inflow dissolved oxygen concentrations rose as a result of the input of relatively recent surface waters inputs.

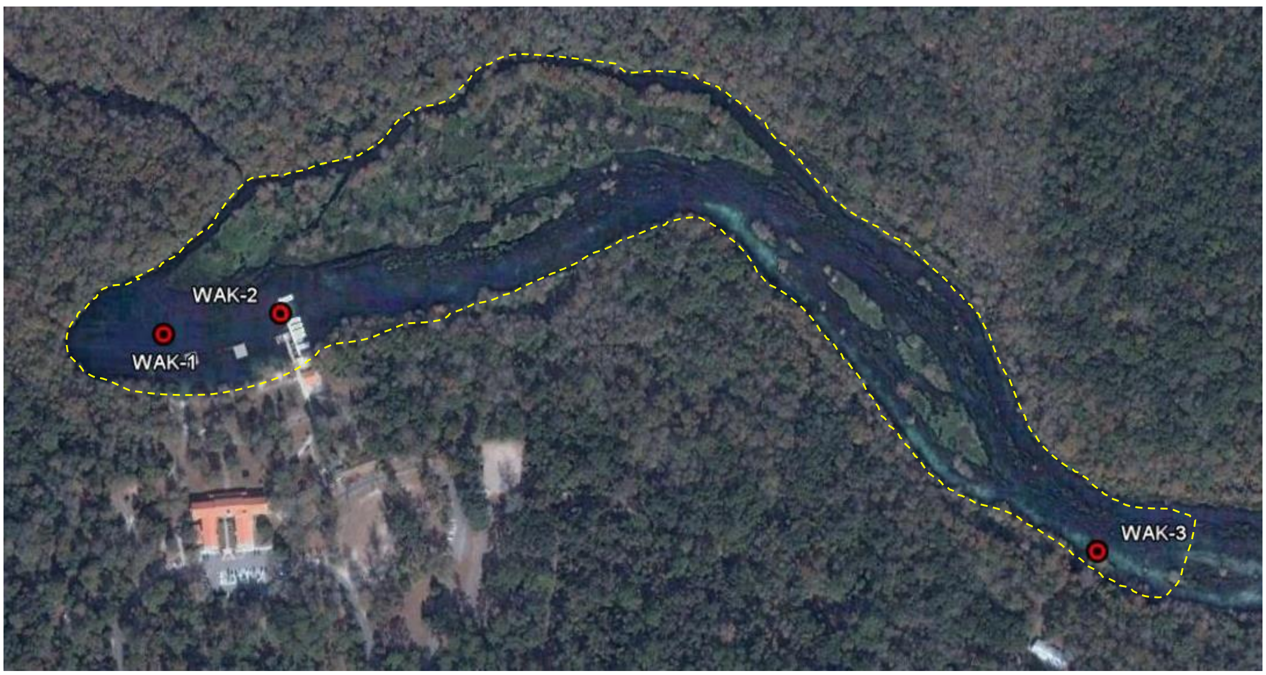


Figure 5-10. Study area for the WSI (2010) Wakulla Spring ecosystem study (with data sonde locations indicated by red icons).

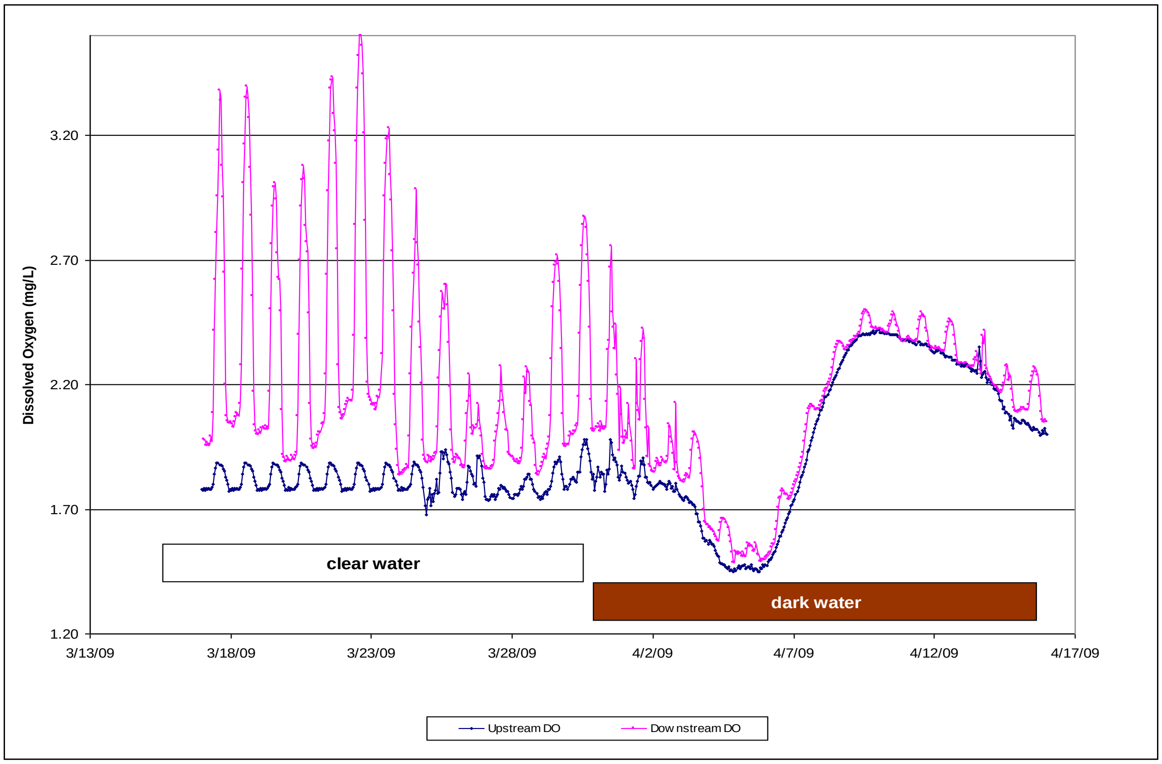


Figure 5-11. Diel curves for dissolved oxygen at Wakulla Spring during March and April 2009 illustrating the daily changes in response to photosynthesis and respiration under clear and dark water conditions.

Water clarity conditions in Wakulla Spring shifted during the WSI study period, from clear to tannic-stained due to high rainfall events in the springshed. Figure 5-12 displays the ecosystem metabolism data collected over this period. Gross primary productivity for the aquatic plants and algae averaged 14.5 $gO_2/m^2/d$ during the clear water conditions and declined to an average of 7.1 $gO_2/m^2/d$ during the dark water period. Community respiration increased from an average of 10.8 $gO_2/m^2/d$ during the clear water period to 28.2 $gO_2/m^2/d$ during the dark water period. The combined effect of these changes was a shift from positive net primary productivity during clear water conditions (3.7 $gO_2/m^2/d$) to negative net productivity during the dark water period (-21.1 $gO_2/m^2/d$).

These data provide evidence that dark water conditions in Wakulla Spring and in the downstream spring run significantly increase the overall community respiration rate and reduce the net primary productivity of the aquatic plants and algae, resulting in a shift in the aquatic ecosystem from an autotrophic condition to a heterotrophic condition. The long-term effect is a reduction in sunlight reaching the submerged plants and algae and a net reduction in the biomass and types of plants and animals supported by the Wakulla Spring and Wakulla River ecosystem.

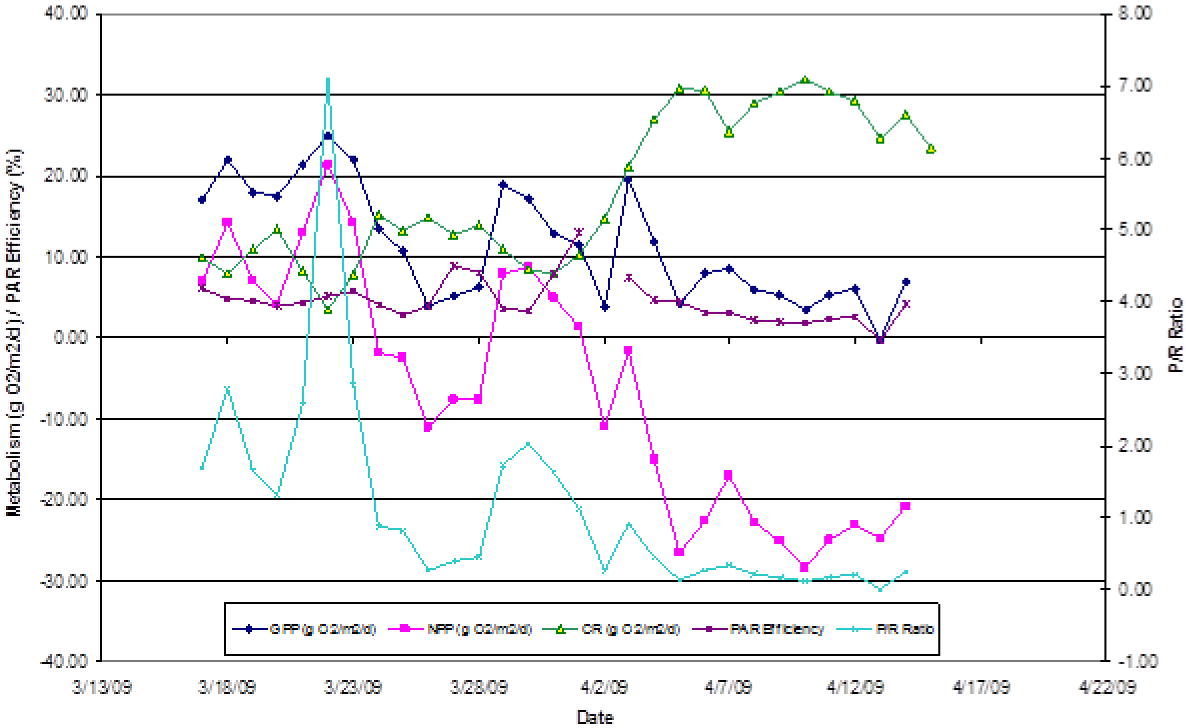


Figure 5-12. Time series data for ecosystem metabolism, photosynthetic efficiency, and the ratio between primary production and community respiration in the Wakulla Spring basin in the spring of 2009. The water in the spring was clear until April 2 when it turned dark due to tannic water inputs in the springshed. Updated data from WSI (2010).

Section 6.0 Human Use

Recreational activities at Wakulla Spring include swimming, guided boat tours, picnicking, and lodging (WSI 2010). As a state park, complete annual statistics of human attendance are available between 1987 and 2008. Peak total annual attendance occurred in 2000 (slightly more than 210,000 people) and peak season use occurs in summer months (Figure 6-1).

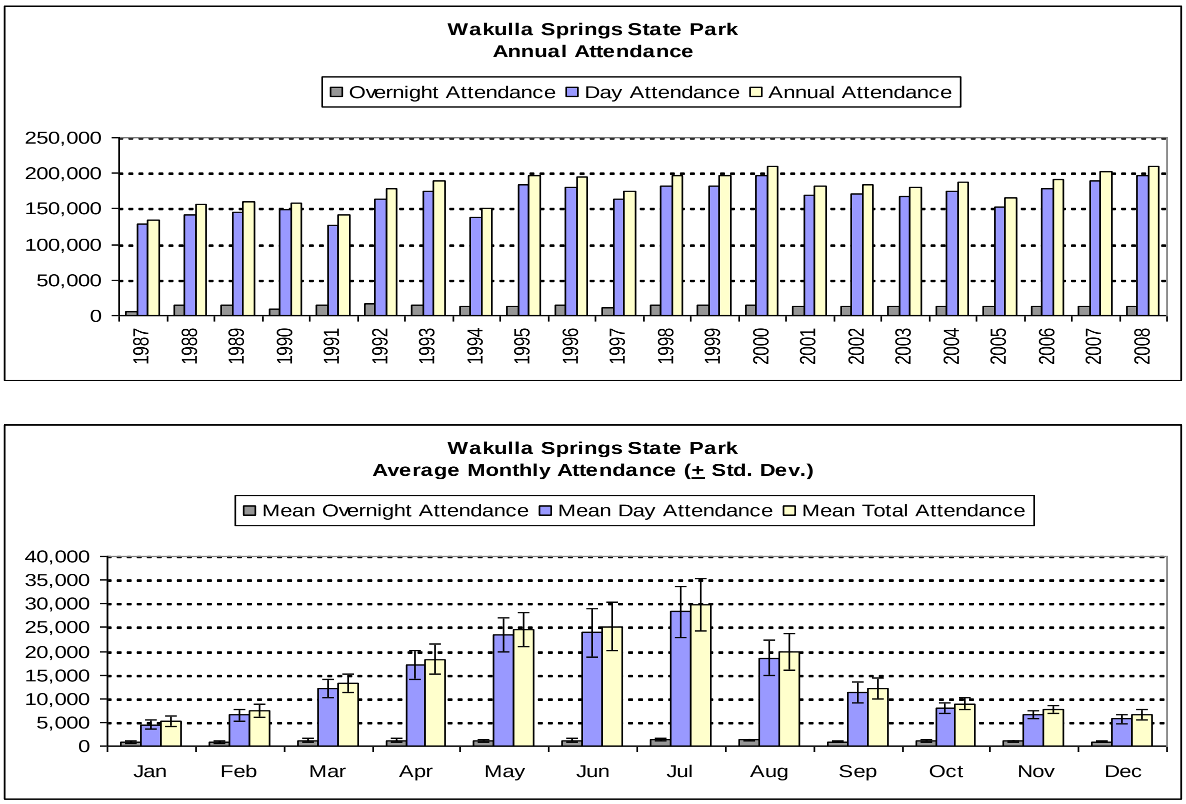


Figure 6-1. Wakulla Springs State Park annual and monthly attendance data.

One of the major public-use attractions at the Wakulla Springs State Park is boat rides around the spring basin and along the upper spring run (Figure 6-2). Two types of boats are used: glass-bottom boats for underwater and above-water viewing and "jungle" cruise tour boats for wildlife viewing. Glass-bottom boats are only run when water visibility equals or exceeds 75 feet as measured by a Secchi disk by park staff. Clear-water conditions occur at Wakulla Spring when older groundwater predominates in the Floridan Aquifer and is discharged at the spring. Under certain water balance conditions (as described in more detail in a later section of this report), Wakulla Spring discharges a blend of clear groundwater and tannic-stained dark water derived from relatively recent surface water flows into nearby swallets (sinkholes that receive flowing streams during rainy periods). A relatively small fraction of dark water in the Wakulla Spring discharge reduces water transparency (Kulakowski 2010) so that glass-bottom boats cannot be used at the park. The frequency of glass-bottom boat tours is variable from year-to-year at Wakulla Spring and has declined over the last 25 years (Figure 2-7). During the period-

Figure 6-2. Wakulla Springs State Park boat concessions include glass-bottom boats (top photo) and jungle-cruise tour boats (bottom photo).

of-record, glass bottom boat tours occurred from 17 to 75% of the days per year from 1987 through 2003 and only 0 to 15% of the time from 2004 through 2010 (personal communication, Scott Savery, FDEP Park Service).

