DEGRADATION OF WATER QUALITY AT WAKULLA SPRINGS, FLORIDA: ASSESSMENT AND RECOMMENDATIONS

Report of the Peer Review Committee
on the Workshop
Solving Water Pollution Problems
in the Wakulla Springshed of North Florida
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ABSTRACT

Wakulla Springs, a natural resource of great ecological and recreational value, is suffering from two problems: (1) ecological decline due to excess nitrate loading and (2) dark water. While the source of dark water and the remedy for this problem remain uncertain, the situation regarding nitrate is reasonably clear. Currently the largest single source of nitrate appears to be the Southeast Sprayfield operated by the city of Tallahassee, but nitrate from septic tanks in Leon and northern Wakulla Counties is a looming problem. The long-term success of efforts to restore Wakulla Springs will depend on a continuing, coordinated research program into the sources of and solutions to the problems facing this unique natural resource.

In order to address these problems and possibly reverse the decline that has occurred at Wakulla Springs, the following six recommendations are intended to serve as guides for future actions by local and state governments:

<u>Recommendation 1</u>. Goal of Wastewater Disposal Activities

A primary goal of all wastewater disposal activities in Leon and Wakulla Counties should be to reduce nutrient loading (nitrogen and phosphorus) to the aquifer.

<u>Recommendation 2</u>. Wastewater Utility

A wastewater utility should be established and charged with improving the operation of all onsite sewage treatment and disposal systems (OSTDSs or septic systems), in accordance with the goal stated in Recommendation 1.

<u>Recommendation 3</u>. Regulate Fertilizers

The amounts and types of fertilizer used in the catchment basin of Wakulla Springs should be limited and regulated through a combination of public education and targeted ordinances.

<u>Recommendation 4</u>. Expedite the Total Maximum Daily Load Process

The Florida Department of Environmental Protection should expedite the establishment of total maximum daily loads and pollutant load reduction goals for Wakulla Springs and River.

<u>Recommendation 5</u>. Hydrologic Observatory

A Hydrologic Observatory should be established and charged with coordinating and facilitating research activities into a number of issues related to the health of Wakulla Springs and River.

<u>Recommendation 6</u>. Public Education

A concerted, prolonged and properly funded effort should be made to educate the public on the importance of the previous recommendations to the long-term health of Wakulla Springs and its ecosystems.

EXECUTIVE SUMMARY

Introduction

Wakulla Springs is the centerpiece of Wakulla Springs State Park and one of the crown jewels of the Florida state park system. On average, 250 million gallons per day (mgd) of water flow from the spring, creating the Wakulla River, which joins the St Marks River some 10 miles downstream. The combined rivers form an estuary at the edge of Apalachee Bay in the Gulf of Mexico. The spring is the above-ground representation of a vast underground water resource, the Floridan aquifer — a thick, water-bearing layer of porous limestone. The springs, river and estuary have historically had exceptional ecological and recreational value; the state park receives about 200,000 visitors per year.

Figure 1: Aerial photo of Wakulla Spring and River – Courtesy of Joe Hand, FDEP

In recent years, there has been a striking change in the basin, illustrated in **Figure 1**, and in the upper reaches of the river. Native aquatic vegetation has been almost entirely replaced by invasive exotic species, most notably hydrilla and algae. This apparently has led to other changes in biota, as many native animals and birds are in decline, and in some instances have disappeared altogether. In addition, there seems to have been an increase in the frequency of dark-water days, during which the water in the basin is too dark to permit the glass-bottom boats to operate.

A workshop, entitled ***Solving Water Pollution Problems in the Wakulla Springshed of North Florida: Science and Technology at Work for a Better Florida***, was convened on May 12 and 13, 2005, in Tallahassee, Florida. At this workshop scientific and engineering experts from government agencies, academia and private industry assessed water-quality problems in Wakulla Springs and River, explored their causes and consequences, and proposed solutions or mitigating strategies. Attention at the workshop was focused on two issues: increased nutrient loading in the water emanating from Wakulla Springs and the increasing frequency of dark-water days.

A peer review committee was charged with synthesizing the research findings of several major studies of Wakulla Springs and summarizing the workshop's conclusions and recommendations. In particular, the committee was charged with developing answers, using the best available data, to the following set of five key questions:

1. *What does the preponderance of evidence indicate are the sources of nutrients (nitrogen and phosphorus) reaching Wakulla Springs, and which are the most important sources?*
2. *Are nutrients (nitrogen and/or phosphorus) responsible for the ecological "imbalance" of the Wakulla River (imbalance as defined by Florida DEP)?*
3. *What are the solutions that should be implemented presently to reduce nutrient loading to Wakulla Springs?*
4. *What are the future threats (say 50 years into the future) regarding nutrient loading to Wakulla Springs, and what planning is now necessary to avoid these threats?*
5. *What additional research, if any, is necessary to provide adequate certainty regarding effective actions to eliminate the Wakulla Springs and River nutrient pollution problem?*

A more complete list of questions posed to the committee is found in **Appendix A**, and its preliminary answers (prior to the development of this report) are in **Appendix B**. A list of experts who were consulted during the preparation of this report is found in **Appendix C**. This document is the report of the committee.

Nutrient Loading

Non-native hydrilla now chokes the spring basin and the upper mile of the river and, together with algal blooms, reduces dissolved-oxygen levels in the water. As a result, the ecosystem has been degraded, and the river's ecological and recreational value has diminished. A number of sensitive species have all but disappeared. In recent years, the Wakulla River has averaged in the lowest 20th percentile for water quality of Florida's rivers, with the ecological health of the upper reaches of the Wakulla River on average being rated as "poor" for the past five years.

Increasing nitrate levels over the past several decades in the waters flowing from Wakulla Springs has caused a decline in water quality and has seriously disrupted the ecology of the basin and river. The nitrate level rose from about 0.2 milligrams per liter (mg-N/L) during the 1970s to about 1 mg-N/L by the end of the 1990s, a fivefold increase in less than 30 years.

The conclusion that nitrogen (in the form of nitrate) is the key nutrient fueling this growth is substantiated by two facts:

- *Nitrogen in the upper Wakulla River decreases more rapidly than phosphorus with distance down river and*
- *The concentration of nitrate in Wakulla's waters has increased substantially in the past 30 years, whereas the concentration of phosphorus has not.*

Further, since phosphorus is buffered by natural processes (particularly leaching from the P-rich Hawthorne group clays that overly the Floridan aquifer north of the Cody Scarp and the adsorptive equilibration of dissolved ortho-P with the limestone matrix of the aquifer), the control of its concentration is not practically possible.

The weight of evidence presented at the workshop, and collected and assessed since the workshop, indicates that the most significant sources of nitrate are as follows:

- *Nitrogen in wastewater applied at the COT's Southeast Sprayfield (SESF),*
- *Septic systems in the unconfined portion of the Wakulla springshed,*[1]
- *Fertilizer (a portion of which is attributable to the SESF operations) and*
- *Residual sludge applied at the airport.*

Data indicate that the SESF, which receives the great majority of the city's wastewater (17 – 22 mgd), is a significant source (70% by one estimate) of the total nitrate load to Wakulla Springs, excluding atmospheric deposition (most of which is taken up by plants) and residual sludge application (which is being phased out as a disposal practice). Additionally, Wakulla Springs and River are vulnerable to pollution from land-use practices because in a significant portion of the springshed (the southern portion) the aquifer lies below porous soils (i.e., the aquifer is unconfined). Specifically, the SESF is located on the Woodville Karst Plain, an unconfined portion of the Floridan aquifer. Thus the nutrients that are not taken up by crops grown on the SESF readily percolate through the permeable, sandy soil and flow directly into the upper portions of the Floridan aquifer system. From there, a significant fraction of the groundwater flows southwest toward Wakulla Springs, as demonstrated by potentiometric-surface data. Tracing experiments, sponsored by the Florida Department of Environmental Protection (FDEP), will be conducted in the coming year to clarify the pathways and travel times for groundwater flowing from the SESF.

Since the SESF is a point source operated by a responsible entity, it is more amenable to rapid modification than other sources. The COT should be commended for making modifications in the operation of its wastewater facilities in recent years that have reduced the release of nitrate into the aquifer (see **Appendix I**). However, further modification of SESF operations may be necessary if the biological and ecological degradation at Wakulla Springs are to be reversed.

In the larger portion of the Wakulla springshed, lying north of the Cody Scarp, the aquifer lies below relatively impermeable soils. Surface runoff in this area is collected and channeled to the sinkhole lakes Lafayette, Jackson, Iamonia and Miccosukee and to other open sinkholes.

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[1] A springshed is the land area that contributes rainfall and runoff to a spring; it is also called the capture zone, catchment basin or contributory area.

Thus, pollutants on the land surface (such as fertilizers) can move rapidly into the aquifer that supplies the flow to Wakulla Springs and River.

Septic systems are a growing problem as the region's population continues to increase. This source, having multiple points of origin, will be difficult to address without change in the administrative structure of local governments. Other sources of concern are fertilizers and livestock. The former is likely to increase as the population in the springshed continues to grow. The adverse impact of fertilizers can be mitigated by suitable storm-water regulation and public awareness campaigns. The contribution from livestock is small, and is anticipated to remain so. There is no evidence that a significant flux of nitrate originating in southern Georgia reaches Wakulla Springs.

It is doubtful that a reduction in nitrate alone will allow the ecology of the Wakulla Springs basin and upper river to recover to a "pristine" state, because it is exceedingly difficult to eradicate invasive plants such as hydrilla. However, it is reasonable to expect that the balance of competition will shift in favor of the native plants as the nitrate concentration is decreased toward natural levels. Reduction of the nitrate loading will slow the rate of growth of hydrilla and algae and facilitate their control by various means. A crucial first step to recovery is a reduction of nitrate loading; if nothing is done, the ecology of Wakulla Springs will remain severely degraded.

Dark Water

Another Wakulla Springs problem presented and discussed at the workshop involves the dark (tea-colored) water frequently evident in the spring basin, which has resulted in a recent increase in the number of days when the state park's glass-bottom boats cannot operate. The periods of dark water in Wakulla Springs are variable and appear to be the result of natural processes. The dark water probably results from tannic surface waters (stained brown in color from percolating through leaf litter) being carried to the aquifer by surface runoff following rainfall. Current understanding of the dark-water problem is insufficient to allow any remedies to be proposed at this time. The development of the requisite understanding will require a concerted, properly funded research effort.

Other Comments

Several of the more specific recommendations presented in the Wekiva Study Report[2] might be applicable to Wakulla Springs, but such specificity is beyond the scope of this report. Further, it may be premature to establish protection zones for Wakulla Springs; at present there is insufficient understanding of the structure of the aquifer and the specific flow paths within the springshed of Wakulla Springs to delineate such zones. However, it is reasonable to expect that such zones could be identified in the not-too-distant future (~5 years), assuming that the research program recommended below is implemented and properly funded.

The FDEP is to be commended for purchasing, and maintaining in a natural state, 11,000 acres of springshed in Wakulla County in order to protect water quality in Wakulla Springs. The continued purchase of land in the springshed is a desirable policy, especially for areas close to the spring or for major aquifer-recharge areas.

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[2] FDEP. December, 2004. *A strategy for water quality protection: Wastewater treatment in the Wekiva study area.*

Wakulla Springs and River has rightly been designated by FDEP as an Outstanding Florida Water. This unique system is under severe stress due to population growth in the springshed. If it is to be preserved for future generations, a suitable suite of protective measures and administrative structures need to be put in place, beyond the efforts to control nitrate and dark water, including the following:

- *Suitable regulation and oversight by responsible state agencies (e.g. FDEP and the Florida Department of Community Affairs [DCA])*
- *A continuing coordinated program of monitoring, data collection and analysis by researchers, perhaps within the auspices of a hydrologic observatory or research station and*
- *The coordinated involvement of community and public-interest groups, such as the Friends of Wakulla Springs, the Wakulla Springs Working Group, the Trust for Public Lands, 1000 Friends of Florida, the Hydrogeology Consortium, etc.*

Recommendations

The six recommendations of the peer review committee, presented below, are addressed principally to state and local governments. Several of the commentaries on these recommendations list specific actions that were mentioned by participants at the workshop. These are presented as illustrations; the committee is not endorsing any specific actions.

Recommendation 1. *Goal of Wastewater Disposal Activities*

A primary goal of all wastewater disposal activities in Leon and Wakulla Counties should be to reduce nutrient (nitrogen and phosphorus) loading to the aquifer.

Commentary: The COT and Leon and Wakulla Counties should, by cooperative and joint agreements, institute means to facilitate and monitor realistic progress toward this goal. Immediate progress may be made by the following:

- *Review and modify practices and activities at the COT's wastewater treatment facilities. In particular, the application of fertilizer to the SESF should be minimized, consistent with maximizing nutrient removal by sprayfield plants. The planned upgrade of the T. P. Smith (and Lake Bradford Road) facilities to improve sewage treatment capabilities should be completed as soon as practicable; tertiary treatment (nutrient reduction) and/or other means of reducing nitrogen (and phosphorus) loading to the Wakulla Springs springshed should be implemented; and*
- *Cessation of the application of wastewater residuals in the Wakulla Springs springshed (if not previously implemented).*

Fertilizer applications at the sprayfield, which have decreased substantially in the last few years, should be further reduced, and the goal of the sprayfield operations should be primarily to remove nutrients from wastewater, rather than to achieve reuse for agricultural production (hay and cattle). Further, the rate of treated sewage application — currently about 120 inches per year vs. 68 inches per year of rainfall — should not exceed the capacity of crops at the sprayfield crops to efficiently remove nutrients before they enter the groundwater.

Consideration should be given to procuring additional land for applying Tallahassee's treated sewage, especially land outside the Wakulla springshed. The reduced application rate of wastewater per acre of land will improve the efficiency of nutrient removal by crop plants, and in addition, land application outside the springshed will decrease overall nitrate loading to the springs. Alternatives would be to remove a greater portion of the nitrate at the treatment plant, increase the reuse of wastewater and/or to pipe wastewater to alternate discharge points. Land costs associated with several of these options are of course a significant factor, and these costs should be compared with other options that do not entail such costs, such as the removal of nutrients via tertiary treatment at the T. P. Smith plant or at the SESF. (A $73 million upgrade to the T. P. Smith plant is planned; tertiary treatment for nitrogen removal at the plant would add about $30 million to the cost.)

Recommendation 2. Wastewater Utility

A wastewater utility should be established and charged with improving the operation of all onsite sewage treatment and disposal systems (OSTDSs or septic systems), in accordance with the goal stated in Recommendation 1.

Commentary: This utility should encompass those areas of Leon and Wakulla Counties not currently served by a wastewater treatment facility (WWTF) and should be funded by an appropriate utility fee. Data from the workshop and our continuing assessment indicate the need for the improved management of septic systems in Leon County and the portion of Wakulla County in the springshed, because nutrient loading from these systems is a critical threat to the future ecological and recreational value of Wakulla Springs and River. In particular, assessment of growth-management options suggests that limits should be placed on numbers, and numbers per acre, of septic systems in the unconfined portion of the springshed.

The workshop's panel of experts strongly recommended the establishment of a wastewater utility, and the committee has adopted that recommendation. The utility should be led by the governments of the COT and Leon and Wakulla Counties, with the assistance of FDEP, the Florida Department of Health, and the DCA. This utility could be initially funded by grants from the US Environmental Protection Agency and sustained over the long term by fees charged to septic-system owners. The most attractive feature of this utility is that it could be responsible for maintaining and monitoring performance-based septic systems (with heightened nitrate-treatment requirements) in the environmentally sensitive, unsewered portions of the springshed, providing a uniform means of ensuring that these systems are operated in an environmentally sound fashion to minimize impacts on Wakulla Springs and River.

Recommendation 3. Regulate Fertilizers

The amounts and types of fertilizer (e.g., slow-release only) used in the catchment basin of Wakulla Springs ***should be limited and regulated*** through a combination of public education and targeted ordinances.

Commentary: This recommendation applies to the entire catchment basin, because fertilizer, mobilized by rainwater, can reach the aquifer by percolation in the unconfined portion of the basin or as stormwater from the confined portions. To be successful, public education would need to be properly funded and supervised by a responsible entity. One possible entity to be responsible for public education related to fertilizer usage and application is the Hydrologic Observatory proposed in Recommendation 5.

Recommendation 4. Expedite the Total Maximum Daily Load Process

The Florida Department of Environmental Protection should ***expedite the establishment of total maximum daily loads*** and pollutant load reduction goals for Wakulla Springs and River.

Commentary: The TMDL process for Wakulla Springs should address all sources of nitrogen to the springshed, including, but not limited to, fertilizer use in southern Georgia and north Florida, atmospheric deposition, stormwater recharge, septic systems, and sprayfield disposal of treated wastewater. These criteria should be put into practice as soon as practicable, guiding decisions on land use, pollution permits, remedial actions, etc.

Recommendation 5. Hydrologic Observatory and Research

A Hydrologic Observatory should be established and charged with coordinating and facilitating research activities into a number of issues related to the health of Wakulla Springs and River, including the following:

- *The contributing areas, flow paths, and travel times of water and pollutants (including nitrate and dark water) discharging at Wakulla Springs;*
- *The nature and fate of pollutants introduced by various sources in the springshed;*
- *The effect of pollutants and nutrients on the biota in the spring basin and upper reaches of the Wakulla River (**Appendix G** provides specific suggestions for research); and*
- *Best management practices (BMPs) for the treatment and disposal of wastewater, retention and treatment of stormwater, and design and operation of septic systems.*

Commentary: There are two types of research that can provide a greater degree of confidence that a given course of restoration is likely to meet with success; the first addresses ecological cause and effect and the second defines the sources that govern that causative factor. Well-designed process and synoptic monitoring studies can help address the cause-and-effect question, while the source relationship with the causative factor is best addressed through the development of a well-defined mass balance. It would be helpful if this research could be conducted within the 12-to-18-month time horizon over which other studies are being conducted on behalf of the COT and Leon County, to confirm the flow linkage between the SESF and Wakulla Springs.

Further, the state should seriously consider designating Wakulla Springs and River as an Aquatic Preserve (a state designation) to protect the ecosystem's esthetic, biological, and scientific values for the enjoyment of future generations, and/or a National Estuarine Research Reserve (a national designation) to establish the area for long-term research, education and stewardship. Such designations would promote the protection of the springs, river, and estuary, and would encourage research efforts to generate data that can be extrapolated to other important spring ecosystems in Florida and the rest of the country. Wakulla Springs and River, and the St. Marks estuary, represent an opportunity to study systematically the effects of land use changes and water quality; this information would be useful in addressing water quality issues in the state's many other springs. Alternative strategies include making the springs, river, and estuary a working case study to promote scientific research, or to apply for a broader research designation through the National Science Foundation. Whatever designation the Wakulla Springs ecosystem is afforded, there is a need to provide a high level of water-quality protection to this unique and valuable ecosystem and, to assist in achieving this, there is a need to develop a Wakulla Springs research station on site to investigate springs water-quality issues — using the staffing resources of the nearby FDEP, US Geological Survey and Northwest Florida Water Management District offices, together with faculty and staff of Florida State University, Florida A&M University and the FAMU-FSU College of Engineering.

Recommendation 6. Public Education

A concerted, prolonged and properly funded effort should be made to educate the public on the importance of the previous recommendations to the long-term health of Wakulla Springs and its ecosystems.

Commentary: This effort should involve state and local governments and agencies, public-interest groups and the geotechnical community. Coordination of public-outreach and education activities could be made part of the charge of the Hydrologic Observatory proposed in Recommendation 5.

CHAPTER 1. INTRODUCTION AND BACKGROUND

1.1 Purpose of this Report

This document is an outgrowth of a workshop entitled ***Solving Water Pollution Problems in the Wakulla Springshed of North Florida: Science and Technology at Work for a Better Florida*** that was held at the Center for Professional Development at Florida State University on May 12 and 13, 2005. The workshop was sponsored by 1000 Friends of Florida, Hydrogeology Consortium, Florida Department of Environmental Protection (FDEP), Florida Geological Survey (FGS), Florida Department of Health, Florida Department of Community Affairs, Hazlett-Kincaid, Inc., Northwest Florida Water Management District (NWFWMD), city of Tallahassee (COT), and Leon and Wakulla Counties.

The workshop focused on two major issues in Wakulla Springs and the upper reaches of the Wakulla River: nutrient loading, which is believed to be responsible for the rampant growth of invasive exotic plants and algae, and the loss of water clarity.

A recent report by the NWFWMD (Chelette *et al*., 2002) identified seven sources of nitrate to the lower St. Marks–Wakulla Rivers watershed: atmospheric deposition, wastewater (generated by wastewater treatment facilities, or WWTFs), residuals (sewage sludge), septic systems (onsite sewage treatment and disposal systems, or OSTDSs), commercial fertilizer, sinking streams, and livestock. The present report considers in detail the following sources:

- *WWTFs including sprayfield operations and the disposal of residuals,*
- *Septic systems and*
- *Stormwater and fertilizers.*

Note: the COT is phasing out the disposal of residuals within the springshed and will eliminate this source of nutrient entirely in the near future.

Atmospheric deposition was not considered at the workshop because it is not specifically a local source, and resolving the issue will require a fundamental change in our national technical infrastructure. In addition, a large percentage of the nitrogen from this source is taken up by plants or otherwise lost, so that little, if any, enters the aquifer. Similarly, livestock are not considered in the present report, as they are a minor nitrogen source in the Wakulla springshed.

To explore further and to provide an understanding of the information presented in the workshop, the organizers charged a peer review committee (consisting of the four authors of this document) to assess the state of Wakulla Springs and to recommend actions aimed at improving the spring basin and the upper reaches of the Wakulla River, focusing on nutrient loading and the loss of water clarity. Part of this charge consisted of a set of key questions to be answered by the committee. **Appendices A** and **B** list the questions posed and the committee's answers, respectively.

This report is based on information presented at the workshop, together with pertinent information obtained from other sources both prior to and following the workshop. Earlier drafts of this report were circulated to a number of specialists for their comments **(Appendix C)** to ensure that the assessment and recommendations presented here are based on the best available scientific information.

The remainder of this chapter discusses the findings of other major reports on the issue of nitrate contamination and provides background information on the physical setting of the Wakulla springshed (including surface water and groundwater). Chapter 2 describes the extent and causes of the nitrate loading and water clarity issues. Chapter 3 contains an evaluation of the sources of the problems and Chapter 4 discusses potential solutions and mitigating strategies. The summary of the findings and specific recommendations of the peer review committee are found in the Executive Summary.

1.2 Other Reports

A great deal of work has already been carried out in terms of scientific research, assessments of issues affecting springs and springsheds statewide, and discussions on the best approaches to restoring and protecting Florida's springs. This section summarizes recent major reports that are useful in understanding and addressing the water-quality problems in Wakulla Springs and River.

1.2.1. Nitrate Loading and Non-point Source Pollution in the Lower St. Marks–Wakulla Rivers Watershed

This subsection summarizes the principal findings of a comprehensive report (Chelette *et al*, 2002) that was developed as a component of the NWFWMD's St. Marks Surface Water Improvement and Management Program, assessing the risk to drinking-water wells and surface waterbodies from nitrate contamination in the lower St. Marks–Wakulla watershed. While the report provides detailed information on the hydrology of the watershed, water quality in the Floridan aquifer, sources of nitrogen, a nitrogen budget, and the results of nitrogen-fate modeling, it stops short of providing specific solutions to the problem of nitrate contamination. The report's principal conclusions and recommendations for the Wakulla springshed are as follows:

- *The quality of water discharged from Wakulla Springs is predominantly determined by the quality of groundwater in the Floridan aquifer. Under low-flow conditions, discharge from Wakulla Springs is composed almost entirely of groundwater from the Floridan aquifer.*
- *Under high-flow conditions, discharge from Wakulla Springs is still primarily composed of Floridan-aquifer groundwater. Surface-water inputs (via sinking streams and other direct, conduit-type inputs to the Floridan aquifer) at all times constitute a relatively small fraction of the total discharge from the spring.*
- *The capture zone (or springshed) for springs within the Woodville Karst Plain (WKP) extends as far north as Mitchell County in southwest Georgia. Volumetrically, most of the water discharged through Wakulla Springs is recharge that occurs on the WKP near the spring or farther north in Leon County. The spring is imbedded in a zone of very high hydraulic conductivity that funnels water to the spring from the northwest, north and northeast. The COT, suburbanized Leon County and developing portions of Wakulla County overlie the spring capture zone.*

- *Given its proximity to both the spring and to the zone of high hydraulic conductivity lying north of the spring, it is a virtual certainty that Ames Sink contributes water to Wakulla Springs. (This conjecture has subsequently been confirmed by tracing studies.) Fisher and Black Creeks, which lie near the presumptive western edge of the capture zone, probably contribute water to Wakulla Springs. Lost Creek sinks too far south to contribute water to the spring; this water likely discharges through the Spring Creek group.*
- *Potentiometric surface mapping indicates a significant flow of groundwater from the Leon Sinks area bypassing west of Wakulla Springs. (However, since this report was written, groundwater tracing has demonstrated a connection between the Big Dismal–Turner Sink conduit system and Wakulla Springs.)*
- *Based on Stream-Condition-Index measurements and other observations, the biota of Wakulla Springs and the upper river have been adversely perturbed by anthropogenic impacts. These appear to have resulted from the introduction of invasive exotic plants and increased nutrient discharge from the spring. Effective efforts to manage Wakulla Springs as an aesthetic and recreational resource require an improved understanding of the complex interrelationship between nutrient concentrations in spring water and attendant biological perturbations.*
- *Nitrate concentrations in waters discharging from Wakulla Springs have increased threefold in the past 25 year, from roughly 80,000 kilograms of nitrogen per year (kg-N/yr) in the mid- to late 1970s to 270,000 kg-N/yr currently. Isotopic analyses indicate that both inorganic and organic sources contribute to the nitrogen load discharged by the spring.*
- *Assuming that removal efficiencies remain at present levels, the nitrogen load discharged through the spring will increase as the populations of Leon and Wakulla Counties increase.*
- *Nitrate concentrations in Floridan-aquifer groundwaters beneath the semiconfined potion of Leon County have been constant or slightly increasing over the past 20 years. This implies that the flux of nitrate from the semiconfined Floridan aquifer into the unconfined Floridan aquifer (along the Cody Scarp) has been relatively constant over this period. The estimated nitrate-N mass flux across this boundary under present conditions is 73,000 kg-N/yr. (Note that the fraction of this flux reaching Wakulla Springs is uncertain.)*
- *The increase in nitrate output from Wakulla Springs over the past 25 years is largely attributable to inputs that have occurred south of the Cody Scarp.*
- *At the scale of the entire study area and under current conditions, atmospheric deposition accounts for about half the total nitrogen load applied to the landscape. OSTDSs, WWTFs, commercial fertilizer, livestock, and sinking streams account for the other half. Ignoring atmospheric deposition and sinking-stream inputs, OSTDSs, livestock and commercial fertilizers are estimated to contribute about 60 percent of the total nitrogen load applied to the landscape, with WWTFs contributing the remaining 40 percent.*

- *At the scale of the Wakulla Springs contributory area and under current conditions, WWTFs are estimated to contribute just over half of the nitrogen load applied to the landscape. Atmospheric deposition, OSTDSs, livestock, commercial fertilizer, and sinking streams contribute the remainder.*
- *The analysis presented here presumes a state of quasi-equilibrium between nitrogen applications to the landscape and nitrogen loads discharged through down-gradient springs. Assuming that the ability of the landscape and hydrosphere to provide denitrification is more or less constant, decreasing the nutrient discharge from springs will require reducing nitrogen loads to the landscape.*
- *Technologies that provide for denitrification in OSTDSs (beyond currently applied technologies) should be encouraged, particularly south of the Cody Scarp and in the Wakulla Springs contributory area. To the extent that they reduce the potential numbers of OSTDSs (or other pollution sources), land acquisitions provide positive water-quality benefits.*
- *If additional denitrification of large, more concentrated sources (e.g., WWTFs) is contemplated, this should be preceded by consideration of the benefit likely to be derived. Effective cost-benefit analysis requires a better understanding of both the fate and transport of nutrients originating at these facilities and the adverse effect of elevated nutrient levels on receiving surface waters.*
- *Nitrogen introduced to the environment via WWTF effluent and residuals disposal comprises a relatively large fraction of the total nutrient budget of the study area. The fate of nitrogen introduced to groundwater from these sites is poorly understood, beyond the immediate site perimeters. While the nitrogen budget presented here assumes this nitrogen is reaching Wakulla Springs, there is no direct evidence for this. Additional data collection and monitoring will be required to prove this hypothesis. Monitoring the evolution of nutrient plumes emanating from concentrated points of application is not a trivial undertaking. The effort is significantly complicated by the distances involved and by the cryptic way in which conduit flow in a karst environment influences contaminant transport. (Several studies are ongoing or planned to resolve this question.)*
- *Continuing, long-term monitoring of stream flow and water quality (potentially Munson Slough; Black, Fisher and Lost Creeks; and the St. Marks River) and spring flow (Wakulla Springs and St. Marks Rise) will provide a better understanding of groundwater–surface water interactions on the WKP.*
- *The age dating of ground and surface waters is an important tool in identifying groundwater–surface water interactions (and associated time scales). The continued speciation of nitrogen isotopes will further elucidate the significance of various inputs of organic and inorganic nitrogen to groundwaters.*
- *This study greatly benefited from accurate and precise data on effluent and residual loads. Future studies in this (and other areas) will benefit from similar high-quality data for other nitrogen streams, in addition to data on effluent and residuals.*

1.2.2. Woodville Recharge Basin Aquifer Protection Study, Phases I and II

This report was prepared for Leon County in April 2005 by McGlynn Laboratories Inc (Prime Consultant), Tallahassee–Leon County GIS (Subconsultant), URS Corp. (Subconsultant) and AE&R Group (Subconsultant).

