FLORIDA DEPARTMENT OF ENVIRONMENTAL PROTECTION

Division of Environmental Assessment and Restoration, Bureau of Watershed Restoration

NORTHWEST DISTRICT • OCHLOCKONEE–ST. MARKS BASIN

Final

Nutrient (Biology) TMDL for the Upper Wakulla River (WBID 1006)

Douglas Gilbert

Watershed Evaluation and TMDL Section

March 22, 2012

Acknowledgments

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Websites

Florida Department of Environmental Protection, Bureau of Watershed Restoration

TMDL Program

http://www.dep.state.fl.us/water/tmdl/index.htm

Identification of Impaired Surface Waters Rule

http://www.dep.state.fl.us/legal/Rules/shared/62-303/62-303.pdf

STORET Program

http://www.dep.state.fl.us/water/storet/index.htm

2010 Integrated Report

http://www.dep.state.fl.us/water/docs/2010_Integrated_Report.pdf

Criteria for Surface Water Quality Classifications

http://www.dep.state.fl.us/water/wqssp/classes.htm

Basin Status Report: Ochlocknee–St. Marks

http://www.dep.state.fl.us/water/basin411/stmarks/status.htm

Water Quality Assessment Report: Ochlocknee–St. Marks

http://www.dep.state.fl.us/water/basin411/stmarks/assessment.htm

U.S. Environmental Protection Agency

National STORET Program

http://www.epa.gov/storet/

Region 4: TMDLs in Florida

http://www.epa.gov/region4/water/tmdl/florida/

Chapter 1: INTRODUCTION

1.1 Purpose of Report

This report presents the Total Maximum Daily Load (TMDL) for nutrients for the Wakulla River watershed in the St. Marks Basin. The Upper Wakulla River was verified as impaired for biology and was included on the Verified List of impaired waters for the St. Marks Basin that was adopted by Secretarial Order in June 2008. The TMDL establishes the allowable level of nutrient loadings to the Upper Wakulla River that would restore the waterbody so that it meets its applicable water quality impairment threshold for biology.

1.2 Identification of Waterbody

The Wakulla River watershed is located within portions of southern Georgia and Leon and Wakulla Counties, Florida. The complete watershed (including the Wakulla Spring springshed) encompasses an area of about 1,165 square miles (mi^2) (**Figures 1.1** and **1.2**).

Wakulla Spring, located within the Ocala Karst District of the Woodville Karst Plain, is the primary source of the Wakulla River. The spring is the discharge point of an extensive natural drainage system, including semiconfined areas in southwestern Georgia; the Tallahassee Red Hills portion of the Tifton Uplands district, where the Floridan aquifer is sandwiched between layers of impermeable or semi-impermeable materials such as clay that impede the movement of water into and out of the aquifer; and most of the unconfined areas of Wakulla County where the Floridan aquifer is at or near the land surface (**Figure 1.3**). As depicted in **Figure 1.4**, the Floridan aquifer system within this area is composed of "a thick sequence of Eocene to Miocene carbonates including the Ocala Limestone, Suwannee Limestone, and St. Marks Limestone," lying within the Gulf Trough, "an erosional trough that is deeply cut in the Eocene and Oligocene sediments" (Loper and DeHan 2004).

Within the Wakulla River watershed, the Cody Scarp (**Figure 1.5**) generally separates the semiconfined and unconfined areas. The Cody Scarp marks the northern limit of the Pleistocene sea level. During this period, the interaction between the sea and land resulted in the removal of the Miocene and Pliocene sediments, exposing the St. Marks Formation and Suwannee Limestone south of the Cody Scarp and giving rise to what is today called the Woodville Karst Plain (Pratt 1996).

The Wakulla River is about 9 miles long (Chelette *et al.* 2002), starting near Camp Indian Springs and joining the St. Marks River near Fort San Marcos. Major centers of population within the St. Marks Basin include Tallahassee, Woodville, Crawfordville, and St. Marks. As reported by Kincaid (2010), the efforts of numerous underwater cave explorers and scientists have identified a complex system of ground water conduits that interconnect many of the sinking streams in the watershed, as well as the City of Tallahassee (COT) Southeast Spray Field (SESF) to Wakulla Spring and River (**Figures 1.5** and **1.6**). These conduits range in size from 10 to 80 meters in diameter and up to 20 kilometers long, with ground water velocities of 800 to 6,000 meters/day (Kincaid 2010).

Generally, the Floridan aquifer flows in a southerly direction under the watershed to outflow from Wakulla Spring, Spring Creek Springs, the Lower St. Marks River, and the Gulf of Mexico

(Berndt 1990; Chelette *et al.* 2002). These authors found that ground water flow is increased by contributions from local rainfall and sinking streams. Data from potentiometric maps indicate that the steepest hydraulic gradient is just below the Cody Scarp and slowly declines towards the Gulf of Mexico. Both Berndt and Chelette *et al.* report that Wakulla Spring sits in the center of a zone of high hydraulic conductivity with lowered potentiometric surface that "perturbs the general north to south flow regime and funnels water to Wakulla Spring from the northwest, north, and northeast." They report that because of the high hydraulic conductivity, small increases in the local hydraulic head resulting from short-term, intensive rainfall events should result in a significant increase in spring discharge.

The Wakulla River from Wakulla Spring downstream is tidally affected. The potential for saltwater intrusion into the ground water system exists, as the Floridan aquifer is directly connected to the Gulf of Mexico (Pratt 1996). Additional information about the river's hydrology and geology are available in the Basin Status Report for Ochlockonee–St. Marks (Department 2001a).

For assessment purposes, the Department has divided the larger Ochlockonee–St. Marks Basin into numerous water assessment polygons with a unique waterbody identification (WBID) number for each watershed or stream reach. This TMDL addresses the biological impairment in the Upper Wakulla River (WBID 1006) (**Figure 1.2**).

1.3 Background

This report was developed as part of the Department's watershed management approach for restoring and protecting state waters and addressing TMDL Program requirements. The watershed approach, which is implemented using a cyclical management process that rotates through the state's 52 river basins over a 5-year cycle, provides a framework for implementing the TMDL Program–related requirements of the 1972 federal Clean Water Act and the 1999 Florida Watershed Restoration Act (FWRA) (Chapter 99-223, Laws of Florida).

A TMDL represents the maximum amount of a given pollutant that a waterbody can assimilate and still meet water quality standards, including its applicable water quality criteria and its designated uses. TMDLs are developed for waterbodies that are verified as not meeting their water quality standards. They provide important water quality restoration goals that will guide restoration activities.

This TMDL Report will be followed by the development and implementation of a Basin Management Action Plan, or BMAP, to reduce the amount of nutrients that caused the verified impairment of the Upper Wakulla River. These activities will depend heavily on the active participation of the NWFWMD, local governments, businesses, and other stakeholders. The Department will work with these organizations and individuals to undertake or continue reductions in the discharge of pollutants and achieve the established TMDLs for impaired waterbodies.

The problems of Wakulla Spring were brought to public attention at the *Wakulla Springs Woodville Karst Plain Symposium*, held on October 9, 1998 (Schmidt *et al.* 2000). The Department held quarterly public meetings on Florida springs, including Wakulla, to discuss data collection, stakeholder involvement, and future research. Another significant workshop, *Solving Water Pollution Problems in the Wakulla Springshed of North Florida*, was held on May

12 and 13, 2005. The meeting included the publication of a Peer Review Committee report (Loper *et al.* 2005) that summarized current research and mitigation strategies for reducing nutrient loading.

Additionally, in the 2009 update to the NWFWMD Surface Water Improvement and Management (SWIM) Plan for the St. Marks and Wakulla Rivers, the district stated, "Wakulla Spring is on the high priority list for development of a minimum flow and level necessary to protect the ecology of the area." The updated SWIM Plan notes that currently the district "may elect to reserve the flows from the spring through formal adoption of a reservation. A reservation of all flows not already permitted through consumptive uses may be more protective than establishment of minimum flows, which may be too low to sustain or protect the system. . . In order to quantify or at least depict the extent that freshwater flow from Wakulla Springs and the St. Marks River supports downstream aquatic systems, a freshwater needs assessment is ongoing." See **Appendix A** for more information on the 2009 NWFWMD SWIM Plan initiatives.

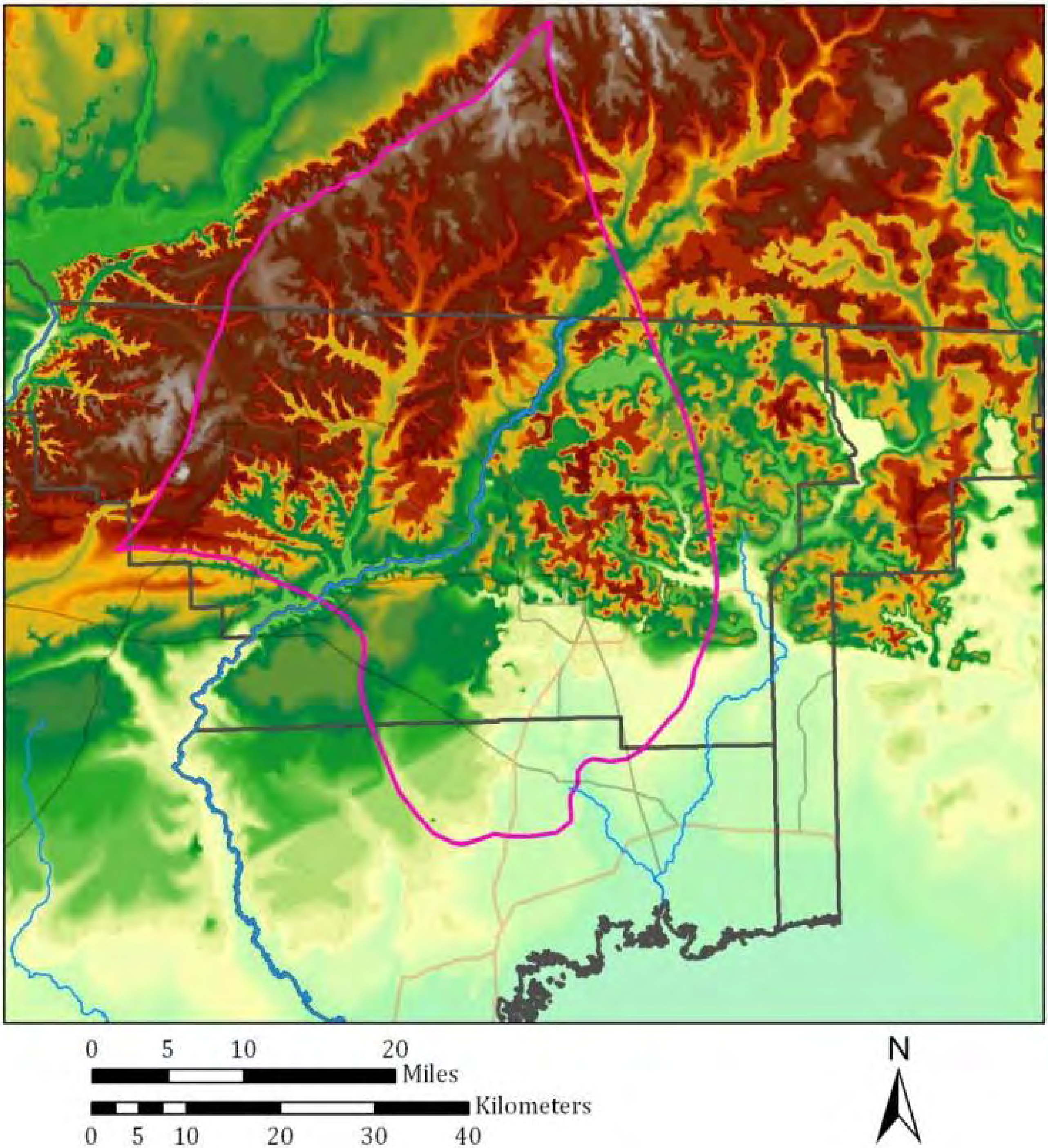

Figure 1.1. Wakulla Spring Springshed

Source: 2010 presentation at Wakulla Spring by Kris Barrios, Northwest Florida Water Management District (NWFWMD).

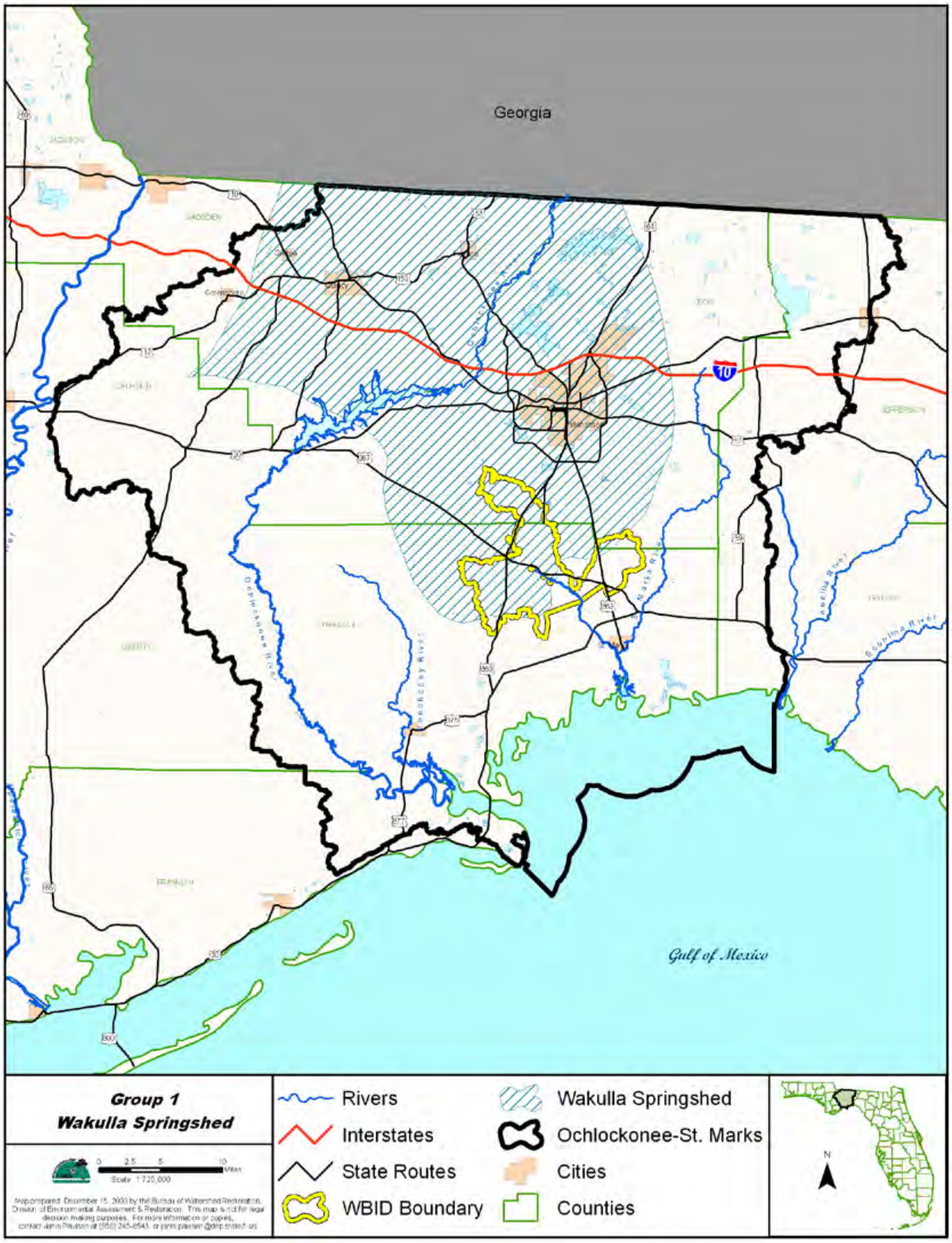

Figure 1.2. Major Hydrologic and Geopolitical Features (Counties), and Impaired WBID 1006 in the Ochlocknee–St. Marks Basin (Florida Portion)

Note: Florida Department of Transportation (FDOT) routes are for illustration purposes only and are not meant to depict roadways for which FDOT is responsible.

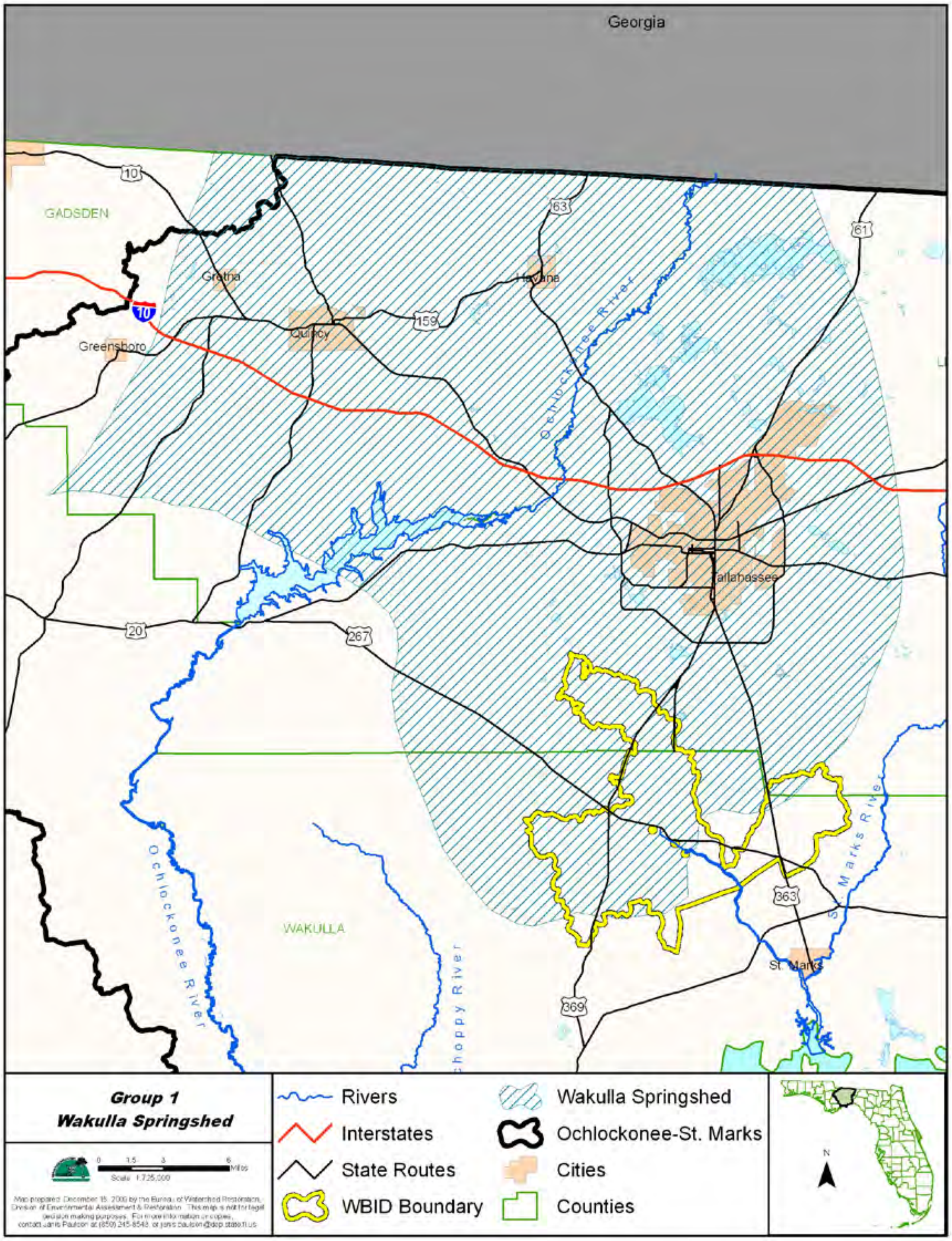

Figure 1.3. Wakulla River Watershed in Florida, Showing Major Hydrologic and Geopolitical Features and Impaired WBID 1006

Note: FDOT routes are for illustration purposes only and are not meant to depict roadways for which FDOT is responsible.

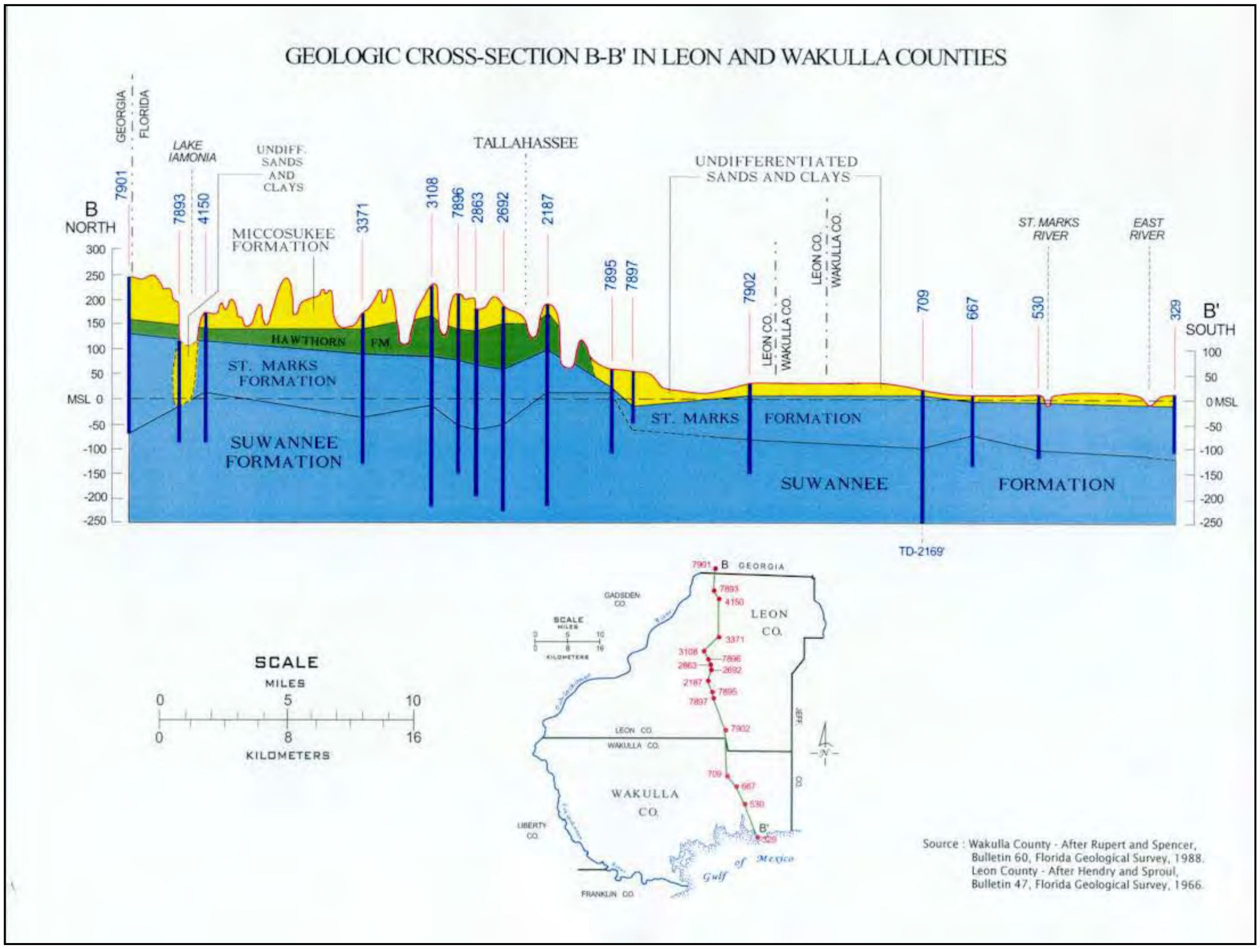

Figure 1.4. Generalized Geologic Cross-Section through the Wakulla River Watershed

Source: T. Scott, Florida Geological Survey (FGS) Hydrogeological Overview, Wakulla Springs Symposium, May 2004.

Figure 1.5. Cody Scarp and Confined Versus Unconfined Areas

Source: Todd Kincaid, Wakulla Karst Plain Project, Presentation at Wakulla Springs Symposium, May 2004.

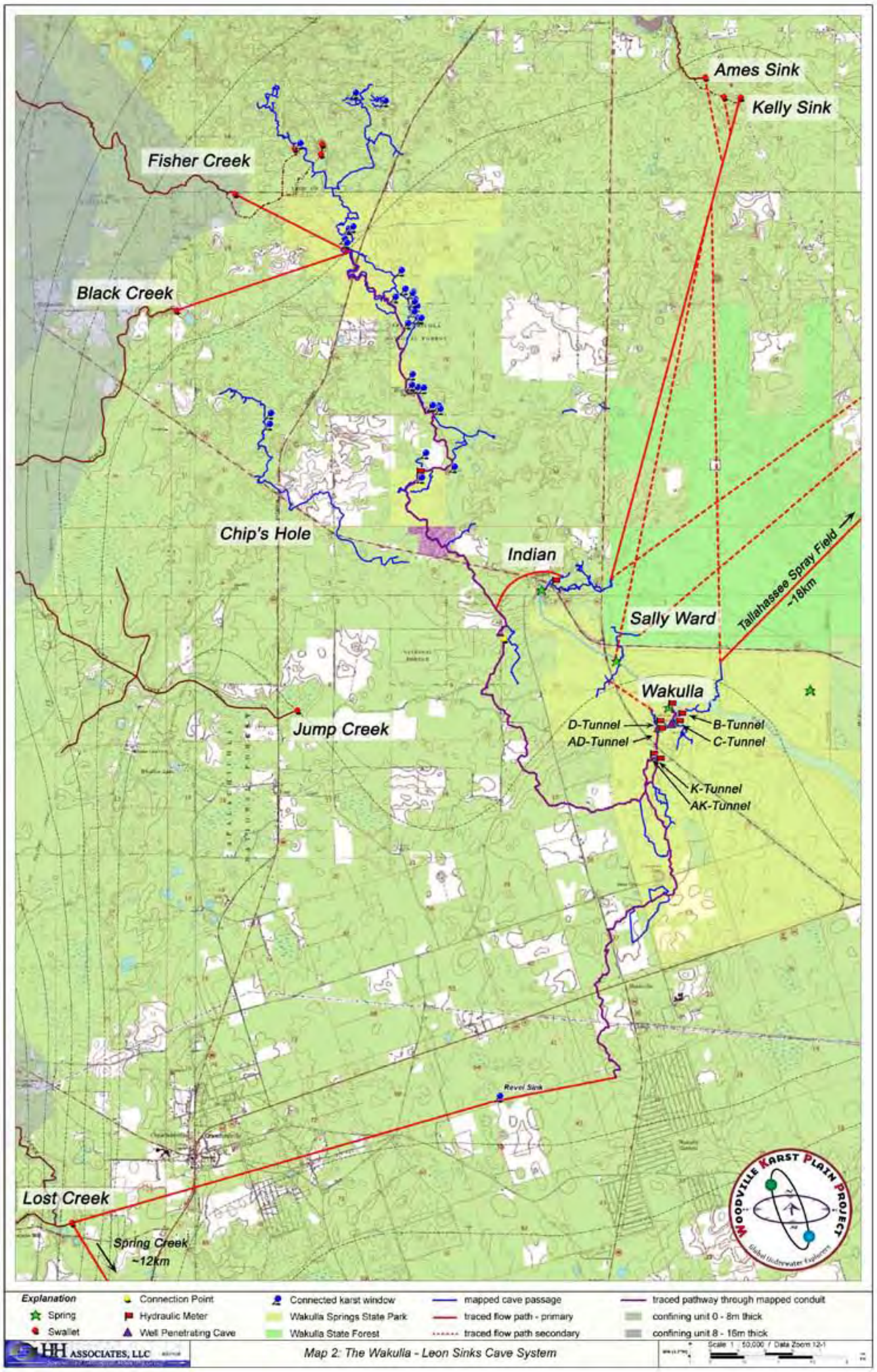

Figure 1.6. Wakulla Spring, Conduits and Sinking Streams

Source: T. Kincaid at http://www.h2hmodeling.com/.

Chapter 2: DESCRIPTION OF WATER QUALITY PROBLEM

2.1 Statutory Requirements and Rulemaking History

Section 303(d) of the federal Clean Water Act requires states to submit to the EPA a list of surface waters that do not meet applicable water quality standards (impaired waters) and establish a TMDL for each pollutant causing impairment of listed waters on a schedule. The Department has developed such lists, commonly referred to as 303(d) lists, since 1992. The list of impaired waters in each basin, referred to as the Verified List, is also required by the FWRA (Subsection 403.067[4], Florida Statutes [F.S.]), and the state's 303(d) list is amended annually to include basin updates.

Florida's 1998 303(d) list included 24 waterbodies in the Ochlocknee–St. Marks Basin. However, the FWRA (Section 403.067, F.S.) stated that all previous Florida 303(d) lists were for planning purposes only and directed the Department to develop, and adopt by rule, a new science-based methodology to identify impaired waters. After a long rulemaking process, the Environmental Regulation Commission adopted the new methodology as Chapter 62-303, Florida Administrative Code (F.A.C.) (Identification of Impaired Surface Waters Rule, or IWR), in April 2001. The IWR has since been modified in 2006 and 2007.

2.2 Information on Verified Impairment

The Department used the IWR (Run 38) to assess water quality impairments in the Wakulla River watershed and has verified the impairments listed in **Table 2.1** for the Upper Wakulla River. Based on the assessment results for dissolved oxygen (DO), the Upper Wakulla River did not meet the criterion for DO. However, no causative pollutant was linked to the low DO. As a result, the WBID was placed in Category 4d, which is for waterbodies not meeting criteria but where no causative pollutant has been identified. In these cases, under state law, no TMDL can be developed until a causative pollutant is linked to the impairment.

Table 2.2 provides the assessment results for the biology-based Stream Condition Index (SCI) survey for the verified period (January 1, 2000, through June 30, 2007) for the Upper Wakulla River. **Figure 2.1** depicts the locations of the SCI stations and Camp Indian Springs, Sally Ward Spring, and Wakulla Spring (as small yellow donuts) within the Upper Wakulla River. During the period from February 28, 2000, to June 8, 2004, the SCI scores were based on a 33-point scale, with scores of 21 and above indicating healthy conditions. The recalibration of the SCI scoring method in June 2004 resulted in a new scale maximum of 100, with scores of 35 and above indicating healthy conditions.

Over the period from February 28, 2000, to May 3, 2007 (quarterly water quality sampling), the SCI scores have indicated healthy conditions in only 7 of the past 27 sampling events in the Upper Wakulla River. The biological community represented by the paucity in the number of sensitive taxa was affected by the smothering of substrate by hydrilla, occasional low DO, and slightly elevated conductivity. These reports, based on data collected between 2000 and 2007, concluded that ammonia levels (mostly below detection) and phosphorus levels (averaging 0.03 milligrams per liter [mg/L]) generally represent excellent conditions, while nitrate concentrations are elevated from anthropogenic sources.

Table 2.1. Verified Impaired Segments in the Upper Wakulla River

WBID	Waterbody Segment	Parameters Assessed Using the IWR	Priority for TMDL Development	Projected Year of TMDL Development
1006	Upper Wakulla River	Biology	Medium	2008

Table 2.2. Summary of Biology Data from SCI Surveys for the Upper Wakulla River

Note: The method for scoring SCIs changed on June 6, 2004. Please refer to the Department's Standard Operating Procedure (SOP) FS7420.