WSI (2010) reported detailed human use data for Wakulla Spring for the period from January through June 2009. In-water use of the spring pool area during periods of observation averaged 13.4 people per hectare (5.4 people per ac) with maximum and minimum daily estimates of <0.05 people/ha (<0.02 people per ac) in January and 59.2 people/ha (24 people per ac) on a weekend day in June. In-water daily person-hour estimates ranged from a low of 0.3 person-hours in the winter to a high of 558 person-hours in June. Out-of-water activities ranged from a low of about 32 person-hours per day in January to 1,444 person-hours per day in June (Table 6-1). Figure 6-4 and Figure 6-4 display the diel pattern of human uses at Wakulla Spring for a typical summer high-use day (June 30, 2009) and a typical winter low-use day (January 25, 2009). Dominant summer in-water uses in the swimming area at Wakulla Springs State Park include bathing, wading, swimming, and snorkeling and appear to peak between about 12:30 and 4 PM. There was essentially no in-water activity observed at Wakulla Spring during the coldest winter days when counts were conducted.

Table 6-1. Detailed human-use counts at Wakulla Spring pool area from January through June 2009 (WSI 2010).

			# Person/ha												Average	
			1/19/2009	1/25/2009	2/26/2009	2/28/2009	3/29/2009	3/31/2009	4/26/2009	4/30/2009	5/29/2009	5/31/2009	6/28/2009	6/30/2009		
Location	Category	Activity	Weekday	Weekend	Weekday	Weekend	Weekend	Weekday	Weekend	Weekday	Weekday	Weekend	Weekend	Weekday	Weekday	Weekend
Spring Pool	In Water	Wading	0.12	0.02	0.11	0.08	1.28	0.41	8.14	0.71	3.42	12.99	21.92	7.33	2.02	7.40
		Bathing	0.00	0.00	0.00	0.00	0.00	0.17	5.32	0.13	1.86	11.04	26.59	9.84	2.00	7.16
		Snorkeling	0.06	0.00	0.00	0.00	0.11	0.00	0.74	0.00	0.05	0.60	2.15	3.74	0.64	0.60
		Swimming	0.06	0.00	0.00	0.04	7.56	0.87	6.03	0.69	3.80	8.49	8.58	5.48	1.82	5.12
		SCUBA	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Out of Water	Sitting	0.24	0.58	0.65	1.32	5.31	1.01	17.34	3.81	5.62	29.39	47.62	11.48	3.80	16.93
		Walking	4.10	2.90	4.67	9.29	18.09	7.66	24.65	8.63	20.31	37.75	54.27	22.20	11.26	24.49
		Sunbathing	0.00	0.00	0.00	0.00	5.04	0.00	14.07	1.36	1.51	19.78	13.71	4.34	1.20	8.77
		Viewing	0.00	4.28	4.91	8.78	18.88	8.33	35.68	10.53	92.85	54.10	62.31	32.75	24.90	30.67
	In Water		0.2	0.0	0.1	0.1	8.9	1.4	20.2	1.5	9.1	33.1	59.2	26.4	6.47	20.28
	Out of Water		4.3	7.8	10.2	19.4	47.3	17.0	91.8	24.3	120.3	141.0	177.9	70.8	41.16	80.86
Spring Run	In Water	Boat Tour	2.68	1.96	4.25	4.57	3.37	3.90	6.08	6.78	5.49	7.65	2.13	5.80	4.82	4.29
		Other	0.17	0.00	0.00	0.12	0.11	0.43	1.16	0.03	0.14	1.34	1.04	0.15	0.15	0.63
	In Water		2.8	2.0	4.3	4.7	3.5	4.3	7.2	6.8	5.6	9.0	3.2	5.9	4.97	4.92
	Entire Spring		7.4	9.7	14.6	24.2	59.7	22.8	119.2	32.7	135.1	183.1	240.3	103.1	52.61	106.06

Note(s):

Hours of Observations:		5.5	9.5	8.5	8.0	7.0	5.5	6.5	6.3	6.3	4.0	6.0	7.5
Spring Pool Wetted Area (ha):	1.569												
Spring Pool Upland Area (ha):	1.353												
Spring Run Area (ha):	6.032												

			Person-Hrs												Average		
			1/19/2009	1/25/2009	2/26/2009	2/28/2009	3/29/2009	3/31/2009	4/26/2009	4/30/2009	5/29/2009	5/31/2009	6/28/2009	6/30/2009			
Location	Category	Activity	Weekday	Weekend	Weekday	Weekend	Weekend	Weekday	Weekend	Weekday	Weekday	Weekend	Weekend	Weekday	Person-Hrs	# People	# People/ha
Spring Pool	In Water	Wading	1.0	0.3	1.5	1.0	14.0	3.5	83.0	7.0	33.5	81.5	206.3	86.3	43.2	7.39	4.71
		Bathing	0.0	0.0	0.0	0.0	0.0	1.5	54.3	1.3	18.3	69.3	250.3	115.8	42.5	7.18	4.58
		Snorkeling	0.5	0.0	0.0	0.0	1.3	0.0	7.5	0.0	0.5	3.8	20.3	44.0	6.5	0.97	0.62
		Swimming	0.5	0.0	0.0	0.5	83.0	7.5	61.5	6.8	37.3	53.3	80.8	64.5	33.0	5.44	3.47
		SCUBA	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.00	0.00
	Out of Water	Sitting	1.8	7.5	7.5	14.3	50.3	7.5	152.5	32.3	47.5	159.0	386.5	116.5	81.9	14.02	10.36
		Walking	30.5	37.3	53.8	100.5	171.3	57.0	216.8	73.0	171.8	204.3	440.5	225.3	148.5	24.18	17.88
		Sunbathing	0.0	0.0	0.0	0.0	47.8	0.0	123.8	11.5	12.8	107.0	111.3	44.0	38.2	6.74	4.98
		Viewing	0.0	55.0	56.5	95.0	178.8	62.0	313.8	89.0	785.0	292.8	505.8	332.3	230.5	37.58	27.78
	In Water		2.0	0.3	1.5	1.5	98.3	12.5	206.3	15.0	89.5	207.8	557.5	310.5	125.2	20.98	13.38
	Out of Water		32.3	99.8	117.8	209.8	448.0	126.5	806.8	205.8	1,017.0	763.0	1,444.0	718.0	499.0	82.53	61.01
Spring Run	In Water	Boat Tour	88.8	112.5	218.0	220.5	142.5	129.5	238.5	255.8	207.0	184.5	77.0	262.3	178.1	27.48	4.56
		Other	5.5	0.3	0.0	6.0	4.8	14.3	45.5	1.0	5.3	32.3	37.8	6.8	13.3	2.36	0.39
	In Water		94.3	112.8	218.0	226.5	147.3	143.8	284.0	256.8	212.3	216.8	114.8	269.0	191.3	29.84	2.47
	Entire Spring		128.5	212.8	337.3	437.8	693.5	282.8	1,297.0	477.5	1,318.8	1,187.5	2,116.3	1,297.5	815.6	133.35	25.62

Note(s):

Hours of Observations:		5.5	9.5	8.5	8.0	7.0	5.5	6.5	6.3	6.3	4.0	6.0	7.5
Spring Pool Wetted Area (ha):	1.569												
Spring Pool Upland Area (ha):	1.353												
Spring Run Area (ha):	6.032												

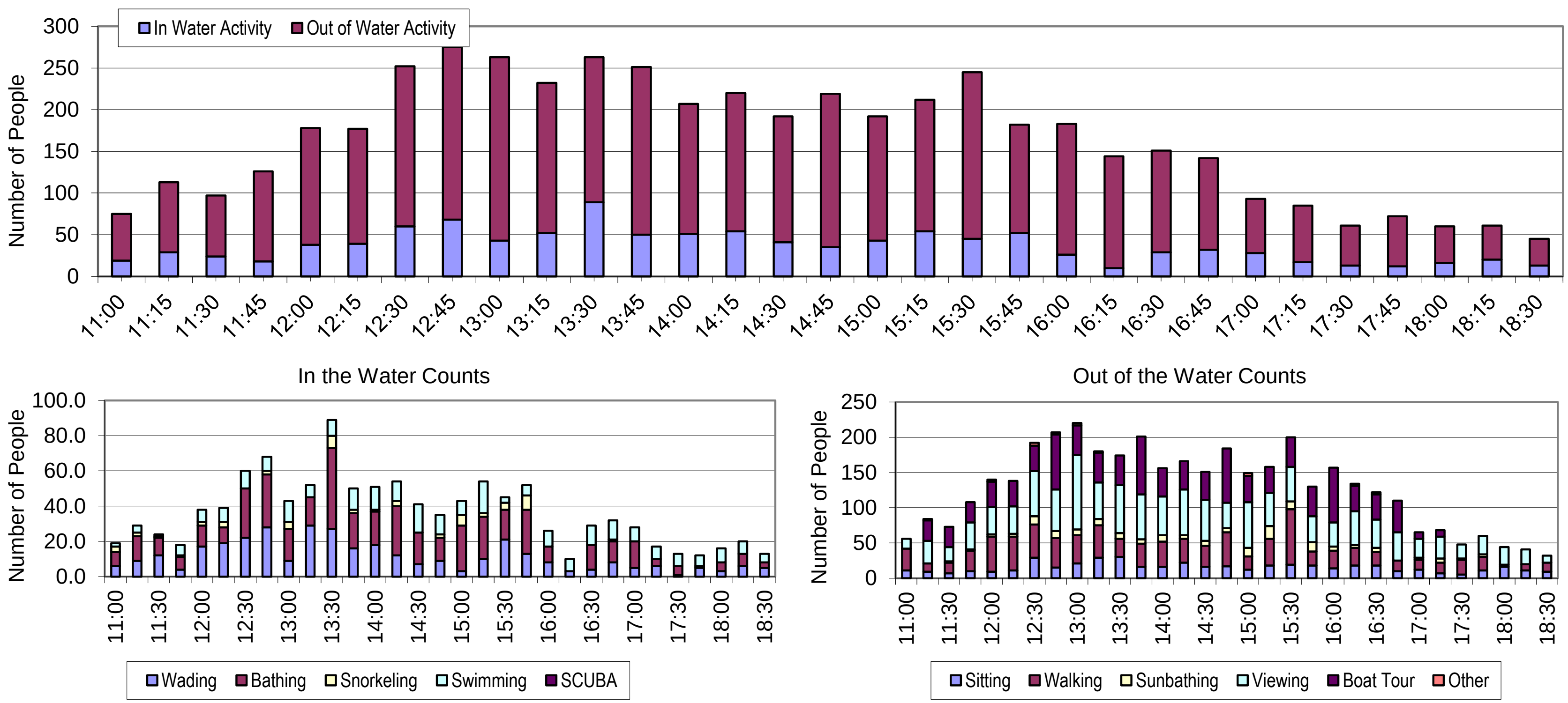


Figure 6-3. Detailed human use activity data for Wakulla Spring June 30, 2009 (WSI 2010).

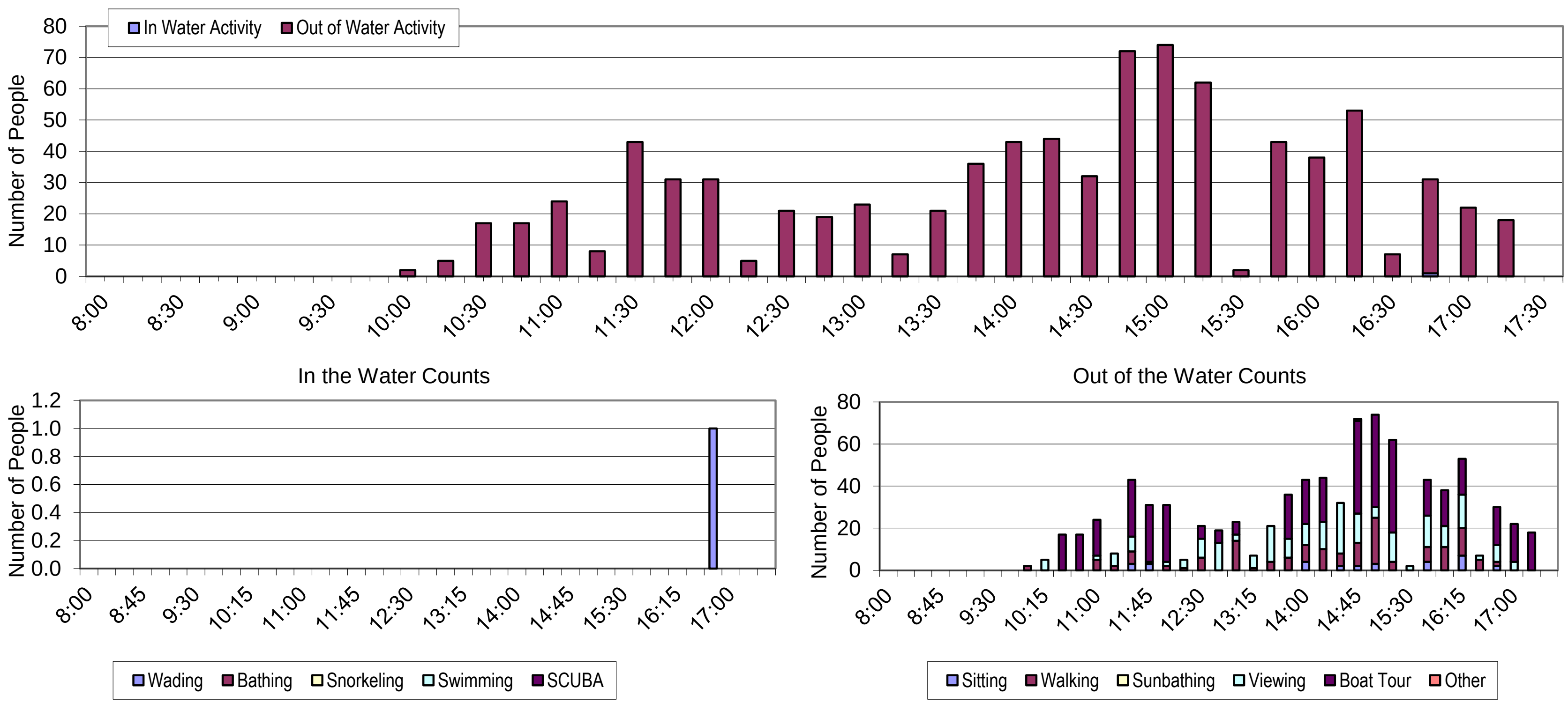


Figure 6-4. Detailed human use activity data for Wakulla Spring on January 25, 2009 (WSI 2010).

Section 7.0 Regulatory Status

7.1 Introduction

Like many of Florida's large, artesian springs, Wakulla Spring is protected through existing federal, state, and local ordinances and designations that are intended to limit or totally prevent ecological impairment. These laws and policies are aimed, directly or indirectly, at protecting the springshed and the springs that nourish the Wakulla River. With each passing year additional protections are being considered and in some cases implemented. However, as documented by the environmental information collected for this report, enforcement of existing regulations has not been successful at halting the continuing decline in the health of Wakulla Spring or the Floridan Aquifer it depends on for nourishment. Examination of existing policies and elimination of their inadequacies and/or lax enforcement of existing laws is necessary to reverse the ongoing decline of Wakulla Spring. A brief summary of these regulations is provided below.