1.2.2.1 The Impact of the Southeast Sprayfield on Wakulla Springs.

The Southeast Sprayfield (SESF) appears to contaminate the shallow surficial sand aquifer only on the SESF property and areas immediately thereto; most of the nutrients sink rapidly to the deeper parts of the aquifer. Karst windows, open to the aquifer, between the SESF and Wakulla Springs have nitrate concentrations significantly elevated above background levels. When nitrate concentrations in these karst features are plotted versus downstream distance, a dilution factor of approximately 10% per mile is evident, indicating that flow occurs primarily within conduits. This data, together with the piezometric elevations and the lack of nitrate in the St. Marks Rise, indicates that the nitrate-laden groundwater flows from the SESF in the direction of Wakulla Springs. Wakulla Springs is enriched with nitrate. Nitrogen/phosphorus ratios suggest that Wakulla Springs is phosphate limited; the enhanced growth of submerged aquatic vegetation and aquatic algae at the spring could be the result of phosphate enrichment (but see Appendix E). While nitrate derives from wastewater inputs to the aquifer (SESF and OSTDSs), phosphate could originate from urban storm water entering open karst features. This phosphate is probably rapidly transported via subterranean conduits to the spring. Lakes Lafayette, Jackson and Munson, which contain open karst features, are likely sources of phosphate loading.

1.2.2.2 Monitoring and Permit Data Reviewed

Data obtained from the SESF monitoring wells shows that the nitrate is occurring primarily in deeper (between 100 and 125 feet) wells near the southern boundary of the SESF. The soils at the SESF are very permeable, and the SESF effluent descends locally, rather than mounds, and may travel south at even greater depths. Water samples from two of the wells on the southern boundary of the SESF have averaged over 6 milligrams per liter (mg/L) nitrate over the last 4 years (see **Figure 2**).

Select historical graphs of the SESF well data for nitrate, all with rather high nitrate concentrations, show maximum nitrate concentrations occurring in 1989. This appears to be due to fertilizers applied to the SESF through the center-pivot irrigation system. The subsequent reduction in nitrate concentrations occurred when the farmer switched to a time-release fertilizer. After 1989, monitoring-well nitrate concentrations dropped several mg/L and have remained rather constant except for a few incidents of elevated nitrate levels caused by problems with the SESF effluent quality in 2002 when the SESF was holding back residuals (see **Figure 3**). This data has been independently compiled by William Landing; see §3.3.2.

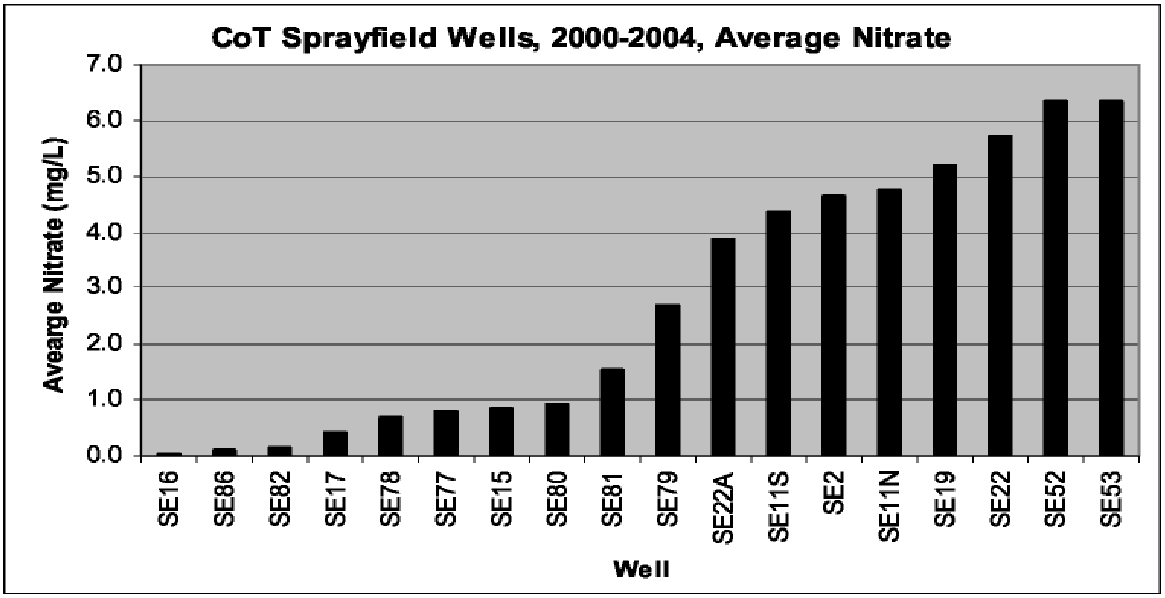

Figure 2: Average nitrate concentrations in ground water sampled from the SESF monitoring wells

*Nitrate analyzed by the COT's Water Quality Laboratory. Graphics produced and analyzed by MLI. Prepared for Leon County by McGlynn Laboratories Inc. See **Figure 4** for well locations.*

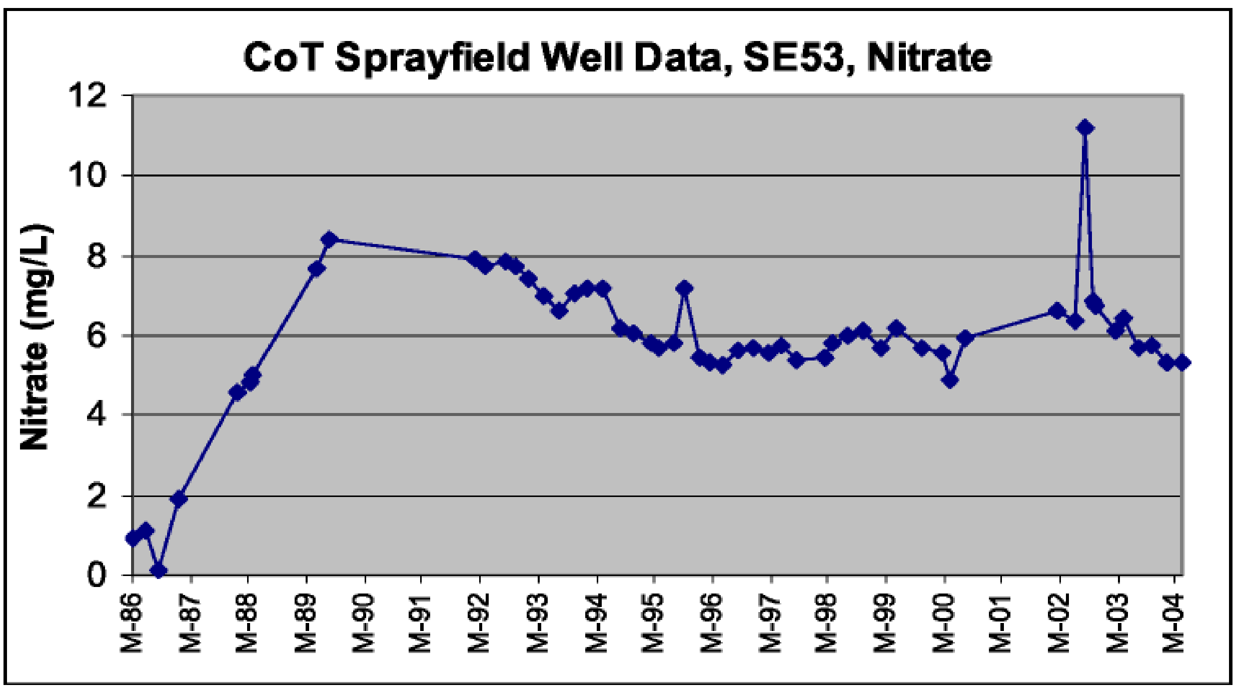

Figure 3: Nitrate data from 1986 to 2004 for the SESF well with the highest average nitrate concentrations

*Well SE53 is on the southern boundary of the SESF (see **Figure 4**) and is about 100 feet deep. M stands for the month of March. Nitrate concentrations in August 2002 exceeded 10 mg/L in one instance. Nitrate analyzed by the COT Water Quality Laboratory. Graphics produced and analyzed by MLI. Prepared for Leon County by McGlynn Laboratories Inc.*

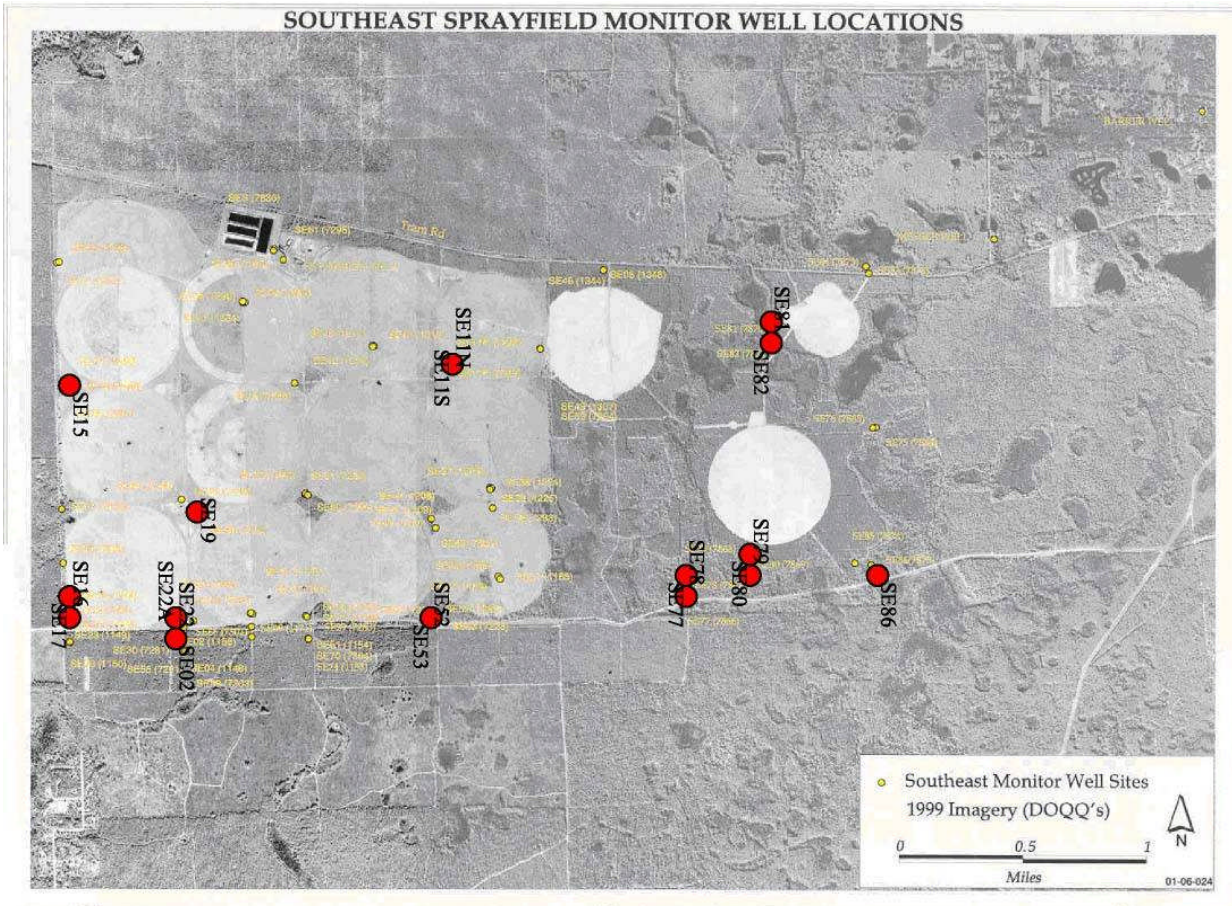

Figure 4: Well locations on the SESF

From Chelette et al., 2002. Prepared for Leon County by McGlynn Laboratories Inc.

1.2.3. A Strategy for Water Quality Protection: Wastewater Treatment in the Wekiva Springs Area

This 2004 FDEP report focuses on developing a strategy to reduce nutrient loading to surface water and groundwater in the Wekiva springshed from wastewater facilities regulated by FDEP (other contributing sources of nitrogen in the springshed are being addressed by other agencies or in different time frames).[3] The report's conclusions are useful for the purposes of this analysis because the aquifer vulnerability in the Wekiva area is comparable to that of the Wakulla Springs area, and because specific and detailed strategies for addressing the nitrate contamination issue are provided.

The Wekiva springshed, which covers about 300,000 acres, contains 27 named springs that discharge an average of 71 mgd. Like the Wakulla springshed, the Wekiva region is underlain by karst geology and characterized by sinkholes, caves, and springs. Generally, higher topographic regions to the west and south of Wekiva Springs recharge the Floridan aquifer system, which in turn feeds the springs and wetlands at lower elevations.

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[3] FDEP. December 2004. *A strategy for water quality protection: Wastewater treatment in the Wekiva Study Area.* Available at http://www.dep.state.fl.us/central/Home/Admin/WekivaReportDecember2004.pdf.

FDEP reviewed existing treatment at the 48 WWTFs (large and small) in the Wekiva River springshed, as well as more advanced nitrogen-removal technologies and associated costs. To focus on reducing nutrient loading from facilities that would most directly affect current or future water quality in Wekiva Springs, the statewide Florida Aquifer Vulnerability Assessment was applied to the Wekiva area.

The report provides a number of recommendations involving more stringent requirements for wastewater treatment. FDEP would not be able to implement these requirements through rulemaking under its existing authorities. However, these could be adopted by crafting a legislative bill; this has already been done for the Tampa Bay Estuary, the Indian River Lagoon, and most recently, the Florida Keys. Local governments might also need state assistance in implementing the requirements and identifying funding sources.

FDEP's specific conclusions and recommendations for reducing nutrient loading in the Wekiva springshed are as follows:

Adopt three protection zones tailored to the specific aquifer vulnerability of the Wekiva area.

Adopt three levels of enhanced wastewater-treatment requirements for groundwater discharges:

<u>Primary Protection Zone (requiring the highest level of wastewater treatment)</u>

- *No new rapid-rate or restricted-access slow-rate land application systems.*
- *Existing large WWTFs[4] with rapid-rate systems as the primary reuse method would be required to reduce nitrogen in applied reclaimed water to 3 mg/L total nitrogen as N within 5 years. Where rapid-rate systems were used only as backup to the regional reuse irrigation system, they would be considered to be part of the regional system.*
- *Existing large WWTFs with regional reuse irrigation systems or restricted-access irrigation systems would be required to reduce nitrogen in the applied reclaimed water to 10 mg/L total nitrogen as N within 5 years.*
- *Existing small WWTFs[5] would be required to connect to a regional WWTF within 5 years, or reduce nitrogen in reclaimed water to 10 mg/L total nitrogen as N.*
- *No land application of wastewater residuals.*

<u>Secondary Protection Zone</u>

- *Existing large WWTFs with rapid-rate systems as the primary reuse method would be required to reduce nitrogen in applied reclaimed water to 6 mg/L total nitrogen as N within 5 years. New systems would have to meet this requirement. Where rapid-rate systems were used only as backup to the regional reuse irrigation system, they would be considered to be part of the regional reuse system.*
- *Existing large WWTFs with regional reuse irrigation systems or restricted-access irrigation systems would be required to reduce nitrogen in the applied reclaimed water*

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[4] Large wastewater treatment facilities are those with a permitted capacity of 100,000 gallons per day (gpd) and greater.

[5] Small wastewater treatment facilities are those with a permitted capacity of less than 100,000 gpd.

to 10 mg/L total nitrogen as N within 5 years. New systems would be required to meet this requirement.

- *Existing small WWTFs would be required to connect to a regional WWTF within 10 years or reduce nitrogen in reclaimed water to 10 mg/L total nitrogen as N.*
- *No land application of wastewater residuals.*

Tertiary Protection Zone

Facilities must meet the existing regulations, with the possibility of requiring an increased monitoring program. The following enhanced wastewater-treatment requirements would be adopted for surface-water discharges:

- *New surface-water discharges would only be permitted as backup to a regional reuse system and would have to comply with the provisions of the APRICOT Act, as codified in Section 403.086(5), Florida Statutes (F.S.).*
- *Existing surface-water discharges would be limited to a backup to a regional reuse system, and would constitute no more than 30% of the wastewater-treatment-plant flow on an annual average basis. Facilities in this category would be required to be in compliance within 5 years.*

1.2.4. Florida's Springs: Strategies for Protection & Restoration

This report[6] by the Florida Springs Task Force presents a number of broad-based strategies for preserving and restoring Florida's springs statewide. These focus on four different areas, as follows:

- ***Outreach strategies*** *center on education (including the development of an up-to-date database of water-quality parameters) and the development of spring-basin working groups composed of stakeholders from all levels of government, agricultural and commercial interests, environmental groups, and citizens.*
- ***Information strategies*** *include springs-monitoring programs and scientific research to support decision making.*
- ***Regulation strategies*** *include the following:*
  - *Enforcing and strengthening existing regulations and groundwater standards,*
  - *Applying a nutrient management plan that includes water-quality-based best management practices (BMPs),*
  - *Expanding Outstanding Florida Water (OFW) designations to include streams and karst features that have hydrologic connections to OFWs,*
  - *Identifying and designating additional springs as OFWs,*
  - *Creating special protection and regulation for springs and spring-recharge basins by rule,*

[6] Florida Springs Task Force. November 2000. *Florida's Springs: Strategies for Protection & Restoration.* Available at http://www.dep.state.fl.us/springs/reports/FloridaSpringsReport.pdf.

- *Establishing and applying quantifiable ground-water quality standards for nutrients that protect the ecological quality and health of surface water systems,*
- *Protecting spring flows and aquifers by establishing minimum flows and levels,*
- *Implementing and expanding water conservation measures and requirements,*
- *Developing alternative water sources,*
- *Evaluating and implementing aquifer recharge and storage technologies, and*
- *Protecting rare, threatened, and endangered species.*

- ***Funding strategies** include creating a Springs Protection and Restoration Fund, increasing funding for water quality and biological monitoring, funding a springs-research grant program, funding educational programs, and providing funding to help landowners and businesses implement BMPs and clean up sinkholes.*

1.2.5. Protecting Florida's Springs: Land Use Planning Strategies and Best Management Practices

This report[7] provides a wide range of detailed information and guidance on the following:

- *Developing and implementing comprehensive planning strategies by using Florida's comprehensive-planning process, establishing a working group, adopting a resolution of support for springshed protection, collecting data and mapping resources, establishing springshed protection zones, creating an overlay protection district, using other land-use planning tools, using acquisition and easement strategies to protect sensitive areas, establishing voluntary stewardship programs, and adopting Comprehensive Plan policies for protecting springsheds.*

- *Managing development impacts by choosing appropriate sites, designing sites appropriately, using sensitive landscape design and management strategies, using effective erosion and sediment controls, addressing stormwater and wastewater management issues, using a combination of BMPs, encouraging water conservation measures, and increasing public awareness. The report also includes information on specific policy and permitting considerations for karst areas.*

- *For golf courses, using a springshed-based approach to siting and development, selecting appropriate sites, integrating environmental planning, establishing a construction management program, and creating a natural resource management plan.*

- *Implementing agricultural and silvicultural BMPs.*

- *Developing a management plan for public recreation and controlling the impacts of public use.*

1.3 Regulatory Framework

The nutrient enrichment of surface waterbodies can result from point-source and non-point-source pollution. Nutrient enrichment from nitrogen and phosphorus can disrupt ecosystems by

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[7] Florida Department of Community Affairs and FDEP. November 2002. *Protecting Florida's Springs: Land Use Planning Strategies and Best Management Practices.* Available at http://www.dca.state.fl.us/fdcp/DCP/publications/springsmanual.pdf.

fueling the rampant growth of aquatic plants. The Surface Water Quality Standards Rule, Chapter 62-302, Florida Administrative Code (FAC), states that excessive nutrients (total nitrogen and total phosphorus) constitute one of the most serious threats to water quality in Florida and that it is FDEP's policy to limit the introduction of nutrients of anthropogenic origin into Florida's waters. This legislation requires that particular consideration be given to protecting waters with high nutrient concentrations, or sensitivity to nutrient loadings, from further nutrient enrichment. Chapter 62-302, FAC, also requires that particular consideration be given to protecting waters currently containing very low nutrient concentrations (less than 0.3 mg/L total nitrogen or less than 0.04 mg/L total phosphorus) from nutrient enrichment.

Section 62-302.530, FAC, lists the following narrative surface water quality criteria for nutrients:

- *Limit discharges of nutrients as needed to prevent violations of other surface-water quality standards contained in Chapter 62-302. Anthropogenic nutrient enrichment (total nitrogen or total phosphorus) is considered degradation in relation to the provisions of Sections 62-302.300 (antidegradation policy), 62-302.700 (OFWs), and 62-4.242 (antidegradation permitting requirements).*
- *In no case shall the nutrient concentration of a body of water be altered so as to cause an imbalance in natural populations of aquatic flora or fauna.*

1.4 Physical Setting

The Wakulla–St. Marks Basin, located in the Big Bend region of the Florida Panhandle **(Figure 5)**, drains 1,204 square miles.[8] One of the more pristine areas of Florida, it has a much lower population density and fewer stresses on the environment than many other parts of the state. Large areas remain relatively undeveloped, and many waterbodies have not been significantly modified (see **Figure 7**).

The Wakulla Springs and River have historically had exceptional ecological and recreational value. The river, with its shallow marshes, old-growth floodplain forest, upland hardwood forest, and longleaf pine forest, provides habitat for numerous native animal and plant species.

Tallahassee, the region's largest city in size and in population (Tallahassee's 2004 population was estimated at 169,000; Leon County's at 264,000), is located between the Ochlockonee and St. Marks Rivers, and its urban and suburban areas lie in both basins. Other, much smaller population centers in the area include Woodville and Bradfordville in Leon County and Crawfordville, Sopchoppy, St. Marks, Medart, Panacea, and Ochlockonee Bay in Wakulla County. Many of those centers in Wakulla County lie to the south of the Wakulla springshed.

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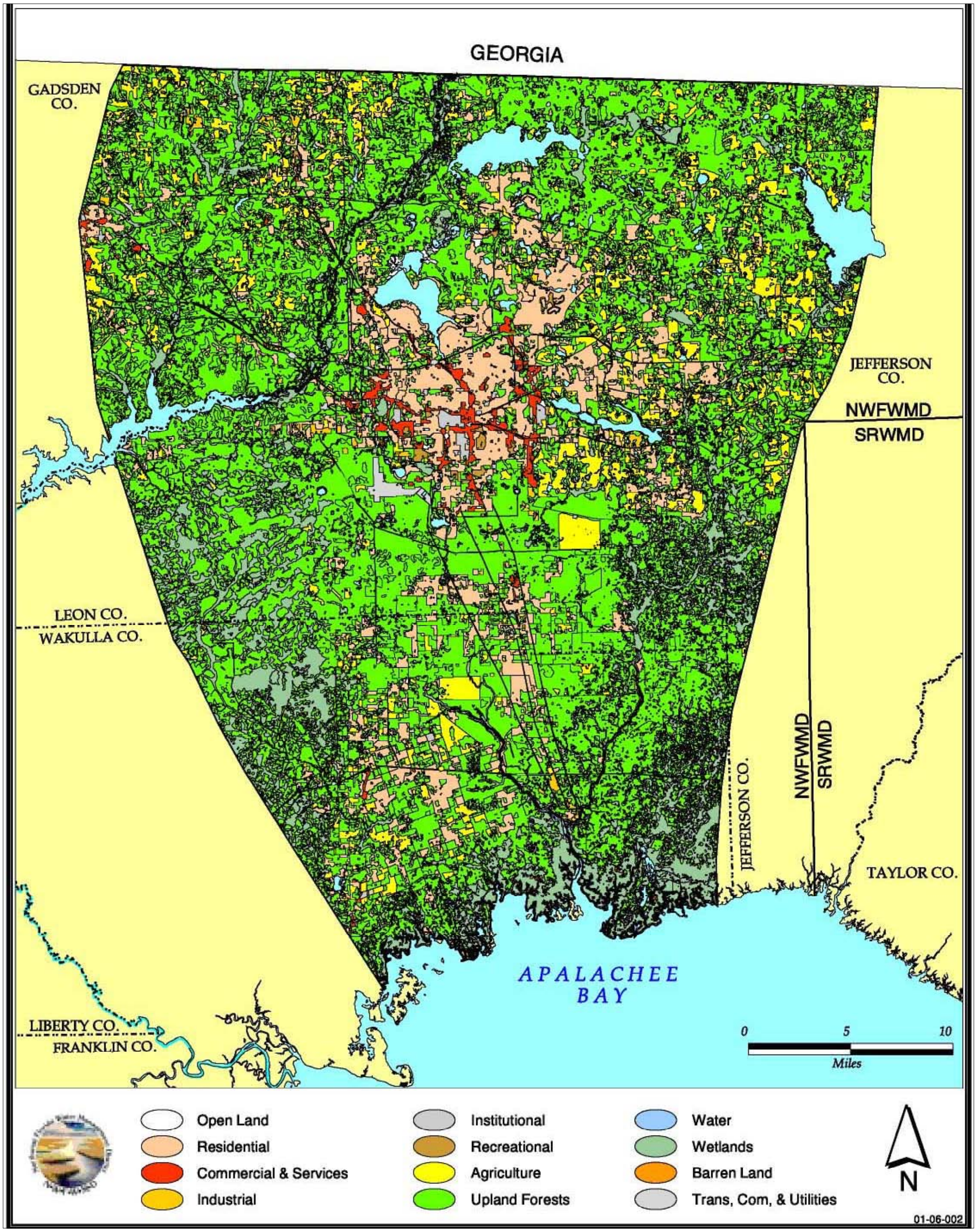
[8] Portions of the text in this section are excerpted or adapted from the *St. Marks River watershed pilot project report* (unpublished), Hand, J., D. Tterlikkis, P. Lee, T. Singleton, and L. Lord (Tallahassee, Florida: FDEP); and the *Ochlochonee–St. Marks Basin assessment report,* August 2003 (Tallahassee, Florida: FDEP).

Figure 5: Florida portion of the Wakulla–St. Marks watershed

From Chelette et al., 2002



1.4.1 Surface Water Features

The surface-water hydrology of the Wakulla–St. Marks Basin is disjointed, with no integrated drainage from most of the northern part of the basin, a short coastal drainage system composed of local streams draining coastal regions, and the St. Marks River being the only somewhat continuous integrated drainage system. There are more than 590 total river miles in the basin, of which more than 460 miles are perennial rivers and streams.

The 40-mile-long St. Marks River, which originates as an intermittent stream in the Tallahassee Hills, in northeastern Leon County near U. S. Highway 90, drains about 871 square miles. From its headwaters, the St. Marks remains swampy and poorly defined as it flows southward to the Cody Scarp through low-density residential areas, pine plantations, and wetlands, receiving direct flow from a few tributaries.

Downstream, the Limestone Creek system, Gum Creek, and Willow Creek feed the river. Below this area, the Horn Spring group and Chicken Branch contribute appreciably to the flow of the St. Marks River. From just north of the Leon-Wakulla County line, the St. Marks River enters the WKP and is fed by Floridan aquifer springs, becoming wider and clearer as more groundwater enters from spring flows.

To the south, at Natural Bridge, the St. Marks River disappears underground. It reemerges a mile downstream at St. Marks Spring (also known as St. Marks Rise) as a spring-run river that is considerably larger, and with different chemical characteristics, than the stream that disappears at Natural Bridge. After emerging at St. Marks Spring, the St. Marks River flows southward as a well-defined spring-run river, flowing at an average rate of 460 mgd (21 m^3/s). Along its course south of the St. Marks Rise, many small springs contribute to the river's flow.

The St. Marks joins the Wakulla River, its largest tributary, in east-central Wakulla County. The Wakulla, a spring-run river fed mainly by the Floridan aquifer, originates at Wakulla Springs and flows south for approximately 10 miles to its confluence with the St. Marks River. From the confluence, the St. Marks widens into an estuary, with most river flow confined to a dredged channel out into Apalachee Bay, approximately 3 miles to the south.