Date	SCI Score	Panhandle East Evaluation
2/28/2000	19	Poor
5/22/2000	21	Good
8/22/2000	13	Very Poor
11/29/2000	19	Poor
2/27/2001	15	Poor
6/6/2001	15	Poor
9/18/2001	17	Poor
11/27/2001	15	Poor
4/4/2002	17	Poor
5/6/2002	21	Good
8/23/2002	17	Poor
10/7/2002	23	Good
1/16/2003	17	Poor
5/13/2003	27	Excellent
8/5/2003	9	Very Poor
10/8/2003	11	Very Poor
2/3/2004	25	Good
4/15/2004	21	Good
7/26/2004	25	Impaired
10/26/2004	18	Impaired
1/31/2005	19	Impaired
5/16/2005	31	Impaired
1/31/2006	36	Healthy
4/11/2006	20	Impaired
11/6/2006	14	Impaired
2/1/2007	28	Impaired
5/3/2007	33	Impaired

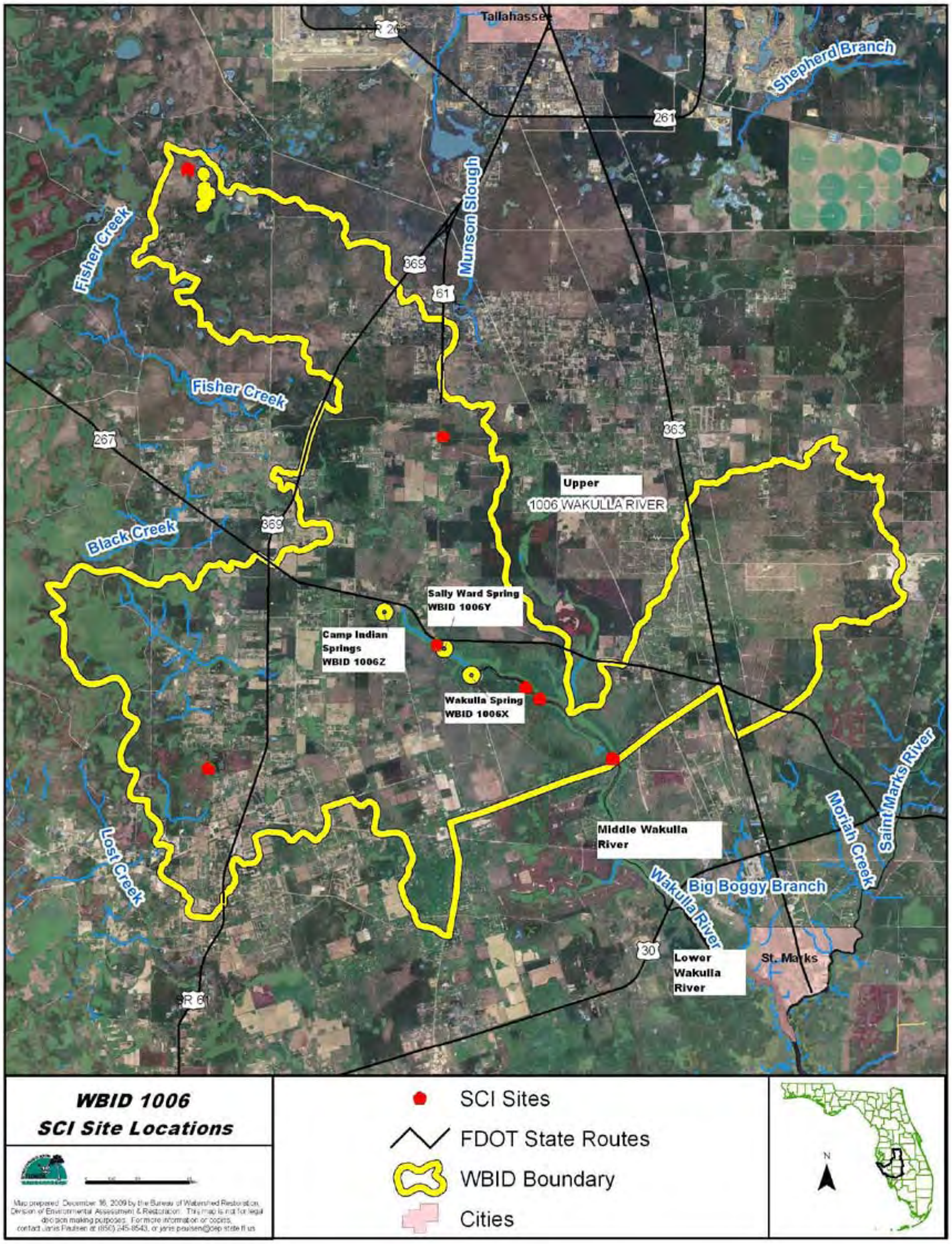

Figure 2.1. Location of SCI Stations and Camp Indian Springs, Sally Ward Spring, and Wakulla Spring in the Upper Wakulla Watershed

Note: FDOT routes are for illustration purposes only and are not meant to depict roadways for which FDOT is responsible.

Chapter 3. DESCRIPTION OF APPLICABLE WATER QUALITY STANDARDS AND TARGETS

3.1 Classification of the Waterbody and Criteria Applicable to the TMDL

Florida's surface waters are protected for five designated use classifications, as follows:

Class I	**Potable water supplies**
Class II	**Shellfish propagation or harvesting**
Class III	**Recreation, propagation, and maintenance of a healthy, well-balanced population of fish and wildlife**
Class IV	**Agricultural water supplies**
Class V	**Navigation, utility, and industrial use (there are no state waters currently in this class)**

The Upper Wakulla River (WBID 1006) is a Class III fresh waterbody (with a designated use of recreation, propagation and maintenance of a healthy, well-balanced population of fish and wildlife) extending from the headwaters (**Figure 2.1**) at Camp Indian Spring (WBID 1006Z), to Sally Ward Spring (WBID 1006Y), to Wakulla Spring (WBID 1006X), and then to what is referred to as the "Upper Bridge," or State Road (SR) 365. The Middle Wakulla River (WBID 1006W) is that portion between SR 365 to the "Lower Bridge," or U.S. Highway 98. The Lower Wakulla River (WBID 1006V) is that portion from U.S. Highway 98 to its mouth at the St. Marks River (WBID 793A) junction. The Class III freshwater quality criterion applicable to the impairment addressed by this TMDL is biology as affected by nutrients.

3.2 Applicable Water Quality Standards and Numeric Water Quality Targets

The problems outlined in this section are similar to those documented in the nutrient TMDLs for the Suwannee and Santa Fe Rivers (Magley and Hallas 2008) and the Wekiva River and Rock Springs Run (Gao 2007).

3.2.1 Biology

Florida does not have numeric criteria for biology or nutrients. The water quality criterion for nutrients states that "in no case shall nutrient concentrations of a body of water be altered so as to cause an imbalance in natural populations of aquatic flora or fauna." The linkage between the narrative criterion for nutrients and imbalances of flora or fauna are made through the implementation of the IWR (Chapter 62-303, F.A.C.).

Biological impairments are defined in Sections 62-303.330 and 62-303.430, F.A.C. Waters are verified as biologically impaired if there were two or more failed bioassessments within the five years preceding the Planning List assessment. A bioassessment for streams consists of either a BioReconnaisance (BioRecon) or SCI survey. These bioassessments were described in **Chapter 2**, and the results are listed in **Table 2.2**.

3.2.2 Nutrients

Numeric criteria for nutrients such as total nitrogen (TN) and total phosphorus (TP) are not explicitly stated in Chapter 62-302, F.A.C. However, the IWR (Section 62-303.351, F.A.C., Nutrients in Streams) states that "segments shall be included on the planning list for nutrients if their annual mean Chl a [chlorophyll *a*] for any year is greater than 20 [micrograms per liter] µg/l or if data indicate annual mean Chl a values have increased by more than 50% over historical values for at least two consecutive years." The IWR allows the use of additional information indicating an imbalance of flora or fauna due to nutrient enrichment, including algal blooms, changes in algal species richness, excessive macrophyte growth, a decrease in the areal coverage or density of seagrasses or other submerged aquatic vegetation, and excessive diel oxygen variation.

While routine water column sampling at the surface did not produce chlorophyll *a* exceeding the criteria listed above, benthic macroalgae mats were shown to be a significant problem (Stevenson *et al.* 2007). These mats cause a variety of ecological impairments, including, but not limited to, habitat smothering; nutrition and habitat for pathogenic bacteria; production of toxins that may affect biota; and reduced oxygen levels and increased diurnal swings of the DO regime in the stream. Macroalgae mats can produce human health problems, foul beaches and boat props, and reduce the aesthetic value of clear springs or stream runs. Ongoing research for many Florida springs, including Wakulla Spring, has made significant progress in relating the threshold concentrations of nitrogen or phosphorus that cause nuisance macroalgae growth (Stevenson *et al.* 2007). Macroalgae may sequester ground water sources of nutrients or sediment nutrients that are not measured with surface water sampling.

In the case of the Upper Wakulla River, TP concentrations average ~0.03 mg/L (within the range of natural background for ground water), and this level is well below the 0.065 to 0.09 mg/L concentration range shown to contribute to biological impairments (Magley and Hallas 2008; Gao 2007). As total ammonia is below detection the majority of the time, the nutrient linked to the biological impairments in the Upper Wakulla River is nitrate nitrogen.

3.2.3 Outstanding Florida Water

The Outstanding Florida Waters (OFW) criterion in Section 62-302.700, F.A.C., requires no degradation of water quality for Special Waters, which include Wakulla Springs State Park and the Upper Wakulla River. The OFW rule language states that the last day of the baseline year for determining the degradation compared with ambient quality is March 1, 1979.

3.2.4 Hydrilla and Algal Mats

The invasive plant hydrilla was first found in Wakulla Spring in April 1997 (Loper 2005). Despite extensive harvesting and the use of herbicides since 1998, this plant has thrived in the Upper and Middle Wakulla River. The nutrient TMDL proposed in this document addresses excessive algal mat formation (**Figure 3.1**) and is not specifically designed to eliminate hydrilla (**Figure 3.2**), but is expected to reduced hydrilla's competitive advantage over more desirable aquatic plants.

Health Aquatic Plant Index (HAPI) surveys of the Wakulla River were conducted on 4 dates in May and June 2001 (Hand 2001, personal communication). Using kayaks and global positioning system (GPS) locations, visual surveys of the percentage of various aquatic plants and apple snail egg clutches were performed for 171 sites from Wakulla Spring to U.S. Highway 98. The survey compiled data for the percent coverage of "good" aquatic plants (eelgrass, coontail, chara [muskgrass], and southern naiad), percent "fair" plants (elodea, egeria), and percent "poor" plants (hydrilla, algal mats), as depicted in **Figures 3.1** and **3.2**.

The results indicate that the "poor" plants, such as hydrilla, dominate the Wakulla River from 0.0 to 0.9 miles, as well as from 4.7 to 5.9 miles, below the main spring. The Wakulla River upstream of the main spring, including Sally Ward Spring, also has a large percentage of hydrilla. Snail egg clutches were more abundant from 0.9 to 3.5 miles below Wakulla Spring, with none found below the power line located about 5 miles below Wakulla Spring. Water quality data (**Table 3.1**) collected during the 2001 survey indicated that nitrate concentrations (0.97 mg/L) were highest at the spring boil, as was the hydrilla density. Algal mats were significant in that part of the Upper Wakulla River (**Figure 3.1; Table 3.1**), where nitrate concentrations ranged between 0.97 and 0.51 mg/L. At the southern boundary of the Upper Wakulla River, the nitrate concentration was 0.24 mg/L (no algal mats present) and continued to decline through the Middle Wakulla River to 0.11 mg/L (no algal mats present).

Another HAPI survey was conducted on May 12, 2003, to determine the effects of herbicide treatment in 2001 (Hand 2007a). Hydrilla coverage of the Middle Wakulla River declined from 50% (May 2001) to 9% (May 2003), while eelgrass went from 50% coverage to 30%.

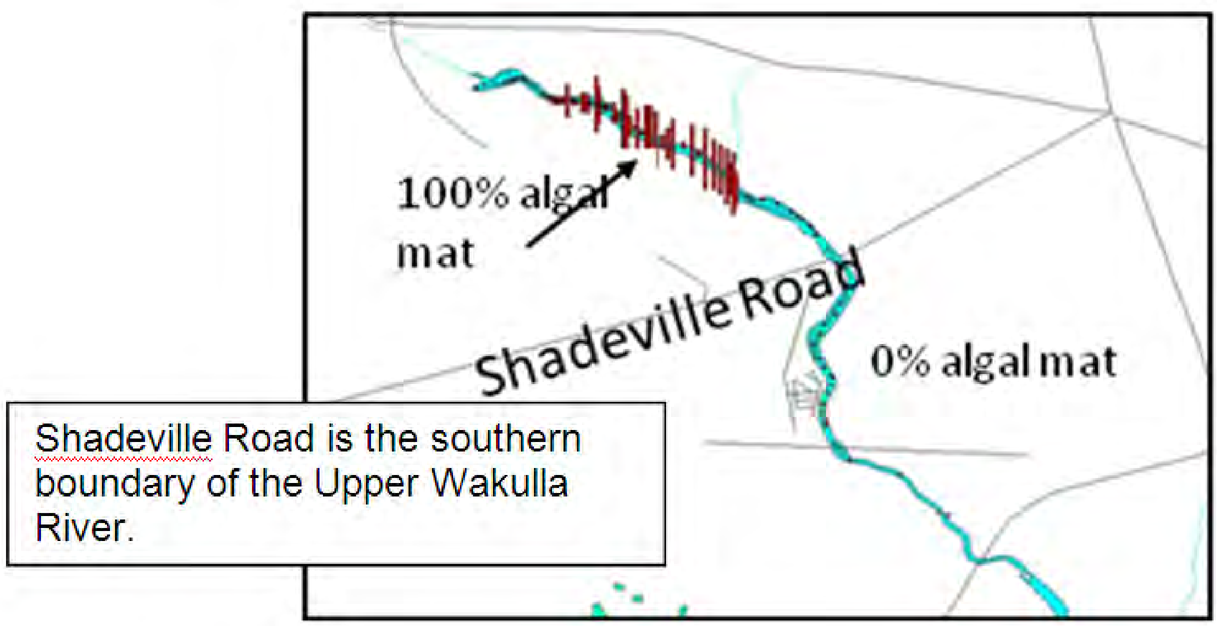

Figure 3.1. HAPI Survey Results (2001) Showing Algal Mat Distribution in the Upper Wakulla River

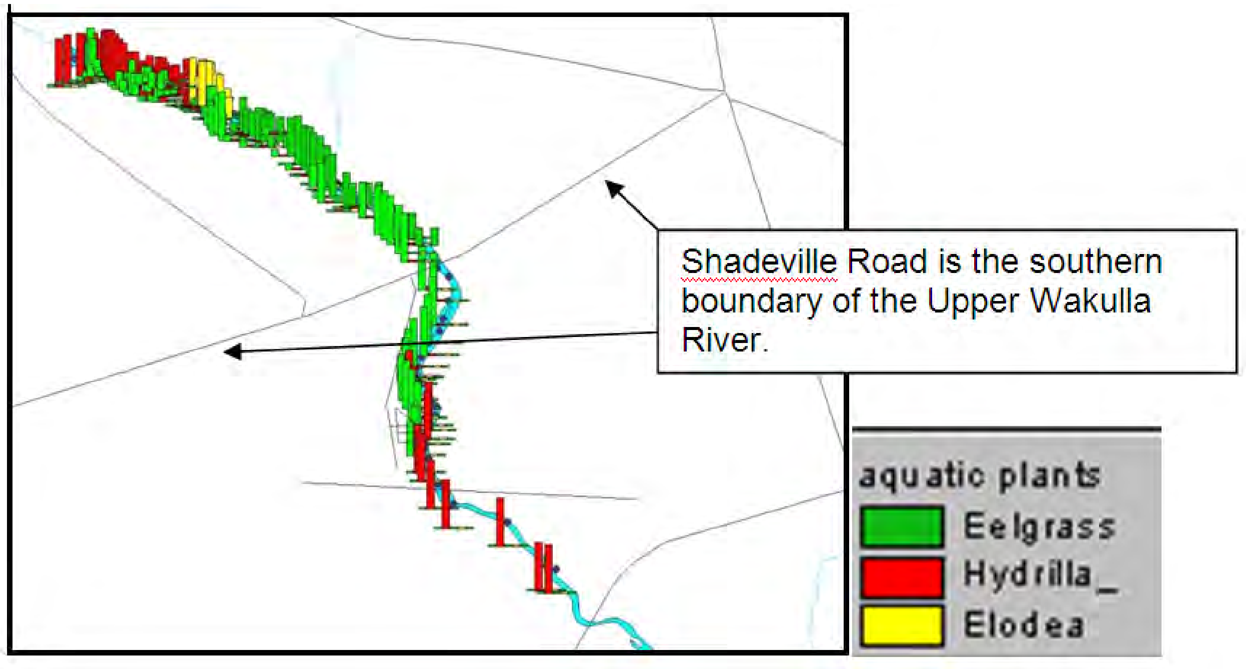

Figure 3.2. HAPI Survey Results (2001) Showing Macrophyte Distribution in the Upper and Middle Wakulla River

Table 3.1. HAPI Survey Results (2001)

NO_3 = Nitrate; TKN = Total Kjeldahl nitrogen

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

3.2.5 Water Color

Wakulla Spring and River have also experienced recurring episodes of highly colored water discharged from the spring vents that have reduced the number of days per year glass-bottom tour boats can operate at Wakulla Springs State Park. These "dark days" are defined as water visibility less than 75 feet. Since patrons of the park expect to see the spring bottom (at 125 feet), the lack of transparency reduces the spring's recreational potential. The number of dark days has been compiled daily from 1987 to1998 and did not meet the 75-foot visibility criterion 58% of the time. At the 2004 Wakulla Springs Symposium, it was reported that annual park attendance ranges from 180,000 to 200,000 people per year. The estimated total spending and wages for Fiscal Year (FY) 2001–02 related to Wakulla Springs State Park was $26.5 million.

3.2.6 Other Ecological Issues

Other ecological problems documented for the Wakulla River include the potential loss of limpkins and one of their major food sources (apple snails) (Peer Report 2005).

3.3 Monitoring Results

Figure 3.3 depicts the routine ambient water quality sampling locations in the Wakulla River watershed, and **Table 3.2** lists the organizations that have been involved in collecting data.

Flow data, as well as the data for color, specific conductance, TP, TN, ammonia, organic nitrogen, combined nitrate+nitrite (referred to as nitrate), and chlorophyll *a* from Wakulla Spring (WBID 1006X) and the Upper Wakulla River (WBID 1006), are presented below as graphs and summarized in tables (IWR Run 38) found at the end of this section. Thirty-year rainfall and temperature data from the nearest weather station are also provided.

In this report, nitrate is NO_3 as nitrogen (NO_3N) and for the purposes of this report, unless otherwise stated, the sum of NO_3 and nitrite (NO_2) is used to represent NO_3 due to minimal contributions of NO_2. **Chapter 5** discusses the nitrate (NO_3) nutrient impairment and the setting of the target concentration of NO_3.

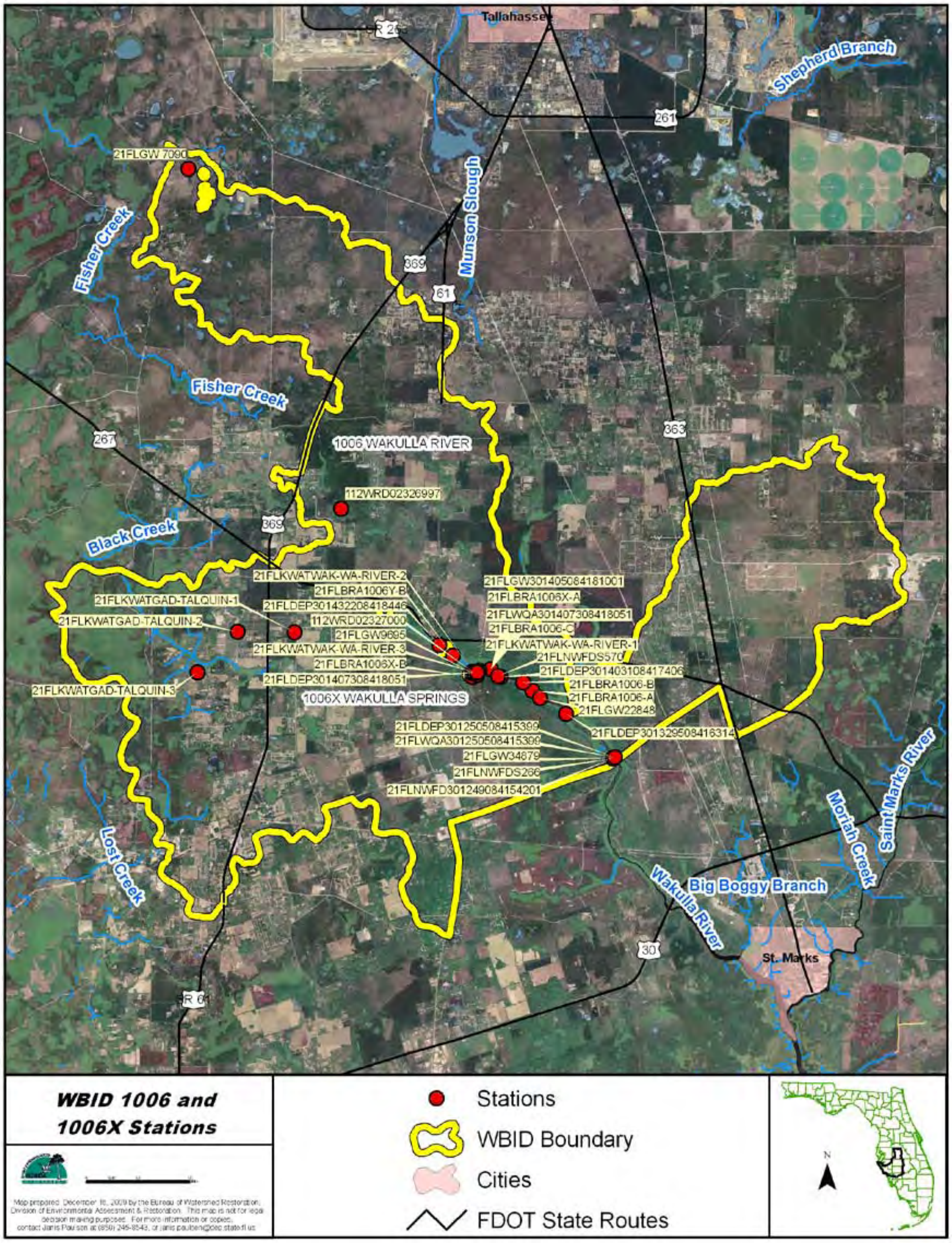

Figure 3.3. Monitoring Sites in the Wakulla River Watershed

Note: FDOT routes are for illustration purposes only and are not meant to depict roadways for which FDOT is responsible.

Table 3.2. Organizations Sampling in the St. Marks Basin

Organization
Biological Research Associates
City of Tallahassee
Florida Department of Agriculture and Consumer Services
Florida Department of Environmental Protection
Florida Department of Environmental Protection, Ambient Monitoring
Florida Department of Environmental Protection, Northwest District
Florida Department of Environmental Protection, Watershed Assessment
Florida Department of Health
Florida Fish and Wildlife Conservation Commission
Florida Marine Research Institute
LAKEWATCH
Leon County
McGlynn Laboratories, Inc.
Northwest Florida Water Management District
U.S. Environmental Protection Agency, Environmental Research Laboratory, Eastern Lake Survey, Phase 1
U.S. Environmental Protection Agency, Environmental Research Laboratory, Nationwide Stream Survey
U.S. Environmental Protection Agency, Lake Eutrophication Survey
U.S. Environmental Protection Agency, Region 4
U.S. Forest Service
U.S. Geological Survey

Figure 3.4 depicts the available flow data (in cubic feet per second [cfs] for the southern boundary of the Upper Wakulla River (at County Road 365, Shadeville Road) and at Wakulla Spring (for both the flow is divided by 10), together with the flow data for several of the other springs that discharge to the river. The graph shows that the river and all associated springs appear to follow the same general flow pattern.

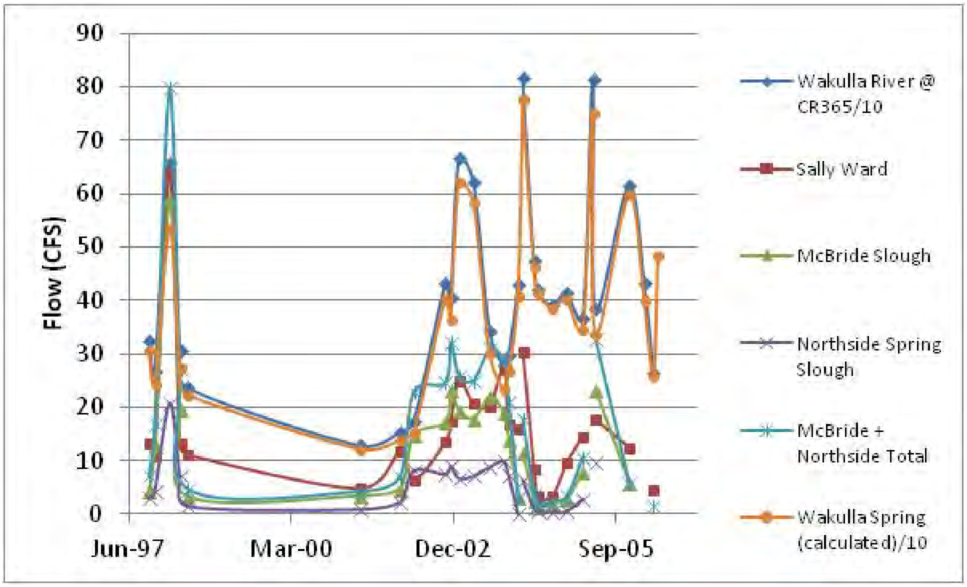

Figure 3.4. Flow (in cfs) in the Upper Wakulla River, Wakulla Spring, McBride Slough, Northside Spring, and Sally Ward Spring, 1997–2005

Figure 3.5 and **Table 3.4** depict the color data (in platinum cobalt units [PCUs] for the Upper Wakulla River and Wakulla Spring. These data show that historically the color of the river appeared to vary over a greater range (< 10 to 100 PCUs) than the color of the water from the spring (< 10 to 40 PCUs). Recent sampling has focused on the color of water flowing from the spring, with very few data for the river. These recent data exhibit a similar pattern (most data with color < 20 PCUs) as the historical data. For many water quality constituents, there were almost no sampling events during the 1980s and 1990s.

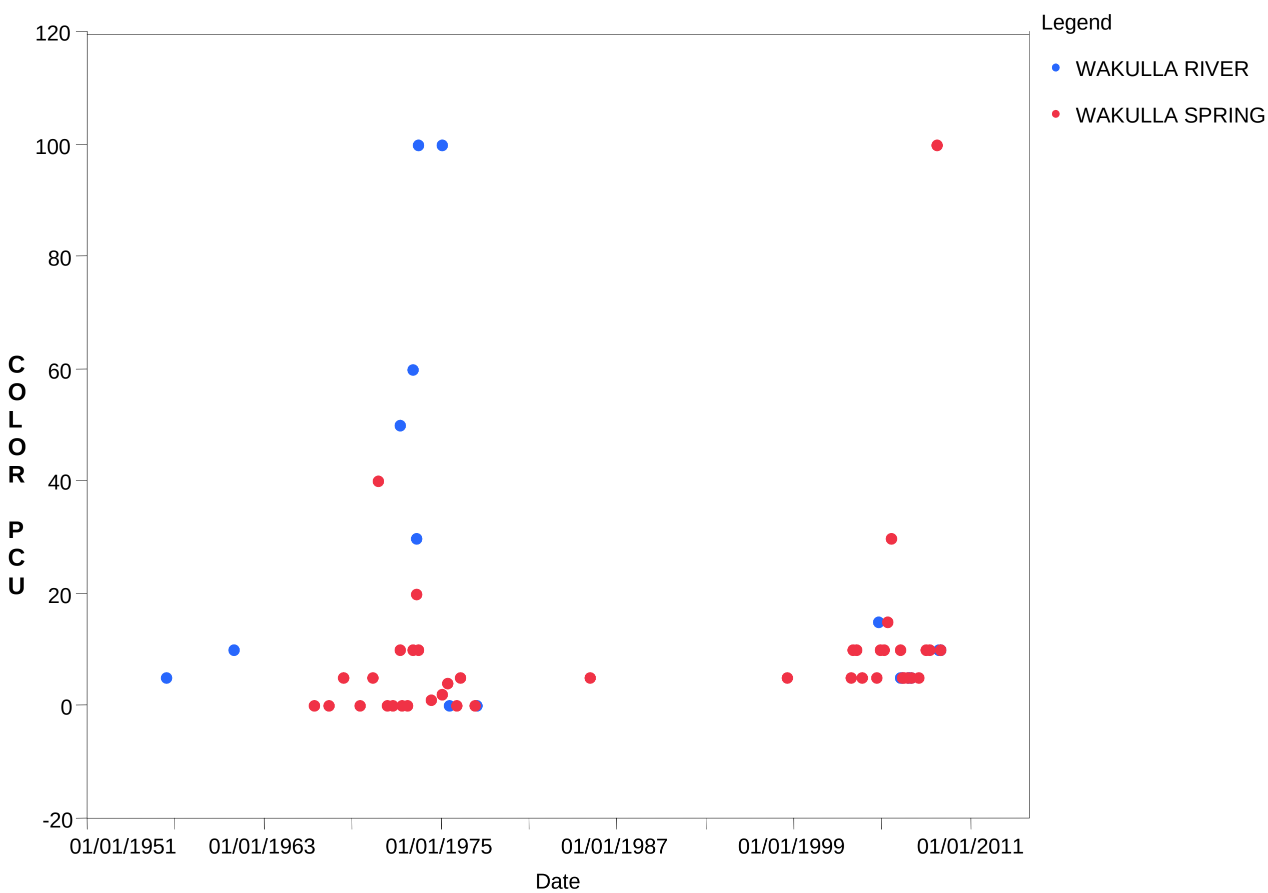

Figure 3.5. Color (in PCUs) in the Upper Wakulla River and Wakulla Spring, 1951–2011

Figure 3.6 and **Table 3.5** show the specific conductance data (in micromhos per centimeter [µmhos/cm]) for the Upper Wakulla River and Wakulla Spring. From these data, it can be seen that historically the conductance of the river was generally below the conductance of water from the spring. Additionally, it appears that conductivity in Wakulla Spring may have increased slightly over time, with recent data depicting both the river and spring with similar conductivities.

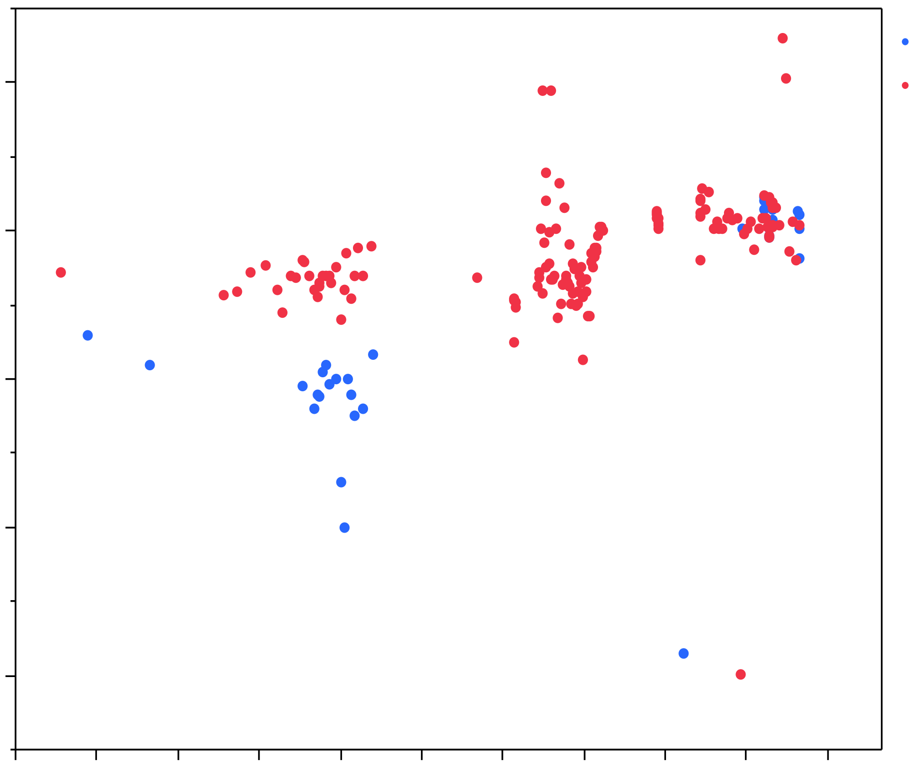

Figure 3.6. Specific Conductivity (in µmhos/cm) in the Upper Wakulla River and Wakulla Spring, 1951–2011

Figure 3.7 and **Table 3.6** depict the TP data (in mg/L) for Wakulla Spring and the Upper Wakulla River. These data show that historically the TP of the river was generally below the TP of the water from the spring. More recent data indicate an overall decline in the TP concentration for both systems and a reduction in the annual variation in TP concentration.