7.2 Federal Designations and Protections

The Federal Clean Water Act (CWA) protects all of the nation's surface water bodies from the uncontrolled discharge of pollutants. Passed in 1972, the objective of the Federal Water Pollution Control Act, commonly referred to as the Clean Water Act (CWA), is to restore and maintain the chemical, physical, and biological integrity of the nation's waters by preventing point and nonpoint pollution sources, providing assistance to publicly owned treatment works for the improvement of wastewater treatment, and maintaining the integrity of wetlands. The principal body of law in effect is based on the Federal Water Pollution Control Act Amendments of 1972 which was a significant expansion of the Federal Water Pollution Control Act of 1948. Major amendments were enacted in the CWA of 1977 and the Water Quality Act of 1987. Some of the requirements of the Federal CWA are delegated to the states. The original intention of the CWA was to eliminate all pollutant discharges to U.S. surface waters by 1984.

In PUD No.1 of Jefferson County, *et al.* v. Washington Department of Ecology (511 U.S. 700 [1994]), the U.S. Supreme Court found that the CWA also provides authority for addressing hydrologic modification issues where water quantity affects water quality of surface waters. The U.S. Supreme Court ruled that due to competition and drought, states are making decisions on water use and must ensure their decisions are consistent with protection of the designated uses, numeric and narrative criteria, and antidegradation components spelled out in the CWA.

The CWA does not directly address groundwater contamination. Groundwater protection provisions are included in the Safe Drinking Water Act, Resource Conservation and Recovery Act, and the Superfund Act.

7.3 State Designations and Protections

During 1970-71, Florida recorded its worst drought up to that date, spurring state leaders to take action to effectively manage and protect the state's finite water resources. Four major pieces of state legislation were enacted by the 1972 Florida legislature: the Environmental Land and Water Management Act, the Comprehensive Planning Act, the Land Conservation Act, and the Water Resources Act. These laws were based on the philosophy that land use, growth policy, and water management cannot be separated and led to the establishment of a unique regional water management system based on natural hydrologic boundaries and funded by local taxing authorities. Five water management districts were established by the 1972 Florida Water Resources Act and were given the responsibility to provide conservation and allocation of water supply, water quality protection, flood protection, and natural systems management (Purdum 2002). The Northwest Florida Water Management District (NWFWMD) extends from the middle of Jefferson County to the western terminus of the Florida Panhandle and includes Wakulla Spring, the Wakulla River, and the Florida portion of the ground and surface water springshed that feeds these waterbodies.

Florida's surface water quality standards, designated uses, antidegradation requirements, and protections for minimum flows and levels were codified in 1972 under the state's Water Resources Act.

Of Florida's 1,700 rivers, the Wakulla River was designated a "Special Water" as one among only 41 which are recognized as Outstanding Florida Waters (OFW). The OFW designation recognizes diverse ecosystems and is meant to protect the water body from degradation of ambient water quality "under all circumstances" (antidegradation requirement from the CWA). By rule this water quality designation is intended to prohibit any activities that would further lower the ambient water quality based on the quality at the time of the designation (1987), or the year prior to designation (1986), whichever is more protective. There is also a requirement that approved projects that affect OFWs should be in the public interest or at least not contrary to public interest.

7.3.1 Minimum Flow and Levels

By setting MFLs, water management districts are responsible for determining the point at which further withdrawals within a watershed will cause "significant harm" and for ensuring that there is enough water in the Floridan aquifer to protect the hydrological and ecological integrity of lakes, streams, and springs in the water management district. The establishment of MFLs is required both by the Florida Water Resources Act of 1972, and by the state comprehensive plan. MFLs apply to decisions affecting water withdrawal permits, declaration of water shortages, environmental resource permitting, and assessment of water supply sources. Each water management district is required to develop recovery or prevention strategies in cases where a water body currently does not or will not meet an established MFL.

As of 2014, the NWFWMD has not set any MFLs for the Districts springs and other surface waters. The District did update their MFL priority list in 2014 and included Wakulla, Jackson Blue, and the Gainer springs group as required for all first magnitude springs. Based on this list as approved by the FDEP, the NWFWMD started the MFL technical data collection at Wakulla

Spring in 2013, and plans to complete their MFL technical assessment by 2021, and adopt an MFL rule for Wakulla Spring in 2023.

Wakulla Spring MFL rule-making could conceivably result in new criteria for consumptive use permits, new prevention strategies, and/or new constraints in regional water supply planning.

7.3.2 Impaired Waters Rule

The Impaired Surface Waters Rule (IWR) - Rule 62-303, Florida Administrative Code (F.A.C.), was adopted to satisfy the requirements of the Florida Watershed Restoration Act in April 2001. The IWR was developed to replace the past listing of waters based on EPA's Section 303(d). It relies on a "new science-based methodology to identify impaired waters." Based on the definitions within the IWR the Wakulla River was identified by FDEP in 2009 as a waterway impaired by nitrate nitrogen.

This designation as an impaired water initiated the Total Maximum Daily Load (TMDL) regulatory process to develop loading estimates to maintain or reduce impairment. The TMDL process is discussed further below.

7.3.3 Total Maximum Daily Load (TMDL)

In June 2008 the FDEP verified that the Wakulla River biology is impaired for elevated concentrations of nitrate nitrogen (Gilbert 2012). This impairment was evidenced by excessive algal growth and smothering of desirable plants, by invasion of the river by the exotic submerged aquatic plant *Hydrilla verticillata* (hydrilla), by low dissolved oxygen concentrations and slightly elevated specific conductance, and by increasing invasion of tannic or "colored" waters that limit recreational and aesthetic uses of the spring and river (Gilbert 2012).

A TMDL represents the estimated maximum amount of a given pollutant that a water body can assimilate and still meet water quality standards, including its applicable water quality criteria and its designated uses. TMDLs are developed for water bodies that are verified as not meeting their water quality standards and provide important water quality goals that will guide restoration activities. According to FDEP, achieving a monthly average nitrate nitrogen concentration target of 0.35 mg/l will be sufficient to prevent an imbalance in the Wakulla River and will be protective of the aquatic flora and fauna in Wakulla Spring (Gilbert 2012). Achieving this target will require large reductions in nitrate-nitrogen inputs from a variety of sources, including stormwater and wastewater discharges, septic tank discharges, both urban and agricultural fertilizers, and animal waste disposal practices. Based on an estimated existing average nitrate-nitrogen concentration in the groundwater feeding the Wakulla River, the estimated reduction goal outlined in the TMDL is 56.2% (Gilbert 2012). Contributions from each of these nitrogen sources were described earlier in this document in detail and the State's approach to achieving compliance with the TMDL is discussed in additional detail below.

7.3.4 Basin Management Action Plan (BMAP)

The means of achieving the TMDLs for Wakulla Spring and the Wakulla River is development and implementation of a Basin Management Action Plan (BMAP). A BMAP is a restoration plan developed by FDEP and basin stakeholders that formalizes the activities that will are necessary to reduce the pollutant loads and achieve the TMDL. Stakeholders in these BMAPs include the NWFWMD, local governments, agriculture and other businesses, and interested local citizens. Given that agricultural activities are a significant source of the nitrate nitrogen loads, the Florida Department of Agriculture and Consumer Services (FDACS) will also need to play an important role in the implementation of restoration activities.

The BMAP process for the Wakulla River began in January 2013. After an extended period of no FDEP activity and at the time of this report's release (Summer 2014), the BMAP process is still in its formative stages. The stated goal of the BMAP is to return nitrate levels in the Wakulla River to 0.35 mg/L. Periodic meetings are being convened by FDEP to bring affected stakeholders together to develop and commit to the BMAP by 2014.

7.4 County and Municipal Ordinances

Counties and municipalities have a number of regulatory tools that can be used either to protect or to compromise the health of springs and other water bodies. These tools include comprehensive plans, zoning, land development regulations (LDRs), and water quality/quantity ordinances. Many of these tools – for instance regulations on dumping of hazardous materials – have been on the books for years. However, comprehensive springshed protection language like that adopted by Leon and Wakulla Counties is still the exception in North-Central Florida counties rather than the rule.

7.4.1 Leon County Springs Protection Measures and Nitrate Reduction Strategies

Leon County has been actively engaged in protecting natural water bodies from nitrogen pollution over the last several decades. The county has little ability to regulate certain nitrogen sources, such as septic tanks, but they have taken a number of actions and done a lot of studies to try and determine where some of the sources are occurring. The Leon County Aquifer Vulnerability Assessment (LAVA) study was completed to determine vulnerability areas for inputs to the springs. A map developed as part of the assessment shows the areas south of the Cody Scarp are the most vulnerable. This does not mean that other areas do not need to be addressed because there are large inputs from north of the Cody Scarp.

Leon County established the Primary Springs Protection Zone (PSPZ), enacted a fertilizer ordinance to regulate commercial applicators, and enacted a pet waste ordinance. The county completed the Lake Lafayette Watershed Study, which was a nutrient study to determine the health of the lake system and potential impacts to the lake. It is still unknown where the sink in this lake discharges, whether to the Wakulla River or St. Marks River. The county adopted many land use codes that exceed state standards, and they jointly funded a regional septic tank report that specifically focused on areas south of the Cody Scarp for nitrate loadings to the springs. The county also adopted several comprehensive plan amendments. One amendment reduced the allowable development in the urban fringe area around Woodville within the PSPZ. A set amount of development is allowed within this area, and while credits can be moved around, there can be no net increase in densities within the PSPZ.

Leon County has implemented the ordinances and comprehensive plan amendments to limit impacts up front but they have also completed structural projects to reduce nutrient loading after development occurred. One example project is a 25-acre stormwater facility on Lake Henrietta, which includes an 85-acre wetland restoration for nutrient uptake. This area is the receiving waters for the Cascade Park system. Another project was completed in Lake Munson to remove a 15-acre sediment delta, stabilize the slough, repair the dam, and move the gate locations to help with flood protection and reduce erosion. On Lake Jackson, the county was part of a joint project to remove two million cubic years of muck between 1999 and 2001. The county also constructed two stormwater retrofit ponds with wetland plantings in Harbinwood Estates in 2008. In addition, the county and the Northwest Florida Water Management District (NWFWMD) completed the Fuller Road Regional Facility, which is a 10-acre retrofit. These were all voluntary projects implemented by the county.

Leon County has also acquired land in the basin. The Fred George Basin includes restoration and rehydration of stressed wetlands. The Eight Mile Pond project was a conveyance from the Florida Gas Transmission and they had to donate land for enhancements to improve water quality. The county has in house water quality sampling that exceeds the municipal separate storm sewer system (MS4) requirements. This occurs at 73 sites on a quarterly basis, when there is flow. The county puts together a water quality report that summarizes trends to help determine what else they may need to do or consider in the future to improve water quality.

The county is also involved in legal actions to be proactive about what is coming into the county from its borders. Leon County and the Georgia Environmental Protection Division (EPD) took action against Cairo, Georgia, which resulted in them closing the old sewage land application facility that was failing and building a new treatment plant. The county also has an ongoing action against the Georgia EPD to require the BASF (chemical company) plant in Attapulgus to treat for nutrients. This plant currently pumps one million pounds of nitrate per year into the Little River, which flows to Lake Talquin in Leon County.

Leon County also has several proposed projects. The Woodville water quality project is a sales tax proposal that would need to be approved by the board before being voted on by the county's citizens. The focus of this project would be to sewer the main part of the Woodville area where the county wants future development to happen. During the Lombardo workshop, the county's board directed staff to make amendments to the code because the code had specific provisions that limited the ability for the county to do anything else. In order to have the ability to take advantage of new technology, the specificity in the code needs to be removed. The code will also be modified to require advanced wastewater treatment (AWT) nitrogen standards for new construction in the PSPZ. Amendments will also be made to require that repairs of existing septic tanks will include retrofits to create at least a 24-inch separation from the wet season groundwater level.

Leon County also has planned actions to help with the BMAP. The county's health department knows where most of the septic tanks are located; however, they do not know where all the tanks are located since the records do not go back very far. The board provided $50,000 for a complete countywide septic tank identification program. The board also recommended additional sampling to determine inflow sources to Leon County from Georgia and Gadsden County.

7.4.2 City of Tallahassee Springs Protection Measures and Nitrate Reduction Strategies

In 2008, the City of Tallahassee made the commitment to go to advanced nitrogen removal at their wastewater treatment facility. In 2009, there was a tri-party agreement between Leon County, Wakulla County, and Tallahassee, which led to the Lombardo septic tank report. Also in 2009, a second regional workshop was held where it was identified that septic tanks need to be the next focus since the city was working on the wastewater inputs. In 2010, Leon County updated the comprehensive plan to include the PSPZ. In 2011, the city came out with its sewer master plan and the Lombardo onsite system report was completed (LAI 2011).

Both the Lombardo study and the U.S. Geological Survey (USGS) study are important for load quantification. The USGS report had good agreement with real world concentrations, and information about how changes in loads on the surface would affect the springs. The Lombardo report is an assimilation of other studies, with the background of the total maximum daily load (TMDL), which was adopted after the USGS study was completed. The Lombardo report compares what occurs when different sources are addressed to what reductions are needed to achieve the TMDL. From the Lombardo report, the annual nitrate load to Wakulla Springs was 229,900 kg/yr, before the AWT upgrade at the wastewater facility. At that time, the biggest source was the city's wastewater sprayfield, which was followed by septic tanks, inflow, and other smaller sources (atmospheric deposition and livestock). The inflow loading represents everything north of the Cody Scarp that is coming into the modeled area including septic tanks, irrigation, fertilizer, and possibly even Georgia inputs. The allowable TMDL load, based on the target concentration of 0.35 mg/L of nitrates, is 110,000 kg/yr. Therefore, a reduction of 119,900 kg/yr of nitrates is needed.

The City of Tallahassee has implemented source control measures through ordinances and they also have education and outreach efforts. The City agrees that it is much cheaper to remove nitrates at the source through education than to remove nitrate once it is in the system. The City has a fertilizer ordinance, pet waste ordinance, fertilizer applicator certification program, Think About Personal Pollution (TAPP) program, and a springs protection zone ordinance. The city also removed biosolids application in the watershed, implemented reuse, implemented a water quality charge in the utility fee to provide funding for projects, and completed upgrades to the sewer collection system. The largest project the city has completed is the AWT upgrade, which reduced the nitrate concentration in the wastewater effluent from 12 mg/L to 3 mg/L. This was a $227 million project that the taxpayers funded, which reduced nitrate by 75%. The city completed the AWT project ahead of schedule. The project was scheduled for completion in January 2014 but the facility reached AWT in November 2012.

The AWT upgrade resulted in an 80,900 kg/yr nitrate reduction. With the AWT upgrade, septic tanks and inflow are now much larger sources than the city's wastewater plant. The Lombardo study includes information through 2007, so it does not factor in that the city stopped applying biosolids in the springshed. John stated that the verified period for the TMDL also ends in 2007 so this biosolids removal should count for BMAP credit. It takes about four to five years for complete flushing through the system; therefore, the benefits of removing the biosolids are just now being seen in the springs. John noted that about 45,000 kg/yr of nitrates were removed by stopping the biosolids application.