South of Tallahassee in the Sandhills Region, Munson Slough flows into Lake Munson, a 255-acre, cypress-rimmed freshwater lake. The lake is located at the Cody Scarp, the transition between the Tallahassee Hills and the coastal lowlands known as the Lake Munson Hills. The Lake-Munson watershed is the largest and most urbanized in the Wakulla–St. Marks Basin. Formerly a cypress swamp formed in a solution depression, Lake Munson was impounded decades ago as a mill pond. In the early 1950s, a new dam structure and control valves were installed to control flooding in the area to the south.

Because Lake Munson has historically received treated wastewater, as well as urban stormwater from more than half of the COT, through a network of channelized urban streams and ditches, nutrient loading and sedimentation have caused serious problems. By 1973, Munson was the most polluted lake in the southeastern United States and was experiencing fish kills, algal blooms, floating aquatic vegetation, high nutrient and bacteria levels, low game-fish productivity, and depressed oxygen levels. The outfall from the lake discharges downstream to Eight Mile Pond and Ames Sink, where it disappears underground into the Floridan aquifer. In 1982, the city began eliminating wastewater effluent discharges to the lake, upgrading wastewater treatment, and correcting sewage-spill problems. As Chapter 2 of this report makes clear, however, good intentions may have unintended consequences — that is, addressing the surface-water-quality issue in Lake Munson has created a groundwater–surface water issue in Wakulla Springs and River.

Other significant sinking streams in the Wakulla/St. Marks Basin include Lost Creek, Fisher Creek, and Black Creek. These originate in flatwood swamps in the southwestern part of the basin and, like the St. Marks River, disappear underground into sinkholes after they enter the WKP, becoming "lost." Recent tracing studies have shown that water in Fisher and Black Creeks flows to Leon Sinks, with a portion continuing on to Wakulla Springs. Lost Creek is not believed to contribute to Wakulla Springs. According to Chelette *et al.* (2002), nitrogen loading to these streams totals about 72,600 kg-N/yr, with Lost Creek contributing more than half of this amount, at 39,600 kg-N/yr.

Closer to the coast, numerous tidal streams (creeks) discharge directly to the Gulf of Mexico. The largest of these, East River and Stoney Bayou, originate at impounded wetlands in the St. Marks Wildlife Refuge and flow into Apalachee Bay near the mouth of the St. Marks River, contributing to the Wakulla–St. Marks estuary. Farther to the west is Spring Creek, a local creek associated with the largest-magnitude spring system in Florida. Tidal fluctuations dominate flow in these coastal creeks to varying extents.

Apalachee Bay, a large, open, shallow bay in the northern Gulf of Mexico, supports numerous aquatic habitats and is an important recreational and commercial fishery in the region. It also contains part of the Big Bend Seagrasses Aquatic Preserve, the most extensive span of seagrass beds in the country, encompassing about 450,000 acres of seagrass beds and salt marsh.

1.4.2 Groundwater Features

In the Wakulla springshed, and in the surrounding St. Marks Basin, groundwater occurs primarily in the Floridan aquifer, a vast carbonate aquifer system that is present throughout virtually all of Florida, as well as southern parts of Alabama, Georgia, and the Carolinas. The Floridan is the source of water for potable supply, irrigation, and industrial uses throughout most of the region. The Tallahassee municipal wellfield is the primary user of groundwater from this aquifer within the Wakulla springshed.

In the Tifton Uplands/Tallahassee Hills, north of the Cody Scarp, the Floridan aquifer is confined by a thick overburden of sediment that helps to protect against contamination. However, breaches in the confining layer, mainly sinkholes, provide pathways for recharge and the introduction of contaminants. The unconfined or poorly confined regions of the Floridan aquifer (regions with less than 25 feet of sediment cover) extend well north of the Cody Scarp into the southern part of the Tallahassee urban area.

- *Woodville Karst Plain*

The 288,000-acre WKP, which is part of the Gulf Coastal Lowland physiographic region, extends from the southern edge of Tallahassee to the Gulf of Mexico, in southeastern Leon County and eastern Wakulla County. Its northern border, the Cody Scarp, formed about 100,000 years when ocean levels rose. The WKP is bounded on the west by the Apalachicola Lowlands (which begin west of U. S. Highway 319) and on the east by the Wacissa River in Jefferson County; see **Figure 6**.

Capped by less than 20 feet of quartz sands, the WKP gently slopes toward the Gulf. Relict dunes and terraces associated with ancient sea stands now mantle St. Marks (early Miocene) and Suwannee (Oligocene) Limestones. The porous sands allow water to move rapidly to the underlying soluble carbonates (limestone) that are present at or near the land surface, recharging the Floridan aquifer in the area. Over time, this acidic water has dissolved the limestone, resulting in karst terrain characterized by abundant springs, sinks, sinking streams, dolines, karst windows (collapsed segments of underground streams), swallets (caves or holes that swallow a stream), and dolines (collapsed caves), as well as a well-developed system of tunnels or conduits. As discussed earlier in this chapter, a number of "lost" rivers in the area flow a short way before being captured by subterranean conduits. Dissolution continues to wear down the entire foundation of the WKP.

While some of these hundreds of depressions remain dry, most hold water, forming lakes and swamps. If confined to the surface, the water is typically tannic, while depressions that breach the aquifer are often filled with clear groundwater—unless fouled by murky runoff or topped with algae-laden thermoclines. These waters provide recharge to groundwater, the conduit network, springs, and eventually the rivers.

Of Florida's 27 first-magnitude springs (i.e., discharging more than 64.6 mgd) about one-fourth are found in the WKP. These include Spring Creek Springs, St. Marks Spring, Wakulla Springs, Wacissa Springs, Kini Spring, River Sink Spring, and Natural Bridge Spring. Nine other named springs and numerous unnamed, smaller springs and seeps are also found in the WKP. Springs provide most of the flow in the St. Marks River (downstream of Tram Road) and virtually all of the flow in the Wakulla River.

Currently, more than 37 miles of conduits in the WKP have been physically mapped by cave-diving explorers. The Leon Sinks Cave system, with 58,444 feet (more than 11 miles) of mapped groundwater passages, is the longest surveyed underwater cave in the United States. This cave stream, which is exposed to the surface by 26 karst windows, probably contributes flow at both Wakulla Springs and the Spring Creek group.

In **Figure 6**, note that water from the disappearing streams (Fisher Creek, Black Creek, and Munson Slough) flows to Wakulla Springs either directly or via a flow path that intersects Wakulla Cave somewhere in the southernmost region of the cave system, and that groundwater flow directions, as predicted by the potentiometric surface contours (flow is perpendicular to the contours in the down-gradient direction), in the region between Wakulla Springs and the SESF is also toward Wakulla Springs.

- *Wakulla Springs*

Wakulla Springs is the centerpiece of the 2,680-acre Edward Ball Wakulla Springs State Park. One of the largest and deepest freshwater springs in the world, its surface expression covers about 3 acres. On average, 250 mgd of water flow from the spring vent, creating the Wakulla River. The spring is the above-ground representation of a vast underground water resource, the Floridan aquifer—a thick, subterranean, water-bearing layer of porous limestone.

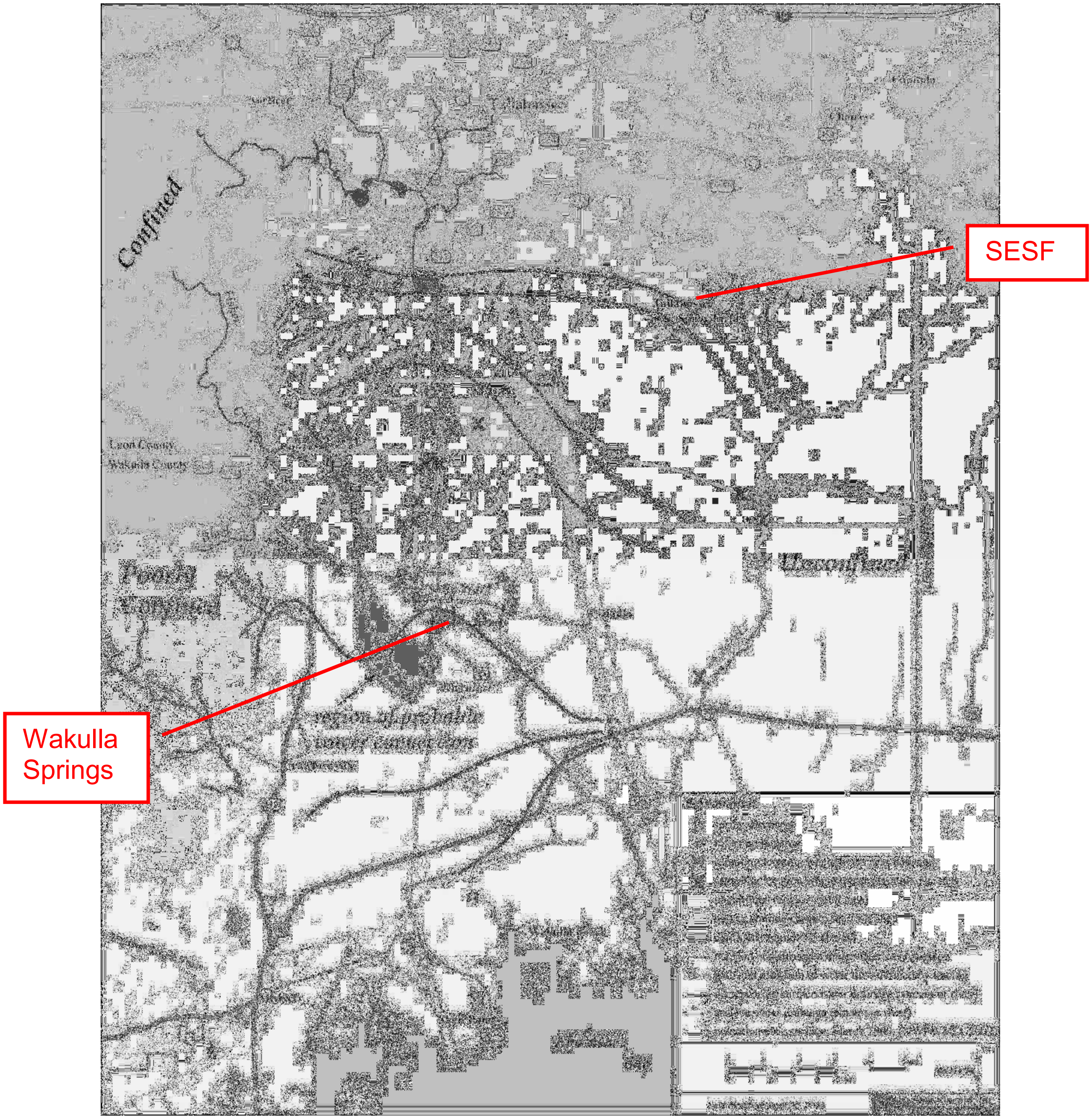


***Figure 6**: A map of the WKP*

showing the distribution and thickness of confining material, tracer-defined ground water flow paths and the potentiometric surface of the upper Floridan aquifer, as defined by water level in wells relative to the position of the major springs and caves in the Wakulla–St. Marks Basin

Figure 7 shows a projection view (looking southwestward) of the cave system beneath Wakulla Springs. In this figure distance northward is shown on the left-hand side of the graphic, with distance eastward shown to the right. The upper portion shows a color-filled contour map of the land surface and channel bottom in the Wakulla River (in blue). Part of a US Geological Survey (USGS) topographic quadrangle (Crawfordville East USGS 7.5 min) is projected beneath the cave system (shown in gray). It has been modified to show the approximate location of an east-west groundwater divide (the pink band across the center of the graphic), as defined by flow directions in the cave reported by Woodville Karst Plain Project explorers. The largest tunnels trend south, away from Wakulla Springs, while the smaller tunnels trend north toward the projected recharge area. Note that the groundwater divide crosses the cave south of Wakulla Springs in the largest tunnels, suggesting that the spring's base flow is derived primarily from water flowing south through the smaller tunnels.

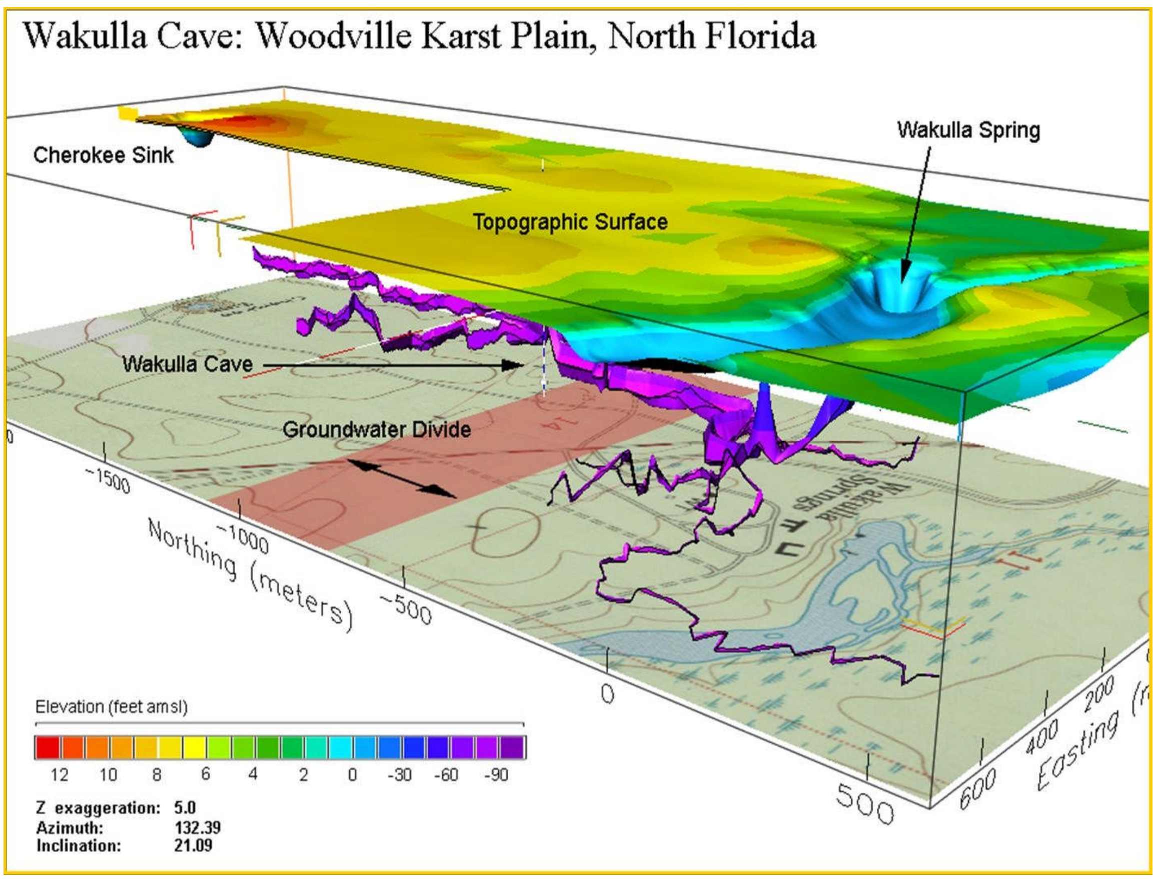


Figure 7: Three-dimensional rendering of the Wakulla cave system

as defined by 1999 survey data. Courtesy of Hazlett-Kincaid, Inc

Figure 8 depicts a water budget for the portion of the Wakulla springshed in the WKP; the blue line in the center of the map outlines this zone, which covers 95,898 acres. A computer-modeling program was used to estimate groundwater inflows and outflows to the area around

Wakulla Springs.[9] The zone consists of the Floridan aquifer bounded by the Cody Scarp on the north, the boundary between the confined and unconfined Floridan aquifer in Wakulla County on the west, and a "no-flow" boundary on the south and east. Wakulla Springs lies at the southern boundary of the contributory area. The eastern boundary was positioned on the basis of potentiometric surface maps. The no-flow boundary west of Wakulla Springs is based on the assumption that the Big Dismal–Turner Sink conduit system eventually flows to Wakulla Springs, and also that it completely captures Floridan aquifer groundwater flow in its vicinity. The numbers shown are illustrative; the actual flows are quite variable.

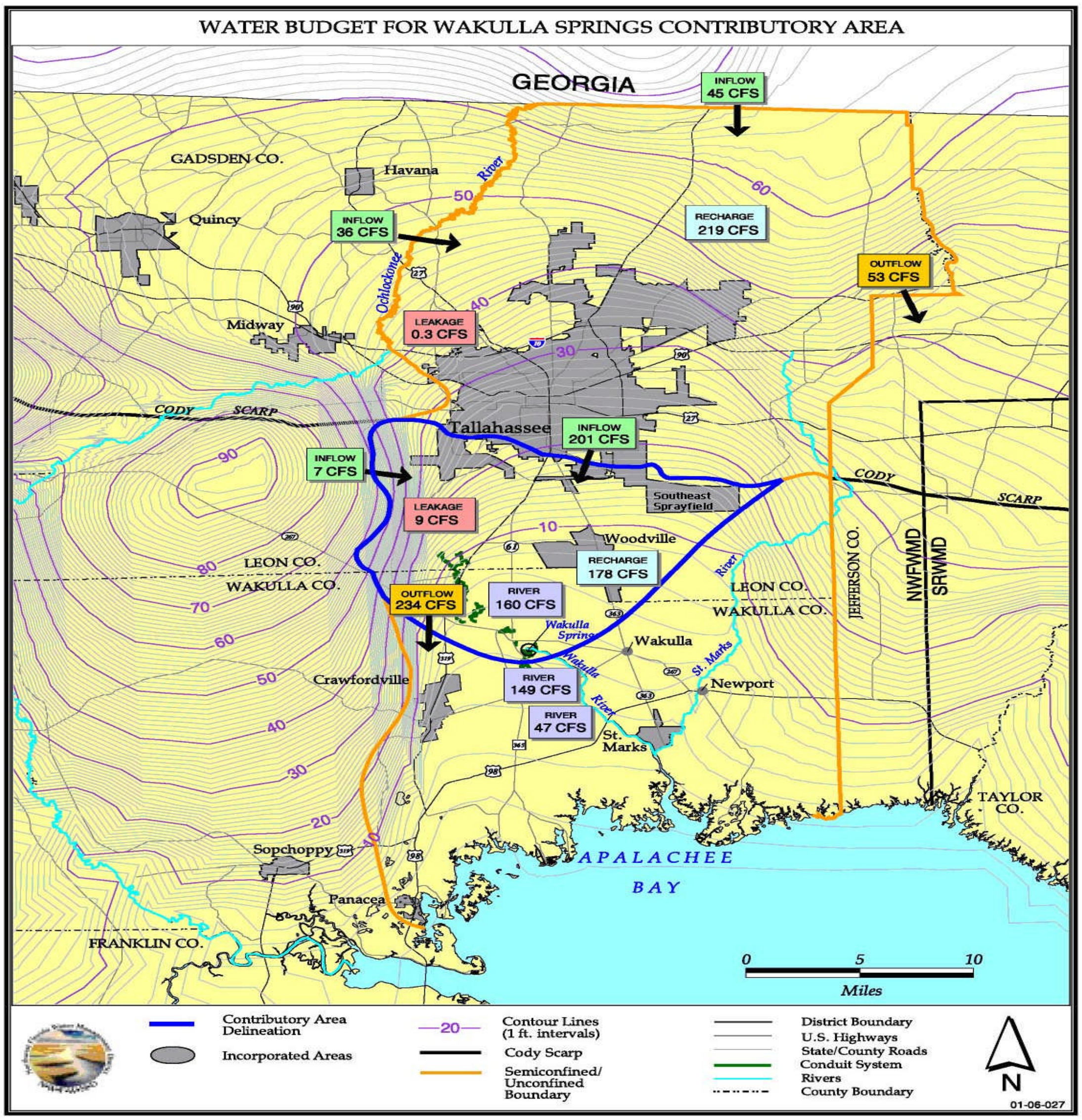


***Figure 8**: Estimated water budget for the Wakulla Springs contributory area*

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[9] The computer program used was Zonebudget (Harbaugh, 1990). The map is taken from Chelette *et al.,* (2002). The text explaining the graphic was also adapted from this report.

CHAPTER 2: WATER QUALITY PROBLEMS IN WAKULLA SPRINGS AND RIVER

2.1 Nitrate Loading

2.1.1 Nitrate and the Nitrogen Cycle

Nitrate ($NO3^-$) is a common form of combined nitrogen in most natural surface (fresh) waters and some groundwater in Florida.[10] Nitrate occurs naturally and is also produced by human activities. Most plants cannot directly use nitrogen in its molecular form (N_2), but instead use nitrogen in the form of either nitrate or ammonium. The primary natural sources of nitrate on the earth's surface include volcanic activity, lightning, and biological fixation. In biological fixation, molecular nitrogen is fixed by a special bacterium associated with certain plants, most notably legumes, sugarcane, and some ferns, and may be further oxidized to nitrate by other bacteria. Nitrate is also produced from the breakdown of animal manure and dead plants.

According to Vitousek *et al.* (1997) "Human activities are greatly increasing the amount of nitrogen cycling between the living world and the soil, water, and atmosphere. In fact, humans have already doubled the rate of nitrogen entering the land-based nitrogen cycle, and that rate is continuing to climb." Elevated concentrations of nitrate in groundwater commonly result from agricultural and urban land-use practices in groundwater recharge areas. The proximity of these areas to points of discharge (i.e., springs) can result in elevated nitrate levels in surface waters.

Nitrate ions are quite mobile in groundwater and surface water. There are essentially no solubility constraints on the amounts found in groundwater. The nitrate ion does not sorb to soils or rock, and thus nitrate can move freely through the soil and the groundwater system. Groundwater in highly permeable sediment or fractured rock generally contains dissolved oxygen, as does most surface water. In this aerobic environment, nitrate ions can migrate long distances.

In surface waters, nitrate acts as a fertilizer for aquatic plants. Nitrate levels much less than 1 mg/L can cause a significant shift in the balance of springs' ecological communities. With an overly abundant supply of nutrients, aquatic plants and algae grow rapidly, filling the water with thick masses of green vegetation. Oxygen in the water is used up, leading to the depletion of fish, and other species.

2.1.2 Extent and Causes of Nitrate Contamination

Nitrate does not naturally occur in Florida's groundwater at concentrations higher than 0.1 mg/L. Increasing nitrate levels in the Floridan aquifer in the WKP in Leon and Wakulla Counties, as well as in water emanating from Wakulla Springs, are a significant ecological concern. Because a spring is a discharge point, the quality of spring water can be considered characteristic of a large cross-section of the aquifer. Water comes to Wakulla Springs from a number of sources. An increase in nitrate concentration in Wakulla Springs can be interpreted

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[10] Portions of the text in this chapter are adapted from the *St. Marks River watershed pilot project report* (unpublished), by J. Hand, D. Tterlikkis, P. Lee, T. Singleton, and L. Lord (Tallahassee, Florida: FDEP).

either as a widespread increase in nitrate concentration in the groundwater from a large area of the aquifer (resulting, for example, from septic tanks) or as a significant increase in one or a few specific inputs (such as a WWTF). Nitrate sources for Wakulla Springs appear to be a combination of both types, with the latter making the larger contribution.

Figure 9 illustrates the sources, reservoirs, and pathways of nitrogen in the unconfined portion of the Wakulla springshed. In this figure the black horizontal line denotes the land surface. Ignoring the thin veneer of sand, below this is a limestone matrix, the voids of which are saturated with groundwater below the water table, indicated by the blue horizontal line. The horizontal striping indicates the water-filled conduit that conveys water and pollutants to Wakulla Springs. The large checkered arrow denotes stormwater and sinking streams. Inputs of nitrate consist of atmospheric deposition, fertilizers, septic systems, land spraying, and residuals. Reservoirs consist of soils, vegetation, and livestock. Brown arrows indicate transfers of nitrogen. Sinks of nitrogen (not illustrated) include the harvesting and decay of vegetation and removal of livestock. The nitrogen that enters groundwater finds its way to Wakulla Springs.

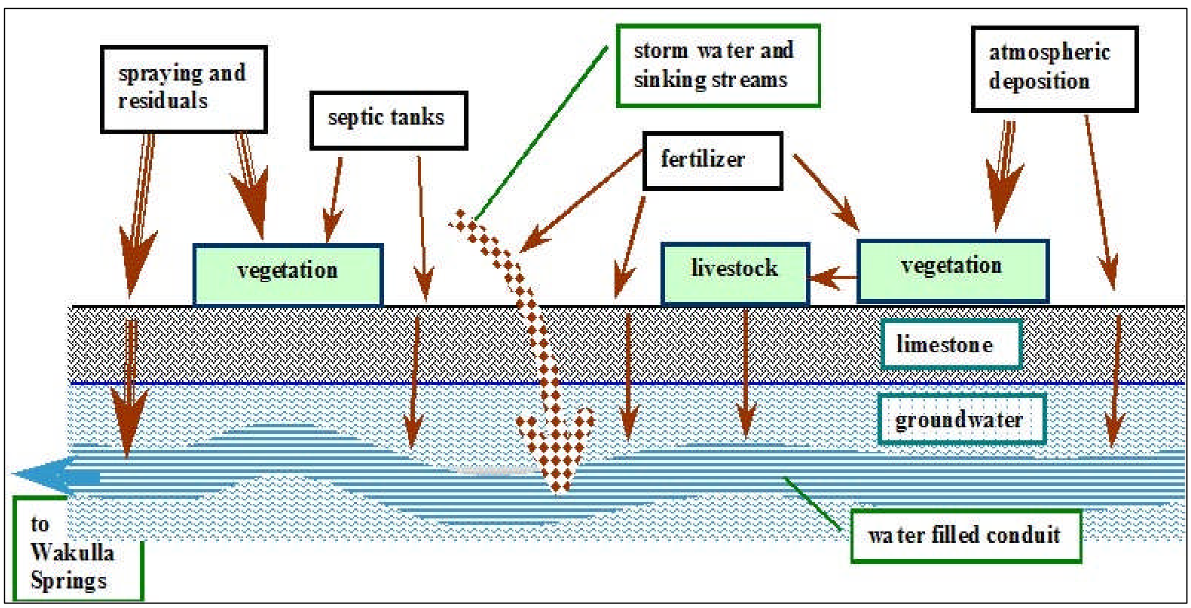


Figure 9: A schematic illustration of sources, reservoirs, and pathways of nitrogen in the unconfined portion of the Wakulla springshed

Coincident with the shifts in the plant community in the Wakulla River described in §2.1.3 (below), concentrations of total nitrogen increased from about 0.2 mg/L to 0.6 mg/L between 1970 and 1975, and from about 0.6 mg/L to more than 1 mg/L between 1995 and the late 1990's — a fivefold increase in 30 years. The current groundwater quality standard of 10 mg/L of nitrate was developed to protect drinking-water supplies. Overall, nitrate levels in wells of the Wakulla–St. Marks Basin are considerably lower than Florida's drinking-water standard and currently cause no public health concerns, except in isolated instances. However, the groundwater standard for nitrate does not address the fact that, in Florida, groundwater becomes surface water when it flows from springs. What is safe for human consumption is, in the case of nitrate, often detrimental to the ecological health of receiving surface-water bodies. As discussed in the preceding subsection, nitrate levels far less than 1 mg/L can cause the degradation of spring ecosystems.

FDEP has rated the ecological health of the upper reaches of the Wakulla River, on average, as "poor" for the past five years.[11] **Figure 10** provides these ratings in graphical form. The red lines on this graph indicate the first three times that herbicide was dispensed in the spring waters (April 16-18, 2002; November 19-21, 2002; November 12-14, 2003; the last two applications — May 4-6, 2004 and April 27-29, 2005 — occurred later than the timeline on the graph), in an attempt to reduce the amount of invasive exotic aquatic plants. In addition, the bird count on the Wakulla River has sharply declined; the number seen in the annual Christmas bird survey dropped from an average of 1,893 between 1987 and 2002, to less than half that average recently. In 2003, 888 birds were seen, and 914 in 2004.

