Working Draft

Wakulla Spring – An Adaptive Management Strategy

Prepared for

The Wakulla Springs Working Group

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Prepared by

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Acknowledgements

This ***Wakulla Spring Adaptive Management Strategy*** provides a public outlet for information 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 Working Group, originally organized in 1992 by Jim Stevenson, head of the Florida Springs Task Force when he was employed by FDEP. The information summaries and new data analyses included in this report were conducted by Dr. Robert Knight and Debra Segal of WSI with input from members of the working group, numerous technical presentations, and the published and unpublished scientific literature. These summaries and analyses are draft pending review and revisions as additional information becomes available. This report represents another step in a 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 working group on any of these complex issues.

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 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. Over 200,000 people visit Wakulla Spring each year.

Similar to most other springs in Florida, Wakulla Spring has been impacted for over 25 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 (*Vallisnaria americana*) and strap-leaved sagittaria (*Sagittaria kurtziana*), periods of decreased transparency due to influxes of tannic-stained water, increasing flows 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 Spring 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 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 this 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 when the Wakulla Springs contract was terminated at the end of the first year. 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. That document is available by request directly from the FDEP project manager (Richard Hicks or Kathryn Holland).

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. This updated report does not necessarily reflect FDEP's views regarding the sources of impairment to Wakulla Spring. However, this document is the next iteration of an adaptive management strategy to maintain stakeholder momentum for eventual recovery and protection of Wakulla Spring.

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 decline 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, the 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 draft TMDL for the Upper Wakulla River posted on the FDEP web-site at: http://www.dep.state.fl.us/water/tmdl/draft_tmdl.htm

- A draft 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 at the Southeast Sprayfield and land application of nitrogen-containing biosolids. Following these changes, nitrate concentrations in water from the Wakulla Spring vent have 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.

- Wakulla Springs State Park has had an increasing number of "dark water" days over the past 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 days increased to the point where glass-bottom boats ran less than 15% of the time. Research has demonstrated that this tannic-stained water is originating from inputs of black water runoff into swallets at the western margin of the Wakulla Springshed in the Apalachicola National Forest. Preliminary hydrogeologic research suggests that the increased frequency of black 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 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.

- As noted above, 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 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 ground water 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 Adaptive Management Strategy 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.

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 stakeholders. While FDEP plans to continue with finalization of the nitrogen TMDL for the Upper Wakulla River and development of a BMAP, a core group of those stakeholders may wish to join forces to identify a timely and comprehensive path forward to refine the proposed actions needed to fully meet the Wakulla Spring Working Group's restoration goals.

Introduction

Background

Wakulla Spring is a true natural wonder. One of the largest first-magnitude artesian springs in Florida, 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**). 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 daily 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 all 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 of 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 intense agricultural and urban development. However, existing nitrate 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 2010). The draft 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 2010).

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 "colored" water days of low light transparency that not only reduces the aesthetic properties of the spring and river for nature-based tourism, but also decreases 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 colored water flows at Wakulla Spring is the combined result of rising sea levels and declining clear water flows from the Floridan Aquifer (Kulakowski 2010; Davis 2011; Kincaid *et al.* 2010).

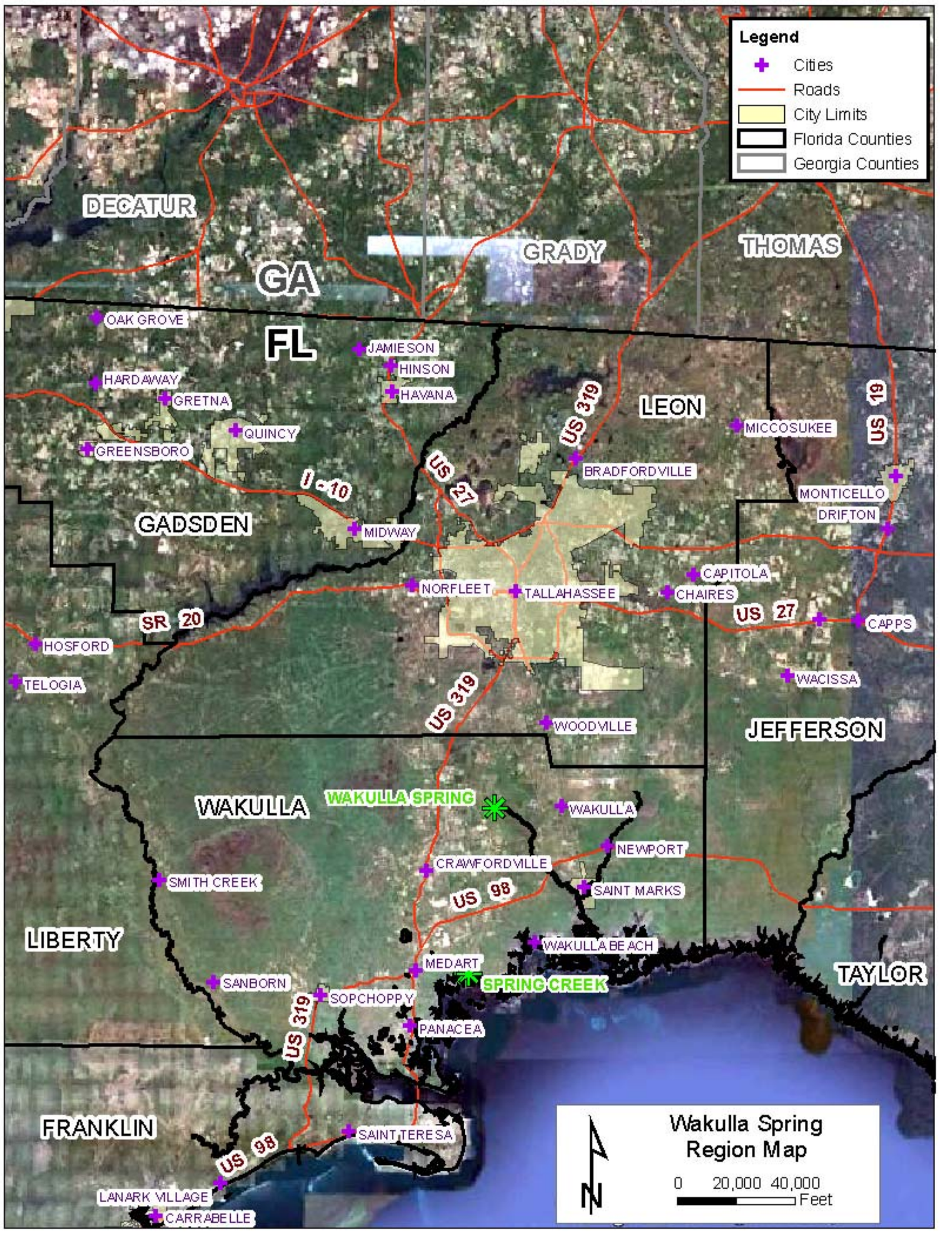


Figure 1 - Location of Wakulla Spring South of Tallahassee in the Florida Panhandle

Increases in nitrate concentrations and dark-colored water at Wakulla Spring have been reasons for concern for over 20 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 goals of this Wakulla Spring Adaptive Management Strategy are to summarize detrimental changes that have occurred at Wakulla Spring and to suggest some decisions and actions that should be made to achieve the desired restoration of Wakulla Spring.

List of Accomplishments

The Wakulla Spring Basin Working Group 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 Spring Working Group:

Research:

- Numerous research projects have been conducted at Wakulla Spring - more research projects than for any other Florida spring.
- Dye trace studies have been implemented throughout the spring basin at many of the sinks, swallets, and City of Tallahassee Sprayfield in order to better understand water 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

- DOT 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 is spending $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 has protected vulnerable sinkholes on their lands and leased lands to hunt clubs which increased protection.
- 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.
- FFWCC implements a drawdown of 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 implemented 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 February16, 2010

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

Planning Process

As noted above, numerous activities have already been implemented 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 appear to be sufficient to-date 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 Strategy that constantly evolves and improves 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. **Table 1** summarizes the quarterly working group meetings and planning meetings that were facilitated by WSI between July 2010 and June 2011.

Table 1 - Wakulla Spring working group and planning meetings between July 2010 and June 2011

Month/Year	Type of Meeting	Description
August, 2010	Planning	Meeting with NWFWMD
August, 2010	Planning	Meeting with DEP Park Service, Spring Ambassador, Friends of Wakulla Spring, and Wakulla County Extension 4H
August, 2010	Planning	Meeting with DEP
August, 2010	Planning	Tour of the springshed
September, 2010	Quarterly	First Quarterly Meeting – developed a vision for restoration of Wakulla Spring and prioritized the restoration issues
November, 2010	Planning	Tour of the Lake Munson drawdown
November, 2010	Planning	Meeting with the City of Tallahassee
November, 2010	Planning	Meeting with planners from Department of Community Affairs, 1,000 Friends of Florida, DEP, City of Tallahassee, and Leon County
November, 2010	Planning	Meeting with hydrogeologists from US Geological Survey, Florida Geological Survey, NWFWMD, FSU, and GeoHydros
December, 2010	Quarterly	Second Quarterly Meeting – developed a future scenarios vision for Wakulla Spring
January, 2011	Planning	Meeting with Leon County
January, 2011	Planning	Meeting with Wakulla County and Apalachee Regional Planning Council
March, 2011	Quarterly	Third Quarterly Meeting – multiple presentations on water flows, water quantity, and water budgets followed by development of restoration goals
May, 2011	Quarterly	Fourth Quarterly Meeting – multiple presentations on water quality followed by development of a restoration assessment 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 program of Florida's Eden 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. This draft Wakulla Spring Adaptive Management Strategy was developed by the FSI based largely on technical information collected and summarized by WSI in their final draft deliverable to FDEP. This Wakulla Spring Adaptive Management Strategy builds on the work initiated by WSI and the Wakulla Spring stakeholders and contains the following essential elements:

- An updated 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 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 draft Wakulla Spring Adaptive Management Strategy provides a preliminary road map for the activities that need to be completed to achieve the vision of the Wakulla Spring Working Group. The original scope of WSI's project with FDEP included a three-year schedule of quarterly Working Group meetings and annual refinement of the restoration plan. Due to the abrupt cancellation of the contract, the Wakulla Spring Restoration Plan was not completed, nor was the draft document reviewed by any of the stakeholder groups. It is hoped that the major stakeholder groups will unite and share the responsibility for reviewing and continuing the Wakulla Spring Adaptive Management Strategy and will work together to coordinate implementation of the recommended management strategies.

Description of Wakulla Spring

General

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 (**Figures 1 and 2**).

Ownership and History

One of Florida's largest springs, the area around Wakulla Spring was developed as a retreat/attraction in the 1930s by Edward Ball, and is presently administered by FDEP/FPS as a state park consisting of approximately 1,214 ha (3,000 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 1.6 km [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 4.8 km [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*.

Physical Description

Wakulla Spring is an unusual spring due to its large physical size (**Figure 3**). The circular pool is roughly 91 m (300 ft.) in diameter, with an immense vent opening of 15 m (50 ft.) by 25 m (82 ft.), and at a depth of approximately 56 m (185 ft.) (**Figure 4**) . 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 49,607 m^3 with a surface area of 15,685 m^2 (3.9 ac) and a calculated average depth of 3.2 m (10 ft.).

The Wakulla Spring cave system (**Figure 5**) has been extensively explored by cave divers (Olsen 1958), including most recently the members of the Woodsville Karst Plain Project (WKPP). This figure provides a map of the Wakulla-Leon Sinks Cave System as of September 2008. This network of explored passages contains a total of 51,484 m (32 miles) connecting 27 named sinkholes and springs and its full extent has yet to be determined (Kincaid and Werner 2008).

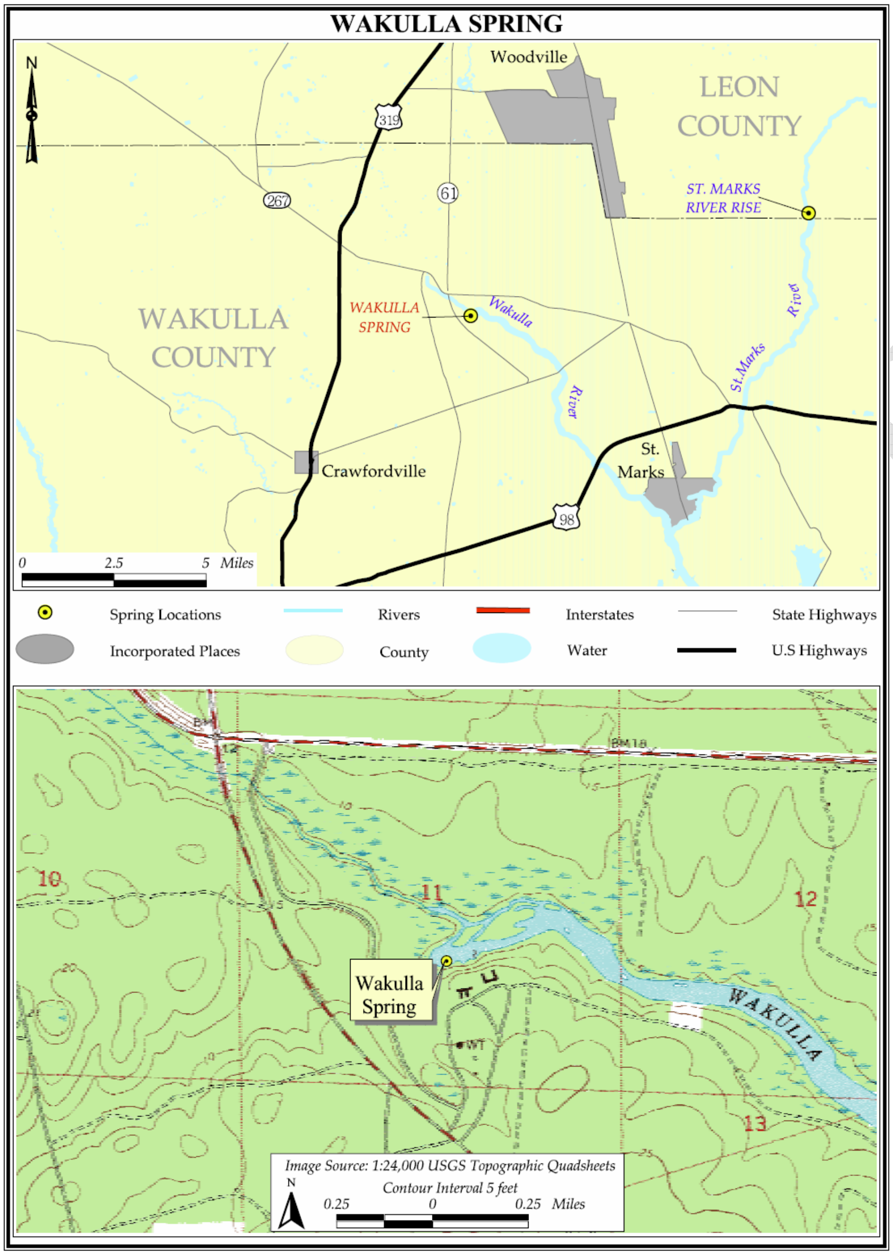


Figure 2 - Wakulla Spring geographic location (from Scott et al. 2002).

Figure 6 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", to tannin-stained, as a result of ground water recharge 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 4.8 km (3 mi) of the resulting spring run is about 100 m (330 ft.) wide, and ranges in depth between 1 m (3.3 ft.) and 3 m (10 ft.), and has sandy sediments. In total, the Wakulla River travels southeast for about 14.5 km (9 mi) before joining the St. Marks River. Wakulla Springs lodge is approximately 22.5 km (14 mi) due south of the capital 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 Woodsville Karst Plain.

Figure 3 - Aerial photo of Wakulla Spring, the vent is left of the diving platform.

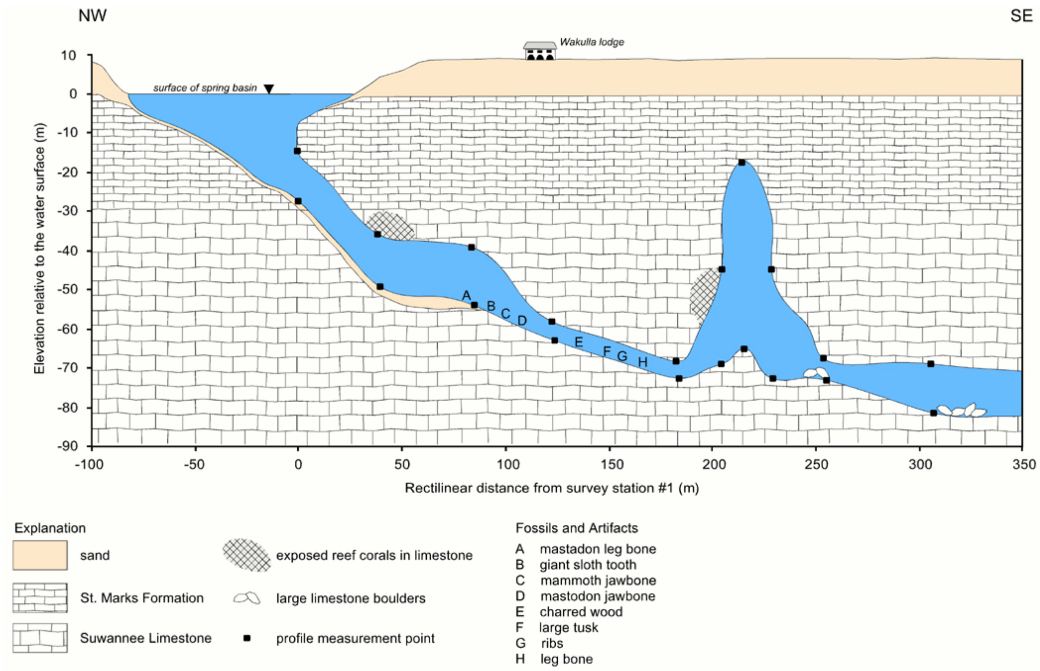


Figure 4 - Cross sectional view of the main vent at Wakulla Spring, locations of fossils from Olsen (1958) and depth profiles by WKKP divers (from Kincaid 1999).