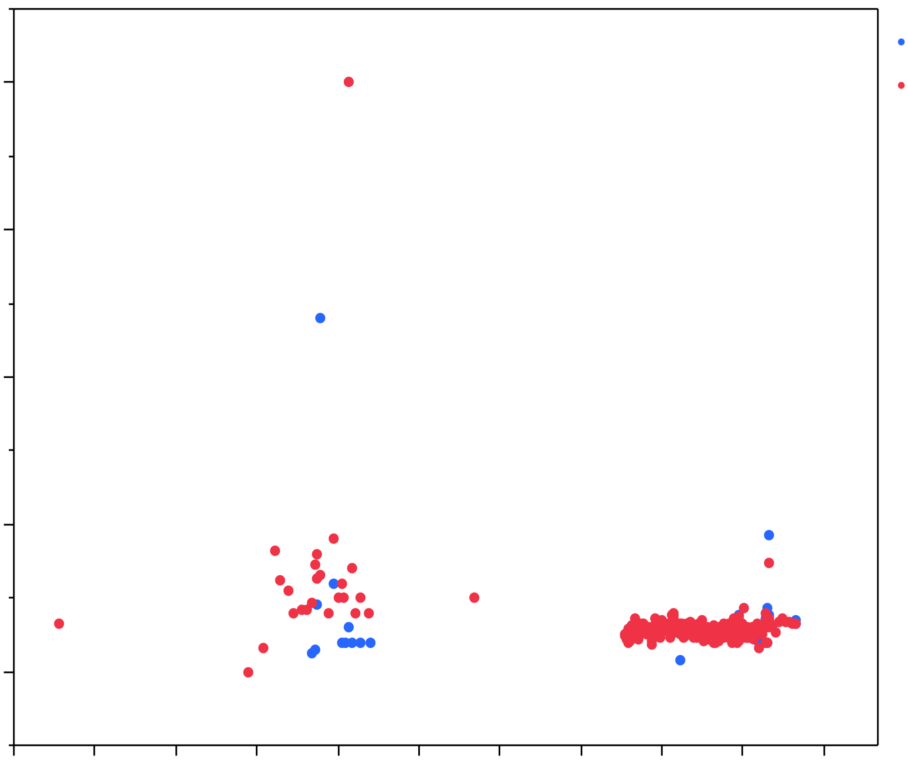

Figure 3.7. TP (in mg/L) in the Upper Wakulla River and Wakulla Spring, 1951–2011

Figure 3.8 and **Table 3.7** show the nitrogen series data (in mg/L) for the Upper Wakulla River with results as mg/L. From these data, it can be seen that both ammonia (blue) and nitrite (red) concentrations are generally less than detection. Historically, the nitrate (green) concentrations were mostly below 0.10 mg/L. Over time, nitrate concentrations have increased from generally less than 0.15 mg/L before 1975 to generally greater than 0.4 mg/L by 2000, when routine sampling in the Upper Wakulla River resumed.

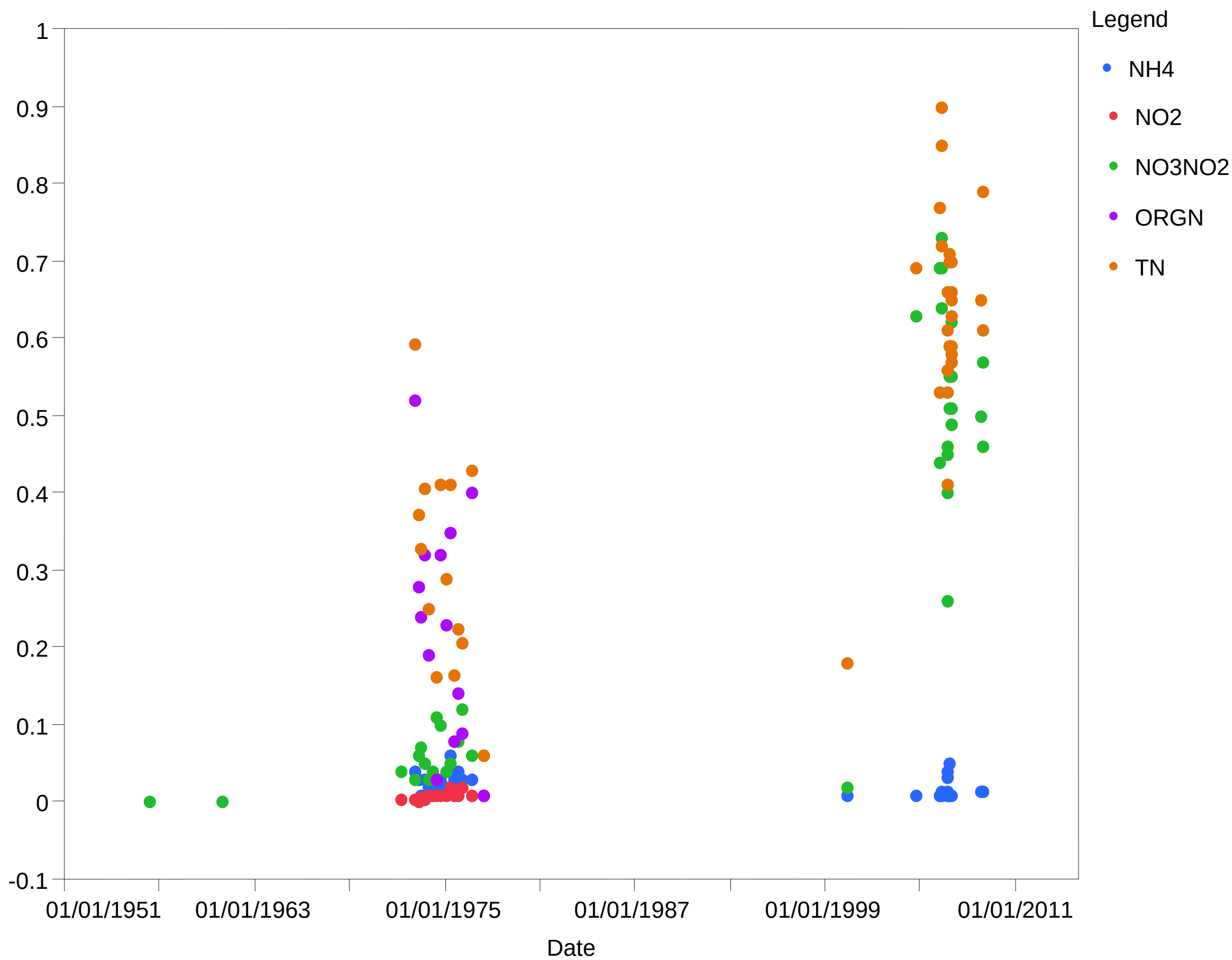

Figure 3.8. Nitrogen Species (in mg/L) for the Upper Wakulla River, 1951–2011

Figure 3.9 and **Table 3.8** depict all of the nitrogen series data (in mg/L) for Wakulla Spring with results as mg/L. From these data, it can be seen that in the mid-1980s, nitrate concentrations in the spring were reported at over 10.0 mg/L. These elevated data visually compress all other data due to scale differences. **Figure 3.10** and **Table 3.9** present these same data without the outlier results.

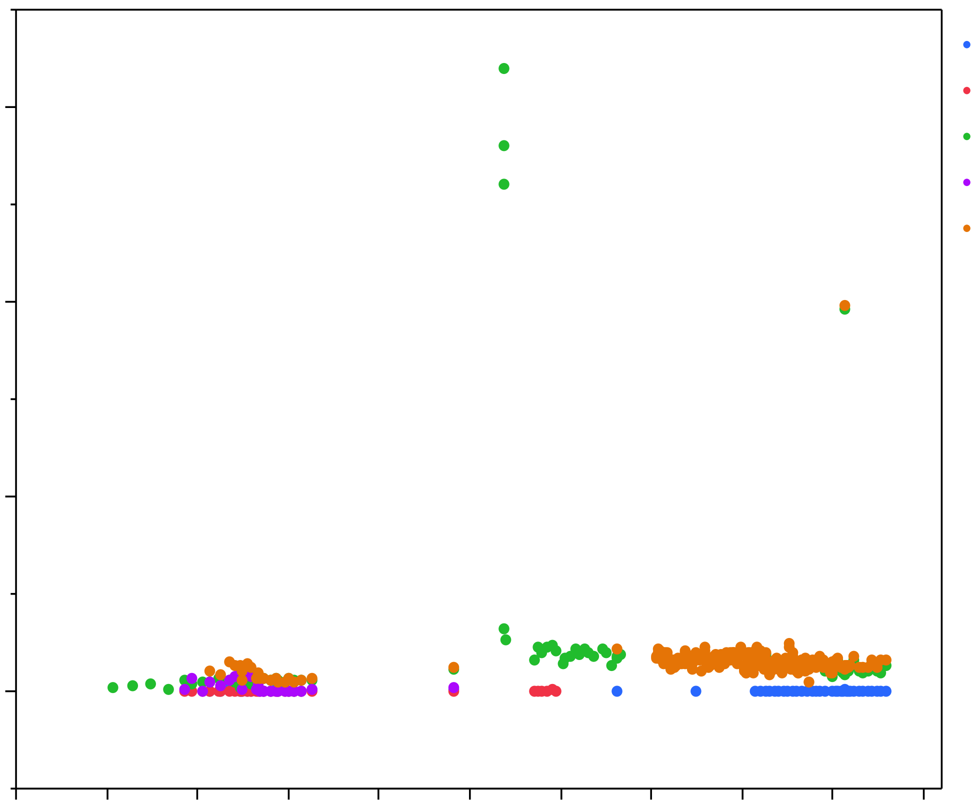

Figure 3.9. Nitrogen Species (in mg/L) for Wakulla Spring, with Outliers, 1961–2011

Figure 3.10 and **Table 3.9** depict the nitrogen series data (in mg/L) for Wakulla Spring without the outlier values from the mid-1980's. These data indicate that both ammonia (blue) and nitrite (red) concentrations are generally less than detection. Like the river, the historical data indicate a predominance of nitrogen as organic (purple) and the nitrate (green) fraction as low (nitrate concentrations mostly below 0.2 mg/L). While there are few data representative of the late 1970s to the early 1990s, the data collected do depict that nitrate has become the dominate form of nitrogen in the spring and the concentrations were increasing through the late 1980s, when nitrate concentrations peaked and started to decline. Recent data indicate that nitrate still dominates the various forms of nitrogen and remains significantly elevated over historical values. Comparing the nitrate concentrations in the river with those in the spring shows that the water flowing from the spring is the dominate source of nitrates in the river, with nitrate reductions in the river, perhaps resulting from a combination of dilution and biological uptake.

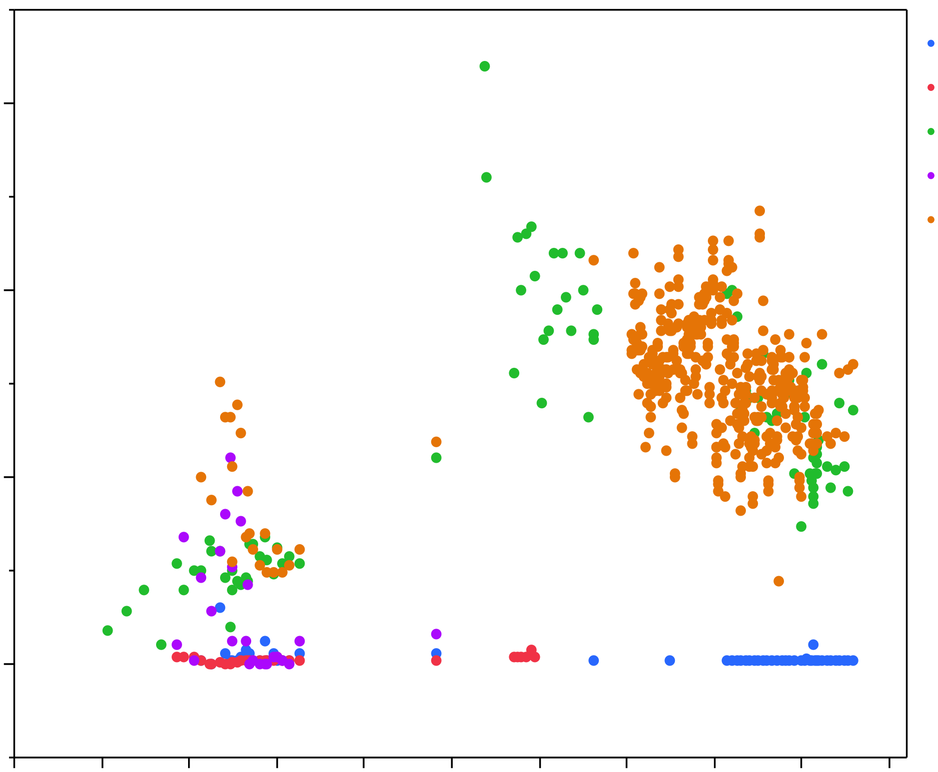

Figure 3.10. Nitrogen Species (in mg/L) for Wakulla Spring, without Outliers, 1961–2011

Figure 3.11 and **Table 3.10** depict the chlorophyll *a* (in µg/L) data for the Upper Wakulla River and Wakulla Spring. From these data, it can be seen that there are very few data for either system and there are almost no data collected at the same time for both the river and the spring. Even so, the data do not indicate a problem with chlorophyll *a* (phytoplankton) in the Upper Wakulla River.

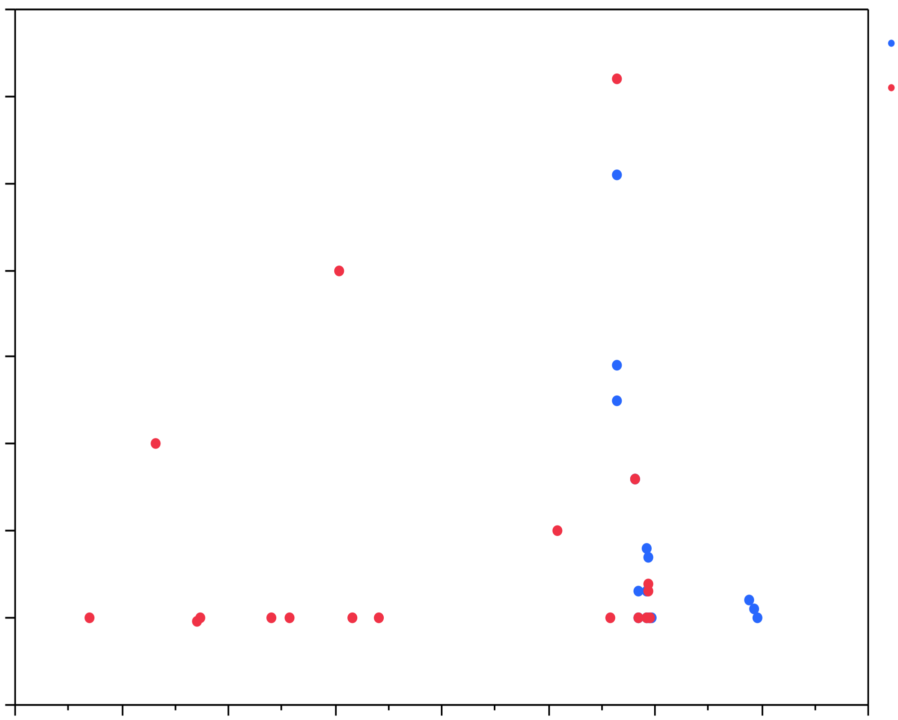

Figure 3.11. Chlorophyll a (in µg/L) in the Upper Wakulla River and Wakulla Spring, 1996–2011

Table 3.3 reports the monthly average temperature (in °F) and rainfall (in inches) at the Tallahassee Regional Airport for the past 30 years. These data show that the summer months (June, July, and August) generally have the largest rainfall amounts and the highest average temperature. July has both the highest average rainfall and temperature.

Table 3.3. Thirty-Year Rainfall (inches) and Temperature (°F) at Tallahassee Regional Airport

Analysis	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
30-Year Mean–Maximum Temperature (°F)	63.8	67.4	74.0	80.0	86.5	90.9	92.0	91.5	88.5	81.2	72.9	65.8	79.5
30-Year Mean–Minimum Temperature (°F)	39.7	42.1	48.2	52.8	62.3	69.8	72.7	72.7	69.2	56.9	47.9	41.6	56.3
30-Year Mean–Average Temperature (°F)	51.8	54.8	61.1	66.4	74.4	80.4	82.4	82.1	78.9	69.1	60.4	53.7	68.0
30-Year Mean–Precipitation (inches)	5.36	4.63	6.47	3.59	4.95	6.92	8.04	7.03	5.01	3.25	3.86	4.10	63.21

Table 3.4. Color (in mg/L) in the Upper Wakulla River and Wakulla Spring, 1956–2008

Notes: - = Empty cell/no data; N = Number; Min = Minimum; Max = Maximum

Year	N	WBID 1006 Mean	WBID 1006 Median	WBID 1006 Min	WBID 1006 Max	N	WBID 1006X Mean	WBID 1006X Median	WBID 1006X Min	WBID 1006X Max
1956	1	5.0	5.0	5.0	5.0	0	-	-	-	-
1960	1	10.0	10.0	10.0	10.0	0	-	-	-	-
1966	0	-	-	-	-	1	0.0	0.0	0.0	0.0
1967	0	-	-	-	-	1	0.0	0.0	0.0	0.0
1968	0	-	-	-	-	1	5.0	5.0	5.0	5.0
1969	0	-	-	-	-	1	0.0	0.0	0.0	0.0
1970	0	-	-	-	-	2	22.5	22.5	5.0	40.0
1971	0	-	-	-	-	2	0.0	0.0	0.0	0.0
1972	1	50.0	50.0	50.0	50.0	3	3.3	0.0	0.0	10.0
1973	3	63.3	60.0	30.0	100.0	4	12.5	10.0	10.0	20.0
1974	0	-	-	-	-	1	1.0	1.0	1.0	1.0
1975	2	50.0	50.0	0.0	100.0	2	3.0	3.0	2.0	4.0
1976	0	-	-	-	-	2	2.5	2.5	0.0	5.0
1977	1	0.0	0.0	0.0	0.0	1	0.0	0.0	0.0	0.0
1985	0	-	-	-	-	1	5.0	5.0	5.0	5.0
1998	0	-	-	-	-	1	5.0	5.0	5.0	5.0
2002	0	-	-	-	-	1	5.0	5.0	5.0	5.0
2003	0	-	-	-	-	3	8.3	10.0	5.0	10.0
2004	1	15.0	15.0	15.0	15.0	2	7.5	7.5	5.0	10.0
2005	0	-	-	-	-	3	18.3	15.0	10.0	30.0
2006	22	5.0	5.0	5.0	5.0	13	5.4	5.0	5.0	10.0
2007	0	-	-	-	-	2	7.5	7.5	5.0	10.0
2008	3	10.0	10.0	10.0	10.0	3	40.0	10.0	10.0	100.0
Period of Record	**35**	**14.6**	**5.0**	**0.0**	**100.0**	**50**	**8.7**	**5.0**	**0.0**	**100.0**
Verified Period	**7**	**6.4**	**5.0**	**5.0**	**15.0**	**12**	**10.0**	**10.0**	**5.0**	**30.0**

Table 3.5. Specific Conductance (µmhos/cm) in the Upper Wakulla River and Wakulla Spring, 1954–2008

Notes: - = Empty cell/no data; N = Number; Min = Minimum; Max = Maximum

Year	N	WBID 1006 Mean	WBID 1006 Median	WBID 1006 Min	WBID 1006 Max	N	WBID 1006X Mean	WBID 1006X Median	WBID 1006X Min	WBID 1006X Max
1954	0	-	-	-	-	1	272.0	272.0	272.0	272.0
1956	1	230.0	230.0	230.0	230.0	0	-	-	-	-
1960	1	210.0	210.0	210.0	210.0	0	-	-	-	-
1966	0	-	-	-	-	1	257.0	257.0	257.0	257.0
1967	0	-	-	-	-	1	259.0	259.0	259.0	259.0
1968	0	-	-	-	-	1	272.0	272.0	272.0	272.0
1969	0	-	-	-	-	1	277.0	277.0	277.0	277.0
1970	0	-	-	-	-	2	252.5	252.5	245.0	260.0
1971	0	-	-	-	-	2	268.5	268.5	268.0	269.0
1972	1	195.0	195.0	195.0	195.0	3	276.3	279.0	270.0	280.0
1973	5	194.2	189.0	180.0	209.0	6	263.8	264.0	255.0	270.0
1974	2	198.5	198.5	197.0	200.0	3	270.0	270.0	265.0	275.0
1975	4	154.8	159.5	100.0	200.0	4	259.8	257.0	240.0	285.0
1976	2	177.5	177.5	175.0	180.0	3	276.0	270.0	269.0	289.0
1977	1	216.0	216.0	216.0	216.0	1	290.0	290.0	290.0	290.0
1985	0	-	-	-	-	1	268.0	268.0	268.0	268.0
1987	0	-	-	-	-	5	246.4	252.0	225.0	254.0
1989	0	-	-	-	-	6	292.8	270.0	258.0	395.0
1990	0	-	-	-	-	12	300.5	295.5	267.0	395.0
1991	0	-	-	-	-	10	275.9	266.0	241.0	332.0
1992	0	-	-	-	-	12	258.2	258.5	213.0	278.0
1993	0	-	-	-	-	11	272.2	279.0	242.0	289.0
1994	0	-	-	-	-	5	300.6	300.0	297.0	303.0
1998	0	-	-	-	-	9	308.0	309.0	301.0	313.0
2000	1	15.0	15.0	15.0	15.0	0	-	-	-	-
2001	0	-	-	-	-	7	307.3	312.0	280.0	328.0
2002	0	-	-	-	-	4	312.0	310.0	302.0	326.0
2003	0	-	-	-	-	4	306.0	305.5	301.0	312.0
2004	2	302.0	302.0	302.0	302.0	4	228.3	302.5	0.3	308.0

Year	N	WBID 1006 Mean	WBID 1006 Median	WBID 1006 Min	WBID 1006 Max	N	WBID 1006X Mean	WBID 1006X Median	WBID 1006X Min	WBID 1006X Max
2005	0	-	-	-	-	4	298.8	301.0	287.0	306.0
2006	20	308.9	306.5	296.0	323.0	15	309.8	308.0	296.0	324.0
2007	0	-	-	-	-	4	363.3	359.5	304.0	430.0
2008	4	301.8	306.5	281.0	313.0	4	294.0	295.0	280.0	306.0
Period of Record	**44**	**254.5**	**299.5**	**15.0**	**323.0**	**146**	**286.0**	**285.5**	**0.3**	**430.0**
Verified Period	**27**	**296.4**	**305.0**	**15.0**	**323.0**	**46**	**304.5**	**306.0**	**0.3**	**430.0**

Table 3.6. TP (in mg/L) in the Upper Wakulla River and Wakulla Spring, 1954–2008

- = Empty cell/no data

Notes: - = Empty cell/no data; N = Number; Min = Minimum; Max = Maximum

Year	N	WBID 1006 Mean	WBID 1006 Median	WBID 1006 Min	WBID 1006 Max	N	WBID 1006X Mean	WBID 1006X Median	WBID 1006X Min	WBID 1006X Max
1954	0	-	-	-	-	1	0.033	0.033	0.033	0.033
1968	0	-	-	-	-	1	0.000	0.000	0.000	0.000
1969	0	-	-	-	-	1	0.016	0.016	0.016	0.016
1970	0	-	-	-	-	2	0.072	0.072	0.062	0.082
1971	0	-	-	-	-	2	0.047	0.047	0.039	0.055
1972	0	-	-	-	-	2	0.042	0.042	0.042	0.042
1973	4	0.078	0.030	0.012	0.240	5	0.066	0.065	0.047	0.080
1974	1	0.060	0.060	0.060	0.060	2	0.065	0.065	0.040	0.090
1975	3	0.023	0.020	0.020	0.030	4	0.140	0.055	0.050	0.400
1976	2	0.020	0.020	0.020	0.020	3	0.053	0.050	0.040	0.070
1977	1	0.020	0.020	0.020	0.020	1	0.040	0.040	0.040	0.040
1985	0	-	-	-	-	1	0.050	0.050	0.050	0.050
1996	0	-	-	-	-	27	0.027	0.027	0.020	0.036
1997	0	-	-	-	-	36	0.029	0.029	0.022	0.033
1998	0	-	-	-	-	34	0.028	0.028	0.018	0.036
1999	0	-	-	-	-	36	0.031	0.031	0.023	0.040
2000	1	0.008	0.008	0.008	0.008	36	0.030	0.030	0.023	0.033
2001	0	-	-	-	-	36	0.028	0.028	0.023	0.034
2002	0	-	-	-	-	39	0.026	0.026	0.020	0.035
2003	0	-	-	-	-	39	0.026	0.027	0.021	0.032
2004	1	0.039	0.039	0.039	0.039	40	0.027	0.027	0.020	0.037
2005	0	-	-	-	-	40	0.026	0.026	0.022	0.043
2006	22	0.032	0.034	0.020	0.093	21	0.031	0.030	0.016	0.074
2007	0	-	-	-	-	4	0.032	0.033	0.027	0.036
2008	3	0.034	0.034	0.033	0.035	4	0.033	0.033	0.032	0.034
Period of Record	**38**	**0.036**	**0.032**	**0.008**	**0.240**	**417**	**0.030**	**0.029**	**0.000**	**0.400**
Verified Period	**27**	**0.032**	**0.034**	**0.008**	**0.093**	**259**	**0.028**	**0.028**	**0.016**	**0.074**

Table 3.7. Nitrogen Series (in mg/L) for the Upper Wakulla River, 1956–2008

ell/no data; N = Number; Min = Minimum; Max = Maximum **Year**	N	NH4 Mean	NH4 Median	NH4 Min	NH4 Max	N	NO2 Mean	NO2 Median	NO2 Min	NO2 Max	N	NO3NO2 Mean	NO3NO2 Median	NO3NO2 Min	NO3NO2 Max	N	ORGN Mean	ORGN Median	ORGN Min	ORGN Max	N	TN Mean	TN Median
1956	0	-	-	-	-	0	-	-	-	-	1	0.000	0.000	0.000	0.000	0	-	-	-	-	0	-	-
1960	0	-	-	-	-	0	-	-	-	-	1	0.000	0.000	0.000	0.000	0	-	-	-	-	0	-	-
1972	0	-	-	-	-	1	0.003	0.003	0.003	0.003	1	0.040	0.040	0.040	0.040	0	-	-	-	-	0	-	-
1973	5	0.026	0.030	0.010	0.040	5	0.005	0.005	0.002	0.010	5	0.048	0.050	0.030	0.070	5	0.310	0.280	0.190	0.520	5	0.389	0.372
1974	3	0.020	0.020	0.010	0.030	3	0.010	0.010	0.010	0.010	3	0.084	0.101	0.040	0.111	2	0.175	0.175	0.030	0.320	2	0.286	0.286
1975	4	0.038	0.035	0.020	0.060	4	0.013	0.010	0.010	0.020	4	0.063	0.065	0.040	0.080	4	0.200	0.185	0.080	0.350	4	0.272	0.258
1976	2	0.030	0.030	0.030	0.030	2	0.015	0.015	0.010	0.020	2	0.090	0.090	0.060	0.120	2	0.245	0.245	0.090	0.400	2	0.318	0.318
1977	1	0.010	0.010	0.010	0.010	1	0.010	0.010	0.010	0.010	1	0.060	0.060	0.060	0.060	1	0.010	0.010	0.010	0.010	1	0.062	0.062
2000	1	0.008	0.008	0.008	0.008	0	-	-	-	-	1	0.020	0.020	0.020	0.020	0	-	-	-	-	1	0.180	0.180
2004	1	0.010	0.010	0.010	0.010	0	-	-	-	-	1	0.630	0.630	0.630	0.630	0	-	-	-	-	1	0.690	0.690
2006	22	0.017	0.010	0.010	0.050	0	-	-	-	-	22	0.525	0.510	0.260	0.730	0	-	-	-	-	21	0.643	0.630
2008	3	0.014	0.014	0.014	0.015	0	-	-	-	-	3	0.510	0.500	0.460	0.570	0	-	-	-	-	3	0.683	0.650
Period of Record	**42**	**0.020**	**0.013**	**0.008**	**0.060**	**16**	**0.009**	**0.010**	**0.002**	**0.020**	**45**	**0.328**	**0.410**	**0.000**	**0.730**	**14**	**0.229**	**0.235**	**0.010**	**0.520**	**40**	**0.518**	**0.585**
Verified Period	**27**	**0.016**	**76.921**	**0.008**	**0.050**	**0**	**-**	**-**	**-**	**-**	**27**	**0.509**	**28.006**	**0.020**	**0.730**	**0**	**-**	**-**	**-**	**-**	**26**	**0.632**	**22.025**

Table 3.8. Nitrogen Species (in mg/L) for Wakulla Spring with Outliers, 1966–2008

Notes: - = Empty cell/no data; N = Number; Min = Minimum; Max = Maximum

Year	N	NH4 Mean	NH4 Median	NH4 Min	NH4 Max	N	NO2 Mean	NO2 Median	NO2 Min	NO2 Max	N	NO3NO2 Mean	NO3NO2 Median	NO3NO2 Min	NO3NO2 Max	N	ORGN Mean	ORGN Median	ORGN Min	ORGN Max	N	TN Mean	TN Median	TN Min	TN Max
1966	0	-	-	-	-	0	-	-	-	-	1	0.090	0.090	0.090	0.090	0	-	-	-	-	0	-	-	-	-
1967	0	-	-	-	-	0	-	-	-	-	1	0.140	0.140	0.140	0.140	0	-	-	-	-	0	-	-	-	-
1968	0	-	-	-	-	0	-	-	-	-	1	0.200	0.200	0.200	0.200	0	-	-	-	-	0	-	-	-	-
1969	0	-	-	-	-	0	-	-	-	-	1	0.050	0.050	0.050	0.050	0	-	-	-	-	0	-	-	-	-
1970	0	-	-	-	-	2	0.020	0.020	0.020	0.020	2	0.235	0.235	0.200	0.270	2	0.195	0.195	0.050	0.340	0	-	-	-	-
1971	1	0.010	0.010	0.010	0.010	2	0.015	0.015	0.010	0.020	2	0.250	0.250	0.250	0.250	2	0.120	0.120	0.010	0.230	1	0.500	0.500	0.500	0.500
1972	2	0.075	0.075	0.000	0.150	3	0.002	0.002	0.000	0.004	3	0.310	0.300	0.300	0.330	2	0.220	0.220	0.140	0.300	2	0.597	0.597	0.440	0.754
1973	6	0.015	0.010	0.010	0.030	6	0.004	0.003	0.002	0.010	6	0.202	0.215	0.100	0.250	6	0.352	0.390	0.060	0.550	6	0.573	0.641	0.273	0.693
1974	4	0.028	0.030	0.010	0.040	4	0.010	0.010	0.010	0.010	4	0.273	0.276	0.220	0.321	4	0.070	0.035	0.000	0.210	4	0.365	0.346	0.308	0.460
1975	4	0.028	0.020	0.010	0.060	4	0.010	0.010	0.010	0.010	4	0.288	0.285	0.240	0.340	4	0.005	0.000	0.000	0.020	4	0.277	0.256	0.246	0.349
1976	3	0.010	0.010	0.010	0.010	3	0.013	0.010	0.010	0.020	3	0.290	0.290	0.270	0.310	3	0.010	0.010	0.000	0.020	3	0.273	0.267	0.246	0.308
1977	1	0.030	0.030	0.030	0.030	1	0.010	0.010	0.010	0.010	1	0.270	0.270	0.270	0.270	1	0.060	0.060	0.060	0.060	1	0.308	0.308	0.308	0.308
1985	1	0.030	0.030	0.030	0.030	1	0.010	0.010	0.010	0.010	1	0.550	0.550	0.550	0.550	1	0.080	0.080	0.080	0.080	1	0.595	0.595	0.595	0.595
1987	0	-	-	-	-	0	-	-	-	-	5	9.180	13.000	1.300	16.000	0	-	-	-	-	0	-	-	-	-
1989	0	-	-	-	-	2	0.020	0.020	0.020	0.020	2	0.960	0.960	0.780	1.140	0	-	-	-	-	0	-	-	-	-
1990	0	-	-	-	-	4	0.025	0.020	0.020	0.040	4	1.090	1.095	1.000	1.170	0	-	-	-	-	0	-	-	-	-
1991	0	-	-	-	-	0	-	-	-	-	4	0.890	0.880	0.700	1.100	0	-	-	-	-	0	-	-	-	-
1992	0	-	-	-	-	0	-	-	-	-	4	0.980	0.965	0.890	1.100	0	-	-	-	-	0	-	-	-	-
1993	0	-	-	-	-	0	-	-	-	-	3	0.920	1.000	0.660	1.100	0	-	-	-	-	0	-	-	-	-
1994	1	0.010	0.010	0.010	0.010	0	-	-	-	-	3	0.900	0.880	0.870	0.950	0	-	-	-	-	1	1.080	1.080	1.080	1.080
1996	0	-	-	-	-	0	-	-	-	-	0	-	-	-	-	0	-	-	-	-	26	0.883	0.865	0.720	1.100
1997	0	-	-	-	-	0	-	-	-	-	0	-	-	-	-	0	-	-	-	-	36	0.787	0.780	0.580	1.060
1998	1	0.010	0.010	0.010	0.010	0	-	-	-	-	1	0.950	0.950	0.950	0.950	0	-	-	-	-	34	0.836	0.835	0.500	1.110
1999	0	-	-	-	-	0	-	-	-	-	0	-	-	-	-	0	-	-	-	-	36	0.796	0.805	0.590	0.930
2000	0	-	-	-	-	0	-	-	-	-	0	-	-	-	-	0	-	-	-	-	36	0.923	0.930	0.700	1.130
2001	1	0.008	0.008	0.008	0.008	0	-	-	-	-	1	0.990	0.990	0.990	0.990	0	-	-	-	-	36	0.761	0.755	0.450	1.130
2002	4	0.010	0.010	0.010	0.010	0	-	-	-	-	4	0.835	0.830	0.680	1.000	0	-	-	-	-	40	0.709	0.700	0.410	1.060
2003	4	0.010	0.010	0.010	0.010	0	-	-	-	-	4	0.718	0.710	0.620	0.830	0	-	-	-	-	40	0.711	0.660	0.430	1.210
2004	4	0.010	0.010	0.010	0.010	0	-	-	-	-	4	0.685	0.665	0.650	0.760	0	-	-	-	-	40	0.684	0.710	0.220	0.870