The City initiated a project in 2011 to televise the entire sewage collection system. They have televised about 95% of the pipes and have identified areas where work is needed. The city has about $10 million programmed for this work. The City has spent almost $100 million on projects in the last 10 years and they spent $1.7 million on the TAPP Program since 2006. As part of the TAPP program, surveys are conducted before and after an educational campaign to determine its effectiveness. The city started the fertilizer applicator certification program for commercial operations and enacted a fertilizer ordinance. The ordinance reduced the number of households applying fertilizer by 49%, and the remaining households have reduced the amount of fertilizer they are applying.

After the City's wastewater facility upgrade, about 45,600 kg/yr of nitrate reduction remains to meet the TMDL. However, the estimated reduction from removing biosolids meets most of this balance. Some of the other sources such as atmospheric deposition, livestock, creeks/sinks, and fertilizer are harder to address. There could be work to address inflow but the low hanging fruit is the septic tanks south of the Cody Scarp. The Lombardo report has general guidance for addressing sources and the report recommends addressing septic tanks in the PSPZ through upgraded systems. There are approximately 7,500 septic tanks in Leon County, 11,000 tanks in Wakulla County, and 188 tanks in Tallahassee.

7.4.3 Wakulla County Springs Protection Measures and Nitrate Reduction Strategies

Wakulla County has a history of protecting Wakulla Springs, especially since the springs are located within the county. The county delineated the Wakulla Springs Planning Area in 1994. A lot of this area is in public ownership, and the rest of the lands are either agricultural or rural. The idea is to maintain low impact development in this area to help protect the springs.

The county has comprehensive plan policies to protect the springs. These policies include several conservation objectives. These objectives establish the special planning area, establish a transfer of development rights policy to encourage development in Crawfordville with connection to sewer, require no net increase in density in the special planning area, restrict fertilizer use based on the Florida Yards and Neighborhoods Program guidelines and best management practices (BMPs), encourage use of low impact design (LID) practices, and consider expansion of the special area for future protection of the springs. The Lombardo report does show an impact to the springs going south to US 98, so this area to the south could be potentially added to the Wakulla Springs Planning Area for protection. The county had a policy for a mandatory inspection program of septic tanks countywide; however, this policy was eliminated in part due to legislative limitations but also because it was never fully implemented. The County's board is interested in drafting an ordinance for inspection of septic tanks within the special area. This inspection program would be implemented through an ordinance to provide more flexibility. The County also has a conservation policy to establish buffers around springs, spring runs, sinkholes, and other karst features.

Wakulla County has a future land use objective that requires Best Management Practices (BMPs) for development. The county also has an infrastructure policy that requires Advanced

Wastewater Treatment (AWT) for any facilities within the special planning area; however, there are no wastewater facilities within this area currently. There is another infrastructure policy that requires performance based treatment systems for parcels less than five acres within the special area, within 150 feet of karst features, within 300 feet of a first or second magnitude springs, or on parcels less than 0.229 acres. This policy for small parcels helps to address septic tank issues within older developments, although this is not a long-term solution. There is more that can be done in the future to sewer these areas.

The Lombardo report has a map that shows sewer service locations. There are parts of the county, including Crawfordville, that have sewer service. However, many areas are not covered by sewer and this is an infrastructure issue that the county will need to address. Luis stated that he believes the best solution for improving groundwater quality is to remove septic tanks and connect those properties to sewer.

Section 8.0 Description of Impairments

8.1 Introduction

For more than a century Florida has attracted new residents because of the moderate climate and natural beauty of the state. This attraction has spurred residential, commercial, and urban development to support the infrastructure necessary to provide for residents and tourists. Additionally, agriculture has taken advantage of Florida's moderate climate to produce large quantities of food and forage, including row crops, livestock, and dairy goods. This increasing economic development has resulted in inevitable stresses on Florida's natural environment as humans have altered the environment to suit their needs. While the natural environment of Florida (for example the beaches, estuaries, rivers, and springs) are what attracted many people in the first place to the State, the inevitable "footprint" of those residents and tourists has taken its toll on these natural resources.

One of the most striking examples of this control has been the ditching and draining of Florida that have resulted in the desiccation of much of the state to provide arable land for agriculture and construction. The removal and draining of wetlands altered the landscape and more importantly the water balance of the state with fewer areas recharging water to the aquifer simultaneous with a need for additional water to irrigate the "new" arable land.

The human population of Florida was approximately 18.8 million in 2010. Given the area of the state (53,900 square miles or 34.5 million acres) and assuming that these people are evenly distributed indicates that the average density of Florida residents is about 350 people per square mile. This density represents a significant increase from about 2.8 million residents in 1950 (51 people per square mile). Population expansion and high intensity life styles characterized by excessive irrigation, fertilizer use, and recreational activities, are ultimately responsible for the observed impairments in Florida's natural environments, including springs. Reversal of the negative trends described in this report can occur by a collective acknowledgement of the detrimental consequences of this human footprint and purposeful reduction of impacting behaviors.

Springs and spring runs are a unique class of freshwater ecosystems. They are different from the majority of fresh surface waters due to the following recognized properties (Odum 1957):

- Relatively minor variation in flows (hydrostatic) compared to the majority of streams and rivers
- High water clarity/transparency unlike most streams and rivers, with optimal light availability for primary productivity
- Consistent chemistry (chemostatic) and water temperature (thermostatic) due to their reliance on groundwater inflows

These unique environmental properties of springs and spring-fed rivers are independent of the presence or absence of contiguous floodplain habitats. Thus, although adjacent floodplain wetlands provide additional ecological benefits to some spring ecosystems, they are not synonymous with springs or a necessary part of their ecological functioning.

The unique combination of physical and chemical properties imparts the following opportunities for optimizing ecological efficiency and wildlife habitat support in Florida's springs and in associated spring runs:

- Highly stable environmental conditions that promote the evolution of complex, adapted plant and animal communities
- Maximum use of available light for conversion to useful gross primary productivity that supports a high secondary productivity of primary, secondary, and advanced consumer organisms
- Autotrophic ecosystems that approach ecological perfection for the full utilization of locally-produced organic carbon
- Export of internally-produced organic matter that augments downstream aquatic ecosystems and attracts the immigration of downstream fauna that complete various portions of their life histories in the springs and spring runs, imparting additional services that help to maximize photosynthetic efficiency (the conversion of incoming solar radiation into organic carbon through the process of photosynthesis)

For these reasons springs and spring-fed rivers like Wakulla are among the most productive freshwater aquatic ecosystems on earth in terms of the production of plants and wildlife. The wildlife habitat function of springs is well documented and (Odum 1957, WSI 2010, WSI 2012).

In addition to the importance of spring runs for the support of highly productive warm-water fisheries, and their support for turtles, alligators, and water-dependent birds, they are critical for the life history of other large and economically-important migratory wildlife such as striped bass, sturgeon, mullet, channel catfish, shad, eels, and manatees. In fact, spring runs in Florida are essential for the life histories of all of those important species. This importance is a direct result of the unique physical/chemical properties of healthy springs and their resulting optimum photosynthetic efficiency.

This section describes the known impairments evident at Wakulla Spring and the Wakulla River and some of the causative factors resulting in those impacts. The review of existing and historic conditions above indicates that the principal environmental changes that have occurred at Wakulla Spring over the past 50 to 100 years include:

- Increased discharge including more frequent occurrence of tannin-stained and "green" water, along with water clarity and transparency issues;
- Elevated nitrate-nitrogen concentrations at the spring;
- Replacement of native submerged aquatic macrophytes by hydrilla and filamentous algae;
- Loss of apple snails and limpkins.

Each of these observed changes can be considered to be "impairments" in the general sense used by the U.S. EPA and FDEP to characterize the protection of designated uses for surface water bodies. An estimate of the level of "impairment" associated with these noted changes is provided in this section.

8.2 Flow Increases and Decreased Water Transparency

Average Wakulla Spring discharge has increased about 85% in the past decade compared to the entire 104 year period-of-record (WSI 2010). Alone, this fact might appear to signal good news for the ecology and aesthetics of Wakulla Spring. With further examination it is clear that the increased flow at Wakulla Spring is tied to increased inputs of surface waters that are high in tannins derived from wetlands feeding stream-to-sink inputs to the Floridan Aquifer. Based on a relatively detailed knowledge of the subsurface conduit system (conduit mapping and dye-trace studies) linking Wakulla Spring to these swallets and the inter-connected nature of Wakulla Spring and Spring Creek Springs, there is general agreement among hydrogeologists that the two springs are fed from the same groundwater sources, depending on the elevation of the potentiometric surface of the groundwater in the interconnected cave system. All of the detailed processes affecting this flow balance between Wakulla Spring and Spring Creek Springs are still not completely understood but there are at least two major factors affecting this delicate balance:

- The relative amounts of clear artesian and colored surface waters entering the aquifer, and
- The elevation and salinity of the Gulf of Mexico at Spring Creek as affected by tides, wind-driven surges, and sea-level rise.

Improved data collection and additional monitoring and modeling are needed to evaluate the relative importance of these two proposed principal driving forces for this flow split. Factors affecting the water budget, the backflow of water into the Spring Creek group of springs, and the increase in dark water days at Wakulla Spring all warrant serious attention.

In the meantime as additional analysis of this situation is conducted, it is reasonable to observe that only one of these two likely factors is within the immediate control of the stakeholders interested in restoration of Wakulla Spring, *i.e.*, the withdrawal of clear groundwater for water supply. Human water uses within the Wakulla Springshed are controllable and the net consumption of artesian groundwater that previously flowed to Wakulla Spring and Springs Creek Springs has been significantly reduced over the period-of-record. Net consumption of groundwater in the Florida portion of the springshed has increased by an estimated 200 percent since the 1960s and it is considered likely that net consumption in the Georgia portion of the springshed has increased at a similar rate.

To achieve a reduction in the frequency of "dark-water" days at Wakulla Spring, it is essential to better quantify the historic and current water balance for the springshed, and to determine the costs and benefits of reducing the net consumption of clear artesian groundwater ultimately discharging at Wakulla Spring.

8.3 Water Quality Impairments

Water quality and quantity protection are important components of environmental law in Florida and in the U.S. Wakulla Spring and the Wakulla River and their adjacent wetlands are Class III Waters with the designated uses of: ***fish consumption, recreation, and propagation and maintenance of a healthy and well-balanced population of fish and wildlife***.

All Florida waters are protected by minimum criteria (Chapter 62-302.500, F.A.C.) against components of discharges that:

1. ***Settle to form putrescent deposits or otherwise create a nuisance; or***
2. ***Float as debris, scum, oil, or other matter in such amounts as to form nuisances; or***
3. ***Produce color, odor, taste, turbidity, or other conditions in such degree as to create a nuisance; or***
4. ***Are acutely toxic; or***
5. ***Are present in concentrations which are carcinogenic, mutagenic, or teratogenic to human beings or to significant, locally occurring, wildlife or aquatic species, unless specific standards are established for such components in subsection 62-302.500(2) or Rule 62-302.530, F.A.C.; or***
6. ***Pose a serious danger to the public health, safety, or welfare.***

A total of 70 water quality constituents are regulated in Class III waters with identified criteria that cannot be exceeded (Chapter 62-302-530, F.A.C.).

In addition to the standard Class III level of water quality protection, Wakulla Spring and the Wakulla River and their contiguous floodplain wetlands are Outstanding Florida Waters (OFWs), Chapter 62-302.700, F.A.C. The OFW rule states that: ***"It shall be the Department policy to afford the highest protection to Outstanding Florida Waters and Outstanding National Resource Waters. No degradation of water quality, other than that allowed in subsections 62-4.242(2) and (3), F.A.C., is to be permitted in Outstanding Florida Waters and Outstanding National Resource Waters, respectively, notwithstanding any other Department rules that allow water quality lowering."***

Based on a decision by the U.S. Supreme Court (1994), the U.S. EPA has declared that flow itself is protected in so far that it affects water quality (Giattina 2013). In a memo to Florida's Department of Environmental Protection, Jim Giattina with U.S. EPA Region 4 stated that:

- ***"Anthropogenic disruptions in natural river and stream flows are called hydrologic alterations and include surface and groundwater withdrawals, dams and impoundments, channelization and stormwater runoff";*** and
- ***"hydrologic alteration may be the primary cause of ecological impairments in the U.S. and impacts freshwater use for drinking water, agriculture, industrial and municipal facilities, recreation and tourism and the jobs associated with seafood and shellfish harvesting";*** and

- ***"reductions of freshwater flows create economic concerns, ranging from loss of outdoor recreation and tourism revenue, the loss of ecosystem services and the loss of jobs…";*** and finally
- ***"hydrologic alterations can be addressed using existing Clean Water Act tools, with a focus on water quality standards."***

Two principal water quality changes have been documented over the period-of-record at Wakulla spring:

- An increase in the frequency of occurrence of dark and turbid water (reduced transparency), and
- Continued elevated concentrations of nitrate-nitrogen.

Other secondary water quality changes have been observed at Wakulla Spring that appear to be due, at least in part if not completely, to the increased occurrence of dark and green water inputs. These ancillary water quality changes include:

- Variable and possibly increasing specific conductance and concentrations of associated cations (calcium and sodium) and anions (chlorides, sulfate, and carbonates);
- Variable and possibly declining dissolved oxygen and pH concentrations; and
- Variable water temperatures.

There have been no notable changes in the concentration of total and ortho-phosphorus, the other possible nutrient contaminants often derived from fertilizer and wastewater influences.

8.3.1 Dark (Tannic-Stained) Water

Anecdotal records indicate that dark water conditions have occurred at Wakulla Spring sporadically since at least the 1930s. Quantitative data on the occurrence of these dark water conditions is only available for the period since 1987. The frequency of occurrence of dark water days (and higher average flows) at Wakulla Spring appears to have increased significantly over the past two decades. The increased frequency of dark water days at Wakulla Spring is a negative change for at least two principal reasons:

- The aesthetic experience for human visitors to the spring is changed when it is not possible to enjoy the visibility of the clear water, and
- The submerged ecological community loses one of its most important forcing functions, namely solar radiation, due to increased light sorption in the water column, in turn increasing ambient water temperature and reducing plant productivity and the food available to the aquatic food web.

Dark water results in a reduction of the transparency of the water, which is defined as the depth of the compensation point for photosynthetic activity and is roughly equal to the Secchi depth. The Class III freshwater criterion for transparency is no reduction more than 10% compared to the natural background (Rule 62-302.530(68), F.A.C.).

The overall importance of this loss of transparency to the ecology and recreational values of Wakulla Spring needs additional quantification. Specifically, continuous recording data sondes could be installed near the head spring area that more accurately record the occurrence and effects of dark water on light transmission and primary productivity.