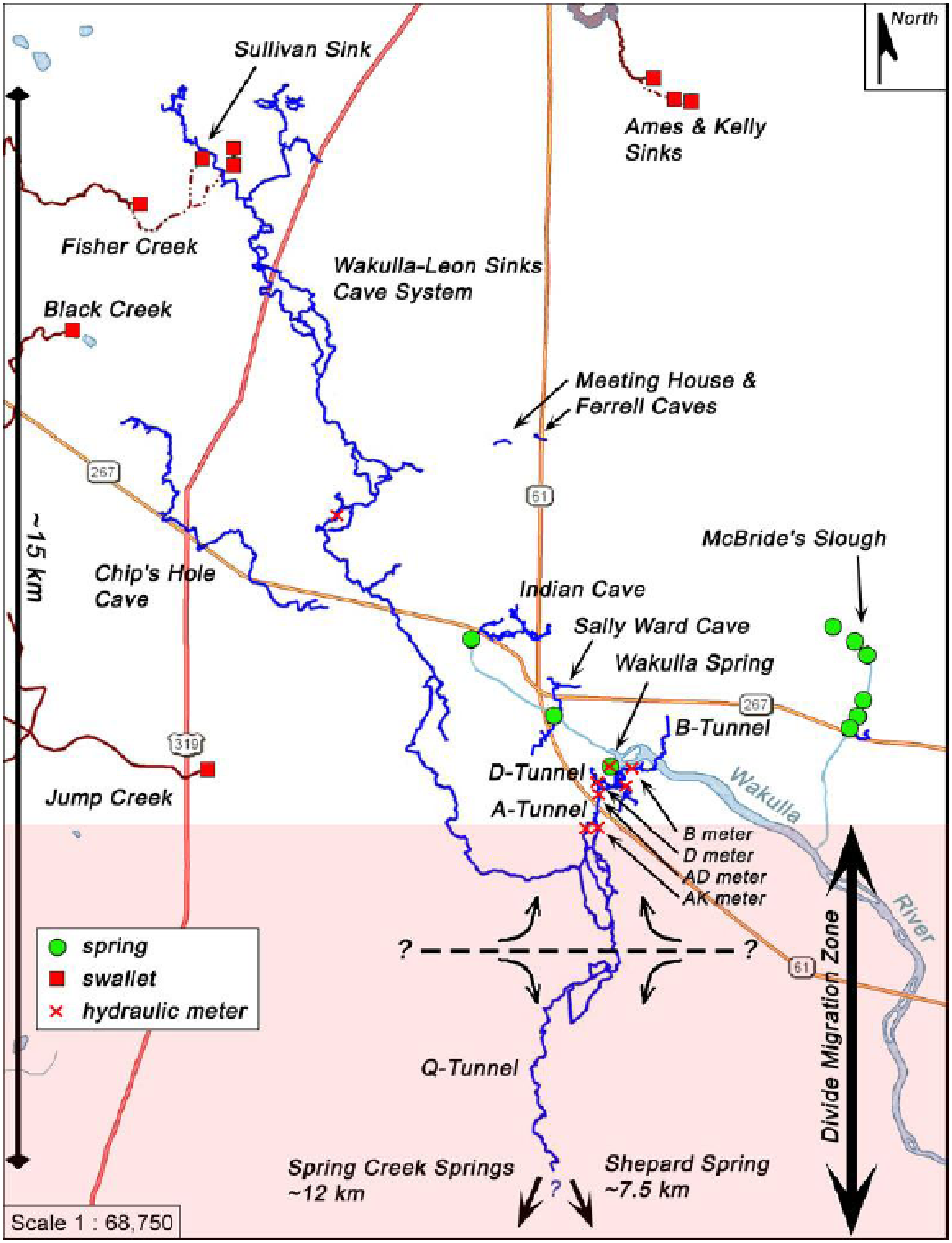


Figure 5 - Map of the Wakulla Spring-Leon Sinks Cave System, springs, sinks, and swallets as of September 2008, including the estimated location of the zone where flow direction varies in response to changing aquifer water pressures (Kincaid and Werner 2008).

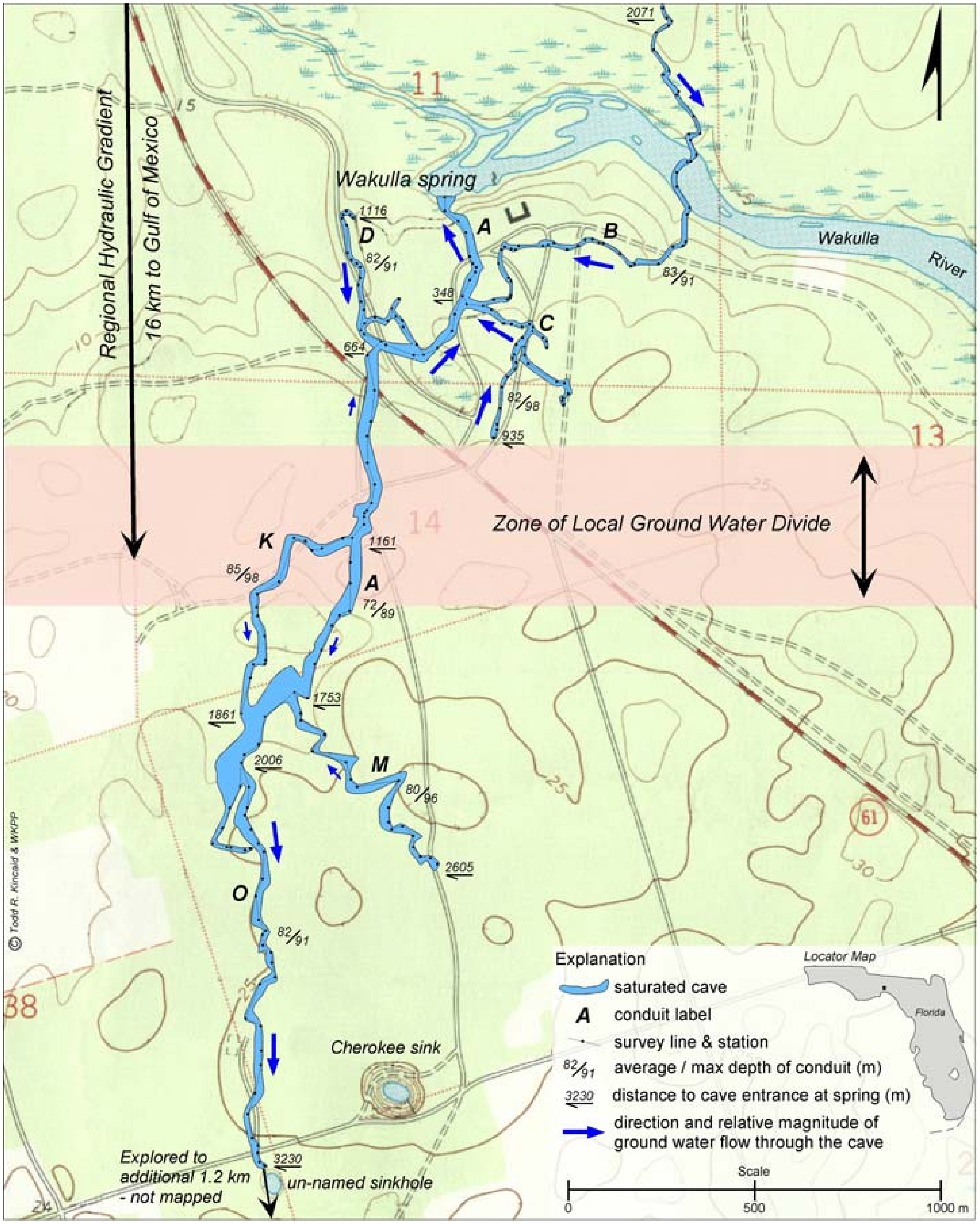


Figure 6 - Map of Wakulla Spring cave system showing the local ground water divide which crosses the conduit system and is marked by a broad zone of low ground water velocities. The southern conduits convey ground water toward the Gulf of Mexico while the northern conduits convey ground water to Wakulla Spring (from Kincaid 1999).

Environmental Characteristics

Spring Discharge and Stage

Wakulla Spring has the largest known range in 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 7**). The USGS also has a discharge and stage station (# 02327022) further downstream (about 1.6 km [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 8** 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 7**). 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. This observed increase in spring discharge is not typical of most other springs in Florida during this same period and cannot be tied to an increase in precipitation in the Wakulla Spring recharge area. Recent studies have 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.

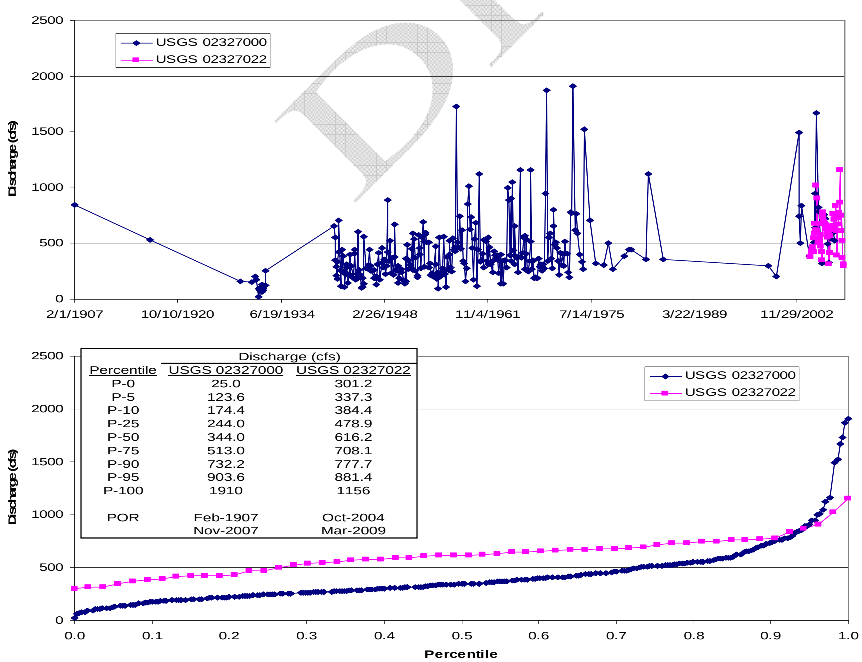


Figure 7 - Monthly average discharge time series and frequency curve for the Wakulla River.

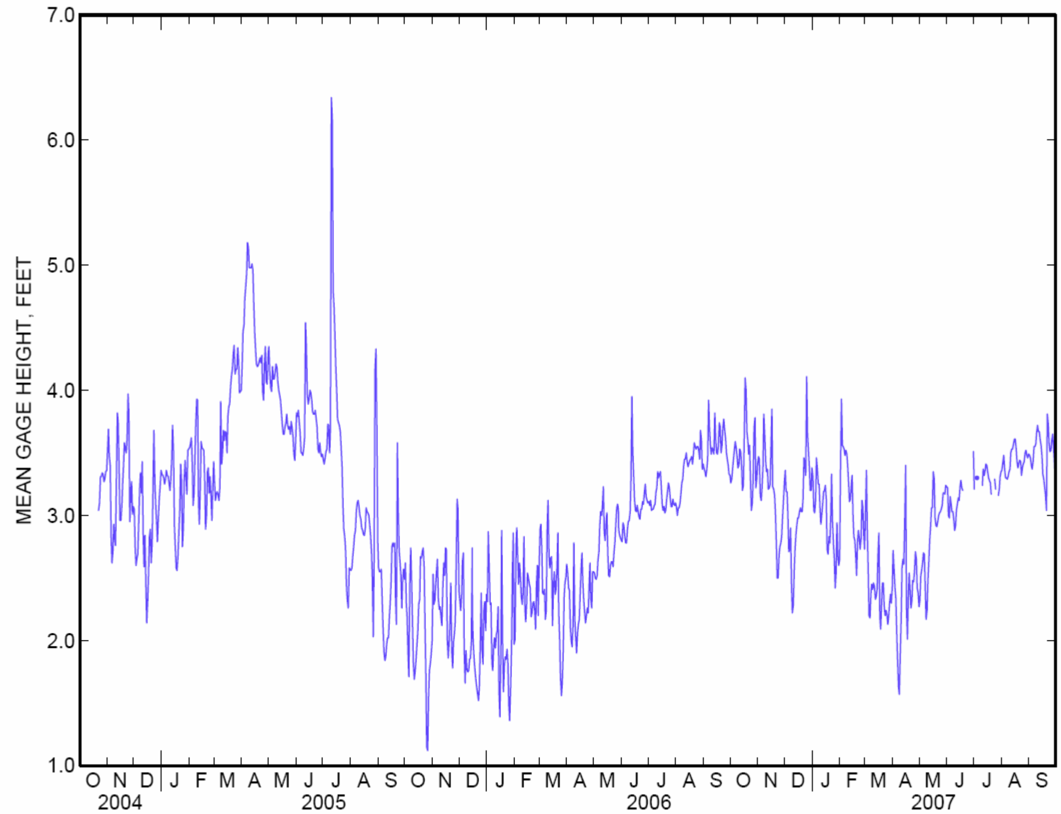


Figure 8 - Wakulla River water stage time series (from USGS 2007).

Water Quality

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 2** 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. 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 9**, 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 2010).

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.

Table 2 - 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	
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 1 (CONTINUED)

Wakulla Spring water quality table for the period-of-record continued.

				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		
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 1 (CONTINUED)

Wakulla Spring water quality table for the period-of-record continued.

PARAMETER GROUP	PARAMETER	UNITS	STATION	Decade 1900	1910	1920	1930	1940	1950	1960	1970	1980	1990	2000	POR Statistics Average	Min	Max	StDev	N	Period of Record	
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

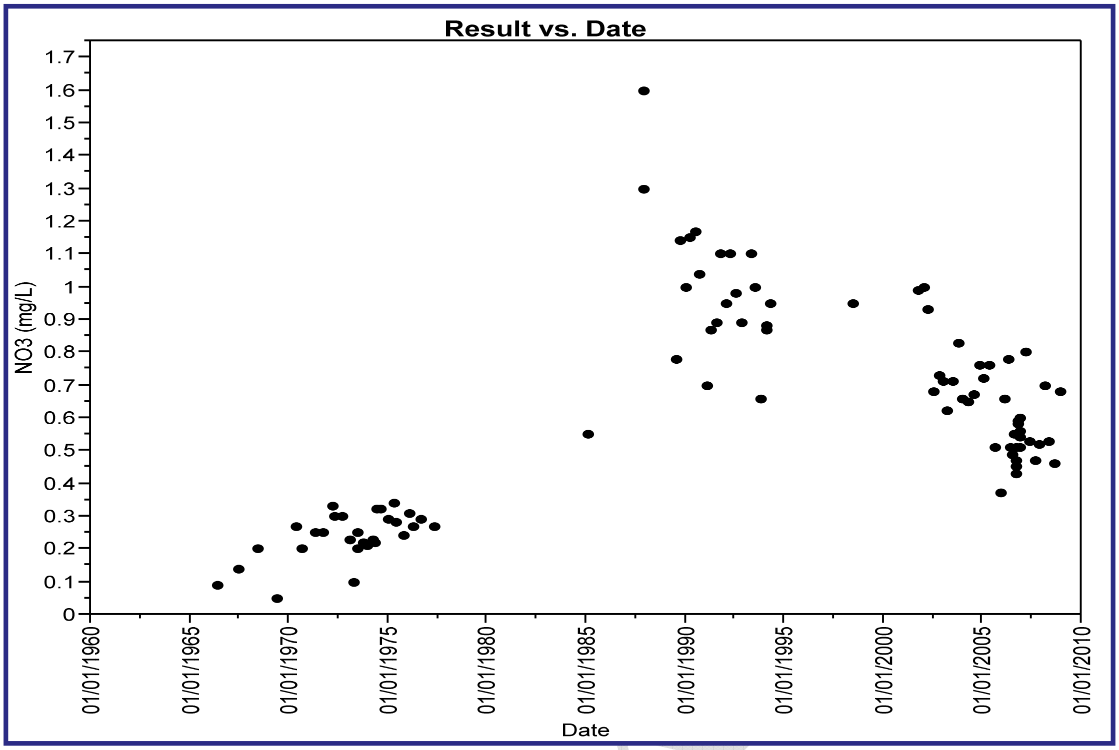


Figure 9 - Wakulla Spring nitrate nitrogen concentration time series (from Gilbert 2010).

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 10**). 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 11**). Temperature over the main boil was about 21 ° C and gradually rose with distance downstream in the spring run (**Figure 11**). 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 11**). 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 11**). 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 11**). This increase in pH likely corresponds to aquatic plant metabolism; while lower pH values from the Sally Ward confluence suggested ground water inputs.

Water clarity in Wakulla Spring varies greatly in response to inputs of tannin-stained surface waters entering swallets in the springshed (Kulakowski 2010; Gilbert 2010). 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) 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 water inputs (WSI 2010).

The frequency and duration of tannic water events at Wakulla Spring has increased during the past two 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.).

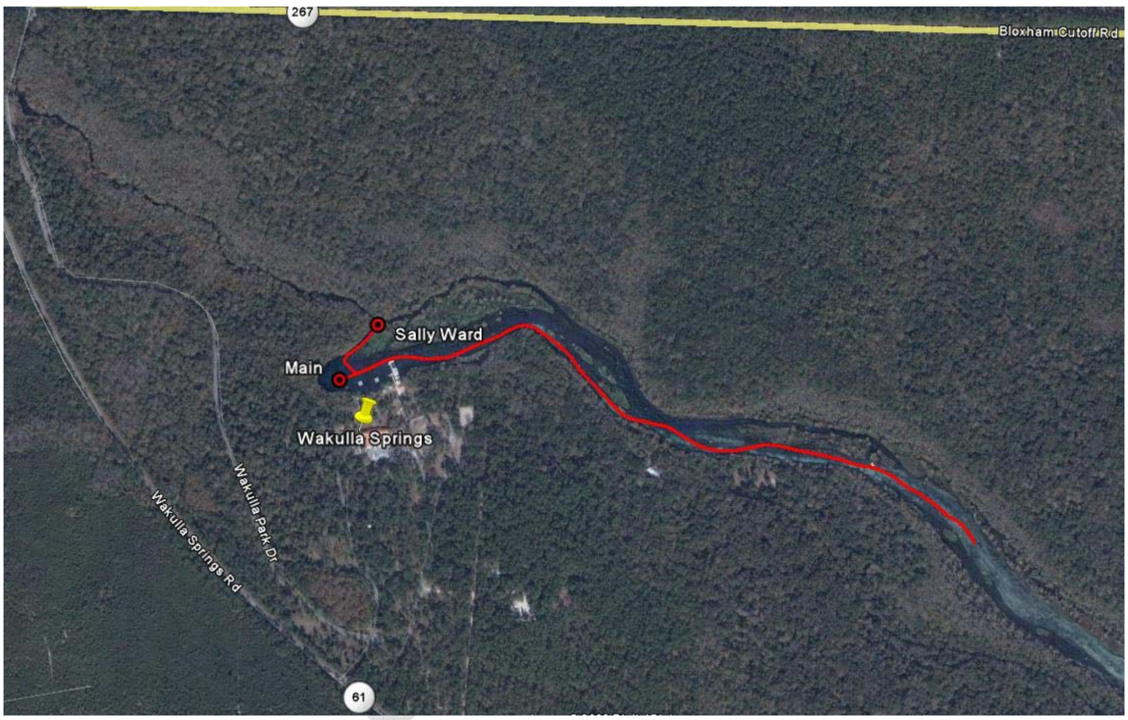


Figure 10 - Image of Wakulla Springs with red icons and path indicating WSI's reconnaissance sampling locations on August 18, 2008.