Year	N	NH4 Mean	NH4 Median	NH4 Min	NH4 Max	N	NO2 Mean	NO2 Median	NO2 Min	NO2 Max	N	NO3NO2 Mean	NO3NO2 Median	NO3NO2 Min	NO3NO2 Max	N	ORGN Mean	ORGN Median	ORGN Min	ORGN Max	N	TN Mean	TN Median	TN Min	TN Max
2005	4	0.010	0.010	0.010	0.010	0	-	-	-	-	4	0.590	0.615	0.370	0.760	0	-	-	-	-	40	0.683	0.710	0.450	0.880
2006	16	0.015	0.010	0.010	0.050	0	-	-	-	-	16	1.127	0.545	0.430	9.800	0	-	-	-	-	20	1.139	0.671	0.570	9.910
2007	4	0.010	0.010	0.010	0.010	0	-	-	-	-	4	0.580	0.525	0.470	0.800	0	-	-	-	-	4	0.675	0.615	0.590	0.880
2008	4	0.010	0.010	0.010	0.010	0	-	-	-	-	4	0.593	0.605	0.460	0.700	0	-	-	-	-	4	0.745	0.785	0.610	0.800
Period of Record	**65**	**0.016**	**0.010**	**0.000**	**0.150**	**32**	**0.012**	**0.010**	**0.000**	**0.040**	**97**	**1.120**	**0.590**	**0.050**	**16.000**	**25**	**0.146**	**0.060**	**0.000**	**0.550**	**415**	**0.770**	**0.760**	**0.220**	**9.910**
Verified Period	**41**	**0.012**	**0.010**	**0.008**	**0.050**	**0**	**-**	**-**	**-**	**-**	**41**	**0.854**	**0.620**	**0.370**	**9.800**	**0**	**-**	**-**	**-**	**-**	**260**	**0.771**	**0.720**	**0.220**	**9.910**

Table 3.9. Nitrogen Species (in mg/L) for Wakulla Spring without Outliers, 1966–2008

Notes: - = Empty cell/no data; N = Number; Min = Minimum; Max = Maximum

Year	N	NH4 Mean	NH4 Median	NH4 Min	NH4 Max	N	NO2 Mean	NO2 Median	NO2 Min	NO2 Max	N	NO3NO2 Mean	NO3NO2 Median	NO3NO2 Min	NO3NO2 Max	N	ORGN Mean	ORGN Median	ORGN Min	ORGN Max	N	TN Mean	TN Median	TN Min	TN Max
1966	0	-	-	-	-	0	-	-	-	-	1	0.090	0.090	0.090	0.090	0	-	-	-	-	0	-	-	-	-
1967	0	-	-	-	-	0	-	-	-	-	1	0.140	0.140	0.140	0.140	0	-	-	-	-	0	-	-	-	-
1968	0	-	-	-	-	0	-	-	-	-	1	0.200	0.200	0.200	0.200	0	-	-	-	-	0	-	-	-	-
1969	0	-	-	-	-	0	-	-	-	-	1	0.050	0.050	0.050	0.050	0	-	-	-	-	0	-	-	-	-
1970	0	-	-	-	-	2	0.020	0.020	0.020	0.020	2	0.235	0.235	0.200	0.270	2	0.195	0.195	0.050	0.340	0	-		-	-
1971	1	0.010	0.010	0.010	0.010	2	0.015	0.015	0.010	0.020	2	0.250	0.250	0.250	0.250	2	0.120	0.120	0.010	0.230	1	0.500	0.500	0.500	0.500
1972	2	0.075	0.075	0.000	0.150	3	0.002	0.002	0.000	0.004	3	0.310	0.300	0.300	0.330	2	0.220	0.220	0.140	0.300	2	0.597	0.597	0.440	0.754
1973	6	0.015	0.010	0.010	0.030	6	0.004	0.003	0.002	0.010	6	0.202	0.215	0.100	0.250	6	0.352	0.390	0.060	0.550	6	0.573	0.641	0.273	0.693
1974	4	0.028	0.030	0.010	0.040	4	0.010	0.010	0.010	0.010	4	0.273	0.276	0.220	0.321	4	0.070	0.035	0.000	0.210	4	0.365	0.346	0.308	0.460
1975	4	0.028	0.020	0.010	0.060	4	0.010	0.010	0.010	0.010	4	0.288	0.285	0.240	0.340	4	0.005	0.000	0.000	0.020	4	0.277	0.256	0.246	0.349
1976	3	0.010	0.010	0.010	0.010	3	0.013	0.010	0.010	0.020	3	0.290	0.290	0.270	0.310	3	0.010	0.010	0.000	0.020	3	0.273	0.267	0.246	0.308
1977	1	0.030	0.030	0.030	0.030	1	0.010	0.010	0.010	0.010	1	0.270	0.270	0.270	0.270	1	0.060	0.060	0.060	0.060	1	0.308	0.308	0.308	0.308
1985	1	0.030	0.030	0.030	0.030	1	0.010	0.010	0.010	0.010	1	0.550	0.550	0.550	0.550	1	0.080	0.080	0.080	0.080	1	0.595	0.595	0.595	0.595
1987	0	-	-	-	-	0	-	-	-	-	2	1.450	1.450	1.300	1.600	0	-	-	-	-	0	-	-	-	-
1989	0	-	-	-	-	2	0.020	0.020	0.020	0.020	2	0.960	0.960	0.780	1.140	0	-	-	-	-	0	-	-	-	-
1990	0	-	-	-	-	4	0.025	0.020	0.020	0.040	4	1.090	1.095	1.000	1.170	0	-	-	-	-	0	-	-	-	-
1991	0	-	-	-	-	0	-	-	-	-	4	0.890	0.880	0.700	1.100	0	-	-	-	-	0	-	-	-	-
1992	0	-	-	-	-	0	-	-	-	-	4	0.980	0.965	0.890	1.100	0	-	-	-	-	0	-	-	-	-
1993	0	-	-	-	-	0	-	-	-	-	3	0.920	1.000	0.660	1.100	0	-	-	-	-	0	-	-	-	-
1994	1	0.010	0.010	0.010	0.010	0	-	-	-	-	3	0.900	0.880	0.870	0.950	0	-	-	-	-	1	1.080	1.080	1.080	1.080
1996	0	-	-	-	-	0	-	-	-	-	0	-	-	-	-	0	-	-	-	-	26	0.883	0.865	0.720	1.100
1997	0	-	-	-	-	0	-	-	-	-	0	-	-	-	-	0	-	-	-	-	36	0.787	0.780	0.580	1.060
1998	1	0.010	0.010	0.010	0.010	0	-	-	-	-	1	0.950	0.950	0.950	0.950	0	-	-	-	-	34	0.836	0.835	0.500	1.110
1999	0	-	-	-	-	0	-	-	-	-	0	-	-	-	-	0	-	-	-	-	36	0.796	0.805	0.590	0.930
2000	0	-	-	-	-	0	-	-	-	-	0	-	-	-	-	0	-	-	-	-	36	0.923	0.930	0.700	1.130
2001	1	0.008	0.008	0.008	0.008	0	-	-	-	-	1	0.990	0.990	0.990	0.990	0	-	-	-	-	36	0.761	0.755	0.450	1.130
2002	4	0.010	0.010	0.010	0.010	0	-	-	-	-	4	0.835	0.830	0.680	1.000	0	-	-	-	-	40	0.709	0.700	0.410	1.060
2003	4	0.010	0.010	0.010	0.010	0	-	-	-	-	4	0.718	0.710	0.620	0.830	0	-	-	-	-	40	0.711	0.660	0.430	1.210
2004	4	0.010	0.010	0.010	0.010	0	-	-	-	-	4	0.685	0.665	0.650	0.760	0	-	-	-	-	40	0.684	0.710	0.220	0.870

Year	N	NH4 Mean	NH4 Median	NH4 Min	NH4 Max	N	NO2 Mean	NO2 Median	NO2 Min	NO2 Max	N	NO3NO2 Mean	NO3NO2 Median	NO3NO2 Min	NO3NO2 Max	N	ORGN Mean	ORGN Median	ORGN Min	ORGN Max	N	TN Mean	TN Median	TN Min	TN Max
2005	4	0.010	0.010	0.010	0.010	0	-	-	-	-	4	0.590	0.615	0.370	0.760	0	-	-	-	-	40	0.683	0.710	0.450	0.880
2006	16	0.015	0.010	0.010	0.050	0	-	-	-	-	15	0.549	0.540	0.430	0.780	0	-	-	-	-	19	0.677	0.670	0.570	0.860
2007	4	0.010	0.010	0.010	0.010	0	-	-	-	-	4	0.580	0.525	0.470	0.800	0	-	-	-	-	4	0.675	0.615	0.590	0.880
2008	4	0.010	0.010	0.010	0.010	0	-	-	-	-	4	0.593	0.605	0.460	0.700	0	-	-	-	-	4	0.745	0.785	0.610	0.800
Period of Record	**65**	**0.016**	**0.010**	**0.000**	**0.150**	**32**	**0.012**	**0.010**	**0.000**	**0.040**	**93**	**0.600**	**0.560**	**0.050**	**1.600**	**25**	**0.146**	**0.060**	**0.000**	**0.550**	**414**	**0.748**	**0.760**	**0.220**	**1.210**
Verified Period	**41**	**0.012**	**0.010**	**0.008**	**0.050**	**0**	**-**	**-**	**-**	**-**	**40**	**0.631**	**0.610**	**0.370**	**1.000**	**0**	**-**	**-**	**-**	**-**	**259**	**0.736**	**0.720**	**0.220**	**1.210**

Table 3.10. Chlorophyll a (in µg/L) in the Upper Wakulla River and Wakulla Spring, 1995–2008

Notes: - = Empty cell/no data; N = Number; Min = Minimum; Max = Maximum

Year	N	WBID 1006 Mean	WBID 1006 Median	WBID 1006 Min	WBID 1006 Max	N	WBID 1006X Mean	WBID 1006X Median	WBID 1006X Min	WBID 1006X Max
1996	0	-	-	-	-	1	1.0	1.0	1.0	1.0
1997	0	-	-	-	-	1	3.0	3.0	3.0	3.0
1998	0	-	-	-	-	1	1.0	1.0	1.0	1.0
1999	0	-	-	-	-	1	1.0	1.0	1.0	1.0
2000	0	-	-	-	-	1	1.0	1.0	1.0	1.0
2001	0	-	-	-	-	3	2.3	1.0	1.0	5.0
2005	0	-	-	-	-	1	2.0	2.0	2.0	2.0
2006	20	1.9	1.2	1.0	6.1	12	1.8	1.0	1.0	7.2
2007	0	-	-	-	-	0	-	-	-	-
2008	3	1.1	1.1	1.0	1.2	0	-	-	-	-
Period of Record	**23**	**1.8**	**1.1**	**1.0**	**6.1**	**21**	**1.8**	**1.0**	**1.0**	**7.2**
Verified Period	**23**	**1.8**	**1.1**	**1.0**	**6.1**	**17**	**1.9**	**1.0**	**1.0**	**7.2**

Chapter 4: ASSESSMENT OF SOURCES

4.1 Types of Sources

An important part of the TMDL analysis is the identification of pollutant source categories, source subcategories, or individual sources of nutrients in the watershed and the amount of pollutant loading contributed by each of these sources. Sources are broadly classified as either "point sources" or "nonpoint sources." Historically, the term point sources has meant discharges to surface waters that typically have a continuous flow via a discernible, confined, and discrete conveyance, such as a pipe. Domestic and industrial wastewater treatment facilities (WWTFs) are examples of traditional point sources. In contrast, the term "nonpoint sources" was used to describe intermittent, rainfall-driven, diffuse sources of pollution associated with everyday human activities, including runoff from urban land uses, agriculture, silviculture, and mining; discharges from failing septic systems; and atmospheric deposition.

However, the 1987 amendments to the Clean Water Act redefined certain nonpoint sources of pollution as point sources subject to regulation under the EPA's National Pollutant Discharge Elimination System (NPDES) Program. These nonpoint sources included certain urban stormwater discharges, such as those from local government master drainage systems, construction sites over five acres, and a wide variety of industries (see **Appendix B** for background information on the federal and state stormwater programs).

To be consistent with Clean Water Act definitions, the term "point source" will be used to describe traditional point sources (such as domestic and industrial wastewater discharges) and stormwater systems requiring an NPDES stormwater permit when allocating pollutant load reductions required by a TMDL (see **Section 6.1**). However, the methodologies used to estimate nonpoint source loads do not distinguish between NPDES stormwater discharges and non-NPDES stormwater discharges, and as such, this source assessment section does not make any distinction between the two types of stormwater.

4.2 Potential Sources of Nutrients in the Wakulla River Watershed

4.2.1 Point Sources

Chelette *et al.* (2002) identified 69 facilities (domestic and industrial) within the Wakulla watershed with permits issued by the Department, of which 51 are active (**Table 4.1**). Of these 51 facilities, the authors calculated nitrate loads for the 21 facilities with the greatest potential as sources of nitrate (**Table 4.2**). It should be noted that none of the surface water dischargers has been linked to the impairments in the Upper Wakulla River. **Figure 4.1** depicts the two facilities within the Upper Wakulla River WBID, neither of which discharges to the river.

Based on the data reviewed, Chelette *et al.* (2002) found that most industrial wastewater facilities would not be expected to contribute nitrogen loadings to the watershed, except for Primex, which is located in southern Wakulla County (downstream of the impaired WBID). Primex discharges to Boggy Creek, a tributary to the Lower Wakulla River (1992–2000 monthly average TN 1.5 to 56.9 mg/L, or 4,819 to 31,096 kilograms of TN a year [kg-TN/yr]). Based on the location of Primex in the Lower Wakulla River and results from the HAPI survey (**Chapter 3**), Primex is not expected to cause or contribute to the biological impairment in the Upper Wakulla River. These facilities are permitted through the Department's Permitting Program (the state permit begins with FLA or FLG, and the NPDES permit begins with FL0). Only permits beginning with FL0 have the potential to directly discharge to surface waters, and none of these facilities discharges to the Upper Wakulla River. During the past decade, several treatment plants have changed their discharge point and or treatment process (**Table 4.1**).

Table 4.1. Department-Permitted Facilities in the Wakulla River Watershed (from Chelette et al. 2002)

FACILITY NAME	PERMIT NO.	COUNTY	FACILITY TYPE	OWNER TYPE	DESIGN CAPACITY	DISPOSAL METHOD	FACILITY STATUS*	DD_LAT	DD_LONG	DATUM
ARVAH B. HOPKINS GENERATING STATION	FL0025518	Leon	Industrial	City	1.87	Surface water	Active	30.4509	-84.3997	83
WOODVILLE ELEM SCHOOL	FLA010136	Leon	Domestic	Public	0.01	Reuse system	Active	30.3139	-84.2466	83
DISC VILLAGE WWTP	FLA010137	Leon	Domestic	Public	0.02	Spray	Active	30.3046	-84.2285	83
FORT BRADEN ELEMENTARY SCHOOL	FLA010138	Leon	Domestic	Public	0.011	Percolation	Active	30.4404	-84.5161	83
T P SMITH WATER RECLAMATION FACILITY	FLA010139	Leon	Domestic	Public	27.5	Spray	Active	30.3915	-84.3225	83
LAKE BRADFORD ROAD WWTP	FLA010140	Leon	Domestic	Public	4.5	Spray	Active	30.4262	-84.3014	83
TALLAHASSEE MUNICIPAL AIRPORT STP	FLA010141	Leon	Domestic	Public	0.06	Percolation	Active	30.4076	-84.3557	83
BORDEN INC. DISTRIBUTION CENTER	FLA010143	Leon	Industrial	Private				30.4306	-84.3361	
BUDGET RENT A CAR	FLA010144	Leon	Industrial	Private				30.4303	-84.3528	
CAPITAL EUROCARS, INC.	FLA010145	Leon	Industrial	Private				30.4569	-84.3572	
WESTVIEW MOBILE HOME PARK	FLA010146	Leon	Domestic	Private	0.015			30.4428	-84.4033	
LAKE BRADFORD ESTATES STP	FLA010148	Leon	Domestic	Private	0.036	Percolation	Active	30.4067	-84.3240	83
RAINBOW CAR WASH	FLA010149	Leon	Industrial	Private		Drainfield		30.4351	-84.3729	
PROCTOR ACURA	FLA010150	Leon	Industrial	Private				30.4585	-84.4543	
SOUTHERN BELL TRAILER PARK	FLA010151	Leon	Domestic	Private	0.015	Reuse system	Active	30.4579	-84.3737	83
WESTERN ESTATES MHP	FLA010152	Leon	Domestic	Private	0.02	Reuse system	Active	30.4351	-84.3729	83
LAFAYETTE KENNELS	FLA010153	Leon	Industrial	Private				30.4314	-84.1886	
COURTESY CARS	FLA010154	Leon	Industrial	Private	0.001	Drainfield	Active	30.4566	-84.3704	83
LEWISWOOD CENTER & SELF SVC STORAGE	FLA010155	Leon	Industrial	Private	0.0013	Drainfield	Active	30.3266	-84.2498	83
MIKE'S LAUNDRY	FLA010156	Leon	Industrial	Private	0.0027	Drainfield	Active	30.3181	-84.2486	83
LAKE JACKSON ANIMAL HOSPITAL	FLA010158	Leon	Industrial	Private	0.0005	Drainfield	Active	30.4940	-84.3255	83
MEADOWS-AT-WOODRUN WWTF	FLA010159	Leon	Domestic	Private	0.07	Reuse system	Active	30.4216	-84.1362	83
FLINT EQUIPMENT CO.	FLA010160	Leon	Industrial	Private		Recycle	Active	30.4582	-84.3817	83
ISLAND FOOD STORE, LTD.	FLA010161	Leon	Industrial	Private		Recycle	Active	30.4403	-84.3141	83
ISLAND FOOD STORE, LTD	FLA010162	Leon	Industrial	Private		Recycle	Active	30.4377	-84.2701	83
DOLLAR RENT A CAR	FLA010163	Leon	Industrial	Private		Recycle	Active	30.4025	-84.3518	83
JACKSON-COOK INC.	FLA010164	Leon	Industrial	Private				30.4389	-84.3347	
AMOCO/SING OIL CO.	FLA010165	Leon	Industrial	Private		Closed	Active	30.5648	-84.2145	83
G.W. HUNTER, INC. # 337 (CHEVRON)	FLA010166	Leon	Industrial	Private				30.4000	-84.2667	
SANDSTONE RANCH WWTF	FLA010167	Leon	Domestic	Private	0.0707	Percolation	Active	30.4347	-84.3954	83
SOUTHDOWN, INC. / TALLAHASSEE	FLA010168	Leon	Industrial	Private	0.8146	Percolation	Active	30.4344	-84.2988	83
DAVIS REFINING CORPORATION	FLA010169	Leon	Industrial	Private				30.4117	-84.3036	
LAKE JACKSON WWTF (AKA LAKEWOOD)	FLA010171	Leon	Domestic	Private	0.3	Reuse system	Active	30.5357	-84.3668	83
FALLSCHASE	FLA010172	Leon	Domestic	Private	0.175	Percolation	Active	30.4632	-84.2129	83
KILLEARN LAKES SUBDIVISION	FLA010173	Leon	Domestic	Private	0.7	Spray/perc	Active	30.5931	-84.2202	83

Table 4.1 (continued)

FACILITY NAME	PERMIT NO.	COUNTY	FACILITY TYPE	OWNER TYPE	DESIGN CAPACITY	DISPOSAL METHOD	FACILITY STATUS	DD_LAT	DD_LONG	DATUM
NATIONAL HIGH MAGNETIC FIELD LAB – FSU	FLA016533	Leon	Industrial	State	0.075	Spray	Active	30.4246	-84.3265	83
SOUTHDOWN, INC. / TALLAHASSEE	FLA016653	Leon	Industrial	Private		Percolation	Active	30.4350	-84.2969	83
SOUTHERN CONCRETE – TALLAHASSEE PLANT	FLA016709	Leon	Industrial	Private		Percolation	Active	30.3770	-84.2731	83
HERTZ EQUIPMENT RENTAL CORPORATION	FLA016876	Leon	Industrial	Private		Recycle	Under Construction	30.4359	-84.3639	83
ENTERPRISE CAR RENTAL	FLA016985	Leon	Industrial	Private		Recycle	Under Construction	30.4370	-84.3499	83
DIVISION OF FORESTRY DISTRICT OFFICE	FLA017296	Leon	Industrial	State		Recycle	Under Construction	30.4566	-84.3999	83
HYCREST DAIRY, INC.	FLA181803	Leon	Industrial	Private			Active	30.5263	-84.0254	83
NEFF RENTAL – TALLAHASSEE	FLA188590	Leon	Industrial	Private			Under Construction	30.3863	-84.2746	
BP OIL COMPANY	FLG910291	Leon	Industrial	Private		Drainfield	Active	30.4802	-84.3039	83
FDOT KATE IRELAND/FOSHALEE FARM	FLG910616	Leon	Industrial	State		Drainfield	Active	30.6605	-84.1897	83
FORMER NORTHSIDE CITGO	FLG910976	Leon	Industrial	Private		Drainfield	Active	30.4699	-84.3609	83
PRIMEX TECHNOLOGIES, INC.	FL0002518	Wakulla	Industrial	Private	0.79	Surface wat	Active	30.1810	-84.2201	83
SAM O. PURDOM GEN STATION	FL0025526	Wakulla	Industrial	City			Active	30.1630	-84.1992	83
MURPHY OIL CORPORATION	FL0032433	Wakulla	Industrial	Private		Spray	Active	30.1670	-84.2006	83
ST MARKS REFINERY	FL0035220	Wakulla	Industrial	Private	0.03	Surface wat	Active	30.1647	-84.2065	83
MCKENZIE SERVICE CO. INC.	FL0042161	Wakulla	Industrial	Private		Surface wat	Active	30.1600	-84.1992	83
WAKULLA COUNTY WWTF	FLA010225	Wakulla	Domestic	Public	0.2	Sprayfield	Active	30.0821	-84.4168	83
WAKULLA CO HIGH SCHOOL	FLA010226	Wakulla	Domestic	Public	0.018		Active	30.1063	-84.3749	83
SHADEVILLE ELEMENTARY WWTF	FLA010227	Wakulla	Domestic	Public	0.016	Percolation	Active	30.2150	-84.3203	83
WAKULLA COUNTY LAW ENFORCEMENT CTR	FLA010228	Wakulla	Domestic	Public	0.02			30.1929	-84.3722	83
WAKULLA MIDDLE SCHOOL	FLA010229	Wakulla	Domestic	Public	0.018	Reuse system	Active	30.1268	-84.3722	83
ACE COIN LAUNDRY	FLA010232	Wakulla	Industrial	Private	0.0068		Active	30.1846	-84.3745	83
MUDBUSTERS	FLA010233	Wakulla	Industrial	Private				30.2114	-84.3703	
OYSTER BAY ESTATES STP	FLA010237	Wakulla	Domestic	Private	0.06	Reuse system	Active	30.0670	-84.2967	83
WAKULLA MANOR	FLA010238	Wakulla	Domestic	Private	0.024	Reuse system	Active	30.0849	-84.3869	83
LAND OF WAKULLA D.B.A. QUIK LUBE	FLA010239	Wakulla	Industrial	Private			Active	30.2066	-84.3660	83
HANNON LIMESTONE PIT	FLA010240	Wakulla	Industrial	Private			Active	30.1603	-84.2918	83
RIVER PLANTATION ESTATES WWTP	FLA010241	Wakulla	Domestic	Private	0.025	Percolation	Active	30.2050	-84.2517	83
SHELL POINT STP	FLA010242	Wakulla	Domestic	Private	0.024	Percolation	Active	30.0587	-84.2895	83
WINCO UTILITIES, INC.	FLA016544	Wakulla	Domestic	Private	0.495	Sprayfield	Active	30.2566	-84.2184	83
ST. MARKS WWTF	FLA102318	Wakulla	Domestic	City	0.05	Industrial reuse		30.1532	-84.2076	
WAKULLA STATION CNTY CAFÉ & LAUNDROMAT	FLA185965	Wakulla	Industrial	Private	0.003		Under Construction	30.2329	-84.2304	83
SANDERS & SON INC CRAB PROCESSING FACILITY	FLA188824	Wakulla	Industrial	Private	0.0005		Active	30.0608	-84.4897	83
BROOKS CONCRETE	FLG110265	Wakulla	Industrial	Private			Active	30.0363	-84.2882	

Table 4.2. Nitrate Loads for Department Domestic Wastewater Facilities in the Wakulla Watershed (from Chelette et al. 2002)

FACILITY NAME	PERMIT NO.	COUNTY	METHOD	DATA SOURCE	FACTOR USED**	1992	1993	1994	1995	1996	1997	1998	1999
DISC VILLAGE WWTP	FLA010137	LEON	design flow factor	Wakulla High School	2	343	390	254	284	512	235		
FALLSCHASE	FLA010172	LEON	design flow factor	Wakulla County	0.87						1025*	2367*	
KILLEARN LAKES SUBDIVISION	FLA010173	LEON	design flow factor	Lake Jackson	1.17	5221	3676	4288	3916	3532	3076		
LAKE BRADFORD ESTATES STP	FLA010148	LEON	design flow factor	Shadeville Elem	2.25	346	634	235	204				
LAKE JACKSON WWTF	FLA010171	LEON	concentration sub	T.P. Smith		4462	3142	3665	3347	3018	2629		
MEADOWS-AT-WOODRUN WWTF	FLA010159	LEON	design flow factor	St. Marks	1.2		231						
T.P. SMITH	FLA010139	LEON				283431	193830	253445	202634	226619	258305	213391	222624
LAKE BRADFORD ROAD WWTP	FLA010140	LEON				127932	128941	96726	108424	87554	95080	124146	102184
TALLAHASSEE MUNICIPAL AIRPORT	FLA010141	LEON				1186	1436	1191	1179	1129	1058		
WOODVILLE ELEM SCHOOL	FLA010136	LEON	design flow factor	Shadeville Elem	0.62	95	175	65	56				
OYSTER BAY ESTATES STP	FLA010237	WAKULLA	design flow factor	St. Marks	1		193						
RIVER PLANTATION ESTATES WWTP	FLA010241	WAKULLA	design flow factor	Shell Point	1	220	147	96	100	206	141		
SHELL POINT STP	FLA010242	WAKULLA	concentration sub	T.P. Smith		220	147	96	100	206	141		
WAKULLA COUNTY WWTF	FLA010225	WAKULLA	concentration sub	T.P. Smith		2087	1861	1881	1963	1827	2085	1059	1853
SHADEVILLE ELEMENTARY WWTF	FLA010227	WAKULLA				154	282	104	90				
ST. MARKS WWTF	FL0040835	WAKULLA					193						
WAKULLA CO HIGH SCHOOL	FLA010226	WAKULLA	concentration sub	Shadeville Elem		172	195	127	142	256	118		
WAKULLA COUNTY LAW ENFORCEMENT CTR	FLA010228	WAKULLA				147	81	80	290	182	146	173*	
WAKULLA MANOR	FLA010238	WAKULLA				202*	301						
WAKULLA MIDDLE SCHOOL	FLA010229	WAKULLA	concentration sub	Shadeville Elem		190	230	112	82	78	122	108*	
WINCO UTILITIES, INC.	FLA016544	WAKULLA	concentration sub	T.P. Smith							478*	1313	1219

*Calculated from less than six months data
**Conversion factor based on design capacity

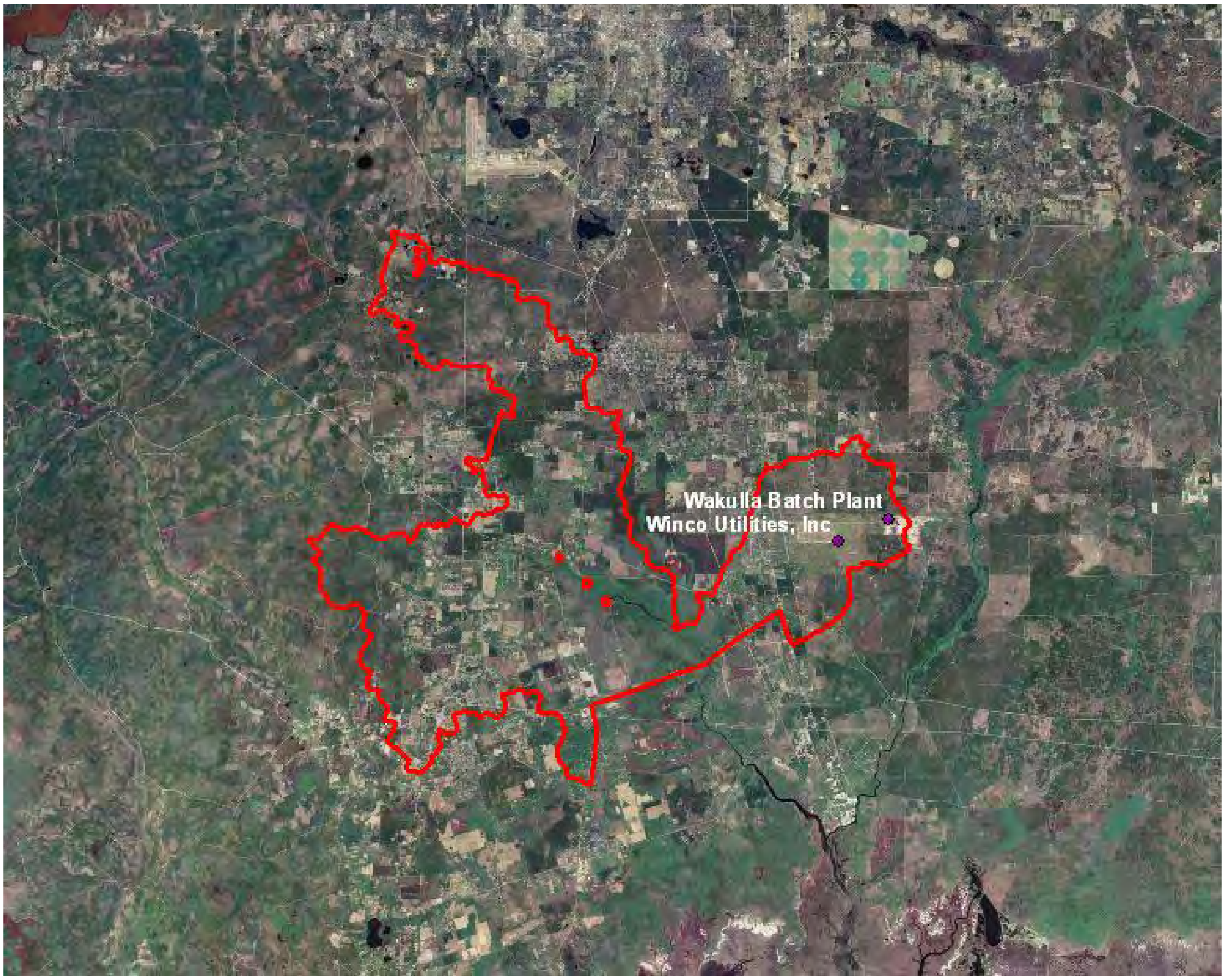

Figure 4.1. Wastewater Facilities in the Upper Wakulla River Watershed

From **Table 4.2**, it can be seen that nitrate loads from the COT domestic wastewater facilities (T.P. Smith and Lake Bradford Road) dominate the point source nitrate loads in the Wakulla River watershed, but none discharges directly to the Wakulla River.