8.3.2 Nitrate-nitrogen

Historical nitrate-nitrogen concentrations in Florida's springs were typically less than about 0.05 mg/L. The earliest reported nitrate-nitrogen concentration reported at Wakulla Springs was 0.04 mg/L in 1956 (Gilbert 2012). Since that time, nitrate-nitrogen concentrations from the mid-1970s to the early 1990s, followed an increasing trend that mirrored human development and population growth within the Wakulla Springshed. The nitrate concentration in the spring remains elevated. Anthropogenic and natural nitrogen sources and loads have been estimated by a number of researchers (Chelette *et al.* 2002; WSI 2011; Eller and Katz 2013). These analyses have determined that the principal sources of excess nitrate-nitrogen to the groundwater feeding Wakulla spring over the past 40 years, in approximate order of importance, include:

- Disposal of municipal wastewater effluent;
- Disposal of municipal wastewater residuals (sludge or biosolids);
- Onsite sewage disposal systems (septic tanks);
- Fertilizer applications; and
- Rainfall contributions.

Considerable effort has been expended to reduce the nitrogen load from the first two sources. The City of Tallahassee is the largest municipal water and wastewater provider in the Wakulla Springshed and has ceased applying biosolids and fertilizer to the effluent disposal site. The City's largest wastewater treatment facility, the T. P. Smith Water Reclamation Plant, has been upgraded to provide advanced removal of total nitrogen, expected to lower the average effluent concentration from about 12 to less than 3 mg/L. This treatment upgrade was completed in January 2014.

Some septic tanks can be replaced by central sewer collection and treatment systems that are designed to meet advanced nitrogen removal standards. For example, Wakulla County has an ordinance that requires all new on-site septic systems to meet these advanced nitrogen removal standards. Existing spray fields can be replaced by constructed groundwater recharge wetlands that can further lower total nitrogen concentrations in the percolating water to less than about 1.5 mg/L and nitrate-nitrogen to less than 0.1 mg/L (Kadlec and Wallace 2009; Knight 2006).

Fertilizer applications should be reduced to the lowest possible levels in all springsheds due to the inevitable increased nitrate-nitrogen concentrations reaching the underlying groundwater and adjacent surface water ecosystems. Considerable evidence exists from Wakulla Spring and elsewhere that elevated nitrate concentrations in springs are tied to resulting detrimental changes to aquatic plant communities in the springs (Gilbert 2012; Hallas and Magley 2008).

Rainfall nitrogen contributions are not within control of the Wakulla stakeholders. However other land use practices that affect groundwater nitrate concentrations are within the public's control. For example, conversion of open unfertilized grassland to unfertilized forestry is likely to reduce the amount of atmospheric nitrogen that reaches the underlying groundwater (Cohen *et al.* 2007).

The overall importance of nitrate-nitrogen as an impairment at Wakulla Spring has been documented by the FDEP in the final TMDL document for the Upper Wakulla River (Gilbert 2012). The TMDL for the Upper Wakulla River requires a 56.2% reduction in the mean concentration of nitrate-nitrogen at Wakulla Spring (from an average of about 0.8 mg/L to 0.35 mg/L). With additional data collection and analysis the cost and benefits of various options for further reducing nitrate concentrations at Wakulla Spring can be evaluated and appropriate action taken. FDEP and Wakulla Spring stakeholders are currently developing a Basin Management Action Plan.

8.4 Biology

8.4.1 Hydrilla Invasion and Plant Community Changes

The relationship between hydrilla invasion and the two principal impairments described above (dark water and elevated nitrate-nitrogen concentrations) has not been determined. One practical approach to address this lack of knowledge is to implement restoration activities that would increase the occurrence of clear water and lower the concentration of nitrate while simultaneously monitoring the cover and spread of hydrilla. A second approach that should be combined with the first approach is the development of a detailed ecological study of the factors affecting hydrilla success in Wakulla Spring and at similar control sites. Both alternative approaches would help increase the understanding of the effects of dark water and elevated nitrate-nitrogen concentrations on hydrilla invasion as well as on the dominant submerged aquatic plants such as eelgrass, tapegrass, and filamentous algae. The ultimate measure of successful restoration with regards to invasion of hydrilla is to replace the dominant hydrilla with the former dominance by eelgrass and tapegrass with low cover by filamentous algae.

8.4.2 Loss of Apple Snails and Limpkins

Although hard scientific evidence is lacking, it is intuitive that the loss of apple snails and the resulting decline in the population of limpkins at Wakulla Springs State Park is somehow related to the increase in dark water, nitrate, high water levels, and hydrilla, either alone or in combination (Cerulean 2004). Any ecological study of Wakulla Spring with the intention of identifying impairments and how to manage the aquatic ecosystem into the future should include specific quantification of keystone species such as apple snails and limpkins, as well as the other important spring fauna.

8.4.3 Ecosystem Metabolism

Whole-ecosystem data collected as part of the FWC twelve-spring ecosystem comparison study (WSI 2010) indicates that dark water and possibly elevated nitrate concentrations are affecting ecosystem metabolism at Wakulla Spring. Unfortunately there is no long-term record of this integrative measure of ecosystem health at Wakulla Spring but there are long-term data from other large artesian springs that provide additional support for these conclusions (Munch *et al.* 2006). It is important to begin to rectify this lack of a site-specific baseline for ecosystem metabolism at Wakulla Spring. Any monitoring plan for Wakulla Spring ecological health assessment should include continuous monitoring of community metabolism.

Section 9.0 Restoration Goals

9.1 Visioning the Future of Wakulla Spring

A Future Scenarios Visioning exercise for the Year 2035 was conducted by stakeholders during the December 10, 2010 Wakulla Spring Basin Working Group Quarterly meeting. Approximately 40 stakeholders participated in this exercise. Participants envisioned both a "best-case" scenario at Wakulla Spring in the Year 2035 that was termed the ***Crystal Bowl of Light***, and a "worst-case" scenario at Wakulla Spring in 2035 that was termed the ***Black Lagoon***. The purpose of the visioning exercise was to develop a general list of the types of important events, decisions, and actions that could occur in the next 25 years that would lead to either the ***Crystal Bowl of Light*** scenario or the ***Black Lagoon*** scenario at Wakulla Spring.

The importance of this visioning exercise was to illustrate the importance of the events, decisions, and actions that will affect the future condition of Wakulla Spring. Conceptualizing these decisions, actions, and events that will contribute to a best-case future scenario for Wakulla Spring allowed the working group members to understand the process whereby Wakulla Spring could achieve a more desirable future. Thus, developing the possible range of events, decisions, and actions allowed the participating stakeholders to understand *that the decision makers and residents of the Wakulla Springshed will ultimately influence the eventual fate of Wakulla Spring*. Conversely, this visioning exercise also identified the general types of important events, decisions, and actions that the working group members collectively thought should be avoided in order to prevent the worst-case scenario from developing at Wakulla Spring. The consensus of the stakeholders was to work towards achieving a "best-case" scenario for Wakulla Spring.

The important events, decisions, and actions were presented by the working group participants in the context of environmental, economic, social, and political context. A summary of the working group consensus for each of these factors is provided below for both the best-case and worst-case scenario.

9.1.1 Best-Case Scenario: Crystal Bowl of Light

<u>Environment Context</u>

- Detrimental land use changes resulting from new development end and in-fill housing becomes more dense;
- On-site wastewater disposal systems are phased out within spring protection areas;
- City of Tallahassee's sprayfield is moved out of the Wakulla Spring springshed;
- River and cave systems within the Wakulla Spring springshed are instrumented with real-time data collection devices;
- Cause of dark water discharge is identified through physical and chemical exploration and study;
- A solution to restore clear water flow to historic levels is developed and implemented; and

- Appropriate research is conducted on how to implement more effective stormwater systems in a sensitive karst region.

Economic Context

- Ecotourism and Green Industries are major sectors of the economy;
- Reduced property tax valuation is implemented for environmentally compatible landscapes;
- Mixed stand longleaf pine silviculture is a major export; and
- Forestry production is used for the biofuels industry and nutrients are balanced with production.

Social Context

- Water quality and environmental protection curriculum is required for public school students;
- Extensive public education for the general public is implemented for protecting groundwater quality, reducing water consumption, and conserving natural resources; and
- Local canoe/kayak and environmental resource- related clubs become very active.

Political Context

- Existing policies for water protection remain in place and are enforced;
- Local governments expand protection areas in springs recharge areas and include meaningful protective measures through comprehensive planning;
- Purchase and preserve land in high springs recharge zones;
- Protection zones are expanded to include all high recharge areas to address land use for those areas with consistent policies across the political entities;
- Ban on bottled water plants in the Wakulla Spring basin;
- Require native landscaping with minimal inputs of water and nutrients;
- Require mandatory public and private recycling;
- A basin-wide stormwater approach is implemented and involves policies and intergovernmental coordination on local and multi-state level;
- Prevent stormwater from directly entering aquifer;
- Require environmental certification program for elected officials;
- Citizens elect representatives that place a high priority on springs protection;
- New development is contained in compact areas in and around existing development and is served by a high quality central sewer system;
- Septic systems are addressed by a Regional Responsible Management Entity that includes management of existing systems and siting, engineering and installation of new higher performing septic systems;
- All central sewer are AWT and under regional management; and
- No expansion of existing City of Tallahassee sprayfield and additional future flows are addressed through a proper reuse system (properly distributed through a regional area).

9.1.2 Worst Case Scenario – Black Lagoon

Environmental Context

- Environmental management ends and results in water quality degradation, loss in productivity, invasion of nuisance flora and fauna, habitat loss and degradation, hydrilla explosion, and exotic snail entrenched in the river;
- Septic tanks continue to be a source of pollution;
- New sinkholes form in vulnerable areas;
- Karst system responds to increased groundwater pumpage with an increase in sinkhole development;
- Karst system collapse: redirects flow to Spring Creek Springs;
- New Gulf Oil spill introduces oil thru Spring Creek Springs; and
- Global climate change stresses water budget.

Economic Context

- New heavy industries located on St. Marks and Wakulla Rivers to promote jobs;
- Industrial facilities located in vulnerable springshed areas;
- New biomass plant permitted (190 tons/yr of TN exceeds TMDL limits);
- Industrial leaks and spills occur with no remediation;
- Job opportunities grow because of heavy industry;
- Several bottling facilities open in Leon and Wakulla County;
- City of Tallahassee unable to implement further nutrient reductions at WWTP;
- New WWTP built in Wakulla Springs watershed;
- Septic tank growth continues;
- Increases in agricultural uses and fertilizer application in Springs Basin;
- Double-digit recession keeps tax base down;
- Growing disparity in income levels creates impoverished community that cannot pay for costs of groundwater protection; and
- Funding for springs management and groundwater flows discontinued.

Social Context

- Stakeholders and community cannot reach consensus to protect Wakulla Spring;
- Restoration Plan not implemented;
- State Park gives concessionaires control of park;
- News media ignore environmental concerns and issues; and
- Disinformation campaigns conducted by special interests sway the public away from environmental protection.

Political Context**:**

- Cascade and repeal of local and State environmental protection regulations (septic tanks, fertilizers, groundwater withdrawals, TMDLs);
- BMAP not adopted for Wakulla Spring;
- TMDL limits are not protective enough of Wakulla Springs;

- Regulations for wastewater (sewer & septic) and stormwater weakened;
- Aquifer protection ordinances eliminated;
- Local governments discontinue water quality monitoring efforts;
- Elections based on producing jobs and income and not on the protection of resources;
- Local & state politicians elected who do not have a vision for environmental protection;
- DCA eliminated, EPA & DEP gutted;
- Relaxed development standards;
- State of Florida files suit to override new EPA nutrient rules;
- Land use regulations relaxed so more roadways, inadequate setbacks in environmentally sensitive areas, and construction BMPs eliminated to promote development;
- Environmental protection considered "pie in the sky";
- All of the above weakens growth management and environmental protection;
- High temperature industrial effluent allowed in Wakulla River;
- As a result of the focus on economic development, there are tremendous increases in population and housing densities and poorly planned development in the basin;
- Re-development occurs in the urban areas without stormwater retrofits, with a decrease in stormwater treatment and a decrease in water quality into the swallets;
- Expansion of consumptive uses results in unchecked growth and lowering discharge of spring and the aquifer;
- South Florida and Georgia increase their consumptive use;
- Georgia not concerned about groundwater issues in Florida;
- Georgia will not cooperate or understand regional issues or responsibilities;
- State of Florida no longer monitors water quality in spring;
- State Parks close;
- Sale of protected public lands sold to generate revenue for state
- No link between job creation and Wakulla Spring protection;
- U.S. Supreme Court ruling allows no limit to political contributions from corporations causing environmental interests to be sacrificed over big business interests; and
- Taxes are cut to such levels that funding is not adequate for public education or environmental protection.

9.2 Stakeholder Goals for Restoration

Three priority restoration issues were discussed at the March 3, 2011 Wakulla Spring Basin Working Group Quarterly meeting regarding the factors that may be contributing to the problems and alternative restoration alternatives. The three priority restoration issues are nitrate-nitrogen (NO_3-N), dark water days, and biological communities. After the presentation, participating stakeholders divided into four groups to develop specific restoration goals related to NO_3-N, dark water days, and biological communities. Each of the four groups then presented their restoration goals to the audience for general discussion and consensus. Approximately 50 stakeholders participated in development of the restoration goals. An overview of the problems and consensus for each restoration goal are described below.

9.2.1 Restoration Goal # 1 – Reduce Nitrate-Nitrogen (NO_3-N)

The historic concentration of NO_3-N at Wakulla Spring is assumed to have been <0.05 mg/L and the current NO_3-N concentration is approximately 0.79 mg/L. The draft Numeric Nutrient Criteria and Total Maximum Daily Load (TMDL) propose a target of 0.35 mg/L of NO_3-N at Wakulla Spring. Potential restoration goals related to Wakulla Spring include:

1. <0.79 mg/L – no action and maintain existing loads;
2. ~0.3 – 0.35 mg/L (the target of the Numeric Nutrient Criteria and TMDL) by implementing the nitrogen reductions at the City of Tallahassee's (COT) facility and allowing no future increase in nitrogen loads;
3. <0.25 mg/L by implementing the planned nitrogen reductions at the COT facility, significantly reducing the number of septic tanks in the springshed, implementing fertilizer reductions, and allowing no new nitrogen loads; or
4. group consensus of a different nitrate goal.

All four groups agreed that the NO_3-N goals for the Restoration Plan should be as follows:

- Meet or exceed the target NO_3-N goal of 0.35 mg/L that is noted in the TMDL
- Develop a Basin Management Plan Action Plan (BMAP) within the next five years
- Reduce the nitrogen loads from septic tanks in the springshed
- Decrease fertilizer use

9.2.2 Restoration Goal # 2 – Reduce Dark Water Days

Between 1987 and 2003 the water at Wakulla Spring was clear enough that the glass-bottom boats could run from 17 to 75% of the time. Between 2004 and 2010 the frequency of dark water days increased to where the glass-bottom boats ran <15% of the time. The cause(s) for the increased dark water flows to Wakulla Spring are not well understood, however, there appears to be a delicate balance between groundwater and surface water flow contributions, and between flows to Wakulla Spring and flows to Spring Creek Springs. Some of the possible factors that may be affecting the balance include lower hydraulic gradient overall, depressed groundwater conditions in the springshed, elevated groundwater conditions in the south around Spring Creek, and increased salt water intrusion.