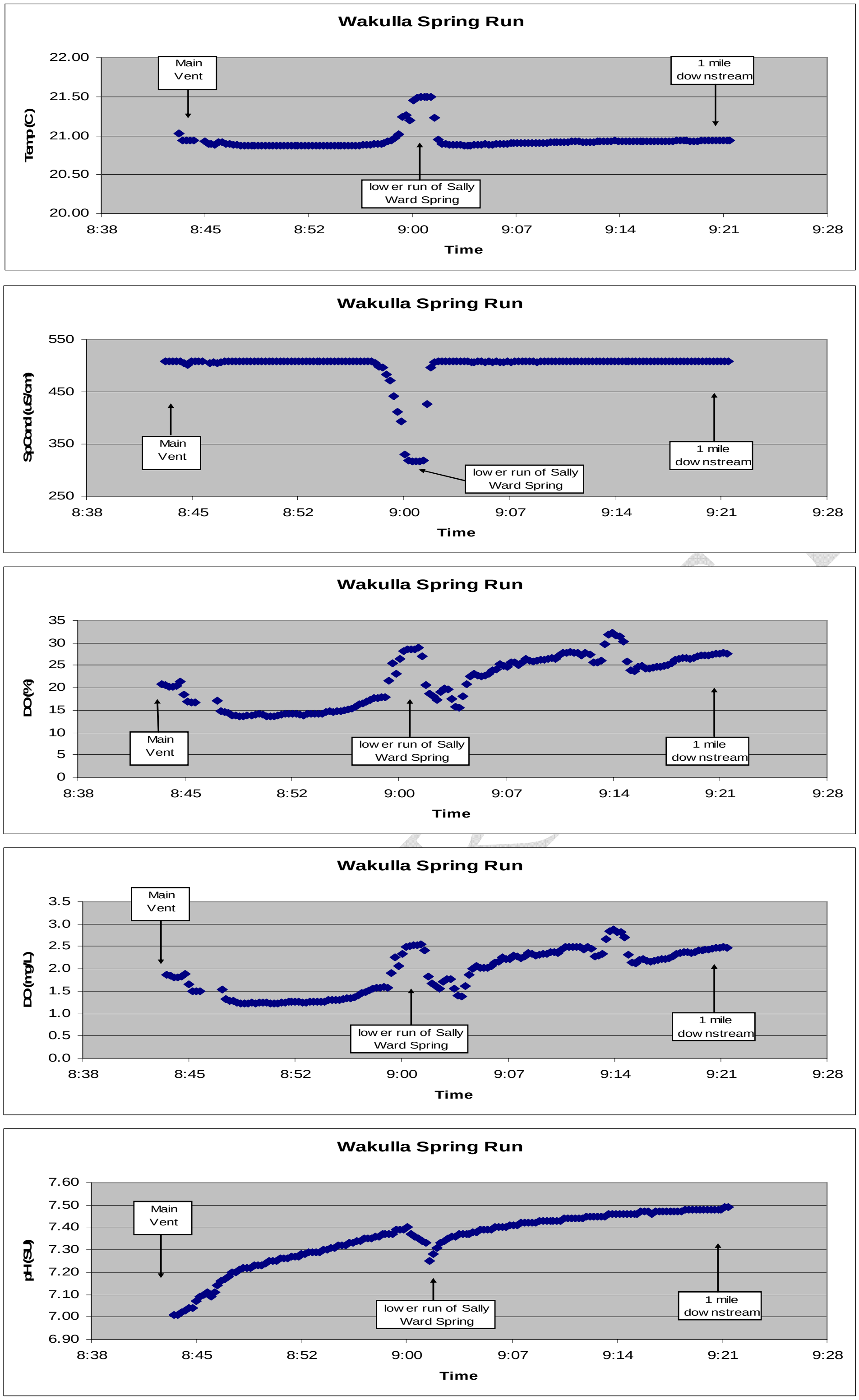


Figure 11 - Field parameters measured by Wetland Solutions, Inc. at Wakulla Spring on August 18, 2008.

Biology

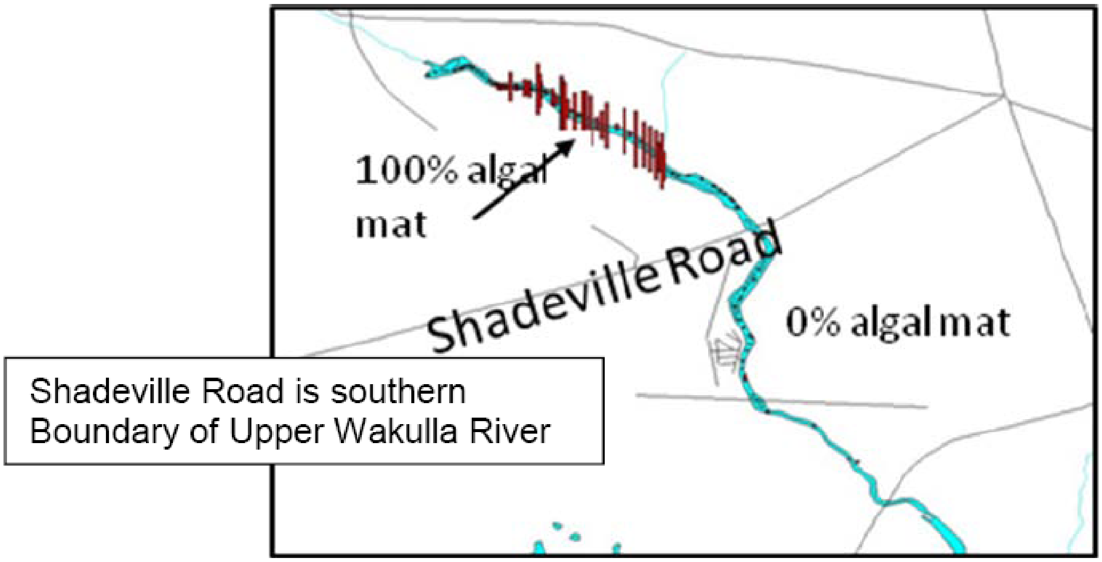
Vegetation

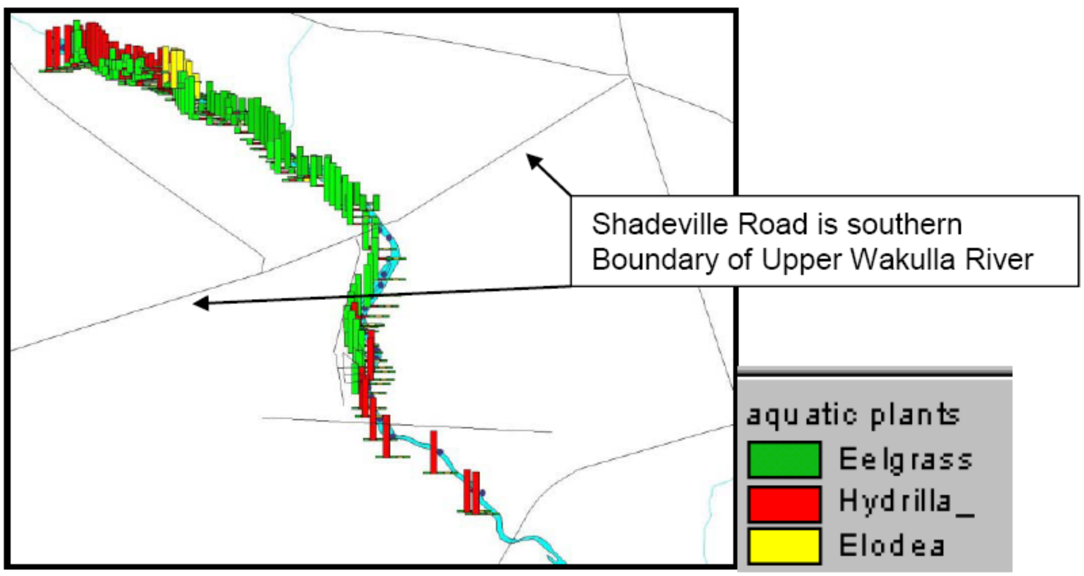
Increasing algal mats in the Wakulla River were first quantified in 2001 (Gilbert 2010). **Figure 12** illustrates the occurrence of areas of 100% coverage by filamentous benthic algae using a semi-quantitative, kayak-based, photographic method (Healthy Aquatic Plant Survey, Joe Hand, FDEP, personal communication). **Figure 12** also illustrates Hand's vegetation cover estimates for native submerged aquatic species including eelgrass (*Vallisneria americana)*, coontail (*Ceratophyllum demersum),* southern naiad *(Najas quadalupensis)*, muskgrass (*Chara* sp.), eleodea (*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 12.7 cm (5 in), while in October the macroalgae coverage was 50.6% with an average thickness of 8.8 cm (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 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 12 - 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 2010)

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 13**). 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).

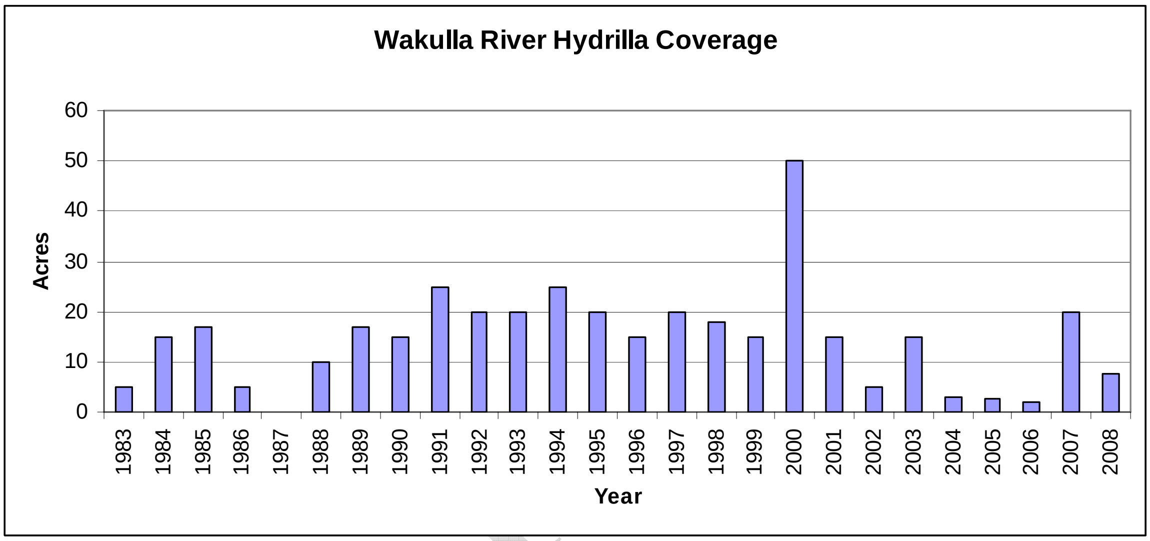


Figure 13 - Wakulla River hydrilla abundance by year (from FDEP 2007).

Macroinvertebrates

The Wakulla River has been monitored up to four times a year since 2000 as part of FDEP's EcoSummary sampling (FDEP 2008). The monitoring site is a 100 m stretch located in the spring run, approximately 3.2 km (2 mi) 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 14**). 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 14**).

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 paludosa*), 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/m^2/d and 23 insects/m^2/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).

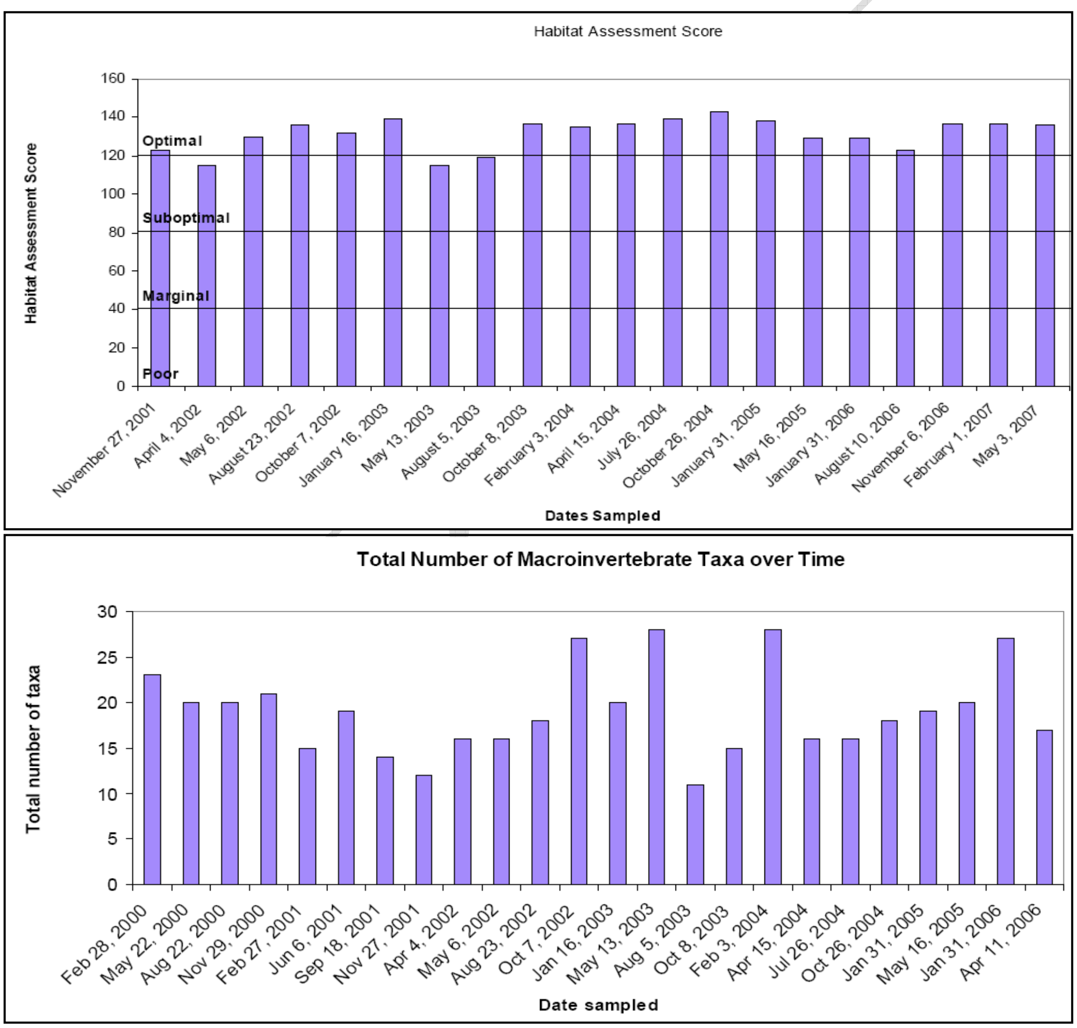
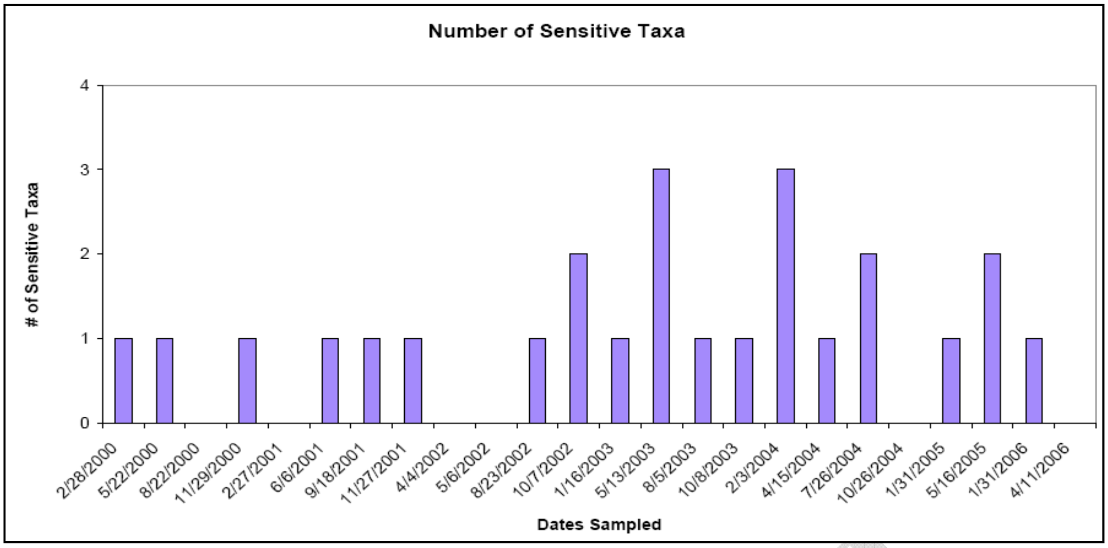


Figure 14 - Time series of habitat assessment, total number of aquatic macroinvertebrate taxa, number of sensitive aquatic macroinvertebrate taxa, and stream condition index (SCI) values for Wakulla Spring (from FDEP 2008).



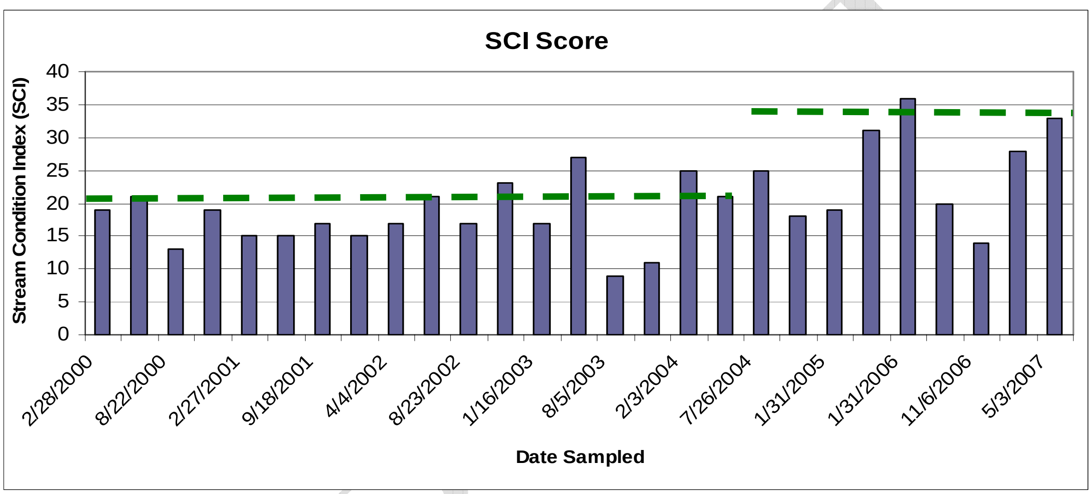


Figure 14 (cont.) - Time series of habitat assessment, total number of aquatic macroinvertebrate taxa, number of sensitive aquatic macroinvertebrate taxa, and stream condition index (SCI) values for Wakulla Spring (from FDEP 2008).

Macrofauna

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 3** (from Walsh and Williams 2003).

Wetland Solution Inc. 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.

Table 3 - 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**	

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 15** 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 16**). 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.

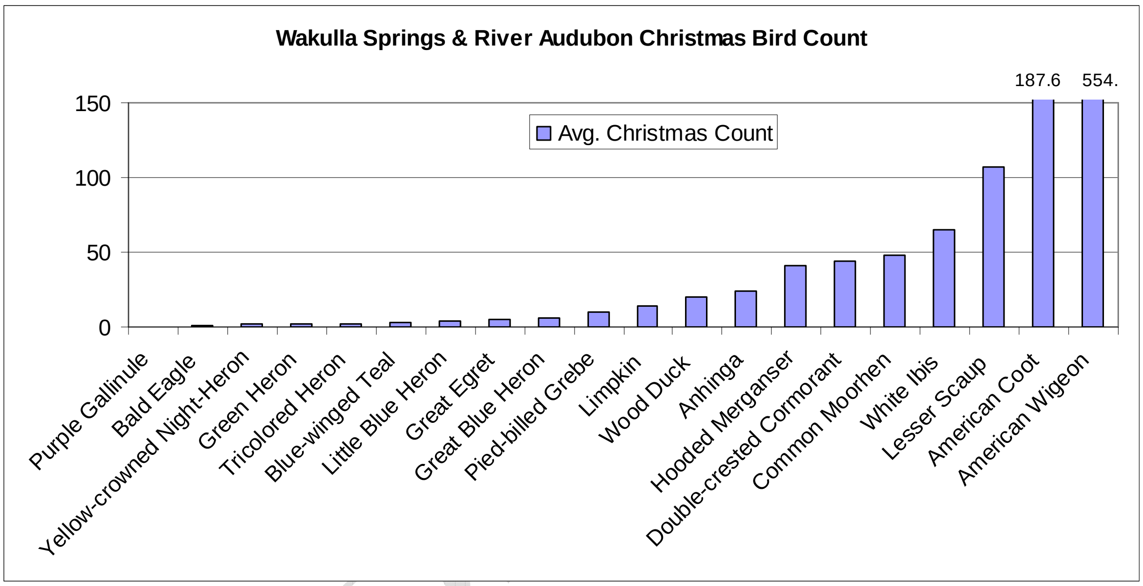
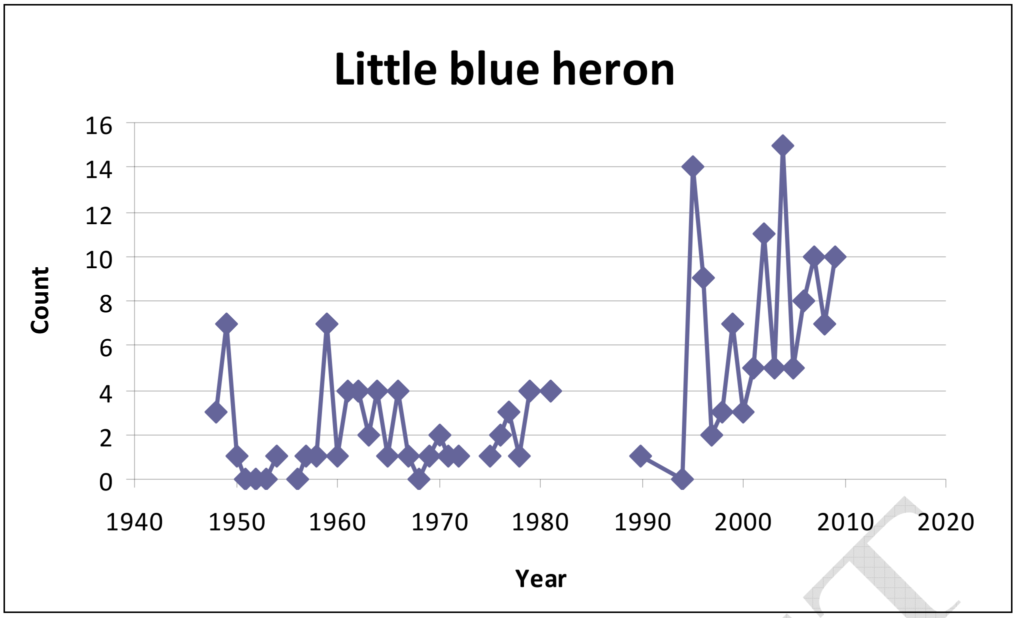


Figure 15 - Wakulla Springs Audubon Christmas bird count data (average number by species for 1948-2009).