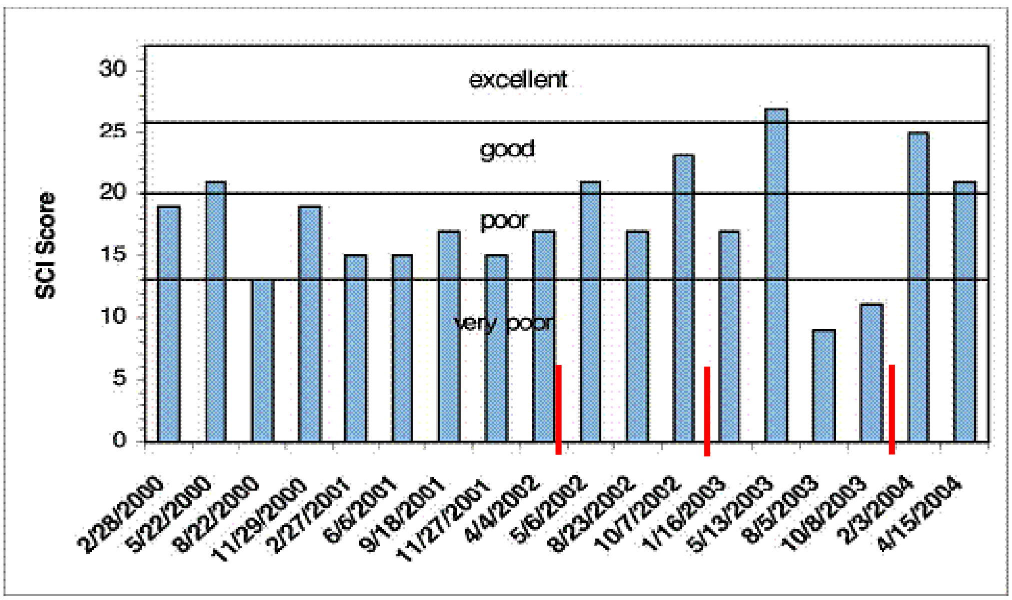


Figure 10: FDEP's Stream Condition Index (SCI) scores and ratings
for the Wakulla River, 2000–04 (above), and stream health rating, January 31, 2005 (below)

[11] Data were taken from FDEP's Wakulla Springs' Ecosummaries, available at http://www.dep.state.fl.us/labs/cgi-bin/reports/search.asp.

2.1.3 Extent and Causes of Invasive Exotic Aquatic Plant Growth

The Wakulla Springs basin and upper river have seen a progressive shift in both community structure and the standing crop of primary producers since before at least 1990.[12] In 1990, invasive growths of Brazilian elodea (*Egeria densa*) and parrot's feather (*Myriophyllum brasiliense*) became a concern. Elodea was particularly problematic, extending from the springs downriver at least 2 miles. Since then, both elodea and parrot's feather, as well as native eelgrass (*Vallisneria*), have been increasingly displaced by the macrophyte *Hydrilla verticillata*, which has also been accompanied by increases in attached algae (periphyton), although a thick infestation of elodea continues in Sally Ward Spring and Slough. Hydrilla was first discovered at the park in April 1997, although its occurrence may not have been detected earlier because it closely resembles Brazilian elodea. By December 1997, it had spread down the river to the first turn, approximately one quarter mile past the tour boat dock. During 1998 it invaded the spring basin, the swimming area, and the area behind the spring. In 1999 it continued to invade downriver past the first turn and began to occupy large areas in the middle and on the west side of the river. It also infested the spring to a depth of 60 feet and affected the features on the glass-bottom boat tour. The channel from the spring to the boat dock had also become infested with hydrilla. In 2000 hydrilla continued its spread downriver, going beyond the boat tour turnaround and continuing into the upper edge of the tree islands. With the growth of hydrilla, there was a drastic decrease in the presence of eelgrass and elodea. **Appendix D** describes the extensive efforts undertaken since 1990 to control these undesirable aquatic plants, first by mechanical harvesting and then by herbicides.

Nitrate values measured in the Wakulla River decrease with distance downstream from the springs, reflecting the uptake of nitrate by aquatic vegetation, now consisting principally of hydrilla and algae. An important question is how the changing nitrogen or phosphorus concentrations in the Wakulla River influence the structure of the plant community. The goal of restoration is not merely to reduce the standing crop; rather, restoration must also induce a shift in the dominant macrophytes from hydrilla to a more typical structure (e.g., *Vallisneria*) that dominated the springs historically.

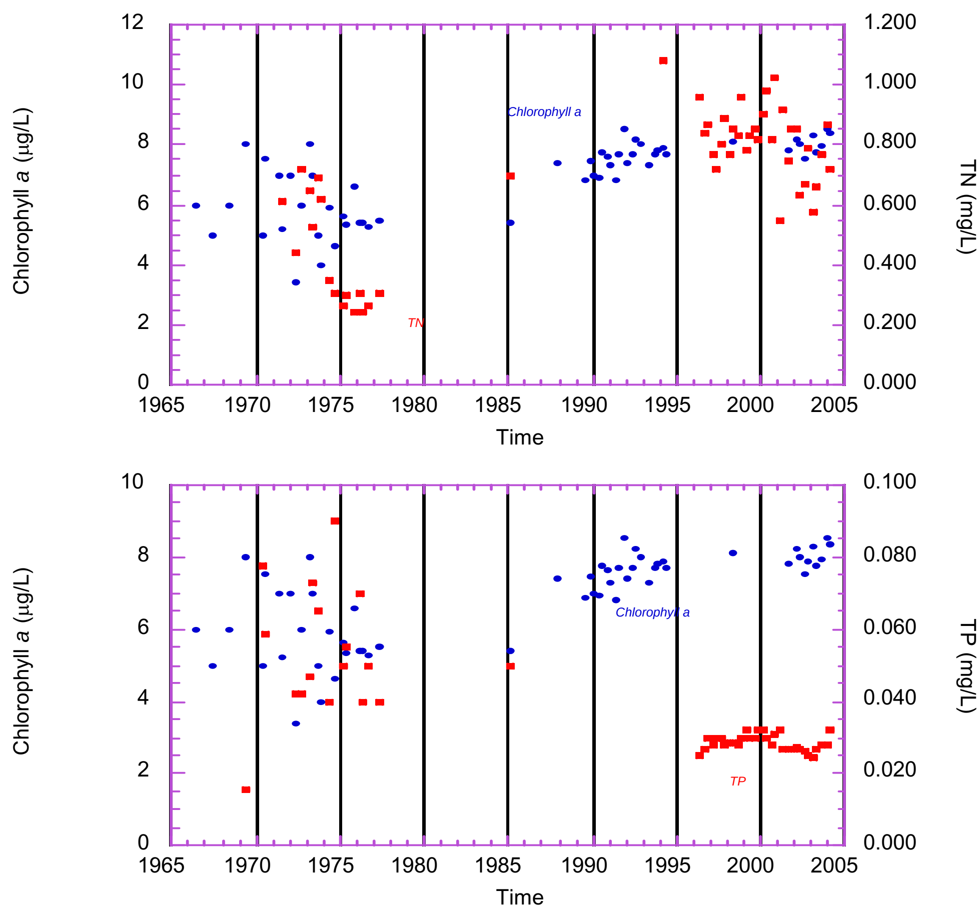
No estimates of changes in plant community standing crop or structural dynamics were presented at the workshop, and thus one of the objectives of this section is to examine the available data and determine to the extent possible whether nitrogen is the limiting nutrient governing the primary producer community dynamics. **Appendix E** presents the cases for and against nitrogen limitation; these are summarized and evaluated in Chapter 3.

Figures 11a and 11b compare the variation in the concentrations of chlorophyll *a* and the nutrients nitrogen and phosphorus, respectively, in Wakulla Springs between 1965 and the present. A comparison of the two figures shows that while a shift has occurred in nitrogen (**Figure 11a**), a similar shift in total phosphorus concentrations in the spring is not apparent (**Figure 11b**),[13] causing many to hypothesize that nitrogen availability is controlling primary (plant) production rates and community dynamics in Wakulla Springs basin and immediately downstream. Since mid-1996, when more intensive routine monitoring was initiated, nitrogen

[12] This summary is based in large part on reports contributed by S. Savery, Park Biologist.

[13] It should be noted that, as part of his presentation, J. Hand of the FDEP indicated that historical concentrations of total phosphorus measured during the early 1970s may be unreliable because of comparatively insensitive detection limits.

concentrations have clearly declined (see **Figure 17**), while phosphorus concentrations show no clear pattern of either an overall increase or decline.



Data courtesy of J. Hand, FDEP.

Figure 11: Variation with time of concentrations of phytoplankton chlorophyll a and nutrients in Wakulla Springs, 1965–present

Upper panel (a): chlorophyll a and total nitrogen. Lower panel (b): chlorophyll a and total phosphorus.

2.2 Extent and Causes of Loss of Water Clarity

Wakulla Springs is known for the outstanding clarity of its water. For years, a major attraction at the park has been the glass-bottom boat ride, where visitors can observe fish and see down over 100 feet into the main vent of the spring.

However, periodic variations in water clarity have been a problem at Wakulla Springs for as long as it has operated as a tourist attraction. When dark water is present in the spring basin, the glass-bottom boats do not operate, because there is not enough visibility (these periods are called "down days"). There has been some concern that the episodes of dark water are increasing in number and duration, and that they may be tied to human activity and changes in land use in the spring recharge area.

To understand the problem, it is first necessary to understand the nature and origin of the dark water. There are two major causes of reduced transparency in natural waters. The first is turbidity, which is caused by the suspension of sediment or other materials such as bacteria, organic debris, and algae in the water. The second is color, a staining of the water that is naturally occurring, and that is usually caused by dissolved or colloidal organic materials leached from decaying leaves and other organic materials. The darkness of the water at Wakulla Springs is believed to be caused by color. The water is dark, but still clear, rather like a glass of iced tea.

Boat operators at Wakulla Springs have noticed that there seemed to be a connection between the amount of rain and the arrival of dark water in the springs. Often, there would be a lag time of several days between rainfall and the darkening of the springs. Sometimes, the springs would darken even when there was only light rain locally (at the springs). At other times, the springs remained clear when it rained locally. Although daily records of the operation of the glass-bottom boats had been kept sporadically since the 1940s, in 1987 park personnel started to record rainfall totals at the park and the days of dark water in the springs.

Figure 12 shows that the amount of dark water and the resulting loss of clarity in the spring basin, as quantified by the annual percentage of down days for the glass-bottom boats, appear to be related to rainfall for the period from 1987 through 2004, although the correlation is far from perfect. Although the percentage of down days has exceeded 80% for the past 3 years, this recent trend toward more down days is not yet statistically significant.

During periods of low rainfall, most of the water in Wakulla Springs is provided by "base flow", which is the slow, long-term steady flow of clear water from the rock matrix of the Floridan aquifer. After heavy rains, flow in Wakulla Springs increases. This initial increase comes from increased base flow created by the physical, downward pressure of rainwater on the top of the aquifer, and flow from rainfall that has entered the aquifer immediately adjacent to the springs. If sufficient rain falls, surface runoff will flow into sinkholes and ponds, and water levels will start to rise throughout the unconfined Floridan aquifer. As time passes, flow from the springs continues to increase as more of the recent rainwater flows through the aquifer from farther away, and as water starts to enter the springs from sinkholes and other surface drainage features connected to the springs by conduits. Colored water from overflowing swamps and forested areas enters the aquifer through these sinkholes and, if present in a large enough quantity, colors the water flowing from the springs.

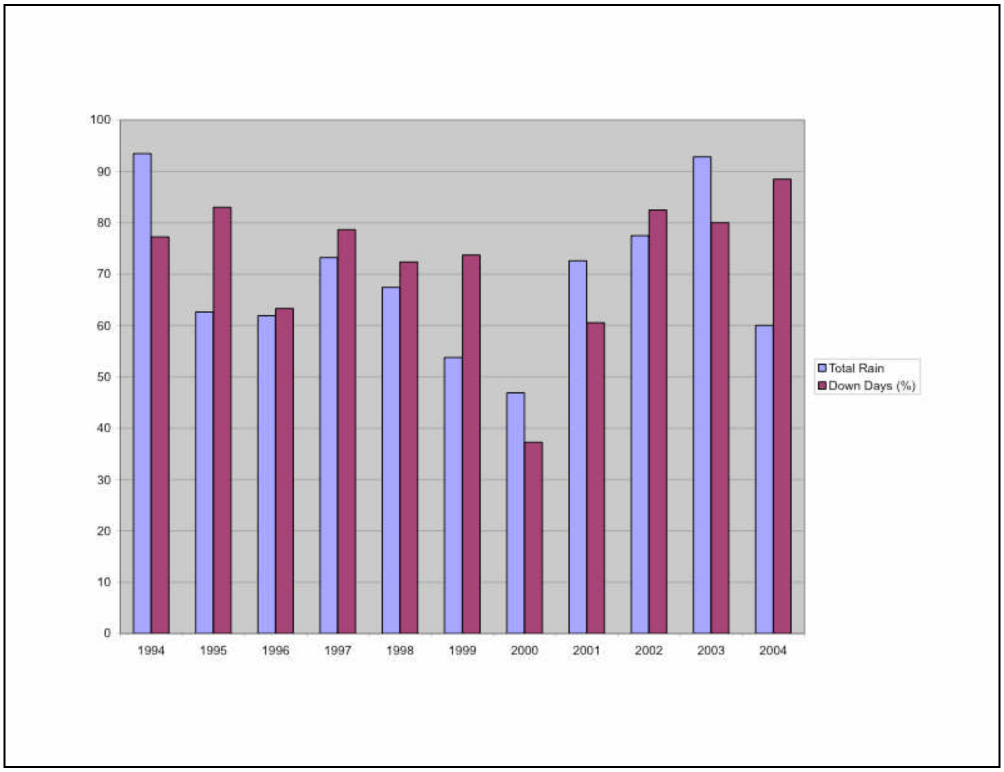


Figure 12. Annual percentage of down days for the glass-bottom boats and annual rainfall in inches, 1994–2004.

In each pair of bars, the percentage of down days is on the left (maroon) and annual rainfall (blue) is on the right.

CHAPTER 3: SOURCES OF THE PROBLEMS

In this chapter the sources of the nutrients (particularly nitrate) are discussed, beginning with a discussion in §3.1 of the case for nitrogen limitation, followed in §3.2 by a summary of the sources of nitrate. The history of WWTFs operated by the COT is presented in §3.3. Key measurements of nitrate concentrations related to the SESF are presented in §3.4. Nitrate sources due to fertilizer, livestock and septic systems are briefly summarized in §§3.5 and 3.6. Finally, the dark water that emanates from the main vent of Wakulla Springs is briefly discussed in §3.7.

3.1 Summary and Evaluation of Nitrogen Limitation

Whether the plant growth rate in Wakulla Springs is nitrogen (N) or phosphorus (P) limited is not completely certain at this time, but on balance, it appears that N is more likely the limiting nutrient (see **Appendix E** for a detailed discussion of this issue). The high N:P ratio in Wakulla River water suggests that the spring is P limited, but these ratios are imperfect indicators of nutrient limitation. While algal assay results conducted by Stevenson *et al.* (2004) appear to corroborate P limitation for most Florida springs, the comparatively rapid uptake of N compared with P with distance downstream from the springhead suggests that nitrogen supply is more critical. Moreover, the striking changes in trophic state observed in Wakulla Springs basin and immediately downstream are contemporaneous with significant increases in nitrogen (nitrate), while increases in phosphorus concentrations have been far more modest or not evident. Based on the *in situ* dynamics of N, P, and the primary producer community, N limitation is more likely than P limitation.

Whether the plant growth rate in Wakulla Springs is N or P limited may not affect options for reducing plant overabundance in the Wakulla River. There is little evidence that Tallahassee is contributing P to Wakulla Springs (**Appendix F**), and it appears that phosphate loading to the springs is determined by both sorption of phosphate by soils and release of phosphate by clays and sands of the Hawthorn Group, a soil formation found in the Wakulla springshed. The result is an equilibrium concentration of P in the water that is very difficult to alter. **Figure 13** shows the effect of the overlying Hawthorn Group on phosphorus concentration in springs; Gainer and Jackson Blue Springs have no overlying Hawthorn Group, while the other springs do.

3.2 Sources of Nitrate

It appears that nitrate is the crucial nutrient feeding the growth of hydrilla and algae in Wakulla Springs and River. Chelette *et al.* (2002) provided the most authoritative and complete study of nitrate sources in the Wakulla springshed. According to Figure 58 of that study (reproduced here as **Figure 14a**), the principal nitrate sources from 1990–99 were as follows:

- *City of Tallahassee wastewater effluent and residuals (sewage sludge), average loads of 360,000 and 130,000 kg-N/yr, respectively, or about 55% of total sources;*
- *Atmospheric deposition, average load of 232,000 kg-N/yr, or 26%;*
- *Fertilizer and livestock, average loads of 60,000 and 14,000 kg-N/yr, respectively, or 9%;*

- *Septic systems, 56,000 kg-N/yr, or 6%; and*
- *Sinking streams, estimated annual load of 33,000 kg-N/yr, or 4%.*

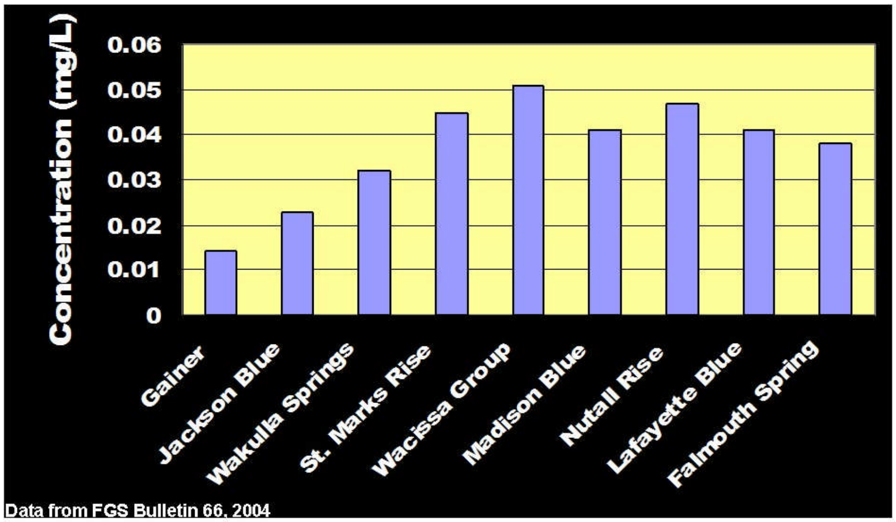


Figure 13. Total phosphorus in Florida's first-magnitude springs

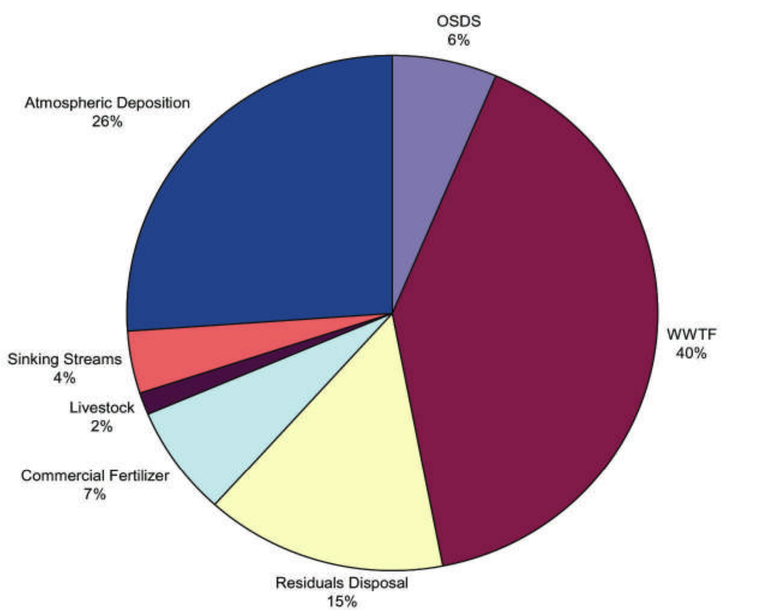


Figure 58. Relative Contribution from Inventoried Nitrogen Sources to 1990-1999 Average N Loading in the Wakulla Springs Contributory Area.

Figure 14a. Pie chart of nitrate contributions to Wakulla Springs

including atmospheric deposition and residual sludge applications, 1990–99 (from Chelette et al., 2002)

The average aggregate loading from these sources totals approximately 885,000 kg-N/yr. Estimates produced by the City of Tallahassee differ somewhat from these, however, reflecting the uncertainty in the estimation process and changes in practices for disposal of residuals.

Chelette *et al*. (2002) found that the sources of nitrate are predominantly local, with 73% (197,000 kg-N/year) originating south of the Cody Scarp. Much of the remaining 27% (73,000 kg-N/year) can be attributed to septic systems and fertilizer applications in Leon County. The committee could find no evidence that a significant flux of nitrate originating in southern Georgia reaches Wakulla Springs. Davis (1996) estimated aquifer flow across the Georgia–Florida border to be 45 cubic feet per second (cfs). However, not all of that flows to Wakulla Springs. The nitrate concentrations (typically 0.2 mg-N/L) from the Tallahassee drinking water wells north of the city should reflect the aquifer input from Georgia. Thus by this estimate the N loading from Georgia that makes it south across the Cody Scarp is less than 45 cfs × 0.2 mg-N/L = 8000 kg-N/year. This is less than 3% of the total nitrate load at Wakulla Springs. Although this number is somewhat uncertain, it is difficult to construct a model in which significant nitrate is coming to Wakulla Springs from Georgia.

Fertilizer and livestock, as well as septic systems, are non-point sources (that is, there are a very large number of inputs to the aquifer distributed over a wide geographic area). In contrast, sewage operations are point sources, and thus are much more easily managed. It should be noted that within the contributory area identified by the NWFWMD that was used for **Figure 14b**, fertilizer application at the city's sprayfield is a large portion of the fertilizer input.

Figure 14b shows the relative nitrate contributions to Wakulla Springs, over and above the background nitrate delivered to the spring in the Floridan aquifer (reported as 0.33 mg-N/L in the

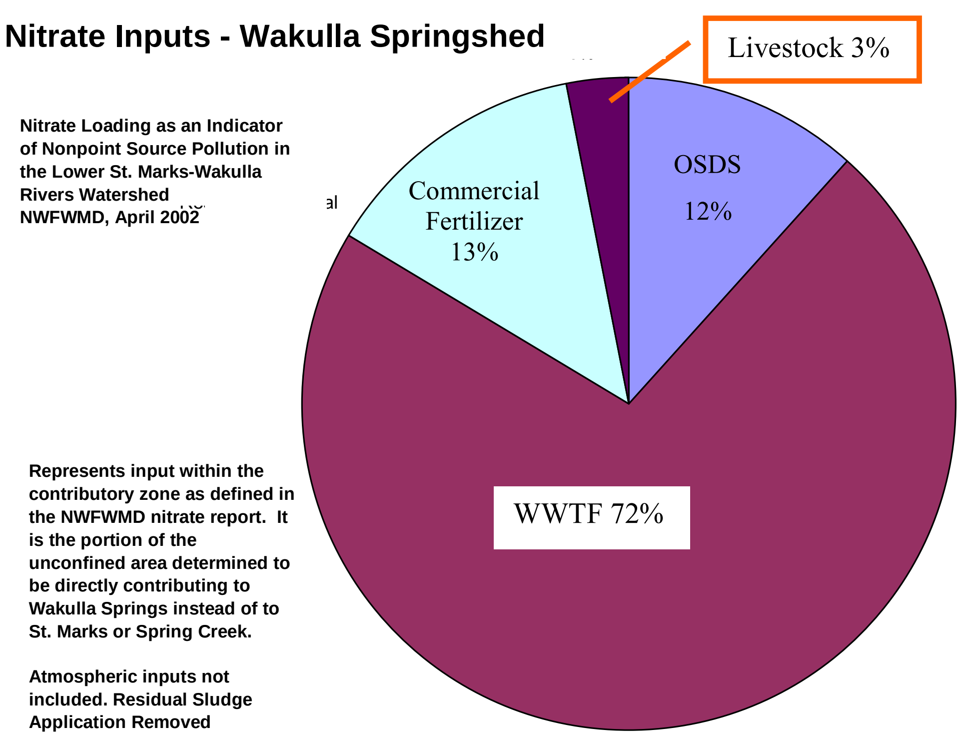


Figure 14b: Relative nitrate contributions to Wakulla Springs

southern conduits in 2004; consistent with 0.2 to 0.4 mg-N/L reported in the late 1970s for the spring). Taking atmospheric deposition, sinking streams and residual-sludge applications out of the accounting, the percentages are as follows: sewage treatment operations 72, fertilizer and livestock 16 and septic systems 12%. Even allowing for some uncertainty in these numbers, it is clear that sewage operations are the dominant contributor to nutrient loading at Wakulla Springs.

3.3 Wastewater Treatment Facilities.

Historically, starting in the 1950s, the COT's treated wastewater was discharged to Lake Munson. Beginning in 1966, however, the city became one of the few municipalities in the country to experiment with using treated effluent water to irrigate crops. By the early 1970s, Lake Munson had become the most polluted lake in the southeastern United States (see §1.4.1). Water quality in Lake Munson began to improve dramatically in the 1980s when the city built a pipeline, diverting treated effluent from the lake and applying it to the land surface.

The COT's sewer system carries raw sewage from homes and businesses to one of two wastewater treatment plants. The T. P. Smith Facility, the city's primary sewage treatment facility, can treat 27.5 mgd and can handle peak flows up to 55 mgd. The Lake Bradford plant can treat 4.5 mgd. After treatment, about 2 mgd are reused for plant operations and landscaping irrigation. The rest is pumped to the Southwest Sprayfield, adjoining the plant, and to the 2,163-acre Southeast Farm Wastewater Reuse Facility (referred to as the SESF in this report), 8 miles to the east. Ongoing programs related to wastewater treatment conducted by the city's Water Utility are described in **Appendix I**.

The SESF is one of the largest and most advanced facilities of its type anywhere in the world and has won a number of awards for its design and operation. At the facility, 13 center-pivot sprinkler systems distribute the treated wastewater to the land surface. Crops such as canola, corn, soybeans, hay (Bermuda grass), and sorghum are grown year-round. Crop rotation ensures that some fields are available as pasture year-round. The crops, which remove nutrients, are then sold or put up for silage to supplement cattle that graze on the pastureland at the farm year-round (about 300 head during the summer and 2,000 head during the winter). Because the cattle receive no grain or other food from offsite while grazing at the sprayfield farm, they act as a sink for nutrients. The system was designed to serve as a huge biological filtration system, aimed at removing excess nitrogen and phosphorus from the treated wastewater. The nutrients are removed from the water in four ways:

1. *Much of the (ammonia) nitrogen volatilizes into the atmosphere during irrigation,*
2. *Sprayfield crops take up nutrients from the treated sewage,*
3. *Phosphorus not used by the crops is physically adsorbed onto the surface of soil particles and*
4. *Naturally occurring bacteria in soils assimilate nitrogenous compounds in the treated sewage.*

When the SESF was created some 25 years ago, it was state of the art. Since then, however, much more has been learned about the nature of the aquifer in the region and the direction of groundwater flow. Nitrate levels in groundwater under the sprayfield rose from less than 1 mg/L in 1982 to 10 mg/L (the drinking water standard) by the late 1980s. Concurrently, nitrate levels in Wakulla Springs, 9 miles south of the sprayfield, increased by a factor of five times over the values prior to the establishment of the SESF.

The SESF lies above the unconfined portion of the Floridan aquifer and potentiometric contour maps produced by the NWFWMD and USGS (**Figure 15)** indicate that this facility lies directly up-gradient of Wakulla Springs. That is, treated sewage with its nitrate load applied at the sprayfield rapidly sinks into the ground and flows southwest, directly toward Wakulla Springs. In this regard, it is important to note that the levels of nitrate measured at St. Marks Spring, located south of the sprayfield, are low, indicating that nitrate of sprayfield origin is not moving southeastward. It is not yet known what fraction of the sprayfield effluent reaches Wakulla Springs and how long it takes to travel there. Tracing experiments are to be conducted in the coming year, with funding from the Hydrogeology Program of the FDEP and the Florida Springs Initiative, to provide this information.

The COT is in the process of phasing out the disposal of sewage sludge in the Wakulla springshed, so that the contribution from that source (27% of sewage operations) is diminishing and will cease in the near future. A new sludge-drying system, which became fully operational in March 2005 at the T. P. Smith WWTF, produces reusable "Class A" biosolids, which can be sold as a beneficial fertilizer and soil conditioner to commercial nurseries, agricultural markets and other businesses. This unique, single-pass drying system reduces the plant's sludge volume by 75%, virtually eliminating the need for spreading biosolids on land. Eighty-five percent of the sludge that used to be spread is now dried and removed from the system. Work continues to further reduce sludge spreading.

Tallahassee's water utility plans to construct at a cost of $3 million a new water-reuse treatment plant in the Southwood area that will take water directly away from the sprayfield. This new Tram Road Reuse Facility, with a capacity of 1.2 mgd, will use highly treated wastewater to irrigate the Southwood Country Club golf course, the extensive landscaping at the state's Capital Circle Office Complex, and the Blueprint 2000 Capital Circle Southeast improvement project.

Two high schools in the Southwood development have also expressed an interest in using the reclaimed water to irrigate their athletic fields. The treated water will be sent via a pipeline from the T. P. Smith plant and then will receive additional treatment at the new facility before being used for irrigation. The additional treatment at the new facility will include filtration and disinfection, making the water safe for irrigation ponds at the golf course. The non-potable water can also be used for fire control or controlling dust during dry periods.