The first domestic wastewater facility constructed by COT was a 1-million-gallon-per-day (mgd) facility built on Lake Bradford Road in 1933. This facility discharged to a tributary to Lake Munson (which flows to Ames Sink and has been connected by ground water dye studies to Wakulla Spring). In 1941, the U.S. Army Corps of Engineers (USACOE) completed a 1 mgd facility for Dale Mabry Field that COT took over and operated through 1982. In 1950, Lake Munson was impounded to alleviate downstream flooding. In 1951, a new 4.5 mgd facility was built on Lake Bradford Road. In 1961, a 0.06 mgd high-rate trickling-filter facility was constructed for the airport that discharged to rapid infiltration basins. As reported in Chelette, et. al., 2002, massive algal blooms began to be reported in Lake Munson in 1956 and 1963 (Beck 1963).

In 1964, COT completed a land swap with the U.S. Forest Service so that it could construct the Southwest Facility, a 2.5 mgd facility completed in 1966 that discharged to Munson Slough above Lake Munson. At this time, a 16-acre experimental spray irrigation site called the Southwest Sprayfield (SWSF) was completed and put into use, averaging 0.25 mgd. By 1969, the facility was receiving 1 mgd and by 1974, 3.5 mgd. At this point (1974), the WWTF capacity was exceeded, and the facility was expanded to 10 mgd and converted to an activated sludge process. This did not change the TN concentration. However, the changes in treatment process did alter the nitrate component of the TN, increasing the nitrate by a factor of 4 through the conversion of ammonia and TKN to nitrate. The SWSF was expanded in 1972 to 38.5 acres and again in 1977 to 118.5 acres.

In 1981, the 1,000-acre Southeast Sprayfield (SESF) was put into operation just south of the Cody Scarp on the Gulf Coastal Lowlands. In 1982, the SESF was expanded to 1,500 acres and to 1,896 acres in 1986. At this time, all treated wastewater disposal to the Lake Munson drainage basin was stopped. In 1999 the SESF was expanded to 2,159 acres. From 1977 on, the SWSF was progressively reduced in size to the 89 acres currently in operation.

Berndt (1990) investigated the sources and distribution of nitrate at the SESF while it was being farmed and nitrate containing fertilizer was being applied. The results indicated that all ammonia and organic nitrogen applied to the sprayfield were converted to nitrate before the effluent plume reached the top of the water table. It was reported that nitrate entering the surficial aquifer under the SESF is primarily transported downward. The results for phosphorus indicated that the phosphorus was retained by organic matter in the soils and sediments.

Katz *et al.* (2010) reported on the ground water quality impacts from the land application of treated municipal wastewater at the SESF. They concluded that there were elevated concentrations of boron, chloride, and nitrate downgradient of the sprayfield and that the downgradient sampling wells had isotopic signatures similar to the wastewater effluent. They reported that the effluent applied to the SESF at the time of the study contained 8.8 mg/L of TKN (ammonia and organic nitrogen) and 7.6 mg/L nitrate. The TKN measured in the UFA was below detection at the downgradient well locations. It has been reported (Berndt 1990) that ammonium and organic nitrogen can be converted to nitrate in the upper portion of the unsaturated zone (just below the root zone).

Katz *et al.* (2010) noted that once nitrate applied to the land surface is incorporated within the UFA, "It appears to move relatively conservatively in the UFA as far south as the Wakulla B Tunnel." These data for chloride and nitrate indicate about a tenfold dilution in concentration from the SESF to Wakulla Spring. The authors reported that both Wakulla B Tunnel and Sally Ward Spring show a greater dilution factor than Wakulla Spring, indicating additional mixing with water from matrix-dominated flow in these locations.

Katz *et al.* (2010) noted that the effluent is released onto the land surface and must pass through a "native reactive barrier" composed of 10 million to 1 billion bacterial cells (~10,000 bacterial types) per gram of soil within the top several centimeters of the land surface (cited Whitman *et al.* 1998; and Torsvik *et al.* 2002). This native reactor zone is functioning as a natural bioremediation area. They further note that septic tank leachate is introduced into the environment below this zone and with no disinfection.

Additionally, Katz *et al.* (2010) report that, based on the results from dye studies from Kincaid (2010), indicates hydraulic connectivity between the SESF and Wakulla B Tunnel. Based on the pattern of peak dye concentrations recorded at the B Tunnel and the different springs, a complex flow path is indicated; these areas are “dominated by a pattern of conduits in the vicinity of the SESF and matrix-dominated slower flow zones.” The average travel time to the springs and B Tunnel was calculated as about two months. All of these sources are considered nonpoint sources and will be addressed as part of the load allocation portion of the TMDL.

4.2.2 Domestic Wastewater Residuals

Chelette *et al.* (2002) reported that the COT residual disposal between 1977 and 2000 varied from a low in 1979 of 70,252 kg-TN/yr to a high in 2000 of 185,851 kg-TN/yr. The residuals are applied at sites located near the Tallahassee Regional Airport. In 1996, COT started the land application of residuals at 3 farms in Wakulla County. In 2001, this practice was stopped.

4.2.3 Municipal Separate Storm Sewer System Permittees

Within the Wakulla River watershed, the stormwater collection systems owned and operated by Leon County, COT, and FDOT District 3, within Leon County are covered by Phase I NPDES municipal separate storm sewer system (MS4) permits. Leon County and FDOT are co-permittees (FLS000033), while COT (FLS000034) is the other major permit holder. Phase II permits are held by FSU (FLR04E051), Florida A&M University (FLR04E095), and Federal Correctional Institution (FLR04E096).

Figure 4.2 depicts the boundaries of the various MS4 permit holders. There are no direct contributions from these MS4 areas to the Upper Wakulla watershed (WBID 1006). While these existing MS4 entities are not currently being assigned a specific allocation or reduction, those values may become known as part of the BMAP process.

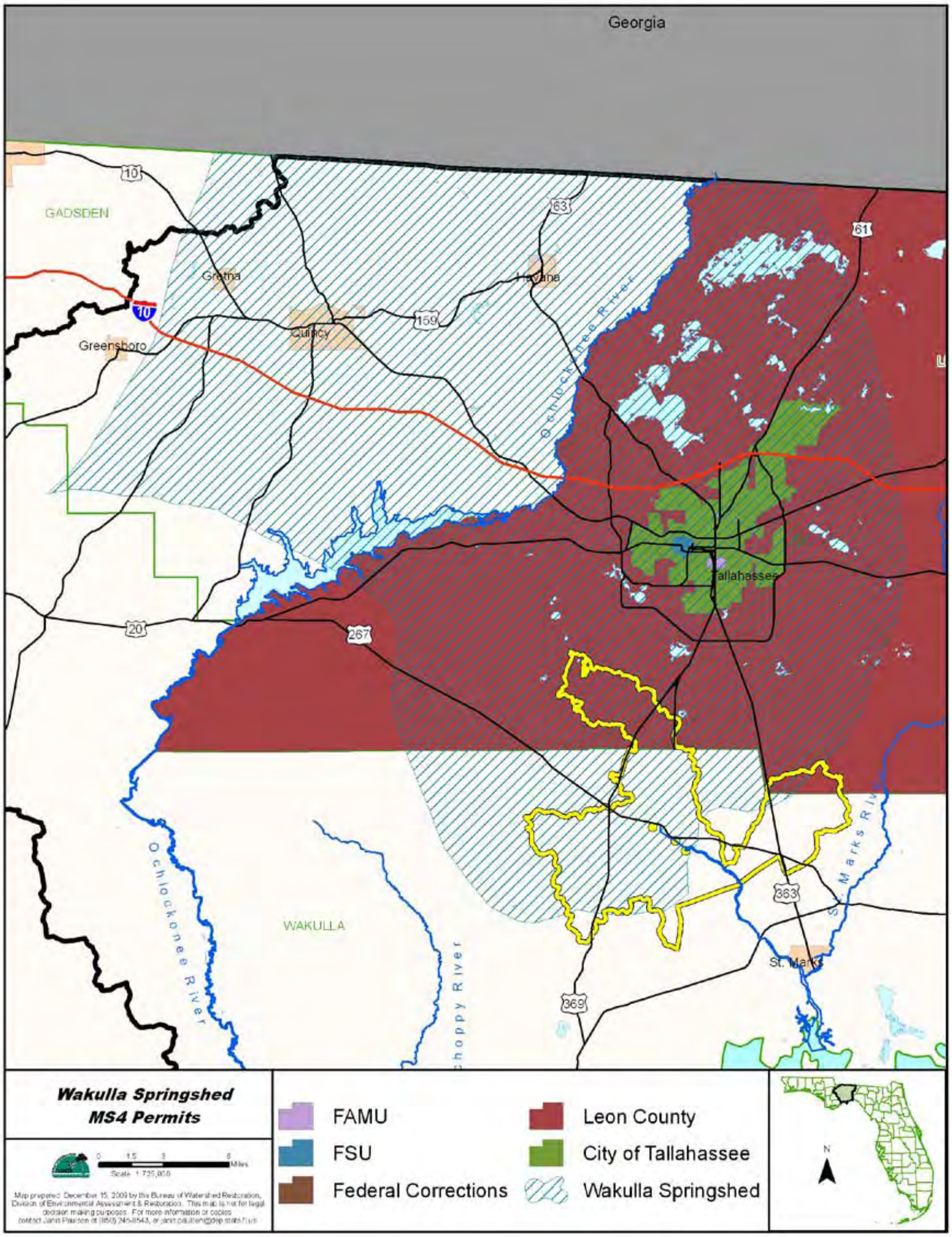

Figure 4.2. MS4 Boundaries

4.2.4 Land Uses and Nonpoint Sources

Additional nutrient loadings to the Upper Wakulla River are generated from nonpoint sources in the watershed. Potential nonpoint sources of nutrients can be characterized by their pathway or delivery to the river, such as tributary runoff, ground water, sediment nutrient release, and atmospheric deposition. They can also be described by the type of land use where the sources are generated.

Land Uses

The spatial distribution (by Hydrologic Unit Code [HUC]) and acreage of different land use categories in Florida were identified using the 1997 land use coverage (scale 1:40,000) contained in the Department's geographic information system (GIS) library. Land use categories in Leon and Wakulla Counties were aggregated using the simplified Level 1/Level 3 codes tabulated in **Tables 4.3a** and **4.3b**. **Figure 4.3** shows the acreage of the principal land uses in the WBID.

Table 4.3a. Classification of Land Use Categories for Leon County in 1997

- = Empty cell/no data

Code	Land Use	Acreage	Square Miles	% of Watershed
1000	Urban Open	15,013	23.458	3.3429%
1100	Low-Density Residential	18,875	29.492	4.2028%
1200	Medium-Density Residential	16,540	25.844	3.6829%
1300	High-Density Residential	27,457	42.903	6.1138%
2000	Agriculture	35,515	55.492	7.9079%
3000+7000	Rangeland	4,427	6.9172	0.9857%
4000	Forest/Rural Open	242,830	379.42	54.069%
5000	Water	13,574	21.210	3.0225%
6000	Wetlands	70,572	110.27	15.714%
8000	Communication and Transportation	4,305.7	6.7276	0.9587%
-	**Total**	**449,110**	**701.73**	**100.00%**

Table 4.3b. Classification of Land Use Categories for Wakulla County in 1997

- = Empty cell/no data

Code	Land Use	Acreage	Square Miles	% of Watershed
1000	Urban Open	1,543.7	2.4120	0.3983%
1100	Low-Density Residential	16,381	25.596	4.2270%
1200	Medium-Density Residential	4,830.7	7.5481	1.2465%
1300	High-Density Residential	197.92	0.3092	0.0511%
2000	Agriculture	6,920.3	10.813	1.7857%
3000+7000	Rangeland	6,680.2	10.438	1.7237%
4000	Forest/Rural Open	198,850	310.71	51.312%
5000	Water	6,101.7	9.5339	1.5745%
6000	Wetlands	144,360	225.56	37.250%
8000	Communication and Transportation	1,673.6	2.6150	0.43190%
-	**Total**	**387,539**	**605.54**	**100.0%**

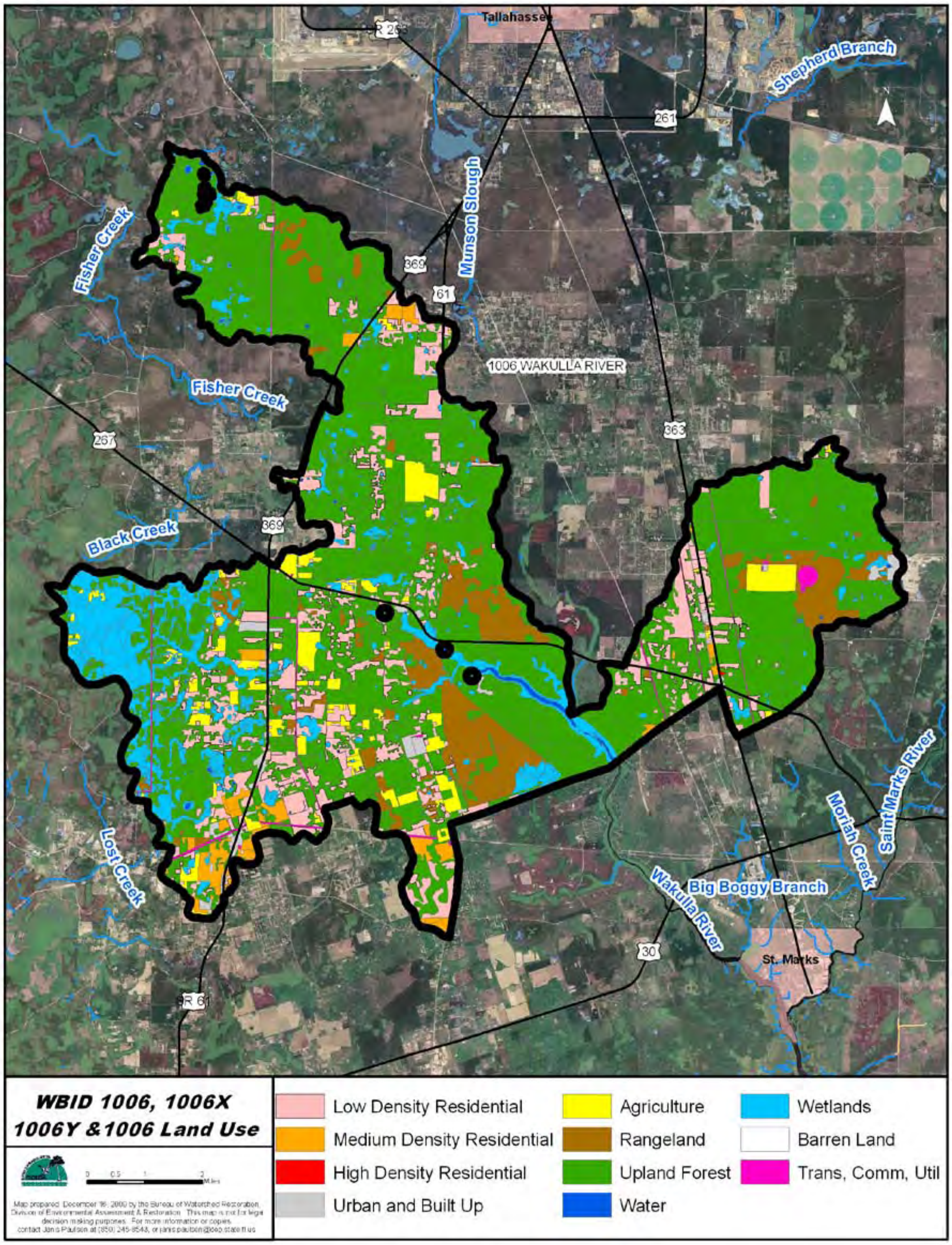

Figure 4.3. Principal Land Uses in the Upper Wakulla River Watershed (WBIDs 1006, 1006X, and 1006Y) in 1997

Population

The U.S. Census Bureau reports that in Leon County, the total population for 2000 was 239,452, with 96,521 households (HH) and 103,974 housing units (HU). For all of Leon County (**Figure 4.4**), the Bureau reported a housing density of 144.8 HH per square mile (155.9 HU per square mile), placing Leon County among the highest in housing densities in Florida (U.S. Census Bureau website 2007). This is also supported by land use data showing that 17.342% of land use in Leon County is dedicated to urban and residences.

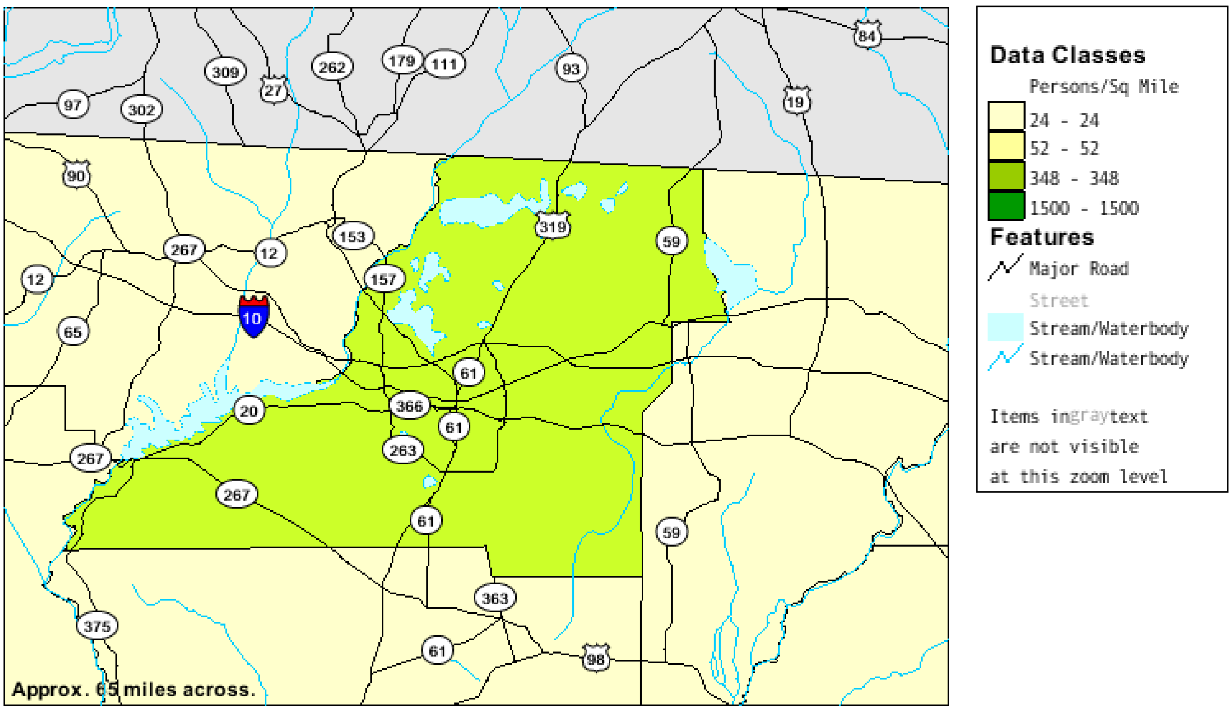

Figure 4.4. Population Density in Leon County, Florida, in 2000

The Census Bureau reports that in Wakulla County, the total population for 2000 was 22,863, with 8,450 households (HH) and 9,820 housing units (HU). For all of Wakulla County (**Figure 4.5**), the Bureau reported a housing density of 16.2 HU per square mile, placing Wakulla County among the lowest in housing densities in Florida (U.S. Census Bureau website 2007). This is also supported by land use data showing that only 5.92% of land use in Wakulla County is dedicated to urban and residences.

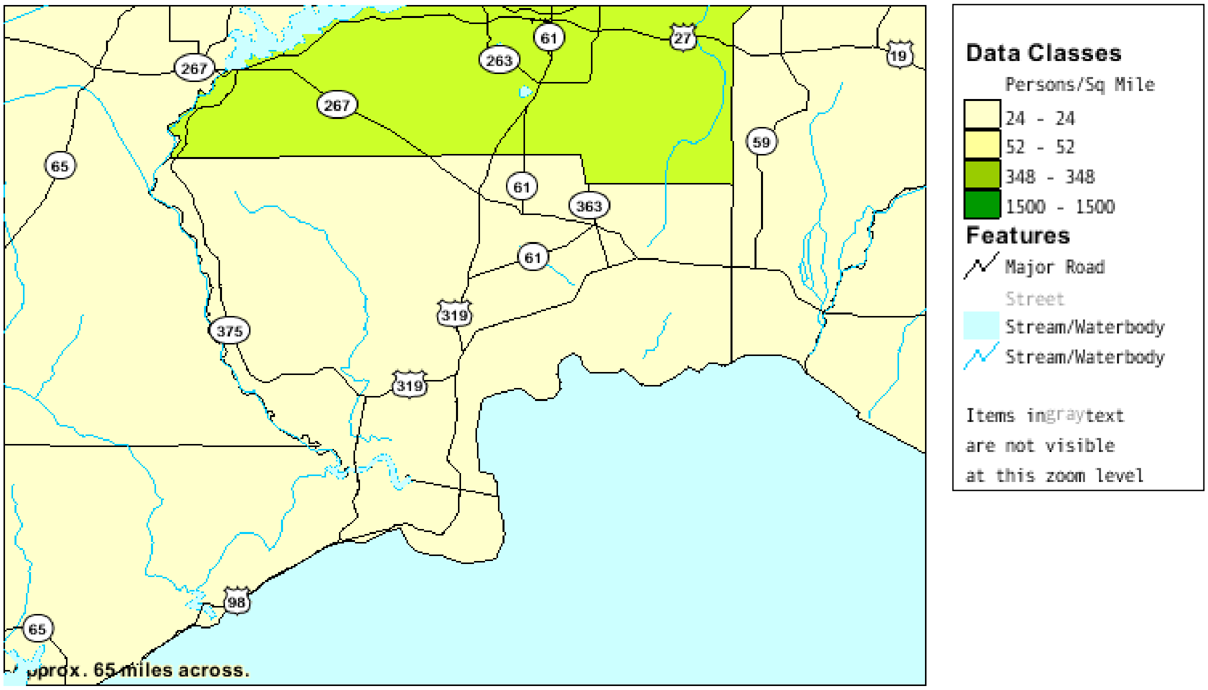

Figure 4.5. Population Density in Wakulla County, Florida, in 2000

Nonpoint Sources

Septic Tanks

Onsite sewage treatment and disposal systems (OSTDS), including septic tanks, are commonly used where providing central sewer is not cost-effective or practical. When properly sited, designed, constructed, maintained, and operated, OSTDS are a safe means of disposing of domestic waste. The effluent from a well-functioning OSTDS is comparable to secondarily treated wastewater from a sewage treatment plant. When not functioning properly, OSTDS can be a source of nutrients, coliforms, pathogens, and other pollutants to both ground water and surface water.

As of 2006, Leon County had roughly 38,530 septic systems (Florida Department of Health [FDOH] website 2008). Data for septic tanks are based on 1970 to 2007 FDOH Census results, with year-by-year additions based on new septic tank construction. The data do not reflect septic tanks that have been removed going back to 1970. From 1991 to 2006, 5,849 permits (389.9/year) for repairs were issued (FDOH website 2008). Based on the number (81,325) of housing units (HU) located in the county (U.S. Census Bureau 1990), approximately 58,881 (72.40%) of the HU are connected to a WWTF, with the remaining 22,090 (27.16%) using septic tanks or cesspools, and 354 (0.44%) using other systems.

As of 2006, Wakulla County had roughly 10,481 septic systems (FDOH website 2008). Data for septic tanks are based on 1970 to 2007 FDOH Census results, with year-by-year additions based on new septic tank construction. The data do not reflect septic tanks that have been removed going back to 1970. From 1991 to 2006, 1,498 permits (299.6/yr) for repairs were issued (FDOH website 2007). Based on the number (6,587) of housing units (HU) located in the county (U.S. Census Bureau 1990), approximately 702 (10.66%) of the HU are connected to a WWTF, with the remaining 5,645 (85.70%) using septic tanks or cesspools, and 240 (3.64%) using other systems.

Hicks 2010, (personal communication) provided information based on data from the Wakulla County septic tank study (Harden *et al.* 2010), conducted by FSU's Department of Earth, Ocean, and Atmospheric Science. The study results indicated that the highest density of septic tanks in the Wakulla Spring capture zone (springshed) is in the Woodville area (**Figure 1.4**) of southern Leon and northern Wakulla Counties. FSU researchers injected a dye (sulfur hexafluoride) into 2 shallow wells (17.5 and 37.5 feet deep). The 2 wells were drilled to the first cavity in the limestone below the water table using a solid pipe with an opening at the bottom. Samples were collected at Wakulla Spring, Sally Ward Spring, Indian Springs, and Double Springs (just northeast of the state park). Samples were also collected from Wakulla Spring Tunnels B, C, and D; the A/D Tunnel junction; K Tunnel; and the A/K Tunnel junction.

Dye was recovered in Wakulla Spring, Sally Ward Spring, Indian Springs, and the 6 tunnels. However, no dye was recovered at Double Springs. Peak dye concentrations were measured at Wakulla Spring after 92 days, 99 days at the A/D Tunnel junction,105 days for the C Tunnel, more than 113 days for Sally Ward Spring and K Tunnel, 119 days for the A/K Tunnel junction and the B and D Tunnels, and 133 days for Indian Springs.

Based on distances from the 2 wells (5.2 and 6.0 miles) to Wakulla Spring, the dye traveled at a rate of about 327 feet (100 meters) per day. Harden *et al.* (2010) note that the SESF dye studies (Hazlett-Kincaid [HKI] 2007) reported rates of 640 to 671 feet per day, about twice the rate of the Woodville septic tank study. They note that "the difference in reported flow rates is most likely due to the different depths of the tracer injection wells in the two studies." In the Hazlett-Kincaid study, the tracers were injected into wells at the SESF at depths between 88 and 194 feet, much deeper than the 17.5 to 37.5 feet for the 2 shallow wells used in the Wakulla County septic tank study.

A draft report, *Fate of Effluent-Borne Contaminants Beneath Septic Tank Drainfields Overlying a Karst Aquifer* (Katz *et al.* 2010), was also reviewed. Based on the results from 3 different drainfields in the Wakulla Karst Plain (WKP), the median nitrate concentration beneath the drainfields was 19 mg/L. Of the TN, 25% to 40% was removed by a combination of denitrification, ammonium sorption, and ammonia volatilization as the effluent moved through the unsaturated zone to the top of the aquifer. Dilution was estimated from changes in chloride concentrations to account for about 25% of the total reduction in nitrogen. The calculated nitrate loading to ground water ranged from 3.9 to 12 kg/yr/septic tank. For each 10,000 septic tanks, the annual loading of nitrate to ground water ranged from 39,000 to 120,000 kg/yr. The authors note that while there were only 3 septic tank systems sampled, these were representative of systems installed within the WKP. Chelette *et al.* (2002) reported 10-year average (1990–99) TN loading from the unconfined portion of the watershed as 111,000 kg/yr. Davis *et al.* (2009) reported that total nitrate loadings for 2007 ranged between 180,000 and 300,000 kg/yr. Of this, 11% to 22% (19,800 to 66,000 kg/yr) was attributed to septic tanks.

Given that these studies have different forms of nitrogen (total versus nitrate), areas, times, and methods, the results appear fairly consistent. In all cases, nitrate loadings for septic tanks make up a significant fraction of the total nitrate budget. Modeling conducted by Davis *et al.* (2009) indicates that the percentage of the total nitrate loading to the WKP represented by septic tanks may increase over time, even as the loading from the SESF decreases as a result of improvements in treatment that COT is proposing for implementation.

Livestock

The NWFWMD (Chelette *et al.* 2002) reported the 10-year average TN load (1990–99) from livestock was 157,000 kg/yr (6% of the total).

Fertilizer

The NWFWMD (Chelette *et al.* 2002) reported the 10-year average TN load (1990–99) from commercial fertilizer was 315,000 kg/yr (12%).

Atmospheric Deposition

The NWFWMD (Chelette *et al.* 2002) reported the 10-year average TN load (1990–99) from atmospheric deposition was 1,294,000 kg/yr (49%). Care must be taken to consider atmospheric loadings directly onto surface water separate from landscape loadings to avoid doublecounting the direct loadings onto the water surface.

Sinking Streams

Chelette *et al.* (2002) evaluated several sinking streams, including Munson Slough, Fisher Creek, Black Creek, and Lost Creek. The combined 10-year average TN load from the streams was estimated at 72,000 kg/yr (~3%). The study concluded that the effect on Wakulla Spring from these sinking streams is thought to be temporary in response to large rainfall events.

4.3 Summary of Sources

Tables 4.4 and **4.5** summarize the nitrate loadings to the land surface as calculated by Chelette *et al.* (2002) (TN) and Davis *et al.* (2009), respectively. Both reports note that atmospheric deposition is one of the largest sources to the land surface. Other significant sources include the T.P. Smith wastewater facility, ground water above the Cody Scarp, and septic tank contributions.

Table 4.4. Summary of TN Applied to Land Surface (Not in Ground Water) (from Table 12, Chelette et al. 2002)

Notes: Information in boldface within the shaded area comprises the totals for Munson Slough, Fisher Creek, Black Creek, and Lost Creek.
- = Empty cell/no data

Category	Semi-confined 1999 (Kg-TN/Yr)	Unconfined Leon 1999 (Kg-TN/Yr)	Unconfined Wakulla 1999 (Kg-TN/Yr)	Total Unconfined 1999 (Kg-TN/Yr)	Total 1999 (Kg-TN/Yr)	% Total 1999	1990–99 (Average Kg-TN/Yr)	1990–99 (Average %)
Atmospheric Deposition	479,000	-	-	523,000	1,002,000	45%	1,294,000	49%
Ground Water above Cody Scarp	-	-	-	-	-	-	-	-
COT T.P. Smith WWTF	-	-	-	331,000	331,000	15%	371,000	14%
COT Lake Bradford WWTF	9,000	-	-		9,000	0.40%	-	-
COT Residual (1977–2000)	-	-	-	177,000	177,000	8%	154,000	6%
Septic Tanks Combined	-	-	-	-	-	-	283,000	11%
Leon Septic Tank 1999	172,000	42,000	-	42,000	214,000	10%	-	-
Wakulla Septic Tank 1999	-	-	69,000	69,000	69,000	3%	-	-
Commercial Fertilizer	150,000	44,000	18,000	62,000	212,000	9%	315,000	12%
Livestock	124,000	10,000	23,000	33,000	157,000	7%	157,000	6%
Munson Slough	-	13,600	-	13,600	13,600	1%	**72,000**	**3%**
Fisher Creek	-	-	13,200	13,200	13,200	1%	**-**	**-**
Black Creek	-	-	5,800	5,800	5,800	0%	**-**	**-**
Lost Creek	-	-	39,600	39,600	39,600	2%	**-**	**-**
Other	-	-	-	-	-	-	-	-
Total	**934,000**	**109,600**	**168,600**	**1,309,200**	**2,243,200**	**100%**	**2,646,000**	**100%**

Table 4.5. Summary of Nitrate Load to Basin (Davis et al. 2009)

Notes: Information in boldface within the shaded area comprises the totals for Munson Slough, Fisher Creek, Black Creek, and Lost Creek.
- = Empty cell/no data

Source	40,000 to 60,000 kg-NO3/yr 1966 (%)	250,000 to 400,000 kg-NO3/yr 1987 (%)	180,000 to 300,000 kg-NO3/yr 2007 (%)	160,000 to 260,000 kg-NO3/yr 2018 (%)
Atmospheric Deposition	21% - 43%	-	-	-
Ground Water above Cody Scarp	22% – 44%	6% – 14%	13% – 29%	22% – 44%
COT T.P. Smith WWTF	-	47% – 71%	33% - 57%	13% – 29%
COT Lake Bradford WWTF	-	-	-	-
COT Residual (1977–2000)	-	7% – 18%	-	-
Septic Tanks Combined	5% – 13%	5% – 14%	11% – 26%	16% – 35%
Leon Septic Tank 1999	-	-	-	-
Wakulla Septic Tank 1999	-	-	-	-
Commercial Fertilizer	-	-	-	-
Livestock	-	-	-	-
Munson Slough	**5% – 12%**	-	-	-
Fisher Creek	-	-	-	-
Black Creek	-	-	-	-
Lost Creek	-	-	-	-
Other	<10%	<10%	<10%	<10%

Chapter 5: DETERMINATION OF ASSIMILATIVE CAPACITY

Often the Department uses hydraulic and water quality models to simulate loading and the effect of the loading within a given waterbody. However, there are other appropriate methods to develop a TMDL that are just as credible as a modeling approach. Such an alternative approach was used to estimate existing conditions and calculate a TMDL for the Upper Wakulla River (WBID 1006).