Potential restoration goals related to reducing the number of dark water days at Wakulla spring include the follows:

1. >300 days per year of dark water - no action and maintain existing groundwater balance;
2. ~250 – 300 days per year of dark water – raise groundwater levels by increased recharge or decreased pumpage in the springshed;
3. <~180 days per year of dark water – further raise groundwater levels by increased recharge and decreased pumpage in the springshed; or
4. group consensus on a different dark water days goal.

Following a collective discussion, all four groups agreed that the goal for the number of dark water days at Wakulla Spring should be < 90 days per year. The consensus of the four groups was also to:

- Reduce groundwater pumpage;
- Promote water conservation & education; and
- Continue research regarding a water budget and flow patterns

9.2.3 Restoration Goal # 3 – Restore Spring Ecology

Multiple changes have occurred in the plant and animal ecology at Wakulla Springs – most notably an invasion of hydrilla, a loss of apple snails, and a loss of limpkins, who feed on apple snails. Hydrilla control in Wakulla Spring and Wakulla River has been dependent upon recurring applications of the herbicide, Aquathol. However, herbicide control of hydrilla can result in unintended consequences such as invertebrate mortality, depressed dissolved oxygen levels, loss of desirable submerged plant species, and increased algal cover.

Potential restoration goals related to restoring the ecology of Wakulla Spring are listed below. Some of these restoration goals overlap with those restoration goals noted above for reducing NO_3-N concentrations and dark water days.

1. No change from current herbicide practices;
2. Stop herbicide treatments;
3. Increase herbicide treatments;
4. Increase clear water days (with the actions described above);
5. Lower nitrate concentrations (with the actions described above); or
6. Other alternatives for group consensus.

All four groups agreed on the following:

- Decrease NO_3-N concentrations in order to decrease hydrilla and filamentous algal growth by developing a Basin Management Plan Action Plan (BMAP) within the next five years, reduce nitrogen loading from septic tanks in the springshed, and decrease fertilizer use;
- Increase clear water days by reducing groundwater pumpage, promoting water conservation & education, and continuing research regarding a water budget and flow patterns;
- Continue limited hydrilla management; and
- Increase ecological research.

Section 10.0 Restoration Overview

This report presents an updated comprehensive restoration plan for Wakulla Spring. Key stakeholders and their responsibilities for restoration are described in this section.

10.1 Key Stakeholders

The Wakulla Spring Working Group provided an opportunity for stakeholders to be recognized and their perspectives heard for 18 years. This section briefly lists the key stakeholder groups that participated in the working group and helped support the development of this Restoration Planning document.

Private Landowners

There are tens of thousands of private landowners who will be affected by any comprehensive restoration at Wakulla Spring. This is because the majority of the springshed is in private ownership. While this stakeholder group was not specifically represented at the working group meetings, many of the attendees at these meetings are private landowners in Leon and Wakulla Counties. There was no known representation by private landowners from the Georgia portion of the springshed. Based on our current understanding of the actions that will need to be taken to achieve the desired Wakulla Spring restoration goals, many of these private landowners will be affected by water and fertilizer use restrictions, and possibly increased fees for wastewater management - either through local utility rate increases or by possible upgrades to on-site sewage disposal systems.

Federal, State, and Local Governments

Key public stakeholders identified during this restoration planning effort included:

- United States Government
    - US Congress
    - US Environmental Protection Agency
    - US Forest Service
    - US Geological Survey
    - US Fish and Wildlife Service
    - US Department of Agriculture
    - Natural Resource Conservation Service
- Florida Government
    - Florida Legislature, Governor, and Cabinet
    - Department of Environmental Protection

- Northwest Florida Water Management District
- Department of Forestry
- Florida Fish and Wildlife Conservation Commission
- Department of Economic Opportunity (former Department of Community Affairs)
- Department of Food and Agricultural Services

- Georgia Government
  - Georgia Legislature, Governor, and Cabinet
  - Environmental Protection Division
- Counties
  - Leon County, Florida
  - Wakulla County, Florida
  - Jefferson County, Florida
  - Gadsden County, Florida
  - Decatur County, Georgia
  - Grady County, Georgia
  - Thomas County, Georgia
- Incorporated Areas
  - Tallahassee, Florida
  - Other incorporated areas

Non-Governmental Organizations

- Wakulla Springs Alliance
- 1000 Friends of Florida
- Florida Audubon Society
- Sierra Club
- Howard T. Odum Florida Springs Institute

Private Utilities

- Talquin Electric
- Other private utilities

Agricultural and Forestry Operations

Industrial, Commercial, and Development Operations

10.2 Developing a Restoration Roadmap

A holistic restoration roadmap for Wakulla Spring and the Wakulla River must include the following components:

- Restoration Plan (this report)
    - Summary of Existing Conditions
    - Specific Goals for Restoration
    - Practical Steps Needed to Achieve Those Goals
    - Responsible Parties
- Implementation Plan (future report)
    - A Timeline for Implementing the Restoration Plan
    - Approximate Costs and Funding Sources
    - Monitoring of Progress with Continuing Adaptive Management in Response to Measured improvements

10.3 Specific Goals for Restoration and Practical Steps to Achieve Those Goals

10.3.1 Water Quantity Restoration

The preliminary water quantity restoration goal for Wakulla Spring is to reduce inputs of tannic surface waters while restoring at least half of the estimated clear groundwater that has been lost. This goal will require a reduction in groundwater pumping throughout the Wakulla Springshed of about xx MGD. This reduction should be based on a springshed-wide assessment of groundwater use priorities.

Reductions in groundwater pumping need to be prioritized based on their regional economic importance and can be made through a combination of the following proactive measures:

- Increased water use efficiency;
- Increased water conservation; and
- Increased reliance on alternative surface water supplies to reduce reliance on groundwater uses as much as possible.

Until a detailed economic evaluation is conducted, it is reasonable to assume that all existing groundwater users in the Wakulla Springshed need to reduce their groundwater use by an equal percentage. Public and domestic self-supplies could reasonably achieve this water use reduction goal by reducing or totally eliminating landscape and lawn irrigation with groundwater. If rainfall could be stored locally in ponds, cisterns, or rain barrels, then these outside water use activities could be permitted and continued where necessary.

Agricultural production in North and Central Florida has relatively recently developed a dependency on crop irrigation using groundwater. This use cannot be sustained at current rates if restoring spring flows and springs health is a priority. The most practical first step is to stop issuance of any new groundwater use permits for crop irrigation in North Florida. The next step is to revise existing agricultural permits to restrict water uses to the most necessary and efficient cropping methods and to meter all uses.

Conversion of a large percentage of crops being grown on over-drained, highly vulnerable lands, to non-irrigated crops such as long-leaf pine plantations or in some cases unimproved pasture will be necessary to attain the ultimate water quantity restoration goal. Springs protection zones should be developed based on the aquifer vulnerability maps reproduced in this report. No new high-intensity agricultural operations should not be permitted on vulnerable lands unless they can rely totally on rainfall and surface water storage. Subsidies and tax incentives may need to be developed to lessen the impact of these types of restrictions on existing agricultural producers located in vulnerable areas.

Other significant water uses, including commercial/industrial and recreational will also need to reduce their reliance on groundwater supplies by about 50 percent.

10.3.2 Water Quality Restoration

The preliminary target for nitrate nitrogen concentrations at Wakulla Spring is 0.35 mg/L as determined by FDEP in the Nutrient TMDL for Wakulla Spring (Gilbert 2012). This goal will require an estimated 56 percent reduction in all nitrogen loads to the vulnerable portions of the springshed. This report estimates that there is approximately 163 tons per year of total nitrogen introduced into the Floridan Aquifer in the Wakulla Springshed in the form of nitrogen fertilizer. Other important nitrogen sources include wastewater disposal and septic tank effluents with an estimated annual load of about 287 tons. Rainfall contributes on average about 116 tons per year of nitrogen to the aquifer in the springshed area.

The estimated combined load of total nitrogen reaching the groundwater in the Wakulla Springshed from all of these sources is about 590 tons per year. The average nitrate nitrogen load discharging through Wakulla Spring for the period from 1980 through 2010 was about 470 tons per year. Based on the estimated change in nitrogen load between what is reaching the aquifer and what is exiting the springs, the estimated additional attenuation of nitrogen between the point-of-entry to the Floridan Aquifer and the spring vents due to additional microbial processes, is about 20%. Assuming these assimilative processes will continue at this rate, the total nitrogen applied by human activities to the land needs to be reduced by 56%, for a reduction goal of 1,313 tons per year. The nitrogen load in municipal wastewaters and in septic tank effluents can be practically reduced by about 70% through upgrades to advanced nitrogen removal methods. However, since the nitrogen load to the aquifer contributed by rainfall is not readily controllable, fertilizer uses will also need to be reduced in the vulnerable portions of the springshed by an estimated 70% to achieve FDEP's BMAP goal of 56% nitrogen reduction.

To achieve this goal it may be necessary to discontinue many uses of nitrogen fertilizer in the Wakulla Springshed and to connect all on-site sewage systems to central sewer with advanced levels of nitrogen reduction. A significant portion of this reduction could probably be accomplished in concert with the water quantity restoration described above. Nearly 100% of the springshed is considered vulnerable in terms of groundwater contamination by surface pollutants. Eliminating agricultural and residential fertilizer uses in these vulnerable areas would provide the greatest reduction of nitrogen inputs to Wakulla Springs. A more acceptable solution might be to phase in cuts to all nitrogen fertilizer use in the springshed at about 40 percent reduction in the first five years, followed by a second phased reduction of an additional 50 percent over the next five years, and consideration of one additional phased reduction if found to be necessary based on the measured nitrate nitrogen levels in Wakulla Springs. A phased program to reduce fertilizer use would allow greater flexibility for agricultural producers to develop less polluting cropping strategies.

Nutrient loads originating from livestock will also need to be reduced by about 70% to achieve the TMDL nitrate limit for Wakulla Spring. One way to accomplish this goal is to eliminate all pasture fertilization and then to limit the density of grazing animals to what can be supported by unimproved pasture. A second alternative is to collect all animal manure and to recycle it as an alternative to using inorganic nitrogen fertilizers. Ultimately, the number of large grazing animals in the springshed will need to be reduced significantly to achieve the nitrate TMDL goal.

Human wastewater nitrogen loads in the springshed can be reduced by implementing advanced nitrogen removal for all central wastewater plants and by providing centralized collection and wastewater treatment for all high-density septic tank areas. More than half of the wastewater sources of nitrogen to Wakulla Spring are already being reduced by about 70% through the City of Tallahassee WWTF upgrades. A detailed analysis evaluating and comparing additional nitrogen removal measures using advanced nitrogen removal technologies such as constructed wetlands, biological nutrient removal processes, and nitrogen-removal on-site systems should be prepared as part of the current Basin Management Action Planning process.

In summary, the BMAP must provide realistic but stringent nitrogen reduction measures, regardless of whether or not they affect agriculture or urban land use practices. Costs for these upgrades are likely to be significant and should in turn be compared to costs to reduce other nitrogen inputs to the aquifer from fertilizers and animal/human wastes. The nitrate contamination at Wakulla Spring will not be solved unless all options are on the table and evaluated for cost effectiveness ($ per pound of nitrogen that is prevented from reaching the aquifer).

10.3.3 Exotic Vegetation

Benthic algae prevalence on the Wakulla River is well known and documented (Gilbert 2012). Prevalence of benthic algae has led to the river having a TMDL developed for nitrate pollution.

In addition to the increasing prevalence of filamentous algae, hydrilla has been introduced at the head spring and is common throughout the river. A river-wide approach should be taken to manage exotic vegetation that includes education and coordinated efforts of interested groups to maximize the effective and environmentally-sound solutions.

10.3.4 Holistic Ecological Restoration

The effects of reduced flows, increasing concentrations of nitrate nitrogen, a downstream dam impeding the movement of aquatic fauna, invasions by exotic species, and increasing recreational uses are resulting in visible long-term changes to the natural flora and fauna of Wakulla Spring. Ecological restoration will require a holistic approach to dealing with all sources of impairment simultaneously, rather than a piecemeal approach of divided responsibilities by an array of state and local agencies.

10.4 Education Initiatives

Ongoing public education about the threats facing the long-term health of Wakulla Spring and the Wakulla River will be essential for achieving ultimate restoration. This Restoration Plan provides a preliminary roadmap to fully accomplish restoration goals. However, getting this information out to the public and to the State officials and legislators who are most concerned with springs' protection is an important part of this educational process. This will require public presentations, public meetings, newspaper and TV reporting, rallies at Wakulla Spring, and many partnerships. The Wakulla Spring Alliance, Inc. will most likely be the leader in this effort, with technical support from the Howard T. Odum Florida Springs Institute and other springs advocacy and educational organizations throughout North Florida.

10.5 Regulatory Assistance

The FDEP is currently preparing a BMAP to achieve the TMDL nitrate nitrogen goal at Wakulla Spring. Active participation in this process will be critical to adopt a BMAP that has potential to actually expeditiously reverse the increasing nitrate levels and declining flows so visible in the springs and river. This Restoration Plan can serve as the "People's BMAP" if the FDEP plan does not provide an efficient and timely plan to achieve success with restoration and protection of this spring system.

Simultaneously, in 2013 the NWFWMD belatedly began the process of developing Minimum Flows and Levels (MFLs) for the Wakulla Spring and River. However the District's plan to put off adoption of that MFL until 2023 is totally unacceptable and must be accelerated.

The Florida Department of Agriculture and Community Services (FDACS) is the state agency responsible for regulating agricultural practices in Florida. A paradigm shift is necessary at FDACS and in the development of agricultural Best Management Practices (BMPs). For example, existing BMPs are developed to maximize economic yield while minimizing environmental damage. This prioritization will not result in adequate springs' protection. Agricultural BMPs must be re-designed to first achieve necessary environmental protections and secondly to provide reasonable economic returns. This effort to develop "Advanced BMPs" should result in zoning restrictions on certain intensive agricultural activities like those found for high-intensity urban development. In areas of high groundwater vulnerability the only agricultural crop that is consistently capable of maintaining an average groundwater nitrate concentration of less than 0.35 mg/L is probably long leaf pine. Until a better “Advanced BMP” becomes available, an unfertilized, non-irrigated forestry crop should be mandated by FDACS for the karst areas of the state.

Section 11.0 Wakulla Spring Restoration Challenges and Solutions

Specific recommendations to implement water quantity, water quality, and resource management restoration actions for the Wakulla Spring System are described above in this Restoration Plan. A summary of the general challenges and solutions as well as specific recommendations and entities most likely to be responsible for implementing those actions is summarized as follows:

The Challenges

- Increased awareness by all stakeholders (the public and their local, state, and federal leaders) is necessary to accomplish restoration of Wakulla Spring System (Wakulla Spring and River)
- Reduced consumption of groundwater within and outside of the Wakulla Springshed is needed to restore spring and river flows
- Natural drainage and water storage patterns in wetlands and streams in the Wakulla Springshed need to be restored to enhance spring and river flow and water quality
- Fertilization and wastewater disposal practices need to be improved to reduce the load of nitrogen leaching into the aquifer
- Technical uncertainties still exist concerning the magnitude of human-induced flow reductions and sources of increased nitrogen loads and their effects on the health of the Wakulla Spring System

The Solutions

- Educate the public and local, state, and federal leaders of the importance of restoring the Wakulla Spring System and its natural biodiversity
- Develop a phased plan to restore Wakulla Spring and River flows by cutting back on consumptive uses of groundwater within and outside of the springshed
- Increase protection and restoration of natural drainage and storage patterns in wetlands and streams in the Wakulla Springshed
- Implement consequential improvements in fertilization and wastewater disposal practices in the Wakulla Springshed
- Assess the costs and benefits of restoration efforts, develop a phased restoration timeline, and establish adequate monitoring of the Wakulla Spring System to be able to document whether these efforts are resulting in improved springs health or continued degradation
- The NWFWMD should accelerate the development of a truly protective MFL for the Wakulla Spring System.