3.3.1 Trend of Groundwater Flow

Trends of groundwater are shown in **Figure 15**, with gray lines showing the potentiometric (water level) surface, with the contour interval being 1 foot. Groundwater flow in the aquifer is generally perpendicular to these lines. Blue lines indicate the surface positions of the St. Marks (east) and Wakulla (west) Rivers and blue circles indicate major springs. Red lines mark the positions of the major underwater caves in the basin, with the Leon Sinks and Chips Hole systems to the north and the Wakulla cave system to the south. Green circles indicate center pivots at the sprayfield, and the red area at the sprayfield shows where nitrate levels in groundwater are greater than 5 mg/L.

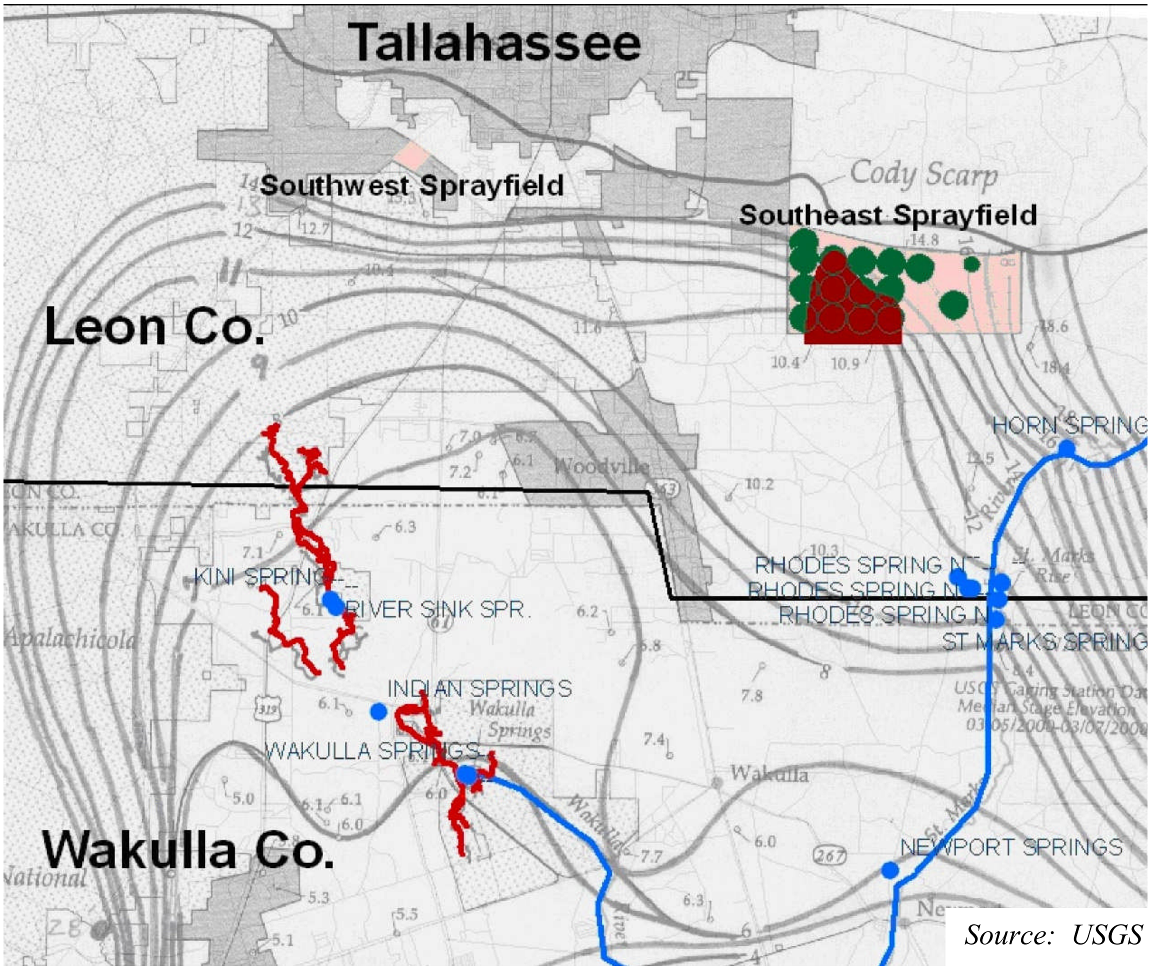


Figure 15. Potentiometric surface map of the upper Floridan aquifer

3.4 Nitrate Data

In this subsection, data on nitrate concentrations collected at key locations near the sprayfield and at Wakulla Springs over the past several decades are presented and discussed. Specifically nitrate trends at COT drinking water well #12 are shown in **Figure 16**, at monitoring wells 02, 15, 19 and 53 in the four panels (labeled a – d) of **Figure 17**, and at Wakulla Springs boil in **Figure 18**.

Nitrate concentrations in Tallahassee's drinking-water well #12 (located near the intersection of Orange Avenue and South Monroe Street, roughly six miles northwest of the sprayfield and 10 miles north of Wakulla Springs), illustrated in **Figure 16**, have increased gradually from 0.4 mg-N/L to about 0.5 mg-N/L since 1980. Similar nitrate concentrations are reported from COT wells #17 and #27 in the southeastern quadrant of the city. This likely reflects the "background" nitrate concentration in the aquifer leading toward Wakulla Springs from the north. "Natural" levels of nitrate are less than 0.1 mg-N/L, and possibly as low as 0.01 mg-N/L (e.g., measurements at monitoring wells SE-82, 83, 84 and 85 on the eastern edge of the SESF; see also nitrate levels at COT wsells #19 and 26, shown in Figure 44 of Chelette *et al*, 2002; Katz, 1992; Upchurch, 1993). The somewhat higher levels seen in this figure are likely due to inputs (fertilizer and septic systems) within the urban area of Tallahassee, but are not due to the SESF, which lies downgradient of this well.

Figure 17 shows the time history of groundwater nitrate concentrations from 1980 to the present measured at four monitoring wells at the sprayfield: one (SE-19; Panel a) in the middle of the field, one on the western edge (SE-15; Panel b) and two on the southern edge (SE-53; Panel c and SE-02; Panel d). The locations of these wells are shown in **Figure 4**. Concentrations at well SE-19 (near the center of the sprayfield) have increased twenty-fold since 1983, as shown in **Figure 17a**. Note the change in scale from **Figure 16**; nitrate concentrations at the SESF are far higher than to the north. Nitrate concentrations in SE-19 peaked in 1992–1993, then declined roughly 35% by 1996, and have remained relatively uniform to the present. Nitrate concentrations on the western boundary of the SESF (SE-15; **Figure 17b**) have increased gradually by roughly a factor of five since 1983 and, although the concentration trend appears to be accelerating over the last few years, values remain significantly lower than in the middle of the SESF. Nitrate concentrations on the southeastern boundary of the SESF (SE-53; **Figure 17c**; this panel is equivalent to **Figure 3**) show a trend that is nearly identical to that seen in the center of the SESF (SE-19), increasing from 1983 through 1992, then decreasing by roughly 40% to the present. The trend measured at a nearby well (SE-52; not shown here) is virtually identical to that at SE- 53, verifying the consistency of the data. On the southwestern boundary of the SESF, well SE- 02 (**Figure 17d**) shows only an intermediate nitrate peak in 1990-1992. Concentrations at SE-02 continued to increase after 1992, until stabilizing from 1997 to the present at levels consistent with the interior wells and the other southern boundary wells. These data trends support the conclusion that the groundwater underneath and to the south of the SESF has been significantly contaminated with nitrate.

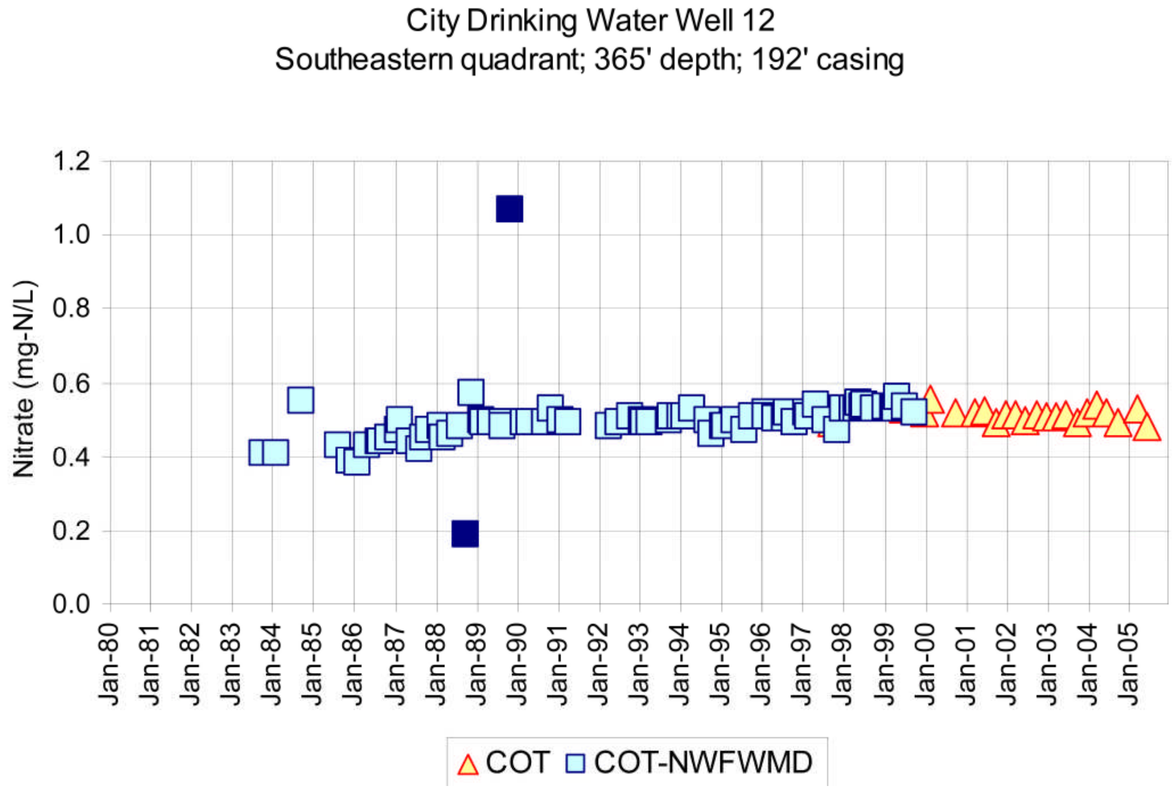


Figure 16. Nitrate levels in COT drinking-water well 12

COT = City of Tallahassee, NWFWMD = Northwest Florida Water Management District. The closed symbols indicate measurements that are deemed not accurate.

Figure 17a:

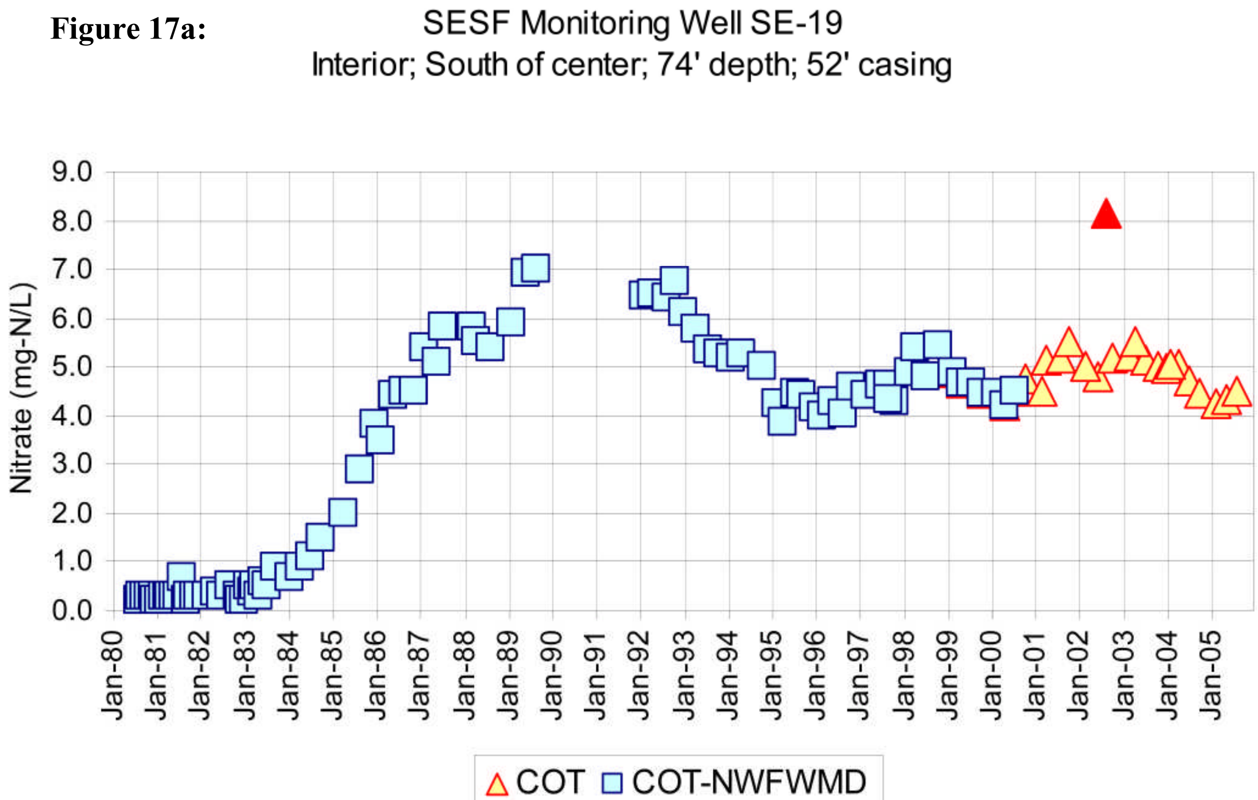


Figure 17. Measured nitrate trends in monitoring wells at the SESF

*The closed symbols in this and other panels indicate measurements that are deemed not accurate. Note the change of scale from **Figure 16** and from panel to panel.*

Figure 17b:

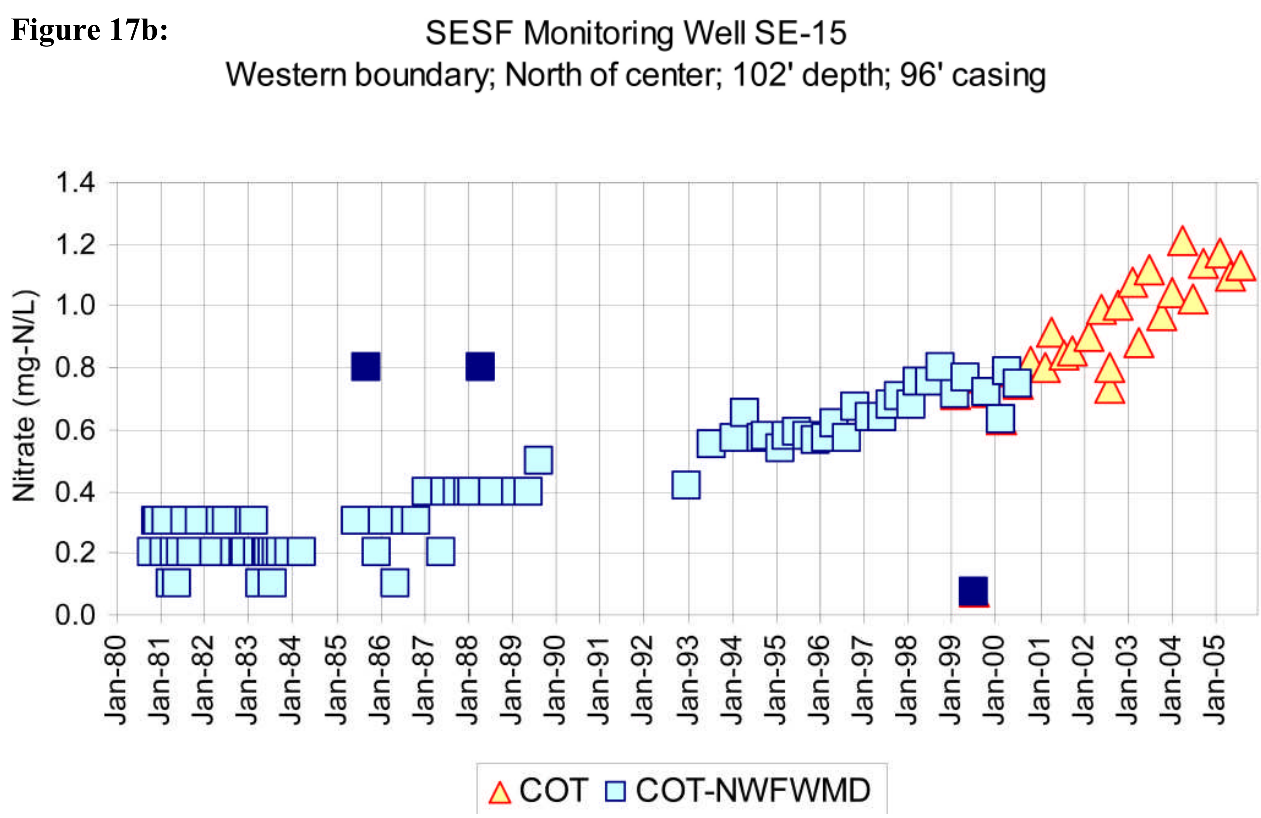


Figure 17c:

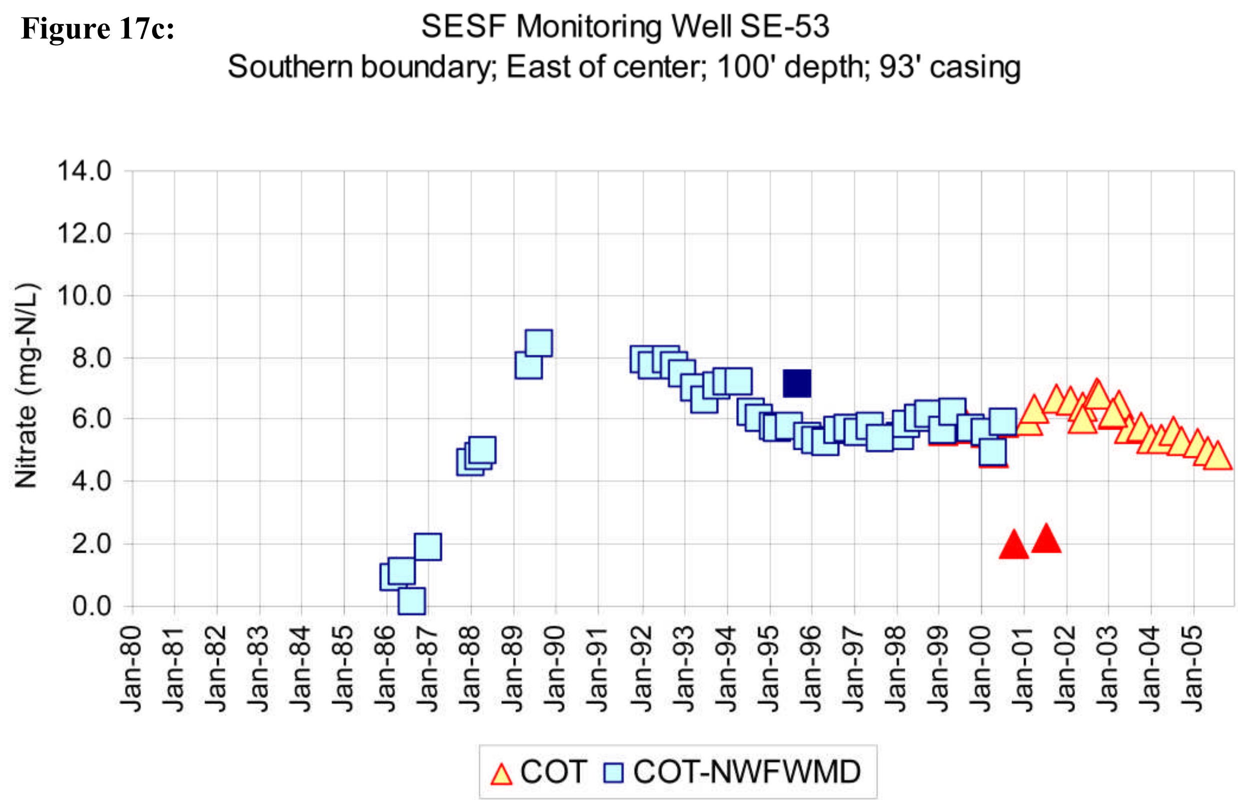
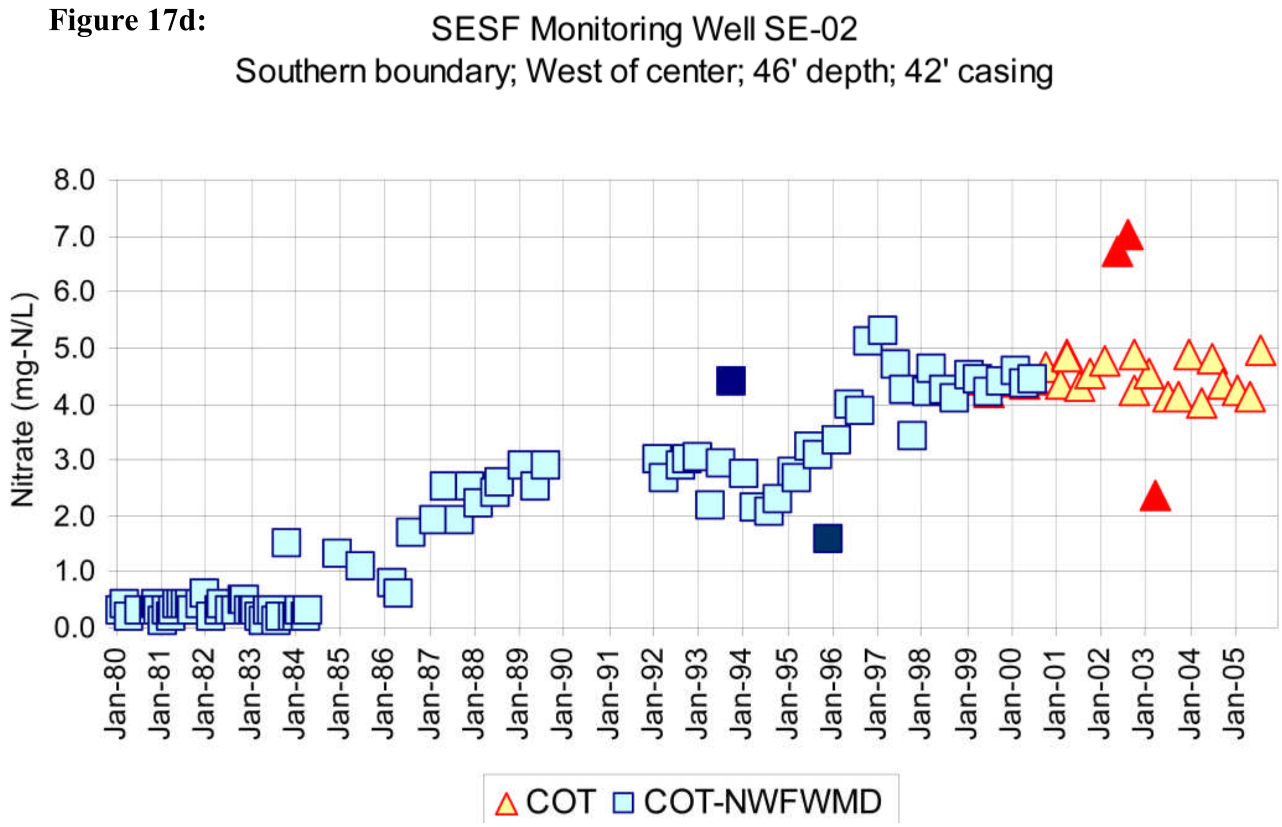


Figure 17d:



Measured concentrations of nitrate, nitrate+nitrite, and total N in the Wakulla Springs boil are shown in **Figure 18**. The data indicate that the majority of the total nitrogen is in fact dissolved nitrate. Note that the duration of measurements extends 10 years earlier than those shown in **Figure 17**; unfortunately nitrate concentrations in Wakulla Springs were not regularly monitored between 1978 and 1989. Also, note that the nitrate concentrations measured at Wakulla Springs are considerably lower than in the monitoring wells. Prior to 1980, concentrations were about 0.3 mg/L, a level comparable to that inferred from COT well 12, shown in Figure 16. The concentrations began to increase between 1977 and 1985, peaked from 1990-94, and have declined by roughly 35% to the present, mirroring the trend seen in monitoring wells SE-19 and SE-53 (see **Figure 17a, c**).

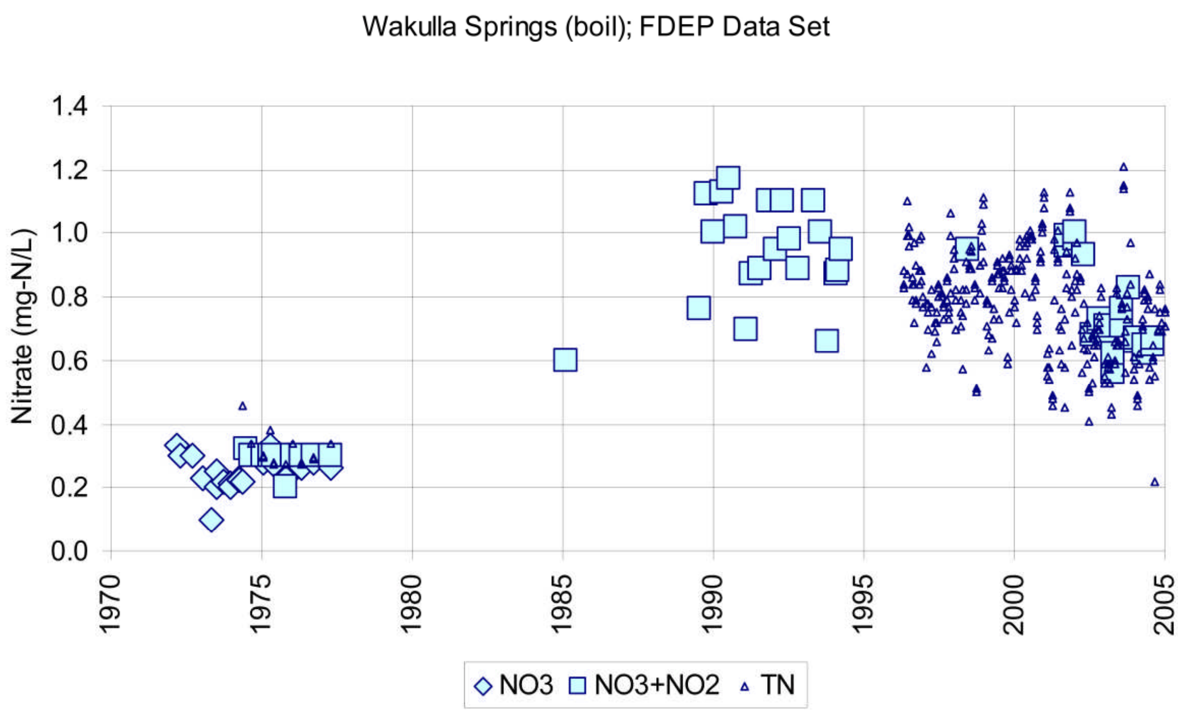


Figure 18. Nitrate time series trends at Wakulla Springs

The discharge at Wakulla Springs is highly variable and is known to come from at least two distinct sources. The scatter in the data since 1989 seen in **Figure 18** is likely the result of a time-varying mixture of two waters, one high in nitrate and one low in nitrate, driven by variations in rainfall. It is possible that the downtrend of nitrate concentration since 1990 is due to an increase in the low-nitrate component as rainfall and net discharge have increased. This hypothesis is supported by **Figure F5**, which shows a negative correlation between nutrient concentrations and discharge. However, annual rainfall for the relevant period (see **Figure 12**) shows no clear trend. A more likely explanation is that the downward trend of nitrate concentrations in the past decade reflects, and is the result of, the decrease in nitrate concentrations in the groundwater beneath the sprayfield. This latter explanation is supported by the similarity in the timing of the nitrate concentration increases and decreases between the sprayfield and Wakulla Springs and the magnitude of the decrease (35-40%). This correlation between variations of nitrate concentrations at the sprayfield and Wakulla Springs strongly suggests that the SESF has been a major contributor to the nitrate loading at Wakulla Springs.

Nitrate loading from the other significant nitrogen source in the springshed (septic systems) would have shown an increase in proportion to population growth between the Cody Scarp and the spring, and there is no reason to expect that source to have declined since 1992–93.