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 17)**. 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 17**). 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.



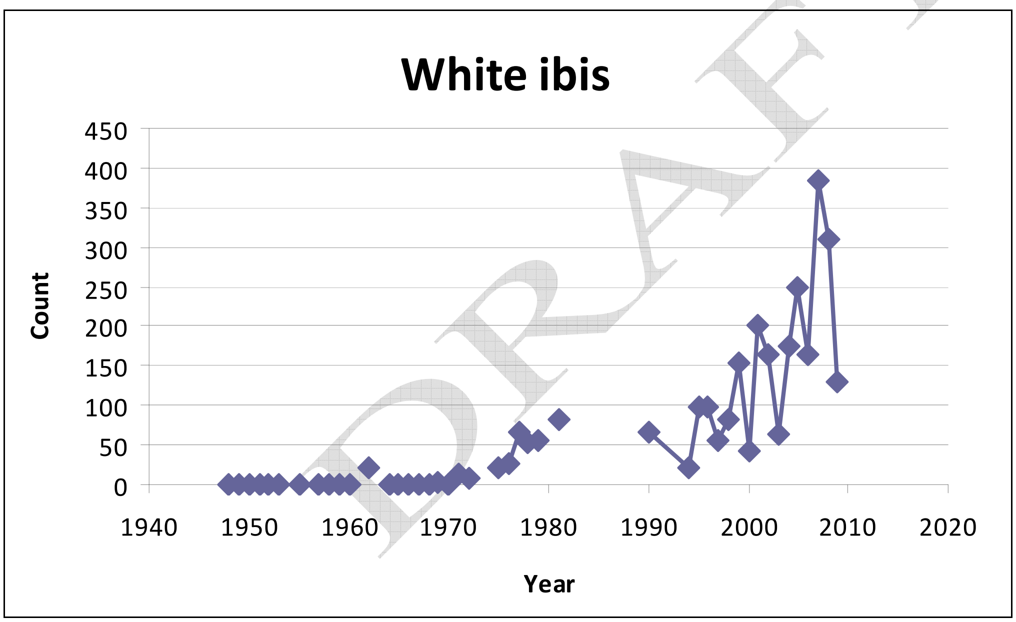


Figure 16 - Representative bird species that have shown increased numbers at Wakulla Springs based on Audubon Christmas bird count data (number of individuals recorded for 1948-2009).

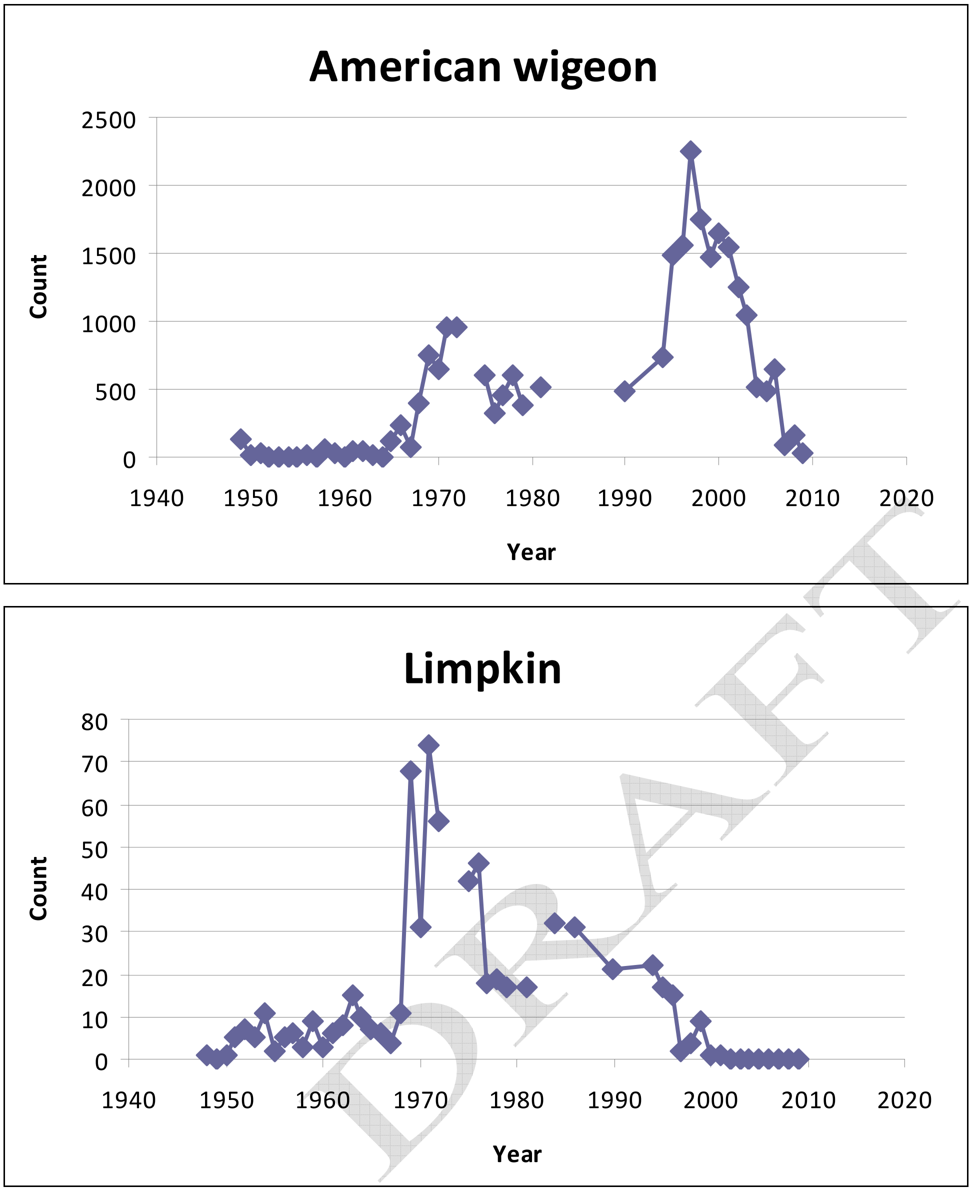


Figure 17 - Representative bird species that have shown declining numbers at Wakulla Springs based on Audubon Christmas bird count data (number of individuals recorded for 1948-2009).

Manatees

Manatees are known to utilize Wakulla Spring in relatively low numbers (**Figure 18**). The current known high manatee count at the spring is 36, documented during the winter of 2010-2011 (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 18 - Two Florida manatees (*Trichechus manatus latirostrus*) relaxing in the pool of Wakulla Spring (photo by S.K. Notestein, 04/14/09)

Ecosystem Functions

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 19**). 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 20**.

Figure 19 - Study area for the WSI (2010) Wakulla Spring ecosystem study (with data sonde locations indicated by red icons).

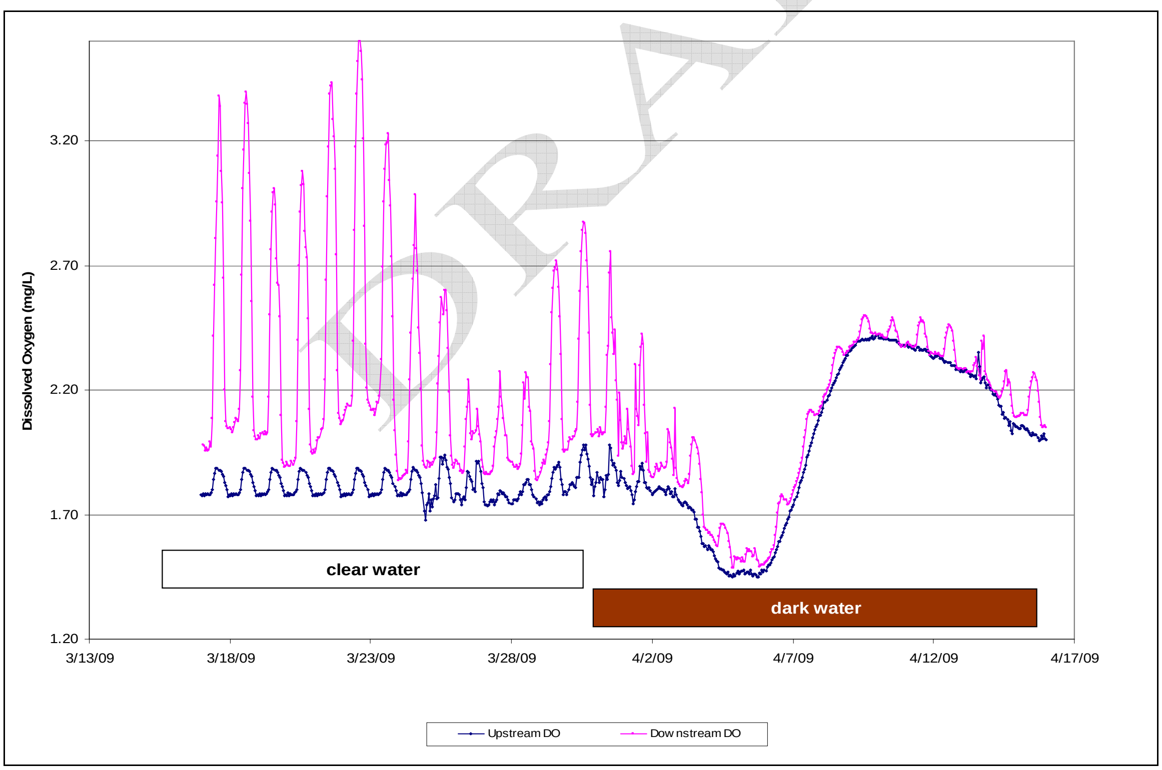


Figure 20 - Diel curves for dissolved oxygen at Wakulla Spring during March and April 2009 illustrating the daily changes in response to photosynthesis and respiration under clear and dark water conditions.

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 21** 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, which causes 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 aquatic ecosystem and a net reduction in the biomass and types of plants and animals supported by the Wakulla Spring and Wakulla River ecosystem.

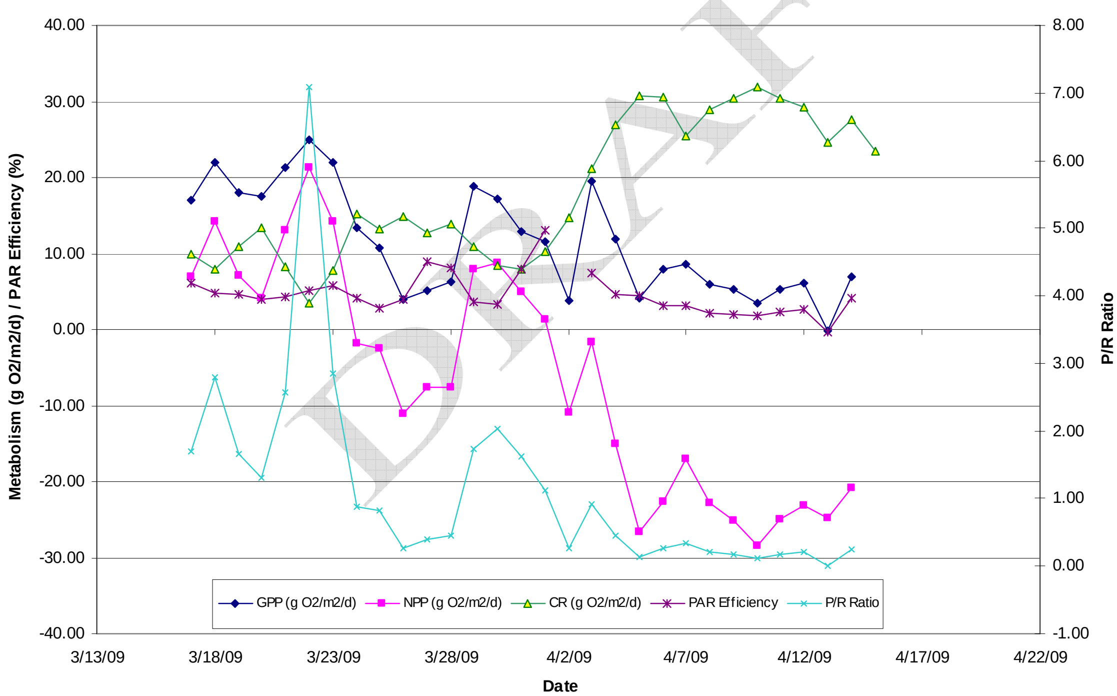
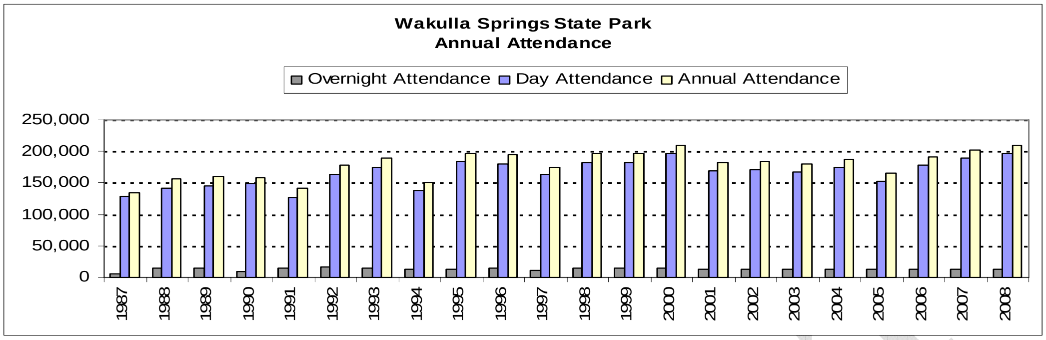


Figure 21 - Time series data for ecosystem metabolism, photosynthetic efficiency, and the ratio between primary production and community respiration in the Wakulla Spring basin in the spring of 2009. The water in the spring was clear until April 2 when it turned dark due to tannic water inputs in the springshed. Updated data from WSI (2010).

Human-Use Attendance and Activities

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 22**).



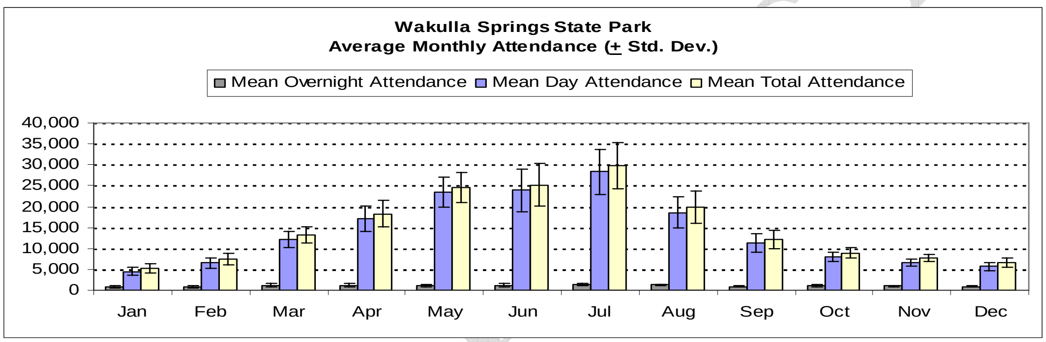


Figure 22 - Wakulla Springs State Park annual and monthly attendance data (Florida Park Service).

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 23**). 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 24**). During the period-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).

Figure 23 - Wakulla Springs State Park boat concessions include glass-bottom boats (top photo) and jungle-cruise tour boats (bottom photo).

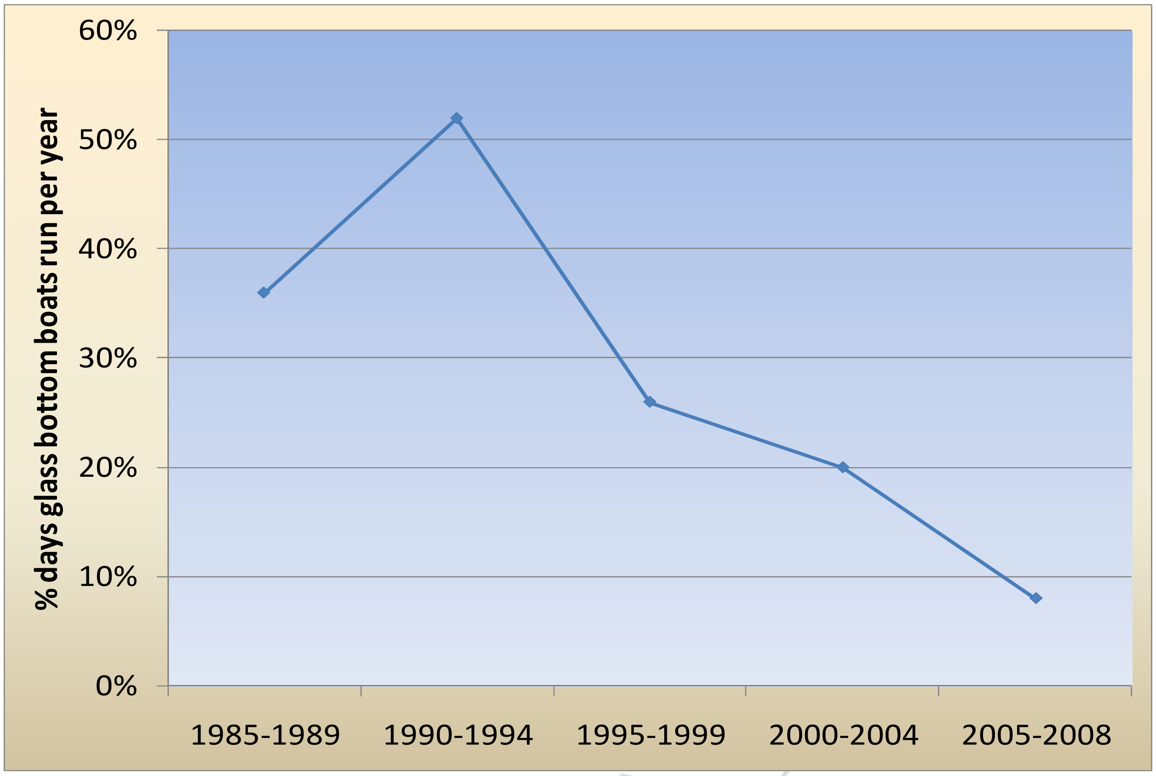


Figure 24 - Percent of time water clarity allowed glass bottom boat use at Wakulla Springs State Park (source Florida Park Service).