Goal #1: Overall Springs Protection

Responsible Entity: Florida Legislature

The Florida Legislature has the ultimate statutory power to provide comprehensive springs' protection and funding to implement restoration actions. In one form or another springs legislation was attempted annually from 2005 through 2010 and again in 2013 and 2014. All of those efforts failed. It will take a significant effort to convince the Florida Legislature to prioritize the importance of springs and water resource protection during a time of fiscal hardship for the state. However, as with rainfall, political priorities tend to be somewhat cyclical. In the event that the political focus shifts back to protecting Florida's unique and priceless environment, including springs, the following recommendations are offered for consideration by the Florida Legislature:

- Fund improved water management (conservation measures), nutrient reduction strategies (best management practices [BMPs], septic system and wastewater upgrades), and springs research by charging a user fee (Aquifer Protection Fee) on all permitted groundwater extractions from the Floridan Aquifer System
- Groundwater use should be priced such that it is no longer in the best interest of large users to maximize their permits despite actual needs
- Amend Chapter 373.042, Florida Statutes to require that alternative water supplies be developed before consumptive use permits create water supply deficits
- Require all Water Management Districts (WMDs) to establish a Regional Groundwater Safe Yield that protects all surface water resources, including springs, from significant harm and Outstanding Florida Waters (OFWs) from any harm
- Strengthen groundwater protection by requiring that consumptive use permits can only be issued when minimum flows and levels for all priority waters are complete and being met
- Change the groundwater nitrate standard (currently 10 mg/L based on human health) to be protective of springs health (less than 0.35 mg/L)
- Adequately fund the Florida Department of Environmental Protection (including the Florida Geological Survey and the Florida Park Service) to be able to provide comprehensive springs resource management

Responsible Entity: Florida Park Service (FPS)

The FPS has authority to regulate human uses and management priorities in Florida's state parks. Recreation is a vital component of springs protection because it develops an awareness of the resource that needs protected. However, excessive recreation is an environmental stress due to erosion, plant trampling, and annoyance of wildlife. The FPS should ensure that recreational carrying capacity is estimated for all spring-based state parks and that authorized human uses are compatible with healthy spring ecosystems.

Goal #2: Restoring Spring Flows

Responsible Entity: Northwest Florida Water Management District (NWFWMD)

The NWFWMD has the responsibility to regulate all human water uses in the Wakulla Springs basin. This responsibility includes the evaluation of the environmental flow requirements of the Wakulla Springs System as well as the need to provide adequate water quantities to meet reasonable beneficial human uses. Preparing and adopting MFLs and a prevention/recovery strategy for the Wakulla Springs System is a critical part of this responsibility. But the NWFWMD also needs more information to effectively manage a finite groundwater resource. This information, namely how much groundwater is available considering the mandate to provide adequate flows for environmental needs, is not available to the NWFWMD Governing Board. The recommendations provided below would insure that adequate information is available for effective and sustainable water management.

- Fund the U.S. Geological Survey or the FGS to prepare an annual water budget for the Wakulla Spring Springshed that specifies the total allowable groundwater available for human uses and reserves adequate groundwater for the natural systems
- Estimate the contribution of groundwater pumping in Georgia to groundwater flow reductions in Florida
- Endorse the USGS reports that demonstrate a regional lowering of groundwater levels and consequent reduction of historic Wakulla Spring System discharge due to human withdrawals
- Work collaboratively with the Leon County Soil and Water District, the Natural Resources Conservation Service, the USGS, and Georgia Department of Natural Resources (DNR) to place mandatory limits on groundwater pumping
- Set a timeline for overall reductions in groundwater pumping necessary to return the Wakulla Spring System flows to >95% of historic conditions, with a focus on effective water conservation practices, development of alternative surface water sources, and a moratorium on issuance of new water use permits if deadlines are not met
- Require metering of all groundwater uses
- Discourage the use of groundwater irrigation in the Wakulla Springshed
- Prepare a database of all existing wells (agricultural, industrial, municipal, and domestic self-supply) in the NWFWMD with geographic coordinates, estimated pumping rates, and historic levels
- Request that Georgia DNR prepare a similar database of wells
- Synthesize existing groundwater level monitoring efforts with the other water management districts to ensure adequate coverage and sampling frequency for semi-annual springshed delineation of all first and second magnitude springs in North Florida
- Work with Georgia DNR and the NRCS to implement a regional network of additional monitoring wells as needed to continuously and more accurately record changes in groundwater levels throughout the Wakulla Springshed

- Instrument a representative group of agricultural and private wells with water meters to increase knowledge of existing and future groundwater pumping rates
- Develop an improved surface water/groundwater model that also accounts for conduit flow within the Floridan Aquifer to improve modeling performance and water balance estimation; this effort should be bolstered through development of accurate water balances for each springshed that are updated annually
- Accelerate development and adoption of the MFLs for Wakulla Spring and the Wakulla River before the current 2023 deadline, and in the interim, before the MFL standard is in place, manage and permit existing and new consumptive groundwater uses prudently while ensuring natural system needs and avoiding deterioration of natural functions.

The NWFWMD should work closely with the other regional Water Management Districts to quantify the finite capacity of the Floridan Aquifer to supply all of the public and environmental needs for the current and future residents of North Central Florida. These water management districts should work together to estimate a Regional Sustainable or Safe Groundwater Yield, and to implement a coordinated water conservation program throughout the historic Wakulla Spring Springshed as well as all of North and Central Florida that includes increased public education, Aquifer Protection Fees for all municipal, commercial/industrial, and agricultural water uses; and enforcement of watering restrictions based on groundwater levels.

Goal #3: Restoring Water Quality

Responsible Entity: Florida Department of Environmental Protection (FDEP)

FDEP has responsibility to protect water quality in the Wakulla Spring System and in the groundwater that feeds these surface water resources. The regulatory approach of TMDL followed by BMAP is the existing regulatory tool that FDEP can use to rectify the existing ground and surface water eutrophication. The following recommendations are offered to help improve and expedite this BMAP process.

- Complete a comprehensive BMAP for Wakulla Spring and the Wakulla River springshed basin on an accelerated schedule
- Phase in advanced nitrogen removal (less than 3 mg/L total nitrogen) at all FDEP permitted wastewater treatment facilities.
- Prohibit wastewater biosolids and septage disposal in the Wakulla Springshed basin.
- Work with Wakulla and Leon Counties, the City of Tallahassee and the Florida Department of Health (through the County Health Departments) to develop and implement a permanent strategy and program to reduce concentrations of standard septic systems below the Cody Scarp. Emphasize program strategies that:

- Guide the siting and use of septic systems or any FDEP permitted WWTP systems toward nitrate reducing systems supportive of meeting the TMDL and adopted water quality standard.

- Implement a strategy to provide cluster sewage collection and advanced treatment for all areas in the Wakulla Spring Springshed with high densities of septic systems (>1 per 2 acres)
- Overtime, manage the populations of septic systems in the basin toward greater nutrient reduction end-points such as:

  1.) Work with central sewer system provider(s) that already treat for nitrate to remove significant numbers of previously installed septic system - starting with the areas of identified vulnerabilities;

  2.) Work with local land planning agencies to coordinate proper land use densities and intensities to fit the natural landscape limitations and suitability's helping to match which system serve what areas based on vulnerability, needs, costs, etc.;

  3.) Work with DOH and the County Health Departments to limit the number and placement of new standard septic systems in the identified vulnerable springshed areas and when acceptable performance-based nitrate reducing systems are available (acceptable to the State), and there is assurance of proper long-term management of these systems at a reasonable cost to homeowners, support the careful use of these systems.

Responsible Entity: Florida Department of Agriculture and Consumer Services (FDACS)

FDACS has the responsibility to encourage the economic vitality of Florida's agricultural community as well as the responsibility to work with other state agencies (*i.e.,* NWFWMD and FDEP) to insure that existing and new agricultural production does not cause unacceptable harm to the state's environment. With these potentially-conflicting goals in mind, the following recommendations are offered for FDACS to help support restoration and protection in the Wakulla Spring System.

- Assess and support the most cost-effective strategies and "advanced BMPs" to reduce overall agricultural nitrogen loads to the Floridan Aquifer in the Wakulla Springshed – necessary reductions on land where the Floridan Aquifer is vulnerable to surface contamination are greater than 81% of current uses
- Promote legislation and funding that incentivizes agricultural producers to voluntarily convert to land uses that require less or no fertilizer use
- Promote legislation and funding that incentivizes confined animal operations (CAOs) and horse and cattle ranches to voluntarily cut their discharge of nitrogen to the groundwater
- Prohibit new CAOs in the entire Wakulla Springshed

Responsible Entities: Wakulla & Leon Counties, City of Tallahassee

Wakulla & Leon Counties and the City of Tallahassee are the government entities with greatest interest in the protection and restoration of the Wakulla Spring(s), Wakulla River, contributory springshed components and underlying groundwater. These local governments can help to protect their renewable Wakulla Springs-based economic interests by using their land use, zoning and taxing authorities to encourage springs protection by following these recommendations:

- Enforce land use restrictions in Primary and Secondary Aquifer Protection Zones based on aquifer vulnerability. Direct development at sustainable densities and intensities within these zones while ensuring adequate sanitary sewer infrastructure is in-place to further efforts toward meeting the adopted springs/run water quality standard for nitrate and that identified nitrate contributory sources (septic systems, lawn/ag fertilization and WWTFs) are managed to reduce pollutant loadings.
- Phase in mandatory reductions in residential and commercial lawn and landscape fertilization accompanied by an intensive public information campaign that relates excessive fertilizer use to springs water quality degradation.
- Require all central wastewater treatment and disposal facilities in the County to achieve less than 3 mg/L TN and work to manage both existing and future septic systems under a comprehensive strategy to reduce cumulative nitrate contributions.
- Within the Primary Aquifer Protection Zone, restrict installation of new on-site wastewater treatment systems (septic systems) to properties with a minimum of five acres, and require smaller lots to be connected to a centralized wastewater treatment system that achieves advanced nitrogen reduction (less than 3 mg/L total nitrogen).
- Provide a "nitrogen-credit" assessment (property tax reduction) for all properties in the most vulnerable portions of the Wakulla Springshed (protection zones) that are in non-fertilized, non-irrigated forested land uses.
- Leon County, with several thousand in-ground septic systems below the Cody Scarp should develop and follow a logical strategy of wastewater disposal and treatment management wherein existing concentrations of septic systems are removed or upgraded to remove cumulative nitrate pollutant sources. New septic systems below the Cody Scarp should be allowed only at rural densities, or when specified performance-based septic systems are approved that meet necessary nitrate removal criteria (per State of Florida and County Health Department approved standards).

Goal #4: Reducing Other Agricultural Impacts

Responsible Entity: Wakulla County Soil and Water Conservation District (SWCD)

Considering the good relationship between the SWCD and the agricultural community which is largely responsible for water quantity and quality impairments at the Wakulla Spring System, the SWCD should consider implementing the following recommendations.

- Educate and encourage local agricultural producers to shift to crops that use less groundwater and nitrogen fertilizer
- Petition FDACS and the NWFWMD for authority to provide local oversight of all agricultural operators with Best Management Practices (BMPs) that are intended to reduce wasteful water uses and the load of nitrate and other pollutants that are released into the ground and surface water environment

- Work with University of Florida Institute of Food and Agricultural Sciences to develop "advanced BMPs" that reduce nitrogen loads to achieve target nitrate concentrations in the groundwater of 0.35 mg/L
- Work with producers to implement existing and "advanced" BMPs

Goal #5: Effective Communication

Responsible Entity: Wakulla Springs Alliance

The Wakulla Springs Alliance is the primary citizen-led, non-governmental advocacy group concerned with lasting protection and restoration of the Wakulla Spring System. The following activities are recommended for the organization.

- Advocate for the implementation of this Wakulla Spring Restoration plan
- Seek funding to continue the efforts of the Wakulla Spring Working Group to continue to engage all stakeholders be involved in implementation of the Restoration Plan
- Work with local Rotary clubs to create the Wakulla Spring Promise to encourage all homeowners in Leon and Wakulla counties to reduce their outdoor water and fertilizer uses
- Support the Wakulla Spring SPRINGSWATCH program of citizen volunteers
- Fund annual or bi-annual springs health report cards

Responsible Entities: Tallahassee Democrat/Florida Currents/Other Media Outlets

A vocal and active press can provide effective communication of issues that affect the public's best interests. This recommendation provides a useful role for the press through informing the public about the condition of their common resource and whether or not progress is being made towards recovery from its existing degraded condition.

- Report easily understandable groundwater level, river flow and stage, and spring flow data summaries (provided daily by the NWFWMD or the FSI), and other new research findings, as appropriate, in newspapers and other news outlets of wide circulation to allow the public to see the results of these efforts and the health (improving/declining condition) of their local water resources

Goal #6: Documenting Spring Health

Responsible Entities: Florida Springs Institute/Leon/Wakulla Audubon/U.S. Geological Survey/University of Florida/Florida Department of Environmental Protection/Florida Park Service

These non-profit, federal, and state-funded organizations are primarily interested in studying and protecting the environmental attributes of the Wakulla Spring and River. Good science is necessary to provide good resource management. In the absence of the Florida Springs Initiative, discontinued by FDEP in 2011, the Florida Springs Institute (FSI) was formed to help fill the resulting gap in springs' knowledge. Leon/Wakulla Audubon is a local chapter of

Audubon of Florida, the statewide group of bird and environmental advocates. Members of the local Audubon Society have particular interest in all aspects of environmental protection at Wakulla Spring State Park. Scientists with the U.S. Geological Survey have conducted much of the basic applied groundwater and faunal research throughout the Wakulla Spring System. Florida State University researchers have conducted numerous applied ecological studies in the Wakulla Spring System. FDEP/FPS continues to conduct environmental studies in the Wakulla Spring System focused on informing wise environmental management. These groups could be most effective at implementing the following recommendations.

- Implement an on-going and comprehensive ecological monitoring program in the Wakulla Spring System and in all of its principal springs
- Expand water quality and biological sampling in the Wakulla Spring and River to accurately track trends
- Prepare and publicize Springs Health Report Cards at least bi-annually

Closing Statement

Implementation of the recommendations listed above will require significant will-power and changes to "business as usual." Eventual restoration and long-term protection of the Wakulla Spring System will require a shift from focusing on short-term needs of individuals and businesses, and taking a longer view for conservation and protection of clean and abundant groundwater, which is one of the most important natural resources in Florida. Currently, the groundwater that feeds the Wakulla Spring System is neither clean nor abundant. As evidenced so clearly by the deteriorating water quality and declining flows of Wakulla Spring, North and Central Florida's groundwater resources are also on a declining trajectory. Fortunately, as long as it rains, groundwater is a renewable resource. Hope for the future health of the Wakulla Spring System and for Florida's springs in general is in the hands of the people who have learned to appreciate the unique value of these public resources.