Several studies are expected to be completed in the next 1-2 years that will help clarify the nitrate sources. The COT will complete its SESF Nutrient Management Report in early 2006. This report should provide accurate net nitrogen loading values for the SESF over time. In addition, the FGS is funding a set of tracing studies, to be conducted starting in 2006, to determine definitively whether groundwater is flowing from the SESF to Wakulla Springs. Successful completion of these tracing studies will remove any lingering doubt about the flow of nitrate-laden groundwater from the sprayfield to Wakulla Springs.

It is very likely that improvements in wastewater management practices by the City of Tallahassee during the past decade have led to the decrease in nitrate at Wakulla Springs. These improvements included reducing the spreading of residuals (sewage sludge), reducing the application of fertilizer at the sprayfield, and improving wastewater treatment processes. This provides hope that further improvements in sprayfield operations will result in beneficial changes at Wakulla Springs.

3.5 Fertilizer and Livestock

Chelette *et al.* (2002, pp. 92–94) presented information on commercial fertilizer use and livestock in the springshed prior to 2002. Fertilizer, which is used in agricultural and residential applications, is a significant source of inorganic nitrogen. Agricultural land use grew from the early 1900s to the 1980s, when land uses changed with population growth. The authors note that in 1999, fertilizer use at the SESF (44,000 kg-N/yr) was about 21% of the total used in both Leon and Wakulla Counties (212,000 kg-N/yr). About 70% (150,000 kg-N/yr) is applied to the semi-confined areas of the aquifer in Leon County, and about 8% (18,000 kg-N/yr) is applied to unconfined areas in Wakulla County. Livestock operations in Leon and Wakulla Counties are small. Chelette *et al.* (2002) estimated that in Wakulla County, 82% of the acreage in pasture and cropland lies in the unconfined portion of the aquifer and contributes 23,000 kg-N/yr. In Leon County, 91% of this acreage is in the semi-confined portion of the aquifer (124,000 kg-N/yr), and about 7.5% is in the unconfined portion.

3.6 Septic Systems

A conventional septic system consists of a tank and a drainfield. Wastewater from a house enters the tank, where bacterial action partially breaks down organic materials. As the tank fills, effluent drains from the tank to the drainfield. This effluent still contains solid materials, partially treated organic matter, bacteria and viruses, and soluble organic and inorganic compounds. As the effluent slowly seeps out through the drainfield, the surrounding soil continues the treatment process. Bacterial action further breaks down the solid and soluble organic compounds, some of the inorganic compounds bind to the soil particles, and the soil filters out the remaining solids, including bacteria. The remaining liquid then drains to groundwater, where any remaining impurities are diluted and possibly further attenuated.

A well-sited, well-functioning, and well-maintained septic system can treat and remove most potential contaminants from wastewater before it reaches groundwater. Successful treatment requires clean, unsaturated soil material around the drainfield to effectively filter and clean the effluent. Septic systems must also be spaced widely enough to allow for the dilution and attenuation of any effluent that may reach groundwater. Septic systems in areas prone to flooding, or located too close together, may not meet these requirements.

Even a well-sited and well-constructed septic system, however, can create problems if it is poorly maintained and operated. Household cleaners, most notably bleach, can kill the beneficial bacteria that digest the waste in the septic tank. A septic system cannot break down common household substances, such as solvents or pesticides, that are disposed of down the drain. Septic systems also require regular maintenance. If the accumulated solids are not periodically removed, over time they may plug the drainfield, reducing contaminant removal.

Contributions from septic systems in the Wakulla springshed, although relatively small at present, constitute a looming problem. Wakulla County is one of the fastest-growing counties in the state, with a 26.9% increase in population between 1990 and 1996. The 1990 US Census counted 14,202 people in Wakulla County. The projected county population in 2005 is 20,000 people, but some estimate that the current population already exceeds this number. Most homes in Wakulla County use septic systems for their sewage waste disposal. The locations of septic systems in Leon and Wakulla Counties as of 2002 are shown in Figure 53 of Chelette et al (2002).

Although public water is available in some parts of the county, many homeowners also use domestic wells for their household water supply. With an increase in population, there is concern that ever-increasing numbers and densities of septic systems will affect the quality of water in the Floridan aquifer, the primary source of drinking water for both the domestic and public supply wells in the county.

As discussed earlier, much of the eastern portion of Wakulla County lies within the WKP — an area characterized by a thin, sandy soil overlying karst features such as sinkholes, springs, disappearing rivers, and underwater caves and conduits. The water table lies close to the land surface, and the geology of this area makes it highly susceptible to groundwater contamination from sources such as septic systems at the land surface.

3.7 Sources of Dark Water

The dark (tannic) water causing the loss of water clarity is believed to originate in the Leon Sinks area. Recent tracing studies show that water from several sinking streams in that area (primarily Fisher Creek and Black Creek) rapidly enters the Leon Sinks cave system and soon appears at Wakulla Springs. Samples of water from several tunnels that convey water to the spring from the west, collected by the NWFWMD, are dark and low in nitrate, confirming the conclusions of the tracing studies.

Jim Stevenson has hypothesized that before the early 1900s, the lands west of the WKP were burned frequently by fires, reducing the amount of organic leaf litter and underbrush that could contribute tannin to surface water (and ultimately groundwater). This condition persisted until the establishment of the Apalachicola National Forest in 1936, when fires were largely suppressed and the land was replanted in pine trees. In subsequent years the amount of organic matter—and thus the amount of tannin that can eventually reach groundwater—has gradually increased. A more complete description of this hypothesis is found in **Appendix H**.

CHAPTER 4: SOLUTIONS TO THE PROBLEMS

The motivation for the workshop and the goal of this report is to identify solutions to the problems of nutrient loading and the associated degradation of biota in Wakulla Springs and River, as well as the loss of water clarity caused by dark water flowing to the springs. This chapter assesses whether the degradation can be stemmed and reversed and enumerates a number of possible mitigation strategies.[14] The peer review committee makes no recommendations regarding specific actions.

4.1 Mitigation Strategies for Nutrient Loading

Although it does not appear possible to eliminate undesired species entirely, it appears possible to limit the rapid growth of both hydrilla and algae. The flux of nitrate (the limiting nutrient) from the main vent of Wakulla Springs is about 750 kg-N/day, and the change in nitrate down the river **(Figure E2, Appendix E)** is due almost entirely to uptake by plants (380 kg-N/day plant uptake). Since 1 kg-N produces 16 kg of vegetation (dry weight), this translates into 6,080 kg of aquatic vegetation added to the spring basin and upper river each day.

The high levels of nitrate (and to some extent phosphorus) favor the growth of vegetation such as hydrilla and algae, which derive nutrients directly from the water, as opposed to native vegetation, which derives nutrients primarily from the river bottom, via root systems. If the levels of nitrogen and phosphorus are reduced, the rate of production of hydrilla and algae will likely be reduced and the fraction of native vegetation will increase. However, it is very likely that regular intervention, such as herbicide treatments, will need to be continued to keep the levels of hydrilla and algae in check.

Even if there are other factors affecting the growth of hydrilla and algae, there seems little hope of reversing the degradation without reducing the concentration of nitrate in the water. Currently, a statewide technical workgroup is examining the feasibility of establishing a spring nutrient standard, and is scheduled to complete its work in 2005. The water-quality standard for nitrate in springs is currently the drinking-water standard: 10 mg/L. While this level is designed to protect human health, it is fifty times the recommended FDEP target concentration necessary to protect the ecological integrity of the system. In this regard, recall that Section 62-302.530, FAC, states that "In no case shall nutrient concentration of a body of water be altered so as to cause an imbalance in natural populations of aquatic flora or fauna."

In the Wakulla system, it is important that FDEP water-quality criteria be developed to provide direction for the control of nutrient sources that contribute to surface water and groundwater pollution; the agency must use these criteria to set acceptable limits on pollution, in order to protect the natural system's ecological integrity. Implementing the TMDL Program and establishing ecologically based water-quality criteria for nutrients and thus, more stringent FDEP permit requirements, are essential to protecting the spring and river; however, these steps will take time. Given the urgency of the situation, it is sensible to give priority to the TMDL process for the Wakulla River.

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[14] Portions of the text in this chapter are adapted from the FDEP document, *A strategy for water quality protection: Wastewater treatment in the Wekiva Study Area* (December 2004).

Further, it is clear that Wakulla Springs, River, and estuary represent an opportunity to study systematically the hydrology of an important karst system and the effects of land-use changes and water quality on the state's many other springs. To facilitate and coordinate such studies two things are needed: special designation and funding. Regarding special designation, Wakulla Springs and River are currently designated as an OFW, a designation meant to prevent declines in water quality, and the FGS is promoting the establishment of a Hydrologic Observatory focusing on the WKP. Another step the state could take is to designate Wakulla Springs and River as an Aquatic Preserve[15] with the specifically qualified intent of using the Wakulla ecosystem as a "living laboratory" to be used to more fully study and thus better understand the nutrient and ecosystem dynamics associated with Florida springsheds. The numerous springs of Florida could benefit by having several "living laboratories" established to identify and frame the long-term research, educational and stewardship needs. In concert with these designations, there needs to be adequate funding of research focused on developing practical answers to critical questions bearing on the quality of groundwater and the health of ecosystems near springs; see **Recommendation 5** in the Executive Summary and **Appendix G**.

4.1.1 Wastewater Treatment Facilities

Strategies for mitigating input of nutrients to the aquifer are aimed principally at the SESF, since it seems to be the largest contributor to nitrate at Wakulla Springs, but these strategies apply to other WWTFs as well. The overall strategy recommended by the committee is to manage all facilities with the goal of minimizing the addition of nutrients and other pollutants to surface water or groundwater. Specific strategies include the following:

- *Stop spreading sludge in the basin (this strategy is being implemented at the SESF),*
- *Minimize fertilizer use at the SESF (fertilizer usage at the SESF has been reduced significantly in recent years) and*
- *Improve nutrient removal at the wastewater treatment plants and/or move the treated wastewater to be disposed of through land application either much farther up in the basin (north of the Cody Scarp) or out of the basin completely.*

The recently published report on protecting water quality in the Wekiva area of central Florida provides a useful approach to mitigating wastewater impacts.[16] Like the Wakulla springshed, the aquifer in the Wekiva region is comparable in terms of its vulnerability to nitrate contamination.

Using information on "natural" spring conditions in the Wekiva region, including nitrogen concentrations, FDEP concluded that the target concentration should be about 0.2 mg/L of nitrate-nitrogen. This is in agreement with the concentration recommended by the State Springs Task Force. Having this target of 0.2 mg/L of nitrate-nitrogen allowed FDEP to recommend a minimum-treatment-level strategy for wastewater treatment systems based on the zone (primary, secondary, or tertiary) and the volume of the discharge (greater than 0.1 mgd or less). The 0.2

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[15] A state designation. Information is available at: http://www.dep.state.fl.us/coastal/programs/aquatic.htm.

[16] FDEP. December 2004. *A strategy for water quality protection: Wastewater treatment in the Wekiva Study Area.* Available at http://www.dep.state.fl.us/central/Home/Admin/WekivaReportDecember2004.pdf.

mg/L target is a starting point; however, any future TMDLs developed for the Wakulla springshed will be crucial in evaluating site-specific impacts of nutrients on surface waters and establishing specific limits to be achieved. The Wekiva report is summarized in §1.2.3 (p. 7).

4.1.2 Septic Systems

Septic systems present a difficult problem for two reasons. First, they are out of sight, and hence out of mind, for the vast majority of the population, and second, the number of such systems in the springshed is projected to increase dramatically in the coming years.

The only sustainable remedy to this looming problem is to establish a wastewater utility and charge it with maintaining all on-site disposal systems and facilitating the necessary environmental education of septic-tank owners. The activities of this utility should be in accordance with the goal of minimizing the input of nitrate and other pollutants to groundwater. This utility should encompass those areas of Leon and Wakulla Counties not currently served by a WWTF and should be funded by an appropriate utility fee. The advantages of a utility would be as follows:

- *Failing systems would get prompt attention,*
- *Advanced systems would be employed where necessary to protect the aquifer and*
- *The cost of maintenance and improvement would be distributed, rather than falling on the individual homeowner.*

4.1.3 Fertilizers and Livestock

Although the peer review committee did not investigate this issue in much depth, it appears that altering fertilizer use could reduce the input of nitrogen to the aquifer. Proactive public education efforts are an essential part of achieving this goal. As noted above, one immediate step is to minimize the use of fertilizer at the SESF. Additionally, the types of fertilizers used elsewhere in the springshed could be regulated by ordinance, permitting only those (e.g., time release) that minimize nutrient inputs to the aquifer.

4.2 Mitigation Strategies for the Loss of Water Clarity

One possible strategy to improve water clarity would be to prevent dark water on the surface from entering the aquifer, perhaps by the impoundment or diversion of streams or by burning leaf litter in key locations. However, more needs to be learned regarding the sources, concentrations, and volumes of dark water before seriously considering this strategy. The committee recommends that the origin and mode of transport of the dark water be systematically investigated.

ACKNOWLEDGMENTS

This workshop and the studies that helped frame the opinions and scientific judgment of the Peer Reviewers was the collaborative product of many individuals and agencies, including 1000 Friends of Florida, city of Tallahassee, Florida Department of Environmental Protection, North Florida Water Management District, US Geological Survey, Florida Department of Community Affairs, Leon County, Wakulla County, Florida LakeWatch, Hazlett Kincaid Inc., and McGlynn Laboratories Inc.

The efforts of two individuals, however, deserve special consideration. First, this workshop was conceived by Dr. Donald Axelrad of the FDEP. Dr. Axelrad also helped organize and promote the workshop, recruited the peer reviewers, assisted in obtaining data critical for the reviewers' analyses, and provided critical comment on earlier drafts. Second, Dan Pennington of 1000 Friends of Florida played a key role in organizing and coordinating the workshop and helped shepherd the report through the production process. Without the concerted efforts of both these individuals, this report and our consensus recommendations for the restoration of Wakulla Springs would not exist.

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TABLE 1: LIST OF ACRONYMS

AWT	Advanced wastewater treatment
BMP	Best management practice
CoT	City of Tallahassee
FAC	Florida Administrative Code
FDEP	Florida Department of Environmental Protection
mgd	million gallons per day
mg/L	milligrams per liter
NWFWMD	Northwest Florida Water Management District
OFW	Outstanding Florida Water
OSTDS	Onsite sewage treatment and disposal system
SESF	Southeast Sprayfield
TMDL	Total maximum daily load
USGS	U. S. Geological Survey
WKP	Woodville Karst Plain
WWTF	Wastewater treatment facility

WEB SITES OF INTEREST

http://www.floridastateparks.org/wakullasprings/default.cfm

http://www.wakullasprings.org/

http://www.wkpp.org/

http://www.hazlett-kincaid.com/FGS/

http://www.tfn.net/springs/

http://www.dep.state.fl.us/labs/cgi-bin/reports/search.asp

http://www.floridasprings.org/

http://www.thiswaytothe.net/springs/

http://www.cafwn.org/

http://www.dep.state.fl.us/coastal/programs/aquatic.htm

http://nerrs.noaa.gov/

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APPENDICES

Appendix A: Questions for the Peer Review Committee

May 9, 2005

Dear Drs. Chan Hilton, Pollman, Loper, and Landing,

After additional review, the Wakulla Springshed Workshop Planning Committee has produced the following 5 general questions for the Peer Review Committee to draft answers to from information available at the workshop, namely:

1. *What does the preponderance of evidence indicate are the sources of nutrients (nitrogen and phosphorus) reaching Wakulla Springs, and which are the most important sources?*
2. *Are nutrients (nitrogen and/or phosphorus) responsible for the ecological "imbalance" of the Wakulla River (imbalance as defined by FDEP)?*
3. *What are the solutions that should be implemented presently to reduce nutrient loading to Wakulla Springs?*
4. *What are the future threats (say 50 years into the future) regarding nutrient loading to Wakulla Springs, and what planning is now necessary to avoid these threats?*
5. *What additional research, if any, is necessary to provide adequate certainty regarding effective actions to eliminate the Wakulla Springs and River nutrient pollution problem?*

The following 15 detailed questions, some of which we may not yet have answers to, can serve as guidance for answering the 5 general questions. It may not be necessary to answer all of these detailed questions in full to answer the general questions.

6. *Is Wakulla Springs especially vulnerable to pollutant inputs from groundwater? If so, why?*
7. *How are pollutants transported to Wakulla Springs via groundwater, from where, and what is the time-of-passage from pollutant sources to Wakulla Springs?*
8. *What were the historical versus present levels of nitrogen and phosphorus in Wakulla Springs and River waters?*
9. *How has the plant community in the Wakulla River changed over time with increased nutrient concentration?*
10. *What is the ecological "imbalance" of the Wakulla River as defined by FDEP that has resulted in the river being listed on the state's "impaired waters" list?*
11. *What are the present sources of nutrients—nitrogen and phosphorus—to Wakulla Springs? Quantify these to the extent possible.*
12. *Are nitrogen and/or phosphorus responsible for the "imbalance" of flora and fauna in the Wakulla River?*
13. *Does nitrogen, or does phosphorus, or do both equally limit the growth rate and biomass of plants (e.g., hydrilla, lyngbya, sagittaria, vallisneria, filamentous greens, etc.) in the Wakulla River?*

14. *What are the likely ecological changes to the Wakulla River that would result from continued increases of nutrient loading to Wakulla Springs?*
15. *Will nitrogen and/or phosphorus load reduction to Wakulla Springs restore the Wakulla River to a "balanced" state or to a more "balanced" state?*
16. *Which nutrient load to Wakulla Springs is it more effective and feasible to control — nitrogen or phosphorus? Nutrient loads from which sources are most feasible to control?*
17. *If nitrogen is the limiting nutrient, or if it will become so with nutrient loading reductions, will controlling nitrogen loading achieve restoration of Wakulla Springs and River, or will it merely impose selective pressure favoring nitrogen-fixing algae, leaving the ecosystem "imbalanced"?*
18. *How much must the nitrogen or phosphorus load to Wakulla Springs be reduced to restore the Wakulla River to a "balanced" state?*
19. *What additional research if any is needed to allow decision making on necessary actions for restoring the Wakulla River to a "balanced" state?*
20. *What are the future threats (say 50 years into the future) to Wakulla Springs and River and what planning is now necessary to avoid these?*

Donald M. Axelrad, Ph.D.
Florida Department of Environmental Protection

Appendix B: Key Peer Review Committee Questions and Answers

The following answers were prepared by the peer review committee immediately following the workshop. Any changes between these responses and equivalent responses found in the main body of this report reflect the input of additional data and information received subsequent to the workshop.

A. Is Wakulla Springs especially vulnerable to pollutant inputs from ground water? If so, why?

Yes. A significant portion of the catchment basin of Wakulla Springs consists of an unconfined aquifer; pollutants applied to the land surface in such areas typically move rapidly into the Floridan aquifer with little natural attenuation, compared with areas where the aquifer is confined. Unfortunately, the Southeast Sprayfield (SESF) operated by the City of Tallahassee, is located within an unconfined region, so that the nutrients in the sprayed water quickly enter the aquifer and pose a particular danger to Wakulla Springs. Further information on the hydrogeology of the aquifer may be found at http://www.wkpp.org/ and http://www.hazlett-kincaid.com/FGS/.

B. What are the main water quality issues affecting the Wakulla River and what are the consequent ecological or aesthetic impairments?

The main water quality issues are nutrient loading (nitrogen and phosphorus) and dark water. The nutrient loading is the direct cause of the excessive growth of hydrilla and algae that is plaguing the spring basin and upper reaches of the Wakulla River. This growth is choking out native vegetation and is severely stressing many aquatic species.

It is unclear at this time whether the increased density of hydrilla is contributing to the decline in the number of birds observed in the park and has contributed to the disappearance of the apple snails and limpkins in the park. It has been proposed that the apple snails were drowned out in the flood event of August 18 to 22, 1994, when the river stage (elevation above NAVD88 sea level) exceeded 9.3 feet, compared with an average stage of 5.4 feet for the interval from 1987 to 2005. The flood hypothesis is supported by the fact that recent efforts to reintroduce the apple snail seem to be succeeding (Scott Savery, personal communication).

The presence of invasive aquatic plants and dark water, the decline in bird counts and the absence of apple snails and limpkins are strongly impairing the aesthetic quality of the Springs and State Park.

C1. What does the preponderance of evidence indicate are the sources of nutrients (nitrogen and phosphorus) reaching Wakulla Springs, and which are the most important sources?

Several independent lines of evidence (the temporal history of nitrate in the spring and in the wells south of the SESF and model calculations of water flow and pollution transport) indicate that the SESF accounts for between one-third and one-half the nitrate in Wakulla Springs. Other nutrient sources of concern include septic systems, fertilizers and municipal waste-disposal activities (other than the SESF).

C2. What does the preponderance of evidence indicate are the sources of dark water reaching Wakulla Springs, and which are the most important sources?

Although the precise source has not been identified, it seems very likely that the dark water originates in the swamps within the Apalachicola National Forest to the west and north of

Wakulla Springs. After rain in that area, this dark water flows to sinkholes on the western edge of the Woodville Karst Plain (e.g., Black Creek and Fisher Sinks), and is conveyed fairly rapidly to the springs by means of a system of natural conduits.

D. Are nutrients (nitrogen and/or phosphorus) responsible for the ecological "imbalance" of the Wakulla River (imbalance as defined by FDEP)?

While both nitrogen and phosphorus contribute to the growth of hydrilla, algae and other undesirable aquatic plants, the limiting nutrient is nitrogen, in the form of dissolved nitrate.

E. What are the solutions that should be implemented presently to reduce nutrient loading to Wakulla Springs?

An immediate and obvious remedy to the excess nitrate in Wakulla Springs' waters is a modification of practices and activities at the Southeast Sprayfield, with a goal of reducing nutrient loading to the aquifer. In particular, the application of fertilizer to the sprayfield should be suspended, until a thorough review is made of its effect on the nutrient load to the aquifer. In addition, the types and amounts of fertilizers used elsewhere in the springshed of Wakulla Springs should be reduced, insofar as is practicable, by regulation and/or public education.

F. What are the future threats (say 50 years into the future) regarding nutrient loading to Wakulla Springs, and what planning is now necessary to avoid these threats?

All future threats are a direct result of the projected growth and development in the springshed of Wakulla Springs, particularly in Leon and Wakulla Counties. Looming problems are the projected rise in the volumes of treated wastewater and septic-tank effluent and in the amount of storm water runoff, as the currently rural areas of Leon and Wakulla Counties become progressively more developed and populated. The projected increase in septic systems is particularly worrisome.

To address the looming problem of septic system effluents, it is strongly recommended that a waste-water utility, encompass those areas of Leon and Wakulla Counties not currently served by a wastewater treatment facility, be established and charged with improving the operation of all on-site disposal systems, with the goal of reducing nutrient loading to the aquifer.

G. What additional research, if any, is necessary to provide adequate certainty regarding effective actions to eliminate the Wakulla Springs and River nutrient pollution and dark water problems?

Although some aspects of the problems facing Wakulla Springs are now beyond a reasonable doubt and lead to recommendations for specific actions (see the answers to questions E and F above), further research is necessary because our knowledge and understanding of other aspects of the problems remain incomplete, and problems that are minor at the present time can become much worse as the population in the springshed continues to grow. Specifically, research is necessary to better quantify primary contributing regions, flow paths and travel times for water and pollutants (including nitrate and dark water) in the springshed of Wakulla Springs.

Also, specific research is necessary to:

- *Better understand the nature and fate of pollutants introduced by various sources within the springshed;*
- *Better understand and quantify the effect that pollutants have on the biota in the spring basin and upper reaches of the Wakulla River; and,*

- *Identify BMPs for the treatment and disposal of wastewater, retention and treatment of stormwater and design and operation of septic systems.*

Appendix C. List of Reviewers

A draft of the report was sent to the following people for their review and comment

Jonathan Arthur, Florida Department of Environmental Protection–Florida Geological Survey

Don Axelrad, Florida Department of Environmental Protection

Michael Bascom, Florida Department of Environmental Protection

Commissioner Ed Brimner, Wakulla County

Paul Booher, Florida Department of Health

John Buss, City of Tallahassee

Angela Chelette, Northwest Florida Water Management District

Rick Copeland, Florida Department of Environmental Protection–Florida Geological Survey

Brian Crawford, Wakulla County Health Department

Hal Davis, United States Geological Survey

Richard Deadman, Florida Department of Community Affairs

Rodney DeHan, Florida Department of Environmental Protection–Florida Geological Survey

Richard Drew, Florida Department of Environmental Protection

Dick Fancher, Florida Department of Environmental Protection, Northwest District Director

Russel Frydenborg, Florida Department Of Environmental Protection

Joe Hand, Florida Department of Environmental Protection

Tim Hazlett, Hazlett Kincaid Inc.

Theresa Heiker, Leon County

Val Hubbard, Florida Department of Community Affairs

Todd Kincaid, Hazlett Kincaid Inc.

Commissioner Debbie Lightsey, City of Tallahassee

Eric Livingston, Florida Department of Environmental Protection

Linda Lord, Florida Department of Environmental Protection

Gary Maddox, Florida Department of Environmental Protection

Alex Mahon, Leon County Health Department

Sean McGlynn, McGlynn Laboratories, Inc.

Jim Oskowis, City of Tallahassee

Dan Pennington, 1000 Friends of Florida

Tom Pratt, Northwest Florida Water Management District

Lynn Putnam, City of Tallahassee

Mark Repasky, Sustainable Design, Inc.

Eberhard Roeder, Florida Department of Health

Scott Savery, Wakulla Springs State Park

Walt Schmidt, Florida Department of Environmental Protection–Florida Geological Survey

Mark Sees, City of Orlando

Jamie Shakar, City of Tallahassee

Tom Singleton, Florida Department of Environmental Protection

Jim Stevenson, Wakulla Springs Working Group Coordinator

Commissioner Cliff Thaell, Leon County Florida

Karth Vaith, CDM, Jacksonville

Jessie VanDyke, Florida Department of Environmental Protection

Marty Wanielista, University of Central Florida, Florida Stormwater Academy

Ellie Whitney, Friends of the Wakulla, Tallahassee

Appendix D. History of Hydrilla Removal Efforts at Wakulla Springs

by Scott Savery, FDEP, Wakulla Springs, State Park Biologist

Soon after its discovery, attempts were made to remove hydrilla from the spring and river. Removal by hand was the first method used. The extent of the hydrilla infestation became apparent when it invaded the swimming area and complaints were made about an abrasive plant that was entangling some swimmers. Hydrilla was now a major problem at Wakulla Springs State Park. In February 1998, a full-time OPS position was created and an individual was hired to help in the control and removal of hydrilla. Swimmers and volunteers were first used in the swimming area to help hand-pull the hydrilla and load it onto dump trucks. Shortly after this, divers were used to pull it out of the deeper areas of the spring and swimming area. Tarps were put down to shade out the hydrilla in parts of the spring basin and the area directly behind the floating dock. Shading with tarps can kill hydrilla. However, the tarps must be down for over 80 days or the hydrilla can resprout from the roots and tubers. In April 1998, the approved aquatic herbicide Aquathal was applied to a portion of the swimming area. The hydrilla was observed to turn brown but did not die from this herbicide application. None of these efforts was successful in controlling the spread of hydrilla. At the end of 1998, despite an estimated 260,000 kg removed, involving 4,265 man-hours at an estimated cost of $33,500, hydrilla continued its invasion of the spring and river.

Late in 1998, Prism Ecological Services, Inc. was contracted to remove hydrilla from certain parts of the river by the use of a mechanical plant harvester. In 10 days of cutting during March 1999, totaling 282 man-hours, a total of 100,000 kg of hydrilla was removed from the river. Prism returned 4 times in 1999 and removed 280,000 additional kg of hydrilla. Until October 1999, Prism was cutting hydrilla and harvesting the clippings that were being hauled to a dump site in the park. This method was improved upon; in October 1999, Prism developed a way to mechanically pull hydrilla from the river while leaving some of the native Tapegrass (*Vallisneria americana*). In five days, 64,000 kg of hydrilla were pulled from the river.

Between December 1999 and January 2000, 19 volunteers completed 40 dives and park personnel completed 28 dives. This totaled 24 volunteer man-hours and 21 man-hours for park personnel. Done in coordination with the Prism mechanical harvesting, this massive dive effort greatly increased the efficiency of the hydrilla removal effort. In 11 days a total of 120,000 kg of hydrilla was removed. Some of the hydrilla was being removed off site, but most was still being hauled to the on-site dump. In May 2000, a second loading area was developed at the Warehouse/Railroad area downriver. This new loading site allowed hydrilla removal from farther downriver with a shorter travel time. A third loading site was built between the swim area and the Warehouse/Railroad area.

In May 1999, an attempt at biological control was made in conjunction with Dr. O'Brien from Florida A&M University. Specimens of the fly *Hydrellia pakistane* were collected from central Florida. Approximately 20,000 flies were introduced to a small section of the river near the boat drydock area. In November 1999, several specimens were collected in the area in which they were released. A small population appears to have been established. No other control methods were used in this area designated for biological control. There has never been any evidence of the flies having any negative impacts to the hydrilla and we are not sure if they are present today.