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 4**). **Figure 25** displays 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.

Minimum Flow and Levels

Wakulla Spring was placed on the Northwest Florida Water Management District (NWWMD) Minimum Flows and Levels (MFL) priority list for 2008. As of the date of this report, no MFL has been adopted for this spring group and the priority list data has been changed to 2012 due to the need for additional data and model analysis to quantify uncertainties (NWFWMD 2009).

Table 4 - 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	4.95
	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	79.33

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												

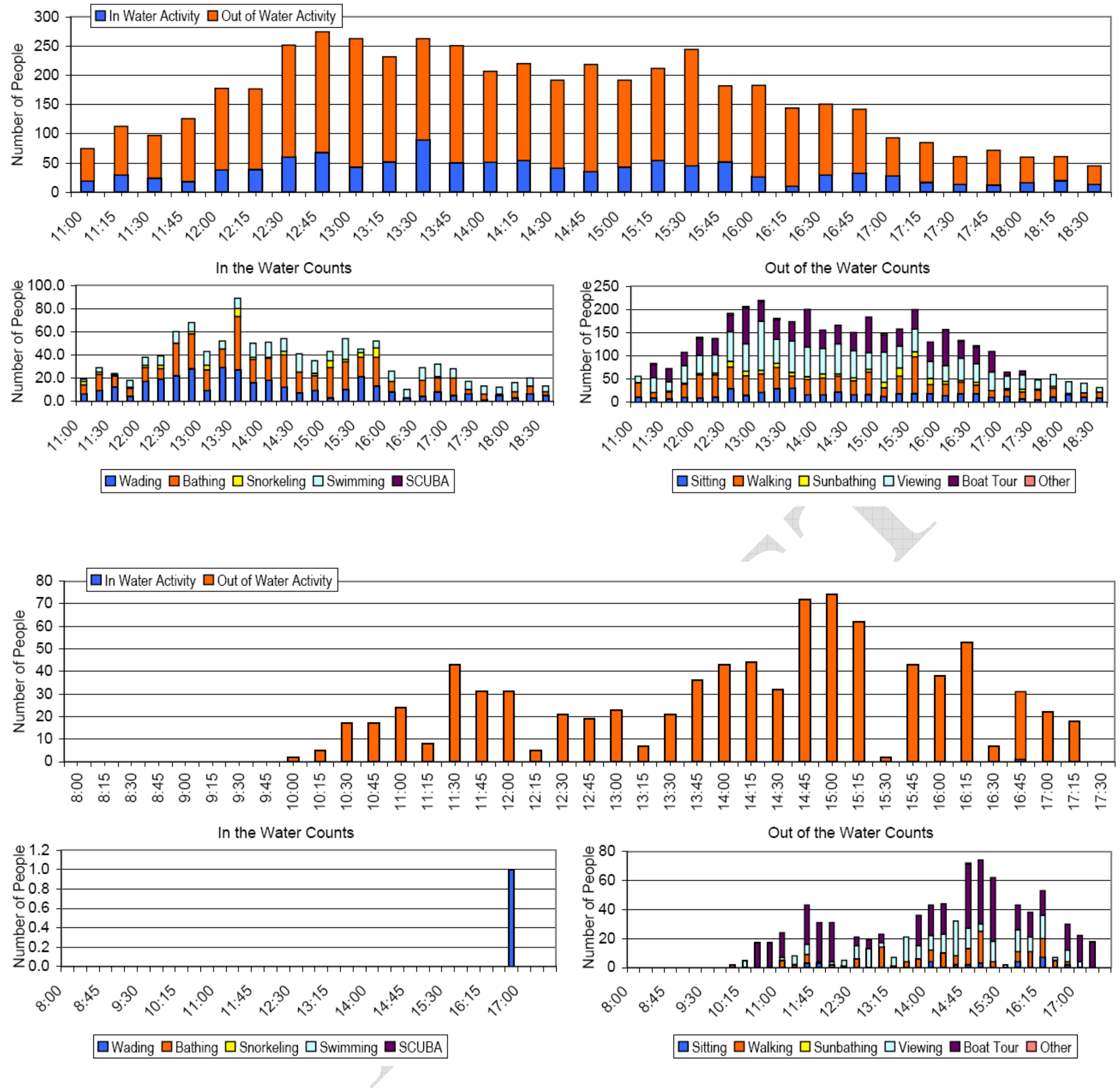


Figure 25 - Detailed human use activity data for Wakulla Spring on January 25 (bottom) and June 30 (top) during 2009 (WSI 2010).

Springshed Characteristics

Delineation

The springshed for Wakulla Spring (**Figure 26**) 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.

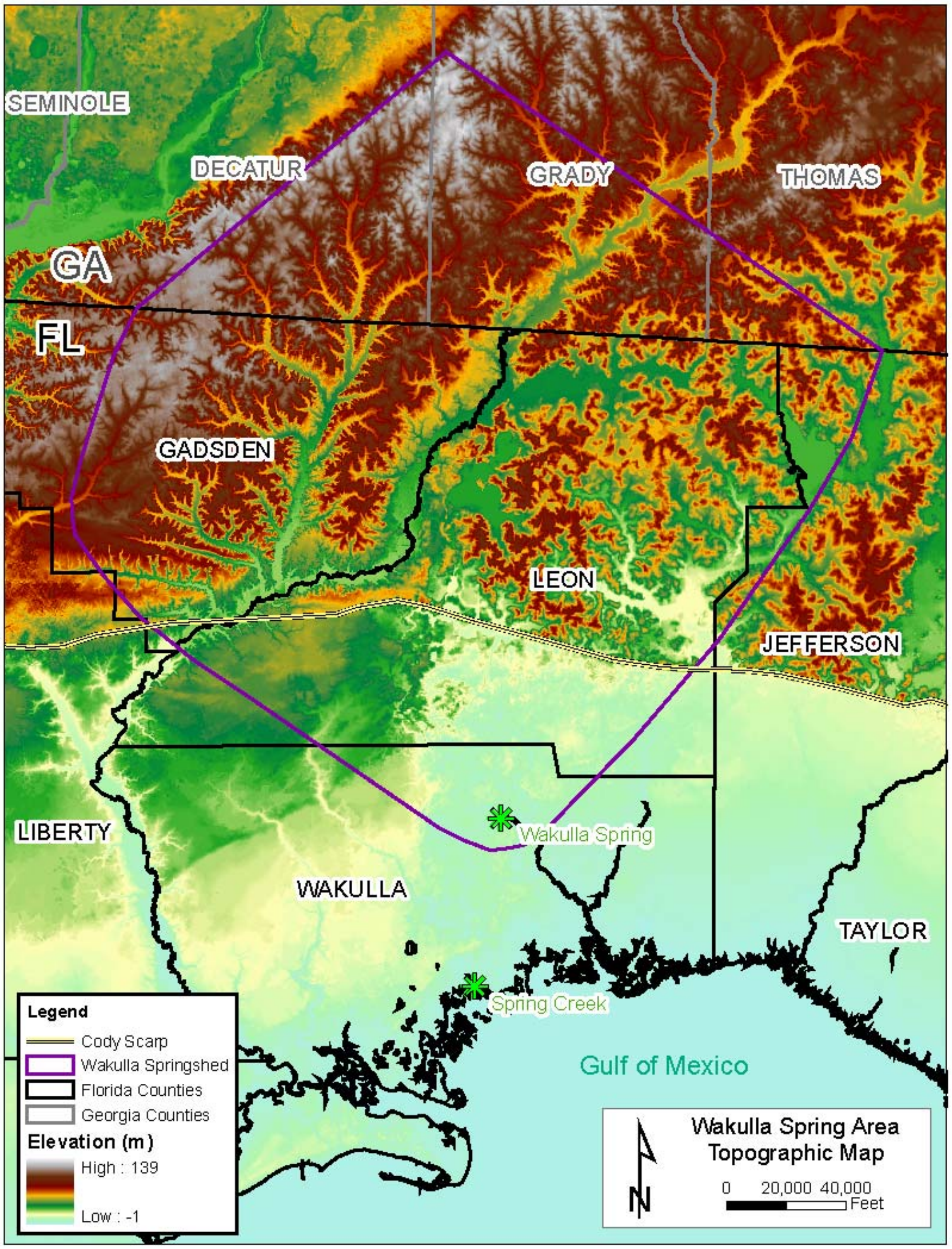


Figure 26 - Topographic landform map of the Wakulla Springshed (springshed delineation from the Florida Geological Survey [FGS]).

Precipitation and Evapotranspiration

Figure 27 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 (1.58 m/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). Evapotranspiration for this portion of Florida can be estimated as about 42 in/yr (1.06 m/yr) or about 3,120 MGD (4,825 cfs), for an estimated net precipitation in the springshed of about 20 in/yr (0.51 m/yr) or about 1,530 MGD (2,375 cfs).

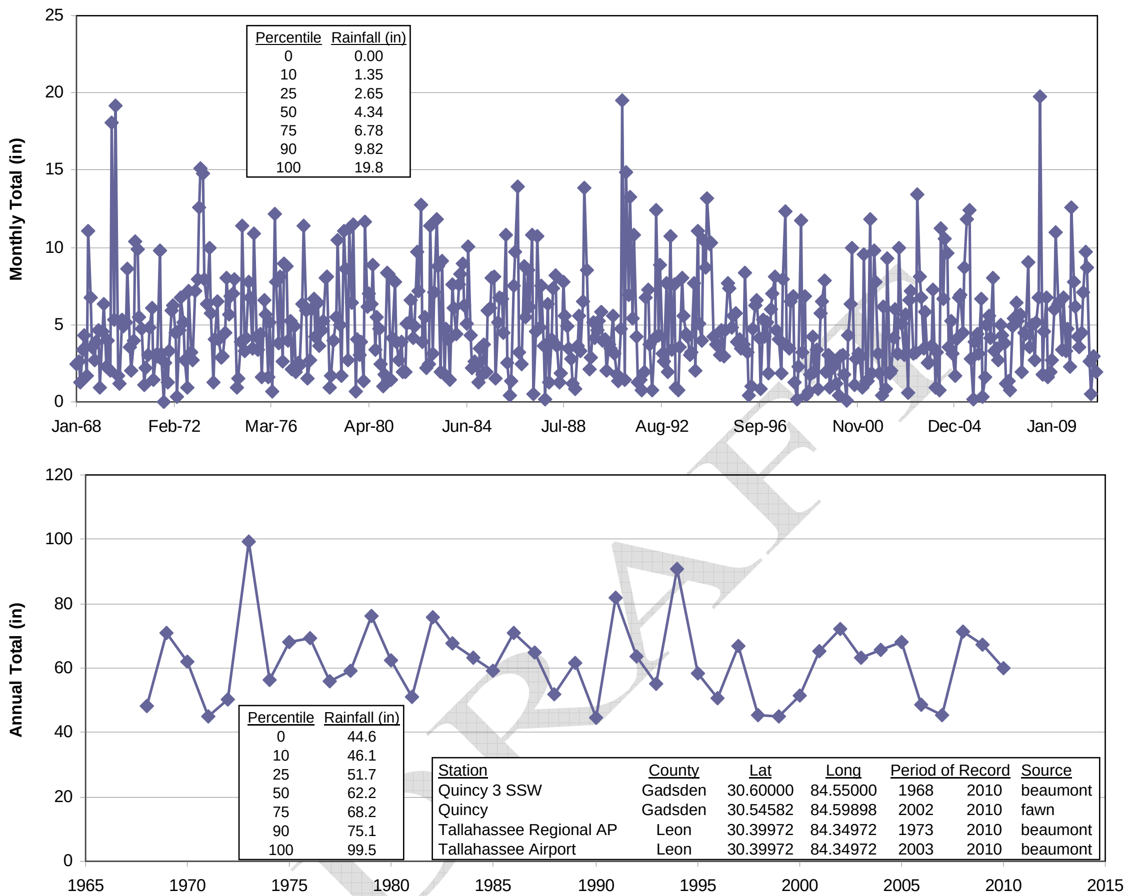


Figure 27 - Average monthly and annual rainfall totals in Leon and Gadsden Counties, Florida (1968-2010) source: http://beaumont.tamu.edu/CLIMATICDATA/WeatherMapSelection

Landform and Surface Watersheds

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 as about 1,165 mi^2 by Chellette *et al.* (2002) and Barrios (no date) and they conceptually divided it into three general areas (**Figure 28**) 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 surface runs off 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 29**. 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 30**. This figure illustrates how a number of streams and lakes in the springshed are not connected with surface channels, but are essentially closed basins that drain to the underlying Floridan Aquifer.

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 31** 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 Hawthorne Group overlying the northern portion of the springshed and absent from the southern portion of the springshed. As described above, groundwater recharge rates are very different depending 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 acidic rainfall and surface water have percolated through the soil over many 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 Woodville Karst Plain, the development of these features is the most advanced. In the Streams region it is much less advanced.

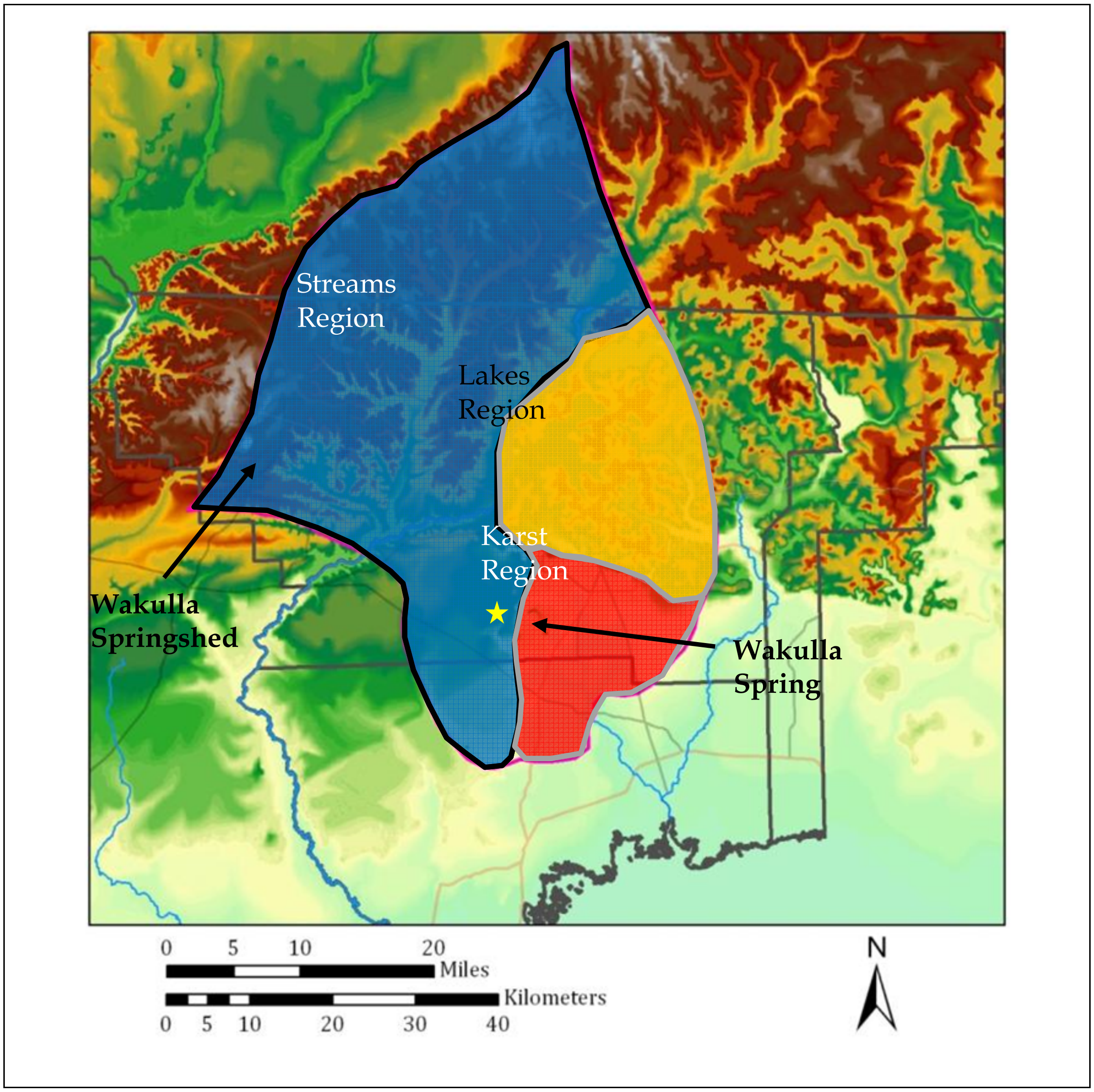


Figure 28 - Conceptual diagram of the Wakulla Springshed with three areas of differing recharge potential highlighted: the Streams Region with low infiltration (about 1 inch/year), the Lakes Region with higher groundwater recharge (about 8 inches/year), and the Karst Plain Region with lowest confinement 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).

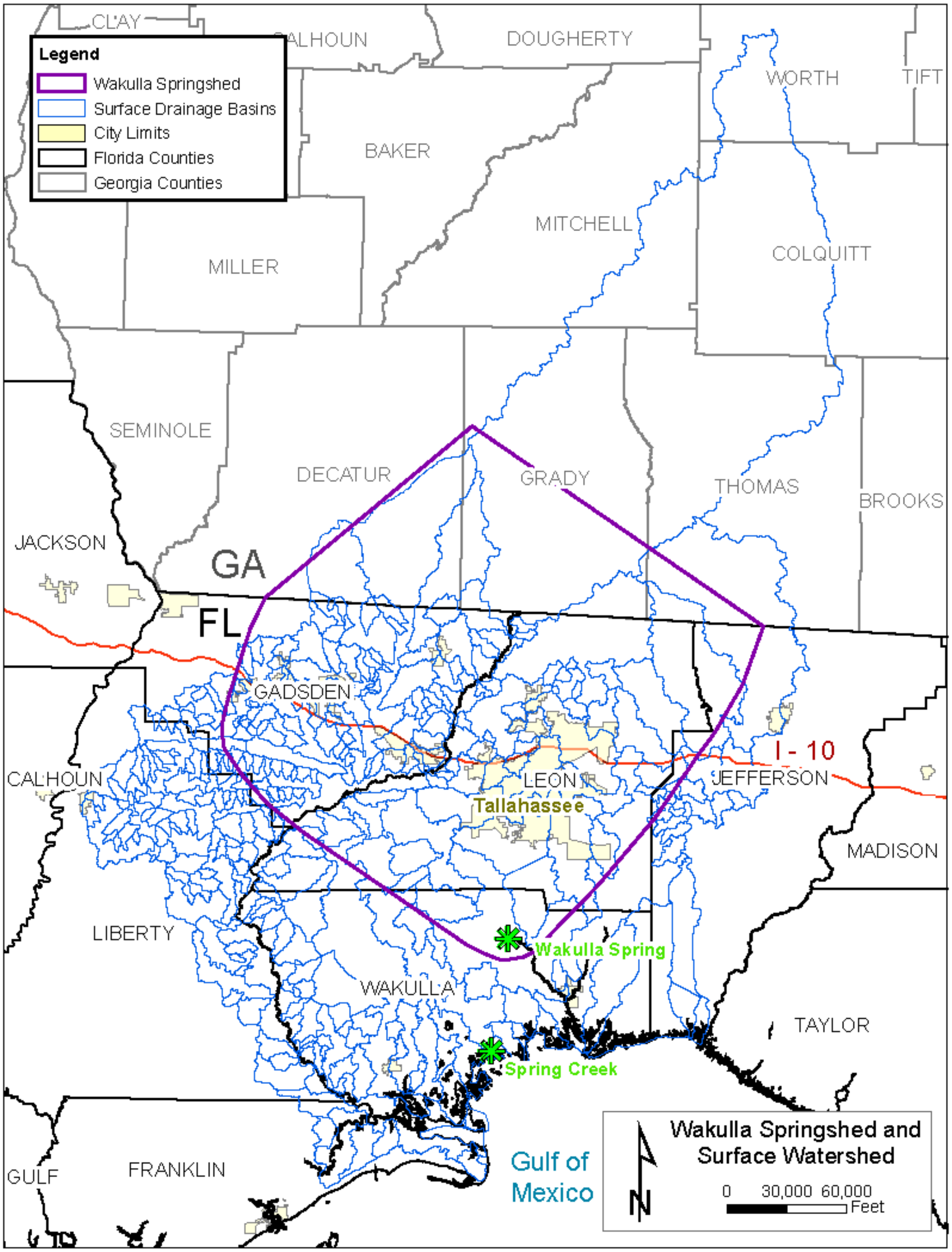


Figure 29 - Surface watersheds outlined by blue lines, intersecting the Wakulla Spring springshed in south Georgia and north Florida.