5.1 Determination of Loading Capacity

Ideally, the target loading and existing loading for a stream or watershed is based on hydrologic and water quality modeling. Many of these models depend on the relationship between flow and surface water drainage area, as well as the relationship between land use and soils and pollutant delivery. These direct relationships are not well-defined for the Wakulla River watershed, and the use of an alternative approach for establishing the nutrient TMDL was deemed necessary.

Existing stream loading can be estimated by multiplying the measured stream flow by the measured pollutant concentrations in the stream. To estimate the pollutant loading this way, synoptic flow and concentration data measured at the outlet of each stream segment under investigation are required. These data were not available for all sources covering the same period. The Department considered the feasibility of using the available flow measurements to estimate the flow at each segment outlet based on the drainage area ratio among these stream segments. This method would normally provide an approximation of flow estimates at the stream segment outlets.

However, because of the large number of sinks and springs in the Wakulla River watershed, flow estimation based on drainage area ratio will not give an accurate result. Estimates of current nutrient loads from Wakulla Spring could still be made based on spring flow and concentration. As both current and TMDL loads would be generated from the same flow data, there would be a straight linear relationship between the two estimates.

Therefore, the loads of nitrate were not explicitly calculated. Instead, the percent load reduction required to achieve the nitrate concentration target was calculated assuming the percent loading reduction would be the same as the percent concentration reduction. The percent reduction required to achieve the water quality target was calculated using the following formula:

[(existing mean concentration – target concentration)/existing mean concentration] x 100

5.2 TMDL Development Process

5.2.1 Nitrate (NO_3) Target

The target nitrate concentration for the Upper Wakulla watershed (WBID 1006) was established based on several lines of evidence, including (1) carrying out laboratory nutrient amendment bioassays; (2) comparing metabolic rates, specifically, the ecological efficiency, of aquatic communities; (3) examining the ecological condition of algae and nutrients in the Florida Springs Report; and (4) examining the relationship between periphyton biomass and cell density and the nitrate concentration from studies in the nearby Suwannee and Santa Fe River Basins.

5.2.2 Laboratory Nutrient Amendment Bioassays

The nutrient amendment bioassay work was conducted by Cowell and Dawes (2004), who examined the required nitrate concentration in the Rainbow River, Marion County, Florida, to achieve a reduction of biomass of *Lyngbya wollei*. *L. wollei* is a nuisance blue-green benthic algal species that dominates the Rainbow River due to elevated nitrate concentrations. Using *Lyngbya* cultures incubated in a series of nitrate amendments, Cowell and Dawes (2004) found that, at the end of the nutrient amendment experiments, both the biomasses and growth rates were low in treatment groups, with nitrate concentration at or below 0.30 mg/L, while the growth rates and biomass were significantly higher in treatments with nitrate concentrations at or higher than 0.60 mg/L. The experiment also showed that the biomass and growth rate in the 0.30 and 0.070 mg/L treatment groups were similar, suggesting that the further reduction of nitrate concentration below 0.30 mg/L probably would not achieve a dramatic further reduction of *L. wollei*.

5.2.3 Relationship between Ecological Efficiency and Nitrate Concentration

As contained in the 2006 "Wekiva River and Rock Springs Run Pollutant Load Reduction Goals" publication, Wetland Solutions, Inc. (WSI) studied the effects of nutrient concentrations on the community metabolic rates in the Wekiva River (WR), Rock Springs Run (RSR), Alexander Springs Creek (ASC), and Juniper Creek (JC). The gross community primary production, community respiration, net primary production, and ecological efficiency were measured and examined. The community metabolic parameter shown to have a significant functional relationship with nutrient concentrations was ecological efficiency, which is defined as the quotient between the rate of gross primary productivity (GPP) and the incident photosynthetically active radiation (PAR) during a specified interval. It is an ecosystem-level property that estimates the overall efficiency of an aquatic ecosystem to use incident solar radiation. **Figure 5.1** shows the correlation between ecological efficiency and nitrate concentration.

The target ecological efficiency defined using this method is 0.25 grams of oxygen per mole (g O2/mol). Using the ecological efficiency nitrate concentration equation defined in **Figure 5.1**, the target nitrate concentration is 0.293 mg/L.

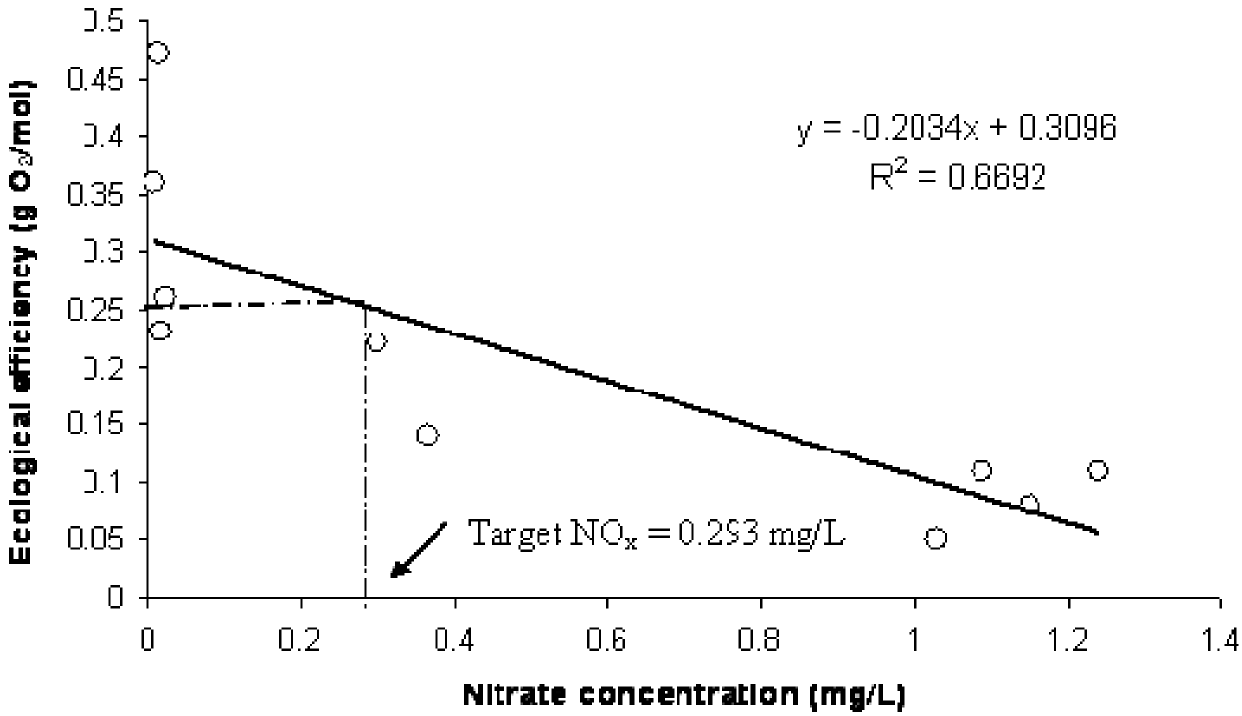

Figure 5.1. Correlation between Ecological Efficiency and Nitrate Concentration in the Wekiva River, Rock Springs Run, Alexander Springs Creek, and Juniper Creek

5.2.4 Examining the Ecological Condition of Algae and Nutrients in the Florida Springs Report

The saturating concentration (i.e., the nutrient concentration at which macroalgae growth is predicted to be elevated by 90% above the level for which no effects of nutrient reduction would be expected) was reported (Stevenson *et al.* 2007) for two species of macroalgae (*Lyngbya wollei* and *Vaucheria* spp) documented to produce extensive algal mats. Surveys of Florida springs indicated that almost all springs had macroscopic algae growing in them, an average of 50% of the spring bottoms were covered by macroalgae, and the thickness of macroalgal mats was commonly 0.5 meters (m) and as thick as 2 m in one spring boil. *Lyngbya wollei* and *Vaucheria* spp. were the 2 most common taxa of macroalgae that occurred in areas with extensive growths in the studied springs; however, 23 different macroalgal taxa were observed in the spring survey.

The study involved both field and laboratory components. In the field experiments, excessive growth and cover of *Vaucheria* were found at sites with nitrate-nitrite concentrations at or above 0.454 mg/L. In the laboratory experiments, the taxa *L. wollei* and *Vaucheria* spp. were found to have saturating nitrate concentrations of 0.230 and 0.261 mg/L, respectively (Stevenson *et al.* 2007). Twenty-eight springs throughout Florida were studied, including Camp Indian Springs and Wakulla Spring, both located within the Upper Wakulla River (**Figure 5.2**).

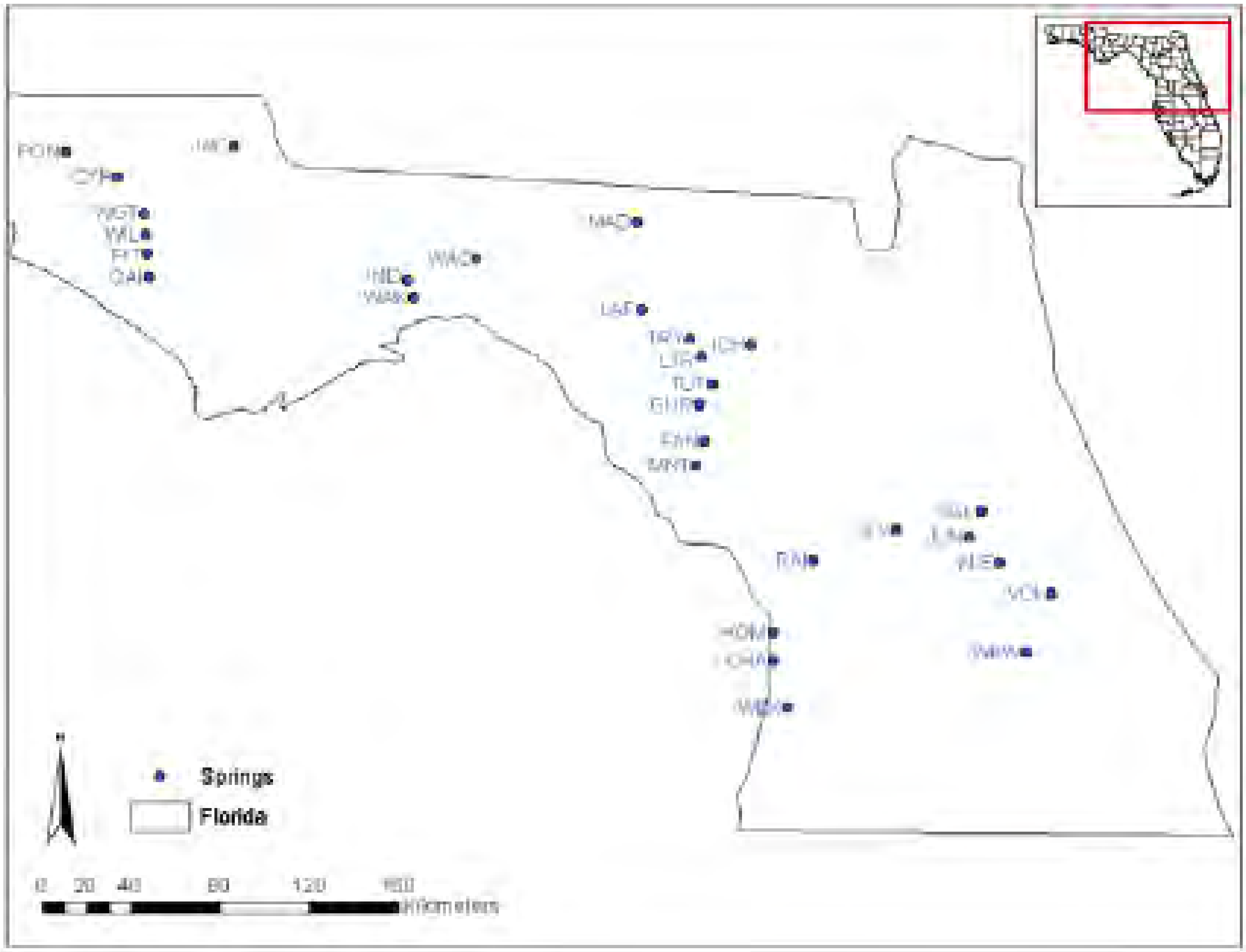

Figure 5.2. Springs Included in the Florida Springs Report (Stevenson et al. 2007)

5.2.5 Relationship between Periphyton Biomass and Cell Density and Nitrate Concentration

The nitrate target suggested by the Rainbow River study was corroborated by the findings of Hornsby *et al.* (2000), who evaluated periphyton and water quality data collected from the Suwannee River and 2 tributaries, the Withlacoochee River and Santa Fe River. Much of the length of the Suwannee River was heavily influenced by spring inflow. Hornsby *et al.* (2000) showed positive correlations for both periphyton biomass versus nitrate concentration and cell density versus nitrate concentration. The functional relationships of periphyton biomass (represented as ash free dry mass, or AFDM) versus nitrate concentration and cell density versus nitrate concentration are shown in long-term average biomass, cell densities, and nitrate concentrations measured at 13 stations across the Suwannee River system (including the Withlacoochee and Santa Fe Rivers) (**Figure 5.3**).

Figure 5.3. Change Point Study Sites

To further define the nitrate concentration that may significantly impact the periphyton biomass and cell density per unit increase of nitrate concentration, the Department contracted with Dr. Xufeng Niu of FSU's Department of Statistics to conduct a change-point analysis for a dataset of 13 long-term periphyton monitoring sites over the 1990 to 2007 period provided by the Suwannee River Water Management District (SRWMD). The applied method fits a step-function through observed data by examining the probability of each data point as the change-point. A nitrate concentration change point was identified (at a 5% significance level) if the change of cell density or periphyton biomass caused by the nitrate concentration was 3.5 times higher (the T-test critical value) than the standard error of the change of cell density or periphyton biomass.

The identified step-function (the change-point model) was also compared with linear regression and nonlinear regression models for its goodness-of-fit and the extent of overfitting based on the Bayesian Information Criterion (BIC). For both periphyton cell density and periphyton biomass, change-point step functions were shown to be the best model among those tested. This supports the use of the change-point model identified in the T-test. **Appendix C** provides details of the change-point analyses. For both methods based on these analyses, the major changes in mean abundance and mean biomass happened at a mean NOx around 0.441 mg/L (**Figures 5.4** and **5.5**).

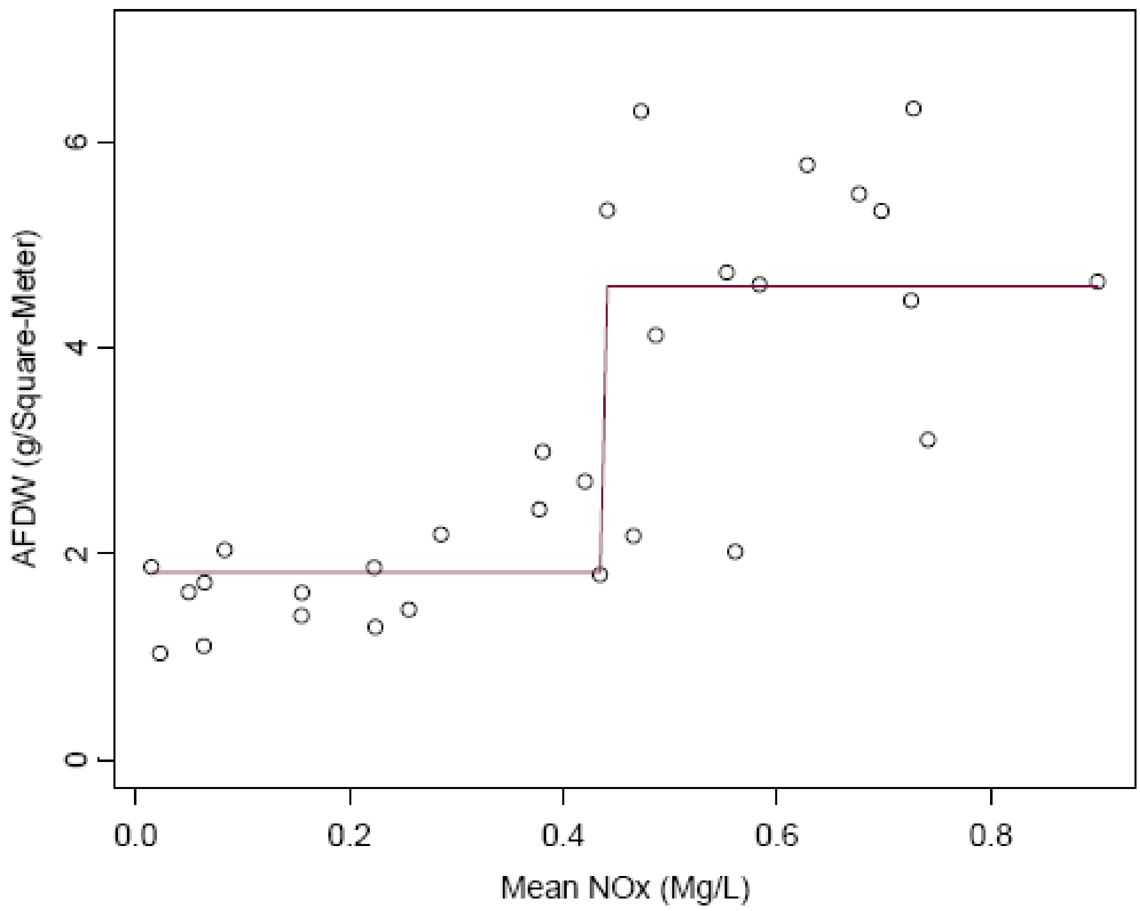

Figure 5.4. Relationship between Mean Nitrate Concentration and Mean Periphyton Biomass from 12 Sampling Sites on the Suwannee, Santa Fe, and Withlacoochee Rivers

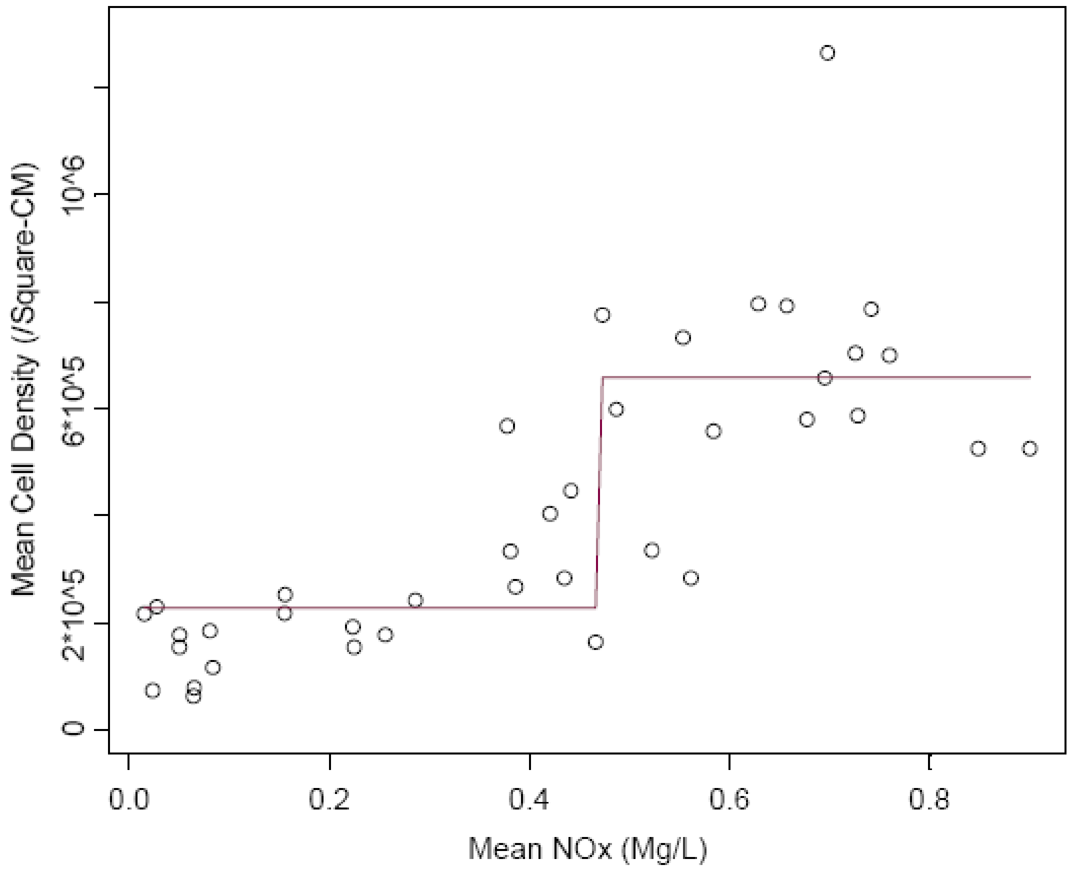

Figure 5.5. Relationship between Mean Nitrate Concentration and Mean Periphyton Cell Density from 12 Sampling Sites on the Suwannee, Santa Fe, and Withlacoochee Rivers

When explaining the functional relationship between cell density and nitrate concentration, the change-point step function identified 2 cell density levels (Table 2 in **Appendix C**). One level is about 218,732 cells/cm^2 (P = 0.00), and the other is about 218,732 + 427,894 = 646,626 cells/cm^2 (P = 0.0001). In this study, the 218,732 cells/cm^2 was considered the baseline condition under which no significant nitrate impact was detected.

The nitrate concentration that significantly changed the cell density level from 218,732 to 646,626 cells/cm^2 was identified by the change-point step function as 0.441 mg/L, indicating that, to prevent periphyton cell density from switching to the higher level, the nitrate concentration should not exceed 0.441 mg/L. In addition, the cell density switch occurred when the nitrate concentration reached 0.441 mg/L.

Based on the functional relationship between periphyton biomass and nitrate concentration, the change-point step function identified two biomass levels (Table 4 in **Appendix C**). One level is about 1.82 g/m^2 (P = 0.00), and the other level is about 1.82 + 2.97 = 4.79 g/m^2 (P = 0.00). In this study, the 1.82 g/m^2 was considered the baseline condition under which no significant nitrate impact was detected. The nitrate concentration that significantly changed the biomass level from 1.81 to 4.79 g/m^2 was identified by the change-point step function as 0.441 mg/L, indicating that, to prevent the periphyton biomass from switching to the higher level, the nitrate concentration should not exceed 0.441 mg/L. In addition, the highest observed nitrate concentration that allowed the biomass baseline condition was 0.441 mg/L (**Appendix C**).

5.2.6 Target Setting

Based on the above lines of evidence, nitrate was the primary factor causing elevated growth at levels above 0.230 to 0.263 mg/L. Nuisance accumulations of *Vaucheria* occurred at nitrate-nitrite concentrations at or above 0.454 mg/L. Nitrate concentrations lower than 0.441 mg/L should be appropriate to maintain periphyton cell density and biomass at baseline conditions, respectively. An appropriate target (neither under- nor overprotective) should include a margin of safety to address uncertainty, as well as to sustain environmental conditions below the imbalance point.

In the change-point analysis for mean cell density, the mean NO_3 was 0.441 mg/L, with the test statistic of 7.68 and confidence level over 95%. The 95% confidence interval for the change point was between 0.378 and 0.629 mg/L of NO_3 (**Figure 5.6**), the lower bound being 0.378 mg/L NO_3.

It is important to note that the change-point analysis provides a concentration of nitrate for which change occurs. The TMDL target must be established at a level that prevents such a change. Given that the Department is 95% confident that change occurs between 0.378 and 0.629 mg/L NO_3, the TMDL threshold must be established below that interval to be protective of the resource.

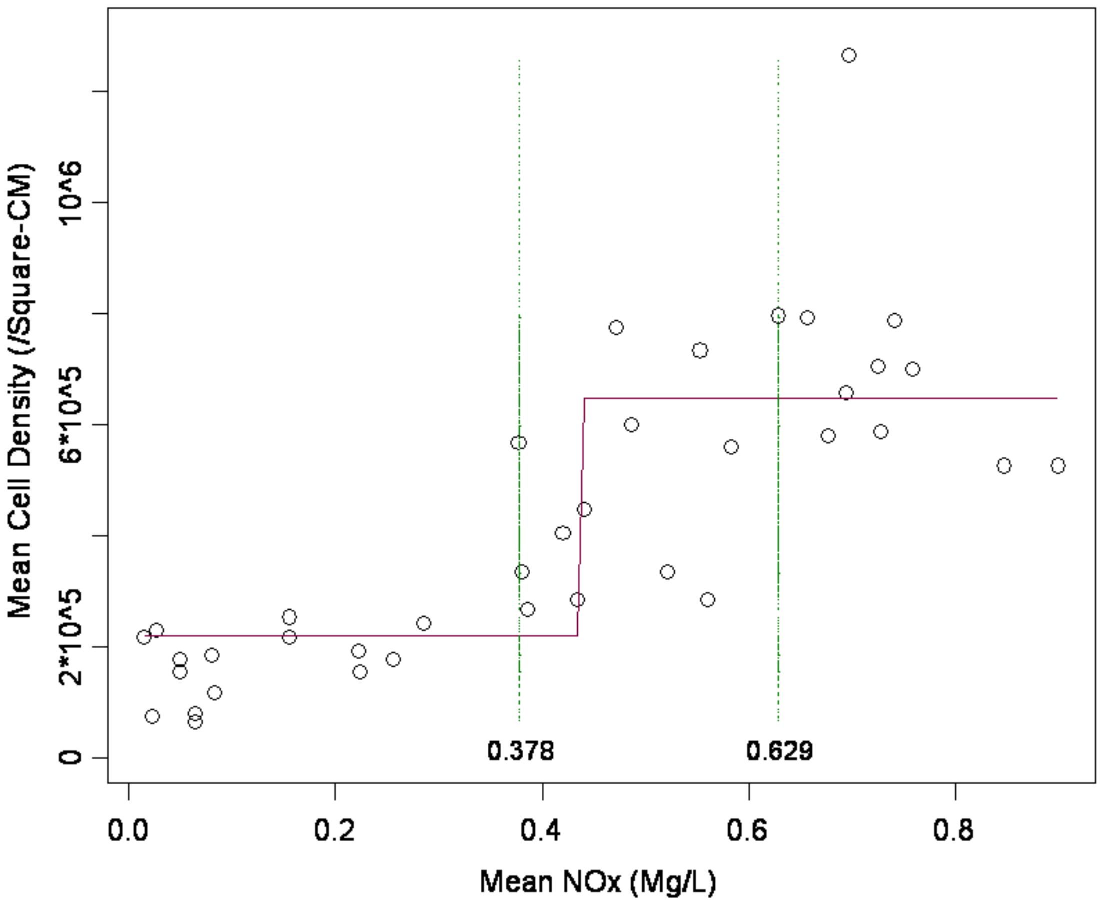

Figure 5.6. Change-Point Analyses (the 95% Confidence Interval)

While the change-point analysis provided a definitive conclusion that the change in periphyton was related to nitrate, the second part is finding the relationship of nitrate concentration to periphyton. The best relationship between nitrate and periphyton cell density is an exponential relationship, as shown in **Figure 5.7**. This relationship can be used to define a nitrate target that prevents change. The first approach to finding a target was using the change point of 0.441 mg/L to identify an equivalent cell density concentration relative to the central tendency (an exponential curve R^2=0.72) of the relationship. Once identified, the nitrate concentration prior to the change point can be identified by finding the equivalent upper 95% Confidence Interval, i.e., an NO_3 value of 0.38 mg/L.

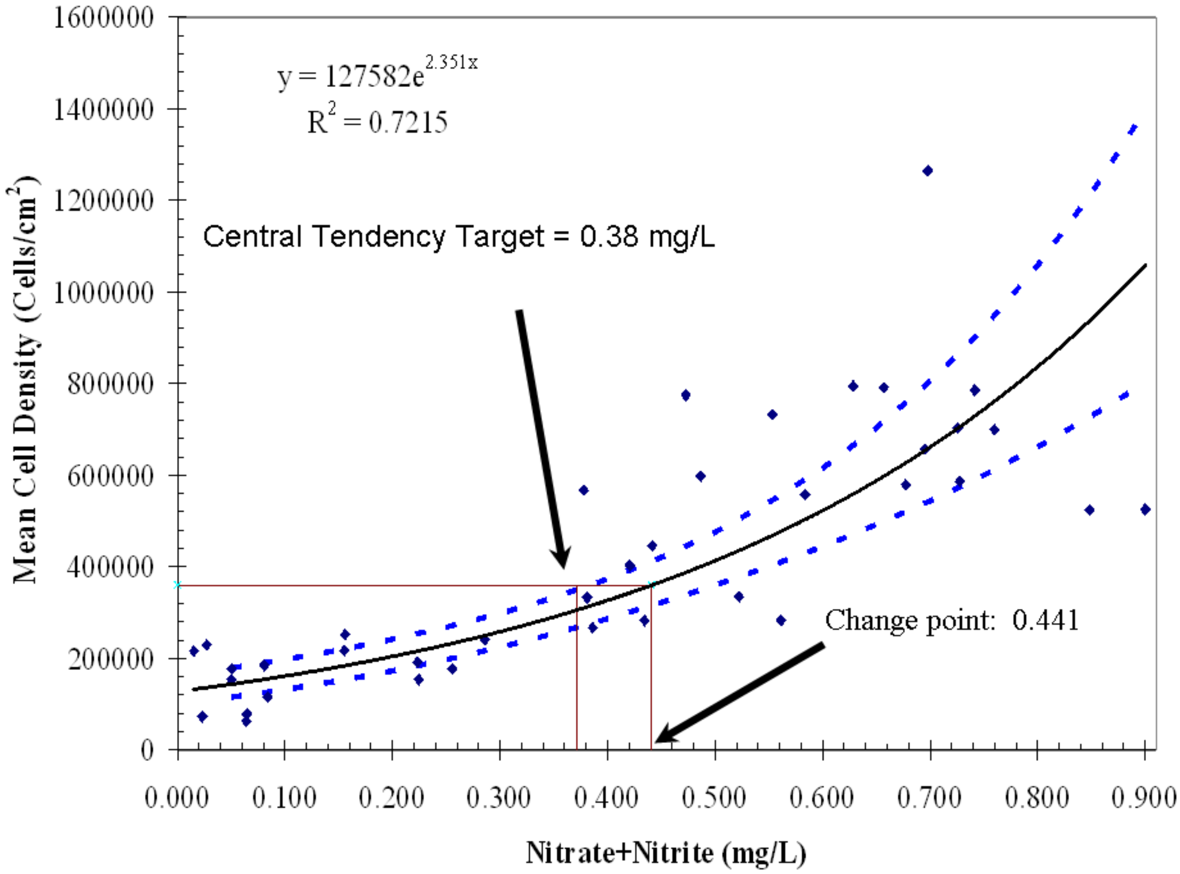

Figure 5.7. Central Tendency and Upper 95% Confidence Interval Approach

In the next approach, the same change point of 0.441 mg/L was used to find the lower 95% Confidence Interval of cell density, which helped establish a margin of safety. The relationship between nitrate and cell density has Confidence Intervals, between which the Department is 95% confident that the relationship holds. Taking the lower cell density at the change point of 0.441 mg/L targets a more conservative condition in the waterbody. Once the lower cell density was identified, the Department again used it to identify a nitrate number prior to the change points by finding the equivalent lower 95% Confidence Interval (**Figure 5.8**), i.e., an NO_3 value of 0.33 mg/L.