Hydrilla removal by mechanical harvesting and diving (in the swim area and spring) continued until April 2002. This method of treatment was somewhat successful for short-term control of the hydrilla in the swim area, the spring, and the boat tour route. A total of over 2,000,000 kg of hydrilla was removed at a cost of over $400,000. But the infestation was getting worse in areas that were not being used and downriver past the tour route. In 2002 it was determined that alternative treatments were needed. A herbicide application of Aquathol K was done on April 16, 2002, for 52 hours at a rate of 4.25 parts per million (ppm) (a total of 1,750 gallons). The results were remarkable. Since then herbicide treatments at lesser rates (1.5–2.15 ppm) were completed in November 2002, November 2003, May 2004, and April 2005. The treatments cost about $80,000 each.

Since the herbicide treatments of hydrilla, the vegetation of the river has changed. There has been a decrease in most plants, most notably hydrilla, musk-grass and *Sagittara kurziana*. There have also been some increases and spread of Illinois pondweed, Southern naiad (*Najas guadalupensis*), and *Vallisneria americana.* The system acts like a yo-yo; after the herbicide treatment there is much less vegetation and algae covers most everything in the water. As the system recovers, the natives (pondweed, naiad, *Sagittaria,* and *Vallisneria*) grow back faster than the hydrilla, but over time the hydrilla grows back and overtakes the natives. This yo-yo effect takes 6 to 8 months to occur. But there has been improvement. We do now have large areas with good native growth and little hydrilla, but we also have large areas where hydrilla continues to dominate.

Appendix E: The Case Against and For Nitrogen (N) Limitation in the Upper Reaches of the Wakulla River

E.1 The Case against N Limitation

For Florida springs and rivers, the evidence for N limitation of aquatic plant production is scant. In a study of 28 springs of north and central Florida, Stevenson *et al*. (2004) found mixed evidence supporting N limitation of algal growth. Most spring sites, including Wakulla Springs, were deemed as phosphorus (P) limited (56%), or N and P limited (22%), whereas N limitation occurred at only 19% of the sites and was species specific. The study did not address successional dynamics of macrophytes in relation to changing nutrient regimes, which is perhaps arguably the more important ecological question confronting Wakulla Springs. Other factors related to disturbance in the springshed other than nutrient supply can also influence primary producer dynamics. For example, despite recent increases in N concentrations, Hoyer and colleagues (M. Hoyer, personal communication) concluded that eutrophication changes in Wekiva Springs were related to changes in substrate dynamics and an increase in light penetration due to the removal of the terrestrial canopy.

Traditionally, the Redfield stoichiometric ratio of N to P concentrations in phytoplankton has been used to help identify N or P limited regimes. This ratio is 16:1 when expressed on a molar basis (7.2 on a mass basis) and is best evaluated using dissolved inorganic N and P concentrations. The N:P mass ratio for Wakulla Springs — which is calculated from total nitrogen (TN) and total phosphorus (TP) concentrations, since there are limited if any data on dissolved inorganic phosphorus concentrations for the spring — has generally declined since 1996, ranging between 22 and 34 (**Figure E1**). These results follow from the overall decline in TN concentrations, but not TP during the same period. For lacustrine systems, Smith (1983) found that blue-green algae tended to become more dominant and bloom when TN:TP mass ratios fell below 29:1, although this ratio has not been found to be a reliable indicator of cyanobacterial dominance in Florida lakes (Canfield *et al*., 1989). Stevenson *et al*. (2004), however, indicate that N may be limiting algal growth in streams when water column N:P ratios are greater than 16:1, because P is probably more efficiently recycled than N.

E.2 The Case for N Limitation

One approach to elucidating whether N or P limitation is controlling primary production in Wakulla Springs is to examine the relative loss rates of both nutrients as water moves downstream from the spring boil. Assuming that continued inputs of groundwater downstream are not appreciably contributing to the riverine flux within the first mile of the boil, a more rapid decline in the concentration of one nutrient relative to the other indicates that its availability is in more short supply. **Figure E2** shows the change in average concentration of both TN and TP in the Wakulla Springs and River system with distance downstream from the spring boil. The plot also shows predicted concentrations of TN and TP derived by assuming that both nutrients are taken up stoichiometrically according to the Redfield ratio. In other words, using TP as an example, predicted TP concentrations were calculated as a function of the measured uptake of TN downstream (relative to average TN concentrations in the spring boil) and assuming that the stoichiometric equivalent mass of TP was also consumed. A comparison of predicted with observed values (**Figure E2**) clearly shows that TN is consumed preferentially to TP. For example, predicted TN concentrations are much higher than observed, while predicted TP concentrations are much lower than observed. This is also clearly evident in the molar mass uptake ratios of TN relative to TP computed for sites downstream from the boil. The uptake ratios increase monotonically with distance downstream and are all in excess of 29.

The temporal history of nitrate in the wells south of the SESF and in Wakulla Springs, and the timing of excessive growth of aquatic plants in Wakulla Springs and River, also indicate that nitrate is likely responsible for the problem (see **Figures 17** and **18**).

E.3 The Case for Reducing Plant Growth by Limiting Nitrate Loading to the Springshed

Most data indicate that nitrate, rather than phosphate, is responsible for the proliferation of hydrilla and algae in the Wakulla River. Control of either nitrate or phosphate loading to the springshed could be used to control the excessive plant growth rate in the Wakulla River. It may be more feasible, however, to limit nitrate loading to the springshed to reduce the growth of nuisance plants in the river. A larger proportion of nitrate than phosphate loading to the springshed comes from point sources, which means nitrate inputs may be more readily controlled Also, the phosphate-rich rock, known as the Hawthorn Group, that overlies the Floridan aquifer in areas of the springshed may represent a significant and unabatable source of phosphate to Wakulla Springs. FDEP is using 0.2 mg/L of nitrate as a target concentration for the spring-fed Wekiva River to control undesirable aquatic plant growth. Nitrate concentrations in the Wakulla River are 3 to 5 times this target.

Several hypotheses can be proposed to explain the differential rate of uptake of nitrogen relative to phosphorus. A first hypothesis is nitrogen is in critical short supply and thus is taken up more rapidly than phosphorus, despite the fact that TN:TP ratios are indicative of P limitation. [Note: Algal mat N:P ratios reported by Stevenson *et al*. (2004) appear to be greater than 30:1, which would be indicative of higher N uptake, but need to be verified (see Stevenson, Figure 2.22)].

A second hypothesis is that nitrogen is not solely limiting, and phosphorus is more rapidly mineralized than nitrogen by upstream plants. This would account for a higher relative net uptake of nitrogen compared with phosphorus. A third hypothesis is differential dilution rates of nitrogen and phosphorus downstream of the boil also could potentially explain the results. This hypothesis would require that additional sources of groundwater continue to discharge into the Wakulla River below the spring boil, but at ratios of N:P that are lower than waters exiting the boil. This last hypothesis is unlikely, as the inputs by Sally Ward and McBride Springs are relatively small and very likely derived from the same source as the main vent.

Water-column concentrations of chlorophyll *a* increase from less than 0 to approximately 3.4 micrograms per liter (μg/L) approximately 9.2 km downstream from the boil (**Figure E4**). This increase is a kinetic effect related to the time of travel (algae need to time to grow once exposed to sunlight) in concert with an excess nutrient supply. Because P concentrations are so high relative to the rate of suspended algal uptake, it would take a very large decrease to effectively reduce chlorophyll *a* levels below current levels.

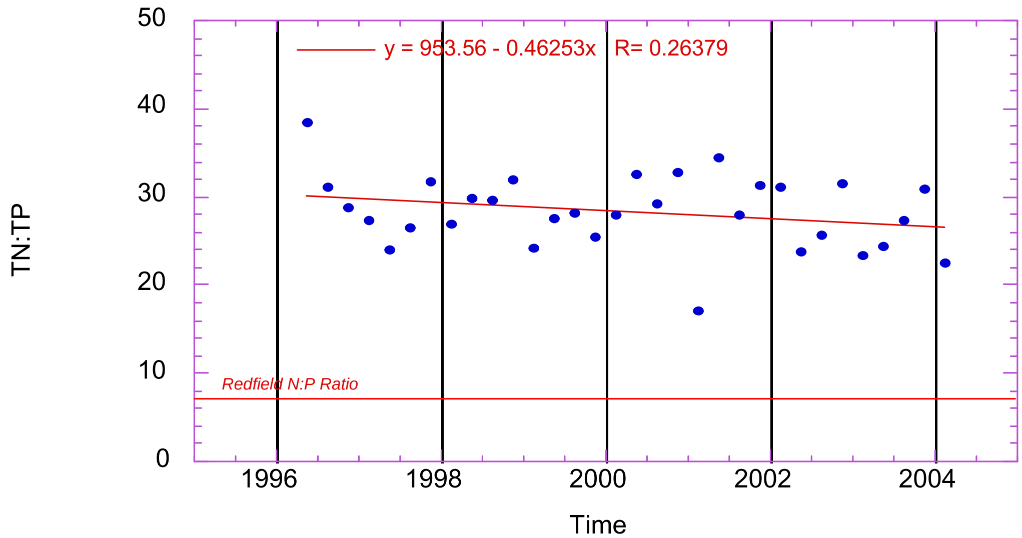


Figure E1: TN:TP ratios (by mass) over time at Wakulla Springs, 1996–2004

Data courtesy of J. Hand. Plots by Curtis Pollman. This plot also shows the Redfield ratio of algal N:P (mass basis; Stumm and Morgan, 1996)

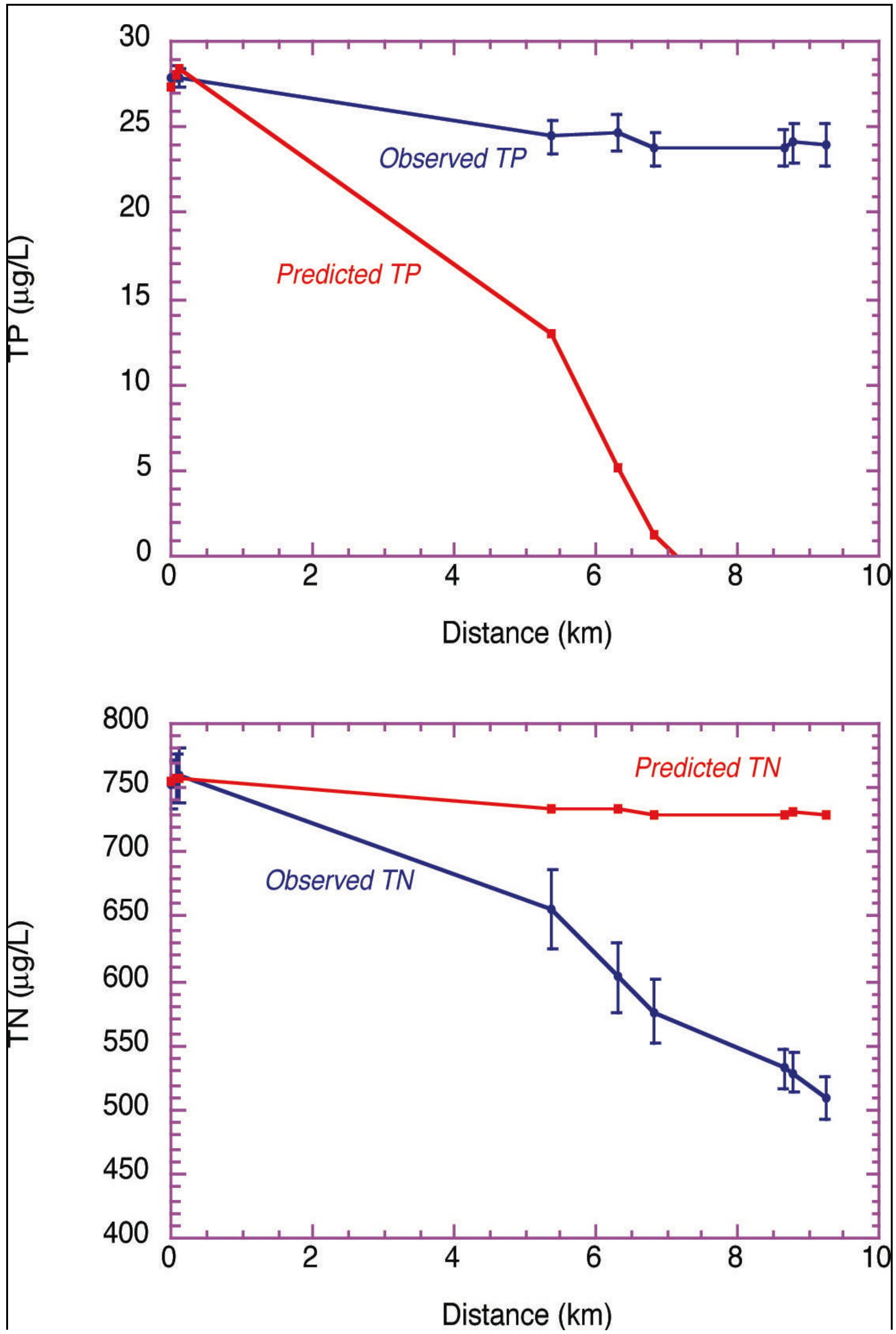


Figure E2. Variations of concentrations of TN and TP in the Wakulla River with distance downstream of the springhead

(upper panel: TP concentrations; lower panel: N concentrations)

The blue lines show average concentrations at a given location measured between 1999 and 2002. Error bars are standard error of the mean. The red lines show the predicted concentrations of, for example, N, assuming that observed changes in P are matched by a stoichiometrically equivalent (based on the Redfield ratio) amount of uptake in N.

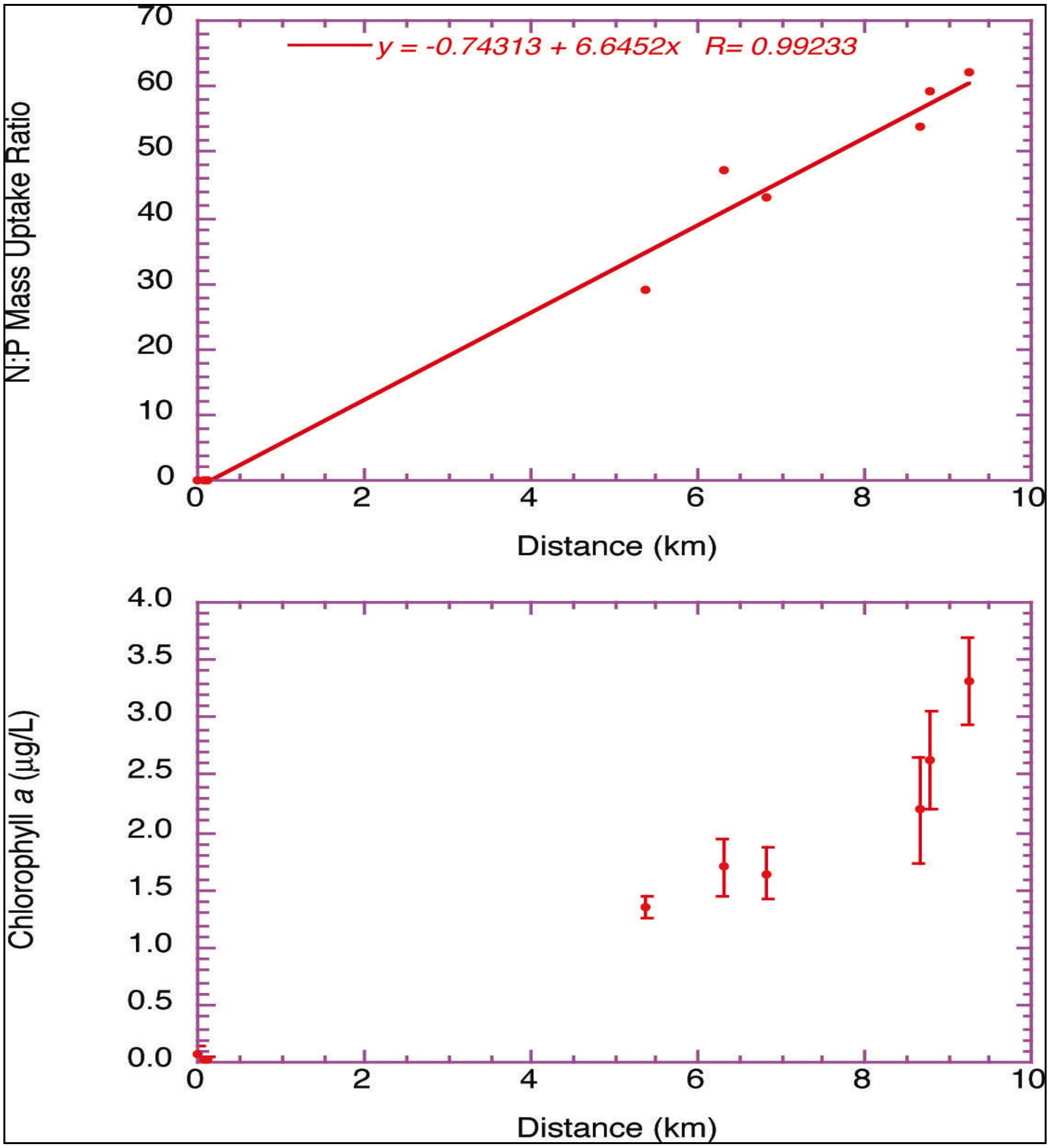


Figure E3. TN:TP mass uptake ratios and changes in algal (phytoplankton) chlorophyll a concentrations in Wakulla Springs and the Wakulla River as a function of distance downstream from the spring boil

(upper panel: TN:TP mass uptake ratios; lower panel: chlorophyll a concentrations)

Data are site averages from 1999 through the present. Error bars are standard error of the mean. Data are from LakeWatch and FDEP routine monitoring sites (J. Terrell, LakeWatch, personal communication.)

Appendix F: Phosphate in the Floridan Aquifer and Wakulla Springs

Summary: The goals of these analyses were to collect phosphate data on stormwater, groundwater, and springs in the Leon and Wakulla County areas and to search for regional and temporal trends as indications of the influence of the city of Tallahassee (COT) on phosphorus loading to Wakulla Springs. Analyses suggest that neither stormwater nor the Southeast Sprayfield (SESF) are a significant source of phosphorus to Wakulla Spring, but that Hawthorn Group sediments in the springshed control phosphate concentrations in groundwaters entering the spring via the kinetics of phosphate dissolution and desorption.

This data summary is based on data received from the COT (Jamie Shakar), Leon County (Melissa Hughes), the Northwest Florida Water Management District (NWFWMD; Tom Pratt), Florida Geological Survey (2004 Springs Report), and LakeWatch (Sean McGlynn).

For this data summary, OP stands for ortho-P. TP stands for unfiltered total P (presumably measured following persulfate/autoclave oxidation of unfiltered samples). All concentrations are expressed as milligrams of phosphorous per liter (mg-P/L = ppm-P).

Stormwater:

Leon County has begun measuring OP in stormwater running into Lakes Henrietta and Munson, and leaving Lake Munson. The concentrations reported for 2005 are all close to the detection limit of 0.014 ppm-P.

City of Tallahassee Drinking Water Well CW12:

CW12 is located NE of the intersection of Orange Avenue and South Monroe Street. The total depth of the well is 365 feet, and it is cased to 192 feet. OP concentrations for February 12, 2002 through august 1, 2005 ranged from 0.02 to 0.04 ppm-P with no significant time trend.

Name	Station_ID	Description	Latitude	Longitude	Original_ Sample_	Sample_ Time	Parameter	Method	Sampling _Type	Result	Original_ Units
LH1	LCLM3040384307	Lake Henrietta 1	30.40366	-84.30789	02/04/05	14:00	Orthophosphate	365.3	surface	0.014	mg/L
LH1	LCLM3040384307	Lake Henrietta 1	30.40366	-84.30789	05/01/05	12:30	Orthophosphate	365.3	surface	0.014	mg/L
LH2	LCLM3040184306	Lake Henrietta 2	30.40155	-84.30673	02/04/05	14:00	Orthophosphate	365.3	surface	0.014	mg/L
LH2	LCLM3040184306	Lake Henrietta 2	30.40155	-84.30673	05/01/05	12:50	Orthophosphate	365.3	surface	0.014	mg/L
LH3	LCLM3039584309	Lake Henrietta 3	30.39514	-84.30947	02/04/05	14:00	Orthophosphate	365.3	surface	0.014	mg/L
LH3	LCLM3039584309	Lake Henrietta 3	30.39514	-84.30947	05/01/05	18:50	Orthophosphate	365.3	surface	0.014	mg/L
LH4	LCLM3039084312	Lake Henrietta 4	30.39084	-84.31271	02/04/05	14:00	Orthophosphate	365.3	surface	0.014	mg/L
LH4	LCLM3039084312	Lake Henrietta 4	30.39084	-84.31271	05/01/05	19:50	Orthophosphate	365.3	surface	0.014	mg/L
LH4	LCLM3039084312	Lake Henrietta 4	30.39084	-84.31271	05/01/05	19:50	Orthophosphate	365.3	surface	0.014	mg/L
LM1	LCLM3037584313	Munson Slough 1 above Lake Munson	30.37522	-84.31391	01/31/05	14:45	Orthophosphate	365.3	surface	0.014	mg/L
LM1	LCLM3037584313	Munson Slough 1 above Lake Munson	30.37522	-84.31391	04/20/05	10:12	Orthophosphate	365.3	surface	0.014	mg/L
LM2	LCLM3036484301	Munson Slough 2 below dam	30.36396	-84.30181	01/31/05	15:20	Orthophosphate	365.3	surface	0.014	mg/L
LM2	LCLM3036484301	Munson Slough 2 below dam	30.36396	-84.30181	04/20/05	10:47	Orthophosphate	365.3	surface	0.014	mg/L
LM3	LCLM3034884301	Munson Slough 3 Gas Pipeline Road	30.34843	-84.30175	01/31/05	15:34	Orthophosphate	365.3	surface	0.014	mg/L
LM3	LCLM3034884301	Munson Slough 3 Gas Pipeline Road	30.34843	-84.30175	04/20/05	11:05	Orthophosphate	365.3	surface	0.014	mg/L
LM4	LCLM3034484302	Munson Slough 4 on forest rd 30031	30.34443	-84.30246	01/31/05	16:00	Orthophosphate	365.3	surface	0.026	mg/L
LM4	LCLM3034484302	Munson Slough 4 on forest rd 30031	30.34443	-84.30246	04/20/05	11:35	Orthophosphate	365.3	surface	0.014	mg/L

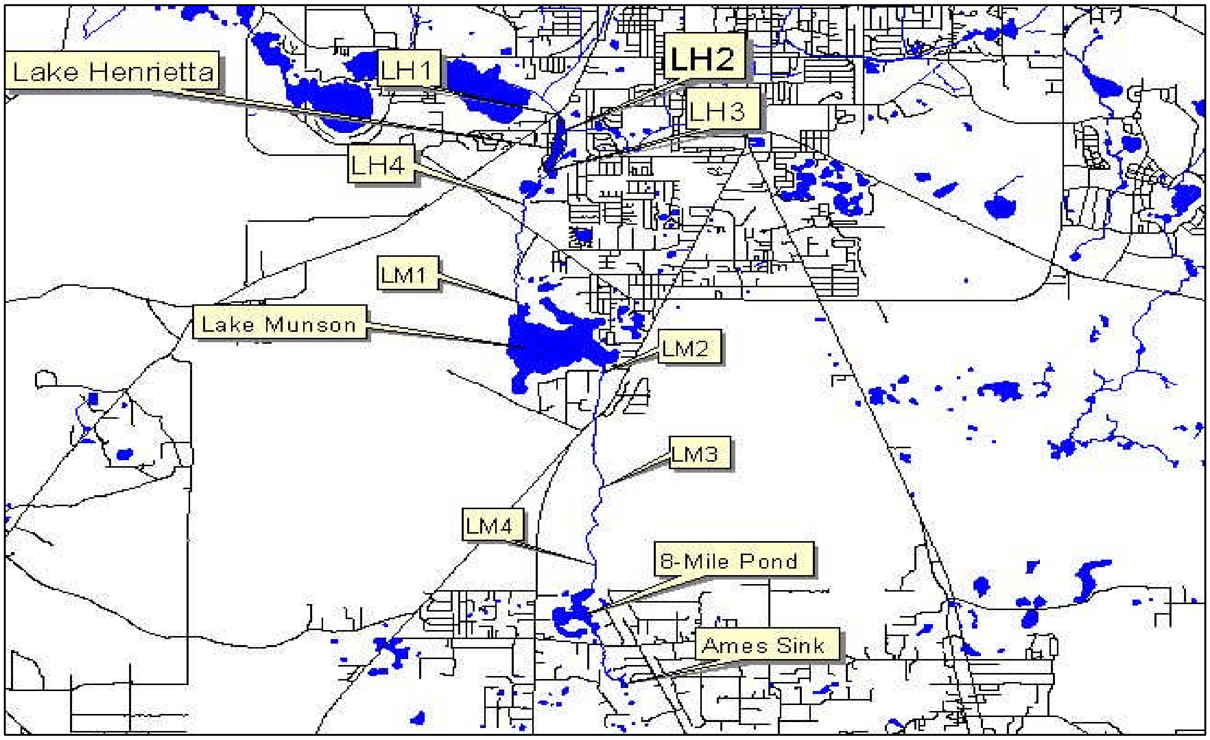


Figure F1. Sampling stations for the Leon County Lake Henrietta/Lake Munson stormwater monitoring program

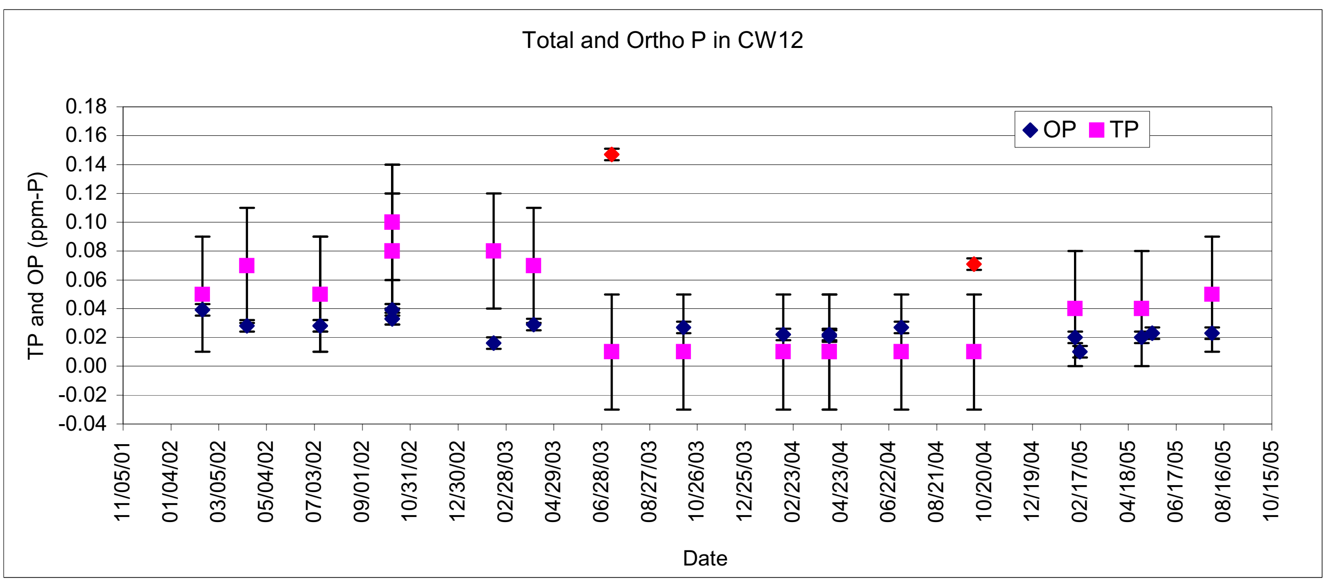


Figure F2. Total-P and ortho-P in the city of Tallahassee drinking water well CW12

Error bars for TP represent the Method Detection Limit (MDL) =0.04 ppm-P. Error bars for OP represent the MDL=0.004 ppm-P. Two OP data points were anomalously much higher than the corresponding TP data and are highlighted in red.

Florida Geological Survey Southeast Leon and Wakulla County Springs:

Natural Bridges Spring (0.03 ppm-P) and St. Marks River Rise (0.05 ppm-P) were sampled in 1972. Samples were taken in 2002 from Horn Spring (0.045 ppm-P), Natural Bridges Spring (0.046 ppm-P), Rhodes Spring (0.045 ppm-P), and St. Marks River Rise (0.041 ppm-P). These data are inadequate to demonstrate any time series, but provide an estimate for OP in this portion of the Floridan aquifer.