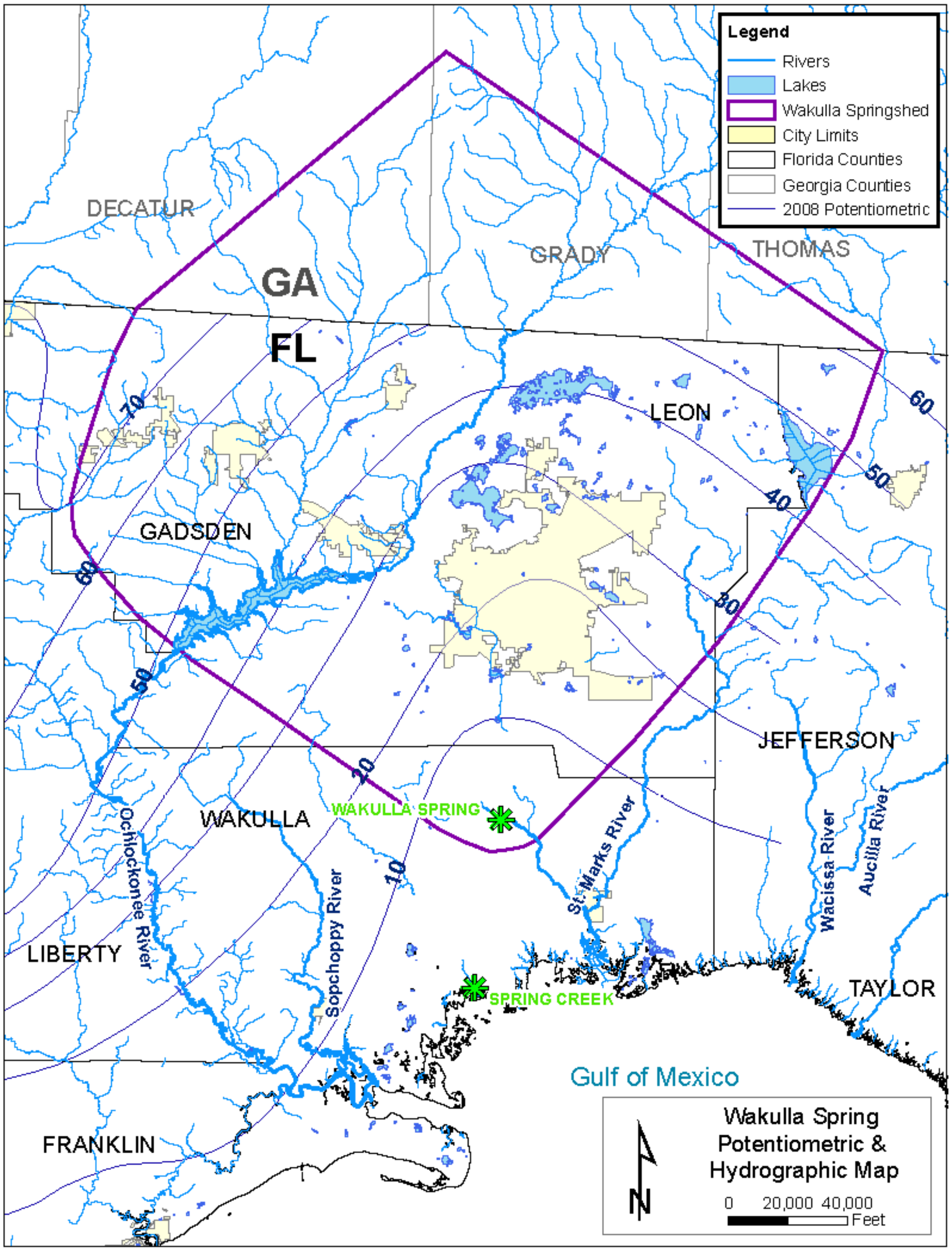


Figure 30 - Surface and subsurface hydrographic features in the vicinity of the Wakulla Spring springshed. The estimated 2008 potentiometric isopleths are included.

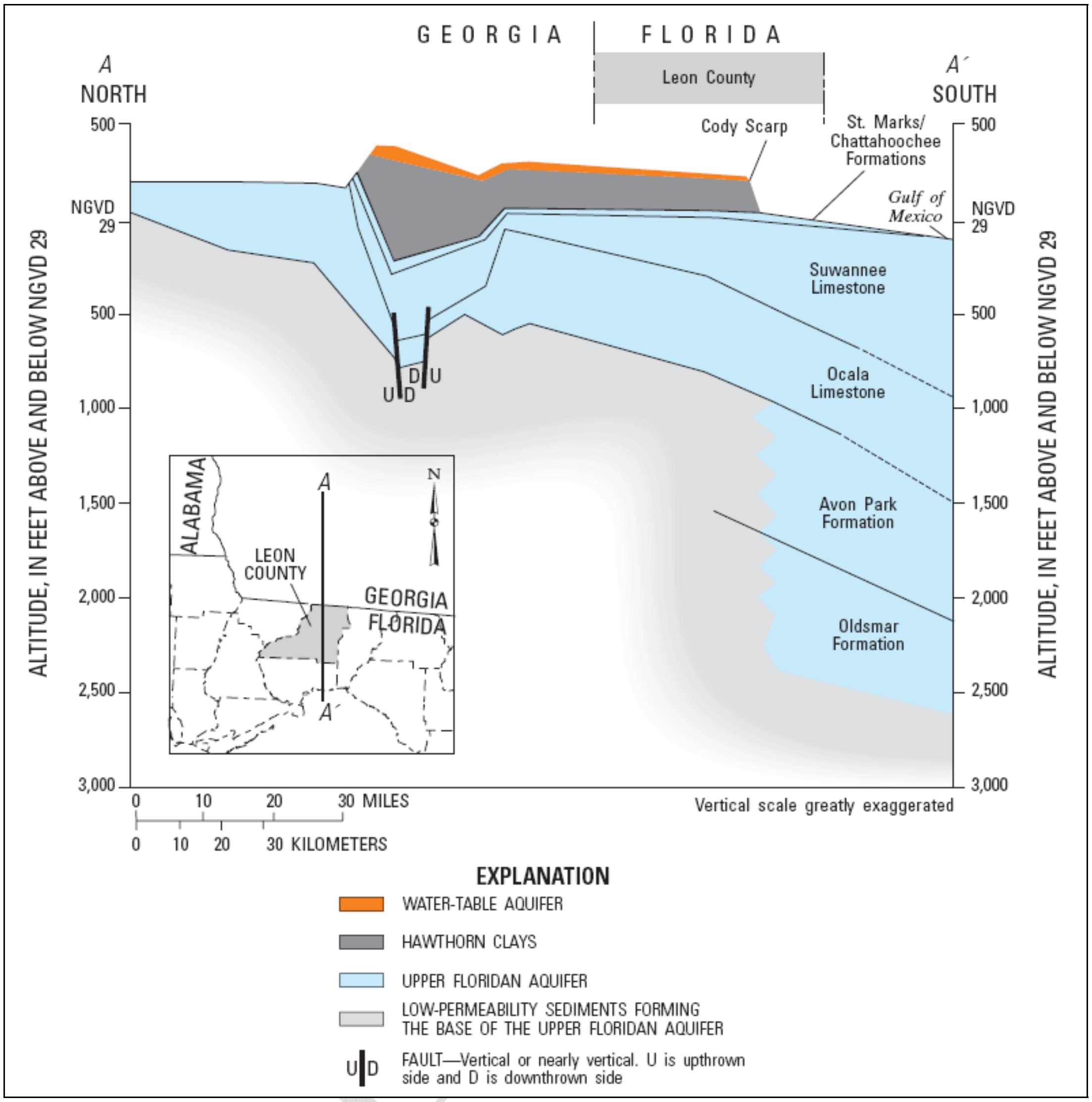


Figure 31 - General hydrogeologic section of the water table and Upper Floridan aquifers from south Georgia south through Leon and Wakulla Counties in Florida (Davis and Katz 2007).

Hydrogeology

Wakulla Spring is located within The Woodville Karst Plain (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 15 m (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 ground water 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).

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 Apalachee Bay about 22 km (14 miles) to the south. Up until recent years, 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 over the past four years, Davis (2011) has provided a theory that describes the fluctuations in ground water flow and spring discharge that occur as a result of this interconnection. There are four general types of flow periods currently evident in this inter-connected conduit/spring system:

1. During a prolonged period of low precipitation, salt water 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 documented 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 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 salt water "plug" out of the conduits feeding the Springs Creek Springs, 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 salt water once again fills the conduits.

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

- The ground water gradient throughout the Wakulla/Spring Creek Springshed
- Hydrological factors that affect ground water 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 25 years (**Figure 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 (2005-2010) the frequency of dark water days has increased to over 92% compared to about 49% during the first five years of measurement (1985-1990). 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.

Human Population and Land Uses

The city of Tallahassee, suburbanized Leon County, and developed portions of Wakulla County overlie the Wakulla Spring capture zone. The 2010 US Census recorded an estimated 471,246 people residing in the seven counties that encompass the Wakulla springshed (**Table 5**). 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 5 - 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

Figure 32 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 6** 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%).

Water Withdrawals, Net Consumption, and Water Balance

Groundwater Withdrawals

Groundwater is the principal source of supply for most withdrawals in the Wakulla Springshed (Chellette *et al*. 2002; Davis and Katz 2007; NWFWMD 2008). **Table 7** 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 1990-2000. The dominant groundwater uses are public and domestic supply (**Figure 33**). 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 50 MGD in 2005 (NWFWMD 2008).

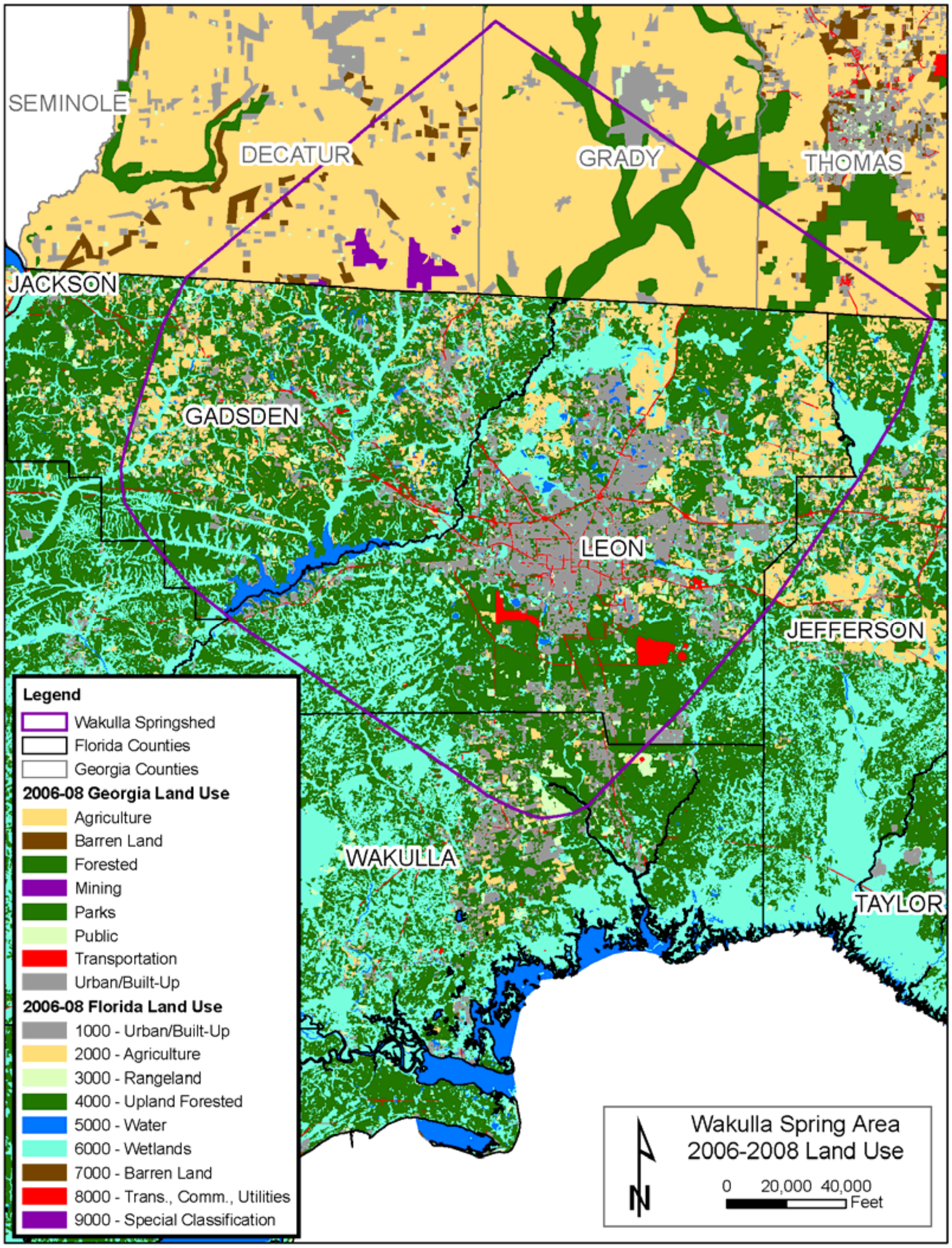


Figure 32 - Land use map for the Wakulla Spring recharge area (based on data for 2006-2008). *Florida land uses are based on the Florida Land Use and Cover Classification System (LUCCS) and reflect both land use and dominant land cover types. Georgia land use categories were less detailed and assumptions concerning their similarity to Florida FLUCCS codes were made in preparation of this map.*

Table 6 - 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.

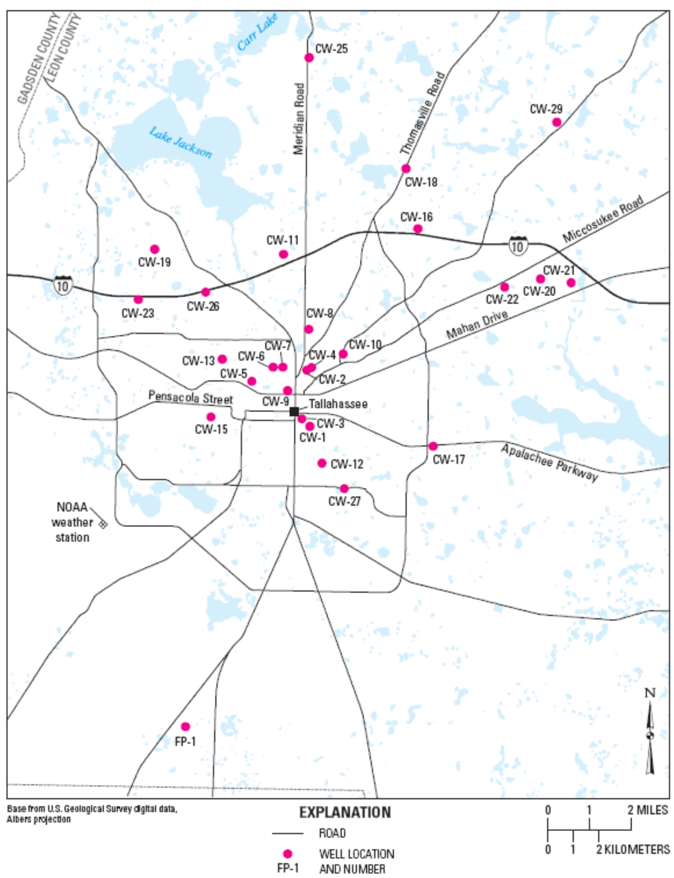


Figure 33 - Map showing the location of the City of Tallahassee's public water supply wells (from Davis and Katz 2007).

Data for Georgia groundwater uses were not available for this analysis. Given the differences in population density and density of agricultural development, it can be assumed that water withdrawals for public and domestic supply in the Georgia portion of the springshed are lower than for agricultural uses. Based on the assumptions that higher agricultural uses offset the lower human population density in the Georgia portion of the springshed and that groundwater pumping if roughly proportional to the areas of the two states in the springshed, it is estimated that Georgia currently withdraws about 25 MGD from the Wakulla Springshed. Based on these assumptions, the estimated total current groundwater withdrawal in the combined Georgia/Florida Wakulla Springshed is about 75 MGD (116 cfs).