Considering that the lower Confidence Interval value of the change-point analysis was 0.378 mg/L and the 2 approaches above found values of 0.38 and 0.33 mg/L, respectively, an average of the 2 techniques was used to set the target of 0.35 mg/L.

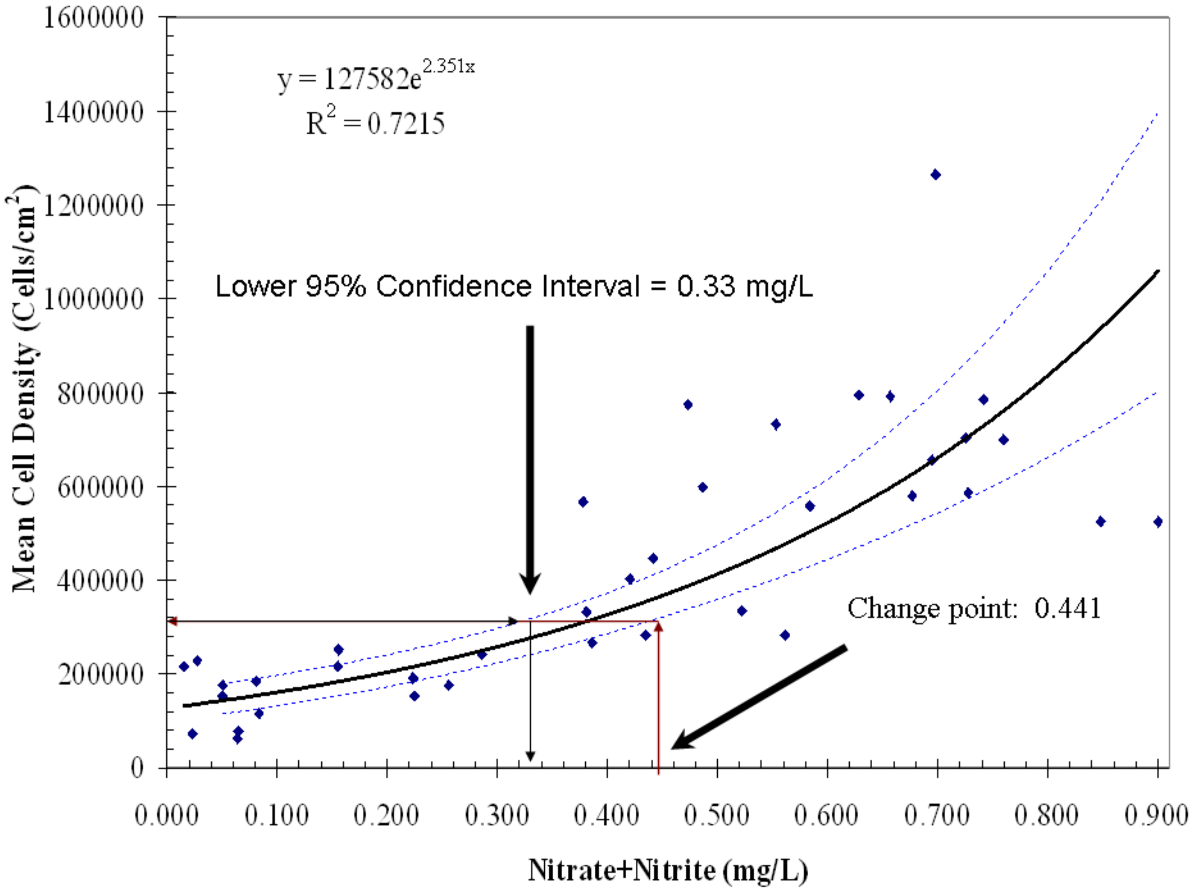

Figure 5.8. Upper and Lower 95% Confidence Interval Approach

In conclusion, based on the information currently available, the Department believes that a monthly average nitrate concentration of 0.35 mg/L should be sufficiently protective of the aquatic flora or fauna in the Upper Wakulla River (WBID 1006). A monthly average is considered to be the appropriate time frame, as the periphyton dataset was based on a 28-day deployment, and the response of algae to nutrients is on the order of days to weeks. An elevated pollutant concentration in the system alone does not necessarily constitute impairment as long as there is no negative response from the local aquatic flora or fauna.

Based on the information provided above, 0.35 mg/L nitrate is the target concentration that will not cause an imbalance in the aquatic flora or fauna in the Upper Wakulla River (WBID 1006). The reductions in NO_3 will reduce any pollutant impacts associated with the excessive growth of algae. The excessive growth may result in localized large diurnal fluctuations in DO due to photosynthesis during the day (oxygen production) and respiration during the night (oxygen consumption). The subsequent decomposition of the excessive algal biomass also consumes large quantities of DO. The implementation of the TMDL for nutrients will improve the DO regime in the river by reducing the excessive growth of algae.

5.3 Setting the Monthly Average Concentration for Nitrate

After carefully reviewing all the studies described above, the Department believes that establishing the 0.35 mg/L nitrate (nutrient) TMDL for the Upper Wakulla River as a monthly average is appropriate, mainly because the changes in aquatic vegetation biomass do not respond to the change of nutrient concentration instantaneously. Therefore, a short-term exceedance of the target concentration may not produce negative biological or ecological effects.

The nitrate TMDL target obtained from the Suwannee River study was based on the correlation between the long-term average nitrate concentration and long-term average cell density and biomass. Therefore the TMDL target should be considered as a long-term average target instead of an instantaneous value. The nitrate range suggested by the *Lyngbya* study was from a nutrient amendment experiment. S differences in growth rate and biomass between the above-0.600 mg/L treatment groups and below-0.300 mg/L treatment groups were not observed until 8 to 12 days after the nutrient amendment study started. This apparently suggested a time lag between the change of the nitrate concentration and the response from *Lyngbya*.

In addition, the *Lyngbya* nutrient amendment study was conducted under tightly controlled laboratory conditions, with no competition from other periphyton and plants, no grazing from aquatic animals, no removal effects from the shearing force of the stream flow, and no light attenuation from the changing of water color. These factors are very common in natural stream systems such as the Wakulla River. All these natural processes could significantly slow down the response of *Lyngbya* to the change of nitrate concentration and further delay the response. Therefore, treating the nitrate concentration obtained from the *Lyngbya* study as an exact instantaneous value is also not necessary.

The same concept also applies to the target nitrate value obtained from the correlation between ecological efficiency and nitrate concentration. The ecological efficiency results are average values for a period from three to four weeks (WSI 2005). The nitrate target value derived from an equation, based on average ecological efficiency, should not be treated as an exact instantaneous value. It is more appropriate that the target number be treated as an average target, over a certain period.

Based on the above discussions, the Department established the nitrate TMDL for both the Wekiva and Suwannee Rivers as a monthly average target. This provides a margin of safety because restoration activities designed to address the highest monthly average nitrate concentrations should help ensure that yearly average nitrate concentrations are even lower.

As discussed above, the nitrate target will be established as a monthly average in this TMDL. Therefore, long-term monthly average concentrations were calculated for each month for each parameter based on measured concentrations for the verified period. To make sure that the monthly average concentrations will meet the concentration target even under the worst-case scenario, the highest monthly average nitrate concentrations were used as existing monthly mean concentrations to calculate the percent reduction required to achieve the nitrate target. This approach adds to the margin of safety of the TMDL.

To calculate the percent reductions required for this TMDL, the monthly values for nitrate were averaged over the verified period of January 1, 2000, through June 30, 2007, and the maximum monthly average was used as the target for percent reduction (**Table 5.1**). **Table 5.1** and **Figure 5.9** depict the monthly medians with monthly average rainfall. These data show that elevated nitrate concentrations occur in both wet and dry months.

5.4 Critical Conditions/Seasonality

Establishing the critical condition for algae growth in a given watershed depends on many factors, including the presence of point sources and the land use pattern in the watershed. Typically, the critical condition for nonpoint sources is an extended dry period followed by a rainfall runoff event. During the wet weather period, rainfall washes off nutrients that have built up on the land surface under dry conditions. However, significant nonpoint source contributions can also appear under dry conditions without any major surface runoff event. This may happen when nonpoint sources contaminate the surficial aquifer and nutrients are brought into the receiving waters through baseflow. In addition, sediments that have accumulated for months may provide a flux of nutrients to the water column under certain weather or DO conditions. The critical condition for point source loading typically occurs during periods of low stream flow, when dilution is minimized.

For the TMDLs established for the Upper Wakulla watershed (WBID 1006), no clear critical seasonal signal was apparent, with elevated concentrations at Wakulla Spring during wet months (June and July) and dry months such as April and October (**Figure 5.9**). Additionally, there were no monthly data for January, March, May, June, or July in the Upper Wakulla River. For these reasons, establishing the percent reductions based on the data for Wakulla Spring for the month with the highest required percent reduction will be protective for all seasons and add to the implicit margin of safety.

5.5 Calculation of TMDL Percent Reduction

Based on an examination of the data depicted in **Table 5.1**, the percent reductions will be based the data from Wakulla Spring using the month (February) from the verified period with the highest average nitrate concentration (0.80 mg/L).

The percent reduction required to achieve the water quality target was calculated using the following formula:

[(existing mean concentration – target concentration) / existing mean concentration] x 100

[(0.800 mg/L – 0.35 mg/L) / 0.800 mg/L] * 100

Equals a 56.2% reduction in nitrate.

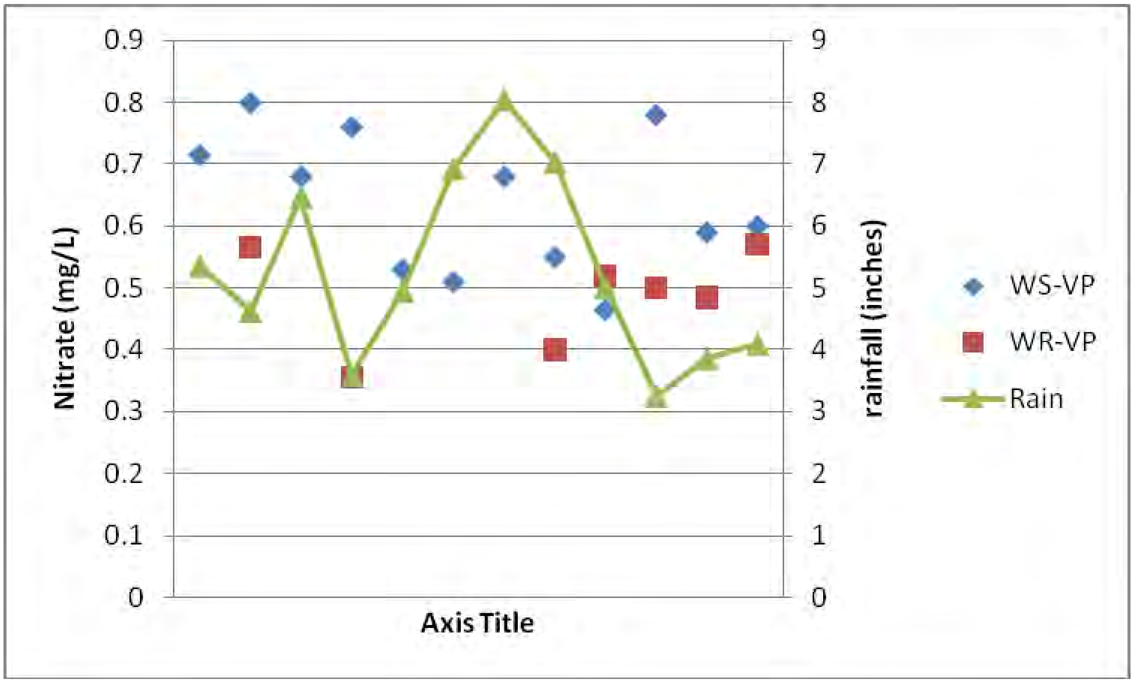

Figure 5.9. Monthly Median Nitrate Concentrations for Wakulla Spring and River for the Verified Period Data

Table 5.1. Monthly Average and Median Nitrate Concentrations for Wakulla Spring and River for the Verified Period Data

ND = No data
VP = Verified period

Month	Wakulla Spring Average (mg/L)	Wakulla Spring Median (mg/L)	Upper Wakulla River Average (mg/L)	Upper Wakulla River Median (mg/L)	Long-Term 30-Year Rainfall (inches)
January	0.77	0.72	ND	ND	5.36
February	0.80	0.80	0.57	0.57	4.63
March	0.68	0.68	ND	ND	6.47
April	0.75	0.76	0.52	0.67	3.59
May	0.53	0.53	ND	ND	4.95
June	0.51	0.51	ND	ND	6.92
July	0.63	0.68	ND	ND	8.04
August	0.58	0.55	0.37	0.40	7.03
September	0.54	0.47	0.48	0.43	5.01
October	0.78	0.78	0.50	0.50	3.25
November	0.58	0.56	0.53	0.51	3.86
December	0.55	0.60	0.57	0.57	4.10

Chapter 6: DETERMINATION OF THE TMDL

6.1 Expression and Allocation of the TMDL

The percent load reductions listed in **Table 6.2** were established to achieve the monthly average nitrate concentration of 0.35 mg/L. While these percent reductions are the expression of the TMDL that will be implemented, the EPA recommends that all TMDLs and associated load allocations and wasteload allocations include a daily time increment in conjunction with other appropriate temporal expressions that may be necessary to implement the relevant water quality standard. Daily maximum concentration targets for nitrate were established using the following equation, which assumes that the nitrate data distributions are lognormal (EPA 2006; 2007):

$$\mathbf{MDL = LTA * exp(Z_p\sigma_y - 0.5\sigma y^2)}$$

$$\mathbf{\sigma y = sqrt(ln(CV^2 + 1))}$$

Where:

LTA = long-term average (0.35 mg/L)
Z_p = p^{th} percentage point of the standard normal distribution, at 95% (Z_p = 1.645)
σ = standard deviation
CV = coefficient of variance

For the daily maximum nitrate concentration, it was assumed that the average monthly target concentration should be the same as the average daily concentration. Also, assuming the target dataset will have the same CV as the existing measured dataset (**Table 6.1**) and allowing 5% exceedance (EPA 2007, pp. 19 and 20), the daily maximum nitrate concentration for the Upper Wakulla River is 0.53 mg/L.

It should be emphasized that these daily maximum targets were developed for illustrative purposes. The implementation of the TMDL will be based on the monthly average concentration targets.

Table 6.1. Daily Maximum for Target Nitrate Concentration (mg/L)

Statistics	Upper Wakulla River (WBID 1006)
Mean (mg/L)	0.51
CV	0.28
Daily Maximum To Achieve Monthly Average Nitrate of 0.35 mg/L	0.53

The objective of a TMDL is to provide a basis for allocating acceptable loads among all of the known pollutant sources in a watershed so that appropriate control measures can be implemented and water quality standards achieved. A TMDL is expressed as the sum of all point source loads (wasteload allocations, or WLAs), nonpoint source loads (load allocations, or LAs), and an appropriate margin of safety (MOS), which takes into account any uncertainty concerning the relationship between effluent limitations and water quality:

$$\mathbf{TMDL = \sum WLAs + \sum LAs + MOS}$$

As discussed earlier, the WLA is broken out into separate subcategories for wastewater discharges and stormwater discharges regulated under the NPDES Program:

$$\mathbf{TMDL \cong \sum WLAs_{wastewater} + \sum WLAs_{NPDES\ Stormwater} + \sum LAs + MOS}$$

It should be noted that the various components of the revised TMDL equation may not sum up to the value of the TMDL because (a) the WLA for NPDES stormwater is typically based on the percent reduction needed for nonpoint sources and is also accounted for within the LA, and (b) TMDL components can be expressed in different terms (for example, the WLA for stormwater is typically expressed as a percent reduction, and the WLA for wastewater is typically expressed as mass per day).

WLAs for stormwater discharges are typically expressed as a “percent reduction” because it is very difficult to quantify the loads from MS4s (given the numerous discharge points) and to distinguish loads from MS4s from other nonpoint sources (given the nature of stormwater transport). The permitting of stormwater discharges also differs from the permitting of most wastewater point sources. Because stormwater discharges cannot be centrally collected, monitored, and treated, they are not subject to the same types of effluent limitations as wastewater facilities, and instead are required to meet a performance standard of providing treatment to the “maximum extent practical” through the implementation of best management practices (BMPs).

This approach is consistent with federal regulations (40 CFR § 130.2[I]), which state that TMDLs can be expressed in terms of mass per time (e.g., pounds per day), toxicity, or **other appropriate measure**. The TMDL for the Upper Wakulla River watershed is expressed in terms of concentration of nutrients and represents the loading the river can assimilate and maintain the biological criterion (**Table 6.2**).

Table 6.2. TMDL Components for the Upper Wakulla River

* N/A = Not applicable

WBID	Parameter	TMDL (mg/L)	TMDL % Reduction	WLA for Wastewater	WLA for NPDES Stormwater % Reduction	LA % Reduction	MOS
Upper Wakulla River Watershed (WBID 1006)	Nitrate as monthly average	0.35	56.2	N/A*	N/A*	56.2%	Implicit

6.2 Load Allocation

Because no target loads were explicitly calculated in this TMDL report, TMDLs are represented as the percent reduction required to achieve the nitrate target. The percent reduction assigned to all the nonpoint sources areas (LA) are the same as those defined for the TMDL percent reduction. To achieve the monthly average nitrate target of 0.35 mg/L in the Upper Wakulla watershed, the nitrate loads from the nonpoint source areas contributing to the Upper Wakulla River need to be reduced by 56.2%. The target monthly average nitrate of 0.35 mg/L and the percent reduction represent an estimate of the maximum amount of reduction required to meet the target. It may be possible to meet the target before achieving the percent reductions. It should be noted that the LA includes loading from stormwater discharges regulated by the Department and the water management districts that are not part of the NPDES Stormwater Program (see **Appendix B**).

6.3 Wasteload Allocation

6.3.1 NPDES Wastewater Discharges

Currently, there are no NPDES wastewater facilities that discharge directly into the Upper Wakulla River (WBID 1006). Any new potential discharger would be expected to comply with the Class III criteria for biology and with nitrogen limits consistent with this TMDL.

6.3.2 NPDES Stormwater Discharges

Currently, none of the NPDES MS4 stormwater facilities identified in **Section 4.2.1** discharges directly into the Upper Wakulla River (WBID 1006). While these existing MS4 entities are not currently being assigned a specific allocation or reduction, those values may become known as part of the BMAP process.

6.4 Margin of Safety

Consistent with the recommendations of the Allocation Technical Advisory Committee (Department 2001b), an implicit MOS was provided in the development of this TMDL by the conservative decisions associated with a number of assumptions and the development of assimilative capacity. For example, the nitrate target was established based on the most conservative concentration from the 4 lines of evidence (**Chapter 5**). Requiring that the 0.35 mg/L target be met every month should result in the nitrate concentration to be even lower than the target concentration during the summer algal growth season based on seasonal analysis on the nitrate concentration, and therefore adds to the MOS. In addition, when estimating the required percent reduction to achieve the water quality target, the highest long-term monthly average of measured nitrate concentrations was used instead of the average of the monthly averages. This will make estimating the required percent load reduction more conservative and therefore add to the MOS.

Chapter 7: NEXT STEPS: IMPLEMENTATION PLAN DEVELOPMENT AND BEYOND

7.1 Basin Management Action Plan

Following the adoption of this TMDL by rule, the Department will determine the best course of action regarding its implementation. Depending on the pollutant(s) causing the waterbody impairment and the significance of the waterbody, the Department will select the best course of action leading to the development of a plan to restore the waterbody. Often this will be accomplished cooperatively with stakeholders by creating a Basin Management Action Plan, referred to as the BMAP. BMAPs are the primary mechanism through which TMDLs are implemented in Florida (see Subsection 403.067[7], F.S.). A single BMAP may provide the conceptual plan for the restoration of one or many impaired waterbodies.

If the Department determines that a BMAP is needed to support the implementation of this TMDL, a BMAP will be developed through a transparent, stakeholder-driven process intended to result in a plan that is cost-effective and technically feasible, and that meets the restoration needs of the applicable waterbodies. Once adopted by order of the Department Secretary, BMAPs are enforceable through wastewater and municipal stormwater permits for point sources and through BMP implementation for nonpoint sources.

Among other components, BMAPs typically include the following:

- *Water quality goals (based directly on the TMDL);*
- *Refined source identification;*
- *Load reduction requirements for stakeholders (quantitative detailed allocations, if technically feasible);*
- *A description of the load reduction activities to be undertaken, including structural projects, nonstructural BMPs, and public education and outreach;*
- *A description of further research, data collection, or source identification needed in order to achieve the TMDL;*
- *Timetables for implementation;*
- *Implementation funding mechanisms;*
- *An evaluation of future increases in pollutant loading due to population growth;*
- *Implementation milestones, project tracking, water quality monitoring, and adaptive management procedures; and*
- *Stakeholder statements of commitment (typically a local government resolution).*

BMAPs are updated through annual meetings and may be officially revised every five years. Completed BMAPs in the state have improved communication and cooperation among local stakeholders and state agencies; improved internal communication within local governments; applied high-quality science and local information in managing water resources; clarified the obligations of wastewater point source, MS4, and non-MS4 stakeholders in TMDL implementation; enhanced transparency in the Department's decision making; and built strong relationships between the Department and local stakeholders that have benefited other program areas.

7.2 Other TMDL Implementation Tools

However, in some basins, particularly those with fecal coliform impairments, and for some parameters, including fecal coliform, the development of a BMAP using the process described above is not the most efficient way to restore a waterbody such that it meets its designated uses. This is because fecal coliform impairments result from the cumulative effects of a multitude of potential sources, both natural and anthropogenic. Addressing these problems requires good old-fashioned detective work that is best done by those in the area.

A multitude of assessment tools is available to assist local governments and interested stakeholders in this detective work. The tools range from the simple (such as Walk the WBIDs and GIS mapping) to the complex (such as bacteria source tracking). Department staff will provide technical assistance, guidance, and oversight of local efforts to identify and minimize fecal coliform sources of pollution.

Based on work in the Lower St Johns River tributaries and the Hillsborough Basin, the Department and local stakeholders have developed a logical process and tools to serve as a foundation for this detective work. In the near future, the Department will be releasing these tools to assist local stakeholders with the development of local implementation plans to address fecal coliform impairments. In such cases, the Department will rely on these local initiatives as a more cost-effective and simplified approach to identify the actions needed to put in place a road map for restoration activities, while still meeting the requirements of Subsection 403.067(7), F.S.

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Appendix A: Background Information from the NWFWMD 2009 SWIM Plan Update Initiatives

County and City Initiatives

1. **Leon County** — In 1992 Leon County initiated an Aquifer Protection Program, as specified in its Aquifer/Wellhead Protection Ordinance, to prevent contamination of the aquifer in Leon County. In 2005, the county updated its Aquifer Protection Code, available at: http://library.municode.com/index.aspx?clientId=10008.

   Leon County has also completed the Leon County Aquifer Vulnerability Assessment (LAVA) to provide a science-based management tool to help minimize adverse impacts on ground water quality. Additional information is available at: www.adgeo.net/lava.php.

   In 2006, COT signed an agreement to invest more than $160 million over 6 years to convert 2 wastewater facilities to advanced wastewater treatment, reducing the flow of nutrients into Wakulla Springs by 75% and significantly improving the quality of reuse water.

   In 2008, COT enacted a pet waste ordinance that requires pet owners to remove and properly dispose of their pet's fecal matter from public areas (Ordinance Number 08-O-23AA). This was a response to concern about coliform bacteria reported in area waters.

   In 2009, COT adopted a fertilizer use ordinance that sets forth specific management guidelines to minimize environmental effects. The ordinance requires training and licensing of applicators (Ordinance Number 08-O-72AA).

   Amendments to the Tallahassee–Leon County Comprehensive Plan that provide further watershed protections were adopted in January 2009. Local ordinances to implement policies of the Comprehensive Plan are under development. City and county governments have already adopted ordinances establishing a Primary Springs Protection Zone, to become effective upon the effective date of the Comprehensive Plan amendments.

   The Tallahassee–Leon County Watershed Protection Initiative is seeking to address flood control and watershed protection through stormwater capital improvement projects. The Initiative is under the guidance of the Watershed Management Policy Board, established to coordinate watershed management plans for COT and Leon County. Both Lakes Munson and Lafayette are included in the capital improvement plan. Additional information is available at: www.leoncountyfl.gov/wpi/home.html.

   Tallahassee–Leon County Blueprint 2000 pledged to protect Lake Munson and Lake Lafayette through funding from a local-option one-cent sales tax. The plan includes several projects for stormwater improvement to these lakes and associated waterways, as well as projects for ground water and floodplain protection. Additional information is available at: http://www.blueprint2000.org/. Additionally, as noted above, Blueprint 2000 has entered into agreement with the District to jointly pursue environmentally sensitive lands in the St. Marks River watershed for acquisition.

2. **Wakulla County** — In July 1994, Wakulla County passed the Wakulla Springs Water Quality Protection Ordinance, which requires the registration of regulated substances in the special planning area and provides for inspection, containment, reporting, cleanup, and monitoring. In April 2008, the county expanded the Springs Special Planning Area to include additional areas that have a demonstrated connection to the Wakulla Springs cave system.

   An aquifer vulnerability assessment is under development in Wakulla County by Advanced GeoSpatial Inc. Version 1.3 is under review with FGS and when finalized will be available on the FGS website at: www.dep.state.fl.us/geology/programs/hydrogeology/hydro_index.htm.

   In 2006 the county passed a wetlands protection ordinance. Ordinance 06-27 identifies allowable and conditional uses of wetlands and wetland buffer zones, establishes a 75-foot natural buffer zone, provides for variances, establishes design standards, and provides for enforcement and penalties.

   Wakulla County Ordinance 2006-58, also passed in 2006, revised the Comprehensive Plan to protect and improve water quality. Among other things, the ordinance requires performance-based treatment systems (PBTS) that remove a higher level of nitrogen (the treatment standard is 10 mg/L) for onsite wastewater treatment and disposal for all new construction. Existing septic tanks and package treatment plants must discontinue service if central sewer is made available, or must be replaced with performance-based treatment systems when they fail. All septic systems, new and existing, must be inspected every three years by a licensed contractor. This ordinance establishes standards and guidelines for central WWTFs.

   On behalf of Wakulla County, the work of Harrington and Guo (2007) was an effort to provide citizens and officials with the best available information for decision making regarding the use of OSTDS and decentralized wastewater systems in order to reduce nutrients in ground water flowing to Wakulla Springs.

   The 2006 ordinance also adds karst buffers; requires a nitrate loading study for any proposed development greater than one acre; incorporates practices of the Florida Yards and Neighborhoods Program and landscaping standards that promote native vegetation for new subdivisions; reduces nitrates from public facilities; and addresses stormwater, water conservation, wastewater facilities, treated wastewater reuse, and natural water flows.

   The county's January 2008 Evaluation and Appraisal Report specifies several areas of the Land Development Code, the Comprehensive Plan, and intergovernmental coordination to be addressed to protect environmental resources. The needed actions include monitoring impacts of multistate water transfers; inventorying water, sewer and stormwater systems; implementing countywide stormwater planning; developing a master plan for centralized or retrofit sewer systems; strengthening buffer regulations; developing a coastal management plan; preserving habitat corridors; and promoting smart development methods. The report is available at: www.mywakulla.com/docs/EAR/WakullaCountyRevisedEAR.pdf.

Wakulla County, in cooperation with the District, is funding the Wakulla Gardens Stormwater Project, a nonpoint source water quality improvement and stormwater management plan for this historic subdivision.

3. **Jefferson County** — The county's comprehensive plan requires a 100-foot buffer around sinkholes and caves to protect ground water. Drainage wells are not allowed for the disposal of stormwater into recharge areas of potable water aquifers. Untreated stormwater discharge is not allowed into natural waterbodies; however, septic systems continue to be allowed in flood areas. Buffer widths of 100 feet are required for rivers, streams, and lakes.

State and Regional Initiatives

1. **TMDL Program** — The federal Clean Water Act, Section 303(d), is implemented in Florida under the Department's TMDL Program to check that surface waters meet water quality standards. The process includes assessing water quality, listing impaired waters, adopting TMDLs, determining pollutant sources, and implementing strategies to reduce pollution. TMDLs are the thresholds of pollutants that a waterbody can assimilate and still maintain water quality standards. The Department's 2002 listing of impaired waters included 16 waterbodies in the St. Marks River and Apalachee Bay watershed, and that may increase to 24 under proposed list revisions. TMDLs have not yet been developed for the watershed. Additional information is available at: www.dep.state.fl.us/water/tmdl/index.htm.

2. **State Land Acquisitions** — Florida has acquired 2,590 acres along the Upper St. Marks River corridor for a new state park. The state plans to protect additional lands in this area through fee simple acquisition under the Upper St. Marks River Corridor Florida Forever Project. Additional acquisitions have increased the size of Edward Ball Wakulla Springs State Park to 6,055 acres. Nearby, the Wakulla State Forest has been established and is now 4,219 acres. Additional lands may be acquired through the Wakulla Springs Protection Zone Florida Forever Project.

3. **Florida Aquifer Vulnerability Assessment (FAVA)** — The FGS developed this GIS-based model to show the relative probability that an aquifer could become contaminated from activities on the land surface. The maps are useful in guiding land use decisions and in identifying ground water recharge areas in need of protection. Additional information is available at: www.dep.state.fl.us/geology/programs/hydrogeology/fava.htm.

4. **Sensitive Karst Areas Map** — The FGS developed a Sensitive Karst Areas map for use in the *Environmental Resource Permit Applicant's Handbook – Volume II, Engineering Requirements for Stormwater Treatment and Management Systems – Water Quality and Water Quantity.* The map is used when siting proposed stormwater ponds and establishes additional design criteria for these structures. The designated area covers most of Leon and Wakulla Counties. Additional information is available at: www.dep.state.fl.us/geology/programs/hydrogeology/hydro_resources.htm#Sensitive_Karst_Areas.

5. **Florida Springs Task Force** — The multiagency task force was formed in 1999 with the support of the Governor and Florida Legislature to address declines seen in many of the state's springs. The manual *Protecting Florida's Springs: Land Use Planning Strategies and Best Management Practices* was developed to inform land use decision makers about strategies for the protection and restoration of springs and specifies permitting considerations for karst areas (Florida Department of Community Affairs and Department 2002). In 2001, the Florida Springs Initiative within the Department was established as a comprehensive, coordinated program to increase the protection of the state's springs. Additional information is available at: www.floridasprings.org.

6. **Seagrass Monitoring** — The Big Bend Seagrasses Aquatic Preserve is initiating seagrass monitoring in eastern Apalachee Bay, between the St. Marks and Aucilla Rivers. Twenty-five fixed sites will be monitored every other year, and various measurements will be gathered (Charbonneau 2008).

7. **Urban Turf Fertilizer Rule** — The new rule by the Florida Department of Agriculture and Consumer Services requires that fertilizer products for urban lawns and sports turf limit the amounts of nitrogen and phosphorus to that needed for healthy turf maintenance. This should reduce nutrients entering the state's water resources. Additional information is available at: www.flaes.org/complimonitoring/fertilizer.html.

8. **Coastal Change Planning** — The Century Commission for a Sustainable Florida is developing technical information, recommendations, and policy proposals related to climate change, emerging sustainability technologies, and coastal resiliency in Florida. Related documents and information are available at: http://www.collinscenter.org/?SustainabilityHome.