In Wakulla County, Wakulla Spring was sampled in 1972 and 2002, showing 0.03 ppm-P OP both times. Newport Spring (southeast of Wakulla Spring near the St. Marks River) was also sampled in 1972 (0.01 ppm-P TP) and again in 2002 (0.014 ppm-P OP). Once again, there is no obvious time trend, but the time series is not adequate to be conclusive.

NWFWMD Aquifer Data:

In 1999-2000, the NWFWMD measured 0.02 to 0.03 ppm-P OP in the Floridan aquifer north of the Cody Scarp. In 2004, the concentrations were 0.013 to 0.057 ppm-P OP. No samples were taken under the SESF (sprayfield) in 1999, but the value in 2004 was 0.013 ppm-P OP.

Northeast of Wakulla Spring, between the spring and the SESF, OP concentrations in 1999–2000 were 0.02 to 0.05 ppm-P. In 2004, the concentrations in this area were 0.004 to 0.029 ppm-P. In 2004, the wells around the spring showed 0.021 to 0.034 ppm-P OP.

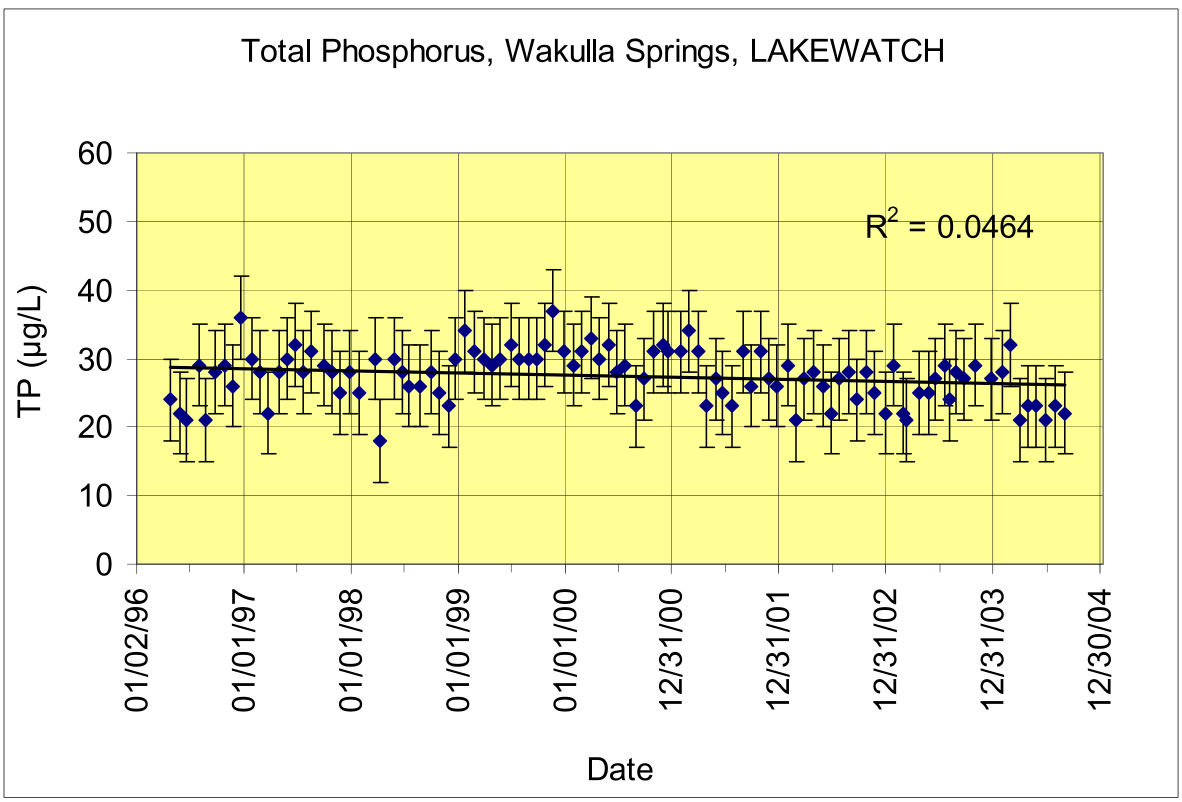


Figure F3. Total P data from the Wakulla Springs boil

The error bars represent the method detection limit = 6 ppb-P. The data are not significantly correlated with time.

LakeWatch Data:

TP concentrations at the Wakulla Spring boil from 1996–2004 range from 0.02 to 0.04 ppm-P and show a very slight, statistically insignificant, decrease with time. Because the samples are taken so soon after the water exits the cavern mouth, it is unlikely that a significant portion of the TP is present as particulate P (phytoplankton or detritus). Therefore, it is likely that the OP concentrations are very close to these TP concentrations, although they must in fact be less than or equal to the TP concentrations.

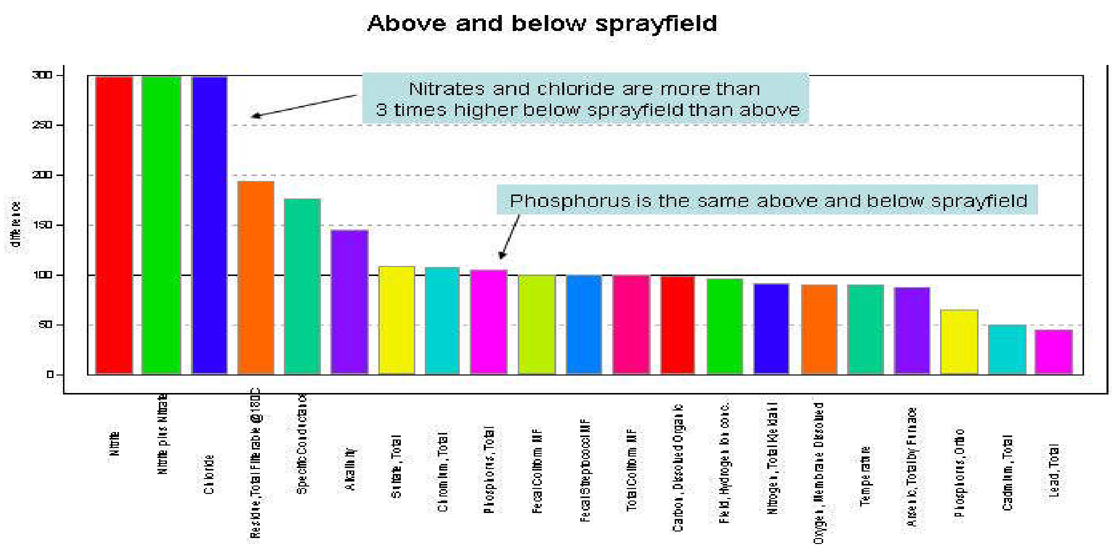
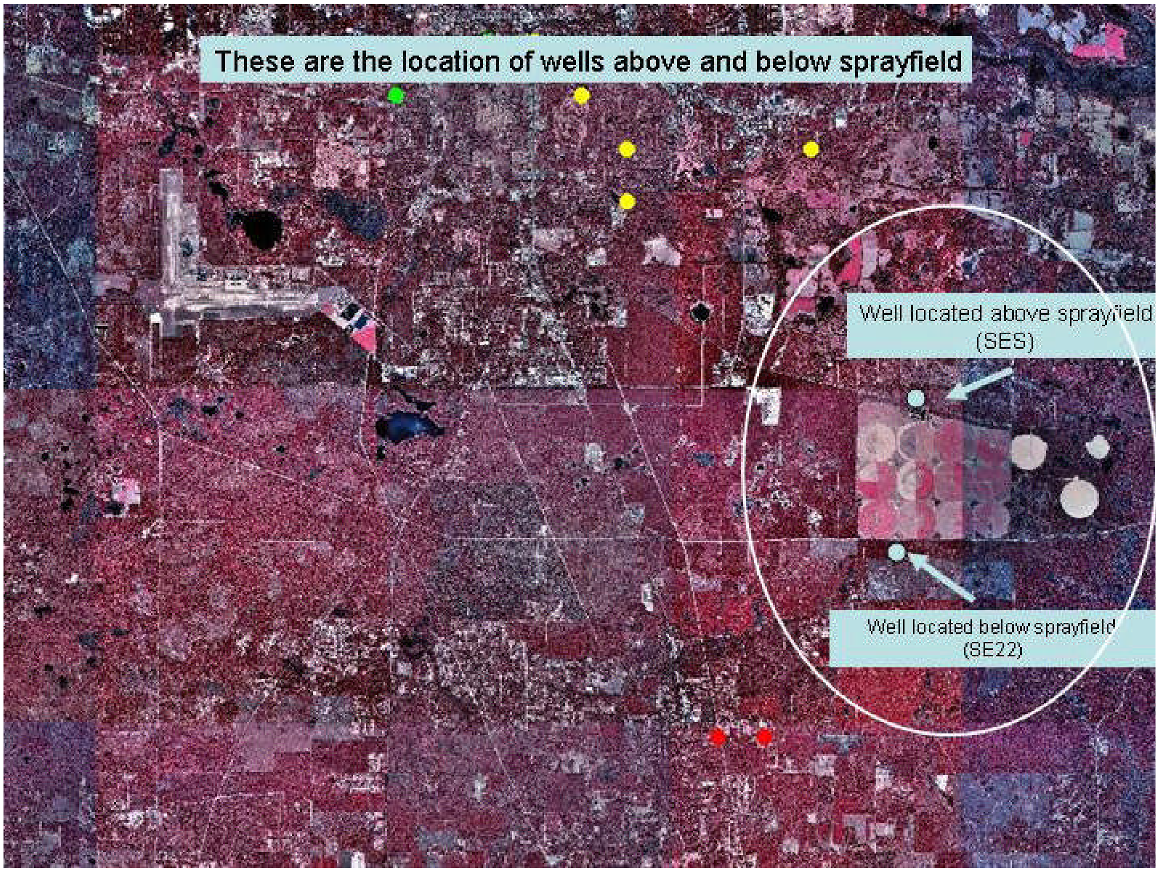
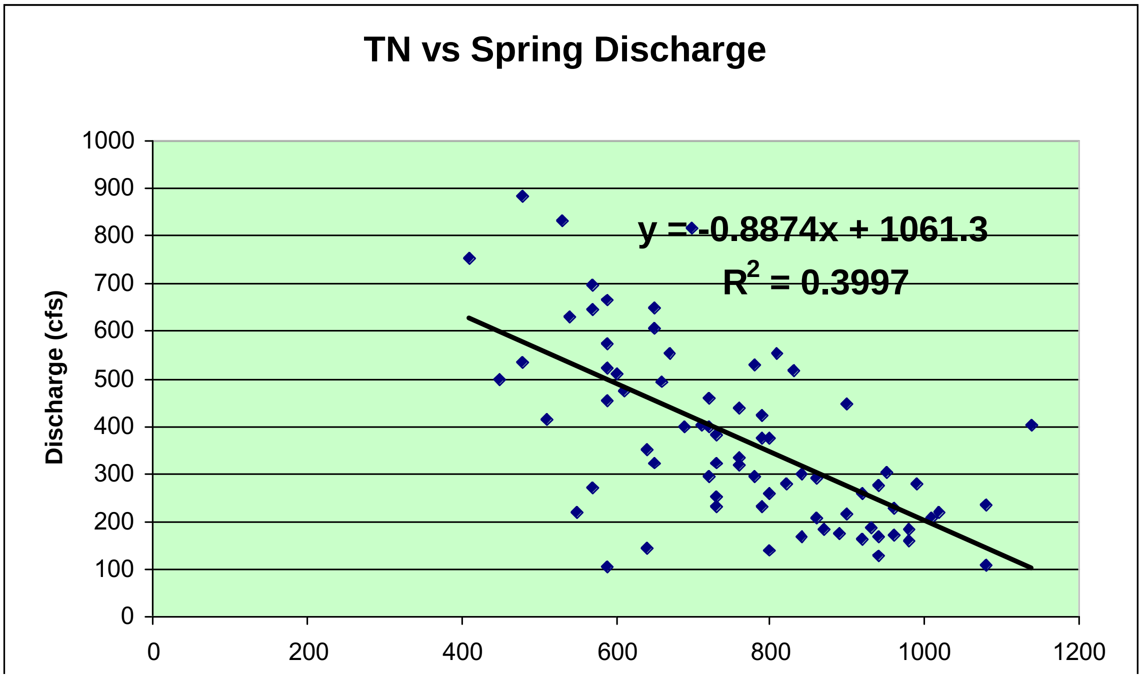


Figure F4. Nitrate concentrations north and south of the sprayfield

Nitrate concentrations south of the sprayfield are 300% of values north of the sprayfield, while total phosphorus concentration is unchanged north to south (J. Hand, FDEP). These data suggest that the sprayfield is not a source of total phosphorus to Wakulla Springs, and support the hypothesis that phosphorus concentration in groundwater in the springshed is controlled by the kinetics of dissolution or desorption with Hawthorn Group sediments.


These are the location of wells above and below sprayfield
Well located above sprayfield
(SES)
Well located below sprayfield
(SE22)



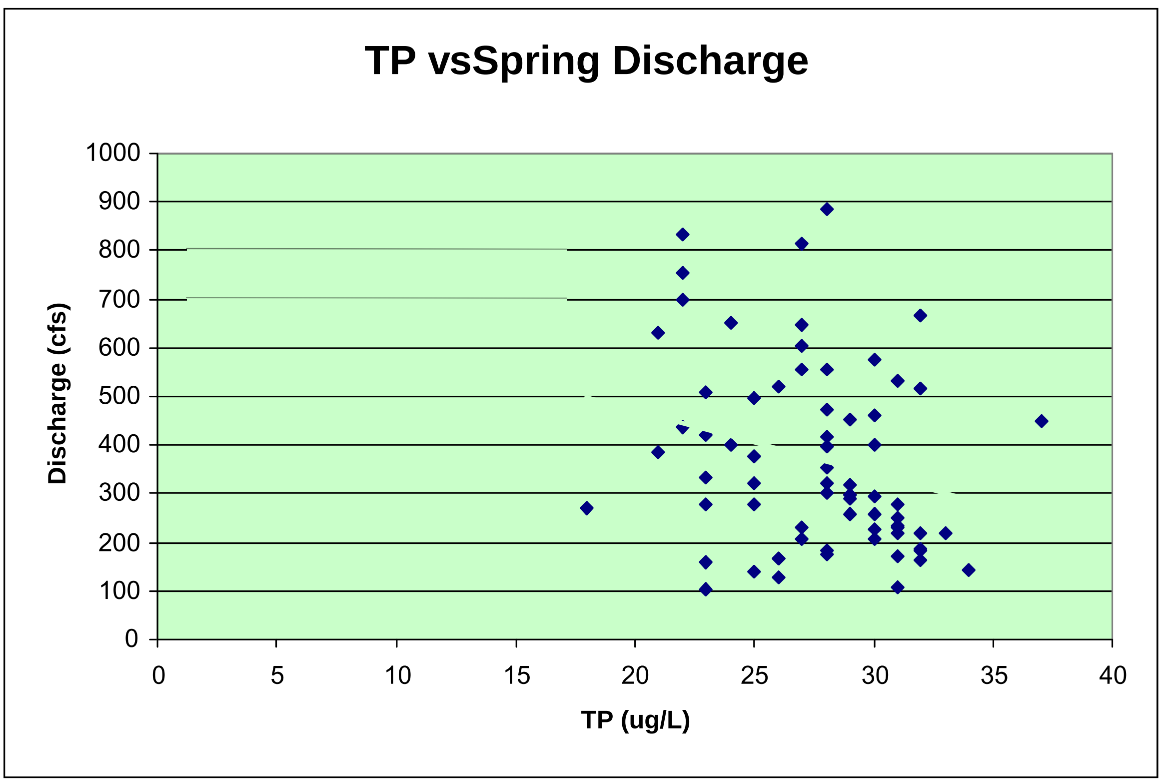


Figure F5: Relationship between total nitrogen and total phosphorus concentration and discharge at Wakulla Springs

at station 1 "Henry's Pole" 50 feet downstream from the Wakulla Spring boil

Data from Lakewatch (McGlynn Laboratories Inc., April 10, 2005, Revision 3. Woodville Recharge Basin Aquifer Protection Study. BC-07-19-02-29. Phase I and II Summary, p. 33.) TN shows an inverse relationship with discharge; suggesting rainwater dilution of an unvarying TN load to the watershed. TP showed no statistically significant relationship with discharge; suggesting that stormwater TP inputs, which should peak at times of high rainfall/high discharge, are not significant relative to other TP sources.

The TN vs. spring water discharge plot is a classic inverse relationship that occurs when the pollutant source is limited and becomes diluted with increased (rainfall-driven) flow. In contrast, the independence of concentration of TP from flow is indicative of a dissolution type source such as the Hawthorn Group (i.e., an essentially infinite phosphorus source over the time scales of interest and where the kinetics of dissolution or desorption reaching equilibrium is faster than the kinetics of increased flow.

Conclusions:

Conclusions from these data, and from literature regarding the behavior of OP in limestone aquifers, are as follows:

- *OP rapidly equilibrates/adsorbs in limestone aquifers. The equilibrium concentration is a function of the water chemistry (mainly the ionic strength) and the limestone matrix. High OP concentrations in low ionic strength "feed" water lead to adsorption yielding lower equilibrium concentrations. Low OP concentrations in higher ionic strength feed water can lead to de-sorption and a higher equilibrium OP concentration. These processes reach equilibrium within 10 to 50 days in the Key Largo Limestone (Dillon et al., 2003; Elliot, 1999). Thus, it appears that OP concentrations in the 0.01 to 0.04 ppm-P range (NWFWMD aquifer data) may represent the equilibrium concentration one expects from the interaction of stormwater and treated sewage water with the limestone aquifer. It may take decades or centuries to some day exhaust the adsorption capacity of the aquifer between the city of Tallahassee and Wakulla Springs. To avoid this, OP input should be minimized as much as possible.*
- *Aquifer samples taken on the southern edge of the SESF in 2004 (0.013 ppm-P) are lower than the concentrations in Wakulla Springs. This is less than or equal to OP concentrations in the aquifer in this region, suggesting that higher OP concentrations in the aquifer could be due to desorption of OP from the limestone matrix.*
- *OP in stormwater reaching Lake Munson, and leaving Lake Munson, is very close to the detection limit (0.014 ppm-P) and is lower than the OP concentrations in the aquifer and coming from the spring itself. Therefore, stormwater does not appear to be a significant source of OP to the spring.*

None of the available aquifer data shows any significant time trend, although the data set is too limited to conclude whether OP concentrations in the aquifer or Wakulla Springs have increased or decreased with time. The LakeWatch TP time series from Wakulla Spring (1996–2004) is by far the most extensive data set from the region. It shows no significant trend with time.

Appendix G. Specific Suggestions for Research on Nutrients and Biota

If additional confirmation is needed of the link between nitrate inputs to the springshed and excessive plant biomass in Wakulla Springs and River, further research could be conducted within the 12-to-18-month period over which other studies are being conducted on behalf of the city of Tallahassee and Leon County, to confirm the flow linkage between the Southeast Sprayfield and Wakulla Springs.

If doubts remain regarding whether nitrogen or phosphorus is more important as regards controlling nuisance plant growth in the Wakulla River (our conclusions support nitrogen control both from the limiting-nutrient standpoint and because we are better able to control nitrogen loading), we recommend that an *in situ* nutrient-dosing study be conducted in the Wakulla River. This could be conducted downstream of the spring boil in a reach that has been relatively un-impacted based on its primary producer (plant) community structure. Like studies conducted by Stevenson *et al*. (2004) in other Florida springs, this study should involve a controlled flume that provides quantitative control of nutrient fluxes, and should include two components: (1) controlled-addition studies to help define the thresholds of change for an extended period, and (2) continued studies on the same experimental sites with nutrient reductions to define whether the relationship between the primary producer community and ambient nutrient fluxes is the same, regardless of whether the system is becoming progressively eutrophic or is being remediated. This latter type of study is critical to ensuring that a new, essentially irreversible alternative stable state has not developed downstream from the spring boil that will be unresponsive to mitigative measures. For example, *Hydrilla* is said to grow well under low-nutrient conditions and, once present in a system, is almost impossible to eradicate.

Synoptic monitoring of changes in nutrient concentrations downstream of the Wakulla Springs boil, in concert with monitoring of the structure and density of the primary producer community, should also help define the threshold points where shifts occur in response to increasing nutrient concentrations. There is already in place monitoring of the spring boil concentrations (conducted by LakeWatch) and concentrations at a series of stations located downstream from approximately 5.4 through 9.2 km from the springhead. What is unknown at this point is the degree of vegetative monitoring at the downstream locations (if any). In addition, if the region of most rapid shift in the primary producer community lies less than 5.4 km from the springhead, then additional monitoring stations for both water chemistry and plant community structure need to be established.

The mass balance studies should have two fundamental components — the measurement of loads and source attribution. Load measurements involve quantifying both the flux of water and concentrations of the contaminant associated with the flux. Perhaps even more difficult for the Wakulla Springs problem is quantifying the contribution from a possible source to the measured fluxes in Wakulla Springs. Tracer studies (both those planned and those already conducted) are critical in helping to define these relationships. What is critically lacking in the current studies is any assessment of error in source contributions. Errors inherent in our understanding of source contributions and also in our understanding of the critical endpoint (i.e., primary producer community structure) cause-and-effect relationship need to be quantitatively analyzed to assess the likelihood of the degree of success and cost benefit of a given management option. Given the appropriate error measurements, a Monte-Carlo-type analysis would be quite useful in defining the probability of success.

The planned USGS study on sampling for pharmaceuticals at locations down gradient of the SESF will help indicate the direction of groundwater flow from the sprayfield.

Appendix H. Speculation on the Origin of Dark Water

contributed by Jim Stevenson

Occasional dark water flowing from Wakulla Springs is a natural phenomenon. In the 1890's, Henry Beadel wrote that heavy rain reduced water clarity. During the 1940's, the manager of the Wakulla Spring Lodge occasionally wrote to Ed Ball commenting on the periodic dark water days that kept the glass-bottom boats from operating. However, we don't know the frequency with which this condition occurred.

The lands west of the Woodville Karst Plain are drained by Lost, Black and Jump Creeks. These creeks flow into sinks that are connected to the cave system conducting water to Wakulla Spring. The watershed of these creeks was burned frequently by lightning and human-caused fires for centuries, thereby substantially reducing leaf litter and underbrush. The natural landscape was an open forest of widely spaced longleaf pines and the ground was carpeted with native grasses and wildflowers. During the dry season, fires burned into creek bottoms eliminating organic debris.

During the 1920's, the forest was logged and the land was burned annually to replenish the grasses for open-range livestock grazing. Logging, burning and grazing substantially reduced the amount of vegetation that could contribute tannin to the creeks and sinks.

After the establishment of the Apalachicola National Forest in 1936, all fires were suppressed and the land was replanted in pine trees. With the absence of fire, the density of pine trees and underbrush increased as did titi and other hardwood trees along the creeks and bordering wetlands. Livestock grazing was eventually phased-out in the 1970's and prescribed burning was resumed at intervals of three or more years. The pine trees have steadily increased in size producing more needles which add to the mass of leaf litter.

Therefore, during the last 50 years, the management of this watershed has resulted in a substantial increase in vegetation and leaf litter compared with the condition during the 1920s and 1930s. During periods of rain, the leaf litter releases tannin to surface waters resulting in an increase of dark-water days at Wakulla Springs.

Water clarity is exacerbated by turbid stormwater flowing from Tallahassee through Munson Slough into Ames Sink.

Appendix I: Ongoing Programs, City of Tallahassee Water Utility

Master Wastewater Treatment Plan:

The project entails the development of a 20-year master plan for the treatment and disposal of the city's wastewater. The plan will consider needed treatment/ disposal capacities to meet the 20-year growth; advanced treatment processes for nutrient removal; alternative disposal methods, particularly public access reuse; and potential locations for the new treatment/ disposal facility. The project will look at the feasibility to upgrade the Lake Bradford Road Treatment Plant (LBRTP), which has a capacity of 4.5 million gallons per day to a reclaimed water treatment plant that can produce public access reuse water for primary irrigation and cooling needs. Due to its location, the LBRTP could provide reuse water the downtown area, Florida State University, including the National High Magnetic Laboratory and Seminole Golf course, and the Florida A&M University. Converting the LBRTP to a reclaimed water treatment plant would reduce the treated wastewater disposed at the Southeast Farm Facility and thus mitigating any possible impact on the Floridan Aquifer and Wakulla Springs. Also, the reuse plant would correspondingly reduce the amount of water pumped from the Floridan Aquifer, thus preserving that amount for future drinking water needs.

Phase I of the Master Treatment Plan was completed in May 2005 and entailed a comprehensive review of the operations and facilities at the T.P. Smith Water Reclamation Facility (TPS Plant). The resulting report recommended a 5-year Capital Improvement Plan to upgrade the existing facilities and processes to improve reliability and treatment quality. The treatment improvements would upgrade the secondary treatment process to remove approximately 30% more nitrate-nitrogen and provide additional treatment capacity of 1.5 million gallons per day. The estimated cost for the TPS Plant improvements is $74 million that is subject to City Commission approval.

Reuse Facility:

The Tram Road Reuse Facility (TRRF) is designed with a capacity of 1.2 million gallons per day to provide Part III Public Access Reuse water for irrigation to nearby users including the Southwood golf course, State Office Complex, two high schools, and the Capital Circle Southeast Widening Project. The FDEP permit has been obtained, and the project will be advertised for construction in early 2006. Future expansion of the reuse system may include the City's Hilaman golf course and landscaping for Blairstone Road and the planned Orange Avenue extension. The total estimated cost for the reclaimed water treatment plant and the reuse distribution system is $2,500,000 - $3,000,000. The TRRF will withdraw a portion of the treated wastewater effluent being pumped to the Southeast Farm Facility (SEF) from the T.P. Smith Water Reclamation Facility, which is the city's major wastewater treatment plant. Every gallon of wastewater treated at the TRRF and reused as irrigation is one less gallon disposed at the farm. Moreover, a dual environmental benefit is realized as the wastewater reuse also results in avoided pumping from the Floridan Aquifer and thus preserving the aquifer for future drinking water needs.

Biosolids:

The end products of a wastewater treatment process are treated wastewater or effluent and treated biosolids. The biosolids from the treatment process had been land applied locally to City owned property. In March 2004, the Utility installed a heat drying system to upgrade biosolid quality from Class B to Class AA. The resulting product, which can be used as fertilizer and soil amendments, is sold through a broker to commercial nurseries and other agricultural outlets. By utilizing this advanced technology, the City has reduced land application of biosolids by 90 percent. With planned addition of a new dryer in the next 2 to 3 years, the utility will achieve a 100% (or total) reduction. This corresponds to a significant reduction in the amount of nitrogen that can seep into the ground and potentially impact the Floridan Aquifer and surface waters within the lower St. Marks-Wakulla Springs Watershed.

Nutrient Management Plan

The Utility is conducting an evaluation of the nutrient usage or a Nutrient Management Plan (NMP) at the Southeast Farm Facility with expected completion by January 2006. As part of the NMP various nitrogen and phosphorus sources will be evaluated with the goal of reducing overloading to the system without any detrimental effects to groundwater quality.

Fertilizer is used at the Southeast Farm Facility to ensure healthy plant growth and thereby ensure optimum plant uptake of nutrients. Healthy plants remove more nutrients than unhealthy plants. The fertilizer also maintains healthy plants throughout the year and prevents any surface water runoff, which would have an immediate detrimental effect on area lakes and streams.

Fertilizer usage has decrease by 68% since 2000 and for the last two years averages under 8% of the total nitrogen load at the irrigation pivots, indicating fertilizer usage is not a major contributor of nitrogen to the system at the Southeast Farm Facility.

USGS Study:

In response to concerns of water quality issues at Wakulla Springs and the Northwest Florida Water Management District's report indicating the SEF Facility is a large potential source of nitrogen in the contributing area, the City of Tallahassee Water Utility and the United States Geological Survey have combined efforts into a three-year study, which began in the summer of 2003, to investigate the path and evolution of reclaimed water as it moves from the SEF Facility.

Nitrate alone is a poor indicator of human activity due to the many sources of nitrogen in the natural environment. The study will analyze samples for many of the typical human wastewater chemical parameters including heavy metals, pesticides and herbicides. Two biological methods will help to 'fingerprint" and assist in determining specific contribution groundwater from the SEF Facility. he process should be able to differentiate the contributing nutrient sources; fertilizer, treated wastewater and livestock operations. Effects from the cattle operation versus human contribution should be further determined.

The joint study will also model the groundwater flow leaving the SEF Facility. Although previous reports indicate groundwater flow in a southwesterly direction, monitoring wells at the far southwest corner of the Facility, SE16 & 17, have shown no increase in nitrogen levels both total and nitrate, over the life of the Facility. These wells by their location should indicate varying trends in groundwater quality. The USGS/City joint study will help to answer additional aspects of groundwater flow.