Section 12.0 Evaluation of Success

12.1 Introduction

Wakulla Spring restoration goals may be costly and take many years to accomplish. As specific restoration activities occur it will be important to document changes in the target measures of success. A comprehensive restoration assessment program (monitoring plan) is needed to track progress with adaptive management of the resource. The key to encourage stakeholders to continue on the path leading to eventual restoration is to collect and summarize relevant data about the condition of the Wakulla Springshed and Wakulla Spring. Frequent and comprehensible status reports are essential for success. This section provides preliminary recommendations for evaluating the success of the Wakulla Spring Adaptive Management Strategy.

12.2 Comprehensive Restoration Assessment Plan

A comprehensive monitoring effort will be needed to assess the forward progress of the Wakulla Spring Adaptive Management Strategy. The recommended monitoring plan includes the following elements:

- Springshed Monitoring and Analysis
    - Springshed aquifer levels
    - Springshed delineation (once every three to five years)
    - Springshed land use and land cover updates (once every three to five years)
    - Springshed water balance (annual updates)
    - Springshed nitrogen balance (annual updates)
- Wakulla Spring Monitoring and Analysis
    - Discharge and levels
    - Water chemistry
    - Biology
    - Human use

Each of these types of monitoring and assessment is described in greater detail as follows.

12.2.1 Springshed Monitoring and Analysis

The size, boundaries, and physical, chemical, and land use properties of the Wakulla springshed will be assessed on a three to five-year basis, depending on data availability. Recommended parameters, station locations, and sampling frequency are summarized in Table

12-1. Figure 12-1 provides a map of the approximate springshed boundary as well as preliminary sampling locations.

A dedicated network of Floridan Aquifer wells will be instrumented with continuous recorders to assess real-time changes in potentiometric levels in the aquifer. LIDAR survey data will also be used to measure static water levels in karst windows throughout the springshed.

Floridan Aquifer water quality (particularly temperature, specific conductance, dissolved oxygen, and total nitrogen) and withdrawal rates will be assessed at all public and private supply wells. Self-supplied withdrawals will be estimated by installing totalizing water meters on 100 typical wells in the springshed with monthly measurements.

Aerial photographs will be obtained annually to allow assessment of land use and land cover changes. Rainfall monitoring stations will be distributed throughout the springshed to allow estimation of atmospheric inputs. Select rainfall samples will be analyzed quarterly for total nitrogen.

All perennial streams and significant intermittent streams entering and leaving the springshed will be instrumented for continuous discharge and level measurements and will be sampled monthly for field parameters (temperature, pH, dissolved oxygen, and specific conductance) and for total nitrogen species.

All permitted land application facilities for municipal, domestic, and commercial wastewater effluents will provide monthly records for quantity disposed and total nitrogen concentrations.

All fertilizer sales in the six counties that comprise the Wakulla springshed will be documented on an annual basis using data available from the Department of Agriculture and Consumer Services.

12.2.2 Wakulla Spring Monitoring and Analysis

The environmental structure and function of Wakulla Spring and the Wakulla River will be assessed on a continuous to annual basis, depending on data availability. Recommended parameters, station locations, and sampling frequency are summarized in Table 12-2. Figure 12-2 provides a map of the approximate sampling locations at Wakulla Spring.

All spring vents with average flows above 1 cfs (third magnitude springs) within the Wakulla Springshed will be instrumented for continuous measurement of levels and discharge and will be sampled for water quality field parameters, total nitrogen species, color, and light transparency on a monthly basis. A minimum of two downstream sampling points will be established in each spring run and sampled continuously for levels and monthly for water quality.

Communities of submerged aquatic plants, including all macrophytes and macroalgae species, will be sampled on a quarterly basis. This sampling will be conducted at a minimum of 20 evenly-spaced transects perpendicular to the flow in each spring run.

Spring basin and spring run faunal communities will be assessed quarterly by a combination of Hester-Dendy multiple-plate samplers, Ponar samplers, insect emergence traps and visual counts. Fish counts during dark water conditions will be conducted using electro-fishing equipment.

Table 12-1. Summary of recommended monitoring plan for the Wakulla Springshed.

Description	No. Stations	Parameter(s)	Frequency	Purpose
Floridan Aquifer Wells	20 minimum	Groundwater level by survey and LIDAR	Continuous	Aquifer levels; springshed delineation
Areal photography	Entire springshed	Color photos	Annual	Landuse and cover classification
Precipitation	10 minimum	Quantity, total N content	Quantity –daily Total N - quarterly	Water and nitrogen balances
Surface stream flows	All significant flowing streams entering and leaving the springshed; swallets	Discharge, total N content	Discharge – continuous Water quality – monthly to quarterly	Water and nitrogen balances
Groundwater withdrawals	All public, private, agricultural, commercial, and self-supplied uses	Totalized volumes, total N content	Quarterly	Water and nitrogen balances
Effluent returns	All permitted land disposal sites	Totalized volumes, total N content	Quarterly	Water and nitrogen balances
Fertilizer sales	All commercial and homeowner sales in springshed	Nitrogen content and form	Annual	Nitrogen balance

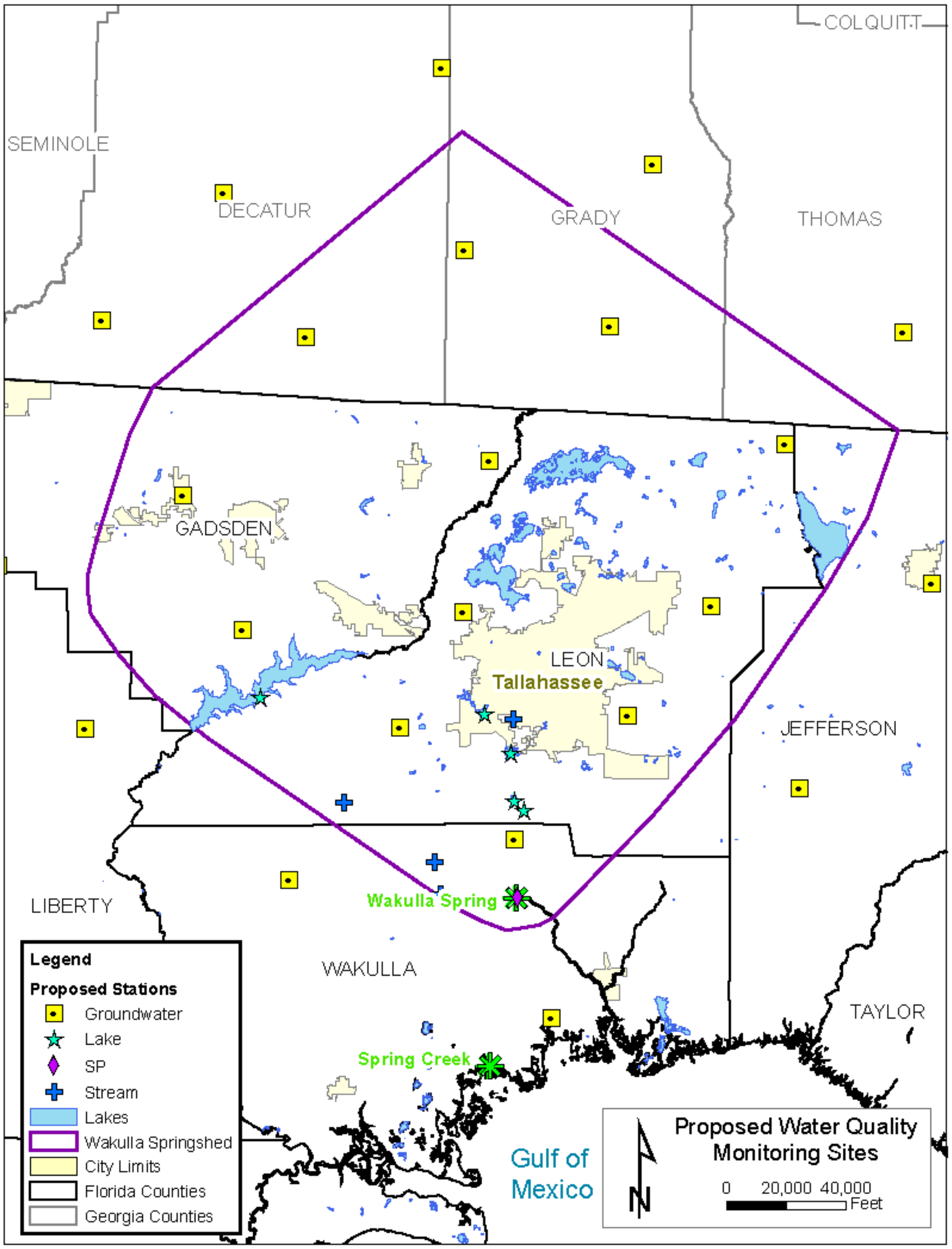


Figure 12-1. Proposed network of restoration assessment monitoring stations in the Wakulla Springshed

Ecosystem monitoring will be conducted continuously for two to four weeks once each quarter using upstream and downstream recording dissolved oxygen sensors. These measurements allow estimation of gross primary productivity, net ecosystem production, community respiration, and photosynthetic efficiency.

Human use of the Wakulla Spring State Park will be assessed through gate entry tallies both into the park and at the boat rides. These counts will be augmented by detailed daily counts during two days each month (one week day and one weekend day).

12.2.3 Reporting

Data collected during the monitoring described above will be reported to the public on a monthly and annual basis on a dedicated project website or in a newspaper of wide circulation. Monthly assessment reports will include aquifer levels, spring discharge, and water quality summaries. Annual reports will include detailed summaries or all data, annual average water and nitrogen mass balances, trend analysis, and analysis of progress towards reaching the Wakulla Spring Adaptive Management Strategy goals. Every three to five years a more comprehensive report will be prepared that provides an assessment of what aspects of the restoration planning efforts are working and recommends changes as needed to optimize restoration success most cost effectively.

Table 12-2. Summary of recommended monitoring plan for Wakulla Spring and the Wakulla River.

Description	No. Stations	Parameter(s)	Frequency	Purpose
Spring vents	All springs in Wakulla springshed	Discharge, water levels, water quality	Discharge and levels – daily Water quality - weekly	Water and nitrogen balances; discharge, levels, and water quality
Spring runs	Minimum of 2 downstream sampling points in each spring run	Water levels, water quality	Levels – daily Water quality - monthly	Water and nitrogen balances, levels, and water quality
Plant communities	Transects – 20 minimum	Plant species ID, percent cover, biomass	Quarterly	Biology
Macroinvertebrate productivity	Insect emergence traps – 10 minimum; snail egg masses	Insect ID and numbers	Quarterly	Biology
Fish biomass	Visual counts or electro-fishing	Fish ID, counts, and biomass	Quarterly	Biology
Herptiles and birds	Visual counts	ID and numbers	Quarterly	Biology
Ecosystem metabolism	Minimum 5 segments	Upstream-downstream dissolved oxygen measurement	Quarterly	Biology
Human use	State park	Total counts; in-water counts	Monthly	Aesthetics

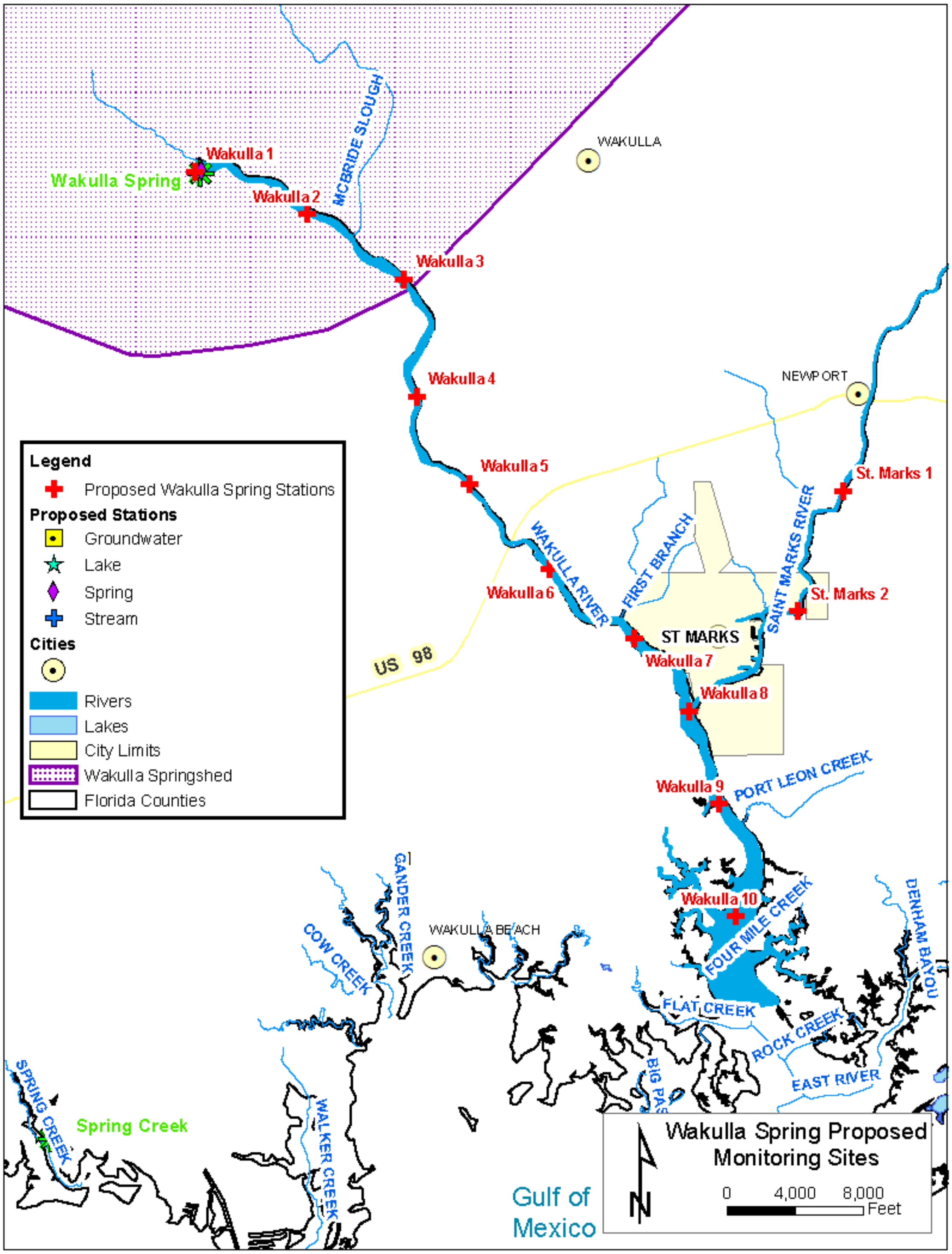


Figure 12-2. Proposed network of restoration assessment monitoring stations in Wakulla Spring and River

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