   The Texas Coastal Watershed Program has developed two publications to assist community leaders and planners address the vulnerability of coastal areas and water resources: *The Resilient Coast: Policy frameworks for adapting the built environment to climate change and growth in coastal areas of the U.S. Gulf of Mexico,* and *The Resilient Coast: Policy frameworks for adapting the wetlands to climate change and growth in coastal areas of the U.S. Gulf of Mexico*. Both reports are available at: http://www.urban-nature.org/publications/publications.htm

Appendix B: Background Information on Federal and State Stormwater Programs

In 1982, Florida became the first state in the country to implement statewide regulations to address the issue of nonpoint source pollution by requiring new development and redevelopment to treat stormwater before it is discharged. The Stormwater Rule, as authorized in Chapter 403, F.S., was established as a technology-based program that relies on the implementation of BMPs that are designed to achieve a specific level of treatment (i.e., performance standards) as set forth in Rule 62-40, F.A.C. In 1994, the Department's stormwater treatment requirements were integrated with the stormwater flood control requirements of the water management districts, along with wetland protection requirements, into the Environmental Resource Permit regulations.

Rule 62-40, F.A.C., also requires the state's water management districts to establish stormwater pollutant load reduction goals (PLRGs) and adopt them as part of a Surface Water Improvement and Management (SWIM) plan, other watershed plan, or rule. Stormwater PLRGs are a major component of the load allocation part of a TMDL. To date, stormwater PLRGs have been established for Tampa Bay, Lake Thonotosassa, the Winter Haven Chain of Lakes, the Everglades, Lake Okeechobee, and Lake Apopka.

In 1987, the U.S. Congress established Section 402(p) as part of the federal Clean Water Act Reauthorization. This section of the law amended the scope of the federal NPDES permitting program to designate certain stormwater discharges as "point sources" of pollution. The EPA promulgated regulations and began implementing the Phase I NPDES Stormwater Program in 1990. These stormwater discharges include certain discharges that are associated with industrial activities designated by specific standard industrial classification (SIC) codes, construction sites disturbing 5 or more acres of land, and the master drainage systems of local governments with a population above 100,000, which are better known as MS4s. However, because the master drainage systems of most local governments in Florida are interconnected, the EPA implemented Phase I of the MS4 permitting program on a countywide basis, which brought in all cities (incorporated areas), Chapter 298 urban water control districts, and FDOT throughout the 15 counties meeting the population criteria. The Department received authorization to implement the NPDES Stormwater Program in 2000.

An important difference between the federal NPDES and the state's Stormwater/Environmental Resource Permit programs is that the NPDES Program covers both new and existing discharges, while the state's program focus on new discharges only. Additionally, Phase II of the NPDES Program, implemented in 2003, expands the need for these permits to construction sites between 1 and 5 acres, and to local governments with as few as 1,000 people. While these urban stormwater discharges are now technically referred to as "point sources" for the purpose of regulation, they are still diffuse sources of pollution that cannot be easily collected and treated by a central treatment facility, as are other point sources of pollution such as domestic and industrial wastewater discharges. It should be noted that all MS4 permits issued in Florida include a reopener clause that allows permit revisions to implement TMDLs when the implementation plan is formally adopted.

Appendix C: Change Point Analysis of the Suwannee River Algal Data

Change Point Analysis of Suwannee River Algal Data Based on an Updated Data Set.

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June-August, 2008

I. Background

Per the request of the Wekiva Parkway and Protection Act (WPPA) passed by the Florida Legislature in 2004 (Chapter 369, Part III, FS), the Florida Department Environmental Protection is developing a nitrate Total Maximum Daily Load (TMDL) for the Wekiva River and Rock Springs Run in the central Florida area. Establishing a nitrate target for the Wekiva River and Rock Springs Run is a critical part of the TMDL development. To define this target, a functional relationship between the periphyton abundance and nitrate concentration needs to be characterized. Ideally, the functional relationship would be built upon data collected from the Wekiva River and Rock Springs Run. Unfortunately, because of the limit amount of time available to this project, not enough data were available to establish the relationship in these two waterbodies. Therefore, this study uses nitrate and periphyton data collected from a monitoring network on the Suwannee River, which was established for the Surface Water Improvement and Management (SWIM) program by the Suwannee River Water Management District (Hornsby, et al. 2000). Much of the length of the Suwannee River is heavily influenced by spring inflow, and the algal communities appear to be generally similar in composition to those in the Wekvia River and Rock Springs Run. Therefore, results from the Suwannee River are considered applicable to the Wekiva River and Rock Springs Run (Mattson et al., 2006).

Nitrate and periphyton data were collected from 13 stations across the Suwannee River and two tributaries (Withlacoochee River and Santa Fe River). **Figure 1** (Niu and Gao, 2007) shows locations of these water quality stations. Periphyton abundance was measured as both the cell density (cells/cm^2) and biomass density (ash free dry mass – AFDM/cm^2). Niu and Gao (2007) performed a change point analysis of the Suwannee River algal data collected during the period of 1990-1998 for the purpose of identifying a threshold for nitrate concentration, in which mean periphyton cell density and mean periphyton biomass were treated as response variables and mean nitrate concentration (NOx) was treated as the predictor. The main findings of Niu and Gao (2007) are: 1) for the change point analysis of mean abundance vs mean NOx, one change point was detected at NOx=0.401 that is corresponding to the data at the site SUW100. The change point is significant at the confidence level 95%; 2) for the change point analysis of mean biomass vs mean NOx, one change point was detected at NOx=0.420 that is corresponding to the data at the site SUW130. The change point is significant at the confidence level 95%.

Recently, the Suwannee River Water Management District (SRWMD) provides an updated data set for the 13 stations along the Suwannee River and its two major tributaries (Withlacoochee and Santa Fe). The updated data set covered the period from 1990 through 2007. In this report, change point analysis of the Suwannee River algal data will be performed based on the updated data set. For self-completeness, the statistical methods used in Niu and Gao (2007) will be restated in this report.

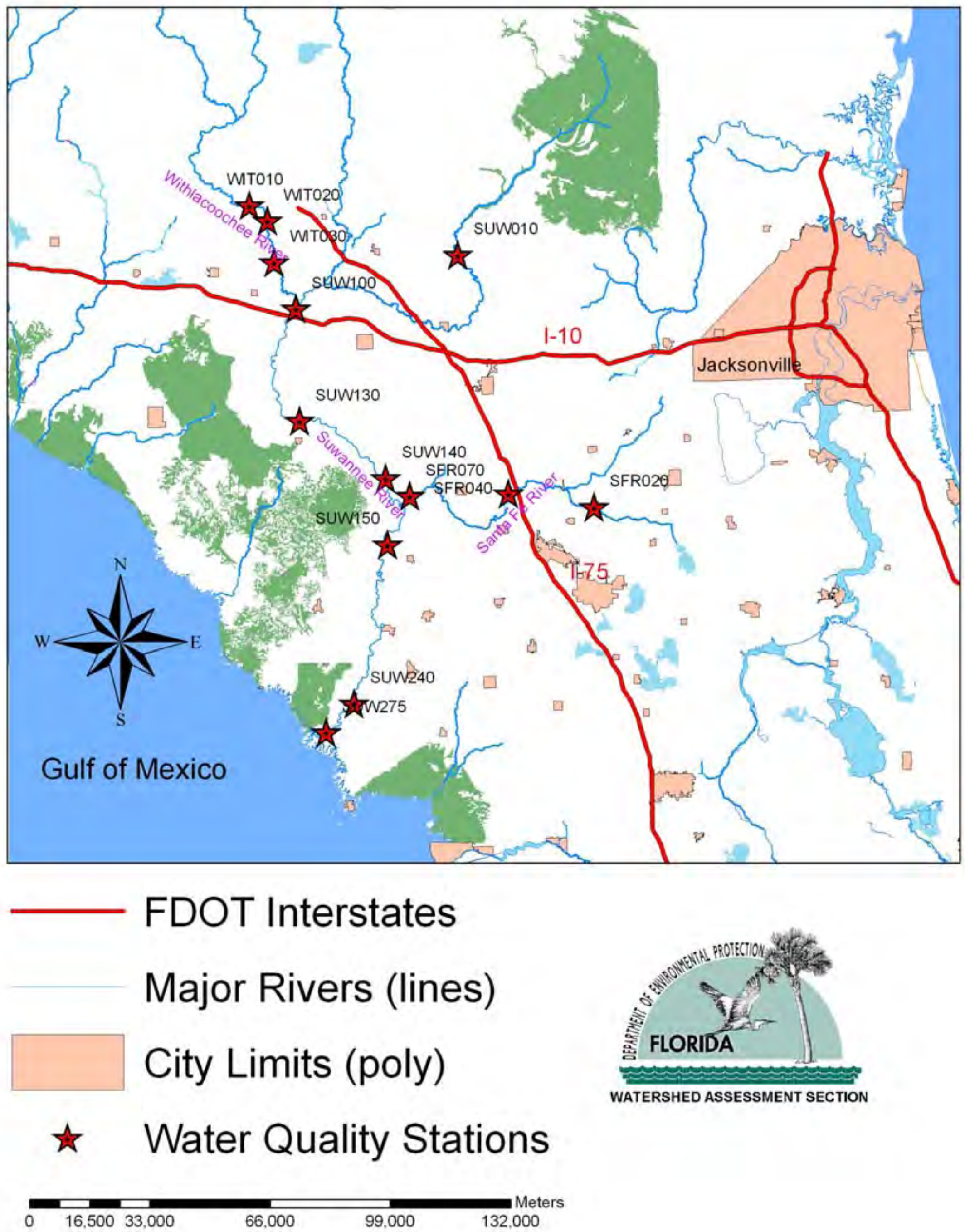


Figure 1. Locations of water quality stations from which measured nitrate and periphyton abundance were used for this analysis.

II. The Detection Procedure

Niu et al. (2000) introduced an iterative procedure for detecting and modeling level-shift change points. Niu and Miller (2007) reported the change point analysis and a model comparison procedure for the Stream Condition Index (SCI) and Biological Condition Gradient (BCG) data. The change-point detection procedure in Niu et al. (2000) is similar to that suggested by Chang (1982) and further developed by Chang et al. (1988) for detecting outliers and level shifts in time series analysis. Statistical details of this procedure can also be found in Pankratz (1991, Chapter 8).

For simplicity, let us consider a response variable *Y*, after an appropriate transformation. Suppose that observations $\{(X_i, Y_i),\ i = 1, 2, \cdots, n\}$ are available where *n* is the sample size and *X* is an independent variable. Moreover, we assume that the observations are arranged in the following manner:

- The values $\{X_i,\quad i = 1, 2, \cdots, n\}$ are distinct. If several Y_i's are corresponding to a single *X* value, the mean or median of the Y_i's is taken to be the response value for the *X* value.
- $\{(X_i, Y_i),\ i = 1, 2, \cdots, n\}$ are sorted according to the values of *X* from least to greatest.

If there exits an integer $r\ (1 < r < n)$ that split the observations into two groups, $\{Y_1, \cdots, Y_r)$ and $\{Y_{r+1}, \cdots, Y_n)$, such that mean value μ_1 of the first group is different from mean value μ_2 of the second group, we define *r* as a change-point in the response variable. The procedure introduced in this report will detect whether such a change point exists or not. In other words, this procedure only detects a possible **level shift** of the response variable but not variance changes. If a level shift of the response variable is detected at $r\ (1 < r < n)$, the corresponding value X_{r+1} is call a change point, i.e., the response variable Y_{r+1} changes into a new level at X_{r+1}.

The detection procedure proceeds as the follows. For each integer $l > 1$, define the step variable $S_i(l) = 0$ for $i < l$ and $S_i(l) = 1$ for $i \geq l$.

Step 1. Fit the linear regression model:

$$Y_i = \beta_0(l) + \beta_1(l) S_i(l) + \varepsilon_i(l), \qquad i = 1, 2, \cdots, n, \tag{1}$$

where for a fixed *l*, the $\varepsilon_i(l)$'s are assumed to be independent and identically distributed normal random variables with mean zero and variance $\sigma^2(l)$.

Step 2. Calculate the values $\{ L(l) = \hat{\beta}_1(l) / se(\hat{\beta}_1(l))$, $l = 2, 3, \cdots, (n-1) \}$ where $se(\hat{\beta}_1(l))$ is the estimated standard error of $\hat{\beta}_1(l)$.

Step 3. Let $L(l_1) = \max\{L(2), L(3), \cdots, L(n-1)\}$ and compare $L(l_1)$ with the critical value C=3.0 (or C=3.5). The critical value C=3.0 (or C=3.5) corresponds roughly to $\alpha = 0.10$ (or $\alpha = 0.05$), or the 10% (or the 5%) significance level, based on the simulation results of Chang et al. (1988). If $L(l_1)$ is significant, we conclude that the response Y has a change point at X_{l_1} with a level-shift $\hat{\beta}_1(l)$.

Step 4. Let $Y_i^* = Y_i - \beta_1(l_1) S_i(l_1)$. Repeat Steps 1-3 on the new response variable Y_i^* for detecting a possible second change point. Continue the process until no further change point can be identified.

Step 5. Suppose that k change points are detected in the response variable Y and the corresponding X values are $\{X_{l_1}, X_{l_2}, \cdots, X_{l_k}\}$. Fit the model

$$Y_i = \beta_0 + \beta_1 S_i(l_1) + \beta_2 S_i(l_2) + \cdots + \beta_k S_i(l_k) + \varepsilon_i, \qquad i = 1, 2, \cdots, n. \tag{2}$$

Then the estimated coefficients $\{\hat{\beta}_1, \hat{\beta}_2, \cdots, \hat{\beta}_k\}$ will be the k estimated level-shift values.

III. Model Comparison

Model (2) fits a step function $\beta_0 + \beta_1 S_i(l_1) + \beta_2 S_i(l_2) + \cdots + \beta_k S_i(l_k)$ to estimate the mean (or median) value of the response variable Y and the predictor variable X. In practice, many other models may be considered to describe the relationship between Y and X. In particular, if the scatter plot of observations $\{ (X_i, Y_i),\ i = 1, 2, \cdots, n \}$ shows a straight line or a smooth curve pattern, a linear regression model or a nonlinear smooth-curve model should be fitted to the data instead of the step-function change point model in (2).

For the response variable Y and the predictor variable X, the linear regression model has the form:

$$Y_i = \beta_0 + \beta_1 X_i + \varepsilon_i, \qquad i = 1, 2, \cdots, n. \tag{3}$$

If the relationship between Y and X is nonlinear, many smooth-curve models may be considered. One of the choices is transforming the predictor variable X and fitting a regression model. For example, we may use the natural logarithm transformation log(X) instead of X as the predictor variable and fit the regression model:

$$Y_i = \beta_0 + \beta_1 \log(X_i) + \varepsilon_i, \qquad i = 1, 2, \cdots, n. \tag{4}$$

When different models are fitted to the observations $\{(X_i, Y_i),\ i = 1, 2, \cdots, n\}$, model selection techniques need to be used to decide which model fits the data better. Statistical inferences such as estimation and prediction will then be based on the best model selected. The Bayesian Information Criterion (SBC) suggested by Schwartz (1978) is one of the popular criteria for model comparison. For a fitted model (linear or nonlinear) with p parameters, the SBC is defined as

$$\text{SBC(p)} = -2\ \log(\text{maximum likelihood function}) + p \times \log(\text{n}),$$

where the likelihood function is based on the distribution assumption of the model such as normal or log-normal or other distribution families, and n is the sample size. When the random errors ε_i 's have a normal distribution, the SBC(p) has the simplified form:

$$\text{SBC(p)} = n \times \log\left(\sum_{i=1}^{n} (Y_i - \hat{Y}_i)^2 / (n - p - 1)\right) + p \times \log(\text{n}), \tag{5}$$

where $\hat{Y}_i$ is the fitted value based on one of the candidate models and $\sum_{i=1}^{n} (Y_i - \hat{Y}_i)^2$ is the **Residual Sum of Squares (RSS)** based on the fitted candidate model.

Intuitively, there are two parts in (5), the first part is

$$n \times \log\left(\sum_{i=1}^{n} (Y_i - \hat{Y}_i)^2 / (n - p - 1)\right) = n \times \log \hat{\sigma}^2,$$

which is a measure of the goodness-of-fit of the candidate model. In general, increasing the number of parameters in a model will improve the goodness-of-fit of the model to the data regardless how many parameters are in the **true model** that generated the data. When a model with too many predicators (significant or not significant ones) is fitted to a data set, we may get a perfect fit but the model will be useless for inference such as prediction. In statistics, fitting a model with too many unnecessary parameters is called *over-fitting*. The second part in SBC, $p \times \log(n)$, puts a penalty term on the complexity of a candidate model, which will increase when the number of parameters in a candidate model increases. Thus the criterion SBC requires a candidate model fitting the data well and penalizing the complexity of the model. **For a group of candidate models, the SBC value can be calculated for each of the models and the preferred model is the one with the lowest SBC value.**

IV. Change Point Analysis of Suwannee River Algal Data

1. Mean Abundance (Cell Density) vs Mean NOx

a). Change Point Analysis

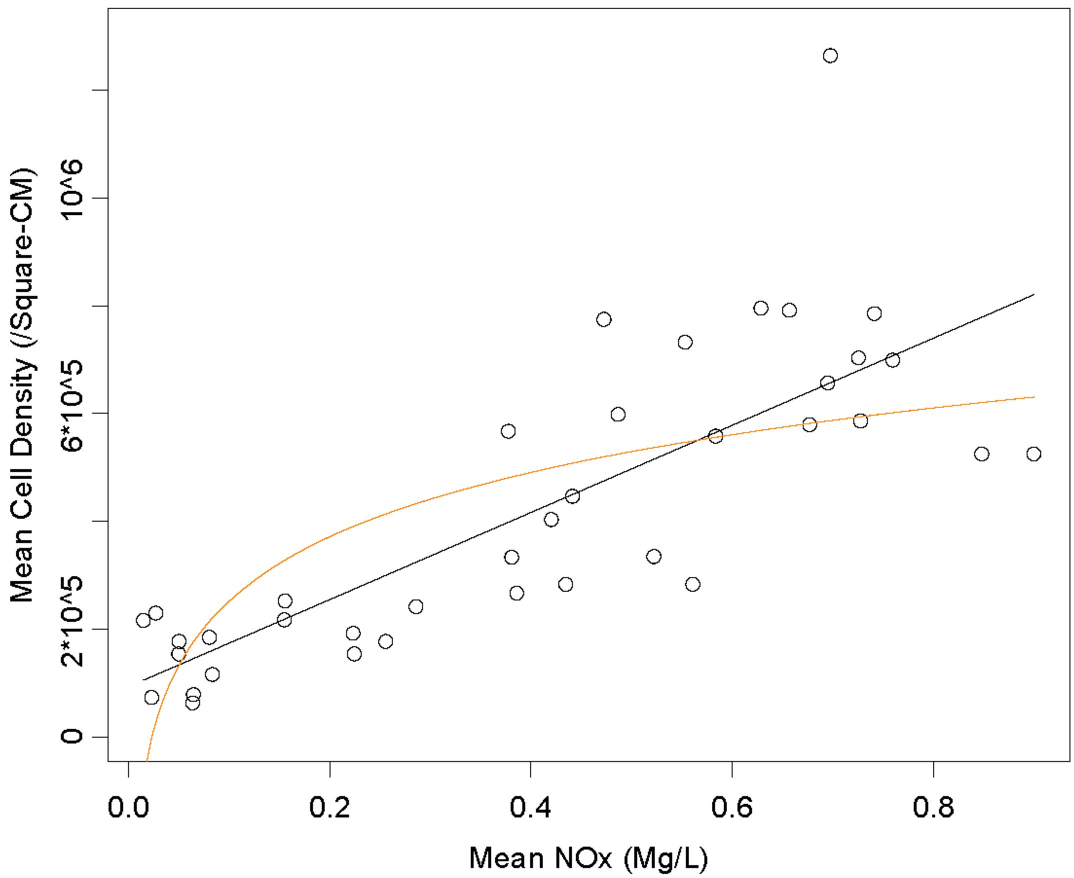
Table 1 presents the mean NOx and mean abundance data at stations along the Suwannee river and its two major tributaries (Withlacoochee and Santa Fe). The data were collected by the Suwannee River Water Management District (SRWMD).

Change point analysis was performed for mean abundance vs mean NOx. When data from the 12 stations are used, one change points was detected at the mean NOx values of 0.441. The change point has the statistic $L(l_1) = 7.68$ and is significant at the 5% level (95% confidence).

b). Model Comparison

For the purpose of model comparison, two other models, a linear regression model and a non-linear regression model, were also fitted to the data with and without the data from the four stations. Figure 3 presents the fitted models.

Figure 3. Linear model (Solid Black) and non-linear model (Mean Cell Density on log(Mean NO)) for data for the 12 stations At the Suwannee River System



The three fitted regression models for data from the 12 stations (SUW275 excluded) are presented in Table 2. The SBC values for the change-point model, the linear regression model, and the non-linear regression model are 923.3, 921.7, and 933.1, respectively. Thus, the linear regression model fits the data slightly better than the change point model. Based on the fitted change-point model, the change point at Mean NOx of 0.441 is extremely significant (with p-values =0.000). The cell density value at the change point increased 427894.7.

Table 2. Fitted Regression Models for Data from the 12 Stations

Model 1. Step-Function Regression (Change Point Model) :

```
Coefficients:
                  Value  Std. Error    t value    Pr(>|t|)
(Intercept) 218732.9466  38352.8296     5.7032      0.0000
         x2 427894.7336  55725.3694     7.6786      0.0000

Residual standard error: 171500 on 36 degrees of freedom
Multiple R-Squared: 0.6209
F-statistic: 58.96 on 1 and 36 degrees of freedom, the p-value is 4.316e-009
```

SBC Value: 923.3

Model 2. Linear Regression Model (Cell Density vs MN=Mean NOx):

```
Coefficients:
                  Value  Std. Error    t value    Pr(>|t|)
(Intercept)  92582.7394  49640.7291     1.8651      0.0703
         MN 809357.3381 102090.3640     7.9279      0.0000

Residual standard error: 168100 on 36 degrees of freedom
Multiple R-Squared: 0.6358
F-statistic: 62.85 on 1 and 36 degrees of freedom, the p-value is 2.073e-009
```

SBC Value: 921.7

Model 3. Non-Linear Regression Model (Cell Density vs MN1 = log(Mean NOx)):

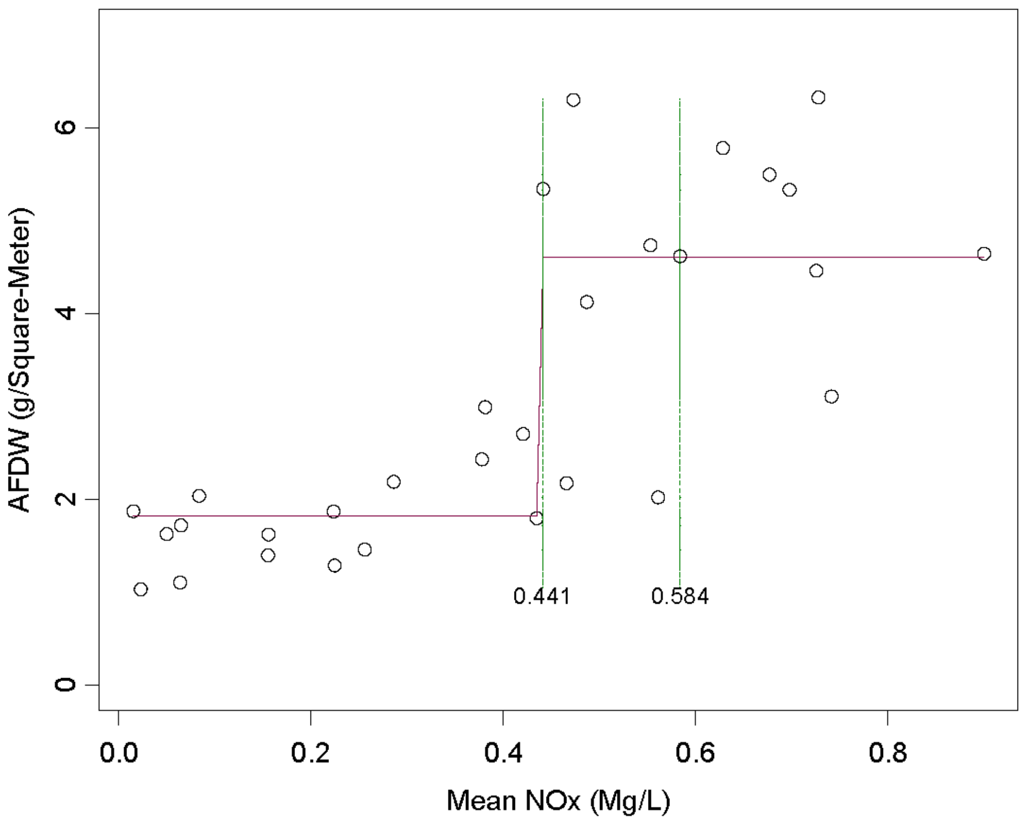
```
Coefficients:
                  Value  Std. Error    t value    Pr(>|t|)
(Intercept) 649141.0952  48888.2774    13.2781      0.0000
        MN1 172786.9495  28267.9784     6.1125      0.0000

Residual standard error: 195100 on 36 degrees of freedom
Multiple R-Squared: 0.5093
F-statistic: 37.36 on 1 and 36 degrees of freedom, the p-value is 4.918e-007
```

SBC Value: 933.1

Figure 4. Change point analysis for data from the 12 stations At the Suwannee River System (Mean Biomass vs Mean NOx).

Change Points: Mean NOx=0.441 with the test statistic of 8.74 and confidence level over 95%.

The 95% confidence interval for the change point based on 1000 Bootstrapping samples is [0.441, 0.584] with Bootstrapping average estimate for the change point at NOx=0.464. There were no potential change points at the significance level of $\alpha = 0.05$ detected below NOx=0.441.



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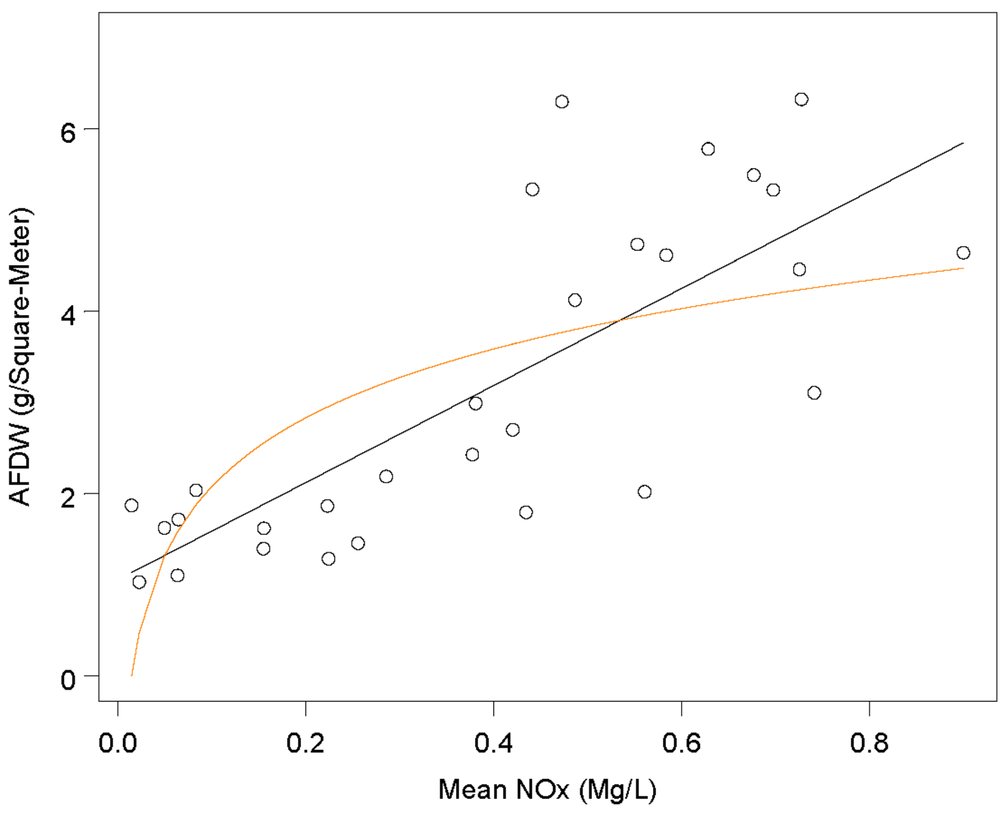
b). Model Comparison

For the purpose of model comparison, two other models, a linear regression model and a non-linear regression model, were also fitted to the data from the 12 stations. Figure 5 presents the fitted models.

Figure 5. Linear model (Solid Black) and non-linear model (Mean Biomass on log(Mean NO)) for data for the 12 stations At the Suwannee River System.



The three fitted regression models for data from the 12 stations are presented in Table 4. The SBC values for the change-point model, the linear regression model, and the non-linear regression model are 1.29, 12.74, and 22.03, respectively. Thus, the change-point model was the best model among the three models. Based on the fitted change-point model, the change point at Mean NOx of 0.441 is extremely significant (with p-values =0.000). The mean biomass value at the change point increased 2.97.

Table 4. Fitted Regression Models for Data from all the 13 Stations

Model 1. Step-Function Regression (Change Point Model) :

```
Coefficients:
              Value Std. Error t value Pr(>|t|)
(Intercept) 1.8193 0.2276     7.9931  0.0000
 NOx_0.441  2.9717 0.3400     8.7414  0.0000

Residual standard error: 0.9105 on 27 degrees of freedom
Multiple R-Squared: 0.7389
F-statistic: 76.41 on 1 and 27 degrees of freedom, the p-value is 2.342e-009
```

SBC Value: 1.29

Model 2. Linear Regression Model (Mean Biomass vs MN=Mean NOx):

```
Coefficients:
              Value Std. Error t value Pr(>|t|)
(Intercept) 1.0551 0.3813     2.7671  0.0101
         MN 5.3270 0.8153     6.5335  0.0000

Residual standard error: 1.109 on 27 degrees of freedom
Multiple R-Squared: 0.6126
F-statistic: 42.69 on 1 and 27 degrees of freedom, the p-value is 5.254e-007
```

SBC Value: 12.74

Model 3. Non-Linear Regression Model (Mean Biomass vs MN1 = log(Mean NOx)):

```
Coefficients:
               Value Std. Error t value Pr(>|t|)
(Intercept)  4.5881  0.3821    12.0071  0.0000
        MN1  1.0920  0.2249     4.8549  0.0000

Residual standard error: 1.302 on 27 degrees of freedom
Multiple R-Squared: 0.4661
F-statistic: 23.57 on 1 and 27 degrees of freedom, the p-value is 0.00004498
```

SBC Value: 22.04

3. Summary and Conclusions

In this report, change point analysis was preformed for the algal data at stations along the Suwannee River and its two major tributaries (Withlacoochee and Santa Fe) based on the updated data set. **The main findings in this report are the followings:**

1) **Change point analysis of mean abundance vs mean NOx**. When data from the 12 stations are used, one change points was detected at the mean NOx values of 0.441. The change point has the statistic $L(l_1) = 7.68$ and is significant at the 5% level (95% confidence). The 95% confidence interval for the change point based on 1000 Bootstrapping samples is [0.378, 0.629] with Bootstrapping average estimate for the change point at NOx=0.480.

2) **Change point analysis of mean biomass vs mean NOx.** When data from the 12 stations are used, one change points was detected at the mean NOx values of 0.441. The change point has the statistic $L(l_1) = 8.74$ and is significant at the 5% level (95% confidence). The 95% confidence interval for the change point based on 1000 Bootstrapping samples is [0.441, 0.584] with Bootstrapping average estimate for the change point at NOx=0.464. There were no potential change points at the significance level of $\alpha = 0.05$ detected below NOx=0.441.

Based on this analysis, we conclude that the major changes in mean abundance and mean biomass happened at mean NOx around 0.441. Confidence Intervals for the change point are provided based on Bootstrapping samples. But cautions should be taken for the bootstrapping intervals when the original sample size is smaller than 30.

For the Change point analysis of mean abundance vs mean NOx, the 95% confidence interval for the change point based on 1000 Bootstrapping samples is [0.378, 0.629]. For protection of the environmental and biological conditions at the river system, threshold for NOx should be chosen below the lower bound of NOx=0.378 of the confidence interval.

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