Table 7 - Estimated groundwater withdrawals within the Florida portion of the Wakulla Springshed

State	County	Category	1965-1970	1971-80	1981-90	1990-2000
Florida	**Leon**	Public Supply	9.44	15.01	21.42	26.31
		Domestic	2.07	3.23	4.54	4.06
		Commercial, Industrial, Mining	0.00	0.94	0.26	0.16
		Agricultural	0.09	1.00	1.44	0.96
		Recreational	0.00	0.00	1.56	1.13
		Power Generation	0.00	2.16	3.75	2.41
		Total	**11.61**	**22.34**	**32.98**	**35.01**
	Gadsden	Public Supply	0.53	0.83	1.48	1.89
		Domestic	1.43	1.69	1.63	1.60
		Commercial, Industrial, Mining	0.11	0.08	1.56	0.74
		Agricultural	0.49	0.18	2.12	1.79
		Recreational	0.00	0.00	0.09	0.10
		Power Generation	0.00	0.00	0.00	0.00
		Total	**2.57**	**2.78**	**6.89**	**6.12**
	Jefferson	Public Supply	0.03	0.04	0.06	0.07
		Domestic	0.05	0.06	0.11	0.10
		Commercial, Industrial, Mining	0.01	0.00	0.00	0.02
		Agricultural	0.03	0.10	0.70	0.71
		Recreational	0.00	0.00	0.01	0.03
		Power Generation	0.00	0.00	0.00	0.00
		Total	**0.12**	**0.21**	**0.88**	**0.92**
	Wakulla	Public Supply	0.01	0.04	0.08	0.15
		Domestic	0.04	0.06	0.08	0.14
		Commercial, Industrial, Mining	0.04	0.09	0.08	0.07
		Agricultural	0.00	0.00	0.01	0.04
		Recreational	0.00	0.00	0.00	0.02
		Power Generation	0.02	0.03	0.02	0.02
		Total	**0.11**	**0.22**	**0.26**	**0.44**
	Total	Public Supply	10.02	15.92	23.04	28.41
		Domestic	3.59	5.04	6.36	5.90
		Commercial, Industrial, Mining	0.16	1.11	1.91	0.99
		Agricultural	0.61	1.29	4.26	3.50
		Recreational	0.00	0.00	1.66	1.28
		Power Generation	0.02	2.19	3.76	2.42
		Total	**14.41**	**25.56**	**41.00**	**42.50**

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

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 deeper aquifer. Several factors affect the net consumption of groundwater in the Wakulla Springshed. These factors include the following:

- 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 the deep groundwater in this region is minimal (about 1" per year) and most water that soaks into the surface of 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 (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 [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 (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 about 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, combined with the mapped 2006-2008 Florida land uses and the general groundwater recharge potential of the Wakulla Springshed, **Table 8** provides estimates of the net consumption of groundwater withdrawn from the Wakulla Springshed. Estimated net consumption of groundwater in the Wakulla Springshed has increased from about 4.3 MGD (6.6 cfs) in the period from 1965-1970 to about 13.4 MGD (21 cfs) during the period from 1990-2000. The overall average estimated net consumption for the Florida portion of the springshed is about 32% of the total water withdrawn from the aquifer. Taking this estimate and multiplying it by the current (2000 – 2010) total estimated groundwater withdrawal in the Florida portion of the Wakulla Springshed (50 MGD) results in an estimated net groundwater consumption of about 16 MGD (25 cfs). Based on the assumed 25 MGD groundwater withdrawal estimated for the Georgia portion of the springshed and the dominance of agricultural uses and higher confinement of the Floridan Aquifer in this area (assume 68% net consumption), it is estimated that an additional 17 MGD (26 cfs) is not returned to the Wakulla Springshed. Based on these data and assumptions, an estimated average 33 MGD (51 cfs) of Floridan aquifer water is currently being removed from the sources of inflow for Wakulla Spring.

Table 8 - Estimated groundwater net consumption in the Florida portion of the Wakulla Springshed

		Estimated Net Consumptive Water Use in the Springshed (MGD)			
State	**County**	**1965-1970**	**1971-80**	**1981-90**	**1990-2000**
Florida	Leon	3.29	6.15	9.80	10.24
	Gadsden	0.91	0.85	2.70	2.42
	Jefferson	0.04	0.10	0.53	0.55
	Wakulla	0.03	0.05	0.07	0.14
	Liberty	--	--	--	--
	Total	**4.26**	**7.15**	**13.09**	**13.36**
Georgia[1]	**Total**	--	--	--	--
Springshed	**Total**	**4.26**	**7.15**	**13.09**	**13.36**

Use Type	Percent Consumed[2]
Public Supply	28%
Domestic	28%
Commercial, Industrial, Mining	20%
Agricultural	68%
Recreational	77%
Power Generation	8%

[1] Georgia data were not available at the time of this report.

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

Wakulla Springshed Water Balance

Chelette *et al.* (2002) prepared an estimated "water balance" for Wakulla Spring based on average conditions and a variety of assumptions (**Figure 34**). 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:

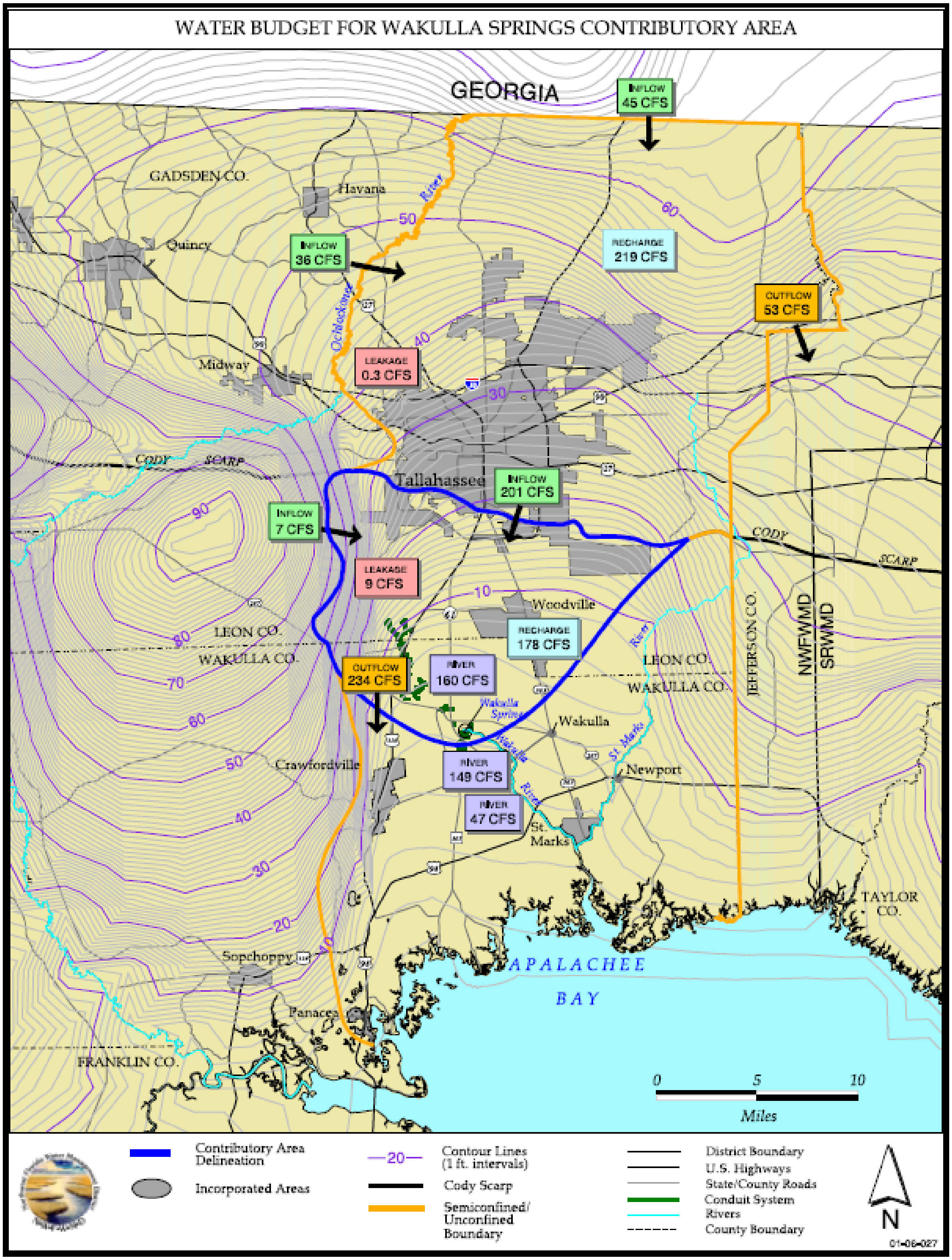


Figure 34 - Estimated water budget for Wakulla Spring (from Chelette *et al.* 2002).

- 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)

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 28**, 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. Both 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 35**).

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).

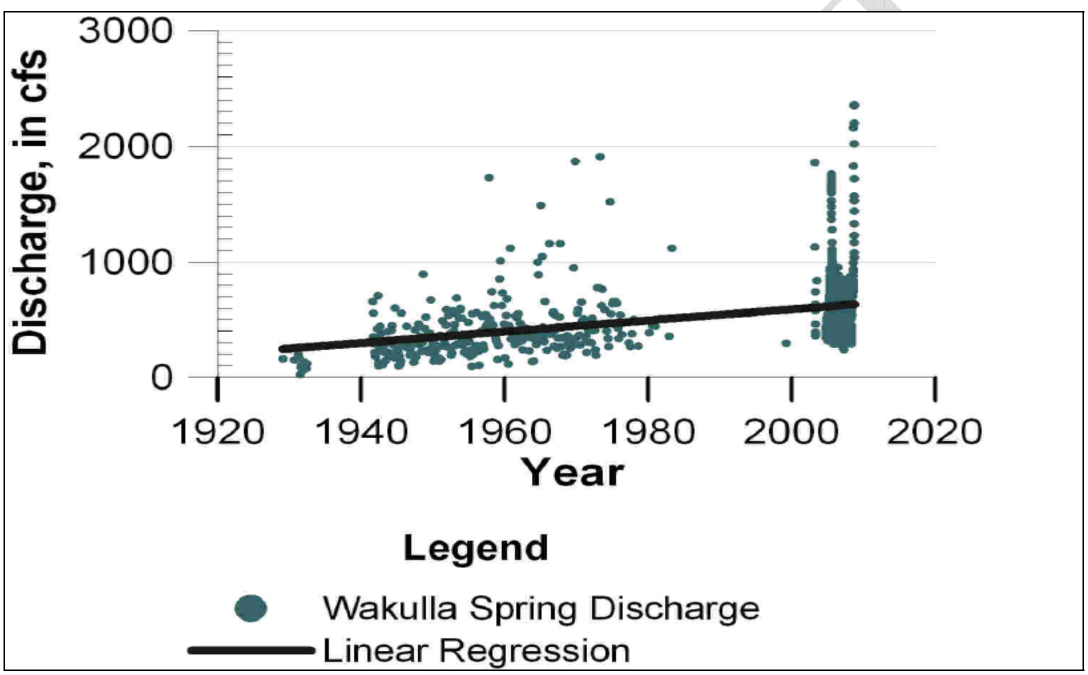


Figure 35 - Wakulla Spring discharge data for the period-of-record with a linear trend analysis (from Davis 2011).

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. The independently estimated inflows and outflows for the current Wakulla Spring water budget are summarized in **Figure 36**.

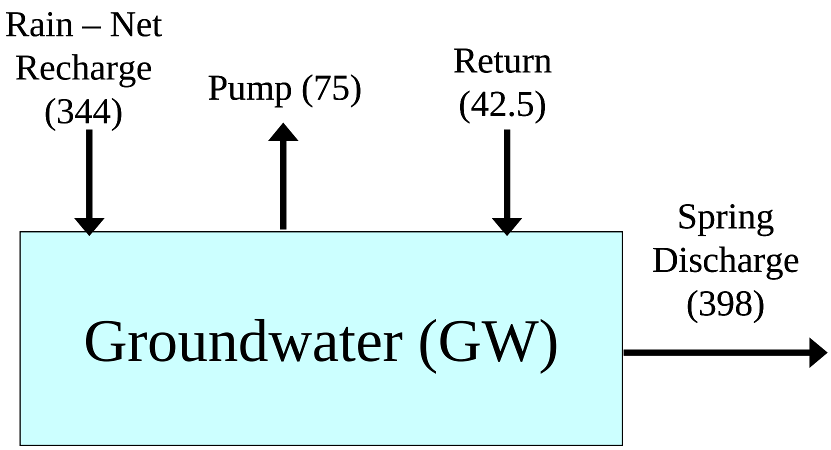


Figure 36 – Wakulla Spring estimated water balance in million gallons per day. These inputs and outputs include the entire Georgia-Florida springshed and have been independently estimated. The approximate difference between the estimated inputs and the estimated outputs at Wakulla spring is about 22%.

Nitrogen Sources, Sinks, and Estimated Mass Budget

Figure 37 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), food products, and man-made fertilizers.

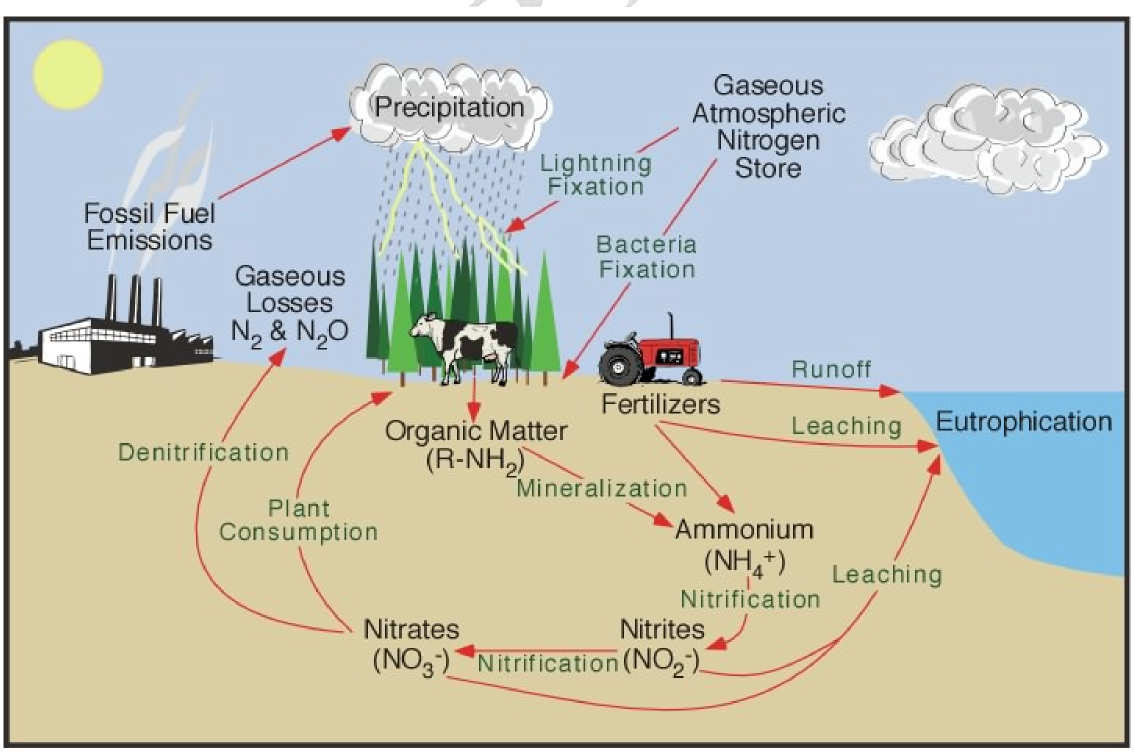


Figure 37 - Typical nitrogen cycle in a mixed agricultural/urban landscape.

Atmospheric

Based on the previous analysis by Chelette *et al.* (2002), atmospheric deposition (wet and dry) contributes a significant nitrogen load to the Wakulla Springshed. The total atmospheric load to the Wakulla Springshed is estimated for this report based on a total average annual precipitation rate of 4,650 MGD and an assumed total nitrogen concentration associated with both wet and dry atmospheric deposition sources. This total nitrogen effective concentration was based on an average dissolved inorganic nitrogen concentration of 0.32 mg TN/L derived from the Quincy atmospheric deposition monitoring site for the period from 1984 through 2010; an assumed concentration of 0.32 mg TN/L for dissolved organic nitrogen in rainfall (see Kadlec and Knight [1996 pp. 410-411] for a range of observed values from south Florida and US stations); and an assumed concentration of 0.32 mg/l for total particulate nitrogen in dry fall; for an estimated total nitrogen associated with rainfall of about 0.96 mg TN/L. Using the average rainfall and total nitrogen concentrations, the estimated atmospheric total nitrogen load to the Wakulla Springshed is about 6,800 tons TN/yr.

Only a relatively small fraction of the total nitrogen in rainfall and dryfall reaches the underlying limestone aquifer. There are a number of important environmental processes that affect these nitrogen losses or "sinks". The principal sinks affecting the transfer of atmospheric nitrogen to the underlying artesian groundwater include the following:

- Particulate nitrogen from atmospheric inputs typically includes particles of living plant materials such as pollen as well as ash from fires and dust. This nitrogen will be initially trapped at the land surface by existing plants and soils and subsequently decomposes over time as it reenters the biological nitrogen cycle.
- Soluble inorganic nitrogen in relatively diffuse rainfall inputs is efficiently assimilated by plants and soil microbes in native habitats such as forests and wetlands, and to a lesser extent in other vegetated areas such as lawns and pastures. The microbially-mediated process of denitrification extracts oxygen from the oxidized forms of nitrogen, including nitrite and nitrate (collectively indicated as NO_x-N), resulting in the transformation of this nitrogen to nitrogen gas (N_2).
- Rain and dryfall nitrogen that falls on the portions of the springshed that are underlain by relatively impervious sediments is not expected to contribute to the underlying nitrogen balance. For this nitrogen balance it is assumed that only the rain and dryfall nitrogen on the Lakes and Streams and Karst areas (assume about 532 mi^2 or 34 percent of the springshed) actually has the potential to reach the underlying Floridan aquifer.

Assuming that the pre-development total nitrogen concentration in Wakulla Spring was about 0.15 mg/L (about 0.05 mg/L as NOx-N and 0.1 mg/L as total Kjeldahl N) and the average Wakulla Spring flow was about 344 cfs, the total nitrogen load from atmospheric inputs minus what was lost within the native, pre-development plant community (assumed to be upland and wetland forest) that reached the groundwater was about 51 tons TN/yr of the estimated 6,800 tons TN/yr total estimated atmospheric input. This calculation indicates that the estimated nitrogen sink through the processes described above and with a native plant community throughout the springshed was greater than 99 percent.

Particulate and dissolved nitrogen that falls directly on impervious surfaces and on internally-drained lakes and watersheds is more likely to reach the underlying groundwater than particulate nitrogen that falls on vegetated areas such as forest, pastures, lawns, and wetlands. Based on the observation that about 72% of the springshed is in forest, wetlands, rangeland, and vegetated urban areas (assuming that about 50% of the total urban and built up landuse is vegetated), a preliminary estimate for the amount of this atmospheric nitrogen input that currently reaches the underlying groundwater in the areas of higher groundwater recharge (34% of the total recharge area as estimated by Chelette *et al.* [2002] and Barrios [no date]) is about 5%, or about 116 tons TN/yr, which is about 2.3 times higher than the estimated pre-development rate. This estimated increase in nitrogen load alone would be 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 (assuming no change in average inflows).

Fertilizer

Total fertilizer sales for Florida by county are available from the Florida Department of Agriculture and Consumer Services (FDACS) for the period from 1997 through 2010. Similar data were not available for the south Georgia counties in the springshed. **Table 9** provides a summary of these data for the Florida portion of the Wakulla Springshed based on the simplifying assumptions that all of the fertilizer sold in these four counties is used in the county and that it is evenly distributed over the county. The approximate fertilizer load of total nitrogen (TN) for the Florida portion of the springshed is about 1,100 tons/yr. Assuming that the Georgia counties apply about the same amount of fertilizer per land area (about 400 tons of TN/yr), the estimated TN fertilizer load applied to the Wakulla Springshed is about 1,500 tons TN/yr.

Table 9 - Estimated total nitrogen in fertilizer sold in the Florida portion of the Wakulla Springshed

		Average Annual Fetilizer Use in the Wakulla Springshed[1] (Tons)		% of Fertilizer Load
State	**County**	**July 1997- June 2000**	**July 2000- June 2010**	
Florida	Leon	215	270	21.4%
	Gadsden	736	677	62.4%
	Jefferson	199	160	15.8%
	Wakulla	6.25	2.30	0.4%
	Liberty	0.03	0.03	0.0%
	Total	**1,156**	**1,109**	**100%**

[1] Fertilizer sold in the county was assumed to be applied in the county based on the proportion of the county in the Wakulla Springshed

Data source: Florida Department of Agriculture and Consumer Services

Nitrogen fertilizer applied to areas of the springshed that have confining layers (e.g., the Hawthorn Group) and resulting low recharge rates (The Streams Region), is not likely to reach the underlying limestone aquifer. A portion of the nitrogen in fertilizer applied to crops and turf in those areas of the springshed that either directly or indirectly recharge the limestone aquifer is more likely to end up in the Floridan aquifer. For the purpose of this preliminary nitrogen mass balance it is assumed that about 66 percent of the springshed is underlain by low permeability sediments (precluding any significant fertilizer nitrogen inputs to the underlying Floridan aquifer water) and that the fertilizer load is evenly distributed over the entire springshed. It is also assumed that the remaining 510 tons TN/yr is reduced by about 75 % through plant uptake and denitrification. This results in an estimated total TN load from fertilizer entering the artesian aquifer feeding Wakulla Spring of 128 tons TN/yr. Since the majority of fertilizer nitrogen is likely to be converted to nitrate as it passes through unsaturated soil layers, the contribution of this nitrogen load to the nitrate concentration in the Floridan Aquifer using this set of assumptions is about 0.33 mg/L.

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. 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. The City can also treat and discharge up to 1.2 MGD of reclaimed water at the Tram Road Reuse Facility.

Chelette *et al.* (2002) estimated a total nitrogen load of about 580 tons TN/yr from the disposal of wastewater effluent and 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 312 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/yr in 2007, 269 tons/yr in 2008, and 215 tons/yr in 2009, illustrating the declining nitrogen loads resulting from the cessation of fertilization and biosolids disposal. The average of these values or about 280 tons/yr was used in place of the estimate provided in Chelette *et al.* (2002).

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 it is 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/yr.

Much of the TN in septic tank effluents leaches directly to the underlying groundwater but some may be denitrified as described above. For this analysis it is assumed that about 40 percent of this load reaches the Floridan Aquifer or 125 tons TN/yr. Based on the total load estimates from Chelette *et al.* (2002) and these assumptions, the total estimated TN load to the groundwater from wastewater and septic tanks is about 287 tons TN/yr.

Other Sources

Data from Chelette *et al. (*2002) were also used to roughly quantify the nitrogen contributions in the springshed from significant sources other than those listed above. The total nitrogen load estimated from livestock was about 173 tons TN/yr. The total nitrogen load from sinking streams in the springshed was estimated to be about 79 tons TN/yr. A portion (assumed 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 35 tons TN/yr. Roughly 30 percent of the TN in the sinking streams is assumed to end up in the underlying groundwater or about 24 tons TN/yr. The total estimated TN entering the groundwater in the Wakulla Springshed from these additional sources is about 59 tons TN/yr.

Estimated Nitrogen Budget

Based on the data presented above and the stated assumptions, the combined total of the annual average estimated nitrogen sources to the groundwater in the Wakulla Springshed for the most recent decade is about 590 tons TN/yr. Based on the average groundwater flow during the past decade (about 355 MGD or 550 cfs), the estimated TN concentration at Wakulla spring should be about 1.1 mg/L. Assuming the TKN is about 0.1 mg/L (based on historic data from Wakulla Spring) this indicates that the nitrate N concentration would be about 1.0 mg/L. **Figure 38** 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. **Figure 39** 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%.

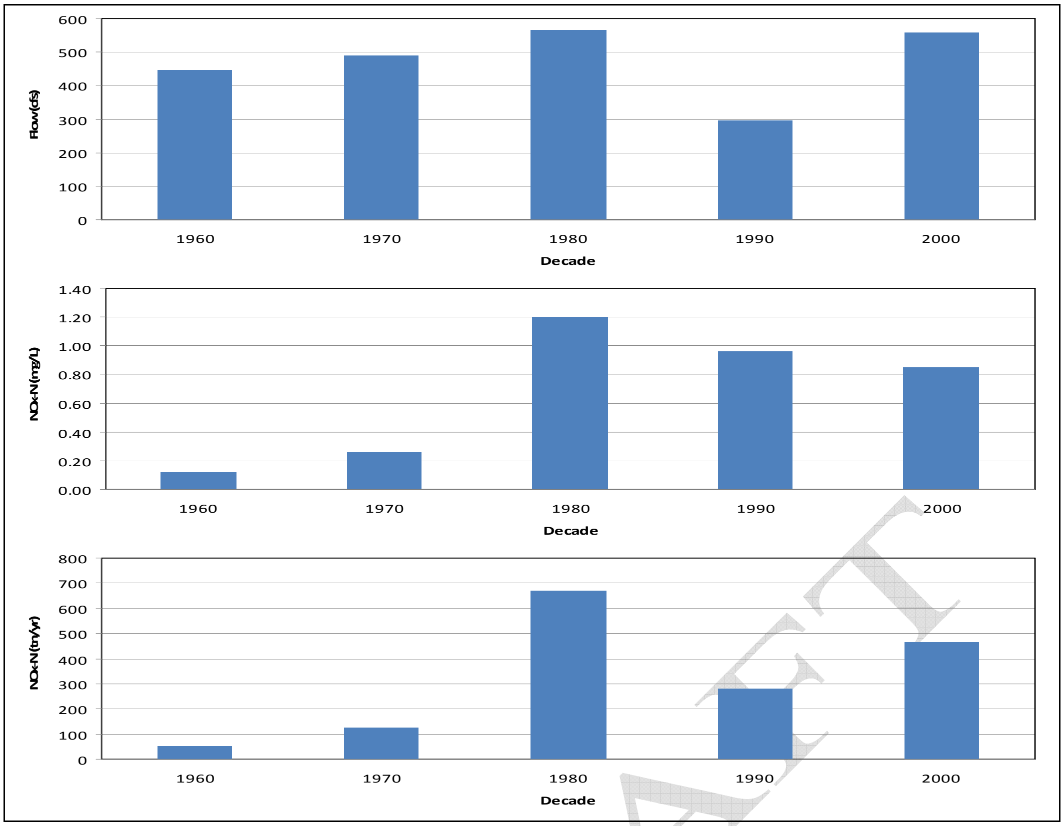


Figure 38 - Wakulla Springs average discharge, nitrate nitrogen concentrations, and nitrate nitrogen loads by decade since 1960.

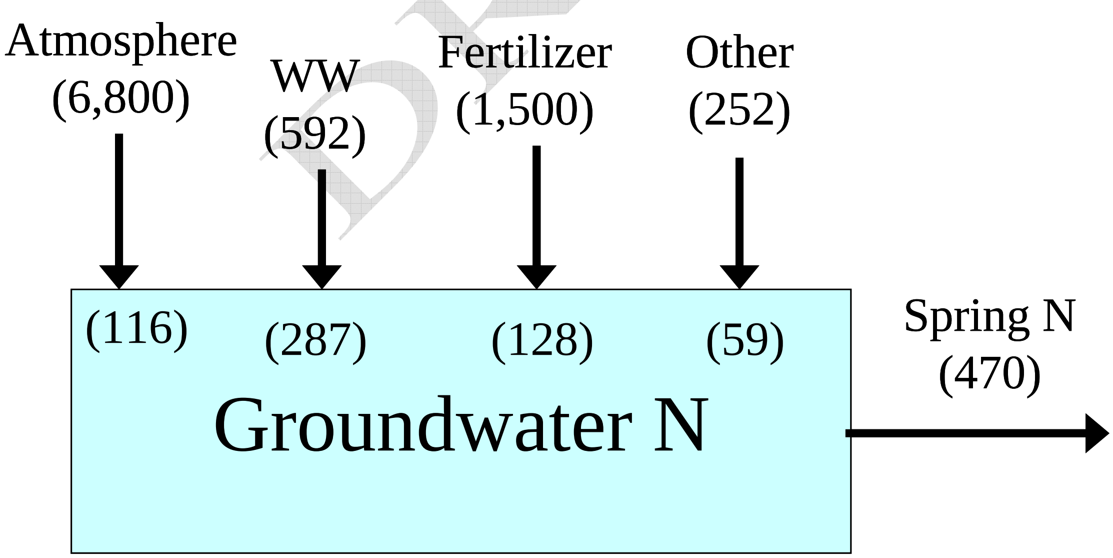


Figure 39 – Wakulla Spring estimated total nitrogen balance in tons per year. These inputs and outputs include the entire Georgia-Florida springshed and have been independently estimated. The approximate error between the estimated inputs and the estimated outputs at Wakulla spring is about 20%.

Description of Existing Impairments and Causes

Overview of Wakulla Spring Changes

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 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.

Increasing Discharge and Decreasing 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 relatively recent 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 inter-connected 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 possible 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.

Water Quality Changes

General

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.

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.

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 2010). 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). 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 or is already in the planning/design stage 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, is currently being 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 is scheduled to be complete by 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 2010; 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 draft TMDL document for the Upper Wakulla River (Gilbert 2010). The Draft 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. After finalization of the Wakulla Spring TMDL for nitrate, FDEP intends to implement a Basin Management Action Plan (Tom Frick, FDEP, personal communication).

Biological Changes

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.

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, 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.

Ecosystem Metabolism

Preliminary 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, WSI 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.

Vision and Goals for a Restored Wakulla Spring

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.

Best-Case Scenario: Crystal Bowl of Light

Environment Context

- 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 polices 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).

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.

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.

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 planned nitrogen reductions at the City of Tallahassee's (COT) facility and allowing no new 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 draft 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

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

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.

Summary

The stakeholders were able to achieve consensus for each of the three restoration goals listed above. The importance of the stakeholder development of restoration goals was to provide a road map for this Adaptive Management Strategy. Further, these restoration goals provide a measure for defining the success of restoration as improvements occur at Wakulla Spring. Certainly the steps towards restoration would differ if the restoration goal for NO_3-N reduction is to achieve the historic concentration of 0.05 mg/L rather than the draft TMDL and Numeric Nutrient Criterion concentration of 0.35 mg/L. The same applies for the restoration goal for dark water days and restoring the biological community. Thus, the restoration goals for NO_3-N concentration, dark water days, and biological community were defined by the stakeholders so the actions for restoration could be developed in this Adaptive Management Strategy.

Restoration Responsibilities, Actions, Estimated Costs, and Savings

This report presents the preliminary Wakulla Spring Adaptive Management Strategy. The work conducted by WSI during the one-year Wakulla Spring Working Group Coordination and Restoration Planning Project was intended to be the first step in a proposed three –year effort to achieve consensus on a path forward for specific actions that will accomplish the restoration goals described in the previous section. Due to funding cuts at FDEP for the Springs Initiative and the Springs Working Groups, this report represents only a small step on the path to the recovery of Wakulla Spring. Additional community resolve will be needed to finalize the Wakulla Spring Adaptive Management Strategy. Since this is the first time this draft assessment of existing conditions and needs is being distributed for public review, it is currently premature to assign specific responsibilities and to estimate costs for the restoration actions. For this reason this section is essentially an annotated outline of what needs to be included in the final Wakulla Spring Adaptive Management Strategy.

Key Stakeholders

The Wakulla Spring Working Group has provided an opportunity for stakeholders to be recognized and their perspectives heard for the past 18 years. This section briefly lists the key stakeholder groups that have been identified and have helped support the development of this draft 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 preliminary 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 Community Affairs
    - Department of Agricultural and Consumer 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

- Friends of Wakulla Springs

- 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

Proposed Restoration Actions

Once stakeholders have had an opportunity to review the technical conclusions provided in this report, specific actions will be proposed.

Restrictions on Consumptive Water Uses

Actions to be determined.

Reductions in Nitrogen Loading

Actions to be determined.

Changes to Land Management Practices

Action to be determined.

Estimated Costs and Potential Savings

Once specific actions and responsible parties have been determined to meet the goals of the Wakulla Spring Adaptive Management Strategy, costs will be estimated. It is anticipated that the responsible stakeholders will provide these cost estimates for the final Wakulla Spring Adaptive Management Strategy.

Restrictions on Consumptive Uses

Costs/savings to be determined.

Reduction of Fertilizer Use

Costs/savings to be determined.

Additional Wastewater Treatment Upgrades for Nitrogen Removal

Costs/savings to be determined.

Alternative Land Management Approaches

Costs/savings to be determined.

Comprehensive Assessment Monitoring

Costs/savings to be determined.

Evaluation of Success

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.

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.

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 10**. **Figure 40** 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.

Table 10 - 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

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.

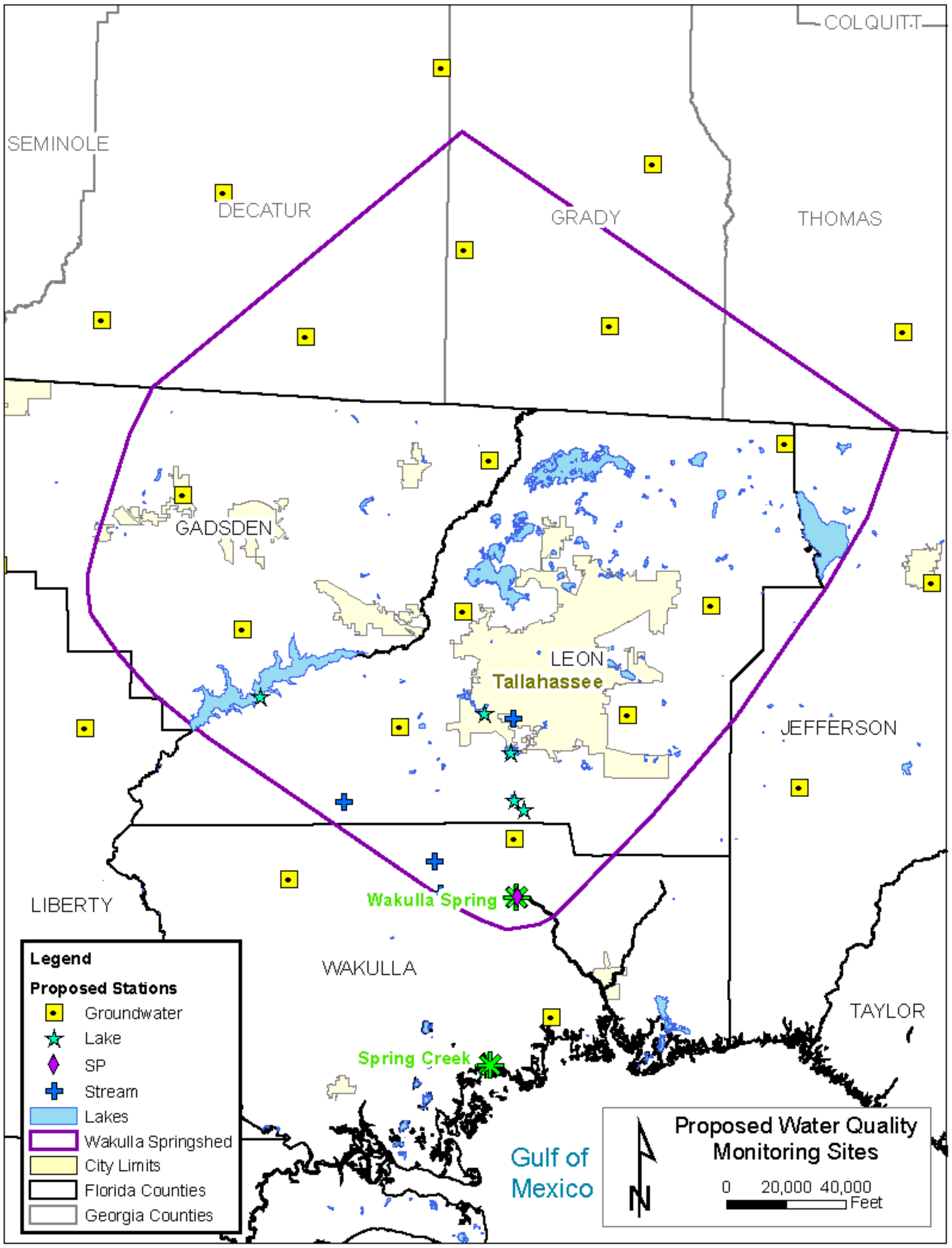


Figure 40 - Proposed network of restoration assessment monitoring stations in the Wakulla Springshed

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 11**. **Figure 41** 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 insect emergence traps and visual counts. Fish counts during dark water conditions will be conducted using electro-fishing equipment.

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).

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 11 - 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

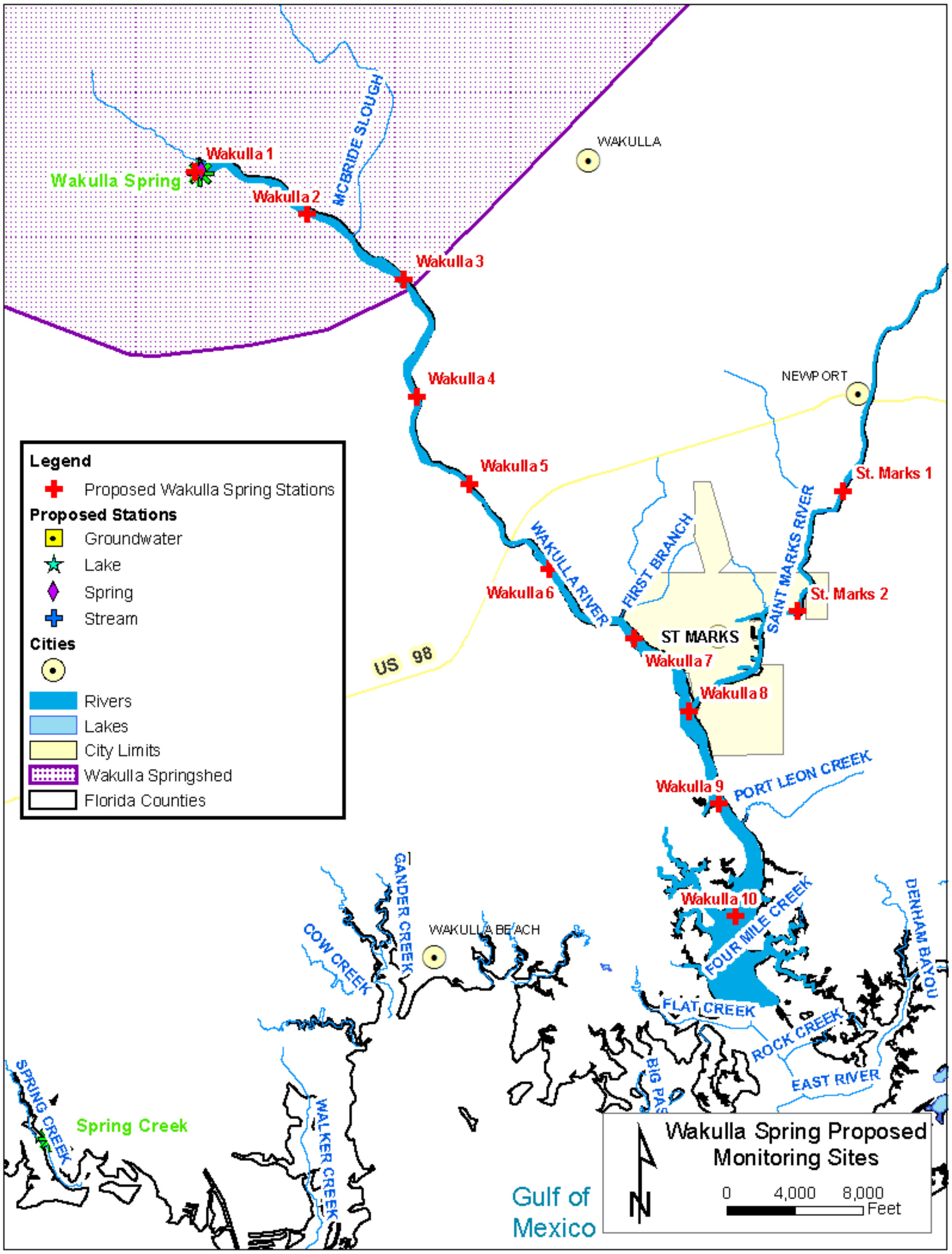


Figure 41 – Proposed network of restoration assessment monitoring stations in Wakulla Spring and River

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